STATE OF MONTANA
Tim Babcock, *Governor*

BUREAU OF MINES AND GEOLOGY
E. G. Koch, *Director*

BULLETIN 63
December 1967

MINING METHODS AND EQUIPMENT ILLUSTRATED

by
K. S. Stout, Chairman, Engineering Division,
Professor and Head of Engineering
Science Department

MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY

MONTANA BUREAU
of
MINES AND GEOLOGY

BUTTE, MONTANA

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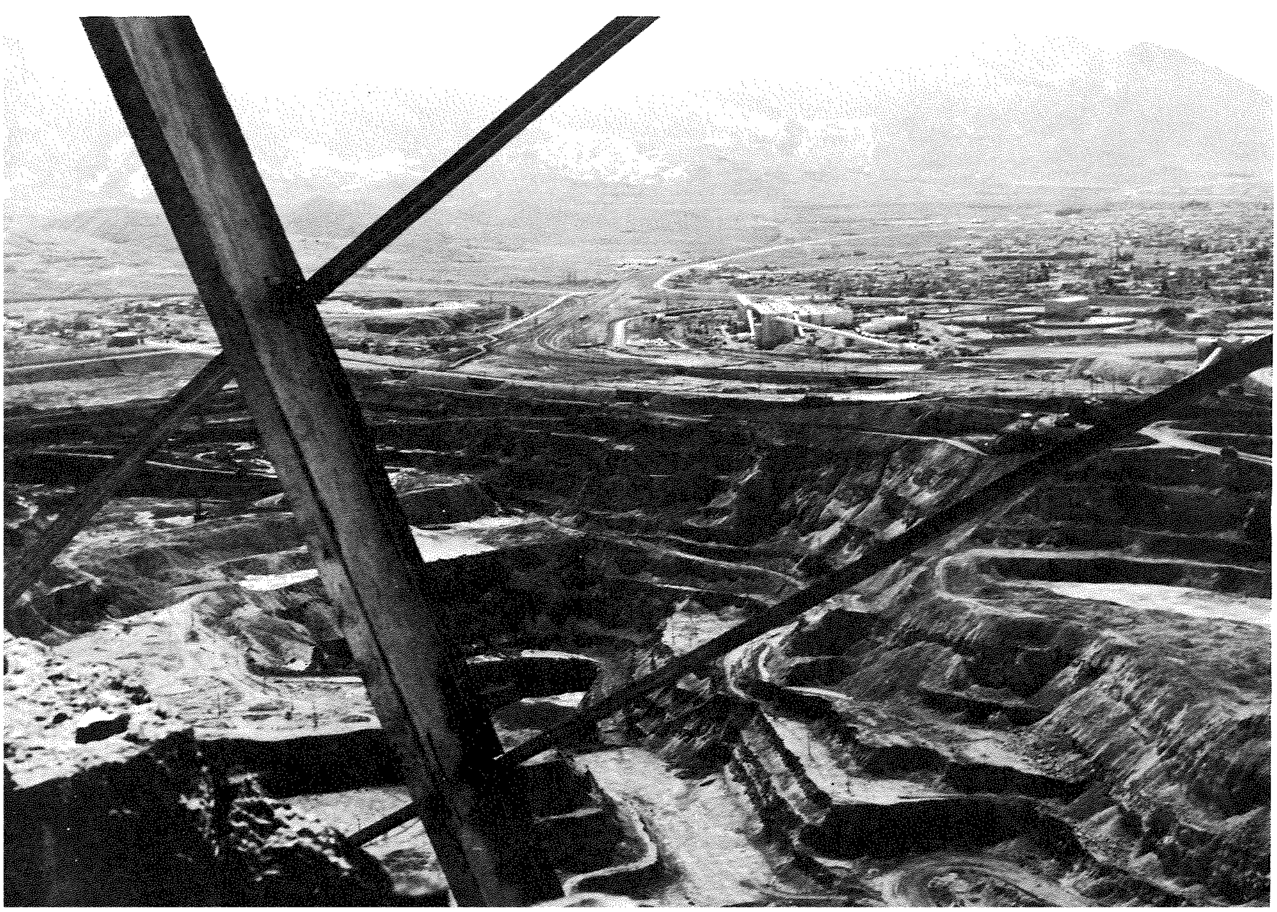
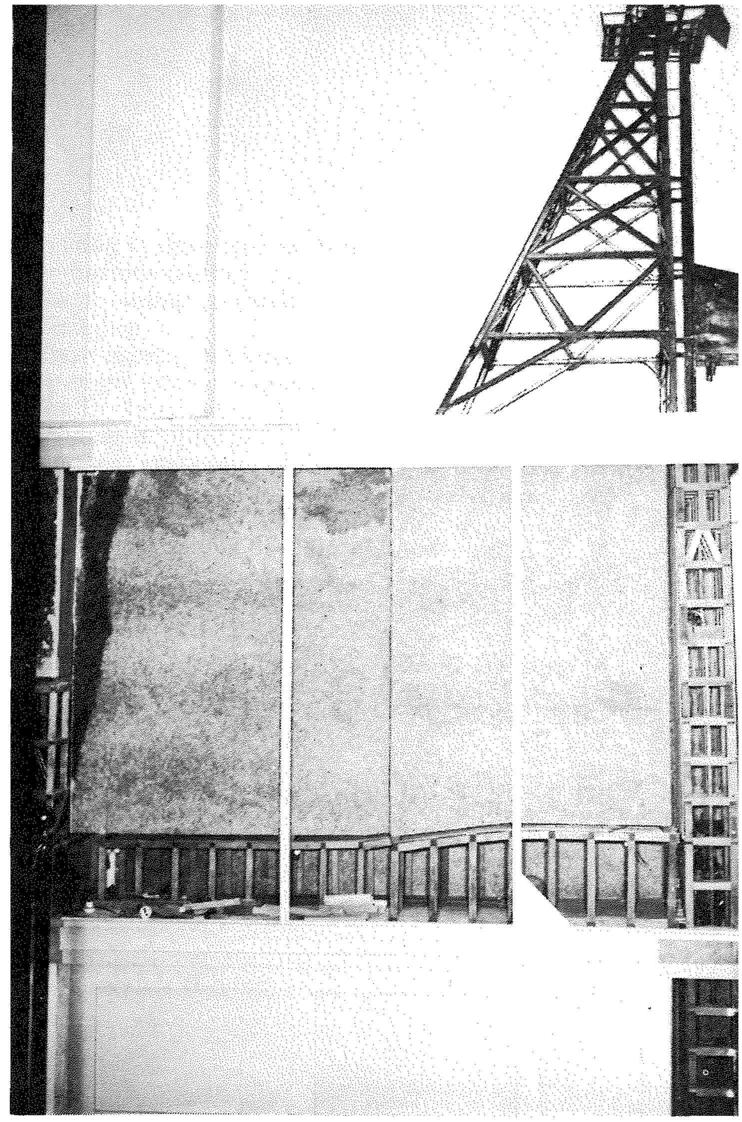
Mining Methods and

Surface: Montana's largest open-pit mine, The Anaconda Company's Berkeley pit at Butte



Underground:

Mine model showing head frame, shaft, and level



Equipment Illustrated

by

K. S. Stout, Chairman, Engineering Division,
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Science Department

MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
Butte, Montana
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ILLUSTRATIONS

Mining Methods and Equipment Illustrated

by

Koehler S. Stout*

INTRODUCTION

Many requests have been received by the Montana Bureau of Mines and Geology for some publication that describes mining methods in general use in Montana. In 1959 Mr. Richard W. Banghart, a senior student in mining engineering, now a mine superintendent for the Newmont Mining Corporation in Tsumeb, West Africa, wrote a report entitled *Mining Methods in Montana*. Much information was taken from that excellent report and incorporated in this work.

It is almost impossible to describe a mining method unless a sketch of the system is drawn. A sketch, however, has only two dimensions, whereas a mine exists in three dimensions. Therefore, special techniques are used to illustrate three-dimensional effects and dimensions. Because not everyone has had experience in reading sketches and maps, the first part of this bulletin describes map and sketch reading. The second part illustrates and describes the shape and type of ore bodies, which influence the mining methods chosen. Pictures of mine models are used throughout the publication in conjunction with sketches because people are more used to the three-dimensional effects that pictures produce. The third part discusses and describes the major operations in mining and some of the various techniques used in these operations. The fourth part discusses development, the work that prepares the ore for mining, which is essential in any mine. Mining is logically divided into surface and underground methods; the fifth part describes surface methods, including placer mining, open pit, and stripping; and the sixth part describes underground methods.

