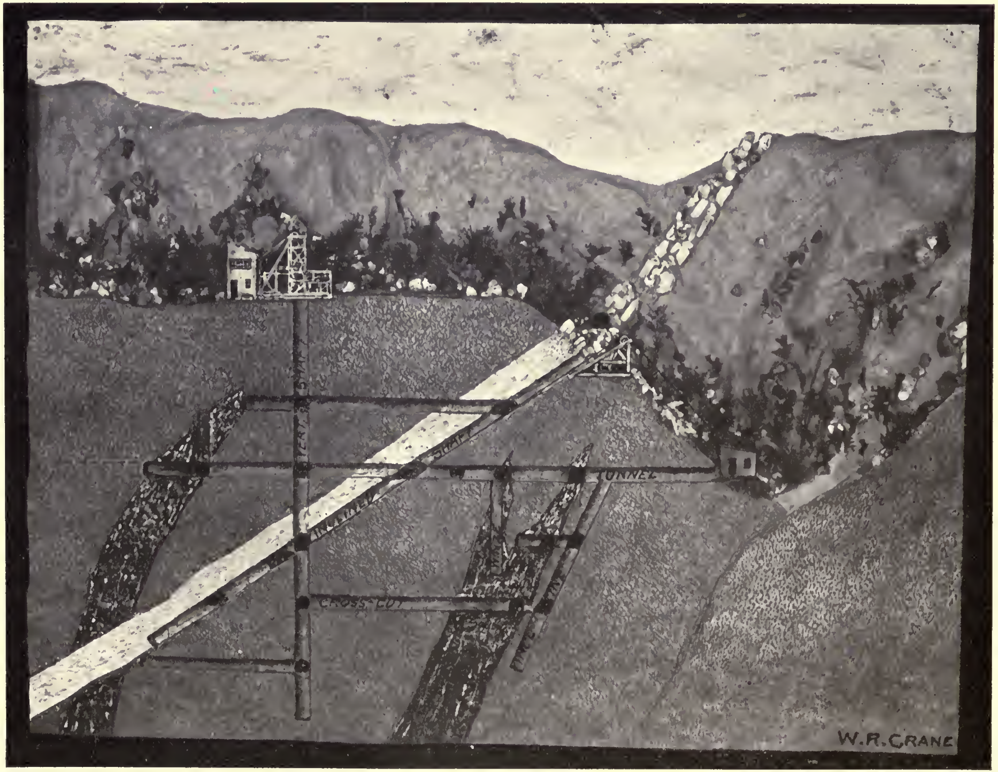

Frontispiece

Photographic Reproduction of Model Made to Show Various Openings and Passages Employed in Development of Mines: The Drift, Tunnel, Inclined and Vertical Shafts, Raises, Winzes, Cross-cuts and Levels are Shown in their Proper Relationship both with Regard to Deposits and the Surface. See page 38.

ORE MINING METHODS

COMPRISING

DESCRIPTIONS OF METHODS OF SUPPORT IN EXTRACTION OF ORE, DETAILED DESCRIPTIONS OF METHODS OF DEVELOPMENT OF MINES, OF STOPING AND MINING IN NARROW AND WIDE VEINS AND BEDDED AND MASSIVE DEPOSITS INCLUDING STULL AND SQUARE-SET MINING, FILLING AND CAVING METHODS, OPEN CUT WORK AND A DISCUSSION OF COSTS OF MINING

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PREFACE

WHILE much has been written with regard to methods of mining ore and many excellent descriptions of the methods employed in the mines of the United States and abroad are to be found in the technical press, yet there is no work in which systematic and detailed descriptions of the various typical methods are to be found.

The writer has therefore attempted to prepare a work on ore mining methods alone, which it is hoped may prove useful to both the student and the practical man in acquiring a knowledge of ore mining and in comparing methods. That the work may be of the most service, the descriptions have been made brief and many illustrations employed to supplement them. Illustrations taken from photographs of mine models have been extensively used and possess the advantage over diagrams in that by relief three dimensions are shown. Further, the application of each method has been specifically stated, together with the advantages and disadvantages of its use.

The classification of methods followed is based upon size of deposit, rather than kind of mineral or metal and character of deposit, which seems the simplest and most logical method of treatment. The idea has been to describe only those methods which have proved successful not only in one locality but several, and not to consider proposed methods nor those in the experimental stage.

In order to verify descriptions and to study methods more in detail the writer has visited the mines in which practically all of the methods described are employed; however, personal inspection has been confined to the mines of the United States.

The present volume, which is the second edition, has been completely revised and much new material has been added, including a chapter on development of mines. Further, extensive use of photographs of models has been made.

Special acknowledgment of suggestions and advice is due to the large number of mining men who have extended many courtesies to the writer while collecting the information upon which the work is based.

WALTER R. CRANE.

THE PENNSYLVANIA STATE COLLEGE
SCHOOL OF MINES, Jan. 1, 1917.

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ORE MINING METHODS

CHAPTER I

SUPPORT OF WORKINGS

INTRODUCTION

METHODS of mining and support of workings are so closely related that the discussion of one necessitates a more or less detailed treatment of the other. It therefore seems eminently proper and even necessary to preface a work of this character with a brief discussion regarding the elements of support. A description of the elemental units of support, such as pillars, props, cribs, stulls and square-sets will not therefore be out of place in this connection. Further, the use of filling is considered, as it is rapidly becoming an important factor in the support of underground excavations; caving as a factor in support is also discussed.

While no particular knowledge regarding methods of support other than may be found in the following pages is essential to a full and complete understanding of the contents of this work, yet a working knowledge of support of excavations will not come amiss, and such knowledge is assumed to be possessed by the intelligent reader of this work.

To the careful observer it is becoming more and more evident that timber cannot be relied upon to support mine workings as mining is, and must of necessity be, carried on today. With the constantly decreasing value of the mineral content of the ores of many mines and the opening up of enormous deposits of low-grade ores, the demand is becoming more urgent for decreased costs of working or extracting

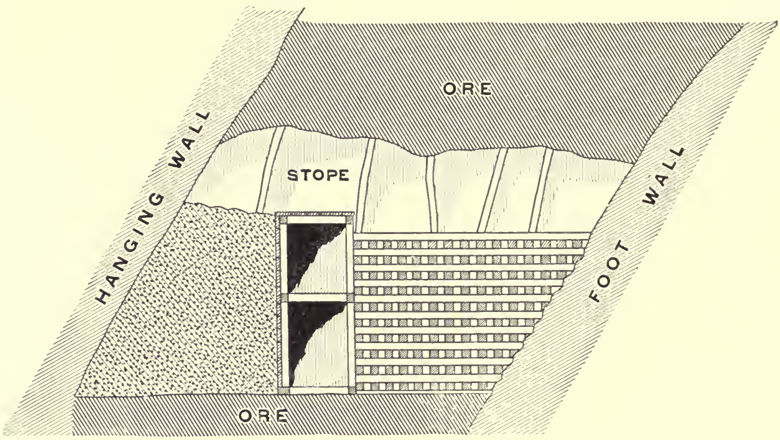


FIG. 1.— Corduroy and Filling in the Comstock Mines.

the ores. Contemporaneously with this general trend of affairs has occurred a scarcity, in many localities, of a suitable supply of timber at reasonable rates. The result has been, then, that with no other available material at hand that was cheaper, methods requiring a minimum amount of timber were resorted to, and as a further advancement filling and caving methods are rapidly coming into general use and are supplanting the older and more expensive methods where much timber is used. As the methods of working mineral deposits have then yielded to the demands of economy, in like manner the old type of conservative mine superintendent is giving way to the ingenious, energetic and efficient modern mining engineer, whose slogan is "increased tonnage at decreased costs."

Further, aside from the question of economy the mining engineer has long since learned that timber or any other similar form of support must be considered as temporary only when we come to maintaining openings at a depth of several thousand feet. To attempt to support a mountain by timber or even pillars of ore or rock is but to invite in the course of time disastrous caves with the possible resulting loss of life and property. The extremes gone to in an endeavor to hold back loose or swelling ground is well illustrated by the close-set cribbing or corduroy employed in the bonanza days on the Comstock Lode and still used there in isolated places. (See Fig. 1.) The veritable forest of closely placed props to be seen in many of our metal mines, and the stulls of three or four feet in diameter employed in the lower levels of the deep copper mines of Keweenaw Point, Michigan, all attest the ever-present and constantly growing need of a radical change in methods of procedure in supporting workings made for the economic extraction of mineral.

While the application of rock-filling to the support of mine workings is by no means recent in the mines of the United States, yet its rapid extension to a majority of the metal mining districts, irrespective of the kind of metal mined, has taken place within the last ten years. By rock-filling, as referred to above, is meant a filling of waste, the excavations receiving little or no other support except of the most temporary character. Filling in connection with square-sets has been used extensively in the mines of this country ever since its application to the mines of the Comstock Lode.

Aside from the question of an available supply of suitable material for filling there are certain objections to its use, some of which are so serious as to preclude its employment except under prescribed and limiting conditions.

Probably the principal disadvantages are shrinkage of the mass of filling and a tendency to become 'quick' and flow. The former action leads to movements which although gradual are nevertheless pronounced and may result in serious disarrangement of the workings, shafts, levels, etc., and may lead, under certain conditions, to the flooding of the workings. However, under normal conditions, these disadvantages may be insignificant compared with the benefits resulting from its use. The latter disadvantage while always present is accentuated only when the filling employed is mixed with a certain amount of earthy or clayey material and becomes charged or saturated with water. Further, the practice, often a necessity, of using the filling over and over again tends to render it less suitable for the work owing to the constantly increasing proportion of fine material produced by the attrition of the moving mass of filling, when drawn from one part of the workings to another, and the accumulation of gouge and muck left from the mining operations.

It is not, however, so much the seriousness of the disadvantages as it is the lack of control of the actions leading thereto. It may be said without hesitation that, where conditions are favorable, such as a moderately strong ore supporting itself sufficiently well to permit introducing and spreading the filling without interference with temporary supports, together with a suitable filling and plenty of it readily available, the filling methods have proved and are proving amply adequate. When such general conditions do not prevail and suitable timber at reasonable rates is not available, some other method not dependent upon such factors must be resorted to. The caving methods might then well be employed.

Caving is confined to ore bodies of considerable size, especially of horizontal extent, and to ores of a fairly uniform mineral content, its application being gradually extended to districts where other methods of mining have long been in use. Often where square-setting, with or without filling, was formerly exclusively employed, caving has now taken its place wholly or in part or a combination of the two is resorted to. Caving is usually employed only where other methods are inapplicable and inadequate. Its use means large-scale, continuous and rapid work, with a consequently large tonnage and small expense per ton.

Caving is not synonymous with scant use of timber; on the contrary a large amount of timber may be required as when the sub-drift system is used, but as the timber is for temporary use only, being often of inferior quality and used in the rough, the expense may be considerably less than a more permanent method of support where less timber is employed. What timber support is used serves mainly for protection to the miners who as parts of an intelligent system are directing and utilizing the tremendous force of the superimposed mass of loose and broken rock and ore which is slowly but irresistibly following the withdrawal of the ore downward.

Methods of Support

The means of supporting mine workings may be outlined as follows:

1. Pillars of ore or waste rock.

2. Timbering, consisting of props, stulls, cribs and square-sets.

3. Fillings of ore or waste; the former temporary, the latter permanent.

4. Support by indirect means, *i.e.*, by arching the workings and by caving methods, where the ore to be mined takes the load temporarily, being reënforced by timber.

Pillars of Ore, or Waste Rock. — Pillars were naturally first employed in the support of workings underground, and will always be used instead of artificial support except when their use means the permanent curtailment of the output of the mine, or when they are less stable and durable than other available supports.

The chief objection to the use of pillars, aside from the loss of valuable mineral, is that it is difficult to ensure their proper formation and location. To secure the maximum benefit of supports of any kind requires that they should be symmetrically and systematically placed, a thing that is next to impossible to obtain in the case of pillars underground. Either there will be ore occurring at the place where a pillar should logically come or some irregularity of or in the deposit will influence a change in location and result in a serious irregularity of the system adopted. In like manner the shape of the pillar may be changed; instead of a square or rectangular section with ends flaring slightly at both top and bottom, where connection is made with the hanging and foot walls, the sections are more usually roughly round or elliptical, while the general appearance resembles an hourglass.

The pernicious habit of gradually cutting away pillars to secure a few more tons of ore results in producing most grotesque shapes and an alarming condition of support. Pillars standing 12 to 15 feet high, in moderately inclined deposits, are not infrequently reduced from a diameter of 16 to 20 feet at the top and bottom to 4 and often 3 feet at the middle, and in certain observed instances to 1 foot diameter at the 'waist line.' Such pillars soon deteriorate under the enormous weight thrown upon them and show signs of distress by vertical cracks extending from top to bottom. The caved stopes of the upper levels of the large copper mines of the Lake Superior region bear witness to the fact that inefficient support in the shape of ill-formed pillars is both inadequate and futile.

Pillars are named according to the position they occupy with respect to the stope; those at the top of the stope are known as 'arch' pillars, those next to the shaft are 'shaft' pillars, while those occupying various positions in the stope are usually known as 'wall' pillars. A special form of wall pillar is the so-called 'dead-end,' a pillar extending the whole height of the stope and spaced at intervals of about 200 feet along the stope. (See Fig. 13.)

Timber as Mine Support. — Timber well adapted to use in underground work is becoming somewhat scarce in many localities in the United States. Oak is excellent but is rarely used owing to its scarcity. On the Pacific coast the cone-bearing or coniferous trees are widely used. Of the thirty-six varieties found there the most important are: the Oregon pine, spruce, yellow pine, tamarack, sugar pine, pinion or bull pine, besides several varieties of fir and redwood. In Washington and many of the Western states the Oregon pine is extensively used for both mine and surface work and is known in different localities by various names, such as, Douglas fir, Douglas spruce, yellow fir or red fir, while in the parlance of the lumbermen it is known as Oregon pine and Puget Sound pine. Yellow pine although of no great durability or strength is widely used.

Fir is quite strong, as is pine also, the softer woods having the advantage over the harder in that they crush more readily, thus taking up the load more uniformly.

Props or posts may be considered as the principal element in mine timbering, being employed in connection with nearly all forms of timbering under certain conditions. Props and posts may be round or square and are set normal to the roof and floor of the workings. They have their widest range of usefulness in flat or slightly inclined deposits and are therefore especially applicable to bedded deposits. In order to increase the bearing surface caps are often provided, which consist of short lengths of plank placed between the ends of the props and roof or floor.

Stulls while performing the same function as props and posts are used only in more or less highly inclined deposits, having their widest range of usefulness in narrow veins, say up to 15 ft. in width. Stulls are, however, used in veins of 35 to 40 ft. in width, and for inclinations up to 90°, or the vertical. The application of stulls is considerably different from that of props owing to conditions brought about by change in dip of the deposit. Like the prop or post the stull often has a cap used with it, but it is placed at the upper end only, the lower end being set into a notch or 'hitch' cut into the lower or foot wall of the vein and wedged tight. The object of the hitch is to prevent the timber slipping from its place. Further, stulls are not set normal to the walls of the vein but in such a position that their deviation from the normal, called 'angle of underlie,' is about one-fourth that of the angle of dip of the deposit, thus:

Dip of Vein	Angle of Underlie of Stull	Dip of Vein	Angle of Underlie of Stull
10°	2½°	40°	10°
20°	5°	50°	12½°
30°	7½°	60°	15°

The reason for setting stulls at an angle with the walls instead of normal to them is to ensure against their becoming loose and falling out of place, which would surely result if they were set normal and a movement of the walls should

Fig. 2. — Position and Use of Stull in Vein.

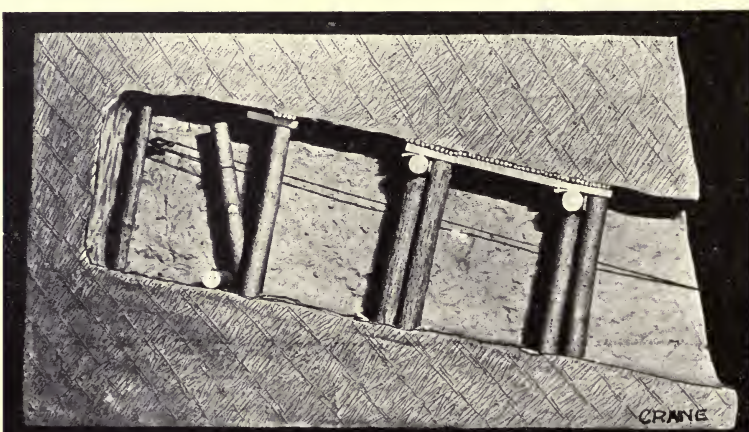


Fig. 3. — Battery Method of Stull Timbering. (Modeled after Sketch by Claude T. Rice.)

take place. When set at an angle any downward movement of the hanging wall serves only to set the stull more firmly in the hitch. (See Fig. 2.)

Stulls are extensively employed at the foot of stopes in veins of steep or moderately steep inclinations and serve both as a protection to the levels and as a support for the ore or waste that is placed upon them. Stulls when covered with lagging may serve as platforms upon which drills may be mounted in the work of stoping. In steep veins, intermediate levels or floors may be formed at intervals of 15 or 20 ft., by rows of stulls, lagged and covered with ore or waste, the stoping of the ore extending horizontally and vertically from the level so formed until sufficient room is made for another row of stulls to be placed. Waste-covered stulls are usually designated as 'waste-stulls.' (See Fig. 13.)

It is often necessary to reënforce stulls, which is usually done by placing several below the one to be reënforced. The auxiliary stulls may be placed directly below or grouped together forming the so-called 'battery of timbers' or stulls. Still another modification in the use of stulls is where they are used in conjunction with square-sets, long stulls often being employed in holding the square-sets in place when for certain reasons it is not considered necessary or desirable to fill the stope with sets. The stulls serve in reality as elongated caps in the system of square-sets. (See Figs. 3 and 4.)

Props or struts and stulls are occasionally used together, especially when long stulls are necessary, the struts being set in between the stulls to hold them in place, thus steadying them and preventing buckling.

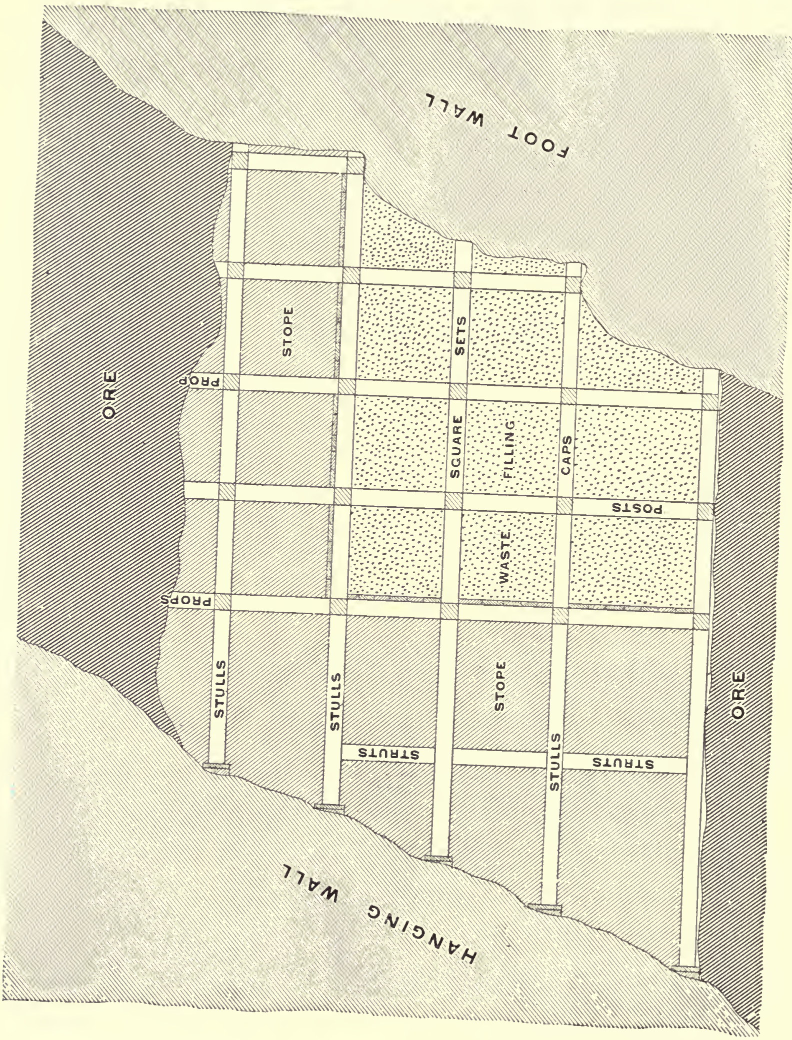


FIG. 4.— Use of Square-Sets, Stulls and Filling.

Cribs or Bulkheads are usually composed of damaged timber, old ties, props and stulls, put together in pigsty fashion, two or more timbers being placed parallel one with the other and then bound together by other timbers laid across their ends and middle, which operation is continued until the roof or hanging wall is reached, when they are wedged fast. In order to make these constructions more stable they are often filled with waste. Cribs filled with waste, or otherwise, probably have their widest range of usefulness in the mining of coal, but are often employed in wide stopes where ordinary methods of support are inadequate and where a certain amount of room for mining and handling the ore is available.[1] Cribs in combination with filling, being built in the stopes during the extraction of the ore and then buried in filling when the stope is abandoned, give added strength and stability to the filling. (See Fig. 5.)

Square-sets have been very extensively employed in the metal mines of the United States and are still used to the exclusion of other methods in certain districts. While especially applicable to wide veins of moderately steep inclinations, square-sets are often used in veins from 15 to 20 ft. in width, and in exceptional cases to much greater widths.

In placing square-sets the usual practice is to begin at the bottom of a stope or a level and lay long sill timbers which are regularly spaced by other timbers, thus covering the floor of the open stope with a system of timbers arranged in

[1] Cribs are extensively used in the mines of Broken Hill, South Australia, where cribs without filling are called 'horses,' while those with filling are designated as 'pigstyes.'

squares. Upon these timbers are erected other timbers which consist of posts, caps and girts or ties. The posts

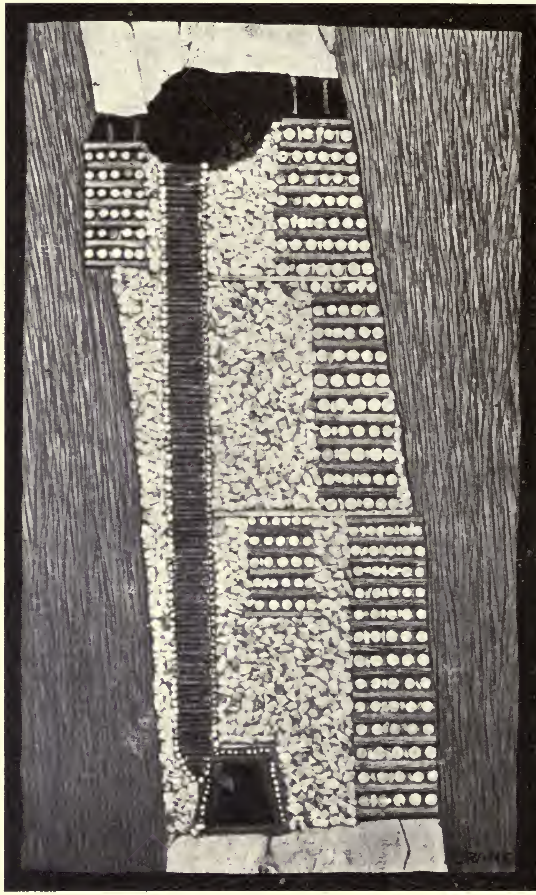


Fig. 5. — Use of Cribs in Filled Stopes.
(Modeled after Sketch by H. L. Hancock, Wallaroo Mines, South Australia.)

are placed upright at the intersection of the sills and cross-pieces, and upon the posts are placed caps, the ends of which rest on two adjacent posts in a direction transverse with the vein. The girts also rest upon the posts but run longitudinally with the vein. The caps and girts when in place form a new level or floor, and by successive additions of posts, caps and girts the timber support can be kept within easy reach of the walls or roof of the stope. In like manner by the addition of sills the sets can be extended indefinitely in either direction along the vein or deposit. A platform or staging as well as support is thus provided for any portion of the roof or sides of the stope. The stopes are then filled with a cellular mass of timbering perfectly matched together and symmetrical in all directions.

In order that the various members of the square-sets may fit together and be in perfect alinement, the posts standing vertically and the caps and girts lying horizontally, it is necessary that they be cut to gauge, and the ends formed so as to both hold the members in place and provide a perfectly fitting joint. Further, the ends of the different timbers are so cut that the largest cross-sectional area is opposed to the greatest pressure, as in the case of the caps which are placed normal to the walls. While there are a large number of different forms of joints suitable to framing both sawed and round timber, yet the details given in Fig. 6 illustrate very well two methods of framing that are widely used. Where the ground is particularly heavy, diagonal braces are placed in the sets and in line with the greatest pressure.

The length of the posts varies largely with the locality, but as a rule the first set of posts, and in fact the posts at any level, where hauling is done in cars, are sufficiently high

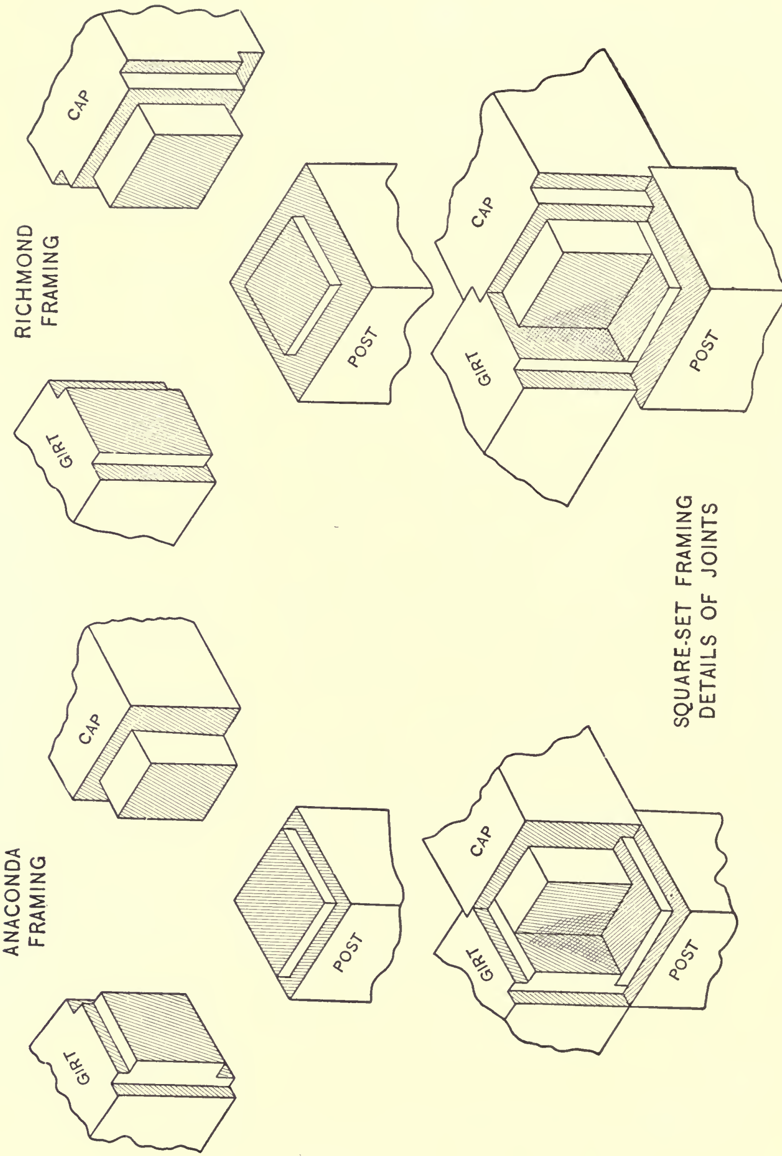


Fig. 6.— Forms of Square-set Framing.

to permit the passage of men. The usual length of posts is 6 to 8 ft. in the clear, the caps and girts being about 5 to 6 and 4 to 6 ft. respectively.

As timber became more difficult to secure for the mines the first and most natural expedient was to modify the construction of the square-sets by using rough round instead of sawed timber and the employment of longer posts. Round timber while being somewhat more difficult to frame is considerably stronger than the sawed forms. Thus the result is decreased cost and increased strength.

Increased length of posts also decreases the cost, but there is a definite limit in this direction if strength and rigidity of support are desiderata. A further modification is the variation in size of the different members of the sets, the posts, caps and girts being of different cross-sectional dimensions.

Experience has shown that it is not so much the depth with consequent increase in pressure as the strength and firmness of the walls that determine the usefulness and safety of square-sets as support for workings. This was demonstrated in the mines of the Comstock Lode, where the support of the upper workings was often fully as difficult as in other localities at greater depth. Further, there is a limit in height to which square-sets can be used, beyond which the timbers will crush under their own weight. The limit in the Homestake mines, South Dakota, ranges between 80 and 90 ft. It is then evident that when square-sets are employed the height of the stopes should not exceed 100 ft. Use of square-sets in a gold mine is shown in Fig. 7.

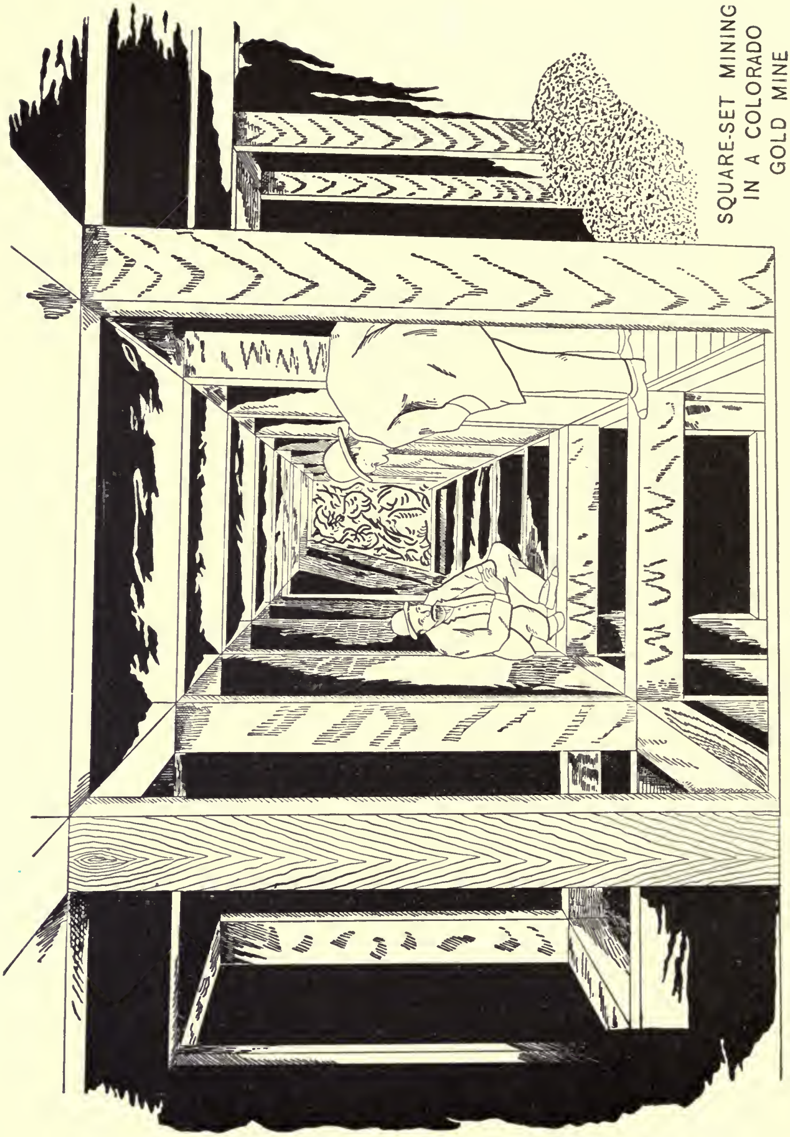


FIG. 7.— Square-Sets in Large Stope.

From the standpoint of economy the use of square-sets is hardly warrantable, although there are instances where owing to the occurrence of cheap timber it may prove to be the most economical method that can be employed.

Fillings of Ore or Waste. — Filling methods have been successfully employed for many years in the mines of this country and are rapidly being extended, especially the use of waste. The filling of underground excavations, as stopes, with ore is a method employed for reasons of utility and economy as well as support. Ore may be located and broken in the stopes but not drawn off, except as is found necessary to provide room for the operation of stoping. As there is an increase in volume of from 30 to 40 per cent in broken ore, it is evident that a certain amount must be drawn off after each round of shots to give space for subsequent work at the face. A large amount of ore may then remain in the mine, forming an 'ore reserve.' The advantages of such a system are: a large force of men may be employed in breaking ore; less danger from falls of rock owing to rapidity of working; reduced cost of breaking and handling ore; a more uniform output; and a more careful grading of ores resulting from not having to rush work in order to keep up with the required output.

The work at the face is materially facilitated by this method of procedure, as the ore serves as a platform upon which the drills are mounted, the height of which may be varied at will. The ore while stored in the stopes also serves as a support for the workings, reducing or eliminating the support that would otherwise be necessary. It is difficult to imagine a case where ore would be introduced into a mine or transferred to any part of it for support, owing to the extra cost involved, as well as the loss in fine ore resulting from attrition in handling. The principal reason for leaving ore in stopes is the establishment of an ore reserve, although occasionally low-grade ore may be held in the stopes until such a time as it can be treated with profit. Further, the temporary need of support may be so urgent that it is expedient to resort to the use of even a fair grade of ore.

The use of waste in the support of underground workings is now a well-established method, and its widespread application indicates how favorably it is looked upon by mining men. The employment of waste-filling depends to a large extent upon its source. There are three possible sources of waste, namely: that resulting from mining operations, being sorted from the ore or portions of the walls that have to be broken down in cutting out the ore; that obtained from special excavations made in the vein walls, usually the hanging-wall; and material from quarries or open-cuts on the surface and the waste products from concentrating works, such as tailings. The first source mentioned is the most important, as comparatively little labor is required in placing it properly in the excavation to be supported. This is particularly true in the case of veins where but a small part of the ore is valuable, the bulk of the vein-content being used as filling; also in certain cases where more waste is required than can be obtained from sorting the ore, the additional amount is secured by blasting several feet off the walls. Much filling is now taken from the surface and by the use of waste chutes is conducted to any portion of the mine desired, being distributed by cars. Underground excavations opened especially to secure waste for filling are occasionally made, but it is a method of procedure which is liable to lead to disastrous results, as in starting caves, unless the ground is particularly strong.

Support by Indirect Means. — Indirect methods are resorted to wherever intelligent supervision is given to the work and where conditions are favorable. The natural arch formed by caving ground, or the so-called 'dome of equilibrium,' may be employed to advantage in the temporary support of underground excavations. The 'fracture prismoid' is another name for the same phenomenon. By arching the roof it is often possible to maintain it without any support or with very temporary constructions. The character of the ground is the governing factor in this work, certain formations not being sufficiently strong to stand even with short spans and high arches, while other specially strong formations may be given exceedingly long spans and low arches. The wide stopes of the Homestake and Alaska-Treadwell mines illustrate remarkably well the application of the 'dome of equilibrium' to strong and stable formations.

Caving may be employed as a supplementary method following some well-defined system, usually with timber supports, until its limit of applicability has been reached or exceeded. The weight of the unmined ore together with the mass of broken waste and timber lying above the ore is temporarily supported by pillars of ore and timber. In the course of time the pillars begin to break up, and by carefully and systematically removing the timber supports and attacking the pillars in such a manner as to assist the disintegration, practically all of the ore remaining above the level worked may be drawn off with little or no danger to the laborers or the integrity of mine workings.

The support of the caving ore and overlying caved material is of the most temporary character and really amounts to a well-defined and scientific control of the movement of the caving mass rather than its definite support.

In order that the methods of support discussed above may be rendered still more comprehensive the following brief statements are made regarding their application and comparative advantages and disadvantages.

Pillars of mineral constitute the most natural form of support for underground workings. The advantages in their use are: the vein-content left in place is probably the strongest possible support obtainable; support can be provided at any desired point; there is no expense attendant upon their use and no risk from fire. The disadvantages are: loss of mineral when formed in ore; a tendency to make them too small to save ore; also a like tendency and for similar reasons to place them irregularly or dispense with them altogether.

Props or Posts can be used to advantage in a vertical or nearly vertical position only. Their chief advantage lies in the ease with which they can be placed and removed if desired.

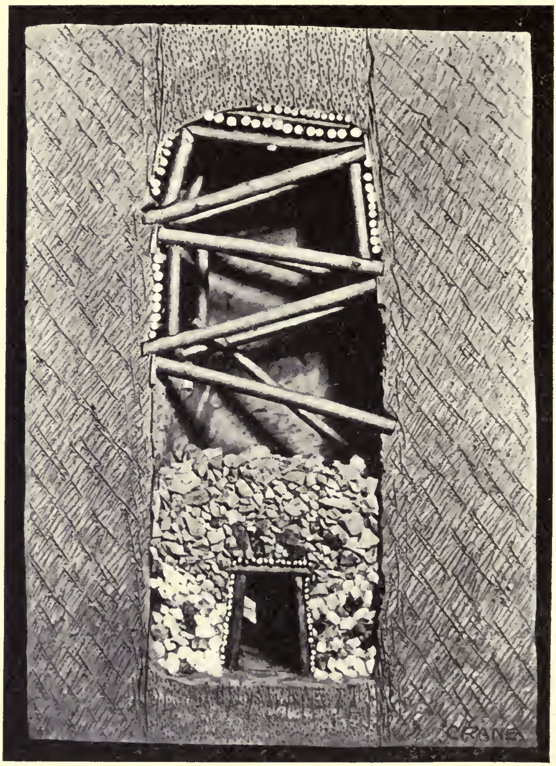
Stulls have a very much wider range of application than posts, as they can be employed in veins ranging from an inclination of about 10° to the vertical. When properly placed they are not affected by slight movements of the walls and are therefore suitable for a great variety of conditions. They may be employed as supports of scaffoldings upon which drills are mounted, forming 'stull-levels' and 'waste-stulls.'

Cribs or Bulkheads owing to their width are more stable than posts or stulls, but to give the best results must be built practically vertical. They cannot be used to advantage except in horizontal or slightly inclined deposits or wide veins. While readily built they are difficult to take down, especially when filled with waste, and occupying considerable space encumber the workings, interfering with handling ore and supplies.

Square-sets like cribs must be built along horizontal and vertical lines and are therefore confined to comparatively wide veins and massive deposits. They are expensive to frame and place and unless filled with waste soon buckle and crush, both under their own weight and that of the walls. However, for the support of large openings they have proven indispensable in the past, the ease with which extensions can be made in any direction being a most important factor in mining.

Filling mine workings, especially with waste, is growing in favor owing to the fact that support can be placed quickly and readily; the waste of the mine can be disposed of at minimum expense, and cheap material can be transferred underground with little work; it can be used a number of times, being drawn from one part of the mine to another; a good support uniformly distributed over the walls is obtained, and there is no fire risk.

The disadvantages resulting from the use of filling are shrinkage of filling disturbing workings and a tendency for the filling to become quick and flow under pressure.



A. — Method of Timbering Vertical Stopes with Weak Walls. (Modeled after Sketch by H. H. Hodgkinson.)

Caving as an indirect method of support is applicable to large deposits only; requires continuous and rapid work; the loss of mineral may be considerable owing to the movement of the caving mass getting beyond control; and a large amount of timber is required with certain deposits. The advantages and disadvantages are: a large output at moderate cost; operations must begin near the surface; and the overlying rock must cave readily.

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For references to the use of filling and caving methods, see page 202.

CHAPTER II

DEVELOPMENT OF MINES

Mining operations may be roughly grouped into three classes, namely: exploration, development, and working. Each of these operations is in most cases necessary and required if a property is to be properly prepared for systematic and economical production of ore, except possibly where the occurrence of the ore is well known and previous operations in the district have developed and established a satisfactory practice. In such cases it is often possible to eliminate or materially reduce exploration and, to a less extent, development work, although it must always be kept in mind that the mining risk is ever present and that unexpected conditions may be encountered at any time. By development work the 'ore reserve' is established, assuring a regular and continuous output, which with large operations is not only desirable but necessary.

By exploration is meant the search for and location of orebodies and it consequently precedes development work. Prospecting is the first stage of exploratory work and consists in the use of ditches crossing the outcrop of veins, test pits sunk in the deposit, bore holes usually placed normal to the dip of the deposit, and under certain circumstances short drifts, slopes or inclines and shallow, vertical shafts may be used which latter work is more properly called exploration. It is evident, then, that there is no sharp line separating prospecting from exploration nor exploration from development work and in a similar way development work merges into the breaking down of the ore or the working of the mine.

The development of a mine consists in connecting the deposit with the surface by means of passages suitable for the handling of ore and supplies, for the going and coming of men, for ventilation and drainage, and in fact for all of the operations necessary for the working of the mine.

At the completion of development work the mine is assumed to be in condition for the economic extraction of ore and should be fully equipped for that purpose; drills and all machinery necessary for the breaking of ore and transferring it to the surface; equipment for drainage and in some cases for ventilation should be installed during development work and should be so designed as to permit of additions with minimum work and expense incident upon the growth and expansion of the mine workings.

Aside from opening mineral deposits and preparing them for the breaking of ore and its transference to the surface, the establishment of an 'ore reserve' is an important consideration. Except in the case of small mines and irregular operations, or where the ore is placed in stockpiles (which are in fact ore reserves) it is generally considered desirable to form an ore reserve in the mine. The object of an ore reserve is to provide a definite amount of ore which is held in reserve and can be drawn upon as occasion demands. There are two forms of ore reserves, namely, 'ore blocked out' and 'ore broken down'; the former ensures a constant supply of probably workable ore for a definite period and thereby tends to reduce the 'mining risk,' the latter provides a fixed tonnage to be drawn upon to maintain the uniform output of the mine. The ore reserve is therefore an effective means of establishing and maintaining stability in mining operations and if formed during the development period, or the early stages of opening mines, may materially reduce the expense of such work and enhance the value of mining properties.

Controlling Factors. — Before proceeding with the details of the methods of development it might be well to outline briefly the factors that determine in a general way the choice of methods, which are as follows:

1. Physical characteristics and primary irregularities of deposits.

2. Secondary irregularities due to earth movements.

Under physical characteristics may be listed: the condition of the ore, shape and size of the deposit, character of top and bottom rock or hanging- and foot-walls, position of deposit with respect to surface, and distance from surface.

The primary irregularities consist of change of the thickness of deposit, occurrence of interstratified bands of impurities, and the presence of irregular masses of foreign material.

Irregularities of deposits due in large part to conditions affecting deposition or the formation of deposits may materially affect the method of development and consequently the method of mining, but usually require a modification rather than a change in method.

On the other hand, irregularities arising from earth movements are of considerable consequence and often require radical changes in both the scheme of development adopted and subsequently the method of mining employed. The two most important irregularities and the only ones that

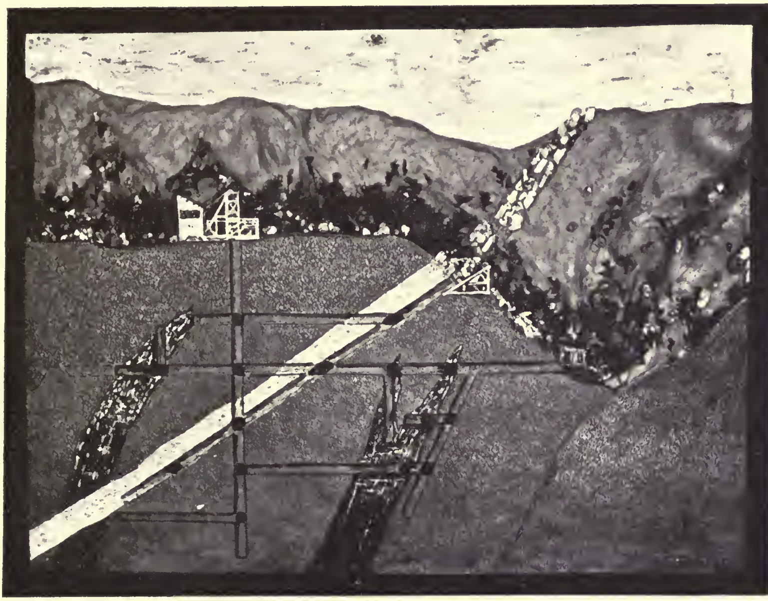

Fig. 8.—Arrangement of Various Development Passages.

need be mentioned in this connection are folding and faulting, the effect of which is most pronounced in bedded deposits. By folding of horizontally lying strata, variations of dip are produced as exemplified in anticlines, synclines, and basins; while by faulting, which is a direct result of folding, fissures are produced and by subsequent movement such irregularities as thickening and thinning of vein-content, branching of veins, occurrence of barren masses of rock or 'horses,' scattering of values, and displacement of portions of veins, are of common occurrence.

Aside from being the controlling factor in choice of the preliminary opening, as drift, tunnel, slope or vertical and inclined shafts, the dip also determines the location of the opening with respect to hanging- and foot-walls and in the case of basins with respect to the lowest point, as drainage as well as haulage must be considered. The presence of faults complicates such conditions but seldom requires a radical alteration of methods.

A working knowledge of the laws governing faults is desirable but not absolutely necessary if one is concerned in the development of deposits occurring in a locality where faults exist; however, the best possible guide is the experience gained from actual operations in the field and the results of such experience should be carefully examined when available.

The shape of deposits and the dip are of the first importance from the standpoint of development and are largely independent of whether the deposits are bedded or occur in veins. For instance a massive deposit may result from the folding of a bed or the impregnation of the walls of a vein or a line of contact of different formations; or a bedded deposit may be to all intents and purposes a vein when it stands at a fairly high inclination, or the enriched portions of beds and veins may be similar in occurrence and due in part to the same cause; and, lastly, the phenomena of thickening and thinning of deposits, also the splitting up into one or more parts, are characteristic of beds and veins, although due to different causes.

Use of Vertical and Inclined Shafts. — Massive deposits require different methods of procedure in development than do bedded deposits or veins, although thick beds and massive deposits may under certain circumstances be developed according to the same general plan. Massive deposits are usually developed in floors, while steeply dipping bedded deposits and veins are developed in levels, which are in fact relatively narrow floors. As a rule, massive deposits are opened by vertical shafts, although it may be desirable owing to the peculiar shape of a deposit to employ an inclined shaft for its development.

Inclined bedded deposits and veins afford a wide range of choice of methods of development, subject, however, to the conditions imposed by the inclination or dip. In a general way it may be said that deposits lying at some distance from the surface with their axes in a horizontal plane, or approximately so, should be developed by means of vertical shafts if possible, otherwise by inclined shafts. Highly inclined beds and veins are developed by inclined and vertical shafts, except where it is possible to employ drifts and tunnels due to outcrops occurring on the slopes of hills and mountains, or where the deposit is so situated as to be readily reached by a tunnel. Slopes should be employed in developing slightly inclined deposits dipping into the hill from the outcrop. (See Fig. 8.)

While there is no sharp line drawn in practice in the designation by means of angle of dip of slopes and inclined shafts, yet it is desirable that limits should be set, which may, however, be varied to suit the practice in different districts.

The limits set by common practice are as follows:

	Angle Made with Horizontal
Drift or tunnel	0° to 3°
Slope or plane	3° " 25°
Inclined shaft	25° " 85°
Vertical shaft	90°

Except in rare cases there can be no doubt as to choice of a drift, tunnel or slope, but with inclined and vertical shafts, or when highly inclined deposits are to be developed, there may be some doubt as to which would be better. In certain districts practice favors inclined shafts, while in other districts vertical shafts are used exclusively. A careful study of existing conditions will, however, usually disclose the underlying reasons, which may not be generally recognized.

In development, as in all other operations, cost is often the determining factor, and in this work in particular both first and operating costs must be considered. Owing to the large amount of dead work necessary to reach the deposits by means of cross-cuts driven from vertical shafts, there is a limit beyond which such work is not permissible. The limit has been determined by practice to be when the deposit stands at an inclination of 36° with the horizontal.