ACKNOWLEDGMENTS

Special appreciation is expressed to Mr. Richard W. Banghart for his original work. The mine operators throughout the state were most cooperative in permitting inspection of their properties and answering numerous questions about their operation. Many pictures in this report were provided by The Anaconda Company Research Department, Mr. Stewart Hurlbut, director, and the Communication Department, Mr. Tom Wigal, manager. The Gardner-Denver Co., Ingersoll-Rand Co., Archibald Co., and Joy Manufacturing Co. were most generous in supplying pictures and providing data.

The excellent drafting of sketches was done by Mr. Roger Holmes. The late Professor William A. Vine, former head of the Mining Department at the Montana College of Mineral Science and Technology, was most cooperative in the photographing of mine models in his department.

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PART 1—PICTURES, MODELS, SKETCHES, AND MAPS

The story of mining can best be told with models, pictures, sketches, and maps. Certain parts of underground mines can be photographed, but it is impossible to illustrate all of an underground mine except by pictures of models, by sketches, or by maps. The operation of an open-pit mine can be easily seen, but sketches and maps illustrate more clearly the mining operation or sequence of operations.

For those who may not have had experience in reading and interpreting sketches or maps, this part of the bulletin will explain what sketches and maps can show and how to interpret them.

TOP, BOTTOM, SIDE, AND END VIEWS (PLATE 1)

Picture A shows a box lying on a table; the picture was taken at an angle.

C is a space or block diagram (sometimes called a space sketch) of the box showing the same general view as shown in the picture. The purpose of this sketch is to show the similarity between the picture and the sketch. Notice that the directions of various other views are indicated by arrows. The top view would be looking directly down on the box; this view is illustrated in D. Sketch E shows the front view and F the side (or end) view.

SECTION VIEWS

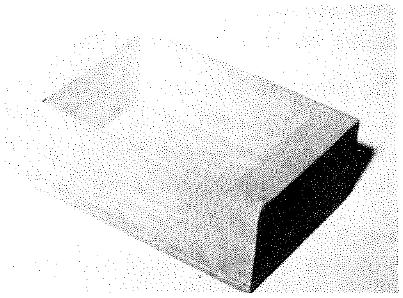
To illustrate a mine by sketches and maps, it may be necessary to use section views, hidden lines, and other devices to illustrate certain details. A mine is an operation in three dimensions, length, depth, and width, but our sketches and maps show only two dimensions, length and width. Therefore, to illustrate certain features, it is necessary to use certain tricks or conventions of drafting.

In E, a front view of the box, the dashed lines indicate the thickness of the sides, which cannot be seen from the front. Drafting convention has us illustrate the hidden thickness by a dashed line where the edge would be if we could see it.

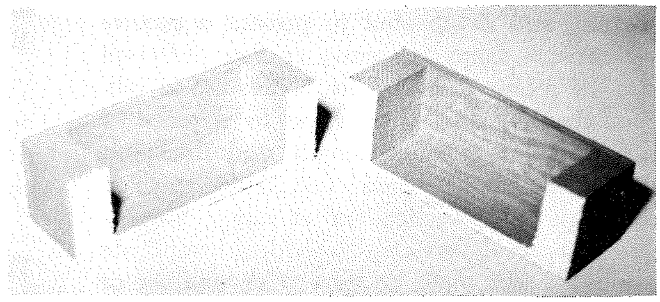
If the structure is complicated, there may be so many hidden lines in a view that their meaning is impossible to interpret. To show complicated details, an imaginary cut is made through the object, but in picture B the box was actually cut. The cut portion of the object is shown with slanted lines or "hatched lines". G is a sketch of the right portion in picture B. Note that the hatches slant in different directions on the bottom and the side pieces, a common practice where two different pieces of material come together. In the small space sketch above G, the edges that cannot be seen are indicated by dashed lines.

H and I are space sketches and resulting views of the box, had it been cut in different directions.

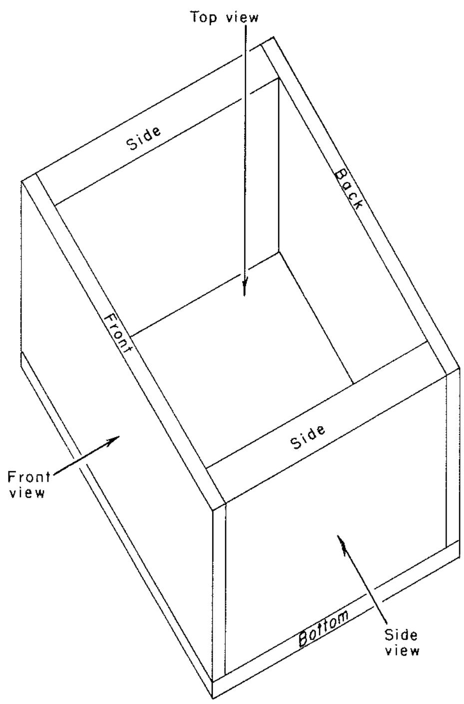
In mining, a section as shown in G is called a longitudinal section, or simply a long section. The top view is called the plan view (H), and the side view is a cross section (I).



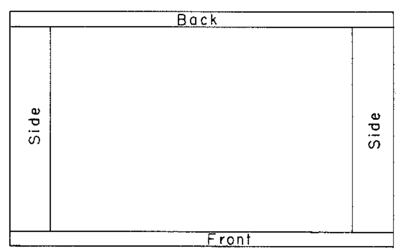
A. Picture of a box.



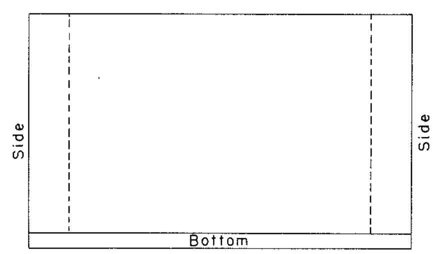
B. Picture of box cut in two.



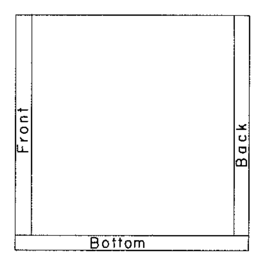
C. Block diagram of box.



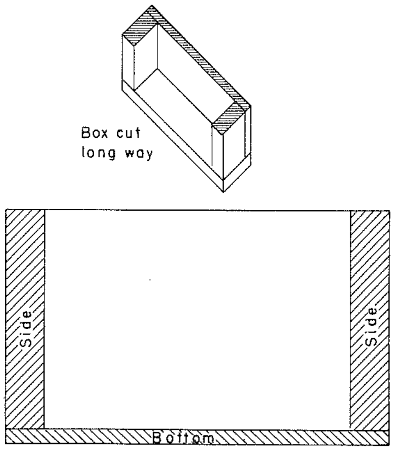
D. Top view of a box.



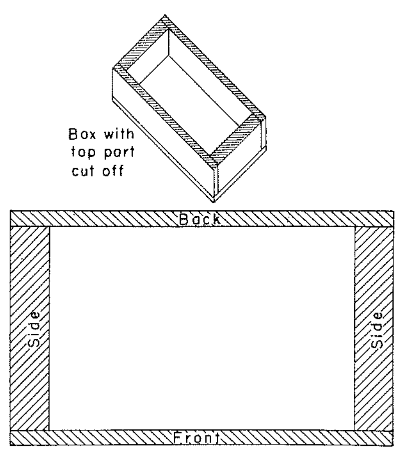
E. Front view of a box.



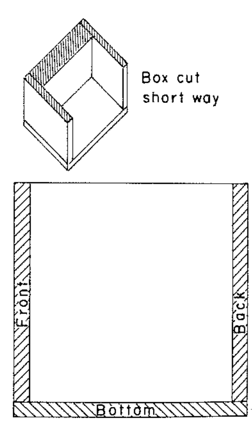
F. Side view of a box.



G. Front or longitudinal section.



H. Top or plan section or view.



I. Side or cross section.

COMMON VIEWS OF A MINE

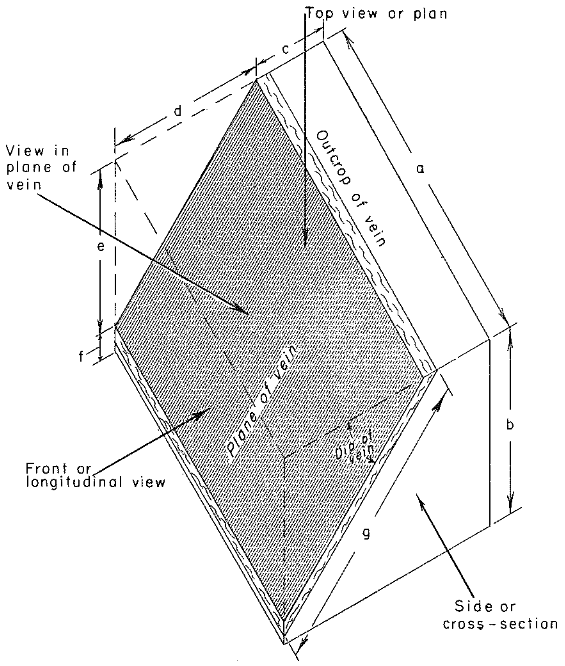
A mine is contained in three-dimension space—length, width, and depth—but to present a picture on two-dimension maps, as many as four different views may be required. Many ore bodies are in tabular veins, that is, similar in shape to a piece of cardboard, which has width, length, and thickness. This tabular vein may be positioned in the earth in a horizontal position, vertical, or at any angle between horizontal and vertical. To further complicate the picture, the vein may be curved or warped or even broken into segments within the earth.

Plate 2 includes a sketch and views of a tabular vein positioned in the earth (dipping) at an angle of 45° below the horizontal plane, but not broken nor warped.

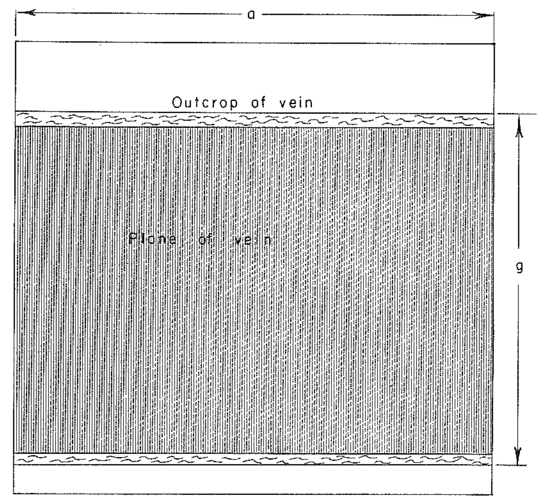
A is a sketch of an imaginary block of the earth containing this vein. The lines depicting the outline of the rock overlying the vein are dashed to avoid confusion. The vein is indicated by hatched lines, except where it was cut on the edges of this block; these cuts are indicated by short wavy lines. Notice the dimensions on this block and on all the other views.

The plan view is shown in C, the side or cross-section view is shown in D, and the front or longitudinal (long) view is shown in E. These views are comparable to the same views in Plate 1.

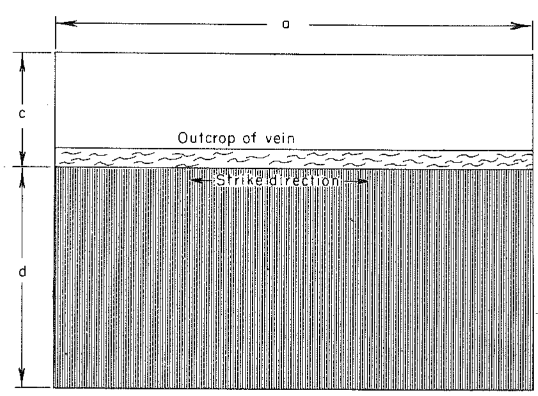
B is a view of the vein in the plane of the vein. This view is different from any of the other views previously discussed. The direction is at right angles (90° angle) to the plane of the vein. Note the arrow labeled "view in plane of vein" in A and D. Note that in B, dimension a is the same as in the other sketches, g now shows its true length on the sides, but none of the other dimensions are true length in this sketch. Plane-of-vein sections are often used where all workings are in the plane of the vein, because in this view the workings are shown in true length and width.



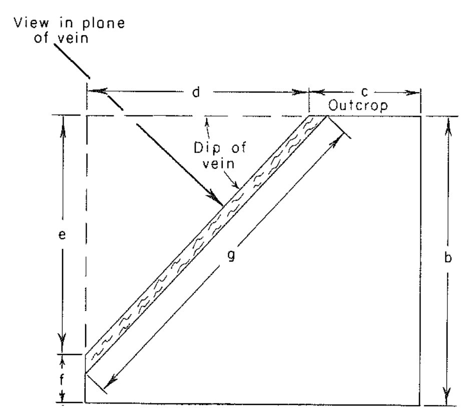
A. Block diagram of a vein contained in a block of earth.



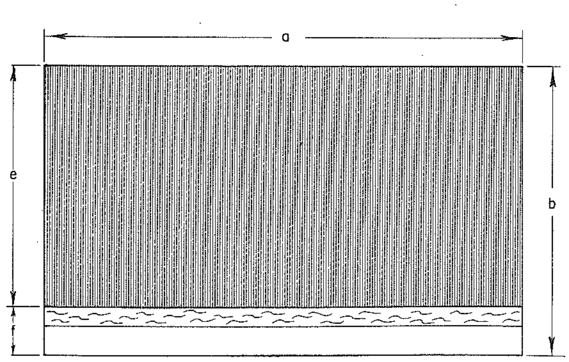
B. Plane-of-vein view.



C. Top or plan view.



D. Side or cross section view.



E. Front or longitudinal (long) view.

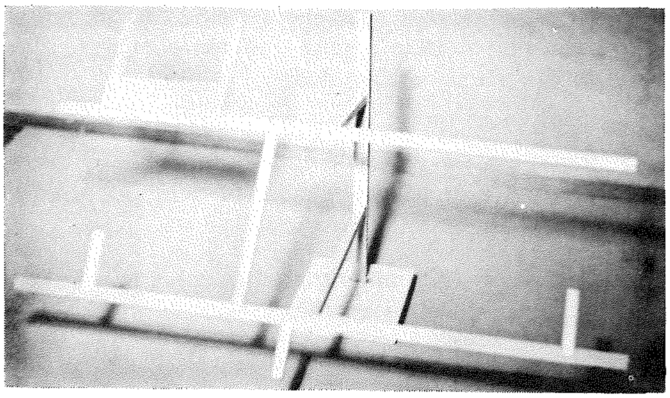
PROJECTION VIEWS OF A MINE

Most drawings or sketches of solid objects are designed to show the solid object as it appears in space. In mining, however, the objects that appear on maps or sketches are spaces or openings in the solid enclosing rock. The model shown in Plate 3A depicts the mine openings as solid pieces of construction material set out in space, whereas the solid rock that encloses the openings in the actual mine is depicted as space in the model.

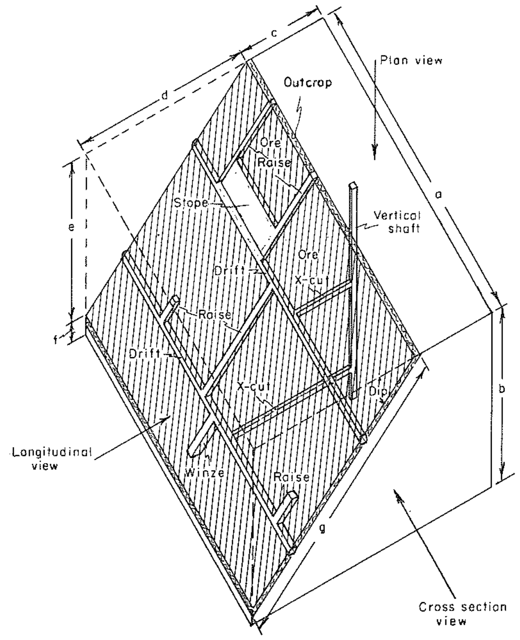
Plate 3 is a block diagram of a vein similar to that in Plate 2, except that mine workings are included and labeled in these sketches. A is a photograph of the model of the mine; B is the block diagram of the mine. C, D, E, and F show the four most common views of the mine. C is a plane-of-vein view; D, the cross-section view; E, the long view; and F, the plan view of the workings. These views were explained in Plates 1 and 2.

To show various openings that are unequal distances from the point of observation, a technique is used that is called projection on a plane. Objects not in the plane are projected to the plane in their true dimensions and at their true distance from one another, rather than in perspective.