Vertical shafts are usually not in the deposit but when possible are placed in the foot-wall and at some distance from the outcrop. Veins with inclinations of 36° and upward usually have the shaft located on the hanging-wall side, thus subdividing the deposit into two portions of approximately the same dimensions vertically with relatively the same amount of development work in each. Further, the longer dimension of the cross-section of the shaft should

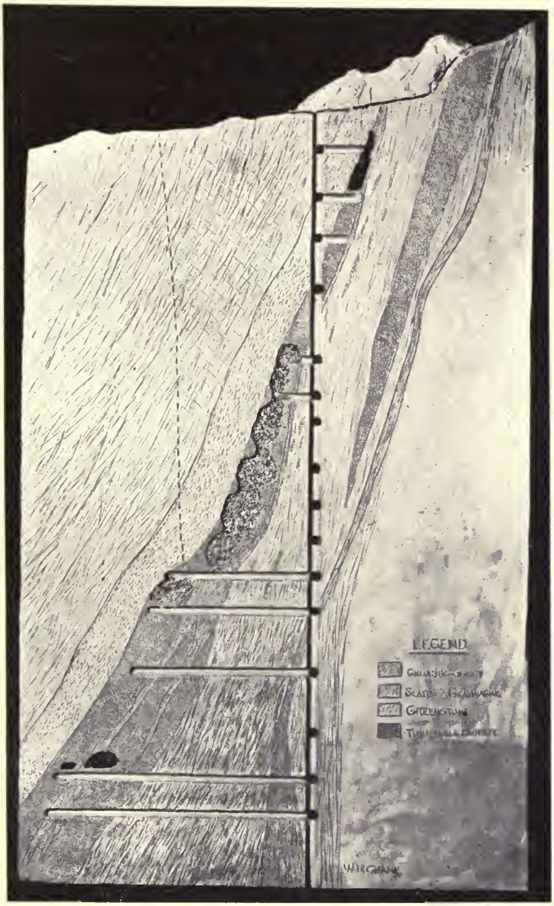

FIG. 9. — Vertical Section through Shaft and Orebodies of the Alaska-Treadwell Mines. (Modeled after Sketch in Mining and Scientific Press, Feb. 10, 1917.)

be normal to the outcrop for the reason that the shaft will be less subject to disturbance arising from movements in the walls of the deposit. (See Fig. 9.)

As indicated above, connection is made with the deposit by cross-cuts or passages driven through the enclosing rock and connecting the shaft and deposit; at the points of intersection of the cross-cuts and deposit, passages are driven forming the so-called levels, thus dividing the deposit into blocks of convenient size for the extraction of ore.

The advantages resulting from the use of vertical shafts are as follows:

1. Vertical shafts are more permanent in character and less affected by removal of ore than are other openings, with the possible exception of tunnels.

2. The distance to deposit is usually less than in the case of tunnels.

3. Vertical shafts are more readily supported than are other forms of openings and the cost of material is less.

4. The wear of hoisting rope is considerably less than when haulage is done in horizontal passages or on inclined planes.

5. Ultimately vertical shafts are employed in working deep-seated deposits and development work should be planned accordingly.

The principal disadvantages of vertical shafts are as follows:

1. They are more difficult to sink.

2. No cost is defrayed until development is practically completed.

3. No information is obtainable regarding the deposit until a late date.

Inclined shafts may be sunk within or without the deposit, either adjacent to the foot-wall side or in the foot-wall itself. If the vein filling is strong it is preferable to place the shaft in the deposit and next to the foot-wall, unless it is desired to remove the whole of the deposit, in which case no shaft pillars are left and the shaft is driven in the foot-wall and at a safe distance from the deposit. The same method of procedure may be followed when the wall-rock and ore are heavy and weak.

The advantages in the use of inclined shafts are:

1. They are somewhat easier to sink than are vertical shafts.

2. Work in the deposit can begin immediately and the ore obtained during development will in part defray the expense. To render a mine productive during the early stages of development, inclined shafts should be employed.

3. Information regarding character of deposit and occurrence of ore is available at any time.

The disadvantages of inclined shafts are:

1. They are not as permanent as vertical shafts.

2. They are more difficult to support than vertical shafts.

3. Hoisting and handling of ore is not so readily accomplished nor as safe as with vertical shafts.

4. While less power is required in hoisting the wear of rope is greater in inclined shafts.

The fact that ore may be produced practically at the beginning of development work together with the added advantage of more rapid work in sinking due to softer formations and better working conditions, make the use of inclined shafts more acceptable for the initial and preliminary openings in steep and moderately steeply dipping deposits.

The combination of inclined and vertical shafts or the so-called 'turned-vertical' shafts are common and result from certain occurrences of formation as well as working conditions; for instance, where inclined beds or veins terminate in fault planes, or where through folding, beds or veins reverse their dip, and where the outcrop of deposit occurs off the property or is too far distant to permit of development by inclined shafts. Turned-vertical shafts possess practically all of the advantages of inclined and vertical shafts and on the other hand have few of the disadvantages of either considered separately.

Use of Drifts, Tunnels, and Slopes. — The use, as well as the advantages and disadvantages of, inclined and vertical shafts have been discussed, but no statement aside from that giving limiting degrees of dip, has been made regarding the use of other development openings. (See Fig. 8.)

In order that there may be no misunderstanding regarding the use of the various openings employed in the development of mines, the following definitions are given: [1]

1. A drift is a passage practically horizontal, begun on the outcrop and lying wholly within the deposit.

2. A tunnel is a passage of slight grade driven from the surface across bedding planes to the deposit. The original idea of a tunnel was that of a passage extending through a

[1] Owing to the number of passages often required for the development of an orebody the distinguishing characteristics noted cannot be held to in all cases, which is particularly true regarding drifts and cross-cuts.

hill or mountain from daylight to daylight, but according to present practice, only one end of the tunnel needs to reach the surface.

3. An adit or adit-level is a passage nearly level which may or may not follow the deposit and which is intended to be used wholly or in part as a drainage opening.

It is evident that with deposits dipping into a hill or mountain side or away from the outcrop, any passage driven within them for development purposes will of necessity have a grade the reverse of that given to the various openings mentioned above, and that such openings cannot be employed for drainage purposes.

Beginning with the opening of lowest dip and consequently that nearest in grade to the drift, tunnel or adit, and proceeding upward to the vertical, we have the slope or incline, the inclined shaft and the vertical shaft.

Slopes and inclines are operated as engine or gravity planes, while inclined shafts are equipped in practically the same manner as vertical shafts as the weight of the load is thrown in large measure upon the hoisting rope. In the former case, several cars are employed in transferring the ore from the mine to the surface, while in the latter case skips holding from a few to as many as twenty tons are used singly, which on high dips must be prevented from overturning by guides, thus resembling cages used in vertical shafts.

Brief comparative statements regarding the use of the various forms of development openings are given as follows:

1. Drifts, slopes, or inclined shafts when driven in the deposit have the following advantages:

a. The cost is less as the deposit is usually easier to work than the enclosing rocks.

b. Mineral extracted often pays a large part of the expense of opening.

c. Valuable information is obtained regarding thickness, shape, size, and extent of deposit. Further, there is little danger of losing vein.

d. Work of breaking ground can begin at an early date.

2. The use of a drift may be preferable to that of a slope or shafts for the following reasons:

a. It is cheaper to drive a passage than sink a shaft: ratio 1–3.

b. It is easier to drive a passage than to sink a shaft: ratio 1–5.

c. A drift is self-draining, thus the operating cost is lessened.

d. Hauling is cheaper than hoisting.

3. The advantages of a drift may be secured by the use of a tunnel, particularly from the standpoint of handling mineral and supplies, ventilation, drainage, etc., although a tunnel cannot be driven as readily as it crosses bedding planes. Further, there are no immediate returns from mineral mined, thus delaying the paying time of the mine, nor is any information available regarding the deposit. A tunnel may, however, be a good means of search for mineral deposits, but may fail to discover an orebody due to crossing the vein at a barren point.

4. Vertical shafts are in some respects better than drifts, tunnels, and slopes for the following reasons:

a. Distance to deposit is usually less than with tunnel, thus reducing the cost of development work.

b. The amount of timber used in support is relatively small and the cost is therefore less than with other openings.

c. Vertical shafts are more permanent than drifts, tunnels, and slopes.

d. The amount of rope required is relatively small and the wear is correspondingly less.

On the other hand, shafts are more difficult to sink, no cost is defrayed during development work, and no information regarding the deposit is obtainable until it is reached.

Development within Deposit. — The methods by which deposits can be reached and connection made with the surface as through drifts, tunnels, slopes, shafts, etc., have been discussed, but there still remain to be considered the methods of preparing deposits of different size, shape, and inclination for the work of breaking and removing the ore.

Bedded deposits and veins may be considered as similar from the standpoint of development within the deposit, with the possible exception of horizontally lying deposits, when a somewhat different method of procedure will be necessary. Very large veins, zones, and massive deposits may also be considered as similar. Orebodies may, for purposes of development, be divided into two classes, namely veins and massive deposits.

Veins when opened by drifts, slopes, and shafts lying in the deposit give the simplest possible method of development, for all that is necessary is to connect such openings with passages driven in the deposit at more or less fixed distances apart, vertically, thus subdividing the deposit into blocks or zones which may be attacked from one or more directions, or by workings driven up or down the dip. The more usual method is to begin the work of breaking ore from below, thus taking advantage of gravity in drilling, blasting, and handling the ore. (See Fig. 8.)

If the preliminary opening is an inclined or vertical shaft not within the deposit, intermediate connecting passages must be driven to the deposit, from which in turn the horizontal passages in the deposit are driven as in the former case. The intermediate passages are known as cross-cuts and it is the driving of such passages that constitutes the limiting conditions in the use of vertical shafts as previously pointed out.

The horizontal or slightly inclined passages driven in the vein and connecting with the preliminary development openings are commonly designated as levels, differing from drifts in that they do not reach the surface. These horizontal passages are in turn connected with each other by other passages within the deposit and run at right angles to them, thus blocking out the ore and rendering it accessible to the miner and at the same time giving a means of determining the value of the ore thus blocked out. Ore so blocked out is commonly spoken of an an 'ore reserve' and differs from the 'broken ore reserve' in that its value is not definitely known and further has to be mined before it becomes available for removal from the mine for transportation to the mill or smelter.

Passages connecting levels are designated as raises or winzes, depending upon whether they are driven upward or sunk; they are both shafts, in fact, driven from points within the mine rather than from the surface.

Massive deposits and large veins are also developed by drifts, tunnels, shafts, etc., the choice of preliminary opening depending largely upon the depth of deposit from the surface and its position with respect to the surface. When once connected with the surface either by levels in the deposit or by cross-cuts through the enclosing rock, the orebody is cut up into horizontal blocks by a system of passages on the respective levels and does not differ essentially from similar work in veins, except that there are of necessity a larger number of passages on each level arranged so as to facilitate the handling of empty and loaded cars.

With veins and relatively small bedded deposits the working places or stopes run longitudinally with the deposit, while with the massive orebodies and wide veins the stopes are usually run transversely, pillars and stopes extending from foot- to hanging-wall and spaced at regular intervals along the greater dimension of the deposit.

Large outputs require provision to be made for handling large tonnages and consequently a definite and well-developed system of haulage ways must be maintained, with adequate means of drawing the ore from the stopes to points in the haulage ways where it is loaded into cars.

'Branched-' or 'broken-chutes,' 'winged-stulls,' steel chutes, shaking conveyors and a system of haulage ways that permit of handling ingoing empty and outgoing loaded cars without interference are essential parts of the system of development that permit of large scale operations as are necessary with

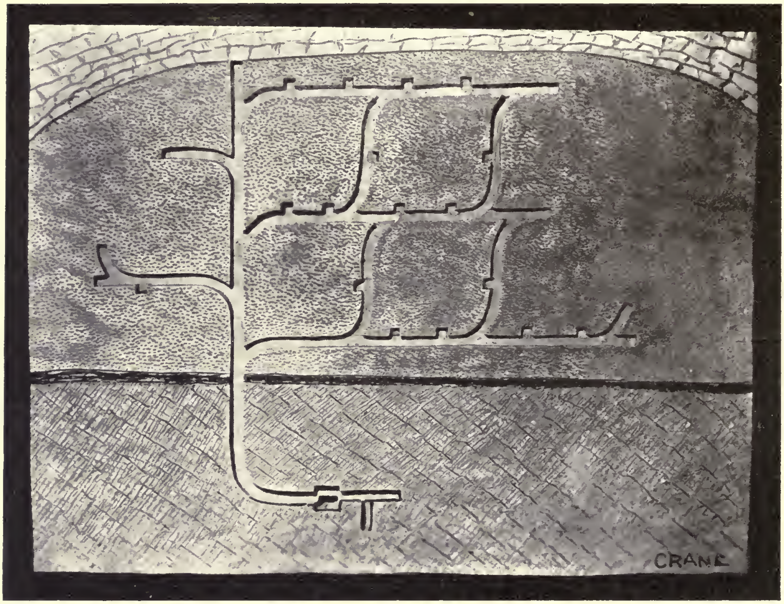

FIG. 10. — Plan of Development on Level in Sub-Level Method. (Modeled after Sketch by Frank Kennedy.)

the employment of filling and caving methods. (See Figs. 10 and 11.)

A well-developed vein or highly inclined bedded deposit may be likened to a high building, narrow but long, the floors of which are served by an elevator. Massive deposits may similarly be likened to a factory covering considerable area, the floors of which are also served by one or more elevators with well-defined passages for handling cars or trucks as well as for the passage of laborers. In a similar manner a horizontal bedded deposit of moderate thickness

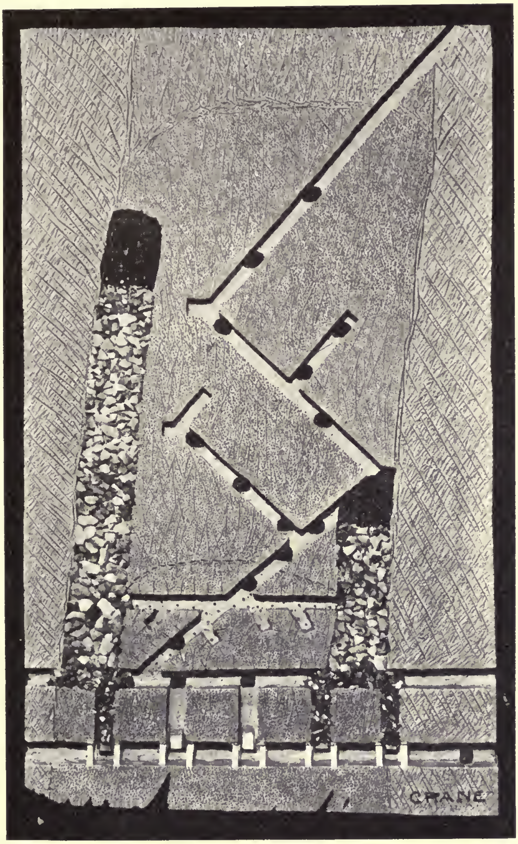

FIG. 11. — Vertical Section through Pillar Showing Development Passages and Chutes for Drawing off Ore. (Modeled after Sketch by T. D. Tallant.)

when developed resembles the streets of a city and not only with respect to the working places in the buildings and the handling of products on the streets and car lines, but with respect to lighting and drainage. As R. B. Woodworth expresses it, "A mine is nothing less than an industrial plant underground."

Maintenance of Output. — Irrespective of the method of development employed in opening a mineral deposit a very important consideration is how large outputs can be obtained and maintained, assuming that the deposit is of sufficient size to warrant large-scale operations. The output from a given opening depends upon a number of factors, such as depth of shaft or length of incline and consequently the number of levels or floors that can be worked, number of hoisting or hauling compartments, capacity of hoist, and method of handling ore underground.

While the capacity of a mine may be increased by adding to the nunber of compartments in the main shaft or haulage way yet there is a limit to the number of compartments that can be efficiently operated. Further increase in output can be obtained only by providing additional shafts or other openings. A mine can, therefore, be considered as made up of a number of units, the unit being a separate opening.

If more than one opening is employed the question as to number of openings and distance between them must be definitely answered. The number of openings required can be obtained directly from the output desired and the capacity of each unit. The distance between openings depends largely upon the method of handling ore underground and consequently upon whether ore reserves are maintained or ore pockets are employed.

The limiting distances for efficient work in moving loaded cars by hand are between 600 and 800 ft.; therefore, the effective width of workings served by a unit is 1200 to 1600 ft., considering the length of levels on both sides of the shaft or incline. With mule or mechanical haulage and well-kept tracks the limits can be materially increased.

The nature of levels is largely exploratory, consequently the knowledge gained in the early work of opening a mine, permits the lower levels to be placed further apart. Greater distances are also permissible with orebodies of large size and uniform in content. Owing to the expense of forming and maintaining track for handling ore on each level, tramming levels may be placed considerable distances apart and the ore delivered to them by ore-chutes and slides.

The number of levels or floors is an important consideration and great care must be taken in the development work in order that the supply of ore coming from the various stopes may be maintained. This can be accomplished by forming ore reserves of either blocked-out or broken ore, which are maintained by opening up new levels below as those above are exhausetd. In many mines it is the practice to open up a new level each month, and yet in spite of such systematic development the occurrence of barren ground, low-grade ore, or the presence of faults, may necessitate radical changes in plans to maintain the ore supply. Exploration by diamond drill is an important adjunct to the work of establishing and maintaining ore reserves, the expense of which is thoroughly justified.

Careful and well-planned development systems are necessary for the proper working of mineral deposits and while the expense may be considerable the saving in operating cost and the high percentage extraction of ore are sufficient warrant for the extra expenditure and time involved.

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CHAPTER III

METHODS OF STOPING

THE openings in metal mines from which ore is taken are called stopes and the methods employed in breaking down the ore are known as stoping. Stoping then constitutes the fundamental operation in the extraction of ore and must be well understood before a discussion of methods of mining is undertaken. Under certain conditions the methods of stoping constitute in themselves methods of mining and give the latter the name of the kind of stoping employed.

The methods of stoping employed in the mines of the United States and, in fact, throughout the mining world may be outlined as follows:

1. Overhand Stoping.
2. Underhand Stoping.
3. Breast Stoping.
4. Resuing.

Other methods of stoping may result through combining overhand and underhand stoping, such as:

1. Combined or overhand-underhand stoping.
2. Side stoping, sometimes called breast stoping.
3. Longwall stoping or cutting-out stoping.

The direction of the working face with respect to the lines of development, as levels, raises and winzes, furnishes the basis for the above classification. The methods of stoping as outlined may then be defined as follows: Overhand stoping is working up the dip and usually in a direction diagonal to raises and winzes; underhand stoping is working down the dip also in a direction diagonal to raises and winzes; breast stoping may be either overhand or underhand stoping applied to deposits of slight inclination and resembles breast work in coal mining; combined stoping is where both overhand and underhand stoping are carried on in the same working place or stope, the two lines of working faces extending diagonally up and down the stope from a common point above or below the center of the stope; side stoping is where the working face is parallel with the winzes; while longwall stoping has the working face parallel with the levels. These terms are, however, more or less elastic and may be employed differently in various districts and mines.

The conditions influencing and controlling the choice of method of stoping are as follows:

1. Character of ore and its value.
2. Occurrence of valuable mineral.
3. Width of vein or deposit.
4. Dip and pitch of orebody.
5. Size and shape of orebodies other than in veins.
6. Character and condition of wall rocks.
7. Cost of timber for support.

Of the conditions given above that of dip or inclination probably exerts the greatest influence on method of stoping, being the principal factor in the choice between overhand and underhand methods. Wide veins or large deposits while often worked by overhand stoping may require breast stoping wholly or in part. The character and occurrence of the valuable mineral while not necessarily influencing the method of attack may require modifications which are more or less radical. The character of wall rock concerns the method of support mainly and therefore affects the general scheme of working rather than the method of attack or method of stoping.

The handling of mineral in stopes varies widely with the method of stoping employed, and may even necessitate a change in method in order that the work may be facilitated and cheapened. The factors which influence the handling of mineral in stopes are, in order of importance, dip and width of vein and character and occurrence of mineral.

Overhand Stoping. — This method of stoping is probably more extensively employed than the other methods, being used in practically all kinds of metal mines where conditions are at all suitable. Overhand stoping is commonly employed in both narrow and wide veins, in moderately highly or highly inclined stratified deposits, and in massive deposits.

The location of a body of ore having been determined by levels and raises or winzes driven through it, the work of cutting out the ore is begun by attacking it on one or both sides of a raise or winze, which connects the two levels and extends through the ore located at that point. (See Figs. 12 and 13.)

As there are several methods of procedure that are dependent upon the character and occurrence of the mineral in the vein, the determining conditions should now be stated. Where all of the vein matter is sufficiently valuable to mine

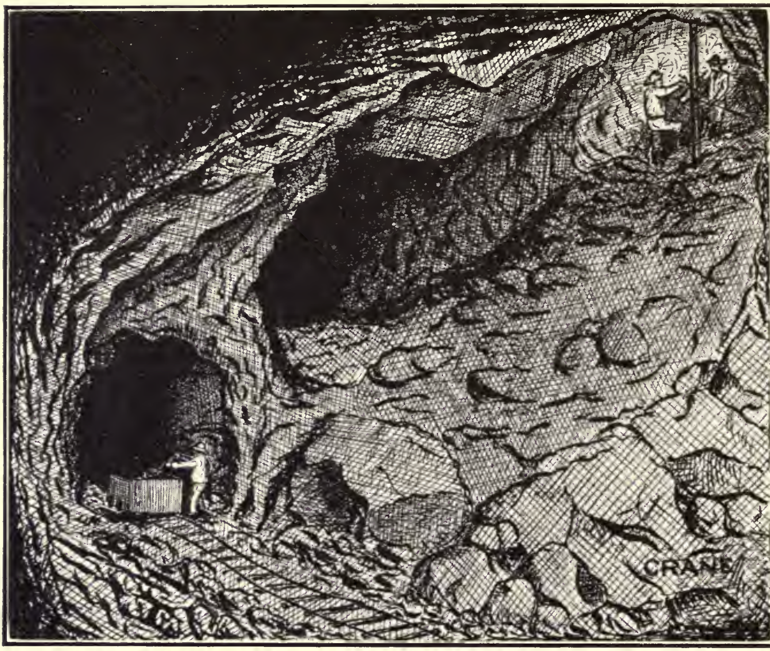

FIG. 12.— Overhand Stoping, 'Breaking-Through.'

it may be broken down, transferred to the level below, loaded into cars and hauled away. There are cases, however, where it is not possible or advisable to dispose of the ore as rapidly as it is mined, although its preparation for withdrawal from the stopes is an important consideration. As ore when broken increases in bulk about 40 per cent it is evident that to provide working space for the miners at the face a certain amount of the broken ore will have to be drawn off after a certain advance has been made. This is known as 'shrinkage' stoping, while the ore remaining in the stope is called an 'ore reserve' and serves a useful purpose in regulating the output of the mine. On the other hand the bulk of the vein matter may be barren or so low-grade as to warrant only the least possible handling, in which case provision must be made for both the storage of the waste and the disposal of the valuable mineral.

In either of the cases mentioned some provision must be made for the support of the ore or waste left in the stopes, if that is done. If all of the ore is removed from the stopes as rapidly as it is broken down, then supports for the maintenance of walls and protection of levels is all that is necessary. Stope marked A–1, in Fig. 13, illustrates the first case mentioned, where the ore is drawn off as soon as broken down. Stopes B and B–1 may be taken as representing the condition where ore is stored in the stopes, forming an ore reserve. Stope A may represent the condition existing in a precious-metal mine where the gold or silver occurs in small veins or stringers, the bulk of the vein-filling being barren or low-grade and is left in the stope.

Stopes may be opened in two ways, namely, by beginning at a winze or raise, or by first driving a 'raise stope.' Raise stoping differs from driving raises mainly in width of passage or cut made, the usual width for a raise stope varying from 20 to 25 feet. From such a starting point the height of the drift may be increased by a 'cutting-out' stope, and consists in removing the vein-content in a more or less regular

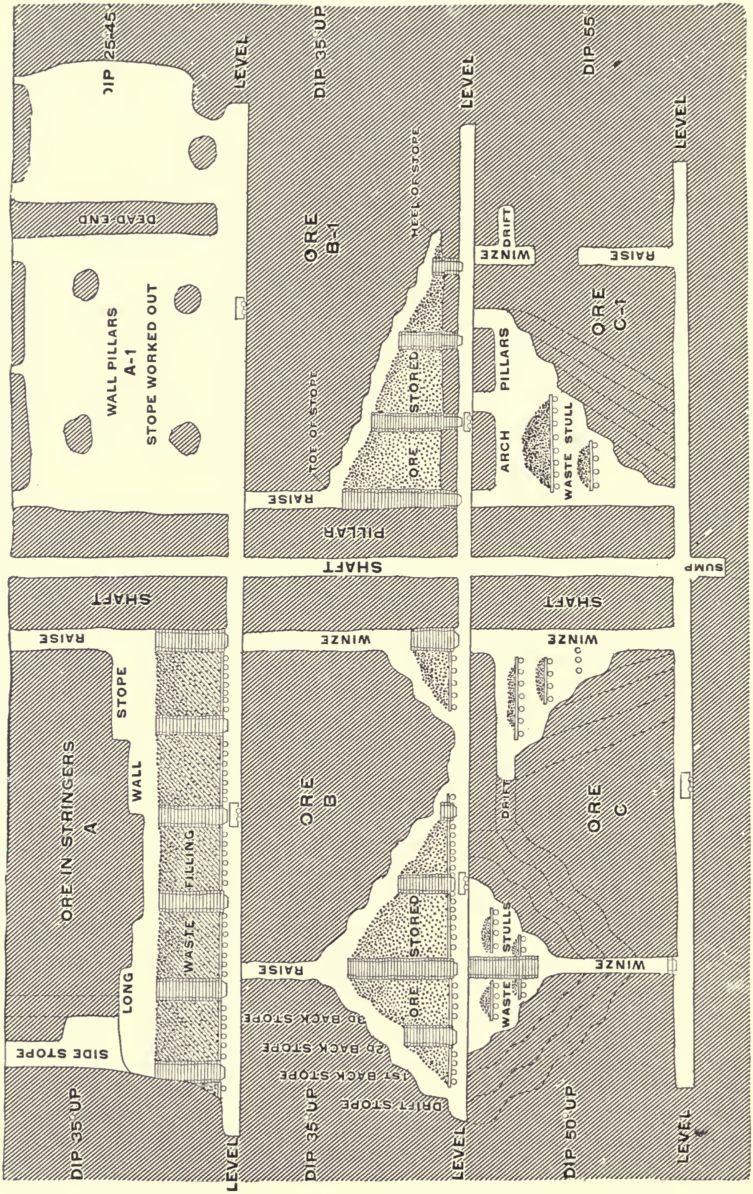

FIG. 13.—Methods of Stoping and Handling Ore. A Composite Sketch.

way, *i.e.*, by cutting out a portion of definite width from the back of the level. This is the usual method of procedure when a stope is started after the level has been run. When, however, drifting precedes breaking ore or stoping by but a few feet, 'drift stoping' is employed in enlarging the level previous to the actual work of stoping, or cutting-out stoping. Drifting and stoping are then combined in one operation

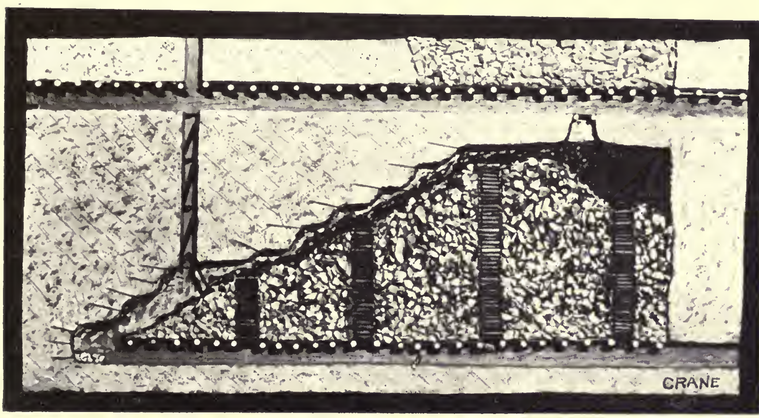

FIG. 14. — Use of Stulls and Waste-Filling.

and consist in carrying a face about 25 ft. high practically the full width of the vein.

As each cutting-out stope is advanced, receding from the common starting point, and is followed by others at regular intervals, the working face of the stope assumes an inverted-stepped appearance as shown in stopes B and B-1, Fig. 13. The successive stope faces are then called 'back-stopes,' being numbered in order from the drift-stope upward (B, Fig. 13). The parts of the stope designated as 'toe' and 'heel' are shown in B-1.

The usual practice in the mines of the United States is to carry the stopes up from the levels without leaving a row of pillars directly above them as shown in stope B–1. Wall pillars are, however, commonly left for support (see stope A–1), which is the usual practice in veins of moderate inclinations. In more highly inclined veins, unless of too great width, stulls and lagging with ore or waste-filling are employed. (See stopes A and B, Fig. 13 and Fig. 14.)

Overhand stoping is employed in veins varying in dip from a few degrees up to the vertical, but may be used more readily in veins of slighter inclination than underhand stoping.

Underhand Stoping. — In many respects underhand resembles overhand stoping, and may be said to be overhand stoping upside down, *i.e.*, the work of breaking the ore is downward instead of upward. (See stopes C and B, Fig. 13.) The relation between the stoping face and the lines of development is also similar to that in overhand work.

The Cornish system of underhand stoping consists in sinking a pit in the floor of a level and then beginning the work of removing the ore by working laterally therefrom. This method has two serious disadvantages, namely: all the ore has to be shoveled out or raised by windlass, and the accumulation of water in the pit so formed will, if the mine is wet, necessitate pumping. Where a piece of ground of limited extent is known to contain valuable ore the Cornish system of stoping may be not only advisable but necessary. When, however, ore has been blocked out between levels and known to extend for some distance along the stope, the method employed in removing the ore should be undertaken on a larger scale and more systematically. Provision will have to be made also for handling the ore quickly and cheaply and for keeping the workings free from water. This can readily be accomplished by beginning stoping on the sides of a raise or winze connecting levels. Ore and water are both discharged through the connecting passage to the lower level, the former being loaded into cars while the latter is conducted by drains to the sumps located in the levels or at the foot of the shaft. (See left-hand portion of stope C.)

Underhand stoping unlike overhand work is not applicable to deposits where only a small portion of the vein-content is valuable, for the very evident reason that there is no convenient place to store the waste. Occasionally a line of stulls may be set in the stope, with a flooring of lagging, thus forming a staging upon which a limited quantity of waste may be thrown. The method is, however, applicable to both high- and low-grade deposits the whole or a large part of which is workable, also to massive deposits where the work of stoping is carried on in horizontal floors.

Underhand stoping may be employed on quite a range of dips, but is most successful in veins of 50° and up, due to the necessity of handling ore by gravity. (See Fig. 15.)

Underhand stoping may be done in very small veins even as narrow as 18 inches.

Both overhand and underhand stoping may begin next to the shaft, the width of shaft pillars, if employed, determining the beginning of the stopes. A winze or raise is driven connecting the levels, forming the shaft pillars and at the same time providing a point of attack in stoping. In overhand work the stope is begun on the corner where the winze and level intersect, successive cuts increasing both the width and height of the stope. With underhand stoping, unless no arch pillars are left, the work of removing the ore cannot begin until a drift is run below the arch pillars, thus

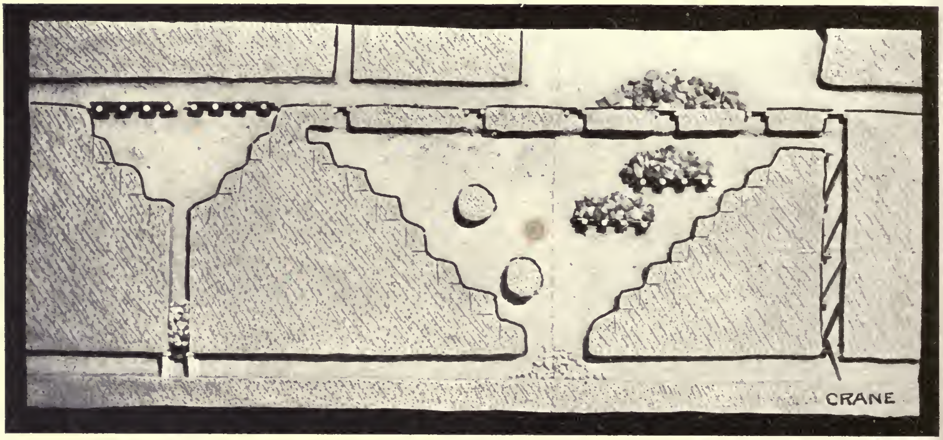

FIG. 15.—Underhand Stoping Methods Showing Wall Pillars and Waste-Stulls.

definitely determining their position and forming them. At the intersection of the drift and winze or raise the work of stoping may begin and extend downward until the level below is reached. The beginning of stoping next to the shaft is shown in stopes B and B–1 for overhand stoping and in stopes C and C–1 for underhand work.

Underhand stoping is largely employed in massive deposits and in slightly inclined bedded deposits of considerable thickness. The opening of a stope may be accom-

Fig. 16. — Plan of Underhand Stoping Workings in Massive Deposit.

plished by sinking a shaft to or near the deposit and drifting into the orebody at a point as near the top as possible. The stope may be increased in height by cutting out the floor of the drift, work beginning at the shaft and extending to the orebody where benches are formed by successively lifting the floor of the drift. The usual height of the individual benches is 8 to 10 ft., but a number may be run together forming a single bench of 50 to 60 ft. in height.

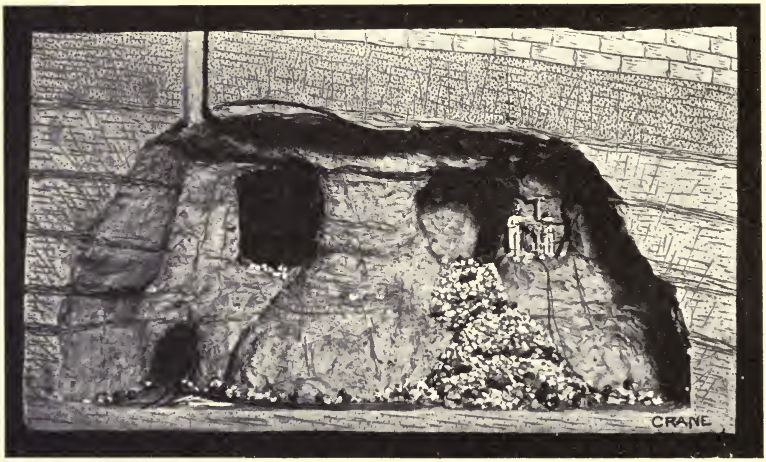

Fig. 17.—Underhand Stoping in 'Sheet-Ground,' Joplin District Conditions Similar to Those in Massive Deposits.

A plan of a mine workings in which underhand stoping has been employed is shown in Fig. 16, the shaded portions indicating parts of the floor that have been stoped to a lower level than the workings in main body of the deposit. The more or less regular arrangement of pillars for support of workings is also shown. (See also Fig. 17.)

As the shape and slope of the face of the stope in such deposits are entirely under the control of the miner and not dependent upon the dip of the vein, the passing of the ore to the foot of the stope can be readily accomplished, its transference to the shaft being done in cars.

Combined Stoping. — Occasionally a stope will be worked by both overhand and underhand stoping, overhand being employed at the bottom and underhand at the top of the stope. The dip of the vein determines the proportionate length of the two working faces; with certain dips as 50 to 55° the length of the underhand stoping face exceeds that of the overhand face, while with dips of 25 to 30° the reverse is true. The reason why underhand stoping is employed at the top and overhand at the bottom of the stope is that with a reversal of the arrangement a reëntrant angle would be formed between the two working faces, thus forming a 'tight corner' which is difficult to work. An advantage of the usual arrangement is that the angle formed by the faces, coming as it does in the center of the stope, makes the forming of wall pillars comparatively easy; the more acute the angle the more readily are the pillars formed.

With high dips the underhand face increasing in length has all the advantages of underhand stoping and at the same time materially assists in handling waste and placing it on 'stull floors' in the overhand part of the stope. When the dip is such as to require that the overhand face be longer, the short underhand stope above may be of advantage in handling a considerable part of the ore at the top of the stope, which can be thrown or raised to the level above instead of being transferred down through the stope to the level below. Higher stopes can be worked to advantage by combining overhand and underhand stoping, which permits the levels to be placed farther apart and so reduces the cost of development work. The chief advantages of the method then lie in the convenience of handling ore and

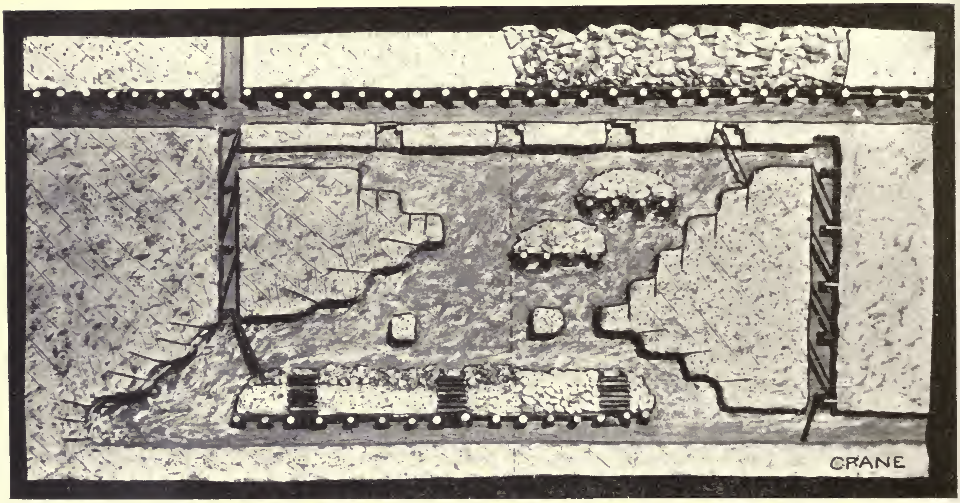

Fig. 18. — Combined Stoping in Moderately Dipping Vein.

waste in the stopes and in reducing development work. (See Fig. 18.)

Breast Stoping. — When the inclination of the vein or bed is such that the broken ore cannot be passed to the level below by gravity, but remains close to the face and must be loaded into cars at that point, neither overhand nor underhand stoping can be employed to advantage. The method employed is then ordinary breast work, and the direction of the face may be carried in practically any direction. This method permits the placing of holes so as best to take advantage of the conditions existing at the face; the principal disadvantage being that the cars must be run to the face, thus increasing the cost of handling.

Side Stoping. — As previously pointed out, side stoping and breast stoping are often spoken of as being similar operations, but strictly speaking they are not. Side stoping is carried parallel with winzes or raises, which as in the case of the other methods of stoping are the initial points of attack. This method of stoping is not confined to slight inclinations as would be the case were it similar to breast stoping.

There is no method of stoping in which the direction of the working face, the distinguishing characteristic of the methods, is more than approximately maintained, and there is no method of stoping which is apt to have the direction of the face vary more than side stoping. Raise stoping and side stoping are similar if parallelism to raises and winzes is the distinction, but raise as well as drift and cutting-out stoping are phases of overhand stoping; however, as the term side stoping has been applied to a certain direction of working in stoping, and as it is similar to raise stoping, the name may be applied to both alike. (See stope A, left-hand side, Fig. 13.) The first cut in side stoping is driven directly up the dip, being commonly employed in forming shaft pillars, dead-ends, etc., and in starting cutting-out stopes in overhand work. When employed in this manner side stoping serves as a supplementary method to overhand stoping, but its application may be extended to the regular work of breaking ore, successive cuts being taken off the sides of the first side or raise stope. The tendency is, however, for the direction of the work to change so radically as to lose its identity as side stoping and merge into overhand work or underhand work, usually the former.

Longwall Stoping. — Raise stoping has been shown to be a phase of overhand stoping. In a similar manner cutting-out stoping corresponds to longwall work. Further, breast and side stoping may be said to be similar to longwall work unless parallelism with the longer dimension of the stope is a desideratum.

As usually carried on, longwall stoping is applied to that class of overhand work where the working face is parallel with the levels and constitutes an important part of the work of breaking ore as the work of stoping is carried on in many districts. (See stope A, Fig. 13.) While longwall stoping may be employed in veins of slight or moderate inclination, as when breast stoping is applicable, and cars are run parallel with the face, yet it is just as often employed in steeply inclined veins where ore or waste is stored in the stopes. (See stope A, Fig. 13.) Although there may be no advantage in breaking ore by this method, yet there is a positive advantage in handling ore on a level floor, compared with similar work on an irregular and sloping bank of ore as in overhand stoping. (Compare stopes A with B and B-1, Fig. 13.)

Resuing. — This method is a special application of stoping to narrow veins or stringers and is in reality a stripping method. Resuing consists in opening up the stopes not in the vein but in the wall rock, by whatever method of stoping seems best adapted to the existing conditions, and when sufficient space has been provided by stripping one wall from the ore it is broken down and handled practically independently of the waste.

When the values are definitely known to occur in the vein alone, this method of procedure is especially applicable, but when, as often happens, the values also extend into the walls, the usual methods of stoping are probably more applicable.[1] The extra width of drifts and stopes may also serve to uncover and discover other workable portions. Where the condition of the vein-filling and wall rock permit, much cleaner ore can be produced, which may be the determining factor in the economical working of a given deposit. However, the sorting of waste rock under the unfavorable conditions existing underground, often resulting in the necessity of sending considerable waste rock to the surface and the treatment of the same, may make it inadvisable to employ resuing.

Resume of Stoping. — The conditions under which the different methods of stoping are especially applicable, with the advantages and disadvantages of their use, are as follows:

Overhand Stoping has a wide range of application both as to character, inclination and width of deposit. The method is employed in very narrow and very wide veins and even massive deposits, but when considered as a distinct method of mining its application is limited to moderately narrow veins or beds, as from 4 to 12 ft., and to inclinations of 10 to 90° with the horizontal.

[1] "A peculiarity of the Porcupine goldfield is the way in which the metal is 'shot' through the schist on either side of the veins. This is so to such an extent that in some of the mines a vein of two inches of quartz is mined to a width of five or six ft."

The advantages of overhand stoping are:

1. Levels may be driven at considerable distance apart, ranging from 100 to 150 ft., and occasionally greater distances.

2. Greater safety to men, as the roof is accessible and can be examined and made safe as signs of weakness develop. This is especially true when the roof is the working face, as is the case with steeply inclined deposits.

3. A large working force can be employed in a comparatively small space, which results in reduced cost of extraction per ton of ore.

4. Either ore or waste can be stored in the stopes, which assists materially in the support of the workings.

5. The ore as broken down falls free of the face and by gravity moves toward the point of delivery.

6. Where ore is stored in the stopes a 'reserve' is formed, thus regulating and maintaining the output independent of temporary stoppage of mining operations.

7. Large and regular outputs are possible.

8. The face of the stope is usually opposite a number of chutes into which the ore may be thrown.

The disadvantages of overhand stoping are:

1. Considerable timber is required for support, or if wall pillars are employed a loss of ore may result.

2. When ore is left in the stopes it serves as a platform for the men to work upon, which may prevent a stope being emptied until all ore is removed up to the arch pillars. This difficulty may be largely obviated by using 'stull-floors,' but this necessitates the use of considerable more timber.

3. Dust is troublesome, especially in dry mines, as the holes are largely drilled 'dry.' By a slightly different arrangement of the working face the direction of the holes may, however, be altered, changing them from 'dry' to 'wet.'

Underhand Stoping is also employed in both veins and massive deposits, but is applicable to higher inclinations (38 to 90°) in veins than is overhand work. As a distinct method of mining, and not simply as a method of attacking the face, underhand stoping is applied equally well to narrow and moderately wide veins and massive deposits.

The advantages of underhand stoping are:

1. Ease in drilling and blasting, especially when hand drilling is done.

2. Comparatively small amount of timber is used.

3. When proper slopes are maintained in the stopes the ore can be handled largely by gravity.

4. Little trouble is experienced with dust.

The disadvantages of underhand stoping are:

1. The method is limited to veins or highly inclined bedded deposits where all or a large part of the deposit is of sufficient value to mine.

2. Levels are run closer together in order to reduce the amount of exposed roof and consequently diminish the danger of falls.

3. The working face is small, the lower part of the stope face being largely covered with broken ore; the output is therefore small.

4. Inconvenience resulting from having no 'ore reserve,' often necessitating underground or surface ore bins of suffi-

cient capacity to maintain the output of the mine should it be necessary to temporarily stop breaking ore.

5. The difficulty experienced in disposing of waste sorted from the ore.

6. Loss of ore in pillars.

Breast Stoping is applicable to inclinations below the angle of repose of broken ore, which is about 38° with the horizontal. As a rule, however, breast stoping is usually carried on at much lower dips as under 10°. Thick deposits may be worked in benches, but this usually leads to a combination of breast and underhand work. A deposit 10 ft. thick can readily be worked by breast stoping; the height of face increasing the fall and consequently the distance that the ore will travel from the face on moderate dips.

The advantages of breast stoping are:

1. Deposits of low dip can readily be worked.

2. The best conditions for mounting drills and taking advantage of working face are obtained.

3. Cars may be run close to the stope face.

4. Considerable waste may be left in stopes without extra handling.

5. Ease of entrance and exit to and from the stopes.

The disadvantages of breast stoping are:

1. Levels are close together.

2. Much timber is used for support.

3. Extra cost of laying track and maintaining proper grade to working face.

4. Difficulty in handling ore in stopes.

Resuing is applicable to very narrow veins alone, *i.e.*, under 30 in. in width; its chief advantage being that a cleaner grade of ore can be mined than when both vein and walls are broken together; further, it is often useful in opening up unsuspected bodies of ore existing in the walls, but as the work is confined to one wall only such application is limited.

Other Methods of Stoping such as *combined*, *side* and *long-wall* stoping are special applications of overhand and underhand stoping and are therefore employed under somewhat similar conditions, especially as to thickness and inclination of deposit.

The advantages of combined stoping are:

1. Long stope backs, *i.e.*, higher stopes may be employed than with underhand stoping especially.

2. Wall pillars can readily be formed at the junction of the overhand and underhand portions of the stope.

3. Waste can be stowed to advantage on lagged stulls in the overhand portion of the stope.

4. A certain amount of ore can be transferred to the level above from the underhand portion of the stope, thus reducing the amount that must be handled below.

5. The intermediate dips between those to which overhand and underhand stoping are applicable can be worked to advantage by this method.

The disadvantages of combined stoping are:

1. The limitations as to dip vary probably between 35 and 50°, above and below which the method merges into all overhand or underhand work.

2. Tight corners are formed both at the top and bottom of the stope, when lines of pillars are left for the protection of the miners in the stopes and above the levels.

Side Stoping is not very extensively employed, having special application in cutting out and forming pillars, such as shaft pillars and dead-ends, but is used very little in the operation of breaking ore. Its principal advantage lies in the fact that it is straight-cut, up-dip work, in which drilling and blasting can readily be done, the face clearing itself by gravity. The tendency for the face to narrow, due to the tight corners and the limited space in which work must be done, especially in making the first cut, is the chief objection to the method.

Longwall Stoping is strictly an overhand method and is extensively employed in the whole range of dips to which overhand stoping can be successfully applied.

Probably no class of overhand stoping presents more advantageous conditions for the work of breaking ore and its disposal than does longwall stoping, the working face being level and adjacent to a larger number of chutes than is the case with any other method. Further, cars or wheelbarrows can be employed to advantage in handling and distributing both ore and waste, but are applicable only when the stope is filled with waste or ore, or there are intermediate levels built on stulls. Irregularities in the deposit, such as barren portions, seriously interfere with the work and often require a change in method.

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CHAPTER IV

METHODS OF HANDLING ORE IN STOPES

The ways and means employed in handling ore in stopes are almost as varied as the methods of stoping, and in fact the handling of ore in the working places often has a controlling influence on the methods of extracting the mineral. As the methods of stoping are fundamental operations in the extraction of ores, so in like manner the methods of handling the ore in the usual stoping operations are similar to all other methods in use regardless of what kind of mineral or metal is mined or how it is mined.

From the standpoint of handling ore the work may be divided into two classes as in open and closed stopes. The former comprises the simplest class of work, while the latter is by far the most important both as to kind and extent of operations.

Open stope work may include practically all methods of stoping, but is usually applied to moderate inclinations and especially such that the broken ore will move downward by gravity with or without assistance. The best results are secured when the deposit dips at an angle of 38 to 40°, or is equal to the angle of repose of the broken ore. With a fairly even footwall or floor standing at a proper angle, ore can be readily transferred for a distance of several hundred feet, and that too regardless of whether overhand or underhand stoping is done.

Handling Ore in Open Stopes

On reaching the bottom of the stope the ore is either shoveled into cars standing on the level tracks or may be run on to docks from which it is shoveled into cars. The latter method is preferable from the standpoint of shoveling, but is not as extensively employed as the former. (See Fig. 19.)

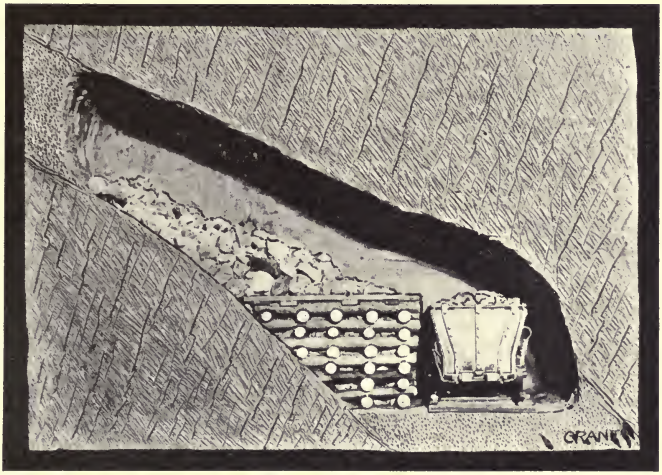


Fig. 19.—Ore-Loading Dock in Open Stope.

When the footwall is somewhat uneven, or the dip is several degrees less than the angle of repose of the ore, it may be found necessary to assist gravity in the transference of the ore either by actually shoveling or raking, or by placing it in chutes of wood or metal, the angle of which is greater than that of the stope floor, or the friction less than that between the ore and stope floor.

Shoveling is still largely employed in certain districts and with both overhand and underhand work. Sheets of boiler plate may be laid on the stope floor as in coal mining, extending from the bottom of the stope to the working face, the sheets overlapping shingle-fashion. Better still is the use of curved sheet-metal chutes, which may be placed similarly to the plain sheets, but are easier to handle and consequently more care is usually taken in mounting them with regard to both direction and inclination. Stopes with inclinations falling to as much as 15° below the angle of repose may have the ore handled without difficulty by such means. In order that the momentum of the ore may be checked somewhat before entering the car at the bottom of the stope, it is customary to materially reduce the slope of the last two or three sections of chute. (See Fig. 20.)

The use of metal chutes may be extended to stopes of very slight dip by giving them a shaking motion, while the monorail and chain conveyors are now being employed to transfer mineral for considerable distances in mines and under practically all degrees of inclination, even reverse grades.

A unique method of overcoming an exceedingly rough and irregular floor of stope is that in use in the North Star mines, Grass Valley, California. The gravity plane idea as employed in coal mines has been adopted. A double line of track is laid directly up the dip of the stope at the upper end of which is set a post to which is attached a three-wheeled device called a 'go-devil.' A steel cable passes from the bottom to the top of the plane, being attached to an empty

Fig. 20.— Loading Cars by Chute, Mohawk Mine.

car below and after passing around the three grooved wheels of the go-devil extends and is attached to a loaded car at the top of the plane. The go-devil is controlled by a hand-brake, and when pushed off the landing the loaded car runs to the level below, drawing up the empty car. This system has proved very successful and is extensively employed in these mines.

In deposits of slight inclination, where breast stoping is employed, cars are run to the face on track laid diagonally up the stope and maintaining a grade such that the cars can be controlled by brakes or sprags. The character of the ore has an important bearing upon the distance that it will travel from the face on being blasted down. This can be illustrated to good advantage by citing the conditions existing in the hard iron ore mines of the Birmingham district, Alabama. To a certain depth below the outcrop the ore has, in many places, been rendered more or less soft by percolating waters; below this point the ores are still hard. Stopes carried on moderate inclinations in the hard ore will deliver a large part of it at the bottom of the stope, as it breaks coarse and rolls well; with the soft ore the reverse is the case, the ore breaks moderately fine and slumps down close to the working face, necessitating the employment of cars throughout the stope. (See Fig. 21.)

Handling Ore in Closed Stopes

Closed stope work as distinguished from open stope work has the levels roofed over and protected by pillars of mineral, by stulls and lagging covered in turn with waste, by pack-

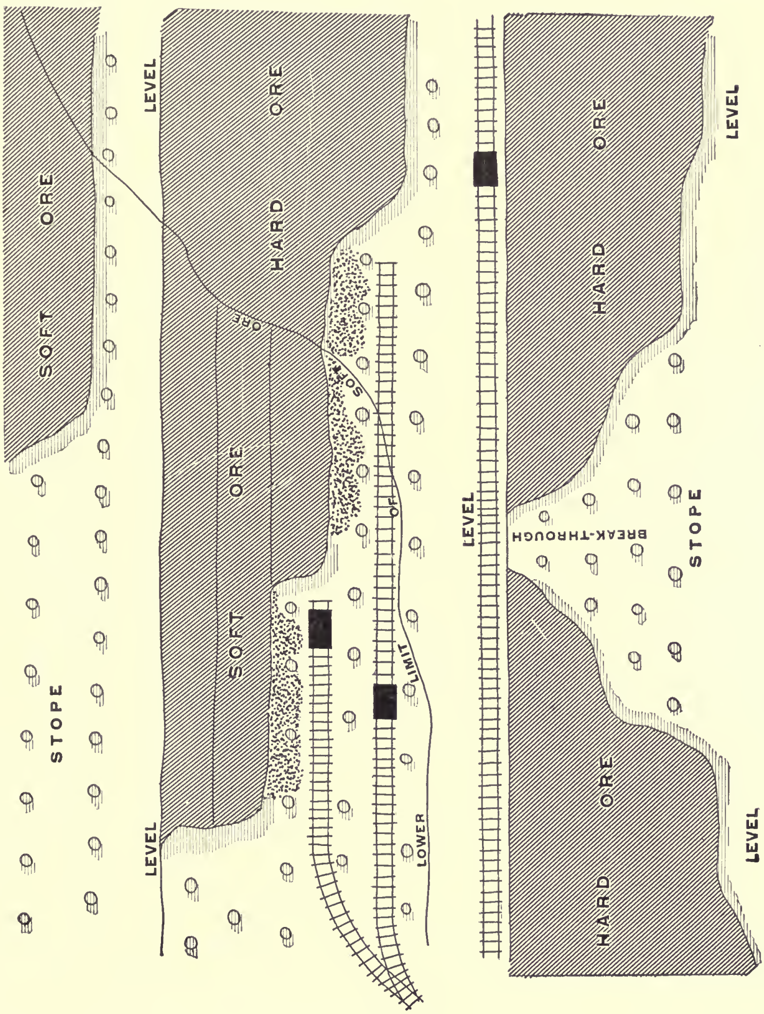


FIG. 21.—Portion of Stope showing Method of Handling Soft Ore.

walls, etc. (Fig. 2.) In wide veins or massive deposits the levels may be protected by sets and square-sets held in place by stulls, filling, etc. (See Figs. 1 and 4.) In either case connection is made between the levels and open stopes by passages commonly known as chutes, mill-holes, passes, etc. (Figs. 11 and 14.)

In both overhand and underhand stoping, pillars are occasionally left directly above the levels which serve the

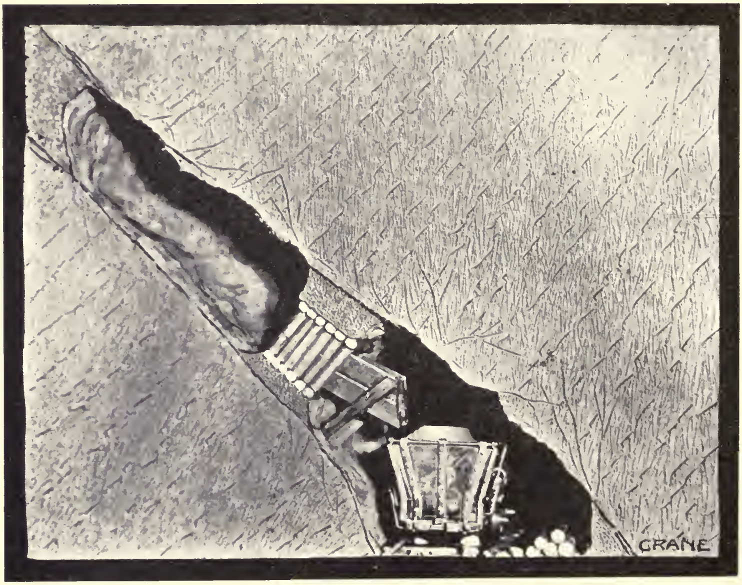


FIG. 22. — Block-Hole Fitted with Chute for Passing Ore through Pillar.

double purpose of support and protection to the levels. Holes called 'block-holes' are cut through these pillars at intervals of 25 ft. or more the ore being passed through them to the cars below. (See Fig. 22 and stope B–1, Fig. 13.) A line of stulls may be employed in place of pillars and serves the same purpose. On moderately flat dips, and where there is little or no waste to be disposed of, the ore may be transferred to the bottom of the stope as in open stopes, the advantages being that the levels are not cumbered by ore running down from the stopes above and that the cars are loaded by gravity.

When stulls are used the line of stulls and covering of lagging may at intervals be extended in a diagonal direction for some distance up the stope, meeting similar lines run in opposite directions. This arrangement is called 'winged stulls' and is useful in collecting the ore sliding downward and in delivering it to the chute gates extending through the line of stulls. (See Fig. 23.) By this arrangement chutes may be placed further apart.

Chutes and Mill-Holes

In stopes where a filling of waste or ore is employed, built-up chutes, consisting of either walled-up, well-like openings, cribbed passages, or passages one side of which is wall rock (usually foot-wall) the other sides timber, are extended through the filling to the stope above. These passages, usually the timbered ones, are often made with two compartments — one for ore, the other for a manway.

Stope-chutes are formed in the ore or rock at the side of stopes and serve to draw off the surplus ore (Fig. 24).

In narrow veins the chutes usually follow the dip very closely and are often built on the foot-wall, while in wider veins they may be vertical or inclined at whatever angle seems best suited to the character of the ore and the chute

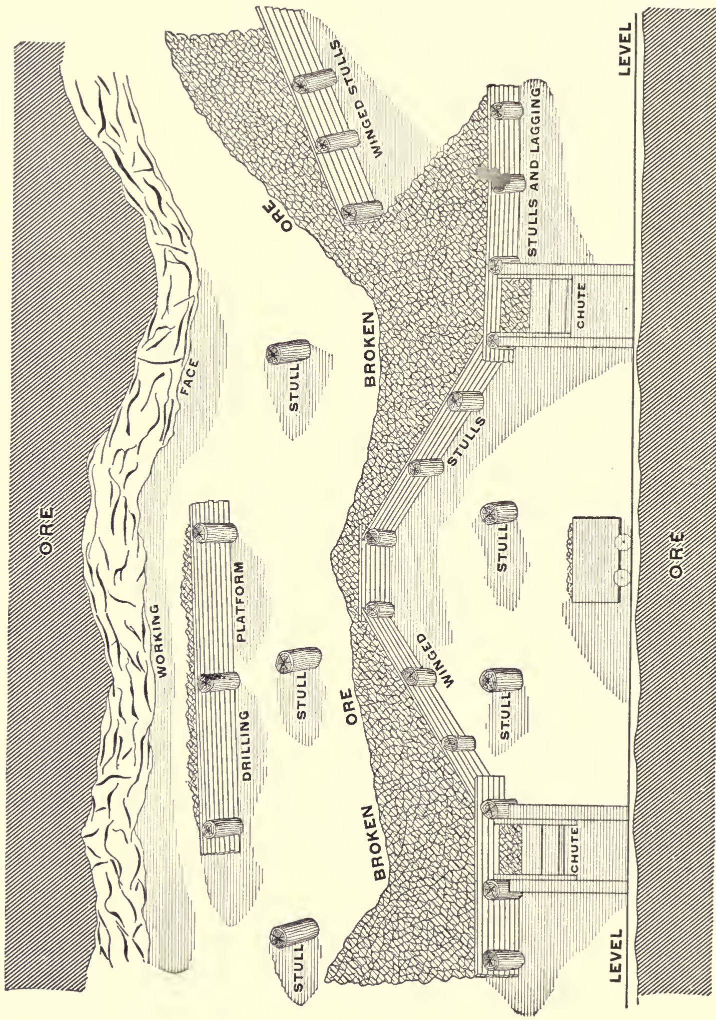


FIG. 23. — Use of Winged-Stulls in Handling Ore.

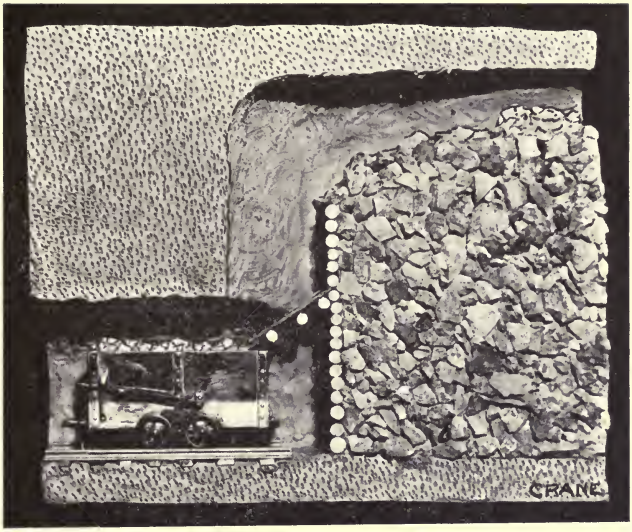


FIG. 24. — Stope-Chute for Handling Excess Ore in Stope.
(Modeled after Sketch in Mining and Scientific Press, vol. 98, p. 556.)

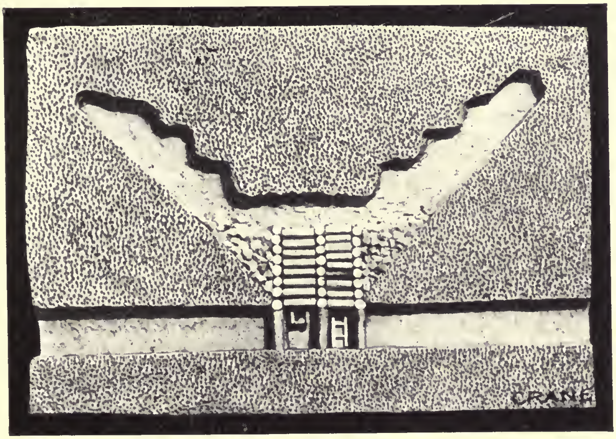


FIG. 25. — Chutes Used in Developing a Shrinkage Stope with Cribbed Chute and Manway. (Modeled from Sketch by J. E. Wilson.)

lining. (Figs. 11 and 25.) In vertical chutes of small section there is danger of their becoming choked up, requiring the use of explosives, which must be used with care to prevent damage to chute walls. Broken-sloped chutes are preferable when long lines must be employed. The branched chutes occasionally used with square-sets in the mines of the Cœur d'Alêne District are good examples of broken-sloped chutes. Several portions of a stope may be served by branches extending at various angles and in a number of directions from the main chute; the movement of ore, especially in steep chutes, can be controlled to better advantage by their use. Broken-sloped chutes driven in solid ground are found to give better results when the first portion above the point of delivery of ore is vertical, the remaining portion standing at an angle of 50° or more from the vertical. It is claimed for such chutes that the change in direction prevents packing of ore and choking of chutes. This arrangement proved very successful in the caving system employed in the Bingham Canyon mines.

Broken-slope chutes also serve a useful purpose in discharging into ore bins, preventing choking of chutes and bins and relieving the gates from excessive pressure. (Figs. 11 and 26.)

At the lower end of the chutes must be some device not only for directing the ore into cars but for controlling the flow of ore from the chutes. This is accomplished by having a sloping spout attached to the bottom of the chute, provided with a gate and controlled by a hand lever. Unless constructed of proper section and given a suitable slope the ore will become jammed in and will not discharge. A method of discharging ore from stopes, often used in the Australian mines, goes by the name of 'chinaman chute.' The chinaman chute consists of a platform, built several feet below the line of stulls, containing a number of openings through which ore is discharged into cars below. The openings are usually provided with grizzlies for sizing the ore. An

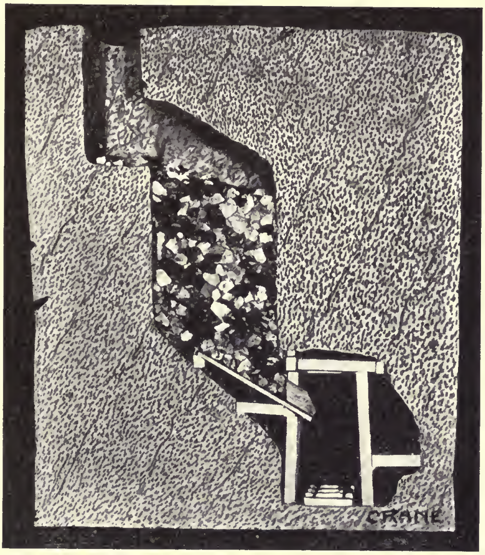


FIG. 26. — Broken-Slope Chute and Ore Pocket as Used in the Copper Queen Mine. (Modeled after Sketch by F. G. Sherman.)

opening in the lagging permits the ore to flow from the stope on to the platform, where it piles up until the opening in the stull lagging is reached. On removing the covers to the platform openings the ore falls into the cars, and when a certain amount has been drawn off a movement of the ore in the stope again takes place. The flow of ore from the stope is then automatically controlled by the operation of loading cars. (See Fig. 27.) Another type of chinaman chute is shown in Fig. 28.

Handling ore at the working face may be done by hand, *i.e.*, by shoveling, but when this is the practice the chutes or mill-holes must be placed closer together and should not exceed 25 ft. apart. In wide veins where the stopes are large,

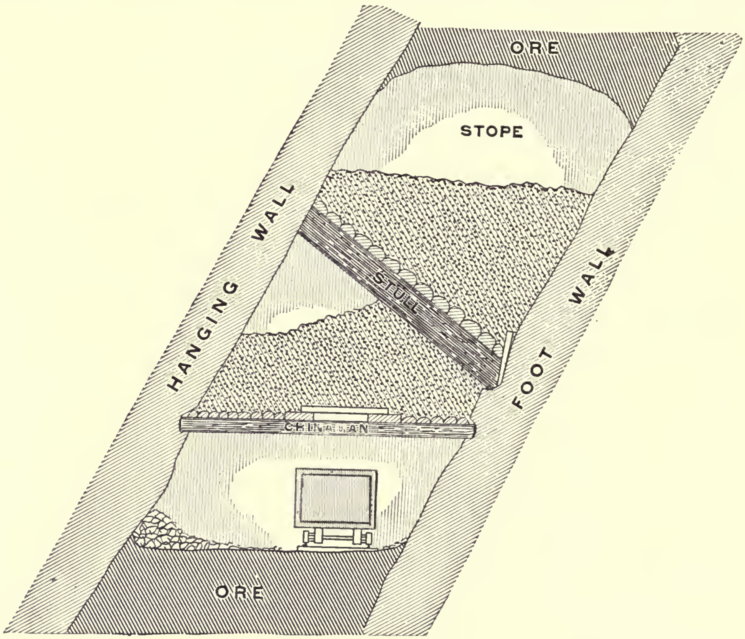


FIG. 27.—A Chinaman Chute as Used in Australian Mines.

wheelbarrows may be employed, also cars; in which case the chutes may be spaced much further apart, as from 35 to 55 ft.

Other devices might be described and cases cited illustrating the uses of chutes and loading mechanisms, but those given will serve to show the general methods of procedure and the importance of efficient methods of handling ore.

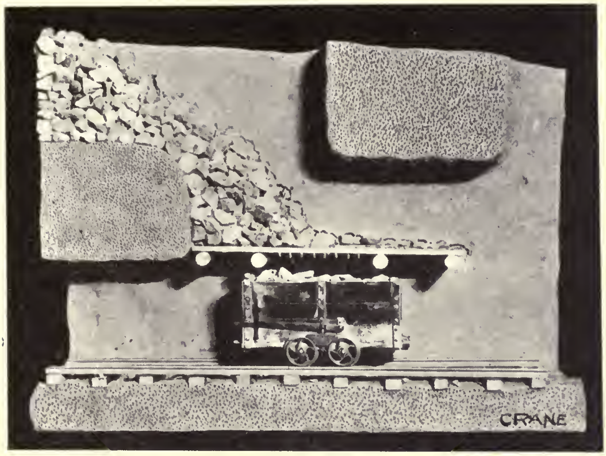
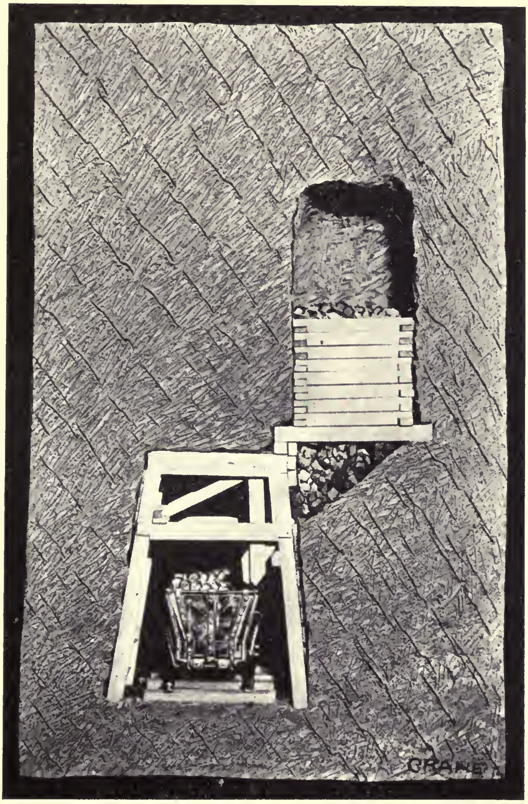


FIG. 28. — Chinaman Ore Chute Provided with Grizzly.



B. — Chute Used for Handling Ore in the Miami Copper Mine.
(Modeled after Sketch by David B. Scott.)

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CHAPTER V

MINING IN NARROW AND MODERATELY WIDE VEINS AND BEDDED DEPOSITS

INTRODUCTION

As the methods of breaking down ore or stoping have already been discussed and their relation to the handling of ore in the working places and the development work of the mine has been indicated, the methods of mining may now be taken up. Mining is the working of mineral deposits and includes all phases of work pertaining thereto, as prospecting, development, exploration and extraction of ore. Methods or systems of mining, as generally considered, consist of the development and working of deposits, but by common usage the meaning of the terms has been extended and now includes the working of deposits, support of workings and handling of the ore. The expressions overhand and underhand mining, square-set mining, the top-slice and sub-drift cavings systems of mining, etc., illustrate the indefiniteness of such a designation as method or system, but it must be admitted indicate the salient features of the work done, and at the same time are probably less cumbersome than other more exact and discriminating designations.

In the following pages are given methods of mining applicable to narrow and moderately narrow veins and bedded deposits and they are considered in order of their simplicity and ease of working. The following methods are discussed: mining bedded deposits by the use of props; mining mineral veins by the use of stulls; mining mineral veins by the use of square-sets; mining mineral veins by the use of filling; and mining veins and bedded deposits by caving.

An endeavor has been made to limit the discussion of methods of mining in this chapter to veins and deposits not exceeding 35 to 40 ft. in width and particularly to much narrower ones, but it has been found difficult to do this. A few descriptions are given of deposits averaging 35 ft. and over, where good descriptions of narrower veins were not available from the writer's personal experience or from technical literature.

Mining Bedded Deposits by the Use of Props

Underhand Stoping with Props

The iron mines of the Birmingham district, Alabama,[1] are good illustrations of the application of overhand stoping to bedded deposits of slight and moderate inclinations. The strata worked vary from 10 to 20 ft. in thickness, while the dip ranges from 8 to 50° and above, but averages about 12°. The ore occurs in the Clinton formation of the Red Mountains; it is hematite and was originally very hard, but owing to the leaching action of percolating waters the upper portions have been changed more or less into a soft ore, due probably to the loss of lime.

1. Birmingham, Ala.
2. Iron ore.
3. Bedded deposit.
4. Thickness 10 to 20 ft.

[1] Iron Mining in the Birmingham District, Alabama, by W. R. Crane, Eng. and Mining Jour., Vol. 79, p. 274.

The irregularity of the limit of soft ore is shown in Fig. 21. The formations overlying the iron ore are largely sandstones, while shale occurs below.

These mines are opened by slopes or inclined shafts in the deposit, from which at intervals of 50 to 60 ft. levels are driven. The levels are run at a width of 12 to 15 ft. for a distance of 100 to 150 ft., beyond which point they are increased to 20 or 30 ft., forming low stopes. On both sides of the shaft, pillars are left which vary in width from 60 to 75 ft. The width of the pillars is definitely determined by airways and manways which parallel the shaft. Along the levels break-throughs are formed in the arch pillars, making connection between adjacent stopes, and serve as means of inlet and exit to and from the stopes as well as a convenience in carrying air lines to all parts of them; ventilation is also facilitated.

The stopes having been driven to the limit of economic handling of ore on the levels, the direction of working is reversed and the ore left standing in pillars during the first part of the operations is now removed. The method of mining then resolves itself into room-and-pillar work by advancing and retreating, the larger part of the ore being mined from the pillars and therefore by pillar-drawing. The drawing of pillars may be accomplished by cutting off longitudinal or transverse slices; the former when the ore is moderately soft and the stopes are high, the latter when hard or moderately hard ore is worked and the levels are close together.

Hard ore breaks up into relatively large pieces which under the impulse of the blast readily finds its way to the bottom of the stopes; while the soft ore, which is more or less earthy in character, slumps down and does not travel far from the working face. It is evident then that when soft ore is mined either the levels must be driven closer together or the cars must be run up into the stopes to the working face; in fact both methods are employed, but as levels should not be run too close together, even if formed by stoping as it is an expensive operation, the running of cars into the stopes is usually preferred. (See Fig. 29.)

With low dips the method of attack, although up the dip, as in overhand stoping, resembles more closely breast stoping and has all the advantages of such work.

Owing to the comparatively slight inclination of the deposit practically the whole weight of the roof must be supported, therefore necessitating considerable support, which is provided by an extensive use of props. These props vary from 8 to 14 and 16 in. in diameter, being used in the rough, and are spaced from 6 to 25 ft. apart according to the condition of the roof. The drawing of pillars in the upper levels and the caving that results relieves the pressure to a certain extent in the lower levels, but with greater depth of working the problem of support will become more serious and may require a change in the method of working.

The advantages and disadvantages of the method described above have already been given under the respective heads of overhand and breast stoping, but, as previously indicated, a serious disadvantage is the high cost of development resulting from running levels close together, but it is

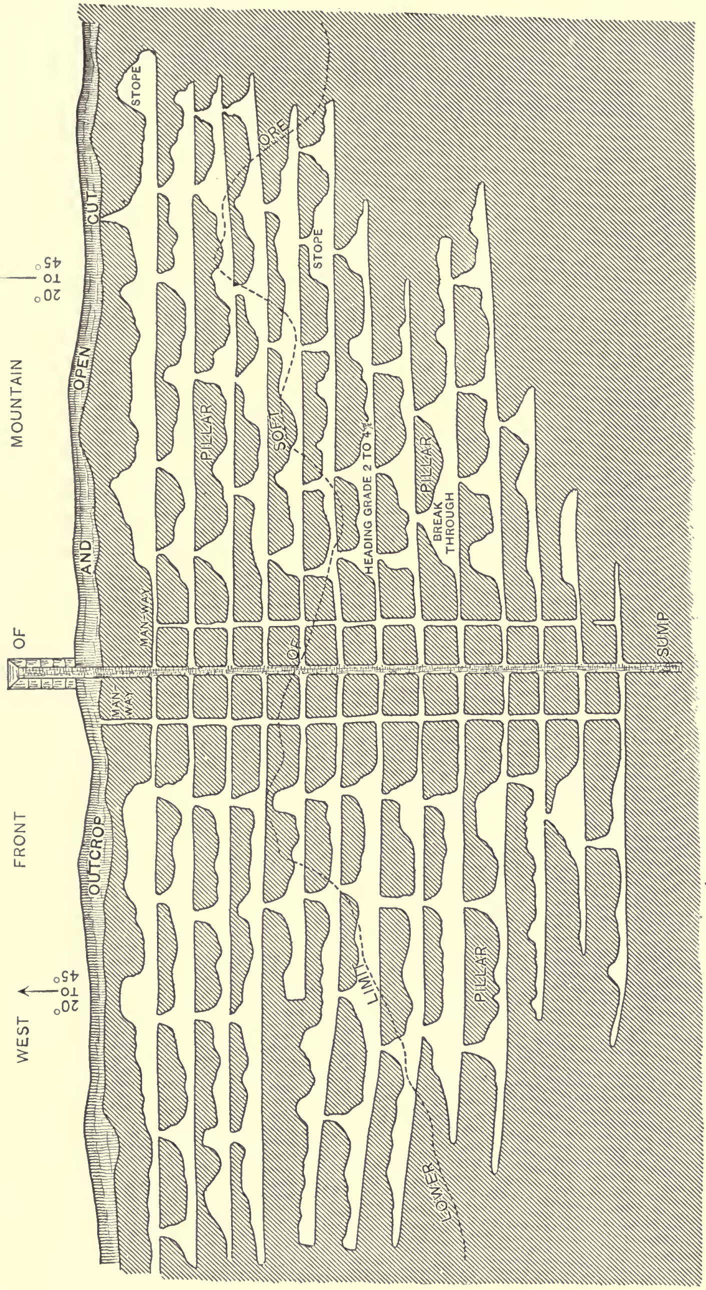


FIG. 29.—Plan of Iron Mine, Birmingham District, Alabama.

claimed that this is largely offset by the thickness of the workable strata and the large outputs obtained from small areas. The cost of timber is also a large item.

Mining Mineral Veins By the Use of Stulls

Stull-floor Method

1. Tonopah Mine, Nev.
2. Gold and Silver.
3. Veins.
4. Width 8 to 10 ft.

Of the various methods of maintaining stopes employed in the Tonopah mines, the use of stulls is probably the most common. Square-sets are also employed, but owing to the cost of suitable timber, that method of support is resorted to only in special cases. Owing to the value of the ores, which ranges from $12.00 to $50.00 a ton, it is desirable if possible to remove the entire mass of the vein-filling and often a part of the wall rock. The total extraction of the ore is then the ultimate aim of the mining operations, which is readily accomplished by the method employed, being overhand stoping by the use of stulls.

The ore formation consists of a broad belt of fissure veins often occurring close together. The deposits occur in andesite either as fissure or contact veins, and but few of them reach the surface. A peculiar feature observed in working some of the larger veins is that their course as followed on the dip is broken by flats and pitches, resembling to a marked degree a huge flight of stairs, which is due to faulting.

The veins are opened and developed by vertical shafts and cross-cuts, which divide the deposits into lifts lying between levels spaced about 100 ft. apart. In the Tonopah Mine stopes are carried up the full width of the vein, the walls being supported by stulls. At a height of 8 to 9 ft. above the sill-floor of the stope a row of stulls is placed in a horizontal position and wedged fast between the walls. In order to properly support the horizontal stulls two or more posts, depending upon the width of the vein, are set up under each stull and upon similarly placed sills on the stope-floor. When lagging has been placed upon the horizontal stulls, the so-called 'stull-floors' are formed. (See Fig. 30.) One or more rows of ore chutes are built in between the stulls, being placed on both sides of the vein or on one side only, the number and arrangement depending upon the width of the vein. A chute placed at one side of the stull-floor, in wide veins, necessitates too much shoveling of ore in finally clearing the stopes. Stoping is continued upward, the walls being supported by other rows of stulls spaced from 6 to 15 ft. apart vertically, depending upon conditions of the wall rock. These stulls also serve as supports for lagging or scaffoldings upon which the miners stand and mount their drills. Owing to the small size of the timbers used, which seldom exceeds 8 in., and the increased width of stopes in many places, it is often found necessary to place props or struts between the stulls to prevent their buckling and breaking. All stulls are provided with blocking called 'stullheadings' which increase the bearing of the stulls and at the same time afford a better footing for them.

A stope having reached the level above and been broken through into it, props are carefully set between the stope-sills and the last placed stulls in the stope below, thus providing a fairly strong support for the level timbers above.

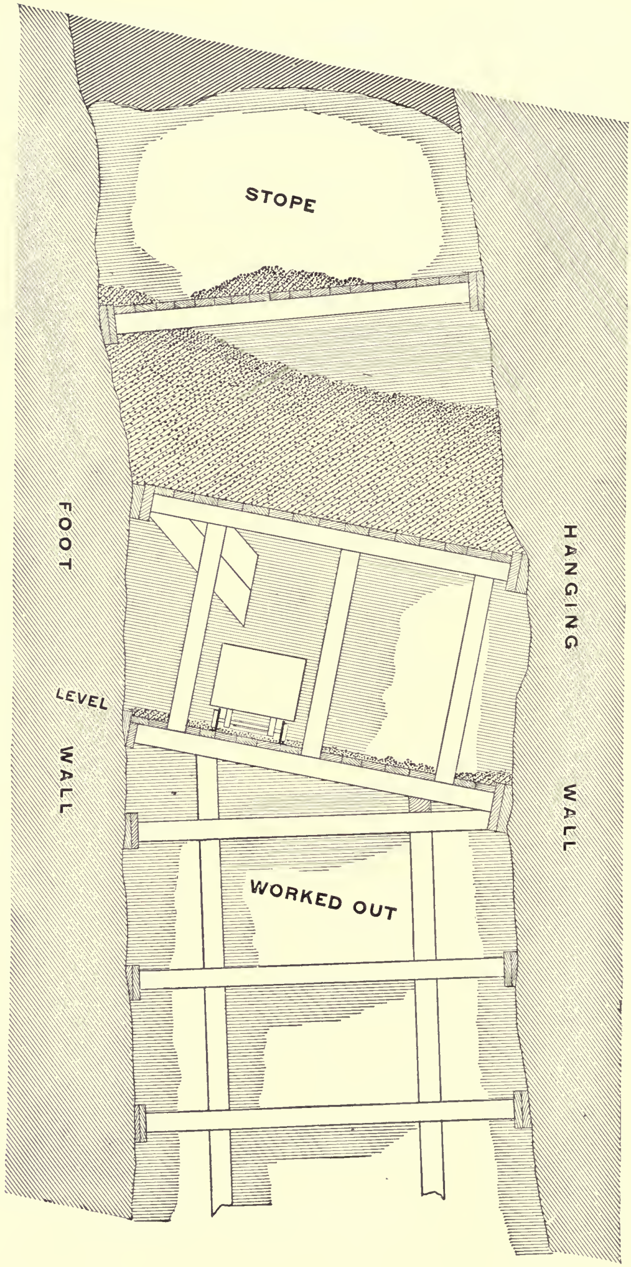


Fig. 30.—Application of Stulls to Moderately Wide Veins.

No stope should be worked out and connected with a level above until the upper level has been worked and the ore drawn off, or the ore should be drawn off practically as fast as broken in order that undue weight may not be thrown upon the stulls supporting the levels. (See Fig. 30.)

At the flatter portions of the veins considerable difficulty is often experienced in setting the stulls, especially the horizontal ones, and consequently square-set timbering is largely employed at such places; greater strength is also obtained.

Filling is occasionally used in connection with square-sets, but probably to a greater extent with stulls, the empty stopes being run full of waste rock, which can be transferred from stope to stope as the upper levels are exhausted.

The method of working with horizontal and inclined stulls as employed in the Tonopah mines is applicable to narrow and moderately wide veins of high dips and with fairly strong and solid walls. While it might be employed in working low-grade ores, it is especially suited to moderately high-grade ores, where it is desirable to make a high percentage extraction of ore.

The advantages of the method are:

1. The complete extraction of ore.
2. Use of relatively small timbers.
3. Ease of handling ore.
4. Ready access to the stopes.
5. A certain amount of ore may be held in the stopes as a reserve.
6. Ventilation is good.

The disadvantages of the method are:

1. Use of considerable timber, which is expensive.

2. Confined to high dips.

3. Lack of stability of workings when stopes are connected.

4. Stoppage of ore chutes, necessitating blasting out the ore, thus injuring chutes.

5. Little opportunity to sort and stow waste rock.

Stull-level Method

1. Combination Mine, Goldfield, Nev.
2. Gold and Silver.
3. Veins or Zones.
4. Average thickness 20 ft.

The application of overhand or back stoping to veins of variable width is shown to advantage in the Combination Mine, Goldfield, Nevada.[1] The lodes of the Goldfield district consist of shattered and fissured zones of silicification. In the Combination Mine the vein-filling as well as the country rock is altered dacite. Occasionally the silicified zones extend into the walls, making the width of the workable deposit rather indeterminate. The width of the silicified zones usually does not exceed 50 ft., while in the majority of cases 20 ft. is a fair average. As a usual thing the ground is easy to support and wide stopes are often worked without fear of collapse.

Referring to the section, Fig. 31, it is seen that the first level was formed at a depth of 80 ft., two passages being driven in the deposit to the limits of the ore-shoot, one on either side of the lode. By cutting-out stoping, both of the

[1] The Combination Mine, by Edgar A. Collins. Mining & Scientific Press, vol. 95, p. 435.

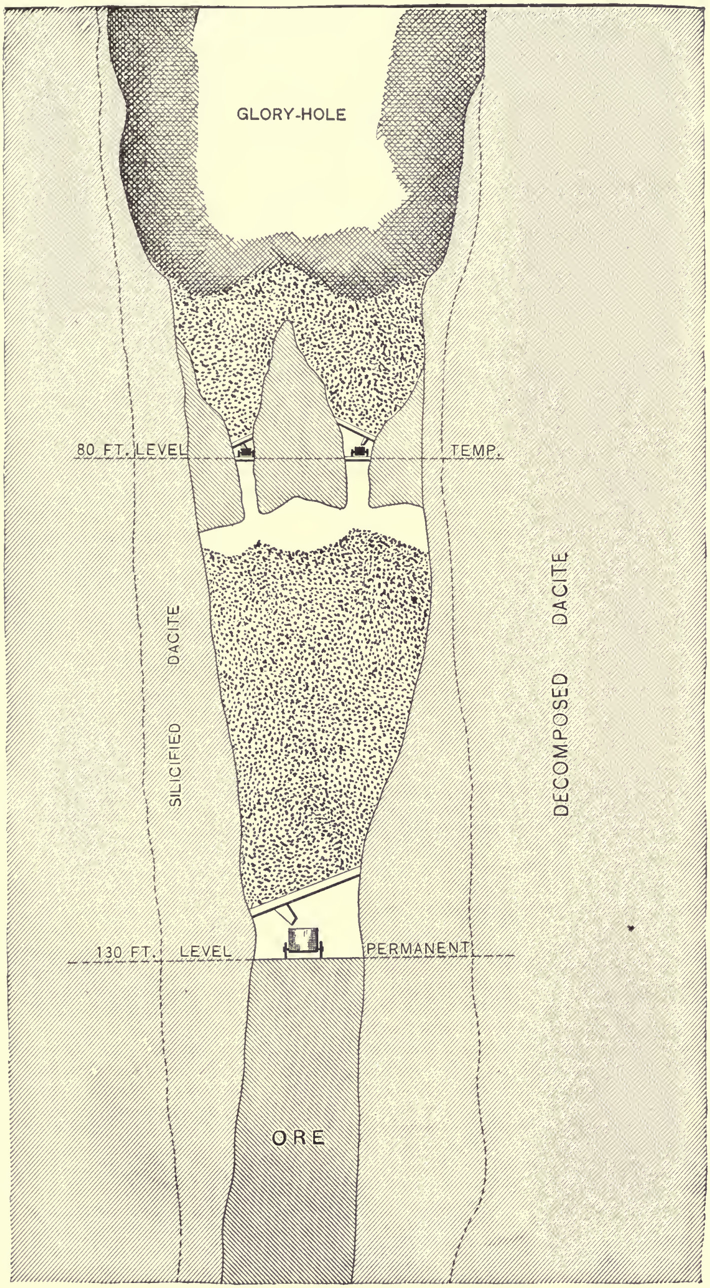


FIG. 31.— Use of Stulls and Stull-Levels in Mining Moderately Wide Veins.

passages were increased in height and width until they ran together in the center of the lode and at the same time were extended to the walls of the lode. As soon as sufficient height of stope was secured to permit the running of cars, stulls and lagging were placed. Subsequent work filled the stope with broken ore which was drawn off as desired by chutes spaced every 20 ft. along the levels. The width of the stope was increased ultimately to 50 ft. at one or more points, but stood without support by carefully arching the back. The combined stopes were raised to within about 15 ft. of the surface, when raises were put up breaking through, the remainder of the arch being cut out by underhand work.

In the meantime a second level was driven, as shown, at the 130-ft. level, which was, however, carried the full width of the lode, being narrower at this point than above, and was stulled and lagged with timbers of suitable size. The second stope was raised to within about 6 feet of the 80-ft. level, and raises were driven connecting the levels above with the stope below. All handling of ore on the first level was then abandoned and the ore from the upper stope was drawn off through the raises connecting the stopes. As the ore was drawn from the upper stope the pillars above the levels were exposed and were attacked and stoped out, at the same time any ore exposed on the walls of the open stope was broken down and ultimately loaded into cars on the 130-ft. level.

The third level was formed at the 230-ft. point, the ground between it and the second level being worked by intermediate levels spaced 50 ft. apart, especially in the weaker ground, as in the sulphide ores. The intermediate levels are strongly timbered. It is proposed to fill the stopes with waste after the ore has been withdrawn.

This particular method of mining is applicable to veins of varying widths and dips, as widths of 20 to 50 ft. and dips of 30 to 90° with the horizontal, also to strong and moderately strong ores and wall rocks.

The advantages of this method are:

1. Little timber is necessary.

2. The ore is handled with little labor.

3. By opening the mine to the surface the ore in the wall rock can be more carefully and systematically mined.

4. Ventilation is good.

The disadvantages of the method are:

1. Short distance between levels and expense of forming a number of levels, especially sub or intermediate levels.

2. A possible loss of high-grade ore by breakage in drawing from one stope to another.

3. The accumulation of water in workings due to open-cuts.

4. The necessity of using long stulls and consequently large ones on those levels where the lode is wide.

The Stull-set Method

1. The Hecla Mine, Burke, Idaho.
2. Lead and Silver.
3. Veins.
4. Width 8 to 35 ft.

The employment of stulls in veins varying in width from 15 ft. and over is shown to good advantage in the lead-silver mines of the Cœur d'Alêne district,[1] where the system has its widest application. The veins occur in slates and quartzites and have rather high angles of dip, being not far from 70° with the horizontal. They range from 8 to 15 even up to 35 ft. in width, the walls often being indeterminate and disintegrating badly on exposure to the air.

The ore is broken by overhand stoping, locally known as 'back stoping,' the walls and back of ore being supported by 'stull-sets' and filling. (See Fig. 32.)

The levels are usually driven 250 to 300 ft. apart, the stopes being opened directly off the levels and usually to the full width of the vein. The supporting stull-sets are built up from the levels and are kept open for the first two floors for convenience in handling timber, after which they are usually filled with barren material, sorted from the vein during mining. The height of the stull posts varies in the different mines from 6 ft. to 8 ft. 3 in., making the distance between floors approximately 9 and 10 ft. respectively. The size of the stulls and posts ranges from 10 to 16 in. in diameter. Occasionally the stull-sets are reënforced by other sets placed below them, which is usually done on the second floor. The posts of the stull-sets are usually placed

[1] Mining Methods in the Cœur d'Alêne District, Idaho, by Robt. N. Bell. Mining Magazine (American), vol. 13, p. 306; Fifteenth Annl. Rept. of the Mining Industry of Idaho, by Robt. N. Bell. pp. 90 and 92, 1913.

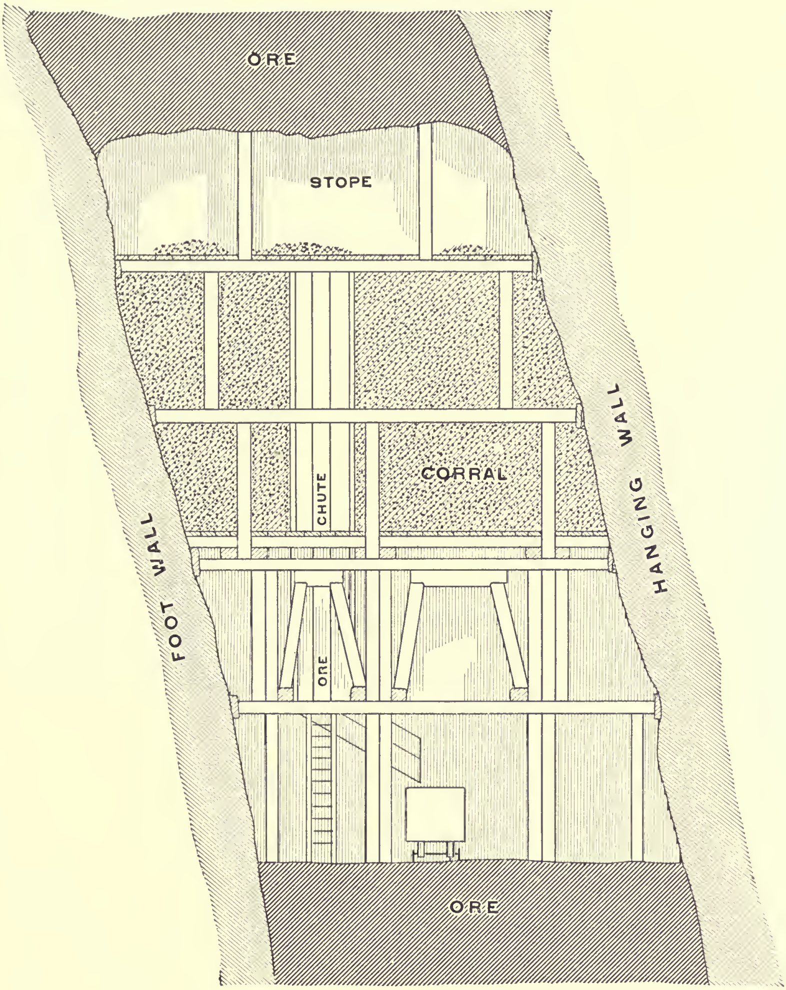


FIG. 32.— Application of Stull-Sets to the Mining of Medium-sized Veins.

from 4 to 6 ft. apart and from 18 in. to 3 ft. from the walls in order to allow for cutting off the ends of the stulls when they begin to break and splinter as the weight of the walls comes more upon them. On cutting away the broken ends of the stulls the old blocking or 'head boards' are removed, the walls smoothed up and new boards placed, the whole

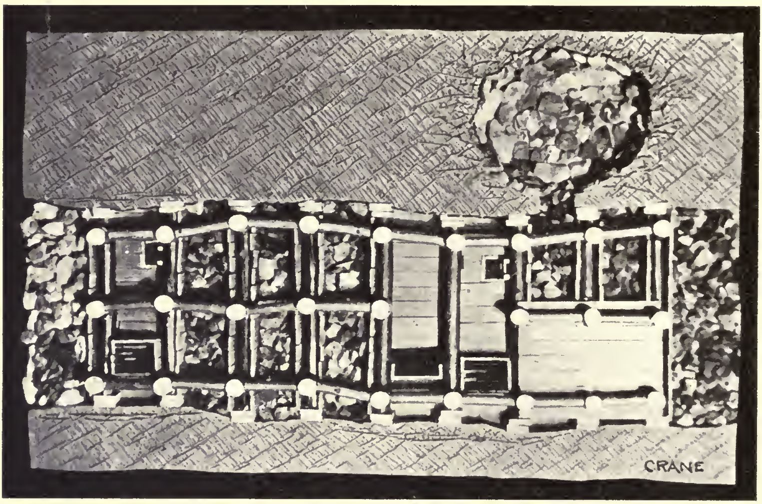


FIG. 33.—Plan of Second Floor of Stull-Set Method. (Modeled after Sketch by Robert N. Bell.)

being wedged fast again. The stull-sets are spaced from 5 to 8 ft. apart along the levels or stopes. (See Fig. 33.)

Above the second floor and on top of the stulls long timbers are placed running longitudinally with the stope, upon which in turn are laid other timbers but extending directly across the vein. These latter timbers or sills are placed about 4 ft. apart, and when covered with lagging form the floor upon which the waste-filling is placed. The lagging is sawed timber 3 by 12 in. and of suitable length to reach at least from the center of one sill to another. (See Fig. 34.)