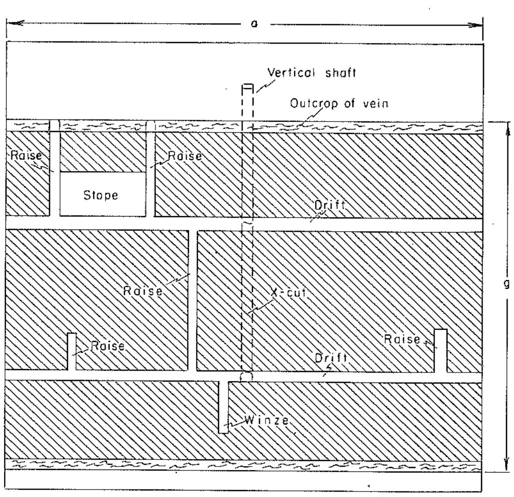
Study views B, C, D, E, and F, and notice which views show the correct lengths or dimensions of the various openings. If the vein were curved, warped, or broken, then even more views would be necessary in order to show the true length of certain mine openings.



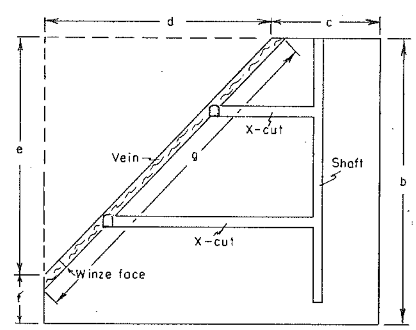
A. Picture of mine model.



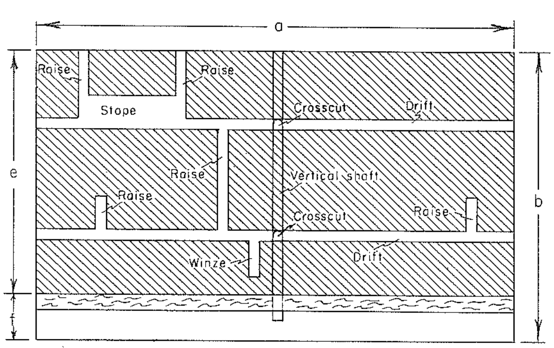
B. Block diagram of mine.



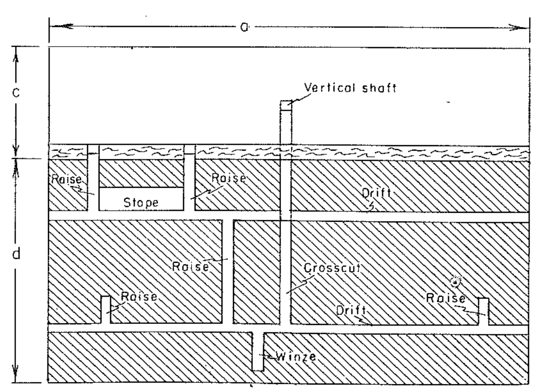
C. Plane-of-vein view.



D. Cross section view.



E. Longitudinal view of workings.



F. Plan view of workings.

MINE TERMINOLOGY

To understand any report on mining, one must know what mining terms mean. On Plates 3 and 4 showing models of mines, the different kinds of openings are labeled. The model in Plate 4 shows the openings in black and the ore in white. (This model was built to demonstrate the movement of air underground.)

The following are the most common mining terms:

Adit.—A horizontal entrance to a mine.

Air shaft.—A shaft used for ventilating mines, downcast when transferring fresh air from the surface to underground workings, upcast when discharging exhausted air to the surface.

Crosscut.—A horizontal or nearly horizontal underground opening driven to intersect a vein.

Drift.—A horizontal or nearly horizontal underground opening driven along a vein.

Entry.—A term commonly used in coal mining for an adit or a gently inclined shaft.

Intermediate level.—A system of horizontal workings started from a raise and not connected directly to the main working shaft.

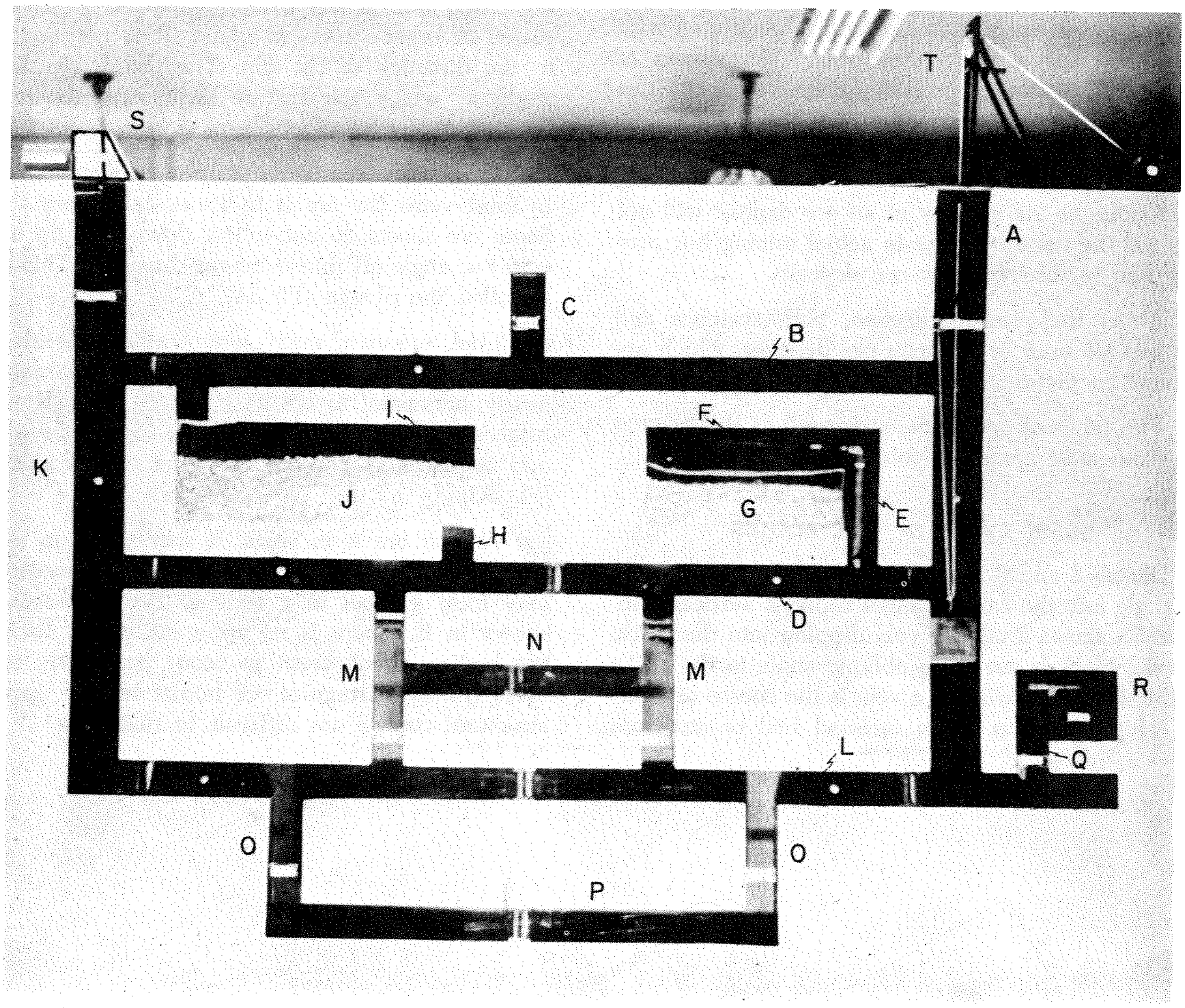
Level.—A horizontal system of underground workings, the basis of operations for excavating the ore above or below. Manner of designation of levels differs in different districts.

Raise.—An underground opening driven upward from one level to another.

Shaft.—A vertical or inclined excavation through which a mine is worked.

Stope.—An underground excavation made by extracting ore.

Winze.—A vertical or inclined underground opening driven downward.



MINE MODEL

Mine openings appear black, ore and waste appear white.

Explanation:

A - Main hoisting shaft
B - Level no. 1
C - Raise
D - Level no. 2
E - Raise
F - Stope
G - Waste fill
H - Sealed raise
I - Stope
J - Waste fill
K - Air raise or shaft
L - Level no. 3
M - Raises
N - Intermediate drift
O - Winzes or internal shafts
P - Level no. 4
Q - Raise
R - Blind stope
S - Main ventilating fan
T - Headframe

PART 2—ORE BODIES

Ore occurs in many forms and is associated with many types of geologic structures. This section of the report illustrates, by commonly used methods, a few of the more common types of ore bodies. The geologic conditions and ore occurrence are major factors in determining the type of mining method. Knowledge of the geology of an ore deposit will not only aid the mine operator in actual mining but may help him to discover new ore deposits.