An open space is maintained around the ore chutes, manways and timber slides, beginning with the second floor of each

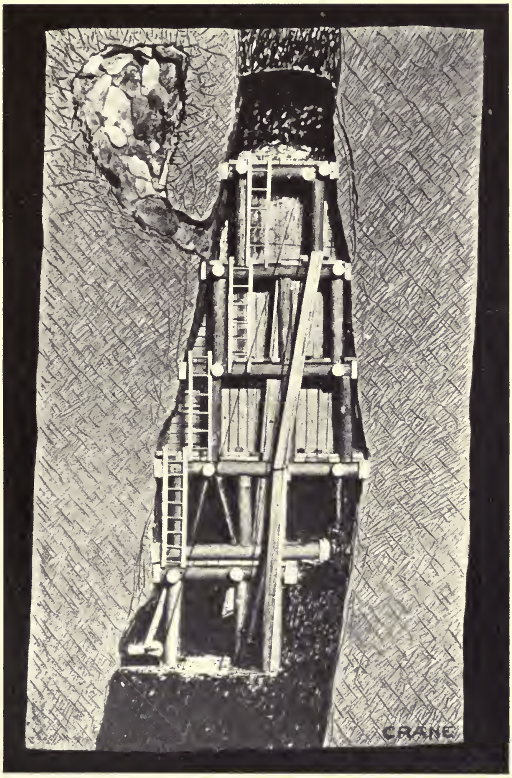


FIG. 34.—Vertical Section through Vein Showing Method of Placing Stull-Sets. (Modeled after Sketch by Robert N. Bell.)

level, by boarding off a portion of the stope, which open space is maintained to the working face of the stope. In narrow veins the boarded-up partitions extend from wall to wall, while in wider veins a relatively large space is fenced in. (See Fig. 35).

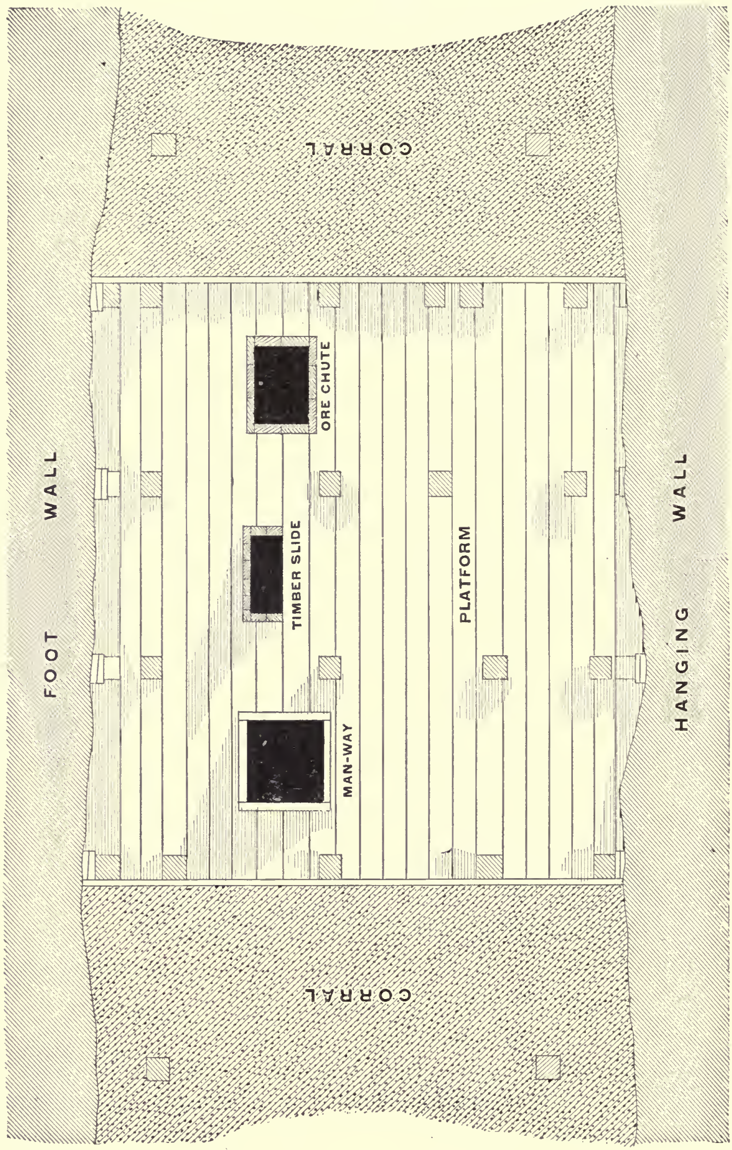


FIG. 35.— Plan of Second Floor in Stull-set Method

Room is thus provided for handling ore and timber and for the passage of men as the stope increases in height. The remaining portion of the vein is filled in with waste and is commonly known as the 'corral.' (See Figs. 33 and 35.)

The waste-filling is carried to within two sets of stulls or floors of the face or back of the stope, the floors upon which the stoping drills are mounted consisting of lagging placed upon the stulls. This lagging is removed prior to placing the filling, and is used over and over again as the stopes increase in height. Temporary supports as posts are placed between the stulls and back of stope and are specially needed in wide veins and heavy ground.

The ore as broken falls upon the lagging of plank, from which it is shoveled into chutes after being sorted; the waste is then stowed in the corrals below.

The stull-set method of mining is applicable to highly inclined deposits varying in width from 10 to 35 and 40 ft. It is possible to work deposits the walls of which are heavy and weak, but it is most applicable to strong walls and ores that will stand well.

The advantages of the stull-set method are:

1. The comparative ease of handling and placing timbers, the number of pieces being less than employed with the square-set method.

2. The possibility of easing up the timbers and repairing broken stulls. Badly broken wall rock can be removed and the support renewed with little trouble.

3. Increased height of stope that can be worked even in bad ground.

4. Convenience of sorting ore and storing waste with little handling.

5. Safety to men, numerous means of escape from stopes being provided.

6. Ventilation in stopes is good.

7. Large percentage extraction is possible.

The disadvantages of the stull-set method are:

1. Considerable timber is used and especially large sizes which are difficult to handle.

2. Method is limited to steep dips and consequently the stopes must be carried nearly vertically.

3. The difficulty experienced in maintaining the large areas of open stopes both horizontally and vertically.

Mining Mineral Veins by the Use of Square-Sets

Horizontal and Inclined Floor Methods

Square-set mining is extensively used in the Cœur d'Alêne lead-silver district, although in the narrow portions of the deposits simple posts and stulls are often employed, especially if the roof is strong and firm. The application of square-sets to the wider portions of the deposits, which range in width from 5 to 50 ft., varies both with the dips and the character of the ore. The older method consists in overhand stoping the deposit in horizontal floors, the stopes being filled with square-sets as rapidly as space is provided for them. The more recent method differs mainly from the earlier method in that the working face is carried normal to the foot-wall or as nearly so as

1. The Bunker Hill-Sullivan Mine, Wardner, Idaho.
2. Lead and Silver.
3. Veins.
4. Width 5 to 50 ft.

possible. The object of this method of procedure is to transfer the weight of the ore largely from the square-sets to the foot-wall.

The method of stoping in horizontal floors represents extensive practice in the working of metalliferous mines in all parts of the world, being applicable to both fairly steep and slightly dipping veins. In the Cœur d'Alêne district it has been successfully employed in lodes dipping from 35 to 70°. The square-sets are usually 9 by 5 by 6 ft., *i.e.*, the posts are 9 ft., the girts 5 ft. and the caps 6 ft. long. (See Fig. 36.)

The veins are usually opened by tunnels, although a few shafts are employed where conditions permit; however, regardless of how opened, the actual development of the orebodies is by shafts, either extending from the surface or beginning underground as winzes, the levels being driven from them to the deposit. In the deposits, especially in the wider veins, two passages are usually maintained through the timbered stopes, which are mainly for the convenience of handling the ore. Two sets of timbered chutes and an occasional manway extend from the open stope above to the passages below, thus maintaining as nearly as possible equal convenience in handling ore across the vein. The stopes are kept filled to within about one set of the top, thus providing ample support to the walls and roof as well as space to work in and protection to the miners.

As previously indicated, where the ore is weak and heavy, throwing much weight upon the square-sets, the more recent method of carrying the working face normal to the foot-wall is now being successfully employed.

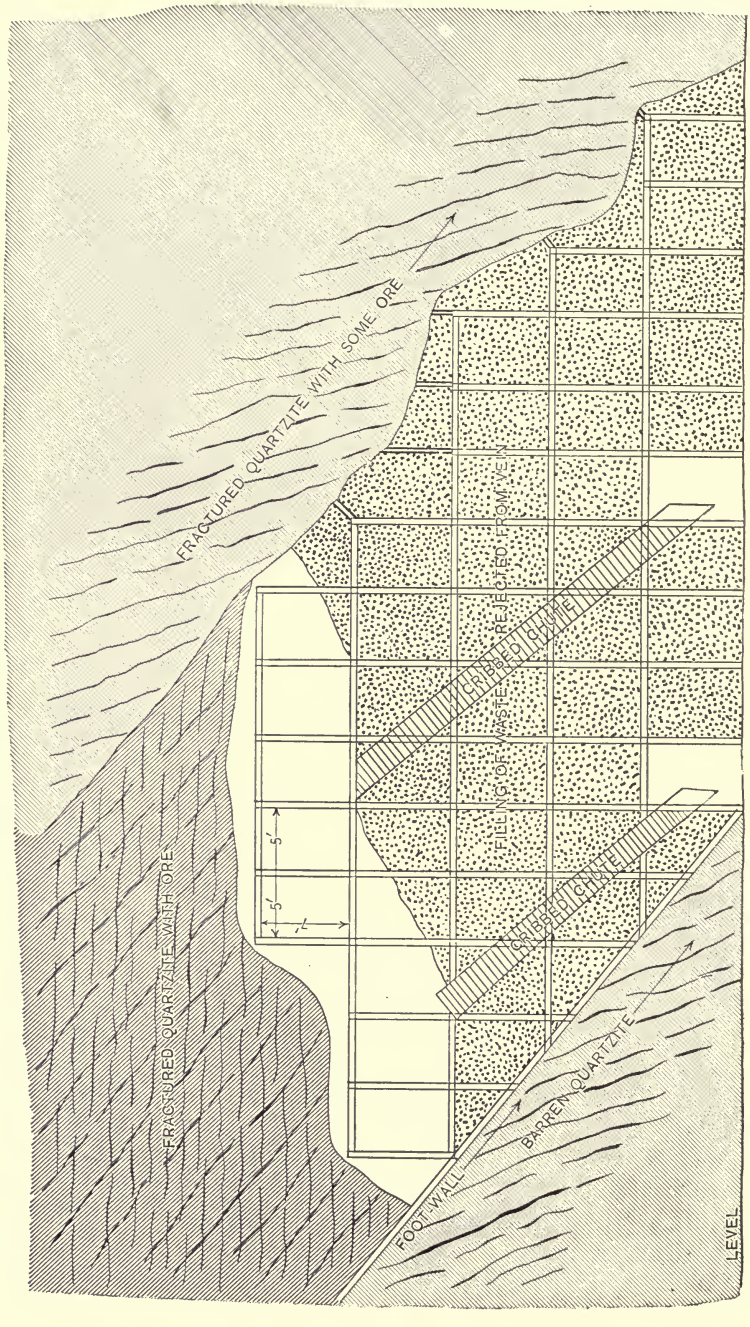


Fig. 36.—Square-set Mining in Horizontal Floors.

The development work is similar in both methods of working, and while two haulage ways may be maintained through the timbered stopes, the same advantage may be secured, so far as handling ore in the stopes is concerned, by employing branched chutes. The branch-chutes may be attached to the main chutes at any desired point before the filling is placed, the slope of the chute being carefully maintained in order to insure positive and rapid transference of ore from the face to the loading chute below. Ore chutes are placed from 15 to 30 ft. apart, while the manways are 50 ft. apart.

In stoping, the face is attacked next to the hanging-wall and the excavation is supported by placing sets as soon as room is made for them. The work of cutting out the inclined slice then proceeds downward until the foot-wall is reached, the placing of sets following the excavation. This operation is repeated until the desired height of stope is reached, when work on a new level is begun. (See Fig. 37.) Filling is drawn from old stopes and from drifts driven into the hanging-walls and is usually kept within one set of the face.

The application of square-sets in mining as a means of support has previously been pointed out, but the latter of the two methods described above illustrates how their usefulness may be extended under particularly difficult conditions.

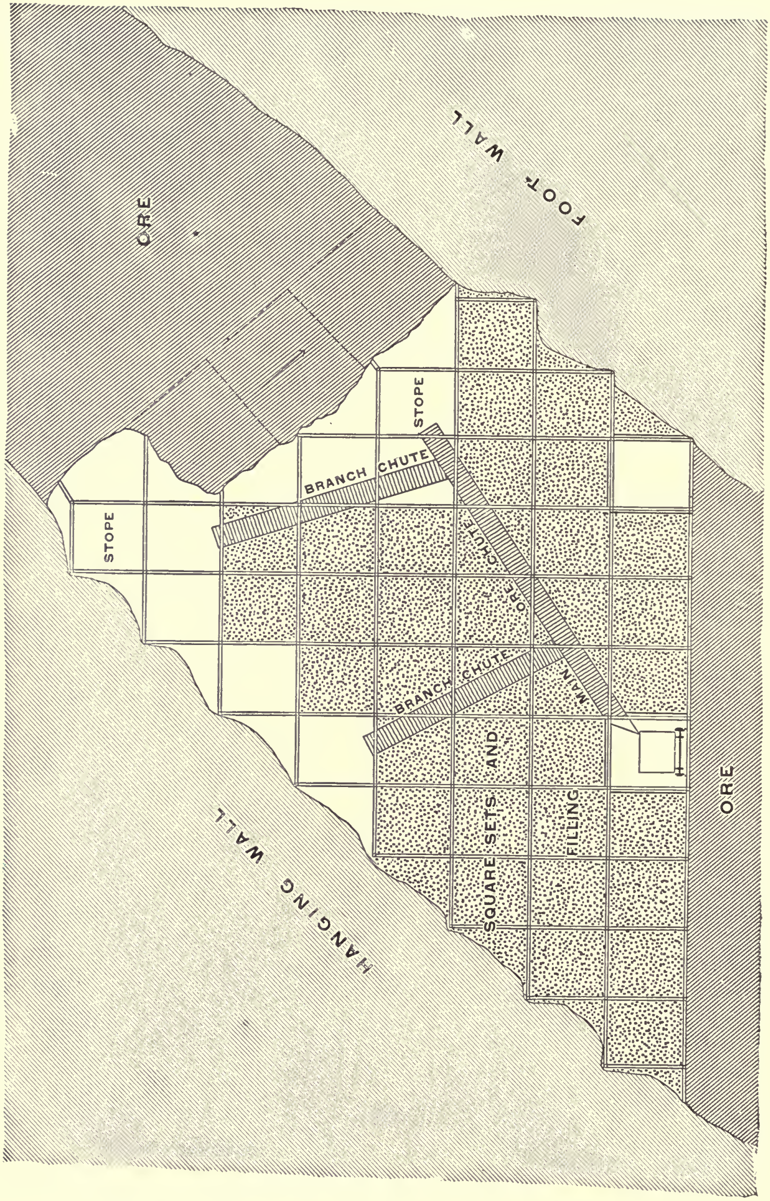


FIG. 37.—Square-set Mining in Inclined Floors.

Mining Mineral Veins by the Use of Filling

Rill Stoping

The application of filling to the working of the gold mines of Zaruma, Ecuador,[1] is somewhat unique in that instead of placing the filling in horizontal floors it is run in from above and stands at about its natural "angle of repose." The vein-matter is quartz bearing considerable quantities of finely disseminated pyrites, and bunches of galena and blende next to the hanging-wall. The wall rock is diorite. The vein is faulted by an extensive fault-plane which lies within the vein and on the contact of foot-wall and vein-matter. Owing to the extensiveness of the movement, a very heavy gouge occurs which ranges between 3 and 4 ft. in thickness and is extremely weak and treacherous. The value of the ore is between $4 and $15 per ton.

1. Zaruma, Ecuador S. A.
2. Gold Ore.
3. Vein.
4. Maximum width 26 ft.

In developing the orebody the levels are run in the foot-wall at a distance of some 20 ft. from the vein, from which cross-cuts are driven every 65 ft., connecting the levels with the deposit. From the various points of attack provided by the cross-cuts entering the orebody stoping is begun, being carried the full width of the vein and to a height of about 8 ft. (See Fig. 38.)

Connection is made between the levels and the surface by means of a number of raises along the foot-wall through which waste rock is introduced into the stopes. Begin-

[1] Notes on the Gold-Mines of Zaruma, Ecuador, by J. Ralph Finlay. Trans. Am. Inst. Mining Engrs., vol. 30, p. 248.

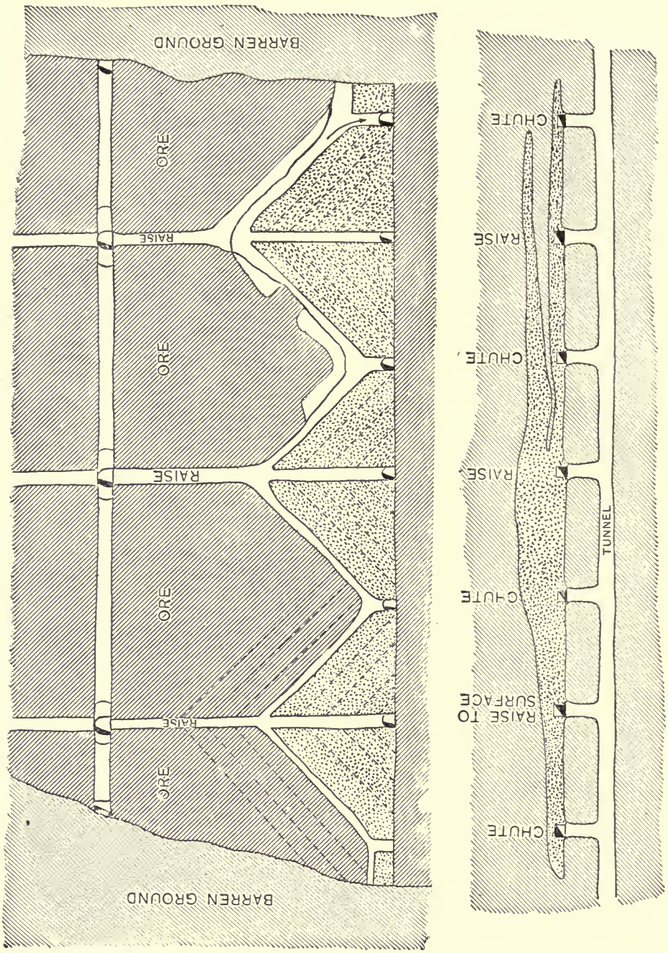


Fig. 38.—Overhand Stoping in Inclined Floors or Rill Stoping — Longitudinal Section and Plan.

ning at the raises the ore is cut out by overhand stoping, the ore being cleared away as rapidly as possible and hauled through the cross-cuts and levels to the main shaft. When the stopes have been carried as high as is considered safe, filling is thrown down the raises until the stopes are nearly filled; the work of stoping is then resumed, but to prevent the mixing of ore and waste rock, slabs of wood are placed upon the sloping sides of the filling. This operation is repeated, each slice being carried as far as is considered safe and then filling is run in to support the walls and bring the footing for the drills sufficiently close to the working face. Further temporary supports, as posts, may be set up between the face and the filling as occasion demands. The filling run in from above distributes itself evenly in the stopes without extra handling, and as the work of stoping is carried on from the slope of the filling the stope face must of necessity be maintained parallel with the slope of the filling, which is practically that of the angle of repose of the waste rock, but slightly less owing to the miners working upon the filling.

In the course of time the various stopes run together and at points midway between the raises, or at the intermediate cross-cuts. At these points cribbed chutes are begun and built upward as the work of stoping and filling proceeds. Cribbed manways are maintained through the center of the stopes to provide means of ingress and egress to and from the stopes. (See Figs. 38 and 39.)

The method of filling employed at the Zaruma mines is applicable to moderately wide deposits of solid and firm ore but not extra strong walls. The method is usually designated as 'rill stoping.'

The advantages of the method are:

1. Little timber is required.

2. Levels may be placed a considerable distance apart.

3. There is a minimum amount of handling of ore and waste-filling.

4. Filling can be carried close to the face, as it does not have to be distributed.

5. Ventilation is good.

The disadvantages of the method are:

1. The inconvenience of working on a sloping bank of filling.
2. Loss of ore by mixing with waste.
3. Stoppage of all work in a stope while running in filling.
4. Little opportunity to sort ore in stopes.

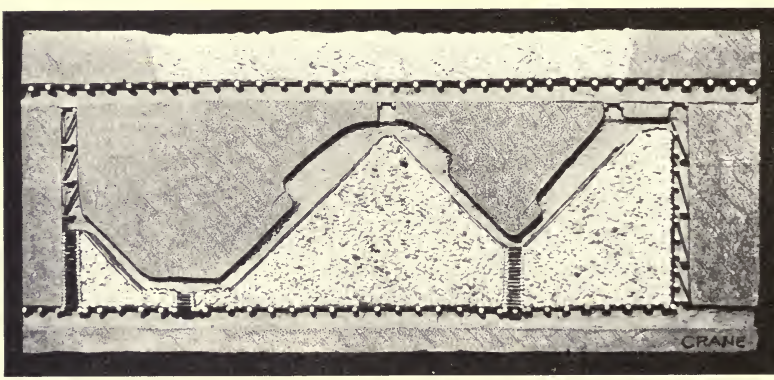


Fig. 39.—Rill-Stoping Showing the Use of Planks on Sloping Banks of Waste-Filling, also Methods of Entering Stopes and Disposing of Ore.

Back-filling Method

A variety of methods of mining is to be found in use in the copper mines of Butte, Montana, some of the more important of which are: the use of stulls and lagging, with or without filling; square-set timbering, with or without filling, and a method of filling without timbering, known as 'back-filling.'

1. St. Lawrence Mine, Butte, Mont.
2. Copper Ore.
3. Vein.
4. 8 to 50 ft. in width.

The width of the veins worked by this method varies from 8 to 50 ft. and they dip at fairly high angles, although that is not a requisite. The country rock is granite, which is usually fairly strong and solid, standing well. The vein-matter is quartz with pyrite and copper minerals.

The deposits are developed by vertical shafts from which cross-cuts are driven to the veins at intervals of 200 ft., levels being run in the veins. Stopes may be opened directly off the levels, or pillars may be left immediately above the levels; in the former case the filling introduced into the stopes to support the walls is held in position by stulls set along the levels, while in the latter case a much more durable and satisfactory support for the filling is provided by the pillars. In either case the work of breaking down the ore is done by longwall stoping. (See Fig. 40.) Preparatory to stoping and before the stopes have been more than opened, waste chutes are formed in the foot-wall connecting both levels and stopes and are spaced 80 to 100 ft. apart along the vein. Ore chutes and manways, built up from the levels, are carried upward along the foot-wall as the stopes increase in height, being strongly timbered. The ore chutes are usually placed at 25 ft. intervals, while the manways are 100 to 125 ft. apart. It is customary to build two-compartment passages, an ore chute and a manway when the two come together, which saves time and expense.

Beginning at a raise or winze cut in the vein, stopes are worked laterally from it, being carried from 12 to 14 ft. high and the full width of the vein. As rapidly as the broken ore can be cleared from the stope by shoveling it

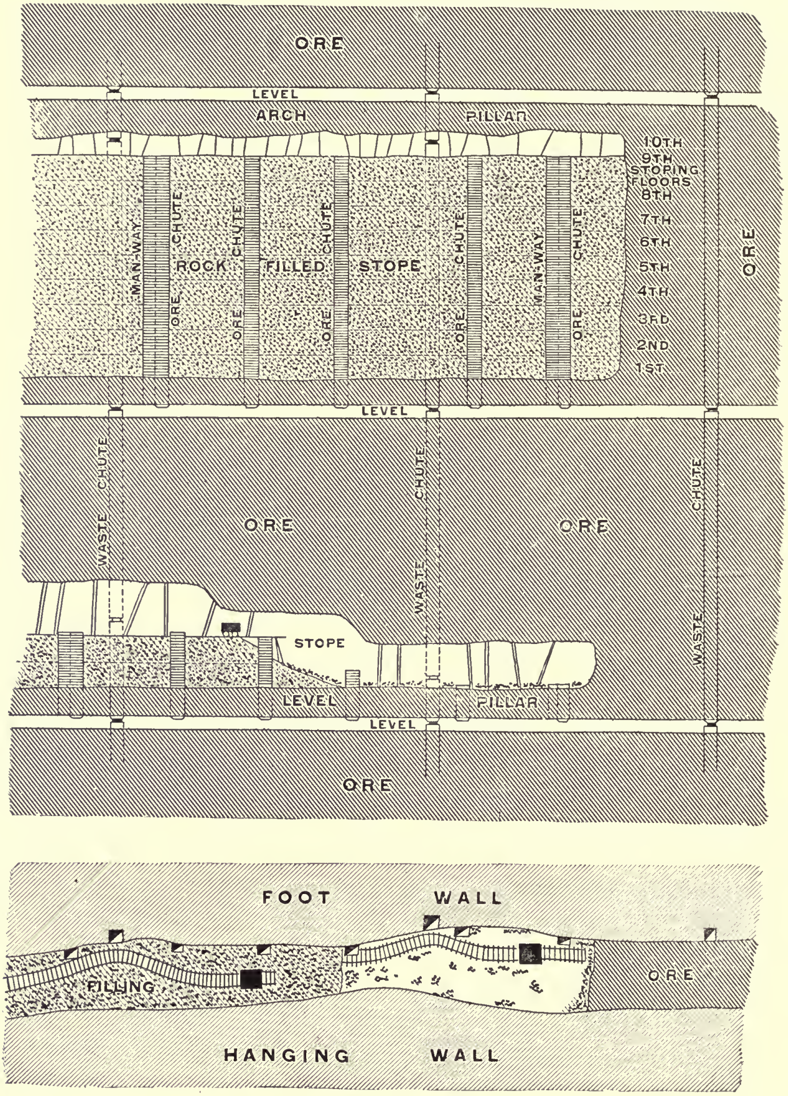


FIG. 40.— Elevation and Plan of Stopes. Back-filling Method.

into the ore chutes, waste is run in, filling the stope to a depth of about 8 ft., being distributed by a limited amount of shoveling. Distribution of waste is done largely by cars running between waste chutes. The ore chutes are timbered up and kept above the level of the filling. A space of 4 to 6 ft. is maintained between the filling and the back of the stope, which provides room for handling the waste in cars. As the filling is carried on back of the working face of the stope this particular method of handling it is known as 'back-filling,' and when employed in a mine the method of mining is commonly spoken of a the back-filling method. Subsequent stoping is carried on in a manner similar to that of the initial work, the stopes being from 12 to 14 ft. high, and the successive layers of filling placed are 8 ft. thick. By this arrangement the stopes where work is being done are 12 to 14 ft. high, while the space between filling and stope-back is maintained at a fairly uniform height of 4 to 6 ft.

The back-filling method is usually not employed except in strong or moderately firm ground, but occasionally ground is worked that is so weak that props must be used. Usually no attempt is made to draw the props prior to blasting, but they are pulled out of the broken ore as it is shoveled up. Comparatively few of the props are reused as supports for the back, but are employed in building chutes. In order to prevent loss of ore from mixing with the waste-filling during blasting a platform or mat of plank is placed on the filling.[1]

[1] It is practically impossible, however, to prevent a certain amount of waste mixing with the ore during mining, which lowers the value of the ore by dilution although the tonnage is increased. The increase has been estimated at between 2 to 10 per cent.

Planks or 'floor-boards' for this purpose are 2 by 8 to 12 in. and are cut in 8-ft. lengths. Shoveling is materially facilitated by the use of such platforms, which are advanced with the stoping face. That there may not be an undue amount of shoveling of waste, the tracks upon which the cars carrying the filling operate are frequently shifted from one wall to the other, the filling being run in to place rather than shoveled. (See Fig. 41.)

A combination of rill stoping and back-filling may be employed, which while it facilitates the placing of waste renders the sorting and handling of ore more difficult. (See the Dry-Wall Method, Fig. 43.)

Stopes may be completely worked out by this method, but it is the usual practice to leave an arch pillar of 12 to 16 ft. in thickness between the stopes and the levels. (See Fig. 40.)

The back-filling method is applicable to high and moderately high dipping veins. The wall rock and ore should be fairly strong and practically self-supporting, although the use of props is common.

The advantages of the method are:

1. Under favorable conditions little or no timber is required for support.

2. Levels are far apart, reducing the amount of development work.

3. The working face is always close enough for thorough inspection, thus reducing the danger of accidents.

4. Large outputs are possible.

5. Ore can be sorted and waste stowed in stopes.

6. Ventilation is good.

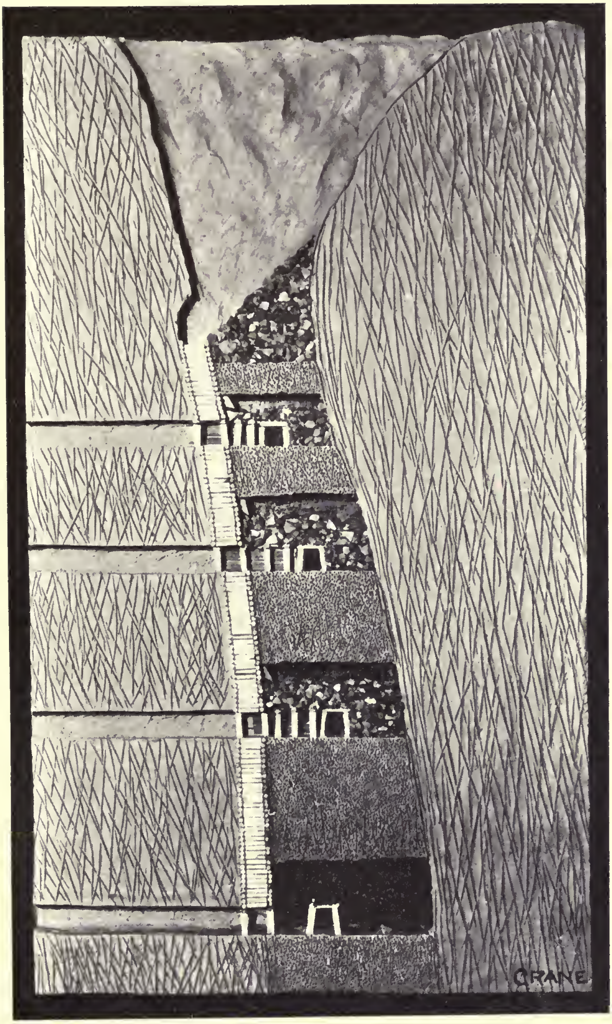


FIG. 41.—Vertical Section through Lode Showing Application of Back-Filling Method. Chute in the foot-wall may or may not be timbered, but should be timbered when manways are combined with ore chutes.

The disadvantages of the method are:

1. Applicable only to veins having strong or fairly strong walls and ore.

2. Difficulty and expense of forming waste chutes.

3. Loss of ore remaining in pillars.

4. Considerable handling of ore and waste-filling.

The Dry-Wall Method

The method of mining employed in the copper mines of the Lake Superior region is overhand stoping with slight modifications in handling ore due to varying inclinations of lodes. The dip of the lodes ranges from 35 to 70° in the various mines. In those lodes where the steeper dips prevail and where the weight of the walls is consequently less, as in the mines of the Copper Range Consolidated, a comparatively new method of mining has recently been adopted, which is variously designated as the 'dry-wall' or the 'rock-wall' and again simply as a 'filling system.'

1. Baltic and Trimountain Mines, Michigan.
2. Copper Ore.
3. Vein.
4. Width 24 to 36 ft.

Copper occurs in the native state in the Lake Superior copper region, being found in both sedimentary and interstratified igneous rocks. The copper constitutes a cement which surrounds and binds together the pebbles and boulders of porphyry conglomerate, or fills the amygdules especially in the upper portions of the interbedded massive rocks. In the Quincy, Franklin and Altantic mines the lodes are amygdaloidal, *i.e.*, are strongly altered diabase, parts of which are known as ash-beds.

Stations are established in the shafts every 100 to 125 ft. along the lodes from which levels are driven 8 ft. high and the width of the lode wide. The level drifts are enlarged by cutting-out stoping, and from the rock broken down the larger pieces of waste are employed in building the pack or so-called dry-walls or rock-walls, which are 8 ft. high and 8 to 9 ft. apart. Occasionally sections of logs

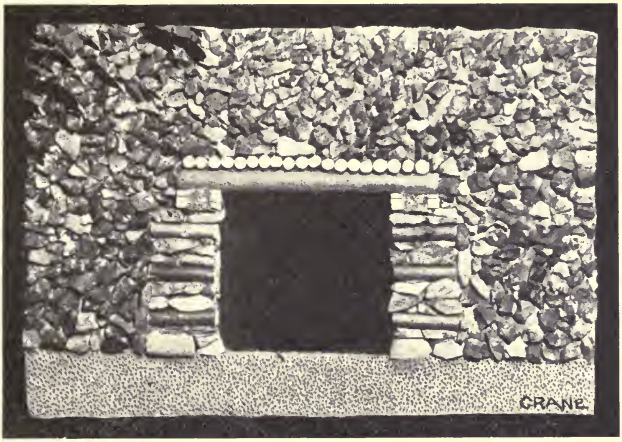


Fig. 42.—Passage Formed on Levels by 'Rock-Walls,' Showing Use of Waste Rock and Logs in Their Construction, and the 'Wall-Pieces' and Lagging Placed on Top of the Walls. (Modeled after Sketch in Eng. and Mining Jour., vol. 97, p. 949.)

are built into the walls and strengthen them by binding the rocks together. (See Fig. 42.) On these walls timbers are placed which reach from wall to wall, upon which in turn is laid a lagging of plank or poles. The timbers are called 'wall-pieces' and vary in size from 18 to 24 in., being 14 ft. long. As the work of stoping proceeds the waste rock sorted out is stowed between the pack-walls and the foot- and hanging-walls until these spaces are full and is then thrown upon the lagging covering the walled passage. Mill-holes are begun on the foot-wall side of the passage and are built up as the stope increases in height. (See Fig. 43.) The mill-holes are round, 5 ft. in diameter, and when completed are about 50 ft. deep. Owing to the steepness and width of the lodes it is necessary to mount the drills employed in cutting-out stoping between the working face and the broken ore and rock below. Pickers and trammers work at the rear of the bank of broken rock, sorting out the pay-rock and stowing the waste in the stope, thus leveling the rock as it is broken down in advance. From 25 to 45 per cent of the lode-rock is waste and is available for filling; however, if there is not a sufficient quantity to fill the stopes, the foot-wall may be broken down to furnish more.

Cutting-out stoping is continued up to within about 20 ft. of the level above, when it is stopped, thus leaving an arch pillar, which is broken at more or less regular intervals by openings or 'break-throughs.'

At the Trimountain Mine, especially, owing to the irregularity of the foot-wall and fairly uniform hanging-wall, it is considered advisable to carry all development work close to the latter.

As the work of extracting the ore proceeds from above downward, an upper stope is first worked out, and when there is no further need of support or protection of the level the filling is drawn off into the next lower stope, where it serves a useful purpose in assisting in stoping out the arch pillars by providing a support for the miners in drilling.

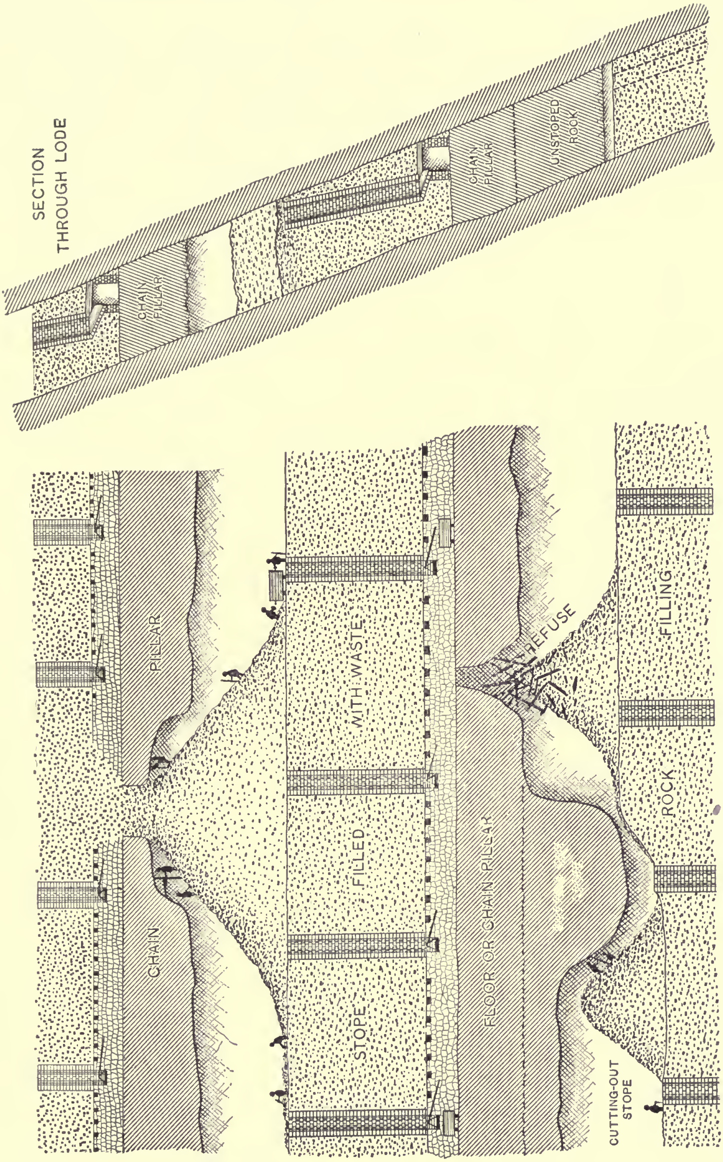


FIG. 43.— Baltic and Trimountain Filling Method.

The filling is drawn off by making openings in the pack-walls of the filled stopes at points directly over break-throughs in the arch pillars of the stopes to be filled. The stopes are then allowed to fill as full as the size of the break-throughs will permit. Drills are then mounted under the ends of the pillars, adjacent to and on the inclined surface of the fills. A portion of the pillars about 10 ft. in width and from 15 to 20 ft. in length is then removed as in cutting-out stoping. The drills are then reversed and holes are drilled which when charged and fired will break down the ends of the pillars, thus enlarging the openings through which the filling flows. By these two successive operations the arch pillars are gradually removed, footing for the miners being provided by the movement of the filling from above, thus maintaining the same relative position with respect to the pillars. The rock as broken from the pillars falls upon the surface of the filling and is carried to the pickers below by its downward and lateral movement. A number of break-throughs may be opened in a similar manner in the same stope, thus permitting rapid removal of the arch pillars and the filling of the stopes. Picking of pay-rock and spreading of waste are carried on as in cutting-out stoping.

The method is applicable to moderately wide and steeply dipping lodes from which considerable waste rock can be obtained by sorting and if necessary from special excavations. The ore and walls should be fairly strong and firm, as they must stand temporarily often for considerable distances without support.

The advantages of the filling method described above are:

1. Little timber is required.
2. The complete extraction of ore in the lode.
3. All waste rock is stowed in the mine with little handling.
4. A fairly clean product is sent to the surface.
5. Ease of stoping and reduced cost of mining.
6. The repeated use of filling for support of workings.
7. Placing of levels a considerable distance apart.

The disadvantages of the method are:

1. Applicable to highly inclined lodes.
2. Cost of building pack-walls.
3. Considerable handling of ore in stopes.
4. Collapse of upper levels on withdrawal of filling and danger of a crush starting and extending to lower levels.
5. Loss of ore by mixing with waste in cutting-out arch pillars.

Mining Bedded Deposits by Caving

Sub-drift System

The sub-drift system of mining has been successfully employed in the Mercur and Golden Gate mines of Mercur, Utah.[1] The ores are oxidized and base, carrying gold and occur in limestone and shale formations. The dip of the ledges ranges from a few degrees up to 25°, necessitating the use of inclines to develop the orebodies, which are often driven next to the roof or in the upper part of the mineralized portion of the

1. Mercur and Golden Gate Mines, Mercur, Utah.
2. Gold Ore.
3. Bedded deposit.
4. 15 to 20 ft. thick and up.

[1] Mines and Mining of the Consolidated Mercur Company, by Ray Hutchins Allen. Eng. Mining Jour., vol. 89, p. 1273.

ledge. When driven at the bottom of the orebody, there is probably more danger of the passage being destroyed by the caving of ground above. (See Fig. 44.)

When the ledge is 15 to 20 ft. thick, that part of the deposit from the hanging-wall to and including the first set of longitudinal drifts on the respective subs would represent the ledge worked, the incline connecting the drifts. With ledges of greater thickness, often reaching 100 ft., the whole

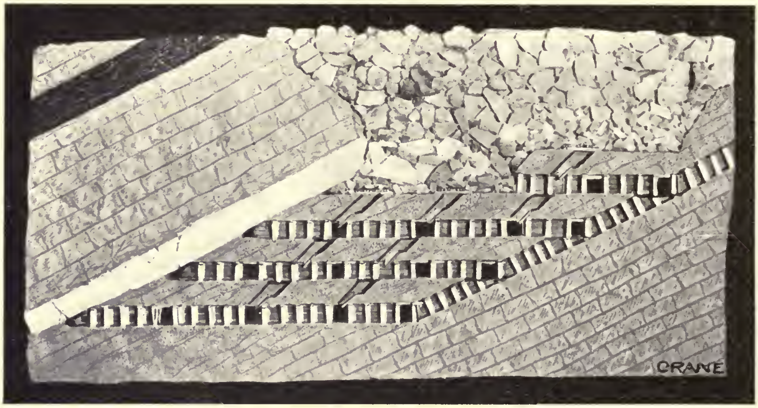


Fig. 44.—Transverse Section through Deposit Showing Method of Developing Thick Deposit. A thin deposit would have the incline near the top or hanging wall.

section, as shown, would represent the conditions, the incline being at the bottom of the ledge. The system of working thin ledges is quite simple and can be described to advantage prior to taking up the more complicated method of working the thicker ledges.

An incline having been run along the floor of the deposit, 'sub-drifts' are driven longitudinally in the ledge, from 15 to 25 ft. apart and to the limit of the workable deposit. (See Figs. 44 and 45.) Stoping is first begun on the sides of 'sub-drift' No. 1, supporting posts or stulls in the higher dips being placed as the stope widens. After the pillars of sub No. 1 have been drawn back 20 to 25 ft. work is begun on sub No. 2 and in a similar manner subs Nos. 3 and 4 are worked in order. When the stope faces of subs Nos. 1 and 2 have been connected, one-half of the pillars between them and that portion between sub No. 1 and the caved ground above are drawn back by breast stoping or 'side-swiping' and the ore in the roof is caved by knocking out posts and blasting the back. The drifts furnish protection for the men when caving is under way. In a similar manner the pillars between subs Nos. 2 and 3 and 3 and 4, and so on, as rapidly as the subs are driven, may be drawn and the roof caved. Each retreating pillar face is kept from 12 to 20 ft. in advance of the adjacent one down the slope, thus maintaining conditions most suitable to pillar-drawing as determined by experience in these mines and similar work in coal mining. Under the most favorable conditions the removal of drift sets and posts is all that is necessary to start the back caving. The miner then shovels the ore into cars and trams it to the incline or in the upper subs to chutes provided at intervals of about 50 ft. (See Figs. 44 and 45.)

When waste begins to come and mix with the ore it is evident that the roof formation is down, and the miner prepares for another cave by taking out the supporting posts next to the face. Under no condition should a lower pillar be allowed to retreat faster than an upper, as a cave would be almost sure to take place in the upper pillar, losing ore and endangering the miners working in the sub above.

In thick deposits the same method of procedure is followed but is applied to a series of inclined benches or layers of deposit, about 15 ft. thick, superimposed one upon

FIG. 45.—Longitudinal Section through the Sub-drifts Showing the Incline on the Right, also Other Passages Driven across the Deposit from the Sub-drifts.

the other, the series of subs in the respective layers or benches being connected by cross-cuts. The upper portion of the deposit is carried considerably in advance of the lowermost bench, each bench being advanced in a manner and amount similar to the retreating pillar faces in the separate benches as previously described. (See Figs. 44 and 45.)

Under certain conditions of deposit and roof the whole deposit throughout the series of sub-drifts may be caved at one and the same operation by beginning at the top and starting a cave in each sub. The whole deposit can in this manner be caved and drawn off without difficulty, but the work has to be conducted with great care.

The caving system as employed in the Mercur mines is suited to both thick and thin deposits inclined at moderate and low inclinations. It is especially applicable to deposits of uniform thickness where both ore and roof or hanging-wall are sufficiently weak to break and cave readily. It is equally applicable to both high- and low-grade deposits.

The advantages of the system are:

1. It has a wide range of application as to thickness of deposit.

2. A large percentage of extraction is possible.

3. A small amount of timber and powder is used.

4. Safety of men.

The disadvantages of the system are:

1. It is limited to deposits of moderate inclinations.

2. It is difficult to keep different grades of ore separate.

3. There is always danger of loss of ore from caving ground.

4. It cannot be employed to advantage where the top formations are hard and firm and do not cave readily.

Note. — See Bibliography of Methods of Mining, page 202.

CHAPTER VI

METHODS OF MINING IN WIDE VEINS AND MASSES

Introduction

The methods of mining employed in large deposits, as wide veins and masses, often vary but little from those used in similar but smaller-sized deposits. Mining with square-sets as well as the filling and caving methods are commonly employed in both large and medium sized deposits and usually with equal facility, with the possible exception of the first named, or square-setting, which has its limitations and probably has its widest range of usefulness in the smaller and medium sized deposits. Square-set mining is now being rapidly replaced by the filling and caving methods, and its use, largely for economic reasons, will be relegated to the working of certain deposits of special shape and occurrence and advantageously located with respect to an available supply of suitable timber or transportation facilities.

The methods of mining described and discussed in this chapter may be grouped into a number of classes, which are arranged in the following order: shrinkage stoping methods; square-set methods of mining; filling methods; and caving methods.

The width of veins considered in this connection ranges from 35 to 40 ft. as a minimum to several hundred feet, while massive deposits of all sizes are included.

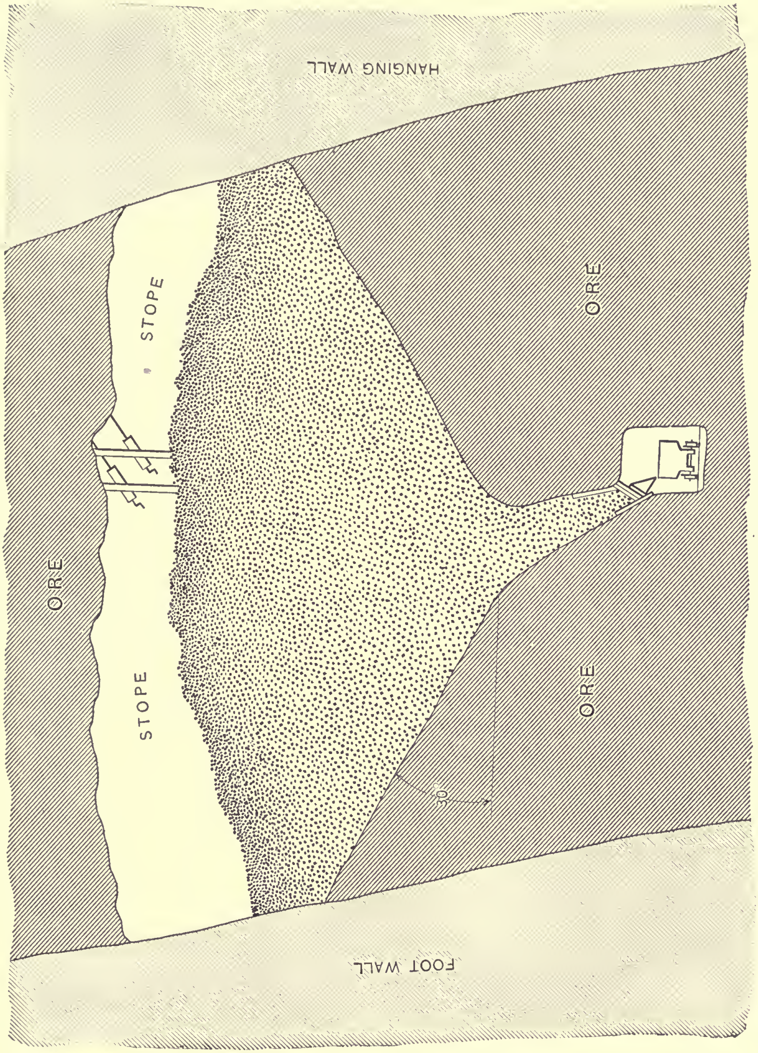


FIG. 46. — Vertical Section through Stope worked by Shrinkage Method.

Shrinkage Stoping Methods of Mining

Shrinkage Stoping at the Gold Prince Mine

1. **Gold Prince Mine, Animas Forks, Colo.**
2. **Gold and Silver**
3. **Vein.**
4. **Width 30 to 130 ft.**

The method employed in the Gold Prince Mine[1] located at Animas Forks, Colorado, illustrates the application of overhand stoping to a very wide lode of low-grade ore. The ore is free gold and silver in a gangue of quartz and associated with various sulphides, the value ranging between $8 and $12 per ton. The lode varies in width from 30 to 130 ft., averaging probably 50 to 60 ft. The wallrock is andesite, usually very tough and strong.

The lode is developed by a tunnel which cuts it, a main level being driven in the lode midway between the walls. (See Fig. 46.) Cross-cuts are driven across the lode at intervals of 200 to 300 ft. along the line of the main level, which determine the width of the lode, also the length of the stopes. Pillars 18 ft. in width are left between stopes through which raises are driven forming manways connecting the levels. Openings are made at frequent intervals in these pillars on either side of the manways in order to provide entrance to the stopes. From the backs of the levels, chute-raises are put up every 30 ft. and extend some 10 ft. vertically, beyond which point four inclined raises are driven, two extending along the line of the lode, the other two running transversely with it until the walls are encountered. Stoping is begun from these raises and carried on both laterally and vertically until inverted conical-shaped

[1] The Gold Prince Mine and Mill, Animas Forks, Colo., by G. P. Scholl and R. L. Herrick. Mines and Minerals, vol. 27, p. 337.

openings have been formed, from the lowermost points of which the chute-raises extend to the levels below, being provided with loading chutes through which the cars are filled. (See Figs. 46 and 47.) As the ore is strong and solid it stands well without support, and the thick back of ore in the form of stump-pillars insures against danger from caving ground in the stopes. Owing to the width and length of stopes, the work of stoping can be carried on very rapidly

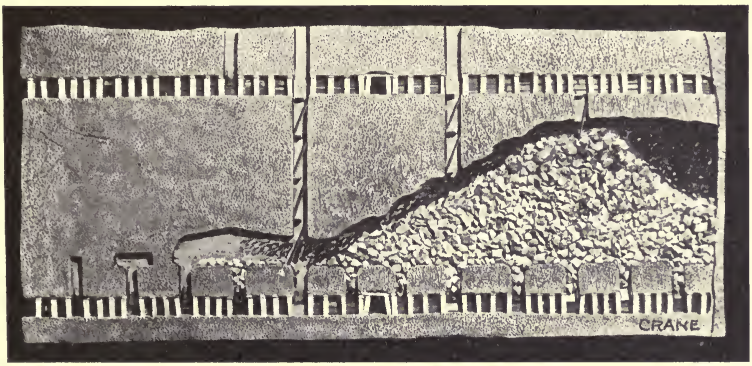


Fig. 48.—Vertical Longitudinal Section through Lode Showing Method of Development and Working by Shrinkage Stoping. (Modeled after Sketch by H. T. Hulst, G. R. Jackson and W. A. Siebenthal.)

and at the same time the large masses of ore or boulders can be reduced to such a size as to readily pass through the chutes. It is only necessary to draw off about 30 per cent of the broken ore to provide room for the miners to work at the face, the remainder being left in the stopes if desired, as a reserve. The ore is hard and dry and does not, therefore, pack in the stopes nor break up while being withdrawn therefrom. A stope having been worked up to the level above, and the ore drawn off, an attempt may be made to cut out the level or stump-pillars, which can be done by underhand stoping to a certain point, after which there is danger of the stope collapsing, although probably the greater part of the ore can be secured.

The method of mining employed in the Gold Prince Mine resembles in many respects the practice in the Alaska-Treadwell mines, although owing to the smaller size of deposit it is on a very much smaller scale. The method is applicable to wide deposits of low-grade ore, which is both hard and strong, standing without support, and with strong wallrock.

The deposit should also stand nearly vertical in order that the method may have the widest range of application.

The advantages of the method are:

1. No timber or other support is required.
2. The output is large.
3. The cost of mining is low.
4. A reserve of broken ore is available at any time.
5. Handling of ore is reduced to a minimum.
6. Ventilation is good.
7. The workings are easy of access.
8. Little development work is necessary.

The disadvantages of the method are:

1. Limited to large highly inclined deposits.
2. There is no opportunity to sort or stow waste rock.
3. Considerable loss of ore in pillars.

The application of shrinkage stoping to a narrower lode is shown in Fig. 48.

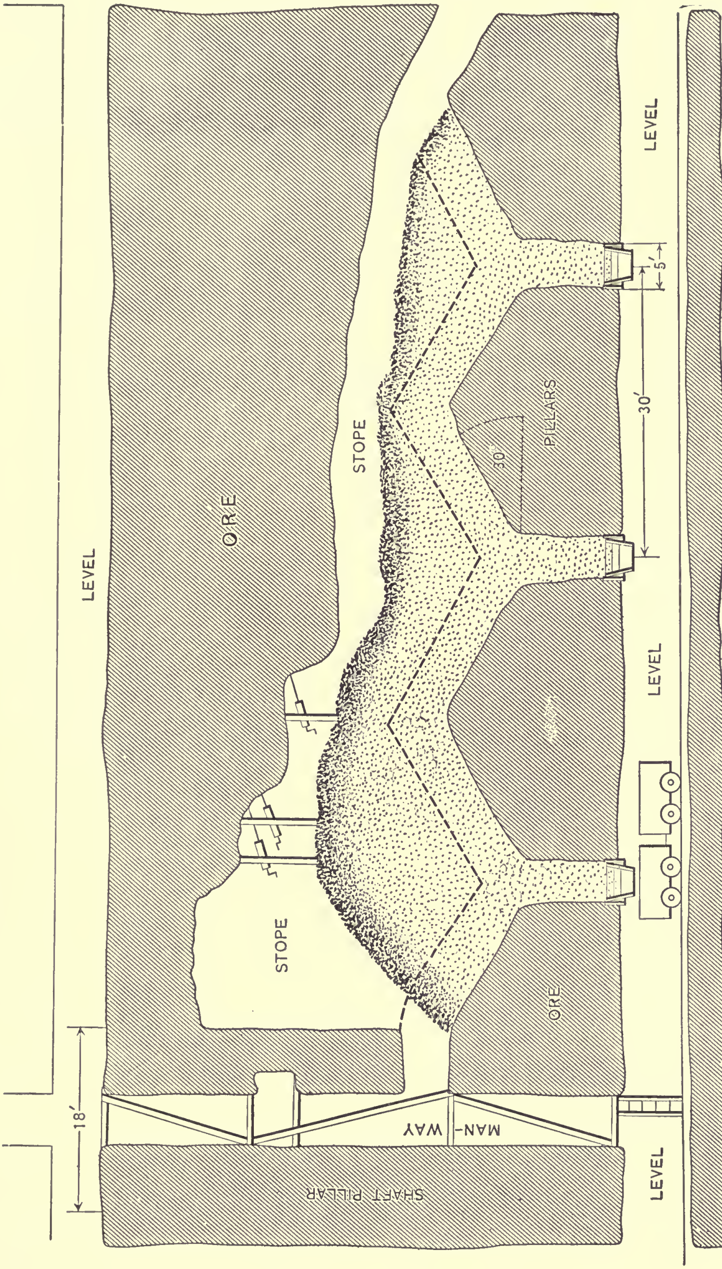


FIG. 47.—Longitudinal Section through Stope showing Method of Working by Shrinkage Stoping.

Shrinkage Stoping at the Alaska-Treadwell Mine

1. Alaska-Treadwell Mines, Douglas Island, Alaska.
2. Gold Ore.
3. Massive deposit standing vertically or nearly so.
4. Thickness several hundred feet.

The mining of the immense deposits of low-grade gold ores of the Alaska-Treadwell mines, Alaska, has been from the beginning of their exploitation the subject of much study and experimentation until a method has been developed which seems to be eminently suited to the existing conditions.

The ore occurs in diorite, is hard and firm, and stands well both in pillars and stope-backs. The orebodies are lenticular in shape and dip from 50 to 65°, the foot-wall being schist and moderately soft, while the hanging-wall is greenstone or gabbro, and is hard.

The method of developing the orebodies consists in sinking a shaft in the foot-wall from which levels are driven to and through the deposit. At the intersection of the levels with the foot-wall, drifts 7 by 10 ft. in section are run partially in the foot-wall and partially in the deposit. The positions of the pillars having been decided upon, those of the various levels being located vertically one above the other, main raises 6 by 7 ft. in section are put up at intervals of about 200 ft., which places a raise in alternate pillars. These raises make connection with the various levels, which are now driven 200 ft. apart. The distance between levels has been increased from 110 ft., the original distance, to the height of 200 ft. now employed. Midway between the proposed centers of pillars cross-cuts are driven across the deposit paralleling the pillars. At intervals of

60 ft. along the cross-cuts, drifts are run normal to them and parallel with the longer dimension of the orebody. Other raises are put up in the pillars along the line of the level next to the hanging-wall. The object of these raises is to ventilate the various levels. Other raises are put up at 25-ft. intervals along both drifts and cross-cuts and are termed 'chute-raises.' At a height of 18 to 20 ft. and thereafter at intervals of 30 ft. 'blind drifts' or 'sub-drifts'

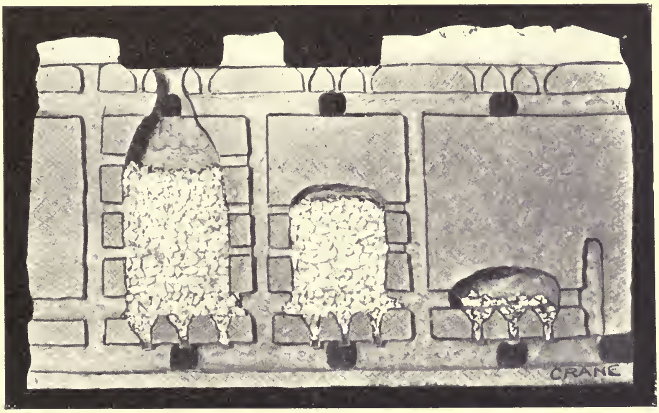


Fig. 49.—Vertical Longitudal Section through Lode and across Stopes Showing Development Passages and Their Relation to the Stopes.

are driven on either side of the main raises and extend at right angles to the pillars. (See Figs. 49, 50, and 51.)

The first sub-drift is driven as a drift-stope across the body of ore lying between pillars, and as it is extended breaks into the tops of the chute-raises. The drift-stope is 8 ft. in height, and when widened out on either side of the line of chute-raises it forms the beginning of the stope or the cutting-out floor. The tops of the chute-raises are enlarged into funnel-shaped openings in order to more

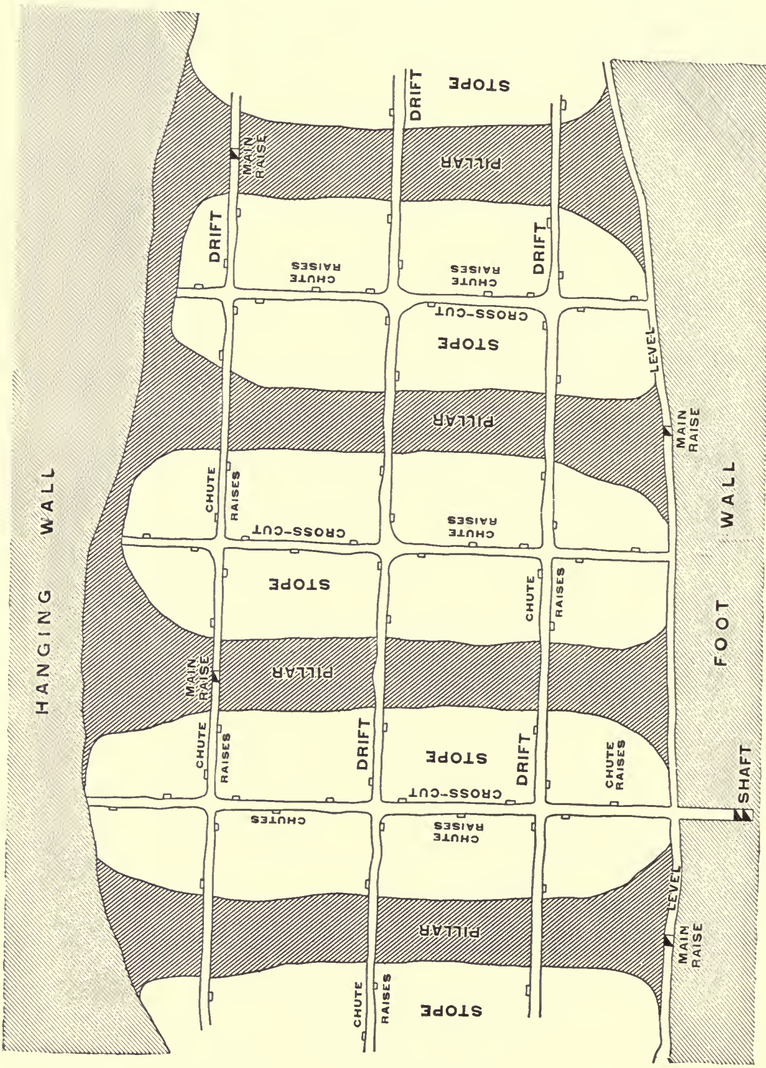


FIG. 50.— Plan of Stopes in the Alaska-Treadwell Mines.

readily collect the ore broken down from above. The chute-raises should be kept full to protect them from falling ore.

After the drift-stope has been extended from one pillar to another and the 'stope floor' established the work of opening the whole stope is begun. Drills are set up in the center of the stope floor and a drift-stope is run longitudinally the full length of the stope. This drift stope is then enlarged laterally by breast work until the pillars have been reached. Considerable care is taken in forming the back of the stope into an arch with sufficient curvature to stand readily. As previously pointed out, the character of the ore is such that it stands well in low arches of wide span, thus permitting wide stopes to be maintained. The larger fragments of ore resulting from blasting in the stopes must be reduced by sledge-hammers and small charges of powder to a size to pass the chutes. The latter operation is known as 'bulldozing.' It has been found that the broken ore requires one-third more space than the solid ore, consequently one-third must be removed to provide room for the miners at the working face. (See Fig. 51.)

As the work of cutting out the back of the stope continues the various sub-drifts are broken into, thus maintaining access to the stopes and providing a passage for air currents. Ultimately the stope breaks into the level above, but instead of carrying it up the full width it is arched, only the crown of the arch being broken through. A ledge is then left in the stope floor above, which is supported by the flaring tops of the pillars below. These ledges are termed 'sheet-

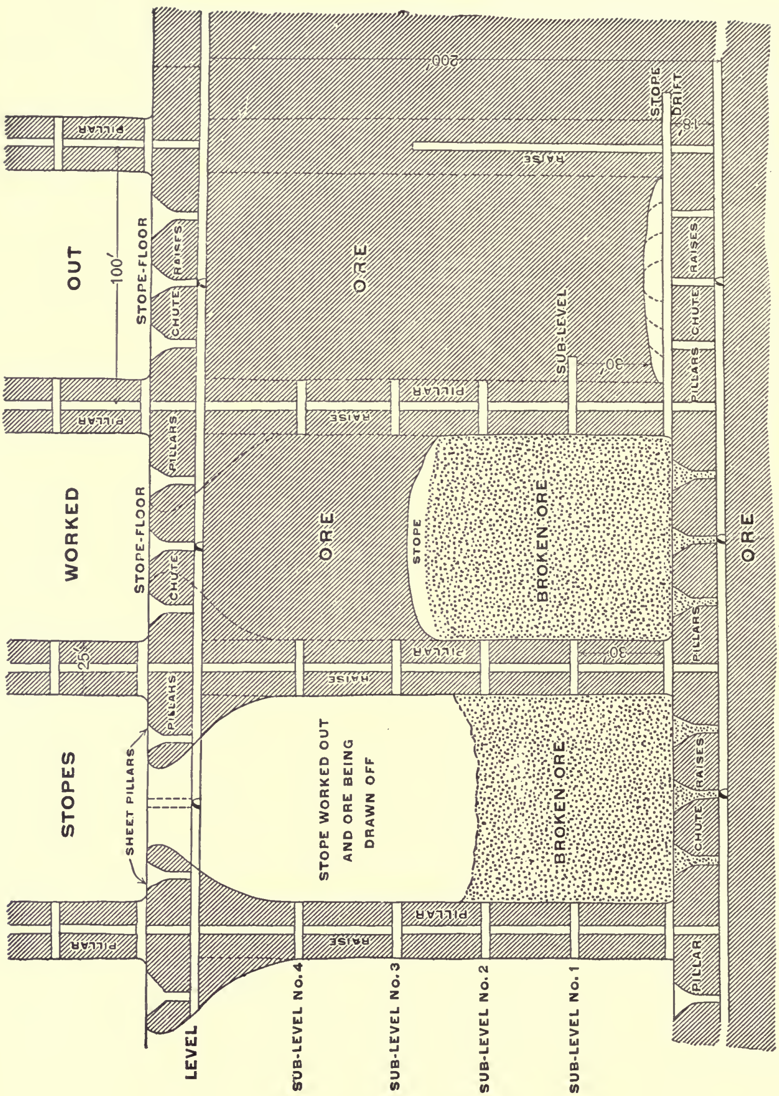


FIG. 51.— Longitudinal Section through Stopes in Alaska-Treadwell Mines.

pillars' and are in reality pentices, as their primary object is to serve as a protection to the men employed in the stopes below.

The pillars are approximately 100 ft. center to center, the length varying with width of orebody and may be 300 ft. The width of the pillars varies from 18 to 25 ft. and they are often considerably wider especially with the height of stopes now employed. The height of the stope is about 185 ft., or twice the width, the increased height being considered more economical, as fewer levels have to be formed.

The method of mining employed in the Alaska-Treadwell mines is applicable to very large deposits of low-grade, hard and firm ore, also to deposits standing at high inclinations.

The advantages of the method are:[1]

1. Levels can be placed far apart.
2. Practically no timber is used.
3. Large output for number of men employed.
4. The cost of extraction of ore is small.
5. Handling ore is reduced to a minimum.
6. Little danger from accidents.

The disadvantages of the method are:[1]

1. Is applicable only to large deposits of high dips.
2. The stopes must be carried up vertically.
3. The amount of development work required for each level is large.
4. System of ventilation is rather complicated.

[1] For disadvantages and advantages of shrinkage stoping see: "Shrinkage" Stoping, by F. Percy Rolfe. Mines and Minerals, vol. 30, p. 210.

5. Loss of ore in pillars rather large, especially if a regular system is followed in laying out workings.

For reference to practice in Shrinkage Stoping see Bibliography at end of chapter on Methods of Stoping.

Square-set Methods of Mining

Use of Square-Sets at Rossland, British Columbia

Timbering by square-sets, in which the members of the sets are unsawed round timbers, is common practice in

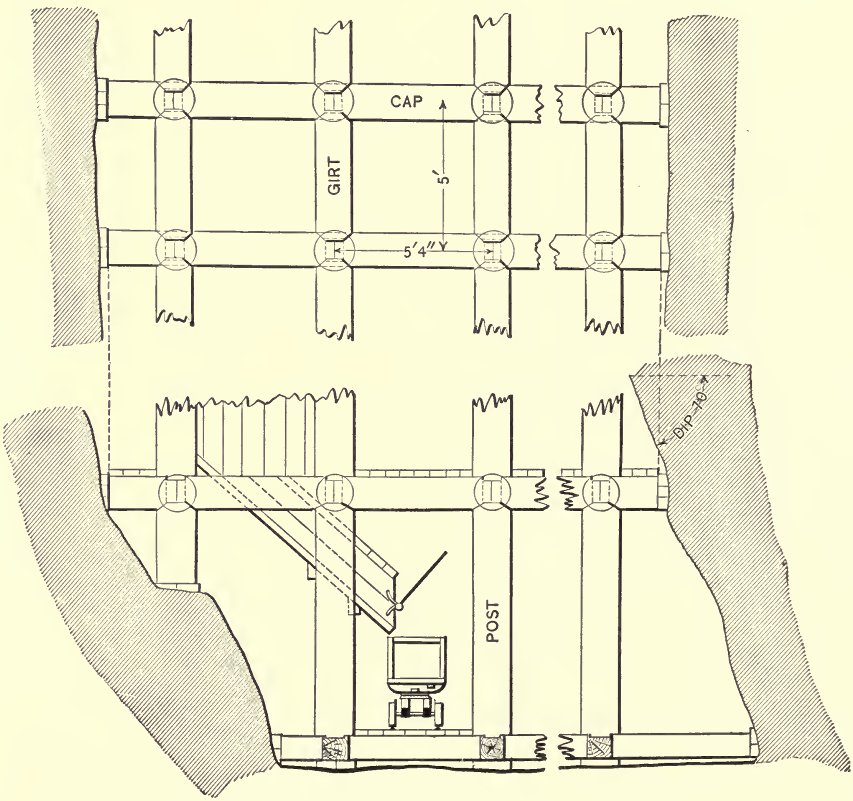
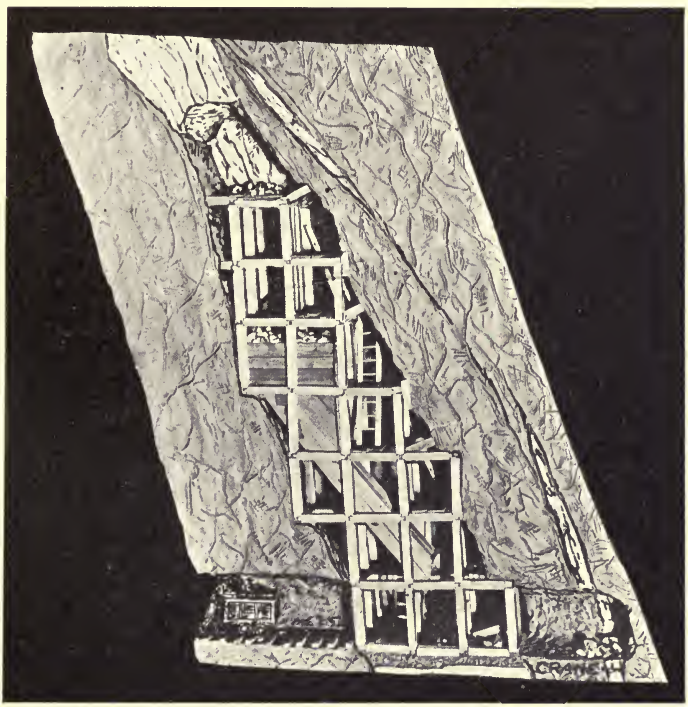


Fig. 52. — Square-Sets Composed of Round Timbers.

many parts of the country. In Fig. 52 is shown the system of square-setting with round timbers as employed in the mines of Rossland, British Columbia. The ore deposits often have widths ranging up to 100 ft. and dip at an angle of about 70°. Both ore and wall rock are very hard, the former being badly fractured and fissured, and is cemented together with aurif-

1. **Mines at Rossland, B. C.**
2. **Gold and Copper Ore.**
3. **Veins.**
4. **Maximum width 100 ft.**



C. — Adaptation of Square-Set Mining to a Highly Inclined Vein, Showing Ore Bin and Chute for Loading Cars in Level.

erous sulphides. The conditions existing in these deposits are decidedly favorable for the employment of square-sets.

Stoping is done by the overhand system, the work being started from a raise or winze and proceeds in both directions. The work is carried on in floors, each floor being somewhat over a set high and terminates in a back-stope, *i.e.*, if there are four back-stopes there are five floors including the drift-stope. The square-sets in the stopes assume a stepped formation, dropping down set by set in both directions from the raise. The timbers composing the sets range in diameter from 12 to 20 in., averaging about 18 in., and are partially seasoned before being used in the mines.

Square-set Mining in the Queen Mine

Square-sets have been extensively employed in mining the iron ores of the Lake Superior region, but have been largely superseded in the massive deposits by the caving methods, such as the top slice, sub-drift and modifications of these with the milling method.

1. **Queen Mine, Negaunee, Mich.**
2. **Iron Ore.**
3. **Massive Deposit.**
4. **Large lens-shaped body.**

A special method involving both the use of square-sets and caving has been employed in the various districts and is at present in successful operation at the Queen Mine, Negaunee, Michigan. The orebody here is large and lens-shaped, being quite regular. It has a dip of 38° to the north and pitches 45° to the west. Owing to its size and regularity it is especially suited to systematic and large-scale operations. (See Fig. 53.)

The deposit is opened by vertical shafts, and on the levels are well-planned systems of haulage ways through which the empty and loaded trains of cars can travel without in-

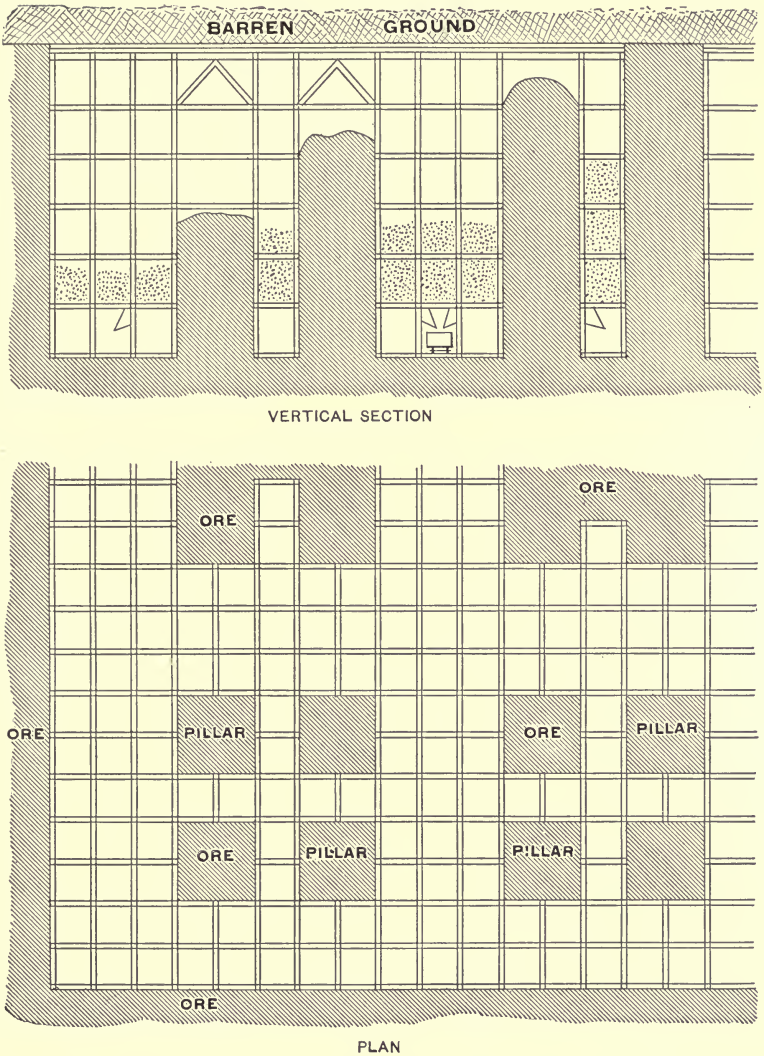


Fig. 53.— Square-set Mining in Massive Deposit.

terference. In the deposit a number of stope-faces are carried three sets wide, usually parallel with the major axis of the orebody, and at intervals of 40 ft. (five sets) apart other similar stopes are then run, cross-cutting the former and at equal intervals. The deposit is then broken up into rooms (stopes) and pillars; the former 25 ft. wide and by continued stoping carried about 50 ft. high, the latter 40 ft. square and of equal height with the stopes. The stopes are carefully supported by square-sets, those of the upper level extending to caved ground, if mining has previously been carried on above, if not to barren ground.

The next operation is the drawing or robbing of the pillars, following which caving begins. A pillar is removed by driving two drifts through the base, *i.e.*, on the level of the stope-floor, cross-cutting it into four equal parts. At the point of intersection of the drifts, or the center of the pillar, an 8 by 8-ft. raise is put up through the pillar, both drifts and raise being timbered with sets. The backs of the drifts are next stoped out to the height of the centrally located raise, thus completely subdividing the pillar into four equal parts. Stoping is then begun at the top of the raise, and the upper portions of the new pillars formed are removed to the depth of one set. A cap of double length is placed next to the roof and lagging carefully put in place above it. The work of cutting away the pillar is then resumed, and other double-length caps are placed as rapidly as possible. On placing the second cap it is usual to reënforce the first or roof cap by two timbers set in A-form. The ore broken from the pillars falls upon lagging placed at the lower side sets, from which it is run or shoveled into cars. That part of the ore obtained from pillar-drawing is mined with the least trouble and expense.

Pillars may also be removed by 'side-slicing,' *i.e.*, by cutting off slices from the sides of the pillars one set wide first on one side then on the other, or if that proves to be too risky, the stopes may be filled with waste and the pillars removed by top-slicing.

The ore having been all mined out, the tracks are removed and the timbers are broken down by blasting every second leg of the sets, which starts the cave. When all movement has ceased, the next level may be worked out in a similar manner, but so far the method has been confined to working out the upper portion of deposits, subsequent work being done by strictly caving methods.

This combination method of square-setting and caving is applicable to massive deposits of hard ore which stand well and to deposits that occur close to the surface and of large lateral extent.

The advantages of the method are:

1. A large output is possible.
2. The cost of mining is low.
3. There is little danger from falls.
4. Opportunity is given for the sorting of ore if desirable.

The disadvantages of the method are:

1. It is of limited application, being seldom used in more than one floor.
2. A large amount of timber is required.
3. Loss of timber is great.

Filling Methods

Methods Employed in the Broken Hill Mines

1. **Broken Hill Mines, N. S. W.**
2. **Lead and Silver Ore.**
3. **Vein.**
4. **Width 25 to 370 ft,**

The economic working of the large orebodies of the lode of Broken Hill, New South Wales, Australia,[1] has necessitated radical changes in methods of mining until at present fully three different methods are in use in various parts of the lode. The ore is lead-silver, although other minerals of economic value are obtained. The lode ranges in width from 25 to 370 ft., averaging probably 70 or 80 ft., and stands nearly vertical. The ore varies from very hard and tough to very friable, the wall rock also varying somewhat in hardness and strength. These conditions are responsible for changes in methods, as well as for the employment of various methods in the different mines of the district. The tendency has been to employ methods in which timber is being used less and less and is becoming of less importance as a factor in the extraction of ore.

There are three methods in use in these mines which may be employed in illustrating the gradual change in working, showing the evolution from one to another and therefore having points of resemblance. These methods are, in the order of their development, square-setting, the 'open-stope,' and the 'pillar-and-stope.'

The application of square-set timbering as a means of support and a convenience in mining and handling ore in

[1] Stoping Systems at Broken Hill, Australia, by A. J. Moore. Mines and Minerals, vol. 27, p. 433.

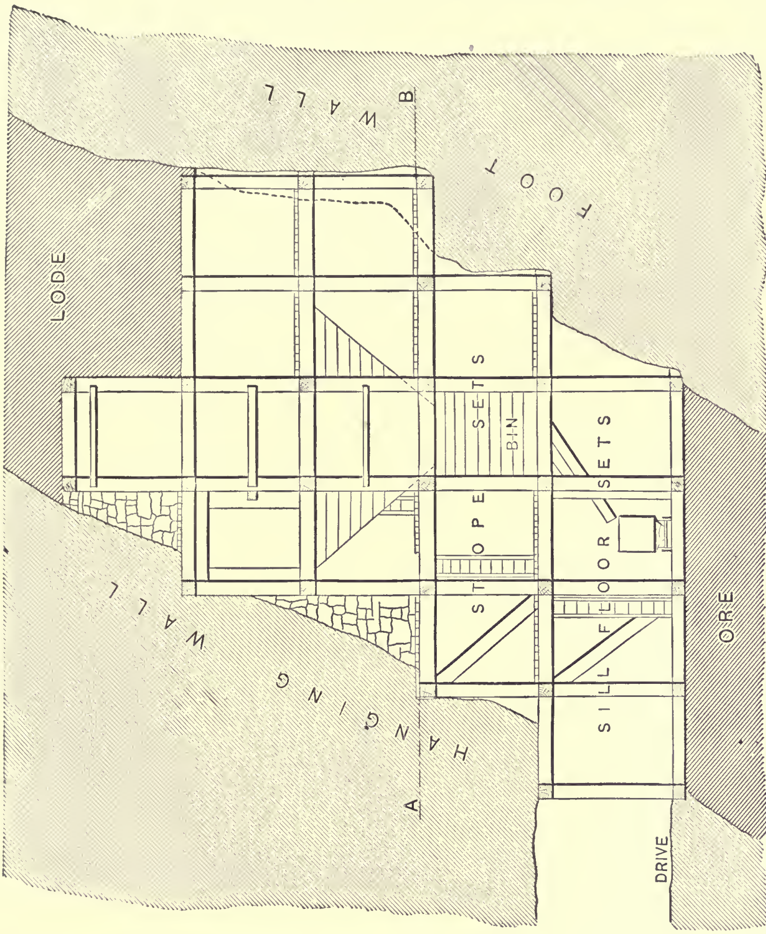


FIG. 54.—Square-Set Mining in Broken Hill Mines, N. S. W.

the stopes is well illustrated by the practice in this district. This system is employed in ground that is not sufficiently strong to stand by itself, as in the friable sulphides. The all-square-set system is usually employed in the narrower portions of the lode, although it has been used in the large orebodies. The sets are usually 7 by 5 by 6 ft., *i.e.*, posts 7 ft., girts 5 ft., and caps 6 ft. long, although in the Central and Proprietary mines the sets are 8 by 6 by 6 ft. When the ore is hard and solid it may stand with only an occasional supporting prop between it and the square-sets, but when friable the sets may have to be kept close to the face. The disadvantage of carrying the timbering close to the face is that blasts are liable to injure or knock down the sets, which is expensive from the standpoint of loss of timber and delay, and may also result in falls of rock. (See Figs. 54 and 55.)

The method of placing lagging for the miners to stand upon while working at the face is shown, also the arrangement of chutes and pockets for handling and holding ore preparatory to loading it into cars.

The open-stope method of mining as employed in the Broken Hill mines is in successful operation in portions of the lode that average 70 to 80 ft. in width and occasionally 200 ft. Where used the walls are firm and the ore is solid, standing fairly well by itself. Owing to the width of the lode, a portion, usually somewhat less than one-half, is left as a pillar, although it is planned to ultimately mine all the ore. (See Fig. 56.)

The lode is developed by vertical shafts sunk in the foot-wall from which levels are driven some 20 to 30 ft. from and paralleling the lode. From the foot-wall levels, cross-cuts are driven at intervals of 80 to 100 ft. to and through the lode until the hanging-wall is reached, when they are opened up on either side. Connecting the cross-cuts and through the center of the lode is a passage, which serves as the main haulage way. Combined ore chutes and manways are placed every 30 ft. along the haulage way, being timbered passages built up as the stope increases in height.

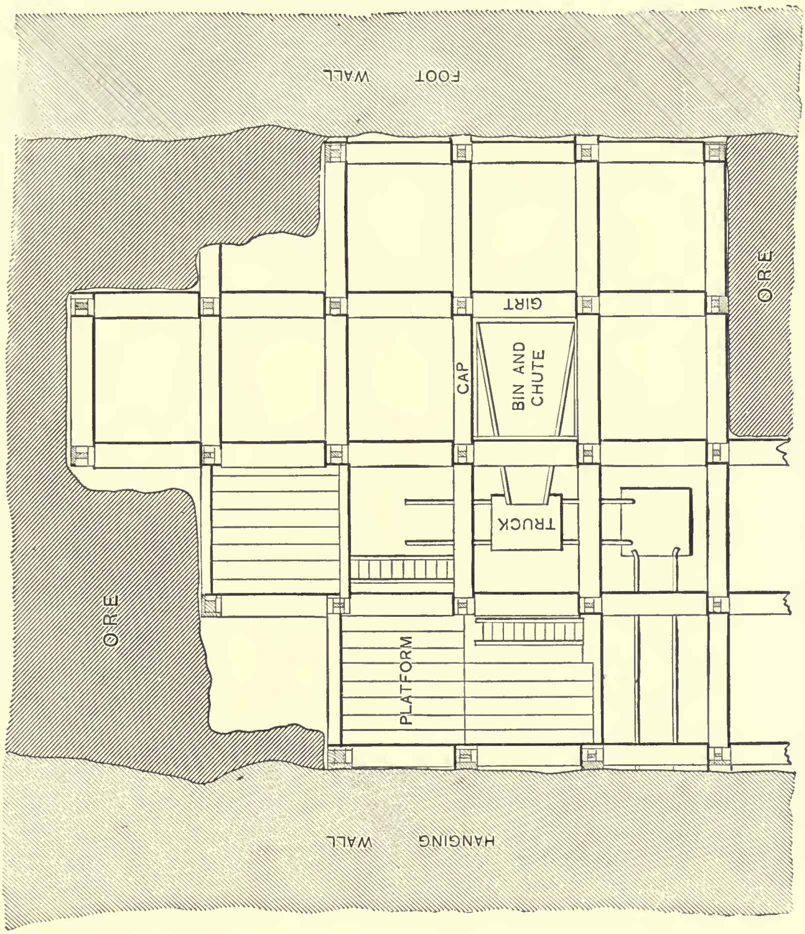


Fig. 55. — Plan of Square-Set Mining in Broken Hill Mines.

The cross-cuts are timbered with square-sets as formed, and are extended laterally until they run together, if that is found desirable, thus forming a long continuous stope. The cross-cuts and afterward the stopes are carried 11 to 12

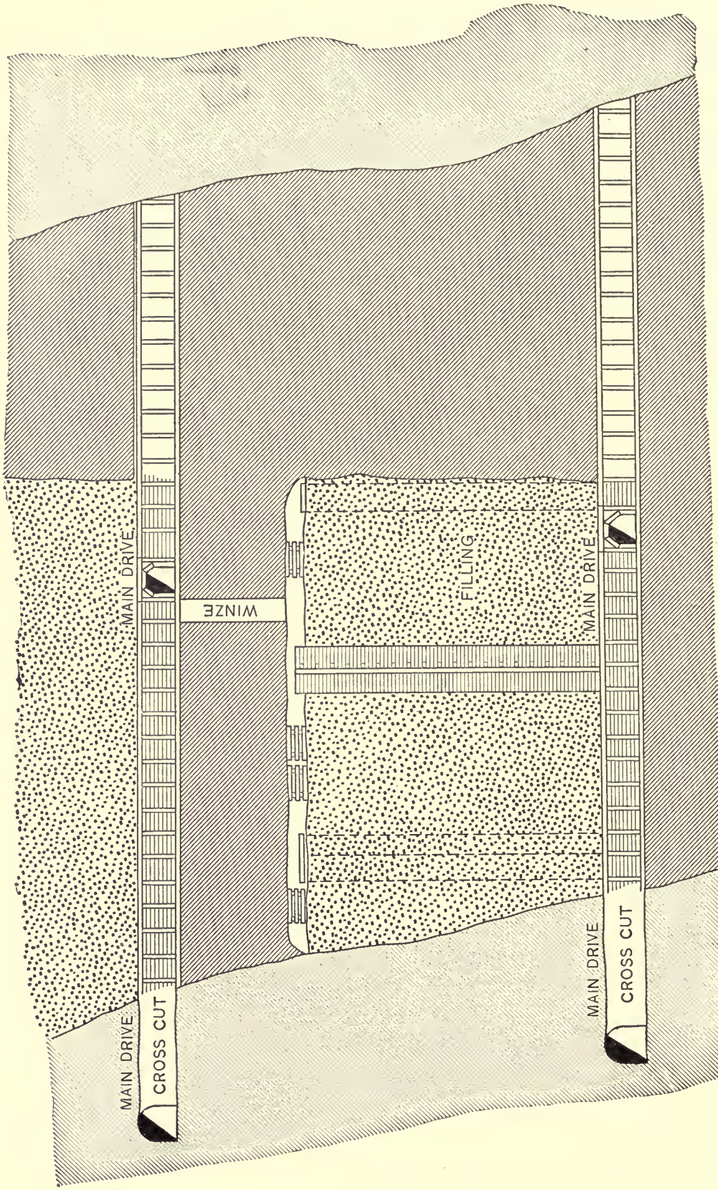


Fig. 56.—Section through Lode, Broken Hill Mines, showing Open-Stope Method.

ft. high, which is done in two operations: the lower 5 or 6 ft. by drifting and breast stoping, the upper 6 ft. by mounting the drills on a crib-work of timbers. Beginning with the foot-wall side of the lode square-sets are placed, but kept far enough back from the face to prevent injury by blasting. As an additional support cribs are built in advance of the sets, thus insuring the support of the back under ordinary conditions. A method of extending certain members of the crib that come next to the back as cantilevers to support bad ground, which is held in place by wedges, is an important factor in the system of control of back. On completing the level or sill-floor and having filled the stope to within a few feet of the back, the work of removing another horizontal slice is begun, the cutting-out being carried on as before, except that no sets are used above the sill-floor, cribs being the only form of timber support employed. The waste-filling is run into the stopes through winzes put down from the level above and spaced 100 ft. apart along the stopes, its distribution being done in small cars operating on temporary track laid on the waste. (See Fig. 57.)

Owing to the ore chutes having become badly worn it is usually found necessary to run ore through the manways after a height of 50 ft. has been reached in the stope. When the stopes have reached a height of 60 ft., it is usually considered advisable to change the method of procedure and remove the remaining 40 ft. by overhand stoping and filling, similar to the filling method employed in the mines at Zaruma, Ecuador. Stoping is begun at the foot of the winzes and carried outward, back-stopes being formed as those previously driven advance, which soon forms the back into faces sloping away from the winzes. Filling is run in from above, providing a footing for the miners and a mounting for the drills. The back may also be supported, if found desirable, by props or cribs built on the sloping sides of the fill. Care must be taken as the levels above are approached or the timbering in them may collapse. To prevent this

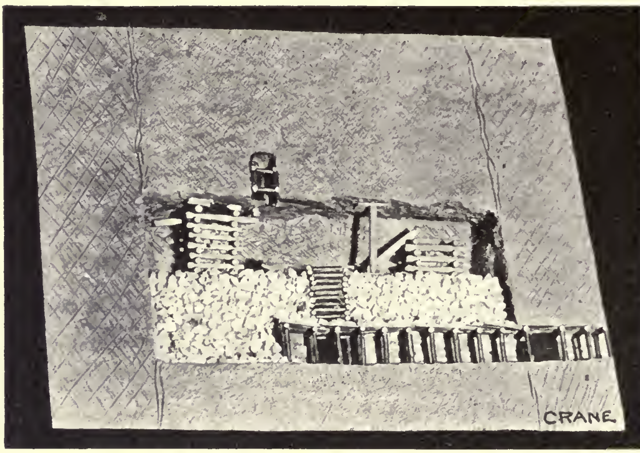


FIG. 57. — Cantilever-Crib in Wide Stope, Australian Mines.

the back is removed in small sections and cribs placed beneath the level timbers, or square-sets may be employed.

The pillar-and-stope method of mining as employed in the Central Mine is applicable to great width of lode and is now operating in a two percent orebody. The orebody is developed by cross-cuts run from levels driven in the foot-wall, which are connected by a drift or level running through the center of the deposit. Stopes are opened up from the levels in the lode, which are run across the lode from wall to wall 50 ft. wide (8 sets) and at intervals of 50 ft., thus dividing the lode into stopes and pillars alternately and of equal width. The stope sections are completely

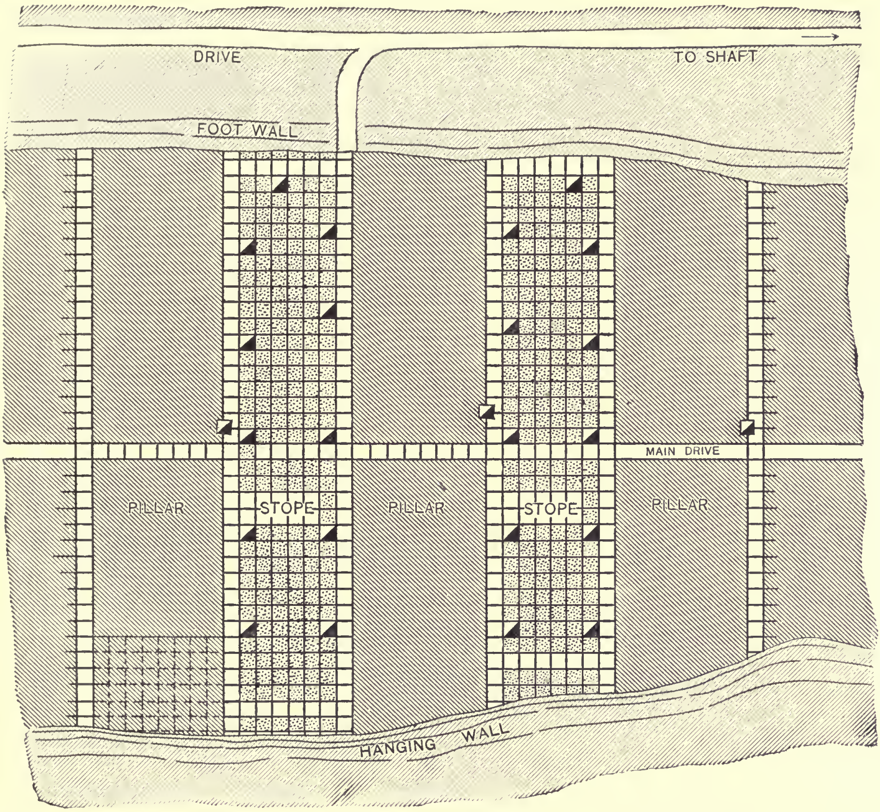


FIG. 58. — Plan of Pillar-and-Stope Method in Broken Hill Mines.

worked out on the sill-floor and carefully timbered with square-sets. Winzes are then put in, connecting the stopes with the level above, but are maintained one-half in the pillar and one-half in the stopes. (See Fig. 58.) The outer rows of sets in the stopes and a line of cross-cuts connecting them at the ends of the stopes are kept open by lagging on the sides and tops of the sets. All other sets with the exception of the chute sets are then filled with waste and the work of stoping out the back is begun. This is accomplished by the open-stope and crib method previously described, the ore being disposed of through the chutes, which are carried up to the full height of the stope. Waste is introduced through the winzes and distributed throughout the stope, filling all parts except the two side rows of sets, which are carried up the full height of the stope and kept open in order that the waste may be kept clear of the pillars and to permit work to be done on the pillars if desired. The stopes are worked out to a height of 60 or 70 ft., after which the arch pillars are worked out by square-sets and filling.

Owing to the weight of the ground, which will have begun to settle and move by the time the stopes are worked out, all of the pillars on one level are robbed at one and the same time, which is accomplished by beginning on the hanging-wall side of the lode and drifting across from stope to stope, the drifts being timbered with sets and filled with waste. From the face thus formed the work of stoping then proceeds both horizontally and vertically until all the pillars on a level have been removed, the space being filled with square-sets and waste.

While the idea is to remove ultimately both arch and stope pillars, yet such large quantities of ore are available that so far little has been done except in the stopes proper.

The open-stope and pillar-and-stope methods of mining at Broken Hill are applicable to very large lodes of solid, low-grade ore and with fairly strong wall rock. High inclination of deposit is also an important consideration in working by these methods.

The advantages of the methods are:

1. Large outputs.
2. Low cost of mining.
3. Comparatively little timber required.
4. Labor of handling waste and ore slight.
5. Opportunity afforded for sorting ore and stowing waste.
6. Development work simple and not extensive.
7. Ventilation is good.
8. Little danger of accidents from falls.
9. The complete extraction of the ore is aimed at, but not attempted at present.

The disadvantages of the method are:

1. Applicable only to large deposits of low-grade ore standing at high dips.
2. Stopes must be carried vertically.
3. Stopes are of limited height, usually not over 100 ft.
4. Loss of ore in pillars large even if ultimately worked.

Methods Employed in the Homestake Mine

There are few mines in the United States which have experienced so many changes in methods of working as have the Homestake mines of the Black Hills, South Dakota. The reason for this is that the ores are low-grade, ranging from $2 to $12 per ton, and to operate them profitably a large tonnage and low cost of mining is necessary.

1. Homestake Mine, Lead, South Dakota.
2. Gold Ore.
3. Vein.
4. Width 30 to 500 ft.

The orebodies are broad zones of impregnations in schists; they are quite irregular, varying from 30 to 500 ft. in width, and usually stand vertically or nearly so.