As in the previous section, both sketches and pictures are used to illustrate ore deposits, which are difficult to picture in two-dimension drawings only.

The types of ore bodies discussed in this section are those most commonly observed in Montana.

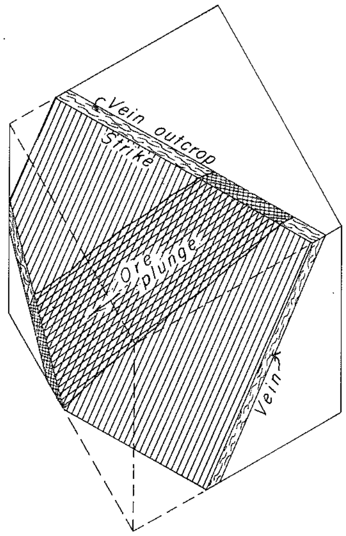
SOME TYPES OF ORE BODIES

Plates 2 and 3 show a tabular vein that dips at an angle into the earth; Plate 4 shows a vertical vein. Plate 5A shows a tabular vein dipping into the earth, but the block is cut at an oblique angle to the strike of the vein. The strike of a vein is the course or bearing of the outcrop of an inclined bed or structure on a level surface, or the direction or bearing of a horizontal line in the stratum, joint, fault, cleavage plane, or other structural plane. It is perpendicular to the direction of the dip. The dip is the largest angle at which the feature is inclined below the horizontal.

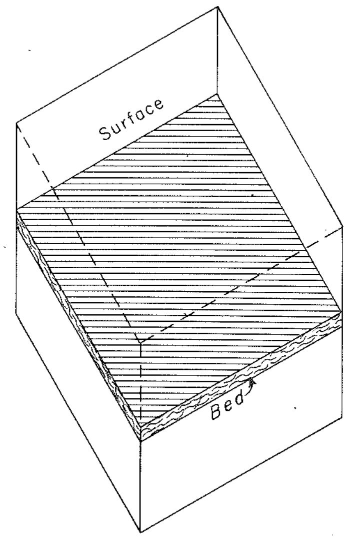
Few veins consist entirely of commercial ore; in most veins the ore is in zones called ore shoots. Some ore shoots do not follow down the dip of the vein but angle off in a different direction. This trend is called the plunge (Pl. 5A).

Coal, uranium, many nonmetallic minerals, and some metallic minerals may occur in horizontal or nearly horizontal layers or beds (Pl. 5B). It is not unusual for the bed or vein to be broken by a fault and displaced in position on either side of the fault (Pl. 5C).

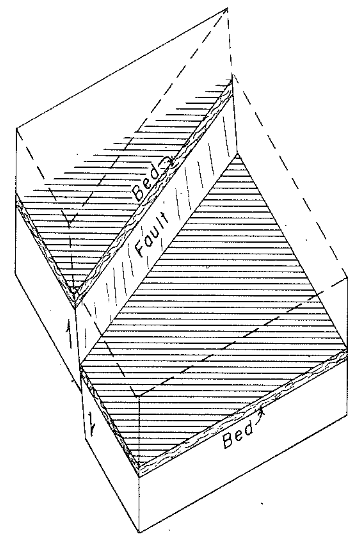
Not all ore is in veins. It may occur in an ore "pipe" as shown in D. Where two veins intersect, ore may form a shoot in a zone at the intersection as shown in E. There is no apparent reason for some ore bodies, which seem to occur irregularly in the earth (Pl. 5F). Irregular ore bodies lacking apparent structural control are difficult to discover.



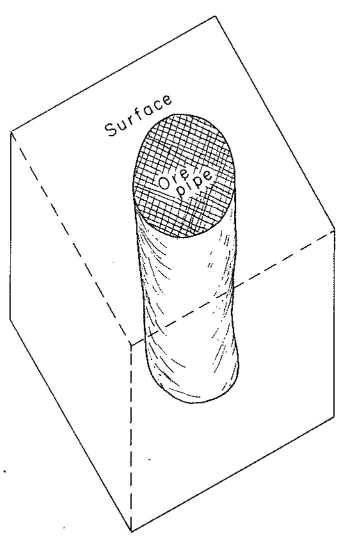
A. Block diagram of ore shoot; plunge in plane of vein.



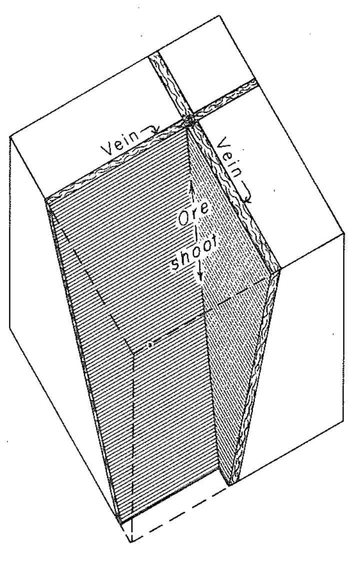
B. Block diagram of a flat, bedded deposit, such as a coal seam.



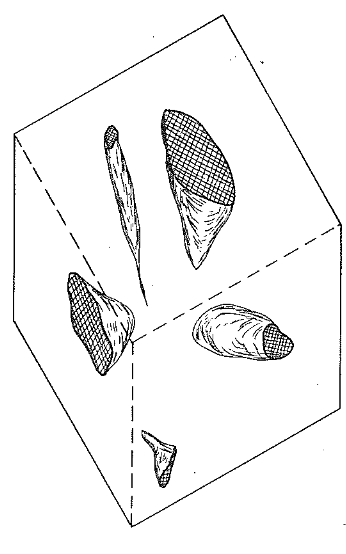
C. Block diagram of a bed or seam broken and displaced by a fault.



D. Block diagram of an ore pipe or ore chimney.



E. Block diagram of an ore shoot at vein intersection.



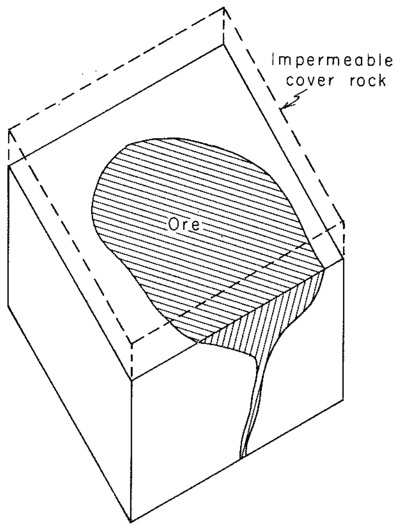
F. Block diagram or irregular ore bodies.

TYPES OF MINERAL CONCENTRATIONS

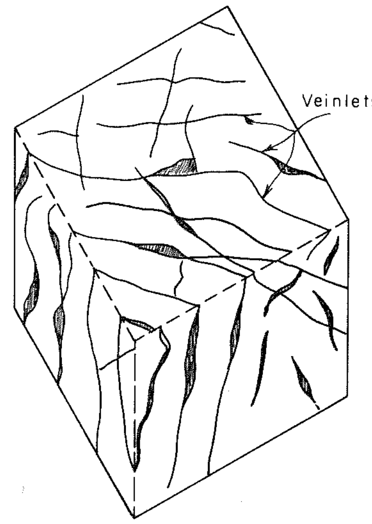
If the upward movement of ore-forming solutions is stopped by a layer of impermeable rock, which will not allow the solutions to pass, and if other conditions are right, an ore deposit may be formed under this cap or cover (Pl. 6A). If ground is fractured and broken, numerous small veins or veinlets may fill these fractures (B), but stringers and veinlets may be found even in regular veins.

An ore vein may be very distinct within the ground and show definite walls (C); it may have only one distinct wall (D); or there may be no clearly defined walls, and the extent of the ore must be determined by assaying (E).

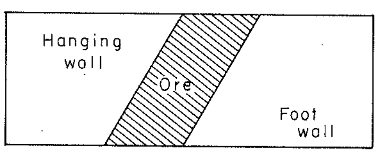
Placer gold was the chief attraction that brought miners into Montana in the early days. F is a block diagram showing the origin of placer gold. Erosion of a vertical gold-bearing vein liberates the gold, which tends to move downstream. But the gold, being much heavier than the rest of the broken and weathered material, tends to move slowly and to concentrate near bedrock. Bedrock is defined as the solid rock underlying gold-bearing gravel, sand, or clay. Although gold tends to concentrate on or near bedrock, it is not evenly distributed along the length or across the width of the bedrock. It tends to concentrate on the inside downstream side of channel bends (G) or on the downstream side of boulders or projecting irregularities in bedrock (H).