Owing to the great width of the deposits the stopes are run transversely, extending from foot-wall to hanging-wall, pillars being left between the respective stopes. Formerly it was customary to employ square-sets to support the walls, which combined with filling permitted the stopes to be worked to a height of 85 to 100 ft., the former being more usual. It was found that square-sets if carried much above 85 ft. would often collapse under their own weight. With the exhaustion of the supply of suitable timber and the consequently increased cost, also owing to the gradually decreasing value of ore, other and cheaper methods of working the orebodies were found to be necessary. While the general method of attack has not changed materially, radical changes in support have been made, the main idea apparently being to reduce the amount of timber employed. Timber is still used, but it is doubtful whether there are many other mines in the world in which so little timber is actually used per ton of ore extracted. This is rendered possible, however, only through the exceptionally strong and solid ore and wall rocks. In many places the ore stands without support in low arched stopes of 60 to 80 ft. in width.

Following the use of square-sets and filling, a system of back-filling was introduced, being first employed with considerable timbering in the form of timbered passages on the ground or stope floor, but as the work is now carried on it would seem that the amount of timber used has been reduced to a minimum. This has been rendered possible by a rearrangement of the drifts and cross-cuts through which the ore is withdrawn from the stopes.

Descriptions of two of the more recent methods of mining are given below and will serve to illustrate the gradual change that is being made in these mines.

Back-Filling in the Homestake Mine

In the first and earlier method levels are driven from 100 to 150 ft. apart, depending largely upon the condition of the ground and the depth of the workings. The levels having been formed and consisting of foot-wall and hanging-wall drifts and one or more intermediate drifts, the work of opening up the stope is begun. This is accomplished by carrying a working face outward and across the deposit from the drift on the foot-wall side. The stope is cut to a width of 60 to 75 ft. and to a height of about 10 ft., the work being done by breast stoping. Other stopes are begun along the line of the level drifts at intervals of 25 to 40 ft., the unworked portions serving as pillars between the rooms or stopes on either side. A stope having been cleared of broken ore, all lines of haulage that are to be maintained within it are carefully timbered and lagged. The passages that are considered necessary for the proper handling of the ore are the sideways and endways, the former being known as cross-cuts and the latter as drifts. The drift in the foot-wall side is timbered with a double row of sets. There are also one or more intermediate passages running transversely with the stope and connecting the cross-cuts. (See Figs. 59 and 60.)

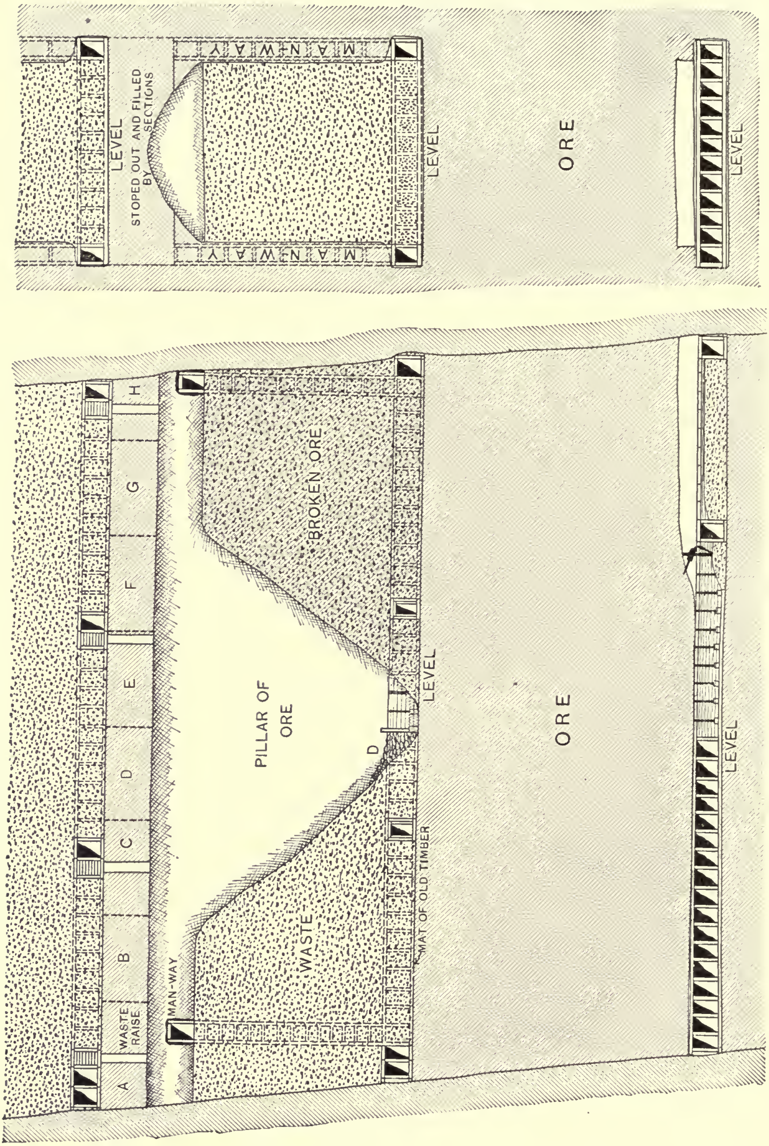


Fig. 59.—Back-filling Method used in Homestake Mines.

Back stoping is then begun, usually on the hanging-wall side, and carried lengthwise of the stope for a distance of about 14 ft. less than that of the first or level stope. By this method of procedure the cross-cuts are set into the pillars and protected by them from movements of ore in the stopes. No attempt is made to remove the ore as it is broken down, except to provide space for the miners above, the excess being drawn off from below along the line of the drifts and cross-cuts.

As the height of the stopes increases it is necessary to provide passages for the men to and from the working face; this is accomplished by putting in raises, which are in line with the cross-cuts and like them are set into the pillars. These raises are timbered, and besides serving as manways assist in ventilating the stopes. With levels 100 ft. apart the stopes are carried to a height of 70 ft., at which point the roof is arched, giving an additional height of 15 ft., thus making the stopes 85 ft. high and leaving an arch pillar 15 ft. in thickness. With greater distance between levels, the height of the stopes is proportionally greater. Finally raises are put through the arch pillars at the highest point of the stope, thus establishing communication with the level above. These raises are subsequently employed in introducing waste into the stopes for filling.

The work of stoping having been completed, the ore may be withdrawn or left in the stope as a reserve supply that may be drawn upon as occasion demands. It is drawn out of the stope by breaking away the lagging on the side of the sets on the foot-wall side, thus permitting the ore to run into the drift, where it is shoveled into cars and sent to the shaft. In the course of time the foot-wall end of the stope is emptied of ore, and as the work continues the

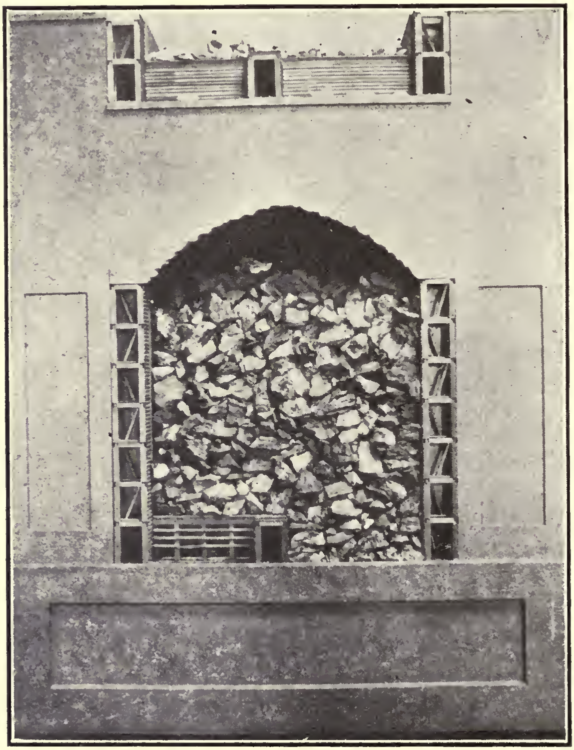


Fig. 60. — End View of Stope in Homestake Mine, Back-Filling Method. (From Model in Engineering Office of Company.)

shovelers leave the shelter of the timbered drifts and work in the open stope. When sufficient room has been cleared of ore the work of filling the stope is begun and continues at a safe distance behind the shovelers. It is customary, however, to cover the floor of the stope with old timber previous to placing the filling. As an extra precaution against accidents dams are often erected to check and hold back larger pieces of waste. (See *D*, Fig. 59.) The filling, as previously mentioned, is run into the stopes through the waste chutes formed in the arch pillars, and is similar in many respects to the back-filling method employed in the Butte mines. Drawing ore from the stopes is not confined to the drifts and intermediate passages, but may be carried on along the line of the cross-cuts. The ore having been completely drawn from the stope, the work of filling is continued until the curve of the arch is reached, when the filling is leveled preparatory to placing square-sets, which are employed in removing the arch pillars.

The arch pillars are removed by overhand stoping and square-setting, the work being done in sections running transversely with the stope. As the floor of the stope above is approached considerable care must be taken to prevent falls, but if the mat of timber has been properly placed there is not much danger, provided the roof is removed in small sections. As each section across the stope is cut out to the stope above and timbered, it is filled with waste, and work on another section is begun. It is obviously necessary to sacrifice the timber employed in removing the arch pillars, which is practically all that is lost, the parts of the sets employed in the drifts, cross-cuts and raises being used again and again until broken, when they are employed in making the timber mat.

More Recent Practice

Owing to the weakening of pillars by under-cutting them for the cross-cuts and by the vertical cuts for raises, also for reasons of economy in the use of timber, a further change was considered necessary. The present method of mining, which has recently been introduced, has had these objectionable features largely eliminated, and with slight modifications is being used extensively where its application seems advisable.

In this method the orebody is divided into stopes and pillars, the former being 60 ft. wide, the latter 42 ft., thus giving the pillars approximately 100-ft. centers. Through the center of each pillar a drift 6 ft. wide is run, from which cross-cuts are driven, one about midway of the pillar and the others spaced at intervals of 30 ft. on either side. Only one passage is maintained in the stopes, which is timbered extending along the hanging-wall side, the main drive or level being driven in the foot-wall some distance from the deposit. (See Fig. 61.) Raises are put up as timbered passages in the stopes and at points opposite the cross-cut openings, but on one side of the pillars only. They are placed a few feet distant from the pillars, but stand wholly within the stopes, and are surrounded by broken ore. Stoping is carried on in a manner similar to that previously described for the earlier method employed. The levels are usually run 150 ft. apart, making the arched stopes some 135 ft. high. The arch pillars are removed by overhand stoping and square-sets.

Ore is drawn from the stopes by shoveling from the cross-cuts and driveways connecting the drifts in the pil-

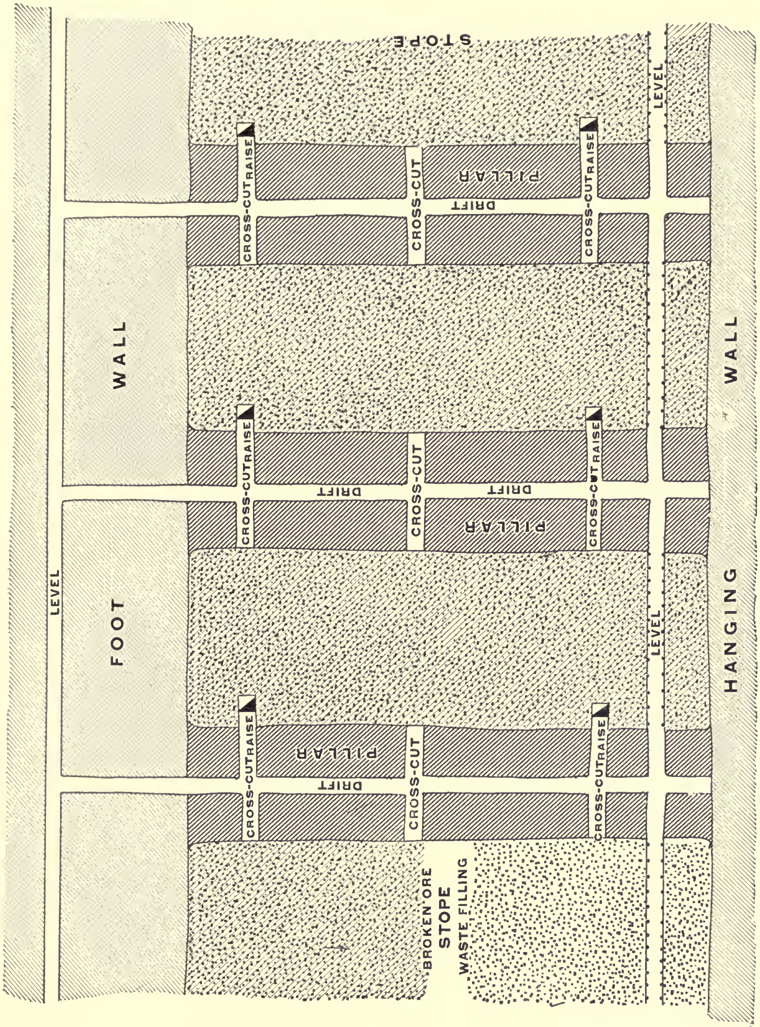


Fig. 61.—Plan of Stopes of Back-filling Method, Homestake Mines.

lars. The stopes in this method of mining may be likened to huge ore pockets, the cross-cuts being chutes through which the ore is drawn off. Filling follows the withdrawal of the ore, beginning with the hanging-wall side, its introduction into the stope being accomplished as described for the earlier method, but the passages through which filling is brought to the waste-raises is not shown in the sketches, being omitted for fear of confusing them with the development openings. It is the intention where possible to remove the pillars after the ore has been drawn and the stopes filled. To accomplish this to the best advantage the sides of the pillars are laced for a height of 15 to 20 ft., beginning with the floor, which is done before filling the stope with broken ore and may be carried upward as the stope increases in height. The lacing consists of 8 by 8 in. timbers placed vertically, to which slabs and planks are spiked. The lacing assists in holding back the waste-filling and prevents mixing with the ore as it is broken in the work of stoping out the pillars. Where the stope extends above the lacing the waste may be held back temporarily by facing-boards and props. Square-sets may be employed in removing the pillars. (See Fig. 62.)

Considerable ore may be lost in drawing it from the stoped pillars, especially during the latter part of the operation. This disadvantage may be largely overcome by removing the ore as broken and placing filling at once.

The methods of mining employed in the Homestake mines, as described above, are applicable to very large deposits of low-grade ore, both ore and wall rock being hard and strong, permitting wide low-arched stopes to be worked with safety.

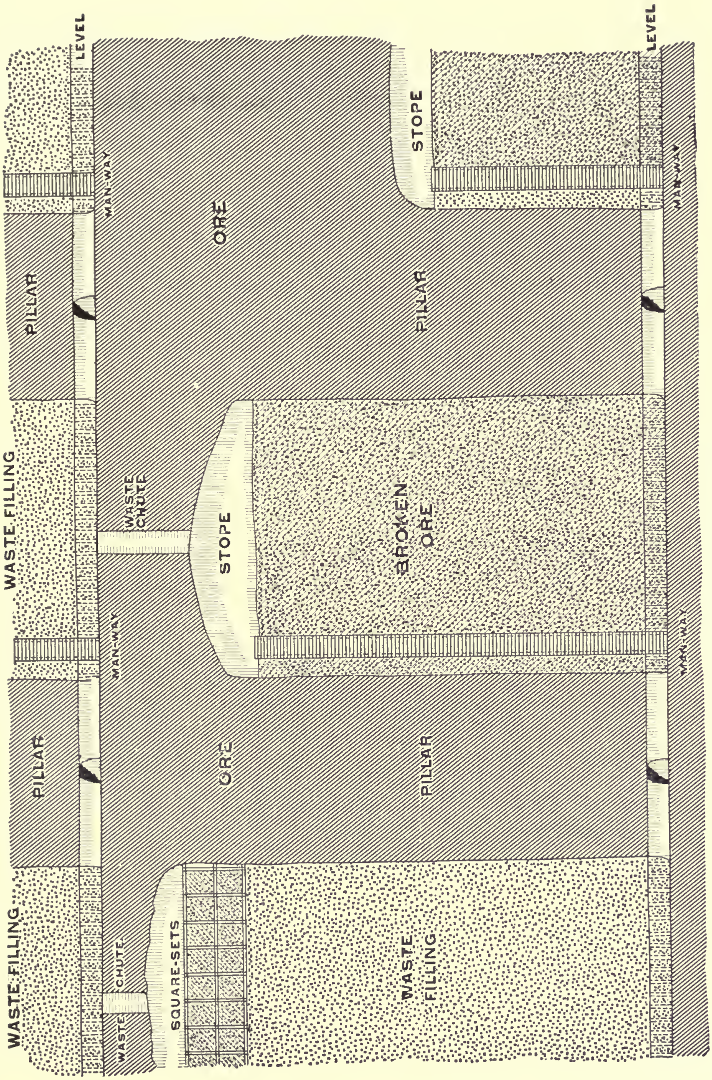


Fig. 62. — Longitudinal Section through Stopes in Homestake Mines — Back-filling Method.

The advantages of the methods, but with special reference to the last described, are:

1. Levels may be placed a considerable distance apart.
2. Little timber is used.
3. Ore is broken at small cost.
4. Shovelers are well protected.
5. Filling is easily and cheaply placed.
6. Percentage extraction is high.
7. Amount of development work is small.
8. Large outputs are easily obtainable.

The disadvantages of the methods are:

1. Applicable only to wide deposits standing nearly vertical.
2. The work must be carried along vertical lines.
3. As the ore breaks in large masses considerable hand work must be done in reducing to proper size to be loaded into cars.
4. The method requires considerable handling of ore.
5. The loss of ore in pillars is large unless they are ultimately removed.

Caving Methods

1. No Local Application.
2. Iron Ore.
3. Massive Deposits and Veins.
4. Width of veins 40 to 80 ft.

During the comparatively short time that iron ore has been mined in the Lake Superior region many changes in methods have been made, which condition of affairs has been brought about largely by experience in mining under varying conditions, lack of suitable timber and a demand for cheaper ore. There are, however, two methods of mining that have been employed for many years, and while modified from time to time to meet certain conditions, they remain fundamentally the same. These are the top-slice and sub-drift methods.[1]

No local application will be made in the descriptions of these methods, other than to state that they are applied equally well to wide veins and masses of considerable extent. Veins ranging in width from 40 to 80 and 100 ft. and with dips of 60 to 80° may be readily worked by both methods. The development of the deposits is the same, except as to the work in the vein, consisting of inclined or vertical shafts sunk in the foot-walls of veins or in the firm ground some distance from masses of ore, levels being 50 to 75 ft. apart.

The Top-Slice Method

In the top-slice method, after the cross-cuts from the shaft have reached and been driven into the deposit, main levels intersecting them are run through the center of the orebody, being connected at intervals of 100 ft. by two compartment raises. These raises contain an ore chute and a manway, the latter being also used for handling timber, and are put up to barren or to caved ground as the case may be. Beginning at the top of the raise driven from a level, a drift is run parallel with the main level below and from both sides of the raise. (See Figs. 63 and 64.) If the work is carried on systematically these drifts should meet other drifts similarly driven from adjacent raises, or encounter caved ground, the ore having been mined out. Cross-cuts are turned off at the ends of the drifts and the

[1] The Top-slice and Sub-drift Methods of Caving Iron Ore, Lake Superior Region. Mineral Industry, vol. 3, pp. 384, 392, 1894.

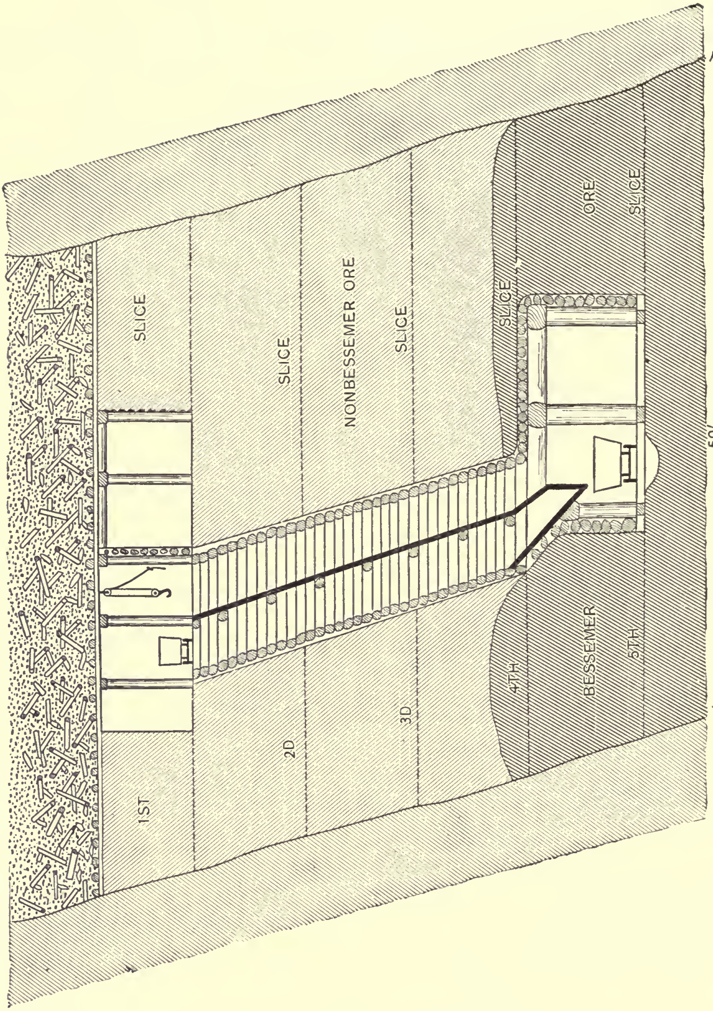


FIG. 63. — Section through Vein, Showing Development in Top-Slice Method.

ore removed to the vein walls. These drifts and cross-cuts must be carefully timbered, the sets often being given double posts. The ore is hauled to the chute in small cars and in some cases handled in wheelbarrows. The cross-cuts having been run to the walls, a mat of timber is placed on the floor,

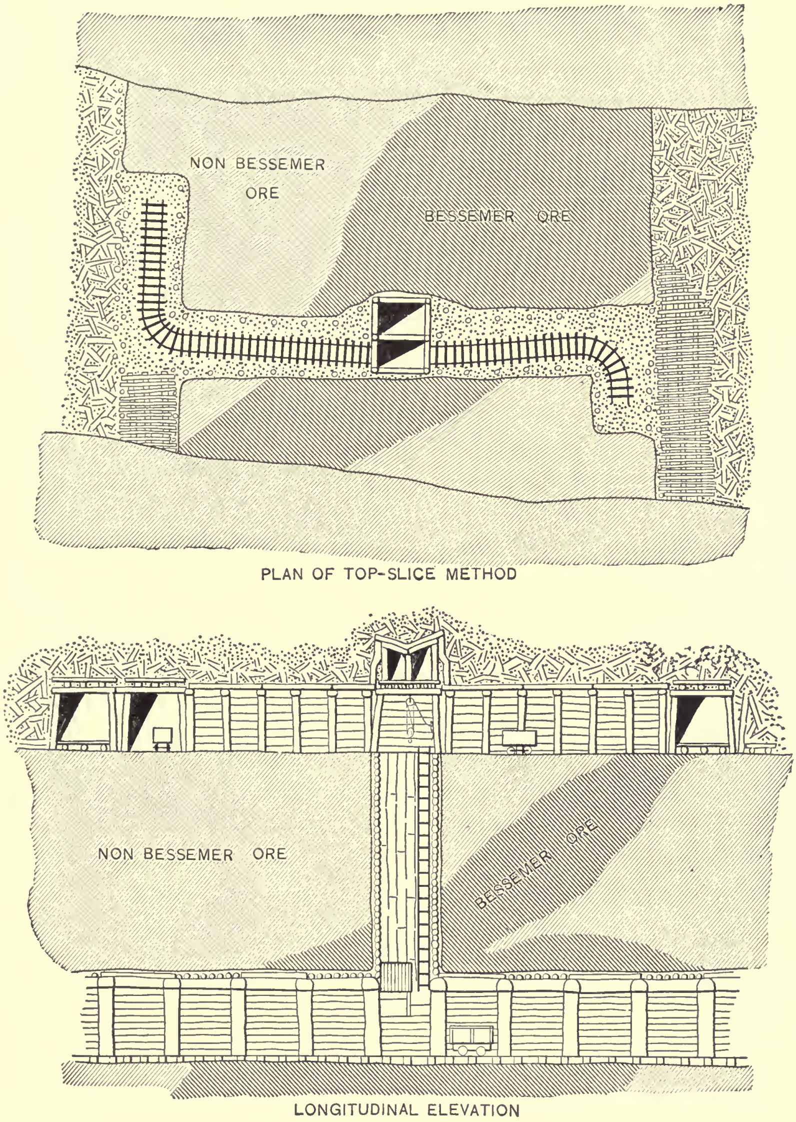


Fig. 64. — Plan and Longitudinal Section of Top-slice Method.

consisting of three long stringers laid next to the posts of the sets and midway between them, upon which in turn are placed split lagging and slabs. This mat of timber supports the caved material when a drift is run beneath it. To facilitate the work of placing the mat, the cross-cuts are driven in only one direction at a time, thus permitting the placing of the mat in the finished cross-cuts on one side of the drift. (See Plan of top-slice, Fig. 64.) The mat having been placed, the sets are blasted out, permitting the roof to cave close up to the ends of the pillars. Other cross-cuts are then opened up at the ends of the drifts adjacent to the caved ground, the same process of cutting out, timbering, placing mat and caving the ground being repeated. This is continued until the pillars are entirely removed, when the drift is of necessity closed and a new drift is opened up at the top of the raise as was previously done, and work on a new slice is begun. Timber is hoisted through the manways to the slicing drifts.

The top-slice method is applicable to large bodies of cheap ore, which may be hard or moderately soft. If veins are worked they should have a dip not less than 60°.

The advantages of the method are:

1. Development is simple and quickly done.

2. Opportunity is afforded for sorting ore, as keeping Bessemer and non-Bessemer ores separate.

3. Practically the complete extraction of ore is possible.

4. Ventilation is good.

5. Little danger of accidents from falls.

6. Cost of mining is low.

The disadvantages of the method are:

1. Number of working places limited, thus limiting output.

2. Levels are close together.

3. Considerable timber is required.

4. Much handling of ore and timber is necessary.

5. Confined to deposits close to the surface.

Sub-Drift Method

The sub-drift method, while employed in the same district and even in the same mines as the top-slice, differs radically from it both in methods of development within the deposit and in working. The development of a wide lode which is to be worked by the sub-drift method is shown in Fig. 65. A main level is run in the deposit, near the foot-wall, connecting the points where the cross-cuts from the shaft enter the lode, from which passages are driven at intervals of about 50 ft., cross-cutting the lode. A second main level is then run close to the hanging-wall and connected with the cross-cutting passages. The ore on the levels is thus cut up by means of the drifts and levels into blocks some 50 ft. wide and the full width of the lode in length. At 50-ft. intervals along the line of the main levels, raises are put up from which drifts are driven, forming the so-called sub-drifts. Beginning at a lower level than is being worked, a raise is put up for a height of 6 or 8 ft. and timbered, after which two drift sets are placed and lagged over, thus forming the starting point of sub-drifts which are driven in both directions, ultimately making connection with other drifts driven from adjoining raises. As soon as the 'subs' are well started the raise is put up another 6 or 8 ft. and a second set of subs is begun. The operation of putting up raises and driving subs is continued until the raises break through

Fig. 65. — Vertical Transverse Section across Lode Showing Method of Development in Sub-Drift Method.

into the level above and the subs have made connection with other subs. It is then evident that when all the subs and raises have been completed the ore between two adjoining levels is honeycombed by both horizontal and vertical passages and is ready for the last stage of the operation of extraction of the ore. Sub-drifting is, then, preliminary development work in the deposit itself, and is an intermediate operation between the opening of the deposit by shafts, cross-cuts, levels, etc., and the actual work of breaking down the ore. (See Fig. 66.) The height of the respective subs is the distance from the floor of one to that of another directly above it, and varies from 12 to 15 ft., depending largely upon the character and condition of the ore.

The work of sub-drifting is followed by the removal of ore from the pillars standing between the subs and the cross-cuts, also that standing in the back above the level of the tops of the subs, and is commonly known as 'stripping.' Consider that the work of stripping has reached the point shown in the longitudinal section, Fig. 66. By knocking down the supporting posts, as shown at the left of the first sub, the back of ore will fall and can be shoveled up and hauled away to the chutes. The settlement of the broken rock above is controlled by the mat of timbers which is constantly being added to by the timbers in the subs that are lost and broken. The method of cutting-out the pillars is shown in the plan, Fig. 66, as at the left where the stubs of pillars are being removed, the back standing on posts. As a sub cannot be worked beneath others not yet removed, it is necessary to either entirely remove the upper sub before beginning work on a lower one, or to carry on the stripping in descending order, each sub being carried some distance in advance of the one below. (See Fig. 67.)

As soon as the stripping operation reaches a main level

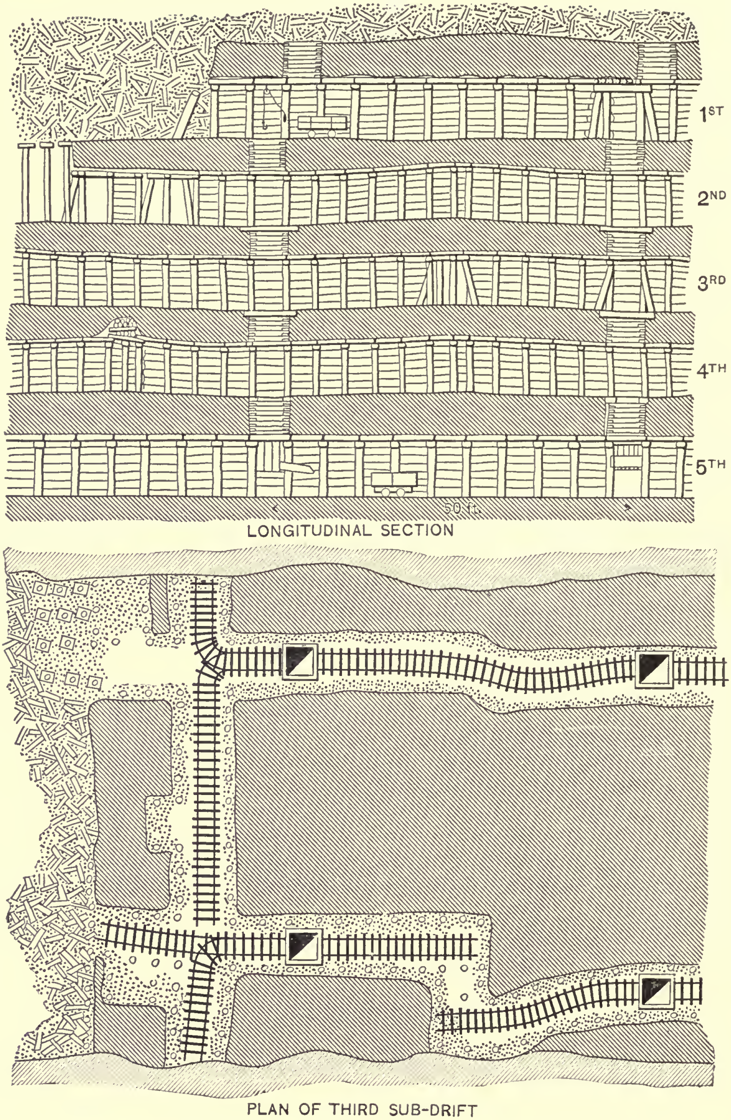


Fig. 66.— Longitudinal Section and Plan of Sub-drift Method.

that level is abandoned and all communication with the subs below must be through the lower level. The usual practice is to have one level or lift (the block of ore between

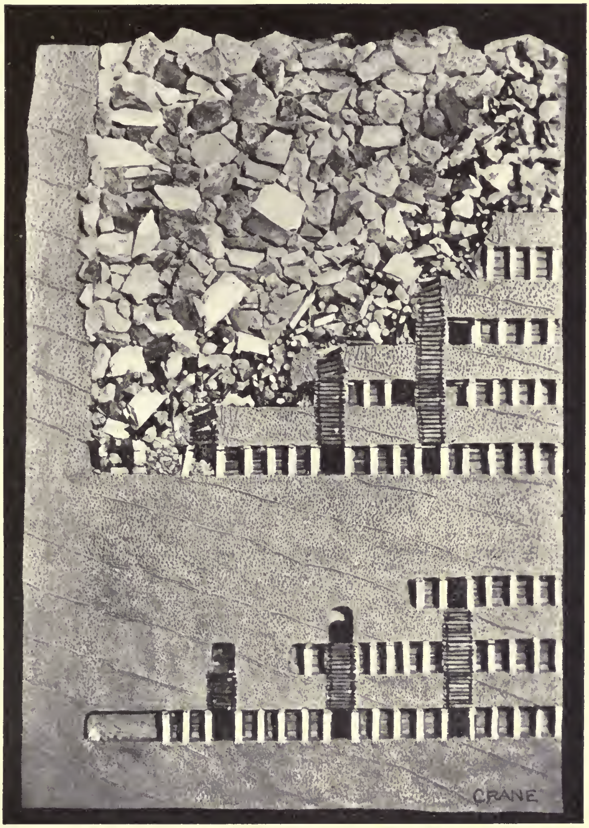


Fig. 67.—Vertical Longitudinal Section through Lode Showing Method of Development and Working of Sub-Drift Method.

levels) in the process of stripping; the next lower sub-drifting, while the third lift below is being opened up by cross-cuts. The ore will also have to be run through the chutes from the upper to the lower sub. In order to facilitate the handling of timber it is brought in from the upper level and lowered to the respective subs instead of being raised as in the top-slice method.

Light but close timbering is the rule and by careful work the caving ground can be controlled with little or no danger of crushes and loss of ore.

Sub-Drifting in Panels

The work of mining by the sub-drift method as described is for comparatively hard and strong formations, but when soft and unstable formations are encountered, either the method will have to be modified to meet the special conditions or a change of method will be necessary. The method of working by sub-drifting as employed at the Susquehanna Mine at Hibbing, Minnesota, is shown in Fig. 68.

On approaching the limits of the orebodies in this mine masses of clay and sand are encountered, which unless carefully controlled will break into and fill the workings. A block of ore or panel is shown, the opening up of which has developed the bad condition of the ground, which is under control by the employment of dams in the drifts and crosscuts and even at the face where stripping is being done. Two sets of dams are shown, which were found necessary in order to hold back the clay and sand. The dams are built of one-inch pine boards strongly reënforced by backing strips and braces. The method of attacking the pillars is shown by the arrows. The back varies from 8 to 12 ft. in thickness, and is caved by blasting out three sets at a time, thus bringing the cave to within one set of the working face.

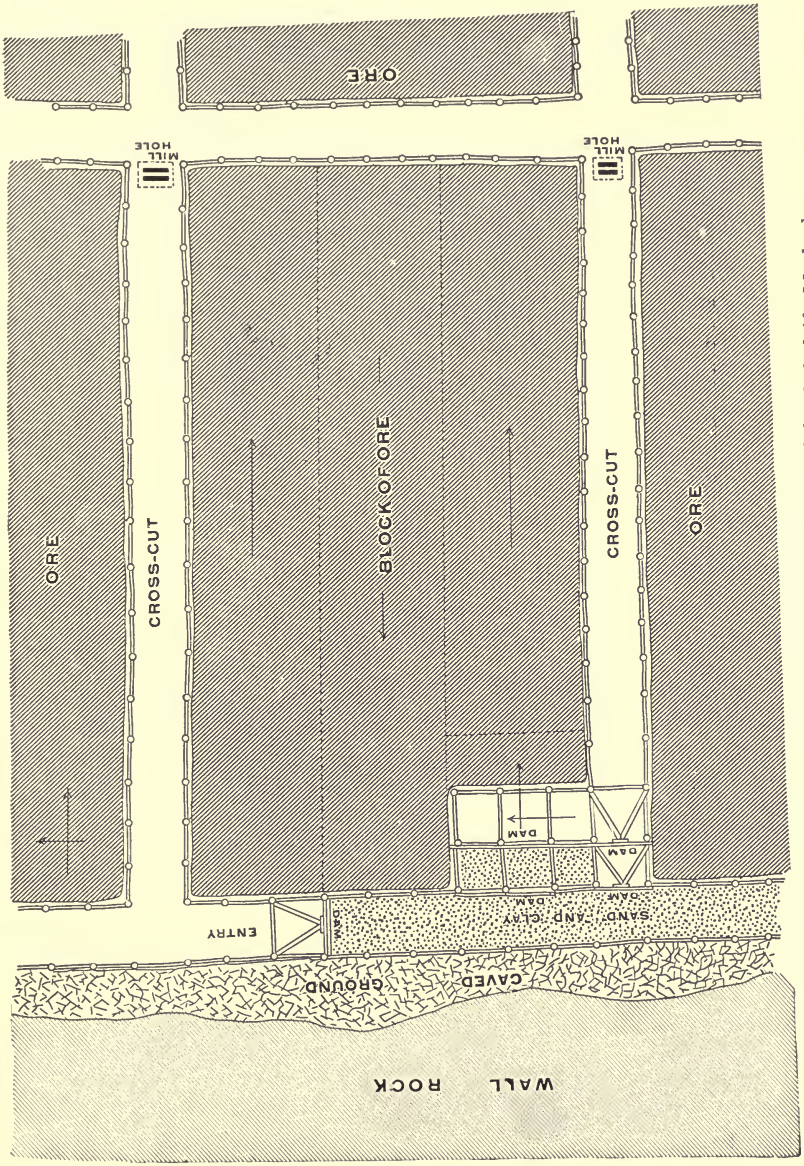
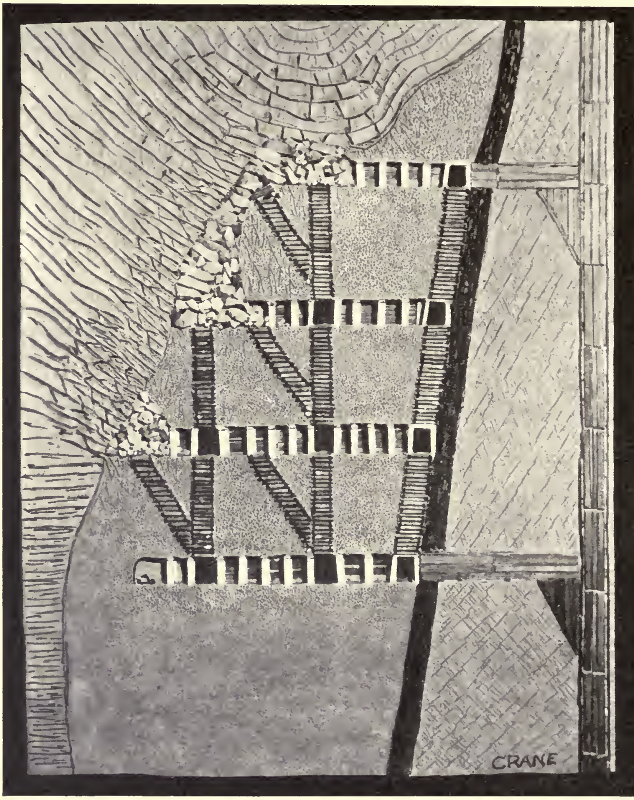


Fig. 68.—Plan of Block of Bad Ground worked by Sub-drift Method.

The timber used for sets in this mine is 8 to 10 in. in diameter, the floor being covered with rough pine boards upon which the sets stand. These boards render shoveling easy and



D.—Vertical Longitudinal Section through Body of Iron Ore Showing Method of Development and Working of Sub-Drift or So-called Sub-Level Method. (Modeled after Sketch by Frank Kennedy.)

make a good mat in controlling the movement of broken ground and waste ore.

The sub-drift method of mining is applicable to both hard and moderately soft ores, preferably the former, but not to mixed ores as where Bessemer and non-Bessemer ores occur together. It is strictly large-scale work and may be applied to massive deposits or large lodes of cheap ore.

The advantages of the method are:

1. Large outputs are possible owing to the large number of points of attack.

2. Cost of mining is low.

3. The complete extraction of ore is practically possible.

The disadvantages of the method are:

1. Much timber is required.

2. Development work is extensive and complicated.

3. Little or no opportunity is afforded for sorting ore.

4. Considerable handling of ore and timber is necessary.

5. Ventilation is poor.

6. Stripping operation is rather dangerous.

7. It is confined to deposits lying close to the surface.

8. It is limited to comparatively hard ores.

Shrinkage Stoping at Miami Mine

The employment of the shrinkage stoping method to massive deposits is shown to good advantage in the mine of the Miami Copper Company at Miami, Arizona.[1] The stopes worked in this mine have dimensions of 50 ft. in width by 200 to 500 ft. in length, with an average height of 125 ft.

Owing to the large amount of ore tied up in the pillars which would be lost through caving and mixing with the capping material, a method of mining all or a large part of

[1] For detailed description of method see Stoping Methods of Miami Copper Company. Bull. No. 114, Am. Inst. Mining Engrs., June 1916, p. 1031.

the pillars has been devised. The removal of pillars is accomplished by means of a retreating system, the pillars being worked in levels from above downward.

The ore deposit of the Miami Mine is a large conical shaped mass with its axis dipping to the northeast at an

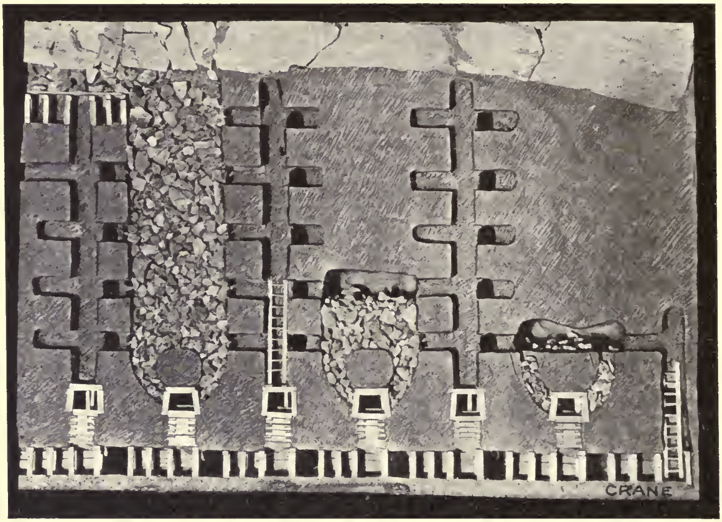


FIG. 69.—Vertical Section across Stopes in Shrinkage Method Employed in the Miami Copper Mine, Arizona. (Modeled after Sketch by David B. Scott.)

angle of about 50°. The orebody occurs in schist in which the mineral chalcocite exists in fine grains and in seams.

The orebody is developed by tunnels driven from shafts establishing the tramming or haulage levels, above which drawing-off levels are opened. In order to facilitate handling of ore on the levels, a separate level is run on either side of the orebody, the two being connected by cross-cuts which determine the center lines and main axes of the stopes and pillars. The two sets of passages, namely, the haulage ways and drawing-off levels, are connected by vertical chute raises, 25 ft. long, through which the broken ore is transferred to the haulage level. All ore regardless of its source, *i.e.*, stope or pillar, is passed through the chute raises, which must therefore be well protected by cribbing. (See Figs. 69 and 70.)

Vertical raises, known as pillar raises, are driven upward, at intervals of 50 ft. along the drawing-off levels, thr ugh the middle of the portions of the orebody to be left temporarily as pillars, which extend transversely across the deposit following the lines of the cross-cuts. At a vertical distance of 25 ft. above the drawing-off levels sublevels are driven from the pillar raises across the pillars and normal to the cross-cuts. Other sublevels are driven in a similar manner and at 25 ft. intervals vertically, which give access to the faces of the stopes as they are broken into by subsequent stoping operations. The first sublevels determine the level of the floors of the stopes and when enlarged laterally by breast stoping establish the stope floors. Ready access to the stope faces is thus maintained and ventilation is materially aided. (See Figs. 69 and 70.)

The stope raises are begun on the sides of the cross-cuts of the drawing-off level and at points where the chute raises connect with the cross-cuts, and are driven at an angle of about 60° to the stope floors above. The stope floors are 50 ft. above the main haulage levels and are connected with them by means of the inclined and vertical raises through which the broken ore is passed and its movement controlled.

When the stope raises have made connection with the stopes, they are enlarged by funneling at the top which constitutes the first operation in the work of stoping, and when completed the stope floors are perforated with funnel-shaped openings extending in two lines along the stopes.

The first sublevels on entering the limits of the stopes are widened out and the backs of the levels next to the sides of the stopes are broken down by long holes and heavy

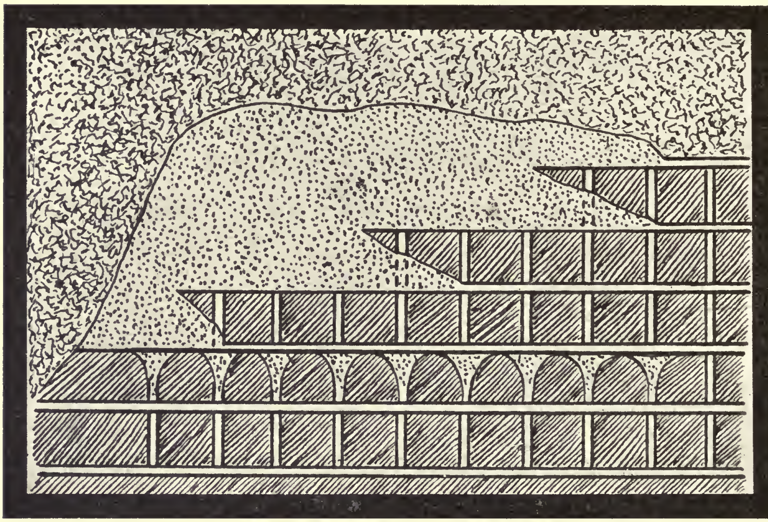


FIG. 70.—Vertical Longitudinal Section through Pillar, Showing Method of Mining Pillars. At the top is broken cap-rock, next below broken ore and below that in turn is the unmined pillar, which is being worked.

shots; the result is that the middle portions of the stope-backs stand as downward projecting ribs. These ribs are next drilled and shot down, thus evening up the backs of the stopes. It is obvious that the ore must be strong or it would not stand without arching, but the particular advantage of forming the ribs of ore is to permit the weight to assist in breaking them down. This method of breaking down the stope backs is continued from one sublevel to the next above it until the full height of the stope is reached, when the stope stands practically full of broken ore, thus providing a large reserve to be drawn upon as needed.

The excess ore is drawn from the stopes through the stope raises, the larger pieces being 'bull-dozed' to prevent trouble in the raises.

Stoping is usually carried upward to a height of 125 ft., *i.e.*, until the capping is reached or the level above is broken into.

In mining the pillars the work of breaking ore is begun on the top sublevel and continued downward from sublevel to sublevel by the retreating method, *i.e.*, beginning at one end of a pillar the ore standing above the top sublevel is broken down by overhand stoping and after the working face has advanced about 100 ft. work on the next lower sublevel is begun. The development work, in the shape of pillar raises and sublevels, that was previously done for the opening and working of stopes provides the points of attack for pillar drawing and at the same time determines the thickness of the respective layers of floors removed. Further development work in the shape of pillar raises spaced at intervals of 25 ft. between the first raises are driven, which with sublevels driven from them both increases the points of attack of the ore in the pillars and outlets for the discharge of broken ore. (See Fig. 70.)

Owing to the excessive weight thrown upon the pillars by the stoping operations and later by the cutting away of the tops of the pillars, it has been found necessary to work the pillars rapidly and continuously.

The ore between the first sublevel and the capping is removed for a height of about 15 ft., thus leaving 10 ft. beneath the capping or the level above, which is done mainly to prevent the mixing of ore and cap-rock. Further, to prevent waste rock from the caving ground above from entering the pillar raises through which ore is being passed, they are covered with bulkheads of timber in the shape of stulls and lagging placed in the raises and several feet below the floors of the sublevels.

No withdrawal of ore from stopes and pillars, except that necessary for providing room for mining, is attempted until at least 70 per cent of both stope and pillar work has been completed, and further no drawing of ore is permitted closer than 100 ft. from the stoping operations.

The method of mining employed in the Miami mine is adapted to large bodies of low-grade ore where sorting of waste is not necessary. The ore must be strong, however, and the enclosing rock must also be strong and tough.

The advantages of the method are:

1. Large outputs are possible.
2. Mining cost is low.
3. A comparatively small amount of timber is used.
4. Ore is handled with little labor.
5. The main levels may be spaced a considerable distance apart.
6. There is little danger from falls.
7. A large extraction of ore is possible.
8. Ventilation is fairly good.
9. There is ready access to and from the stopes.