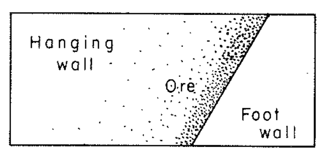
A. Block diagram of ore body localized by impermeable cover rock.



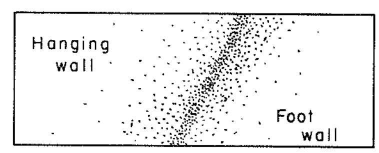
B. Block diagram of numerous mineralized veins and veinlets.



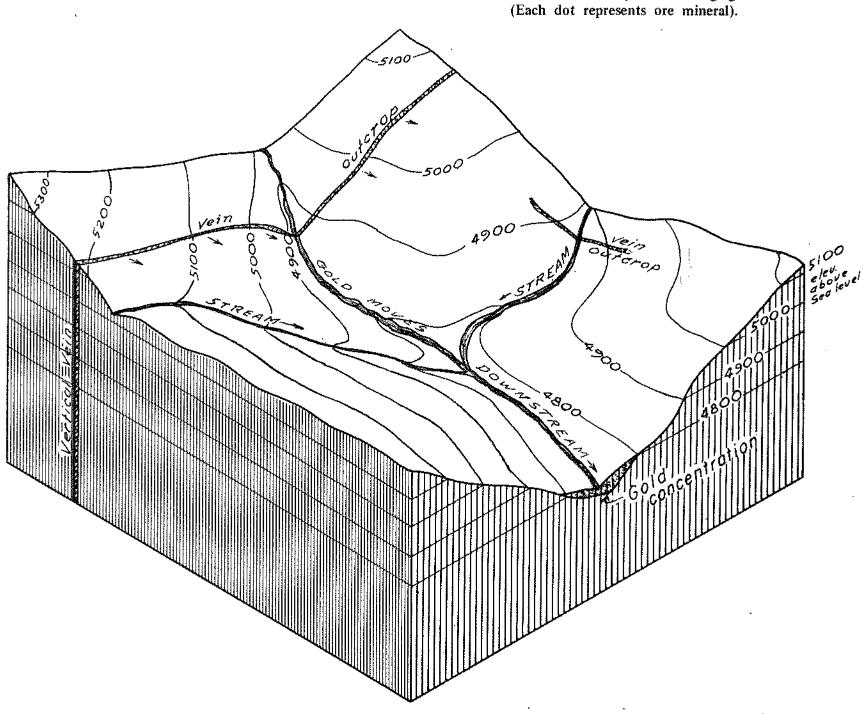
C. Cross section of a vein showing clear-cut walls between ore and waste.



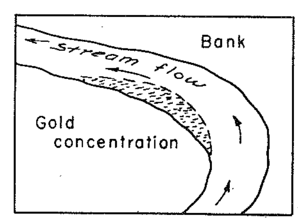
D. Cross section of a vein showing hard footwall and assay cutoff hanging wall. (Each dot represents ore mineral).



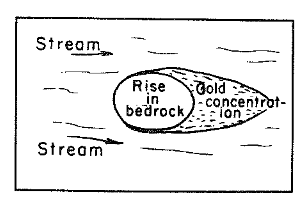
E. Cross section of a vein showing assay cutoff on both walls.



F. Block diagram of a portion of the earth showing erosion of veins and concentration of placer gold.



G. Concentration of gold at curve in stream.



H. Concentration of gold on downstream side of projection in bed rock.

MODELS OF ORE BODIES

Most of the discussion so far has dealt with regular ore bodies generally unbroken by faults. To get a picture of a more complicated deposit it may be necessary to build a model of the ore body and mine.

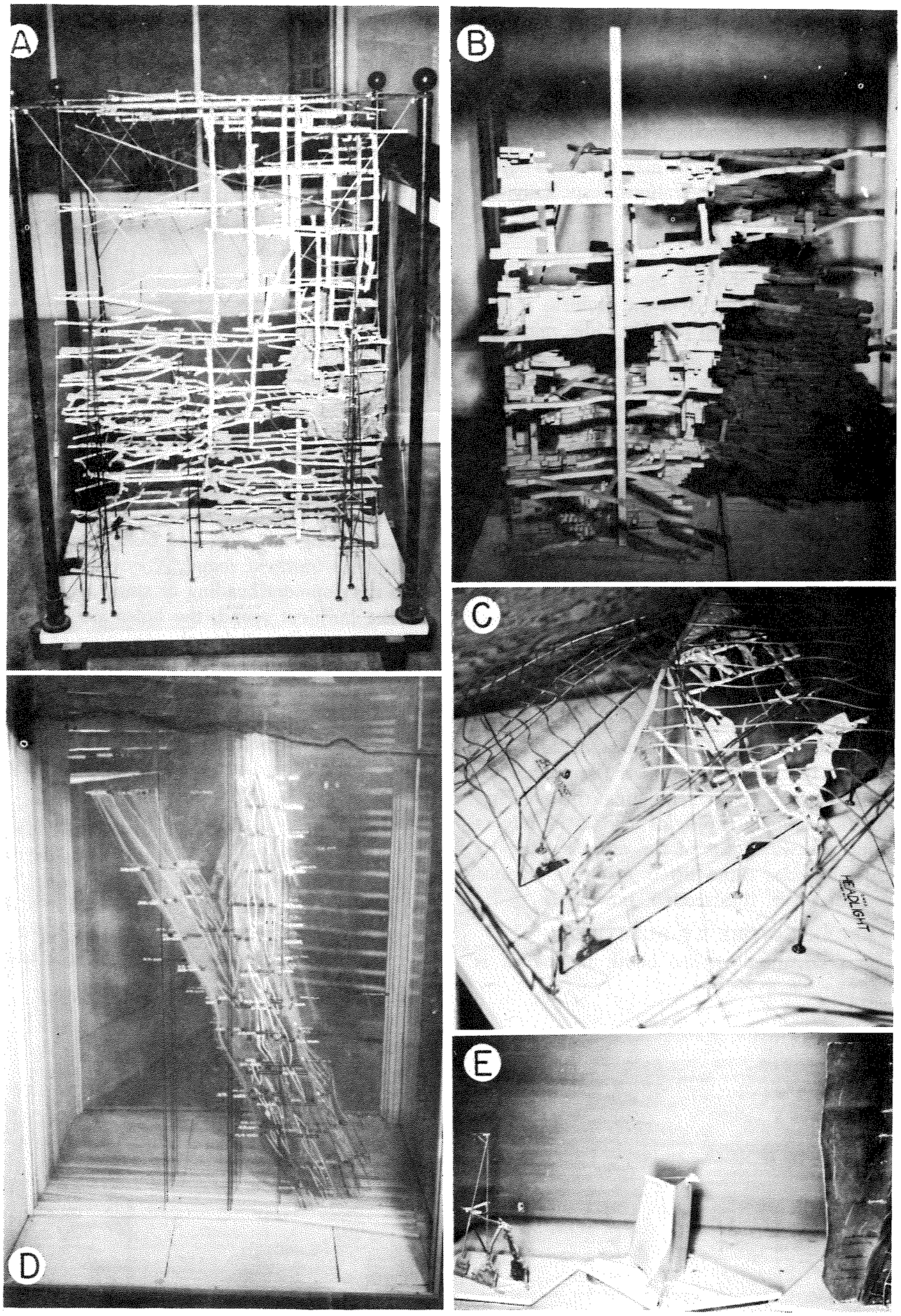
Plate 7 shows pictures of various complicated mine models and the different ways of constructing these models. A and B show models constructed of wood. In A, the white members are development openings, shafts, drifts, crosscuts, and raises; the darker members show the ore bodies. The dark and light members in B show different ore bodies or vein systems.

In C the ore body and the development openings are white. The dark lines (bent wire) are contour lines showing the configuration of the surface of the ground. The outcrop of the vein is shown as a gray solid line from upper center toward lower left.

Complicated geological features can be drawn on glass or plastic sheets, which are then stacked or placed in order (D). A light placed back of the sheets brings out the feature in three dimensions.

Wood, plastic sheets, and colored cardboard sheets glued in position can be used to depict veins and faults (E).