The disadvantages of the method are:

1. The method is applicable to large deposits only.

2. A large amount of development work is necessary.

3. Loss of ore may be considerable through mixing with waste.

4. Much of the timber used is lost.

Sub-Drift Method in the Diamond Mines of South Africa

The diamond mines of South Africa[1] are particularly interesting from the standpoint of economic mining, which has been rendered possible by the application of a caving system operated on a large scale. The deposits of diamond-bearing material occur in ducts or pipes which stand vertically or nearly so and penetrate a number of formations for a known depth of several thousand feet. (See Figs. 71 and 72.) The pipes are roughly round or oval in shape, and vary in area at the surface from a few to 50 acres. The walls with the exception of the black shale are fairly strong and stand well. The shale presents the greatest difficulty to mining, as it weathers rapidly and, falling into the open-cuts, follows the diamond-bearing ground downward as it is mined out from below. For plan see Fig. 73.

1. **Kimberly Diamond Mines, South Africa.**
2. **Diamond-bearing rock.**
3. **Pipes.**
4. **Several acres in lateral extent.**

In order that the method of mining now employed in these mines may be readily understood, as well as the reason for its employment we shall describe the method of working by galleries as previously employed.

[1] The Diamond Mines of South Africa, by Gardner F. Williams. Chapter XI.

The pipes were intersected by cross-cuts extending from shafts sunk in the rim-rock, which cross-cuts were spaced 150 to 200 ft. apart vertically, thus establishing levels in the

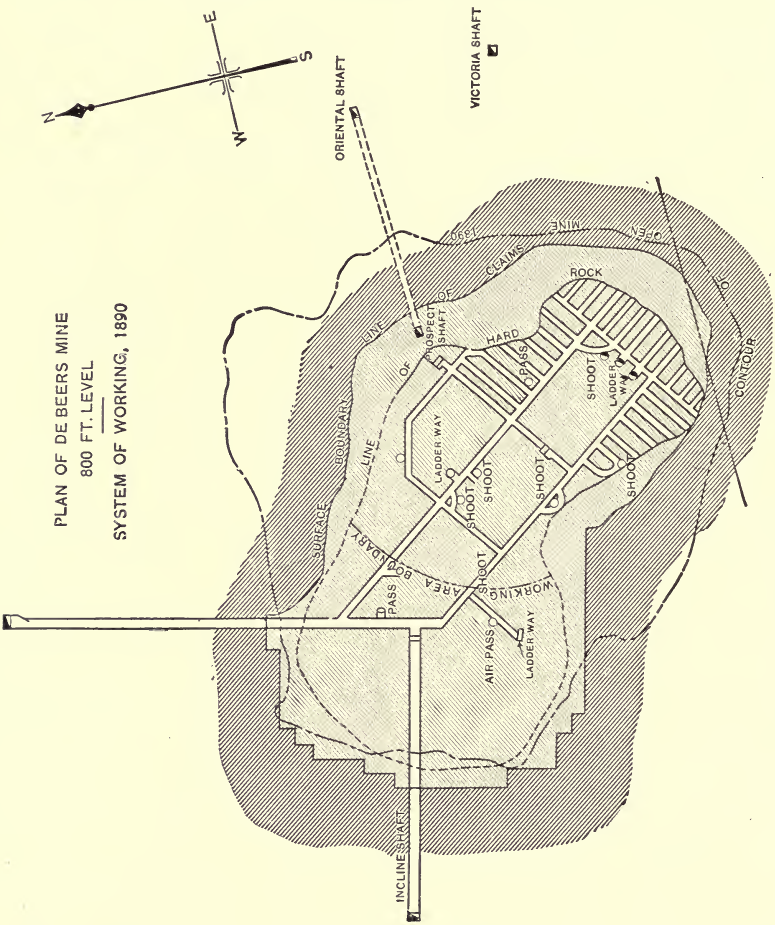


FIG. 73.—Plan of Pipe and Method of Development.

deposits. Intermediate or sublevels were run from winzes connecting the main levels and spaced 30 ft. apart vertically. On each level two or more passages were driven parallel with the axis of the deposit and spaced 120 ft. apart.

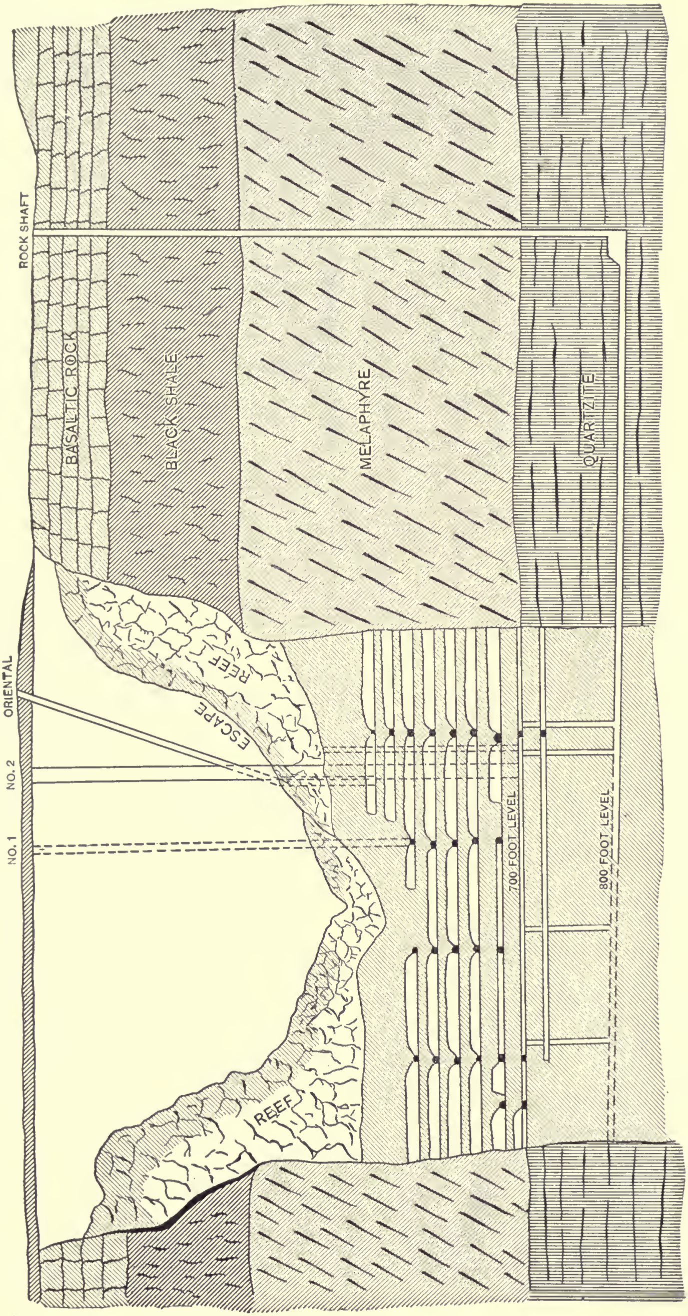


Fig. 71.—Vertical Section through Pipe, showing Method of Working by Galleries.

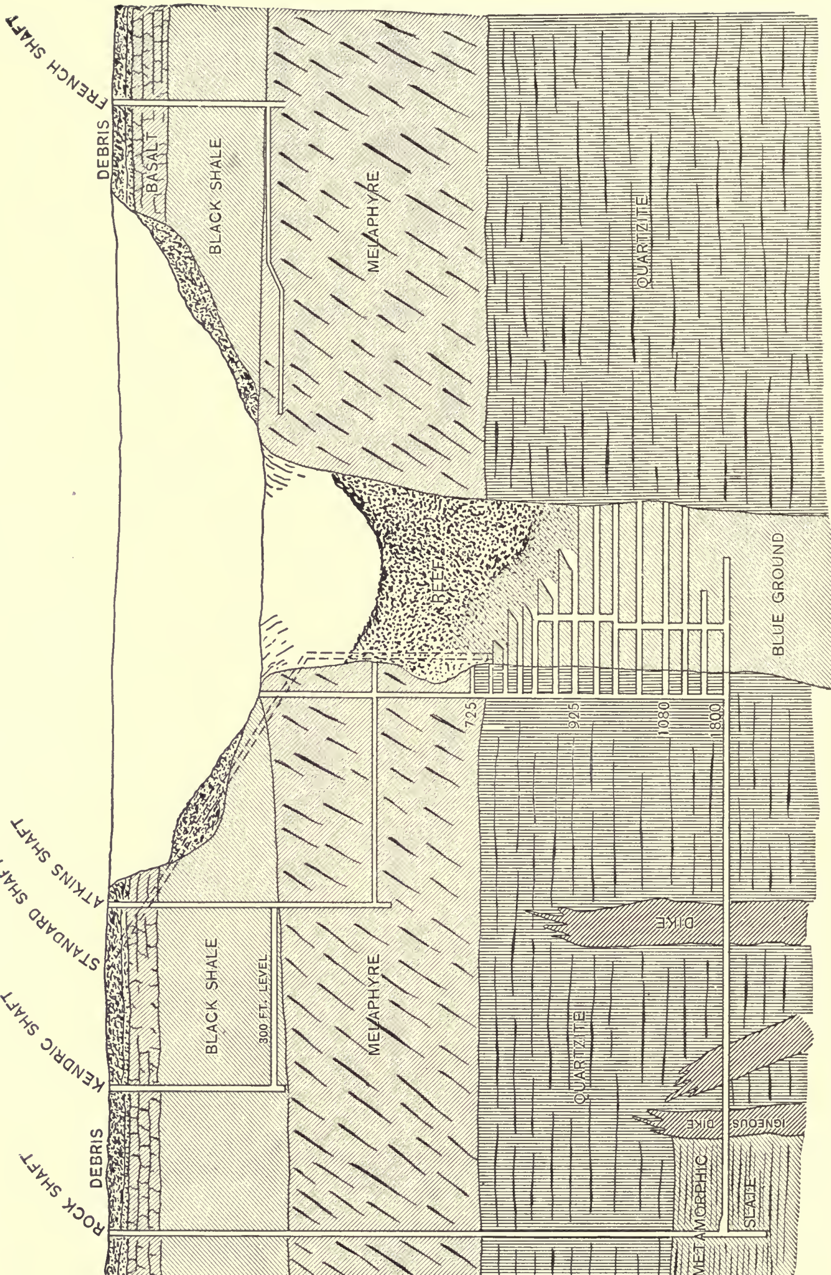


Fig. 72.—Section through Pipe, showing Method of Working by Caving.

From these passages and connecting cross-cuts galleries 18 ft. wide and high were driven at intervals of 36 ft., and were worked to within 12 ft. of the sublevels above, and the uppermost to within 12 ft. of the loose ground. (See Fig. 71.) Beginning just below the loose ground the roof and pillars of an intermediate level were carefully and systematically robbed, thus permitting the caved ground above to settle without danger of a crush. This method of procedure proved fairly successful until considerable depth was reached, when the roofs of the galleries became unsafe and often collapsed, rendering the extraction of the diamond-bearing ground both difficult and dangerous. Could timber have been employed the method would have proven much more satisfactory and would have been applicable to much greater depths. The method proved to be expensive, dangerous and wasteful and was superseded by a form of sub-drift caving.

In the new caving system the method of opening up or developing the pipes is the same as described in the gallery system of working, with the possible exception that the intermediate levels or sub-drifts are somewhat further apart, ranging from 30 to 40 ft. (See Fig. 72.) From the main passages running along the major axis of the deposit, cross-cuts are driven at 30-ft. intervals, being extended to the limits of the deposit. (See Fig. 73.) These cross-cuts are enlarged both horizontally and vertically by stoping until they are connected, thus forming long chambers or stopes. The various stages of opening a stope are shown in Figs. 74 and 75. The roofs of the intermediate levels are cut out by overhand stoping, the men standing upon

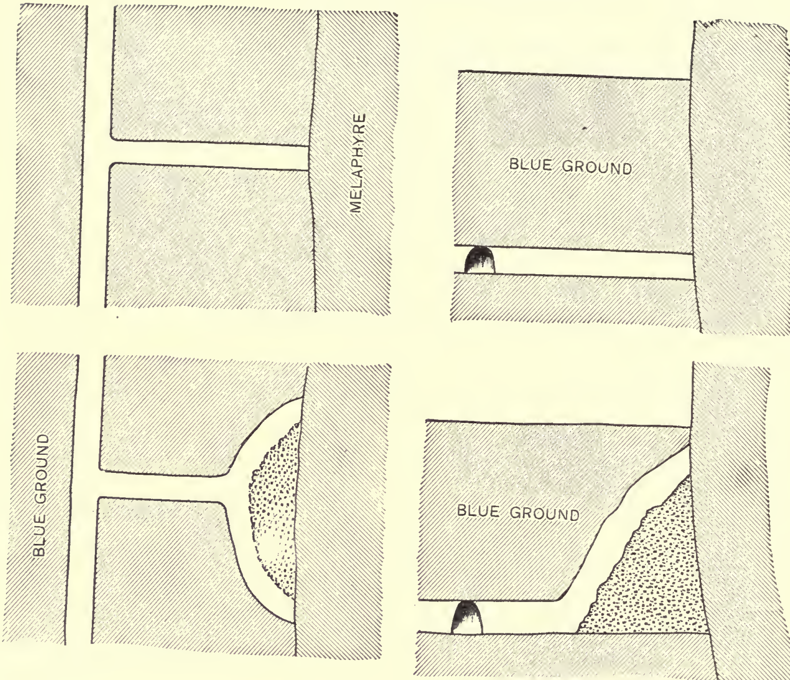


FIG. 74.—Elevations and Plans, Showing Method of Opening Up a Stope.

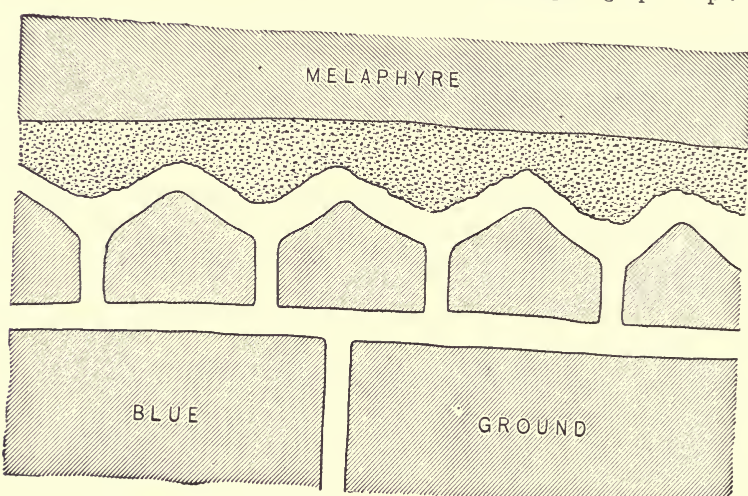


FIG. 75.—Sketch Showing Plan of Stopes Run Together.

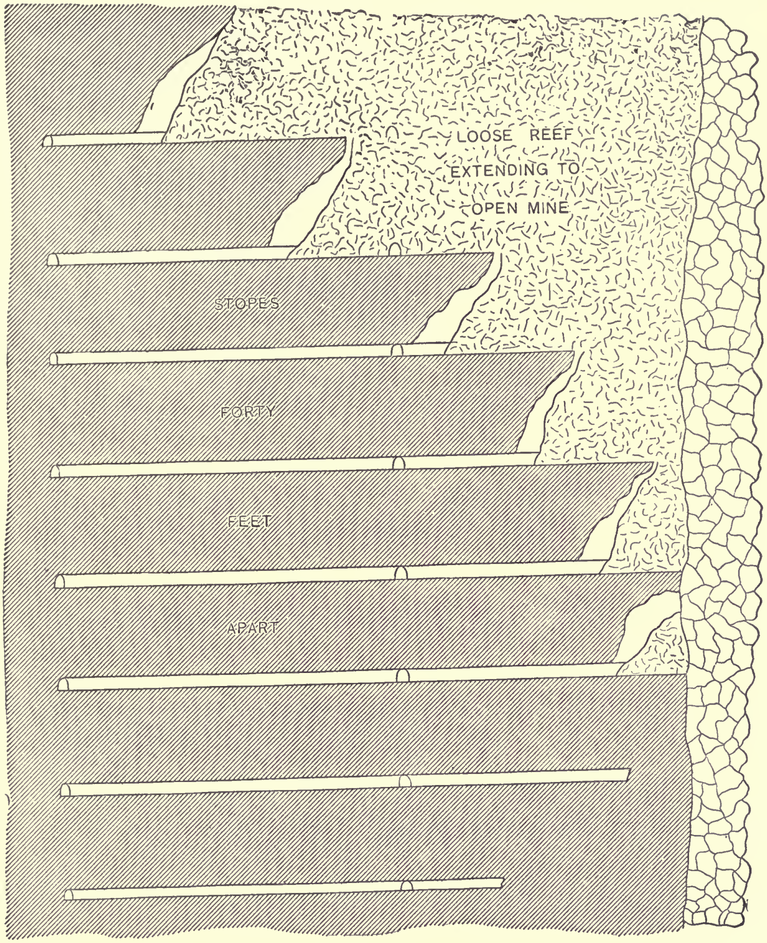


Fig. 76.—Vertical Section Showing Stopes in Various Stages of Working.

the broken ground while drilling. As the work of stoping proceeds and the face of one stope recedes from the wall-rock another stope is broken through from below, and so on until a number of stopes are worked, each level proceeding upward, being in advance of the one below, thus forming terraces. (See Fig. 76.) The diamond-bearing ground falling upon the loose ground flows downward to the floor of the level below, where it is shoveled into cars.

The method of mining employed in the diamond mines of South Africa is applicable to large deposits of considerable vertical extent and to ground of varying degrees of hardness but all moderately strong.

The advantages of the method are:

1. Little or no timber is used.
2. Large outputs are possible.
3. The cost of mining is low.
4. Levels can be placed a considerable distance apart.
5. Complete extraction of valuable ground.
6. Little danger from falls of ground.

The disadvantages of the method are:

1. Can be employed to advantage only on a large scale.
2. The amount of development is large.
3. Loss from valuable ground mixing with waste is considerable at times.
4. Ventilation is rather complicated.
5. Danger from mud-rushes.

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CHAPTER VII

OPEN CUT MINING

Introduction

The surface working of ore deposits is confined to outcrops of veins and orebodies with little or no cover. It may be considered as the initial or preliminary method of extracting ore from such deposits, and is at the same time an inexpensive and rapid method of procedure. Unless especially advantageously situated, as on the side of a considerable elevation or mountain, where the deposit can be attacked at different levels, the work of open cut mining is limited to comparatively shallow depths. Depths of several hundred even up to 500 ft. have, however, been attained. The Swedish iron mines have depths of 400 and 500 ft.; the diamond mines of Kimberly, South Africa, were some 400 ft. deep when open cut work was abandoned; the Tilly Foster iron mine was worked to a depth of over 300 ft.; the Iron Mountain Mine of Missouri reached a depth of 150 ft. before being abandoned; the Rio Tinto mines of Spain are very extensive both as to depth and lateral extent; the slate quarries of Wales have reached a depth of 600 ft.; etc. Many other instances of deep open cut mining might be mentioned, such as the Homestake mines, South Dakota, and the Alaska-Treadwell mines of Douglas Island, Alaska, but these mines may be considered as having passed the stage of open cut work inasmuch as the ore is not removed directly from the surface excavation, except to a very limited extent, but is drawn off underground through the mine workings.

The extension of the surface working of ores to great depths by combining such work with the underground operations has led to the employment of a most interesting and important method, namely, 'Glory-hole' mining.

The methods of open cut mining that are more or less extensively employed in the extraction of ore and similar materials may be grouped under the following heads: surface mining by hand; surface mining by scrapers; open cut mining by steam shovels, and the milling method. As outlined above the methods of open cut mining are discussed not in order of importance, but rather in the order of their development and the extent and complexity of operations. Stripping and mining by hand and scrapers are confined largely to working coal outcrops and superficial deposits, while steam shovel work and the milling methods are employed on a large scale in mining both base and precious metals.

While it is the purpose of this work to discuss methods of mining of ores, yet it seems advisable and almost necessary in this connection to refer to the working of certain non-metalliferous materials in order to properly illustrate the methods as outlined above. This is particularly true of surface work by hand and scrapers, although practically all ores are, in certain localities, mined in a limited way by such methods.

Surface Mining by Hand

Wherever large veins and masses of workable ore occur at the surface, or with a thin cover of barren material or wash, it is customary to employ some method of surface working, the extent of such operations depending upon the size of the deposit. With veins especially, the amount of ore is usually rather limited or the position of the deposit is such as to preclude any but hand work. On the other hand massive deposits of low-grade ore or certain non-metalliferous materials may be worked to advantage by hand. The mining of shale for use in the manufacture of Portland cement is shown in Fig. 77. The shale beds are loosened by hand drilling and blasting, the broken-up shale being loaded into carts and wagons and hauled some distance to the plant.

The application of hand work to a large outcrop of workable ore may be illustrated by a common method of working a bank of iron ore which is to be loaded into railroad cars for transference to some distant point. The railroad track having been established at a certain level, a dock is built up, provided no excavation is necessary for bringing the track to the deposit, otherwise it could be employed to advantage as a dock. The height of the dock should be such that hand cars can be dumped from it into the railroad cars below. Upon the dock a series of hand-car tracks are laid practically parallel to each other and normal to the face of the bank of ore to be excavated and to the track serving the dock. The bank is blasted down and the ore

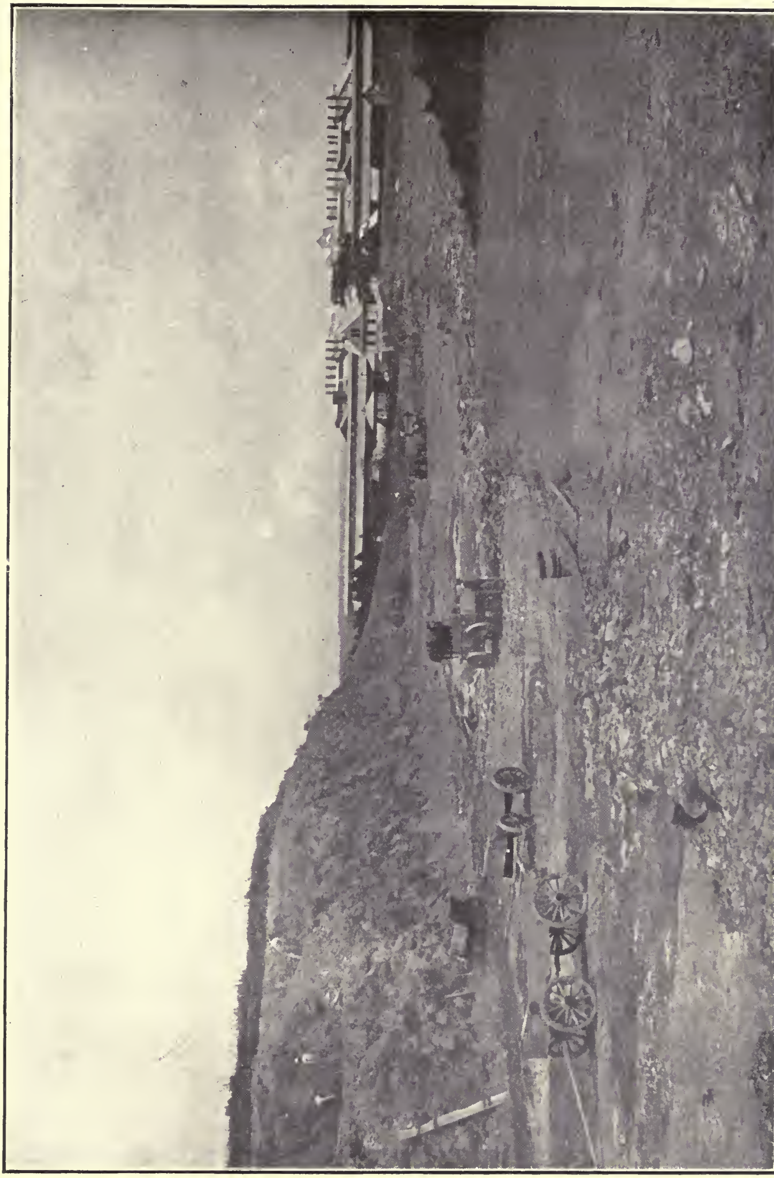

Fig. 77.— Mining Bank of Shale by Hand.

loaded by hand into the small hand cars, which operate back and forth between the bank and the dock, the grade of the tracks being slightly in favor of the loaded cars. In this manner a number of railroad cars can be loaded at one and the same time, and until the face of the bank has receded to a point some distance from the dock, large outputs at low cost are possible.

Hand work has its widest application in earth excavation or the working of other more or less soft and easily broken-up materials, in the working of which it has reached its greatest utility. High banks of earth are formed into terraces sufficiently wide for wagons or cars to operate upon and of such a height as to permit the control of the loosened material. The faces of the terraces are attacked, being divided into sections by vertical cuts and undermined by horizontal cuts made at the bottom of the bank or terrace. The remaining outstanding portions of the bank are then broken down, by bars, a line of holes being made along the top of the bank parallel with the edge and connecting the vertical cuts. Large masses of the bank are thus broken down, and in the fall to the level below are readily broken into a convenient size for shoveling. While rock and ore formations differ somewhat from earth and other similar materials, yet the same general method of procedure is applicable. Terraces are usually formed upon which the men stand while drilling holes, explosives being used in breaking down the face of the banks. Large or mammoth blasts may be employed in breaking down high banks, which necessitate, however, considerable preparatory work in the shape of drilling or tunneling and placing and preparing the blasts.

The application of open cut work to the quarrying of rock is shown in Figs. 78 and 79, the figures showing the condition

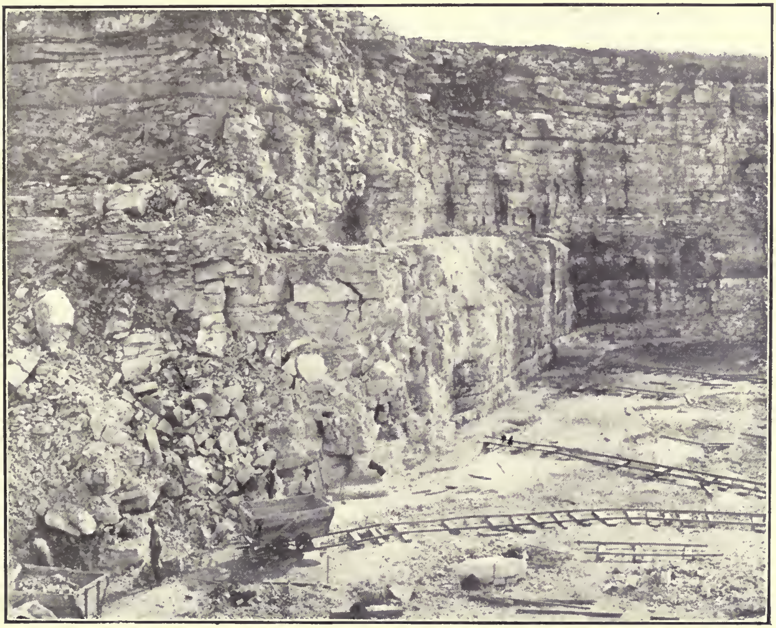

Fig. 78. — Quarry Showing Bench before Blast.

of the bank before and after firing a large charge of explosives.

In the present day of keen competition and large-scale operations all-hand-work, *i.e.*, breaking down the ore and loading by hand, is fast becoming a thing of the past, although it is still used in many localities, as in the soft-iron mines of Alabama, where the ore is easily handled and labor is cheap.

Surface mining by hand is applicable to moderate-sized and large deposits occurring without a cover or with covers of limited thickness. While hard and soft materials can be handled, a material that will break up into moderately

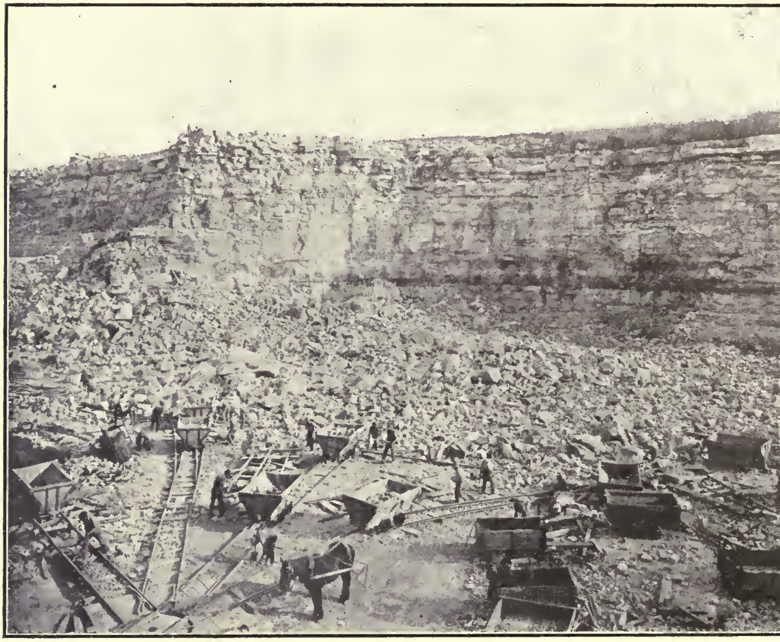

Fig. 79.—Quarry Showing Result of Blast.

small pieces is preferable, as it is more readily loaded into cars or wagons by shovel.

The advantages of hand work in open cuts are:

1. The expenditure for equipment is slight.

2. There is little depreciation of equipment either when the mine is operating or when it is closed.

3. Unskilled labor may be largely employed.

4. May serve to furnish means to carry on development.

5. Removal of overburden is expensive, so cover should be thin.

The disadvantages of the method are:

1. Cost of mining is comparatively high.

2. Operations limited to relatively small outputs.

3. Owing to the number of men employed the method is more subject to interference through labor trouble.

Surface Mining by Scrapers

The use of scrapers naturally follows hand work in excavation, being applied to operations of considerably greater extent, but is limited to earthy and moderately soft materials. Drag scrapers are extensively employed in small-scale stripping operations, where the formations overlying coal beds or other valuable materials consist of earth, clays, sand and gravel, shales or other material readily loosened by pick, plow or small charges of powder. The work of stripping off the overburden is usually begun at the point where it is the thinnest, which is on or next to the outcrop. Outcrops usually occur on hillsides, on the banks of streams, etc., where the materials excavated can readily be disposed of at a lower level.

Strip-pits formed by scrapers are 45 to 60 ft. wide and vary in length from 125 to 200 ft. Larger sized pits cannot be worked to advantage unless wheeled scrapers are employed, owing to too much time being lost in taking and discharging the relatively small loads. Thickness of cover up to 8 and 12 ft. can be removed quickly and cheaply while banks of 16 even up to 25 ft. are occasionally worked. It is doubtful whether it pays under ordinary circumstances to strip an overburden exceeding 16 ft. in thickness; however, all depends upon the character and amount of the material uncovered. A thick stratum of coal of good

FIG. 80.— Stripping Coal by Scrapers.

quality, a good bed of phosphate rock, gypsum or soft-iron ore may warrant extensive stripping operations, but if of considerable lateral extent, more economical methods should be resorted to in preparing for its extraction.

Stripping operations as employed in uncovering a 40-in. coal stratum are shown in Fig. 80. The width and length of the pit are shown to good advantage, also the sloping ends or entrances to the pit, a wagon road being cut to lower grade at both ends leading into the pit to admit wagons by which the coal is hauled out. The waste or waste-bank is shown to the left. The coal having been removed, the resulting excavation serves as a receptacle for the new waste-bank formed by opening up another pit to one side of and adjacent to the previous one.

Water when it occurs in considerable quantities is one of the most serious problems to be dealt with in stripping, as natural drainage cannot always be effected. Steam pumps are employed in the larger-scale work, while endless-belt pumps driven by horsepower are commonly used in freeing small pits of excess of water. A belt pump is shown upon the bank to the right of the pit, Fig. 80.

The size, both width and length, of stripping pits may be materially increased by the use of wheeled scrapers, which take larger loads and can travel greater distances to the waste-bank with less loss of time than can the drag scrapes.

Surface work with scrapers is especially applicable to deposits of large lateral extent and therefore to bedded deposits. In fact the method is practically limited to stripping operations, as in coal, phosphate and gypsum mining.

The advantages of scraper work are:

1. Little equipment needed besides scrapers and plows.
2. Small force required.
3. Capacity moderately large.
4. Cost of mining comparatively low.
5. Unskilled labor may be employed.

The disadvantages of the method are:

1. Overburdens exceeding 16 to 18 ft. cannot be economically removed unless the waste can be stored close at hand.

2. Wear of scrapers excessive.

Open Cut Mining by Steam Shovel

The advent of the steam shovel into mining operations has meant much to the industry, and it is largely due to its

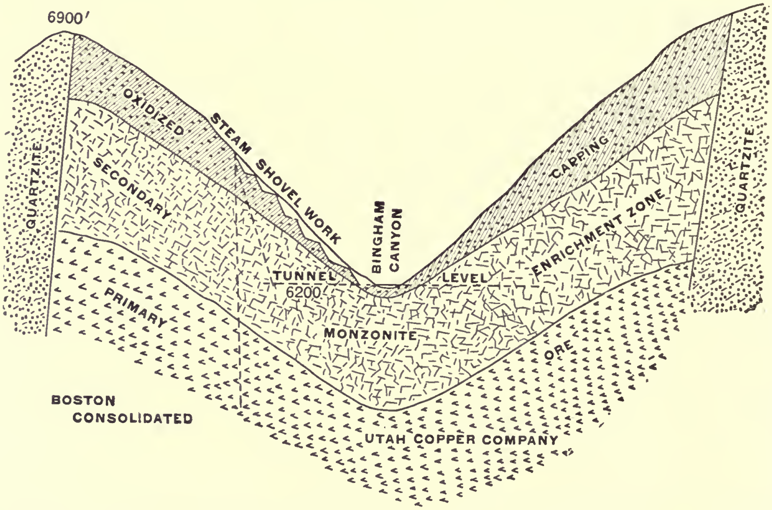

Fig. 81.—Section across Bingham Canyon, Showing Beginning of Steam-Shovel Work in Stripping Capping.

extensive employment that the cost of mining of iron ores has been reduced to an amazingly low figure. Probably the most extensive field of operation for steam shovels is in the large open cut iron mines of Michigan and Minnesota, although very extensive steam-shovel work is being done in the Bingham Canyon copper mines, similar mines at Ely, Nevada, and in the Granby mines, British Columbia. (See Fig. 81.)

Prior to the application of steam-shovel work to the mining of ore the overburden must be removed. This is done by steam shovels, the barren material being loaded into railroad cars or other cars of several tons' capacity. When removed by small cars they are usually transferred to the waste-bank by an engine plane or some form of rope haulage. An overburden ranging up to 40 ft. or more in thickness is not uncommon, and while greater thicknesses might be removed without reaching a prohibitive figure from the standpoint of costs, yet it means that the underlying body of ore must be both thick and of high grade. The thickness of cover considered permissible to remove depends largely upon its character, *i.e.*, if soft or easily broken the maximum economic thickness may be taken, while hard stratified formations may reduce the thickness to a few feet and may even preclude the employment of surface methods altogether. The iron deposits of the Lake Superior region are covered with glacial drift which is easily and cheaply removed; considerable thicknesses extending over many acres are systematically stripped off and hauled from the site of the mine. (For work in Alabama mines see Fig. 82.)

There are three general methods of steam-shovel work; which will be employed in a given case depends upon existing conditions. Lateral extent, elevation with respect to the surrounding country, amount of overburden, and depth to which the deposit extends are controlling factors in the choice of methods of procedure in opening up and working a steam-shovel-operated mine. The deposit having been definitely located by test pits and drill holes and the over-

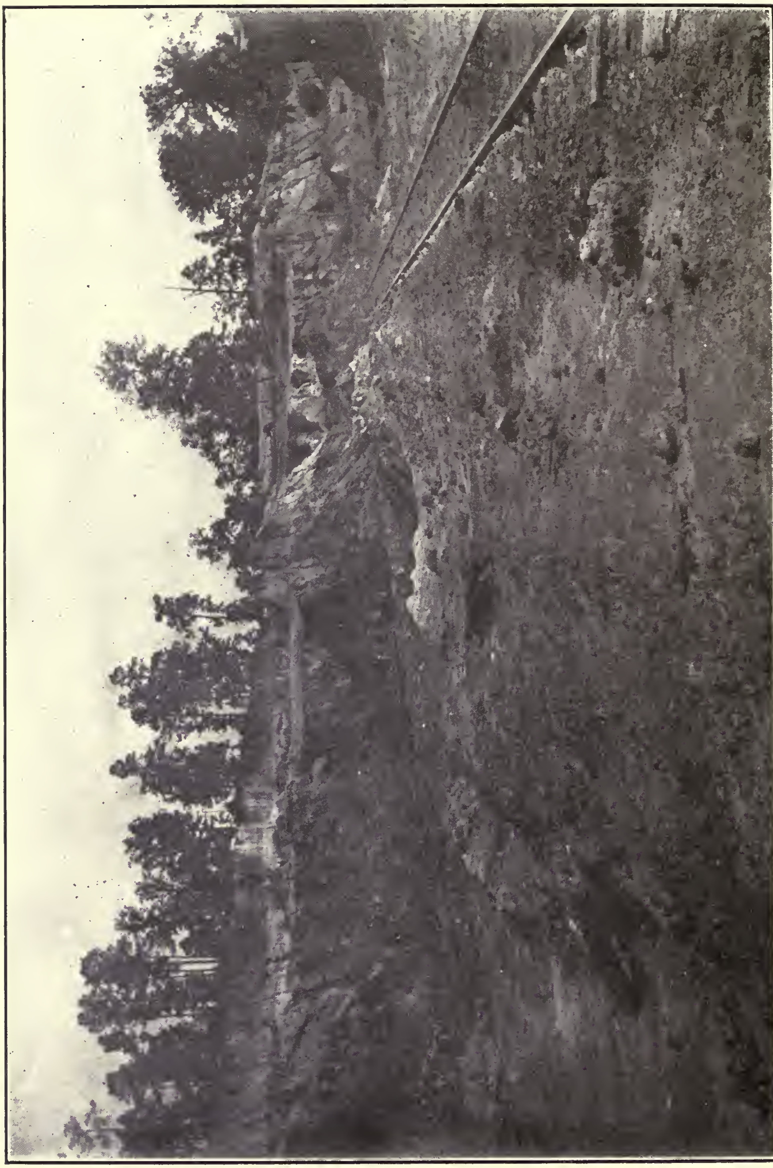

Fig. 82. — Steam Shovel Mining in Soft Iron Ore of Birmingham District, Ala.

burden removed from the area in which mining is to begin, the work of opening up the deposit is begun. The initial opening may be in the form of a cut extending through the middle of the deposit or along one side, whichever seems more advisable from the standpoint of maintaining grades. If an opening is made through the middle of the deposit, the work of cutting out the ore may be carried on laterally in both directions, while if done on one side it will have to proceed in one direction only. Again, and in a similar manner, a deposit may be opened by running a spiral cut partly in the orebody and working radially inward and outward, or the deposit may be attacked and encircled by the cut, the removal of the ore proceeding inward to the center of the deposit. In either case, where a spiral cut is made, the ultimate form of the deposit is a pit, the lowest portion being reached by spiral tracks upon which the steam shovels and ore trains operate. The coils of the spiral are constantly widening as slices are removed from the faces of the banks or terraces. Care must be taken to maintain the proper grade on the spiral.

Ores specially suited to steam-shovel work should be soft or at least easily broken up by moderate charges of powder which are placed in advance of the steam-shovel work. The shovel stands next to the bank from which it takes its load, removing a slice or cut of 6 or 8 ft. in width and depositing the excavated ore in the railroad cars standing on the track to one side of the shovel. A cut having been made of a size to accommodate a steam shovel and line of track for the cars serving the shovel, another cut may be opened to one side, or in the middle of the cut. A series of levels is thus formed, giving the excavation a stepped or terraced form. A large number of points of attack are thus made possible, increasing the capacity of the mine and reducing the cost of mining by getting the most out of the equipment.

Still another method of steam-shovel work is that in which the shovel operates at the bottom of a deep pit where it is employed in excavating and in loading mine cars, which are run to the foot of a shaft and hoisted to the surface as in underground work. In this method the steam shovel is assembled at the bottom of the pit, its chief function being the loading of cars. Hard ores may be blasted down and then loaded into the cars by the steam shovel. While this method is rather limited in its application, yet it serves a useful purpose under certain conditions of ore occurrences necessitating special methods of working.

A not unimportant use to which the steam shovel has been put is that of loading ore from stock piles where it is stored during the winter months, traffic being closed. Practically all underground operations are continued throughout the winter, the ore raised being stored in the stock piles. Further, it is not unusual for ore to be excavated and piled up in the open cuts by the steam shovels, where it remains frozen until spring when it is loaded in the railroad cars by steam shovels in the same way as are the stock piles of hand-mined ore.

Steam shovels are also occasionally employed in excavating materials below water level, as in mining phosphates in the Southern states. In such work it is necessary to operate the shovel on solid ground, which is accomplished by stripping the deposit and then employing a steam shovel with a 'broken' boom, *i.e.*, a boom in the shape of an inverted V, the dipper being supported by the outer and downward sloping part. Further, the dipper faces toward the shovel and takes its load inward rather than outward. By this arrangement the shovel is required to operate backward, but always upon the solid, unexcavated bed of phosphates. The dipper takes its load partially under water, but discharges it into cars standing on a track to one side of that upon which the shovel operates and usually at a higher level.

The combination of steam-shovel mining with improved methods of extraction of metals from low-grade ores will make possible the opening up and successful working of many large deposits which are at present unworkable. The steam shovel has already in many cases been an important factor in reducing the cost of mining cheap ores and has thus made a market for them.

The use of steam shovels is applicable to massive deposits of a wide range in hardness, although those ores that break up readily are the best suited to the work.

The advantages of steam-shovel work are:

1. Large outputs.
2. Low mining costs.
3. Railroad cars may be loaded directly, thus reducing cost of handling.
4. Thick overburdens can be removed economically.

The disadvantages of the method are:

1. Expenditure for equipment rather high.
2. Rate of depreciation high.
3. Skilled labor required for handling shovels.

The Milling Method

That particular application of open cut mining known as the milling method is in reality a combination of open cut

Fig. 84.—The Method Illustrated Here Is Known as the Stull-Room-Milling Method and Is Given in This Connection to Make More Understandable the Open-pit Milling Method. (Modeled after Sketch by F. W. Denton.)

and underground work, or, more strictly speaking, mining in an open cut and handling the ore underground. Owing to the successful application of the milling method as originally employed in surface work, it is now being extended to underground work, where it is also meeting with marked success, in certain instances at least. (See Fig. 83.)

The milling method is underhand stoping applied to large deposits, the work of cutting out the ore being confined to limited areas around the mouths of raises or winzes. In developing a deposit to be worked by the milling method it is essential that the haulageways on the respective levels be so arranged as to facilitate the handling of large quantities of ore, as the milling method is productive of large tonnage. This can best be done by so arranging the haulageways that the going and returning ways are separate, thus eliminating the interference of loaded and empty cars. Parallel, elliptical or roughly circular systems of haulageways, connected by cross-cuts at frequent intervals to facilitate the movement of cars, provide ample opportunity for the handling of both loaded and empty cars. Such development work is done on each level, but not necessarily completed, except on the upper level, until the surface workings have reached and destroyed the haulageways on that level, when a similar arrangement of ways should be in readiness for handling the ore on the level below, and so on, level by level, as the work progresses downward. (See Fig. 83.)

The development work on a level having been completed, raises are put up along the line of the haulageways at intervals of 50 to 75 feet or more. The barren material covering the orebody should be removed before the raises break through to the surface. Chutes for

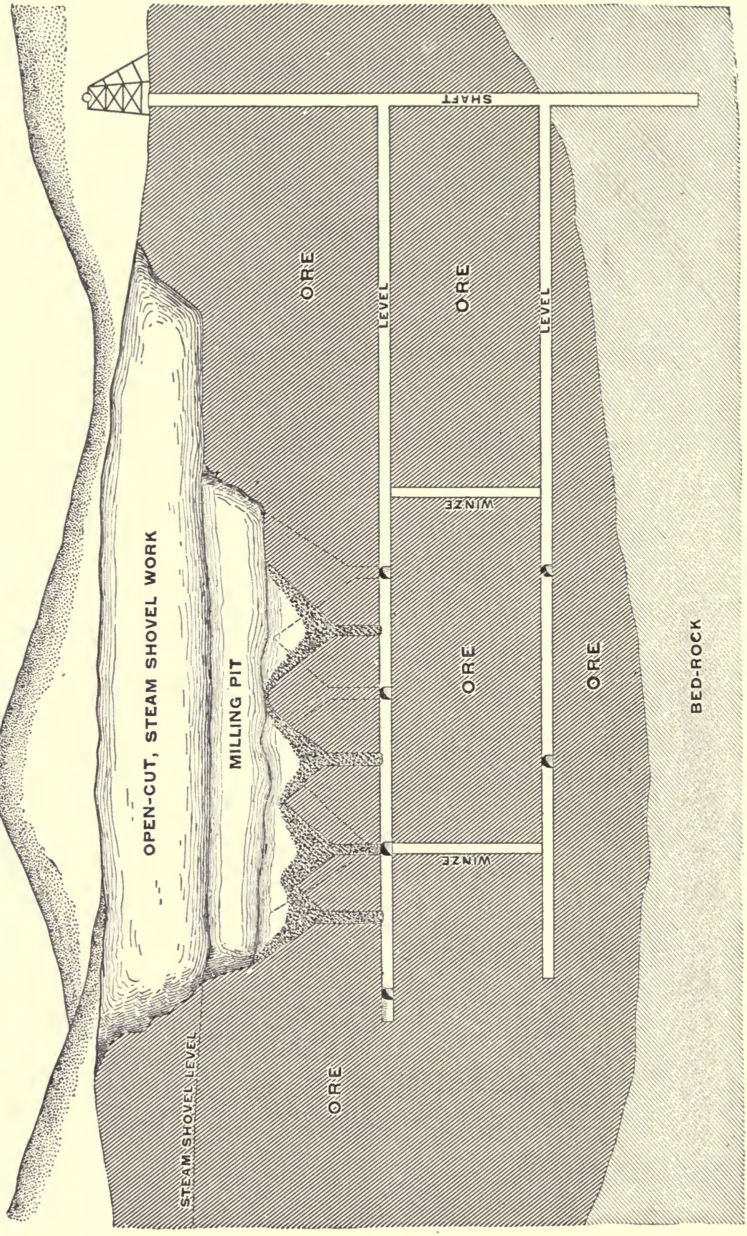

Fig. 83.—Vertical Section through Massive Deposit of Iron Ore, showing Method of Development and Working by Milling Method.

the control of the ore and the loading of cars are placed at the foot of each raise, and when so equipped the work of breaking the ore may be begun. Drills are mounted on tripods at the edge of the raises, and the ore broken by the charges so placed falls by gravity into the raises, from which it is drawn into cars and sent to the surface. Pits are soon formed about the mouths of the respective raises, which as they increase in size provide more room for other groups of drillers. Ultimately the pits formed along the line of a haulageway run together, as do those of different lines of haulage, thus forming a large pit the bottom of which is composed of a number of inverted conical openings connected by raises with the underground haulage system. It is evident that after the pits have coalesced the rims of the raises will have resolved themselves into ridges standing between the pits, upon which ridges the mounting of drills is practically impossible.

Further breaking of ore must then be done in one of two ways, namely: the drilling is done by hand drillers operating miscellaneously on the sloping surface of the pits or by systematic work, beginning at the bottom of the funnel-shaped pits and proceeding upward. Sections ranging from a few up to 10 and 12 ft. in thickness are thus removed from the bottom to the top of the pits, the drills being returned to the bottom after each section is completed, when work upon another section is begun. The work of breaking the ore may then be accomplished by either underhand or overhand stoping, the former at the beginning of the operations, the latter after the milling pits have run together forming one large open cut. As many as twenty milling pits may be worked together, but probably ten or thereabouts is a more usual number.

Those ores that break up into moderately small pieces are best suited to the milling method, although fairly hard ores are worked satisfactorily. Care must be taken to insure against falls of rock or ore while the laborers are at work in the pits, which can only be done by barring down all loose rock and even employing small charges of powder to remove dangerous portions of the walls.