A. Method of depicting ore bodies and development openings by solid material in a mine model. **B.** Different style of depicting ore bodies by solid material. **C.** Ore body near the surface; ore is shown in solid white. Bent wires depict the configuration of the surface. **D.** Ore body depicted by drawing the geology and veins on sheets of glass. **E.** Geologic models showing veins and faults.


A
B
C
HEADLIGHT
D
E

PART 3—MAJOR OPERATIONS OF MINING

The three major operations that involve the big problems in almost any mining operation are:

1. Breaking the ore and waste rock.
2. Supporting the excavation.
3. Loading and transporting the ore and waste.

These three major operations may not have equal importance in all mining operations, especially in open-pit mines, because the ore may be soft or the sides may not need support.

For example, in a shallow open-pit mine, supporting the sides of the pit is not a problem if the sides stand well, but in deep pits the sides may not support themselves at steep angles. The mine operator must choose the proper slope of the pit sides so that wall rock will not slide into the pit. In a placer mine, support and breaking are minor problems compared to transporting, washing, and disposing of the gravel. In most underground mines, each of the three operations requires much attention, although any one may require more attention than the others.

In most mines other operations are not only important but necessary to carry out the main operations. In all mines, both surface and underground, management must supply necessary materials and tools to the working areas, supply compressed air, water, fuel, and electric power where needed in the mine, and provide adequate maintenance and machine service. Operations of utmost importance in underground mines include ventilating the working places with an adequate supply of air for the miners and pumping the water out of the mine if water is a problem. Only the three listed major operations will be considered in this section, however.

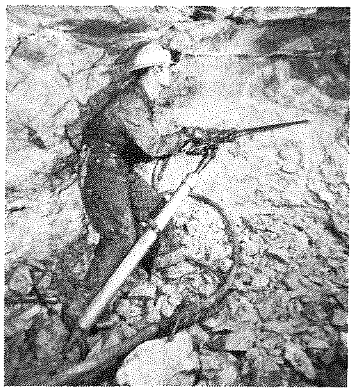
BREAKING ORE BY BLASTING

The most common way to break solid rock is by the use of explosives. For the explosives to do their most effective work it is usually necessary to drill a hole and place the explosives deep within the solid rock. Air drills are used extensively underground (Pl. 8A). For drilling in open pits, churn drills, wagon drills, and electric rotary drills are used.

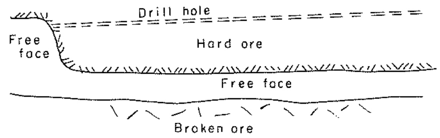
The pattern of drill holes is important. When solid rock is broken, its bulk may become as much as 40 percent greater than its original volume. Unless this broken rock can move out of the way of the next hole to be blasted, the effectiveness of the explosives is greatly reduced. Therefore, wherever possible, holes are placed so that the rock broken by the explosives will be thrown clear of the solid unbroken rock. Two free faces are desirable, but this situation occurs mostly in stopes and open pits (B, C, D).

In most development headings, the explosives can break rock toward only one free face. The holes must be so placed that the explosives can break toward that free face. Two general systems are in use. For long advances per blast, the most common one is the burn-cut round. A system of holes drilled in a development heading or stope is called a round. In the burn-cut round, the holes are all drilled parallel or nearly parallel to the direction of the heading, and the central holes are drilled close to one another. Not all of the holes are filled with explosives, the theory being that the neighboring hole when blasted will break into the unloaded hole. A burn-cut round is shown in E, and various arrangements of burn-cuts are shown in M, N, O and P.

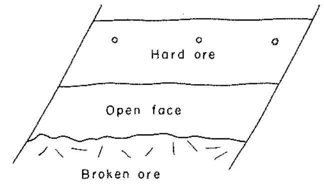
The other system is the angle-cut round. The cut holes are drilled at an angle with the free face. Various patterns of angle cuts are in use. The draw cut is shown as used in a drift (F) and in a shaft (H). V-cuts are used in shafts and raises (G). Various patterns of angle cuts are shown in I, J, K, and L.



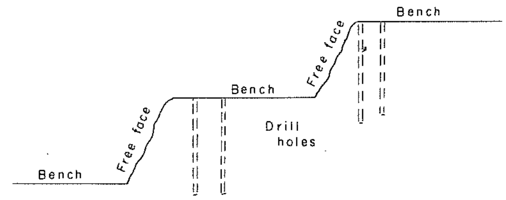
A. Air operated rock drill.
(Courtesy Archibald Co.)



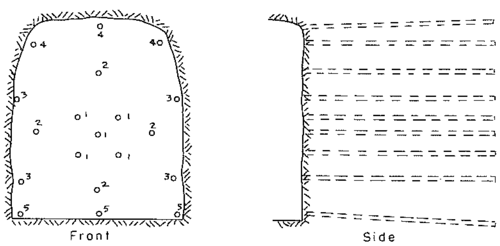
B. Long section of drill holes.



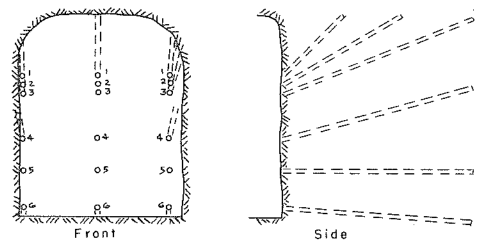
C. Cross section of drill holes.



D. Cross section through open pit showing drill holes.

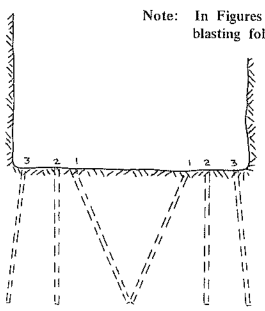


E. Burn-cut drift round. (1. Cut holes 2. Reliever holes 3. Trim holes 4. Back holes 5. Lifters)

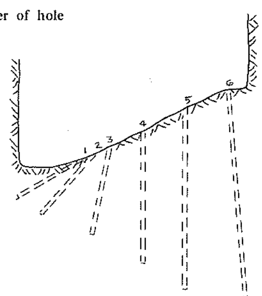


F. Drift round with a top-draw cut. (Commonly drilled with stoper type drill)

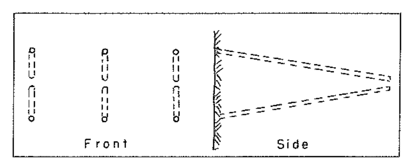
Note: In Figures E, F, G, and H the order of hole blasting follows number sequence.



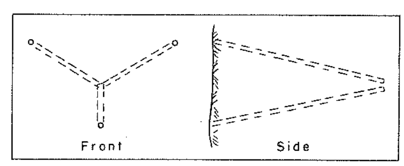
G. V-cut shaft round. (side view)



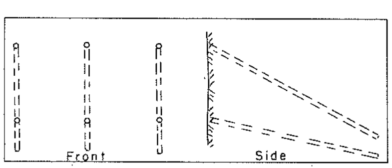
H. Sump or bench type round in shaft. (side view)



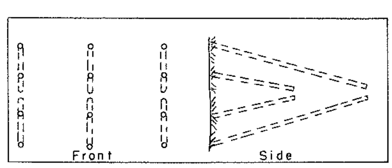
I.



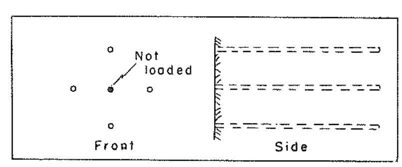
J. Pyramid cut. (3-hole)



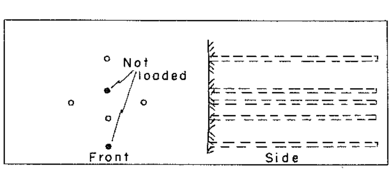
K. Bottom draw cut.



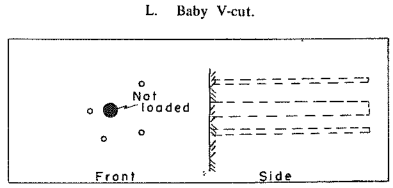
L. Baby V-cut.