Steam shovels are occasionally employed in conjunction with the milling method, being used to excavate the ore and dump it into the milling pits. Owing to the limited space for trackage and the difficulty experienced in properly arranging and maintaining the working of the steam shovels about the pits, this particular phase of the milling method is comparatively little used.

Glory-hole mining is the milling method after it has been fully developed, *i.e.*, after the pits formed by breaking ore round the mouths of the raises have run together and by continued work have reached considerable depth, thus forming a large and deep excavation. Glory-hole mining is employed in practically all mines where large orebodies occur at the surface, the more superficial portions being worked by open cuts operated by hand and in many cases resembling quarrying methods. After a certain depth has been reached tunnels may be employed which connect with a shaft or with the surface at lower levels. In the meanwhile the lode will have been developed in depth and raises put up which finally connect with the bottom of the open cut, when the work of handling the ore is transferred from the tunnel levels to the main levels of the mine by way of the mill-holes. Owing to the likelihood of large masses of rock and ore falling into the mill-holes and choking them, it is common practice to provide a grizzly of logs at the top of the raises, thus separating out the boulders, which are reduced to the proper size to pass the grizzlies by sledge or bull-dozing, *i.e.*, by the use of small charges of powder. Further, in order to prevent, or reduce to a minimum, the choking of the mill-holes it is often necessary to change the direction of the holes. Also in order to reduce or entirely eliminate the weight of the column of broken ore standing in the mill-holes, the holes may be offset to one side of the haulageway or tunnel below, thus requiring less support to maintain them.

While many orebodies are of fairly uniform value throughout, there are others in which the values are very spotted, the workable portions coming and going in a very irregular manner. It is evident, then, that where deposits of variable mineral content are worked by the milling method, especially in the large open cuts where little or no discrimination can be made between ore and waste in breaking down the walls, all material entering the mill-holes must be taken care of, which is usually done by sending the waste to empty or working stopes as filling, while the ore is diverted to the loading chutes for cars. This is made possible by employing a number of mill-holes so arranged that accumulations of ore or waste may be drawn off alternately through one or more of the holes.

It is claimed that it is not uncommon for two men to loosen and mill as much as 300 and 400 tons of ore per day.

The name "glory-hole" probably came to be applied to the large open cuts because of the large number of deaths of laborers working in and about them — the victims of falls were spoken of as having gone to Glory.

As previously mentioned, the milling method of mining is occasionally employed underground, when it is often referred to as underground glory-hole method. Where the overburden is too thick for economical removal and the deposit warrants its use the milling method may be employed, the raises being put up to or close to the top of the orebody and the work of breaking ore begun by working laterally and downward. Large roughly rectangular or circular stopes or rooms are thus formed, in the centers of which are the mill-holes or raises. The overburden is supported either by timbers placed across the top of the stope, usually in A-form, or, if the stope is not too wide and the ore is sufficiently strong to stand, a back of ore several feet in thickness may be left, being formed into an arch, thus doing away with timber supports. Stopes of one hundred or more feet in height may be worked in this manner, but a large part of the orebody is left standing between the stopes. If the mineral is cheap, as rock salt, this might be permitted, otherwise some other method of mining should be employed. A similar method has been employed in the iron mines of the Lake Superior region, known as the 'stull-room'[1]

[1] The following description of the method by F. W. Denton occurs in the Trans. Am. Inst. Mining Engrs., vol. 27, pp. 377–778.

method, but has often to be supplemented by some other method, which is somewhat difficult to do owing to the large open stopes, the collapse of which must not only be expected but provided for. (See Fig. 84.)

Pillars left in the preliminary working of a deposit may later be removed, even when the stopes have been filled or have caved, by putting up raises to the pillars and cutting them out by overhand stoping, or the raises may be run through the pillars, and by careful timbering the pillars may be removed by underhand stoping. In a similar manner the filling in stopes, that was formerly considered too poor to work with profit, but by improved processes has been rendered profitable to treat, may be drawn off by putting up raises and tapping the stopes. Great care must be taken in all of this work in order to control the caving that is almost sure to follow the removal of large quantities of material in comparatively short periods and in limited areas.

"The top of the room is first cut out by driving a wide drift just under the sand, and supporting this drift with saddle-back timbering, which becomes the roof of the room. This roof-timber is put in by driving from sub-drifts on the same level, thereby avoiding the hoisting of timbers. The rooms could be started from the tops of raises if necessary. After the roof is thus securely supported, the ore is stoped underhand, through the raises, to the drift in the center of the bottom of the room, where it is run into the cars and trammed to the shaft. The sides of the room are left unsupported; and the doubtful part of the experiment was, whether these sides would stand. A number of rooms have already been mined in this way without any trouble whatever and, at least for the Fayal deposit, the experiment seems to be successful. Many of the Mesabi deposits, however, are traversed by a system of parallel and almost vertical fissures or seams, filled with crushed quartz which, while only a fraction of an inch in thickness as a rule, would seriously interfere with this method. The Fayal has none of these seams, at least where the saddle-back rooms have been made, and no trouble has arisen from caving sides. The ore obtained from these rooms is probably the cheapest ore obtained underground on the Mesabi, as the advantage of easy breaking is obtained with a low timber-cost."

The milling method is probably most extensively employed in the Michigan and Minnesota iron fields, where it is used both as a surface or open cut method and underground. Similar methods are in use at the Alaska-Treadwell mines, Douglas Island, Alaska; at the Homestake mines, Lead, South Dakota; in the gold mines at Goldfield, Nevada; at the Comstock Lode, Virginia City, Nevada; in the copper mines of Bingham Canyon, Utah; in the Yellow Aster Mine, Randsburg, California; in the Big Indian Mine, Helena, Montana; in the Granby mines, Phœnix, British Columbia, and at numerous other mines.

The milling method of mining is applicable to large bodies of ore either in veins or masses, and to wide ranges in character of ore. The method is elastic, as it is employed in both surface and underground work.

The advantages of the milling method are:

1. Large outputs per man.

2. Low mining costs.

3. Much waste material may be obtained for filling, which is important if other methods of mining are operated in conjunction with the milling method.

4. There is a minimum amount of handling of ore.

5. When working ground previously mined in which considerable timber was used, much of the timber can be picked from the ore and reused.

The disadvantages of the method are:

1. When employed as a surface method of working, the orebody must extend close to the surface to be stripped.

2. Mill-holes choke, especially with ores of certain character; ores breaking moderately fine and granular in form without clay are preferable.

3. Rain and snow interfere with work on the sloping sides of the pits.

4. Considerable danger from falls of men and rocks and flying rock from blasts.

5. When carried on underground there is considerable danger of caves which may extend into the workings.

6. Little opportunity to sort waste from ore.

Generally considered, surface or open cut methods are applicable to the outcrops of large veins and massive deposits occurring at or within a few feet of the surface. Practically all kinds of minerals and ores as well as non-metalliferous materials are, when possible, mined by open cuts. Quarries of stone, slates, etc., are to all intents and purposes open cut mining operations and may be classed as such.

The advantages of open cut mining are:

1. Work can be done on a large scale.

2. Mining cost is low.

3. Lighting workings is eliminated or materially lessened.

4. No timber is required.

5. Sorting can be done to advantage.

6. Practically no danger from fires, gases, etc.

The disadvantages of open cut work are:

1. Cost of real estate for both the open cut and storage of waste is a large item.

2. The depth to which the strictly open cut work can be carried is limited, although with the milling method great depths are worked.

3. The cost increases greatly with depth, unless connection is made with the underground workings as in glory-hole work.

4. Danger of falls of rock and men.

5. Danger of inundations.

6. Inconvenience of working in stormy weather.

7. Proper slopes must be given to the sides of the open cuts to prevent walls from caving — a slope of 1 to $1\frac{1}{2}$ for hard formations and 1 to 3 for clay is commonly given.

The comparative advantages and disadvantages of the various methods of open cut work are as follows:

1. The outputs of the milling method and steam-shovel work are much greater per man than by hand or scraper work, and by scraper than by hand work.

2. The cost of mining per ton is much less with the milling method and steam shovel than with hand and scraper

work, while scraper work is cheaper than hand work, and steam-shovel work is cheaper than by milling.

3. The milling method can be used to advantage in deposits too small for steam shovels to operate upon.

4. Fewer laborers are required in scraper than in hand work, and in steam-shovel than in the milling method, but more skilled labor is required in steam-shovel and milling.

5. Less danger of accidents in hand, scraper and steam-shovel work than in the milling method, and more in hand and steam-shovel work than in scraper work.

6. Ores may be sorted to better advantage by hand, scraper and steam-shovel work than in the milling method, and better in hand and scraper than with steam-shovel work.

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CHAPTER VIII

COST OF MINING

Introduction

The cost of mining is dependent upon a number of more or less general considerations, such as period and extent of operations, character and value of ore, organization of working force, transportation facilities, etc. A number of these factors are interdependent, as time work has been carried on, extent of operation, organization, etc.; the scale of operation and organization naturally requires time for growth and perfecting. The same is true of transportation facilities, but probably to a less degree. Increased output made possible by efficient equipment and organization is without doubt the most important factor in reduction of costs, which is true not only of the breaking of ore but of every other operation both above and below ground. Hard times also act to reduce cost of working, but like the cause that produces them, stringency in the money market, the conditions are abnormal and are to be considered as cause of temporary variations only and not as constantly acting factors.

General Considerations. — Speaking more specifically, the cost of mining is influenced by variations in width of vein or size of deposit and value of ore with depth, hardness of ore and gangue materials, presence of water, cost of labor and supplies, etc. Variations in width of deposits, the mineral content remaining the same per foot in depth, means the handling of more or less material with the same ultimate return, and may be a potent factor in increasing cost of working, as when the vein is very narrow, this necessitates the breaking of much wall rock, as in resuing. The hardness of the ore may also vary considerably with depth and if coincident with reduced mineral content may result in a very material increase in cost of stoping.

The stability of both vein-content and wall rock, *i.e.*, the ability to stand unsupported in moderate sized stopes, is probably of equal importance with hardness of the mineral bearing and non-mineral bearing formations. Weak and unstable formations involve the element of support, which in extreme cases may increase the cost of working to a prohibitive figure. By carefully arching the backs of the stopes, stable formations may be made to stand otherwise unsupported in stopes 50 ft. or more in width; the large open stopes of the Homestake mines of South Dakota, and of the Alaska-Treadwell mines, Douglas Island, Alaska, are good illustrations of such conditions. On the other hand weak and unstable formations may be worked at moderately low costs by the employment of filling methods. As the conditions existing in the majority of the metal mines of the United States are such as to necessitate support, it is evident that the cost of support may enter into the expense of working and often, as in square-set mining, constitutes an important item in such calculations.

The character of the ore is of importance, for if the whole vein-content is uniform in value, the method of working the deposit will differ materially from the case where the values are scattered, occurring possibly in thin stringers or in bunches. In the former case the value can be depended upon and will vary between moderately narrow limits; in the latter case much barren material will have to be mined, thus necessitating considerable sorting and handling. Further, in the latter case we may have a concentrating ore from which the waste may be largely eliminated, in the former case a smelting ore may be the result; in either case the subsequent metallurgical treatment is really the determining factor in the economical working of the deposit. While it costs as much or more to break waste as to break ore, yet the tonnage costs are usually charged to ore alone, which is an important consideration in figuring costs.

The presence of water in considerable quantities does not directly influence the cost of breaking ore; however, there are numerous instances where excessive quantities of water are encountered, even in certain portions of otherwise moderately dry districts, and in such cases the cost of breaking ore may run up to an abnormally high figure. Aside from the inconvenience of working at a stope face flooded with water or in a constant downpour from the roof, the presence of large quantities of water materially increases the peril of working, increasing the number of falls both by preventing adequate inspection and by the tendency to force off the fractured rock and ore by hydraulic pressure. Falls of rock may be largely increased by the action of water under pressure acting in crevices, fault planes and slips, especially when an attempt is made to check the flow by wedging and pumping in cement, clay, sawdust, etc., as was done in the Central Mine of the Federal Lead Company at Flat River, Missouri.

While the wages paid in the various metal mining districts of the United States vary considerably, yet the actual difference in cost for work done is relatively slight. The efficiency of the labor depends directly upon the wage paid, although there are possible exceptions, as under certain conditions of labor, location, etc. The operator then gets a return for his labor expenditure in proportion to the amount paid.

The cost of supplies, such as fuel for power purposes, timber for support, and tools, steel, explosives, etc., for breaking ground, while it varies considerably in various localities, probably does not, as Finlay has shown, even with a variation of 50 per cent in the price, produce a difference of over 10 per cent in total current mining costs.

Other conditions having an indirect bearing upon the cost of mining and especially breaking ore are: abnormal temperature of the mine atmosphere; presence of gases, natural or artificial; dust resulting from operation of drills; altitude, etc. High temperature may be due to inherent qualities in the deposit worked or to poor and inadequate ventilation. Excessive temperatures such as are experienced in the mines of the Comstock Lode and a few other mines in the United States are not of sufficiently common occurrence to warrant consideration in this connection, but temperatures of 75 to 90° are of fairly common occurrence and are to be found in the lower levels of many mines in this country. The deeper mines of Keweenaw Point, Michigan; of the Butte District, Montana; and of other western districts may be cited as illustrations of mines having temperatures above the normal. The reduced efficiency and effectiveness of the labor returns, while apparently inconspicuous and relatively small considered by individual units, are in reality of much importance when the elements of time and numbers are involved. Considered independently of other conditions a few degrees rise in temperature does not in the long run have a deleterious effect upon the efficiency of labor, but when combined with other conditions, such as vitiated air resulting from the presence of moisture, mine gases and powder smoke, may seriously affect the health of the miners and decrease the effectiveness of their labor.

Altitude has a twofold influence upon labor conditions in that it affects the health and general tone of the individual effort, and by its effect upon climatic conditions may seriously curtail the extent and duration of the operations. Further, the operations may be limited to certain seasons by no other causes than the failure of transportation, excessive rainfall and deep snowfall limiting the operation of the railroads, and severe weather. Limited periods of operation in turn affect the labor conditions, requiring high wages to maintain the proper standard of efficiency.

Detailed Discussion of Costs of Mining

The principal factors influencing costs of mining ore have been indicated in the preceding pages, and particularly those entering more or less directly into the cost of breaking ore or stoping. When an attempt is made to investigate the cost of any one single operation, as driving levels, stoping, etc., it at once becomes obvious that there are many difficulties to be encountered. It is rarely the case that reliable information can be secured regarding the cost of distinctively separate operations, the tendency in ordinary mining practice and cost-keeping being to group certain closely related expenses under a few more or less general headings, such as mining, milling, and smelting. These may in turn be subdivided into other more specific yet generalized headings, as in the case of mining, where we may have costs of development, stoping and handling ore.

While the cost of stoping or any other operation in mining may be specifically stated, yet a careful differentiation of expenses between stoping, timbering, handling ore, labor and supplies is rarely attempted. The cost of mining as usually given in published reports of mining operations is more often misleading than otherwise in that there are a number of unknown factors involved, the result being that the figures are of little or no value even for comparative purposes.

Fundamental Items of Cost. — The cost of mining per unit amount, as per ton or cubic yard, fathom, etc., when calculated as closely as possible and when shorn of all superfluous and extraneous charges may be considered as made up of the following items:

1. Cost of labor.
2. Cost of supplies.
3. Cost of power.
4. Cost of lighting.
5. Cost of support in stopes.
6. Cost of handling ore in stopes.

The above considerations apply equally well to the various phases of mining as development and breaking ore.

The first four items given above are costs common to mining operations and are largely independent of local conditions. The two last mentioned items may be considered as special costs in that they involve special methods of working brought about by local conditions and character of deposit.

Labor. — The wage-scale of a district is indicative of both the character and efficiency of the labor. A difference of 30 cents per hour (range 20 to 50 cents in the United States) may be and is usually largely due to the quantity and quality of labor available. In this connection the question might properly be raised as to what constitutes a day's work. Aside from the element of time or hours of work, as determined by local agreement or law, by far the most important consideration is the quality of the work done, and this in turn, as has been indicated, is largely dependent upon wages paid. High wages attract good workmen and by competition the poorer element is eliminated. Difference in length of a working day and of wages per day is, however, more apparent than real; the result being ultimately about the same, the conditions naturally equalizing themselves in quantity and quality of work done. Further, a day's work may be based upon time or work done, and as in practically all other kinds of work the latter has been found to be much more satisfactory, as it encourages competitive effort, which means both more work done and a higher class of work.

In development work, but more particularly in stoping, it is customary to pay for footage drilled or volume of ore broken down, as per cubic foot, yard or fathom, or the unit adopted for calculation of wages earned may be the tonnage extracted, which is in reality figured on the basis of volume. The unit of volume, be it figured in feet, yards or fathoms, or tons, is that commonly chosen for contract work.

Supplies. — The cost of supplies varies with the district and is dependent largely upon transportation facilities, quantity consumed, character of labor, etc. The quality of the supplies and the useful amount of work gotten out of them, whether fair quality or poor, is also comparable with labor and is dependent more or less directly upon the character of the labor employed.

Power. — The cost of power in any particular operation is difficult to determine, as only a part and often a comparatively small part is consumed in the particular operation under consideration. In the case of stoping, however, the proportionate amount of power used is relatively large compared with other power consuming operations underground, yet while the error in estimation of amount to be charged to stoping may be small, it exists nevertheless, but may for comparative purposes be neglected especially in large-scale operations where many drills are employed and the output is consequently large. In estimating power costs as in stoping it is customary to distribute or 'spread' the cost and charge an equal amount to each machine operating, which in itself may be a source of error in that the number of machines in actual operation from day to day as well as the actual time of operation may, together with their consumption of air, vary somewhat causing a variation in computed costs to be charged to a given machine or unit.

Light. — The cost of light in stoping is practically a constant quantity, varying but slightly in the various districts, and while it should not be neglected in comparing costs yet the difference is probably more apparent than real. With light as with labor the amount of work done, *i.e.*, the tonnage produced depends largely upon the character of the factor involved. While illumination is an important factor in mining, yet space and facilities provided determine the number of men that can be employed to advantage.

The following table gives the comparative cost of candles and acetylene lamps in a number of mines:[1]

Name of Company	Number of Men Employed Underground.	Number Using Lamps.	Carbide Consumption per Lamp, Oz. Shift.	Cost Carbide per Lb., Cents.	Cost per Lamp Shift, Cents.	Cost of Candles per Shift, Cents.
Homestake Mining Company	1025	1025	8.0	3.50	1.75	7.00
Ray Con. Copper Company	1400	1200	9.0	4.50*a*	2.50*a*	5.00*a*
Quincy Mining Company	1389	575	6.7	3.50*a*	1.46*a*	....
Osceola Con. Mining Company	625	625	6.0	3.50	1.38	....
United Verde Copper Company	600	575	6.5	5.50	2.23	5.40
Bunker Hill & Sullivan Company	460	208	7.0	5.25	2.30	6.18
Calumet & Arizona Mining Company	1000	60	7.0	5.50	2.40	6.64
Ohio Copper Mining Company	96	37	8.0	5.80	2.90	....
Nevada Con. Copper Company	200	20	4.0	4.67	1.12	3.27
Mammoth Copper Mining Company	....	12	10.0	5.86	3.66	5.15

a Estimated.

[1] Acetylene Lamps for Metal Mines by Frederick H. Morley. Mining and Scientific Press, vol. 108, p. 609.

Support. — The cost of supporting mine workings is far from a constant quantity, although it is possible that there is no great difference where the same methods are employed. Costs of support range from a few cents per ton to more than $1, varying with character of ore and wall rock, and scale of operations.

The cost per ton of the various methods of support is approximately as follows:

Square-set timbering	15 to 25 cents.
Timber with top-slice	about 17 "
Filling with filling method	25 to 50 "
Timber with caving method	5 to 10 "

Methods of handling and forming timbers as in the square-set method may be responsible for a variation of as much as 2 c. to 5 c. per ton. T. S. Carnahan [1] states that the Utah Copper Co. mined over 3,000,000 tons of ore at a cost for timber of less than 5 c., which could hardly have been done except for the large tonnage produced.

Handling. — Handling of ore in mines usually involves a number of operations such as clearing stopes and loading cars in open stopes or drawing ore from closed stopes through chutes, and tramming it to orepockets or the shaft station. The transference of the ore to the surface by haulage through a tunnel or by hoisting may be a continuation of handling or an entirely different operation as in hoisting. There is a wide variation in the method of treating the cost of handling ore and consequently considerable confusion may arise in comparing similar costs. Reported

[1] Trans. Am. Inst. Mining Engrs., vol. LIV, p. 92. Underground Mining Methods of Utah Copper Co.

costs of handling ore varies from 5 c. per ton for short trips in large open stopes to 25 c. for hauls of several thousand feet. If it is possible to give an average it might be placed at about 15 c. per ton.

General Mining Costs

Mining expenses as given under this head comprise all costs connected with the development and working of a mine, and are similar to those previously outlined except that other more general items are usually considered, such as superintendence, depreciation, taxes, amortization, etc. The value of such data is therefore of a general nature and is useful mainly in showing expenditures.

Mining Costs. — T. S. Carnahan, Trans. Am. Inst. Mining Engrs., vol. LIV, p. 90. Utah Copper Co.

	Per Dry Ton
Labor	$0.329
Powder, caps and fuse	0.091
Timber	0.049
Motor haulage	0.025
Gravity tramway	0.020
Supervision and engineering	0.038
Compressed air	0.024
Miscellaneous	0.111
Total	$0.687

William Braden, Bull. Trans. Am. Inst. Mining Engrs., Oct. 1909, p. 905. Braden Copper Mines, Chile.

	Per Ton
Ore-breaking	$0.31
General mine-expense	0.06
Development	0.12
Underground tramming	0.02
Aërial tramming	0.06
Power	0.01
Sampling and assaying	0.05
General expense	0.23
Taxes, insurance, and interest	0.04
Total	$0.92

Hollinger Mine, Porcupine, Canada. Mining & Scientific Press, vol. 106, p. 661 (1913).

	Per Ton
General and superintendence	$0.179
Diamond drilling	0.027
Stoping and driving	1.969
Timbering stopes	0.219
Tramming	0.551
Drainage and pipes	0.092
Hoisting	0.170
Dumping	0.063
Drill steel	0.298
Assaying, sampling, and surveying	0.064
Change house and lights	0.013
Handling explosives	0.025
Handling waste	0.016
Total	$3.686

Great Boulder Perseverance. Eng. & Mining Jour., vol. 93, p. 1034 (1912).

	Per Ton
Wages and contracts	$0.900
Explosives	0.156
Drill parts and air lines	0.043
Candles	0.018
Air for drilling	0.105
Not specified	0.468
Total	$1.690

West End, Tonopah. Mining & Scientific Press, vol. 107, p. 272 (1913).

	Per Ton
Superintendent and foreman	$0.135
Breaking	0.802
Timbering	0.090
Tramming	0.372
Hoist, etc	0.200
Ore loading	0.233
Ore sorting	0.366
Assaying, sampling, surveying	0.091
Surface, ore dump, drayage	0.195
Development	0.862
General expense	0.554
Miscellaneous	0.262
Total	$4.162

Tonopah-Belmont. Eng. & Mining Jour., vol. 93, p. 936 (1912).

	Per Ton
Development	$0.78
Stoping	3.94
Administration, etc.	0.719
Total	$5.439

Many other general mining costs are available from company reports, but it is hardly necessary to add to those given which are representative.

Details of Mining Costs

While costs of the special operations in mining are not as available as the more general costs yet a number of itemized statements are given below which will serve to show the factors involved and some standard costs.

Development. — Montana-Tonopah Mining Co. Mining & Scientific Press, vol. 99, p. 507 (1909).

	Per Foot
Drifting	$6.56
Cross-cuts	5.44
Raises	4.65
Winzes	11.92
Total	$28.57

Portland Gold Mining Co. Cost of Mining, Finlay. The cost of drifting is itemized as follows:

	Per Foot
Tramming	$1.00
Pipe and trackmen	0.14
Machine men	1.88
Machine work, air, etc	0.97
Repairs, cars, etc.	0.08
Explosives	1.43
Hoisting	0.46
General expense, surveying, etc.	0.58
Total	$6.20

The cost of other development work carried on under similar conditions was as follows:

	Per Foot
Cross-cuts	$6.23
Winzes and raises	8.60

Bunker Hill Sullivan, Cœur d'Alêne. Eng. & Mining Jour., vol. 95, p. 1200 (1913).

General development costs are as follows:

	Per Foot
Foreman, blacksmiths, etc.	$0.312
Miners	2.500
Shovelers	1.650
Explosives	0.990
Timber and lagging	0.400
Power, labor and supplies	0.524
Not specified	0.774
Total	$7.150

Cost of Raises and Winzes. Elements of Mining, Young, p. 432.

Location.	Raises.	Winzes.
	Per Foot	Per Foot
Elkton, Col.	$4.62	$12.51
Portland, Col.	7.77	....
Nevada Hills, Nev.	6.30 to 7.47	15.27 to 19.20
Montana Tonopah, Nev.	4.26	....
Goldfield Con., Nev.	5.71	19.47
West End, Nev.	6.68	13.39
Standard Con., Cal.	3.66	5.55 to 8.75
Mesabi, Minn.	3.50 to 5.00	....

The cost of shaft sinking is an exceedingly variable quantity and while costs could be given covering a wide range of conditions such as cross section, depth, character of material worked, amount of water encountered, method employed, etc., yet it is doubtful whether it would be of much value in this connection.

Stoping. — Costs of stoping in a number of the large mining districts of the United States are given in this connection and bring out some interesting facts regarding the methods of cost-keeping and the items which go to make up the costs.

The Copper Mines of Keweenaw Point, Michigan

The following data were collected by the author during a period of some four weeks spent in the Wolverine Mine in 1906. There are three methods of stoping employed in this mine and generally throughout the district, which are: drift, raise and cutting-out stoping. Drift stoping is the usual method of working from a level and consists in carrying a face 25 ft. high practically the full width of the lode; the lower part includes the drift and is run at the required grade of the level. When possible, the lower or drift portion is attacked first, thus forming a sump or opening into which the remaining upper portion may be broken. The average of the total length of holes drilled, in the cases observed, was 174 ft., while the time of drilling averaged from observations on 9 holes in each case was as follows:

Average depth of hole	5.6 ft.	
	Mins.	Secs.
Total time of drilling, per hole	41	47
Delays in drilling, per hole	19	29
Actual time drilling 1 foot of hole	7	27

The total time of drilling 174 ft. of hole was, therefore, 21 hr. and 45 min., or two shifts.

Stoping is paid for by the fathom, the exact amount varying with the particular stope; the price runs from $5.50 to $9 and averages probably $8 per fathom. A fathom is 6 × 6 × 6 ft. or 216 cu. ft., 8 cu. yds. The average height of stope is 12 ft., and the miners are paid for this height regardless of whether the actual height is greater or less. The height of the drift is subtracted from the height of the stope and is paid for as drifting, $5.50 being the usual rate per ft. The miner then receives $8 per fathom for 19 ft. width of stope 12 ft. high, and $5.50 per foot for drift 6 ft. wide and 12 ft. high.

The 174 ft. of holes when charged and fired usually break $4\frac{1}{2}$ fathoms or 36 cu. yds of ore, the result of two shifts' work. The delays due to cleaning up and other causes may reduce the output somewhat, but it is seldom less than one-half or to about $2\frac{1}{4}$ fathoms per shift. Working two shifts per day, as is the practice, $58\frac{1}{2}$ fathoms are broken down per month of 26 working days. At $8 per fathom this gives $468 per month for two crews of two men each, and from it all expenses have to be deducted. The two crews employ a drill boy between them. The $4 charge for drill steel is also divided between the two crews, both crews using the same drill. The following are the itemized expenses of one crew during one month when 40 fathoms or 320 cu. yds. of ore were taken out:

	Total.	Per Fathom.	Per cu. yd.
7 boxes powder at $17.00	$119.00	$2.975	$0.372
2 boxes candles at $8.00	16.00	0.40	0.05
800 feet fuse at 1 cent	8.00	0.20	0.025
200 caps	4.00	0.10	0.0125
3 gallons oil at 30 cents	0.90	$0.02\frac{1}{4}$	0.005
Steel	2.00	0.05	0.0062
Drill boy	15.00	0.375	0.047
Total	$164.90	$4.122	$0.517

It will be seen that 350 pounds of powder were used to remove 320 cu. yds. of ore, or 1.09 pounds per cu. yd. Referring to the above cost of $4.122 per fathom, it may be noted that the average of a number of accounts gave an average of $4.24 per fathom.

In raise stoping the work is more difficult and consequently the cost is higher, while in cutting-out stoping the reverse is true and the cost is correspondingly less. The price paid per fathom is the same as with other stoping operations. When, however, the ground breaks readily and the stopes are large, the amount paid may be reduced, even as low as $5.50 per fathom, while under less favorable conditions a higher price may be paid.

The usual practice in the district is to pay the miner on beginning work $60.00 per month for the first two months' work, at the end of which time his work is measured up and he is paid $8 (or the amount agreed upon) per fathom for stoping and $5.50 for drifting (in drifting and drift stoping). In all contracts the miners furnish supplies, the company providing drills and steel.

The cost of stoping in a number of mines in the same district and for the years 1887 and 1892 are shown in the following tabulation:

Mine.	Year.	Contract Price per Fathom.
Osceola	1887	$9.91
Osceola	1892	11.09
Atlantic	1892	3.98
Kearsarge	1892	9.57
Tamarack	1892	11.86
Average		$9.28

The ore is hard and does not drill or blast very easily.

The following costs have been compiled from reports and data regarding the respective operations.

The Cripple Creek District, Colorado

The distribution of costs of stoping per ton in the Portland gold mine as given for the year 1906 is as follows:

	Cost per Ton.
Labor	$1.142
Machines	0.270
Tramming	0.029
Explosives	0.380
Hoisting	0.230
Supplies	0.036
Superintendency, assaying, surveying, etc	0.450
Total	$2.537

The labor costs may be analyzed as follows:

Machine men	$0.4761
Trammers	0.3214
Pipe and track men	0.0357
Timbermen	0.1666
Timber helpers	0.1428
Total	$1.1426

The ore is moderately hard, but drills and blasts readily. It is evident on examining the above account that the work is thoroughly systematized, the idea being to distribute to each and every operation involved its proportionate amount of expense. There is also indication of a 'spread' of costs, especially in the items of machine drills, tramming, hoisting, superintendency, etc. It is obvious that with such a system a very effective check upon the various operations is possible.

The Alaska-Treadwell Mines, Douglas Island, Alaska

The successful operation of the large gold mines of Douglas Island, Alaska, is made possible by a number of conditions, among which none is of more importance than that of organization.

The large scale of the operations and the comparative low grade of the ore practically necessitate very careful and systematic management in order that the work may be profitably carried on. The figures given below are for the years 1901 and 1902.

	Cost per Ton
Machine work	$0.3793
Rock breaking	0.3124
Tramming	0.0359
Hoisting	0.0486
Explosives	0.2269
Light	0.0085
Total	$1.0116

Ore is hard and firm, but drills and blasts quite easily. Here, as in the last mentioned case, an attempt has been made to distribute costs, charging to each operation the proportionate amount of expenditure, but unless the distribution of costs is carefully made considerable confusion and inaccuracy may result.

The Lead-Silver District, Cœur d'Alêne, Idaho

The detailed cost of stoping in the Bunker Hill and Sullivan Mine for the year 1908 is as follows:

Details for Labor and Supplies.	Total for the Year.	Average per Ton for the Year.	Highest Cost per Ton for 1 Month During the Year.	Lowest Cost per Ton for 1 Month During the Year.
Foremen, bosses, blacksmiths, machinists, tool-packers, etc.	$60,982.27	$0.185	$0.191	$0.165
Timberman and carpenters	25,109.38	0.076	0.082	0.063
Miners	125,148.48	0.379	0.400	0.339
Car-men	15,918.00	0.048	0.042	0.058
Shovelers	133,176.50	0.403	0.450	0.379
Power labor	7,708.40	0.023	0.027	0.021
Repair labor	7,492.70	0.023	0.025	0.021
Explosives	30,019.37	0.091	0.111	0.087
Illuminants	7,482.08	0.023	0.026	0.017
Lubricants	1,329.87	0.004	0.004	0.006
Iron and steel	4,158.20	0.013	0.014	0.012
Miscellaneous supplies	11,667.61	0.035	0.032	0.025
Timber and lagging	61,629.00	0.186	0.199	0.165
Power supplies	7,876.30	0.024	0.024	0.027
Wood	9,292.80	0.028	0.030	0.030
Stable and stock	2,297.20	0.007	0.007	0.006
Total	$511,288.16	$1.548	$1.664 Nov.	$1.421 May.

Ore is not particularly hard to drill and blast.

The comparatively high cost of timber as shown in the above table is due to the fact that square-set timbering is an important adjunct to the mining of the ore in this district. The high cost of labor, particularly for shovelers, is due to the necessity of freeing the stopes from ore and placing waste-filling.

The Goldfield Consolidated Mines Company,
Goldfield, Nevada

The costs of stoping during ten months of 1909 are given in the following tabulation:

	Cose per Ton
Labor	$1.24
Supplies	0.66
Power	0.03
Department	0.25
Construction	0.02
General	0.02
Total	$2.38

Ore is a fair average for drilling and blasting.

The first three items given are regular and legitimate cost for this kind of work; the last three are indeterminate, and while they may be composed wholly or in part of expenditures necessary for the proper carrying on of the work of stoping, yet their designation leaves this in doubt.

The Joplin Lead-Zinc District, Missouri

The cost of breaking ground in the Joplin district varies considerably owing to character of ground, which ranges from very hard to very soft. The usual conditions existing in the sheet ground in the vicinity of Joplin, Webb City, etc., permit the ore to be broken down at moderate cost.

The following costs are representative of the district:

COST OF STOPING IN 1901

2 machine men at $3.00	$6.00
2 machine helpers at $2.50	5.00
2 shovelers at $2.50	5.00
1 blacksmith at $2.50	2.50
1 ground boss at $3.00	3.00
Explosives	6.00
Incidentals	3.00
Total	$30.50

Drilling and blasting are fairly easy, although variable, owing to character of ground encountered.

The $30.50 represents the expenditure for one day when 75 tons of ore are broken; the cost per ton was then about $0.40.

Other more detailed costs of operations that go to make up the cost of breaking ground, also related cost data expressed in cents per ton, are as follows:

COST OF STOPING IN 1903

Cost of drilling, hand work	$0.06800
Cost of drilling, machine work	0.05600
Cost of drill steel	0.00878
Cost of powder, caps and fuse	0.04050
Cost of oil for lamps	0.00080
Cost of timbering, soft ground	0.00045
Cost of pumping, mine pumps	0.00005
Cost of track	0.00009
Cost of shoveling	0.03900
Cost of labor underground	0.19890
Cost of hoisting	0.02860
Cost of tramming	0.02600
Cost of air compressor	0.00150
Total	$0.46867

The cause of the variation of 7 c. per ton noted above is difficult to explain, but is slight when the factors influencing the costs are considered. The period during which the figures from which the averages were calculated is a controlling factor if short, otherwise not.

The War Eagle Mine, British Columbia

The costs previously given are for mines located in the United States. The cost of stoping as given in the company's report of the War Eagle Mine for the year 1909 illustrates, even to better advantage than in the previous cases cited, the spread of costs, involving practically all operations having to do with the underground work. The following costs are figured on a ton basis.

1.	Drilling	$1.53
2.	Tramming and shovelling	0.53
3.	Timbering	0.29
4.	Hoisting	0.13
5.	Smithing	0.15
6.	Ore sorting	0.01
7.	General labor	0.30
8.	Air	0.21
9.	Candles and illuminating oil	0.03
10.	Explosives	0.02
11.	Drills and fittings	0.25
12.	Mine supplies	0.05
13.	Lumber expense	0.04
14.	Stable and teaming	0.03
15.	Assaying	0.04
16.	Surveying	0.05
17.	Electric lighting	0.02
18.	Salaries	0.03
19.	Office expenses	0.18
20.	General expenses	0.05
	Total	$3.95

Ore drills and blasts moderately well.

In comparing this cost of stoping with others which have not been so extensively distributed it would be necessary to eliminate a number of items, those chosen for actual use being 1, 5, 8, 9, 10, 11 and 12. The items 2, 3, and 6 might very properly in this case be included, especially 3, as square-set timbering is employed. The item of drilling is probably labor of operating drills, while the air item indicates the cost of power. Drills, fitting and mine supplies consist of steel and other drill repairs.

Stoping at the Tonopah-Belmont Mine. Eng. & Mining Jour., vol. 93, p. 936 (1912).

	Per Ton, Cents.
Miners	44.500
Shovellers	33.900
Trammers	19.200
Timbermen and helpers	97.800
Filling	4.200
Piston-drill repairs	5.000
Stoping-drill repairs	2.900
Steel and sharpening	7.100
Explosives	28.600
Hoisting to surface	30.900
Auxiliary hoisting	9.400
Ore sorting and loading	27.300
Total	310.800

Stoping at the Bunker Hill, Sullivan Mine. Mining & Scientific Press, vol. 106, p. 727 (1912).

	Per Ton.
Timbermen and carpenters	$0.086
Foremen, bosses, etc.	0.177
Miners	0.367
Carmen	0.052
Shovellers	0.366
Power labor	0.027
Repair labor	0.026
Explosives	0.075
Illuminants	0.020
Lubricants	0.003
Iron and steel	0.012
Miscellaneous supplies	0.035
Timber and lagging	0.215
Power supplies	0.045
Wood	0.034
Total	$1.540

An examination of the above data brings out the fact that the larger the company, and consequently the operation, the more detailed are the working costs, which is not shown to particularly good advantage either owing to the combining of certain costs in this connection. By increasing the number of items in an operation and putting the collection of the data upon which the costs are based in the hands of a sufficient number of competent men it is possible to secure fairly accurate results, but there is always danger of lax work being done, short cuts being taken and approximations made, which if persisted in mean inaccurate and untrustworthy returns. Another cause of error, aside from poor organization of the data-collecting force and arising from the distribution of costs, is that often no account is taken of variations in work done by the factors involved. This can be illustrated by the one item of power, the cost of which is commonly distributed uniformly over all the machines of a kind, as machine drills in stoping. It is rarely the case that out of 100 or even 50 drills employed in stoping, all are being operated at the same time, *i.e.*, continuously day after day. An ordinary piston drill is seldom running more than one-half the time that it is supposed to be in operation. The advent of the air-hammer drill, which is now being largely employed in stoping operations, might be supposed to change these conditions, for where used in similar work as the piston drill it is running the greater part of the time. It would seem then that the consumption of air should be greater, but experience shows that the air-hammer drills use considerably less air, approximately one-half that of a piston drill. Where continuous operation is maintained under conditions such as permit the drilling of a greater footage than with piston drills, there would have to be a different unit of cost calculated if the two types of drills were operating in the same mine, which would lead to still further complication in the estimation of costs of power. Further, the power required for each drill varies considerably both with its period of service and the skill and experience of its operators, and to a less extent with its distance from the source of power, as in the use of air drills. In order, then, to show the correct cost of power for a drill employed in stoping it is necessary to know at least the number of drills that are in actual operation, which can only be determined by daily inspection. This requires a constant and often daily change of unit costs, which is somewhat confusing. A fair and uniform charge per drill-shift is probably preferable, which unit cost multiplied by the number of units will at once give the power cost desired.

The cost per drill-shift for various styles of compressors and at different altitudes is given in the following table.

			Cost per 1000 cu. ft. Free Air, Compressed.			Cost per Drill-shift.		
Style of Compressor.	Maximum Capacity, cu. ft. Free Air per Minute.	Total Cost per H.P. Hour.	Sea Level.	5000 ft. alt.	10,000 ft. alt.	Sea Level.	5000 ft. alt.	10,000 ft. alt
		cents.	cents.	cents.	cents.	dols.	dols.	dols.
Simple steam (non-condensing)	200	2.2	5.9	5.3	4.8	2.07	2.22	2.40
Compound steam (non-condensing)	300	1.5	4.0	3.6	3.3	1.40	1.50	1.65
Simple steam (condensing)....	2500	1.0	2.7	2.4	2.2	.95	1.01	1.10
Compound steam (condensing)....	3000	0.8	2.2	1.9	1.8	.76	.81	.88

The cost will vary, of course, with the character of rock or ore drilled. The above figures were calculated from data collected from work done in granite. The compressors are all two-stage, intercooled.

The value of cost data is twofold, namely, it may be relative and comparative; the former is useful as showing the relative expenditures for various kinds of work in the same mine, the latter may serve a useful purpose in the determination of the cost of the proposed operations in the same or in other districts. The former may be accurate, the latter may be very inaccurate and unreliable owing to the necessity of dealing with many conditions which are largely unknown and conjectural at best.

The question as to how cheaply the various operations in mining can be done, or whether they can be done as cheaply in one district as in another or in different mines of the same district, will have to be determined by ascertaining the cost of the separate items making up the total costs in the work to be compared. This may be accomplished in a number of ways; which is chosen, will depend largely upon the accuracy of the results desired. In order that cost data may be useful they must indicate an amount or expenditure composed of a number of regular factors common to similar operations and independent of locality. These factors to be of the most value should, for comparative purposes, be figured on a percentage basis.

The differentiation between cost of various operations, rendering each account simple and complete in itself, would seem desirable. Tramming, hoisting, etc., might readily be placed under a class of operations separate from stoping, as handling ore outside the stope. In other words, charge to stoping just those operations that are confined to the stopes, thus localizing the operations and their costs. Simplicity, both with regard to the management of the work and the collection of data upon which costs are figured, is of probably the most importance, and this can be effected to good advantage by contract work, where the miner keeps his own accounts largely, or at least is sufficiently interested to keep close check upon them. The operator, in turn, checks off results as the output resulting from the miners' labor, and pays for work actually done. The contract work previously mentioned as in the case of the Wolverine Mine illustrates the point.

The two general contract systems employed are: measurement of volume, as 'advance' in drifting and volume of ore broken in stoping, and the hole-contract, *i.e.*, the measurement of the number of feet of hole drilled. The following data show the saving effected by the employment of the contract system in place of the wage system in stoping as was done in the Center Star and War Eagle mines of Rossland, British Columbia:

	Contract (hole) System, per Ton.	Wage System, per Ton.
Drilling	$0.356	$0.750
Blasting	0.021	
Explosives	0.100	0.115
Total	$0.477	$0.865

The advantage gained by the company was also a gain for the miner in that his daily wage was increased from $4 to $4.25, as against $3.50 under the wage system. The increased wage shows both a saving per ton in cost of stoping and an increased tonnage of ore broken, a natural result due to better pay, as previously indicated.

It might be stated in this connection that the contract system, in which the miner is paid by the fathom or other unit of volume, has proven unsatisfactory in these mines owing to the difficulty of measuring exactly the volume of ore broken in the very irregular stopes — the pay-shoots being very irregular in outline.

Support. — In certain kinds of work, as working slightly dipping deposits, square-set mining, etc., the cost of support may be a necessary and important part of the cost of breaking ore or stoping, being usually figured on the tonnage basis. A single case will suffice to show the cost per ton under average conditions, and for comparative purposes the cost under two different systems of working are given. The figures given below, prepared by Mr. B. C. Yates, are for the

AMOUNT AND COST OF TIMBER, SQUARE-SET METHOD

Name of Piece.	Number of Pieces.	Lineal Feet or Feet Board Measure.	Cost of Material.	Labor, Sawing and Framing.	Total.
Sill-floor posts	421	3,650	$474.50	$96.83	$571.33
Upper-floor posts	2,077	16,616	2,160.08	477.71	2,637.79
Caps	2,410	13,255	1,723.15	506.10	2,229.25
Ties	2,261	12,435	1,616.55	474.81	2,091.36
Sills, 203 long, 382 short	....	4,537	226.85	22.69	249.54
Lagging	13,020	75,906	3,795.30	379.53	4,174.83
Lagging strips	2,410	4,025	64.82	30.00	94.82
Wedges	2,352	784	13.33	11.76	25.09
47 sill-floor chutes, complete	....	....	311.68	16.25	327.93
215 upper-floor bins, complete	....	....	786.22	37.90	824.12
Ladders	14	117	1.99	3.50	5.49
Labor placing timbers and chutes	....	....	....	....	4,745.00
Breakage (10%) of lagging, 5% posts, caps and ties	....	....	....	....	793.97
Totals	....	....	$11,174.47	$2,057.08	$18,770.52

old square-set method and a more recent method now being largely employed in the Homestake mines of South Dakota.

AMOUNT AND COST OF TIMBER, HOMESTAKE METHOD

Name of Piece.	Number of Pieces.	Lineal Feet or Feet Board Measure.	Cost of Material.	Labor, Sawing and Framing.	Total.
Sill-floor posts	421	3,650	$474.50	$96.83	$571.33
Caps	410	2,250	293.15	86.10	379.25
Ties	381	2,095	272.35	80.01	352.36
Sills, long	203	2,436	121.80	12.18	133.98
Sills, short	382	2,101	105.05	10.50	115.55
Lagging	1,752	10,214	510.70	51.07	561.77
Lagging to protect track	764	4,454	222.70	22.27	244.97
Relief lagging	1,684	13,472	673.60	67.36	740.96
Wedges	200	66	1.12	1.00	2.12
Totals	....	....	$2,674.97	$427.32	$3,102.29

AMOUNT AND COST OF TIMBER IN MAN-WAYS, HOMESTAKE METHOD

Name of Piece.	Number of Pieces.	Lineal Feet or Feet Board Measure.	Cost of Material.	Labor, Sawing and Framing	Total.
Upper-floor posts	96	768	$99.84	$22.08	$121.92
Caps	48	264	34.32	10.08	44.40
Ties	48	264	34.32	10.08	44.40
Lagging, floors	96	560	28.00	2.80	30.80
Lagging, sides	720	4,197	209.85	20.98	230.83
Drift pins	1,440	457 lbs.	22.85	....	22.85
Ladders	28	235	4.00	7.00	11.00
Labor standing sill-floor timbers	....	....	....	....	758.16
Totals	....	....	$3,108.15	$500.34	$4,366.65

The costs of the two methods were $0.257 and $0.060 per ton figured on an output of 73,000 tons from the stope, thus showing a saving of $0.197 per ton in favor of the Homestake method.

Comparative costs of a stope in a Cripple Creek gold mine where stulls and filling were used are given in the following table.

STULLED STOPE

143 stulls at $2.50	$357.50
Lagging	10.00
Total	$367.50

FILLED STOPE

Interest on $4640 for 4.5 months at 6 per cent	$104.40
Timber (one-third of $357.50)	119.17
Total	$223.57

Saving in favor of the filled stope $143.93. The filled stope had in this case a filling of ore valued at $20 per ton, which is considered as so much capital tied up for the time being. As G. E. Wolcott, who furnishes these data, points out, there is comparatively small difference between the two cases when considered from the standpoint of amount of ore broken. Further, there is a greater difference with low-grade and a less with higher ore, which with the high-grade ore may even reach a point where the method of support by stulls may be cheaper than with filling. Aside from the consideration of costs there is a decided advantage in favor of ore-filled stopes or the so-called 'reserves' of ore, where the conditions are suitable for such a method of working. Aside from facilitating work at the face, in convenience of placing and setting up drills and giving the miner ready access to the working face, its great advantage lies in the regulation of output of the mine.

Cost of Open Cut Mining

A few costs are given for open cut mining which method has now become of the first importance in the production of low-grade ores such as iron and copper.

Open Cut Mining at the Boston Con. Mine, Utah. Mining & Scientific Press, vol. 99, p. 474.

	Per Ton.
Supervision	$0.0034
Operation, well drills	0.0134
Operation, air drills	0.0066
Blasting	0.0308
Operation, steam shovels	0.0588
Operation, railroads	0.0435
Dumps	0.0147
Operation, tram and ore bins	0.0020
Shop, tools and machinery	0.0078
Maintenance of buildings	0.0002
Miscellaneous	0.0013
Total	$0.1825

Costs of Open Cut Work in the Mesabi Iron Range. J. S. Lutes. Trans. Lake Superior Mining Inst., vol. 18, p. 134.

Stripping ordinary glacial drift, 30 cents a cu. yd.
Stripping ordinary paint-rock, 30 cents a cu. yd.
Stripping ordinary broken taconite, 75 cents a cu. yd.
Stripping ordinary solid taconite, $1.00 a cu. yd.
Steam-shovel mining, ordinary ground, 15 cents a ton.

The last item compared with underground work shows a difference of 60 cents per ton in favor of steam-shovel work.

The economical limit of stripping is about as follows:

One yard of overburden may be removed for 1 ton of ore mined.

For each foot in depth of ore removed 2 feet of overburden may be stripped.

A depth of 150 ft. is the maximum depth that can be stripped.

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