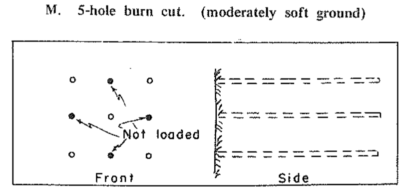
M. 5-hole burn cut. (moderately soft ground)



N. 6-hole burn cut. (medium ground)



O. Large-center-hole burn cut.



P. 9-hole burn cut. (hard ground)

DRILLING MACHINES

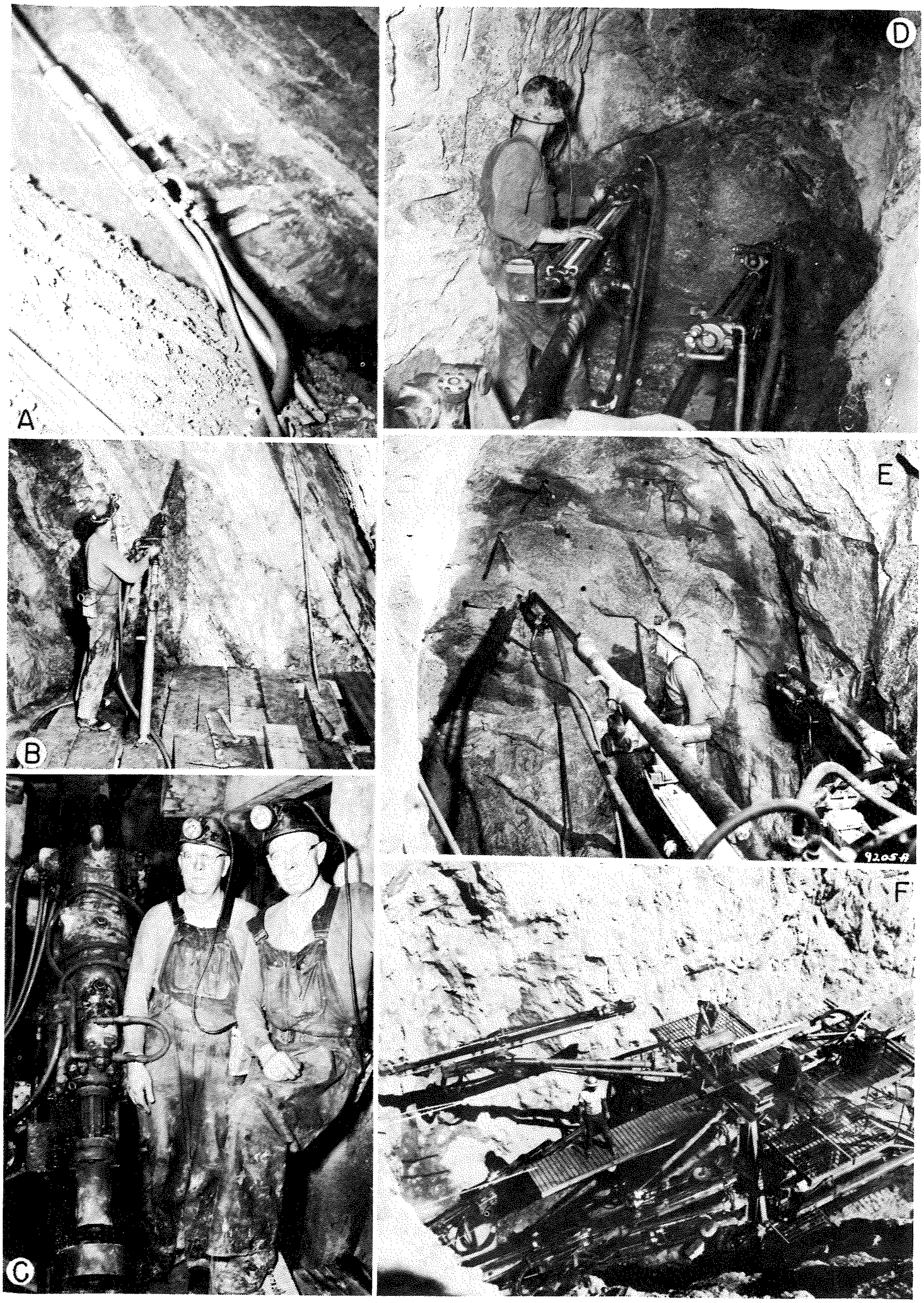
Air-operated drill machines are classified as stopers, sinkers, air legs, drifters, and special machines. Each is especially adapted for a certain type of drilling. The stoper drill (A) is specially adapted for drilling overhead holes. It is used most in stopes and raises. The air leg drill (B) is designed for drilling horizontal holes, but is flexible and works well for other types of drilling. These drills are most used in drifts, crosscuts, and stopes, but they find some use in raises.

A sinker drill is designed for drilling down holes. The sinker is similar to an air leg drill without the leg. The sinker drill is hand held and is most used in shaft sinking.

Drifter drills are in general use for driving entries, crosscuts, and laterals to develop a level. To increase drilling rates, these drills are mounted on carriages called jumbos (C, D, E, and F). The drill is attached to a movable arm mounted on the jumbo so that the drill can be rapidly put in position. The drills shown in E are called underslungs and are pushed into the rock by an air piston. The drill may be advanced by a screw feed (F) or by a sprocket chain (E). The jumbo shown in E is used in high-speed tunnel driving.

The drill shown in C is an air drill used for high-speed drilling of holes greater than 20 feet in length. It is called a rotary percussion drill. In an ordinary drill, air causes a piston to strike the drill steel inserted in the drill. The force of the blow is transmitted down the steel to the attached bit, which cuts and chips the rock. After the blow is struck, the steel is turned by the machine to a new position for another blow. The rotary percussion drill uses the same hammering action, but the steel is rotated much faster and rotates while hammering. This action, plus much greater pressure on the bit, greatly increases the drilling rate.

A. Stoper type of drill designed for overhead drilling. **B.** Air-leg type of drill drilling in a stope face. *(Courtesy Archibald Co., Cleveland.)* **C.** New style of drill used in high-speed drilling—a rotary-percussion type of machine. *(Courtesy Ingersoll-Rand Co.)* **D.** Drill and jumbo drill carriage in a drift heading. *(Courtesy Anaconda Co.)* **E.** Another style of jumbo using an underslung type of drill *(Courtesy Archibald Co., Cleveland).* **F.** Long-feed drill jumbo used in tunnel drilling *(Courtesy Joy Mfg. Co.)*

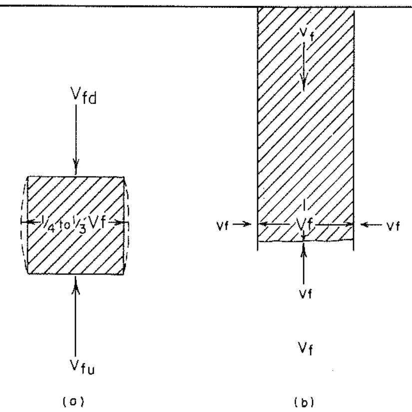

A
B
C
D
E
F

BREAKING ROCK BY NATURAL FORCES

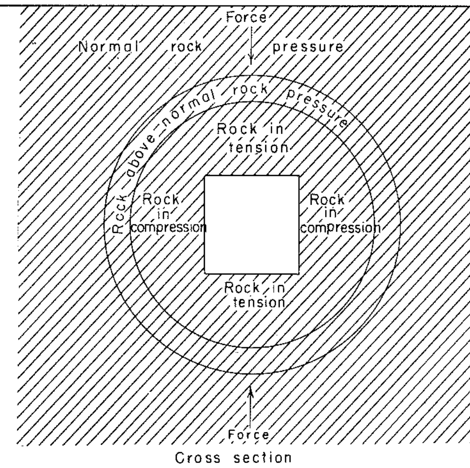
If we dig an opening underground, the weight of the overlying rock will produce pressure effects around the opening. Plate 10A (a) shows a small cube of rock deep within the earth. The arrow labeled Vfd represents the force caused by the weight of the overlying rock, but a force does not exist by itself in such a situation — it must be balanced by an equal and opposite force, Vfu. These forces tend to compress the cube, and this action causes the cube to exert a force on the neighboring cubes of rock. This lateral force is 1/4 to 1/3 of the vertical forces. If the rock acts as a fluid, which it may do under great pressure and high temperature, the force is equal to Vf in all directions. The term pressure is used in B. Pressure is defined as force per unit area. A pressure of 20 pounds per square inch means that there is a total force of 20 pounds distributed and acting over the 1-square-inch area. The total force on a mine opening is the product of pressure times area.

The most usual pressure effects around a square opening are shown in B. Rock and ore are weak in tension, so the rock tends to fracture in the top and bottom of the drift. The rock pressure effects in stopes are shown in C (a) and (b). The rock tends to break in tension at the top of the stope. The lateral pressure effects in the solid rock may also cause the rock to break in the walls of the opening.

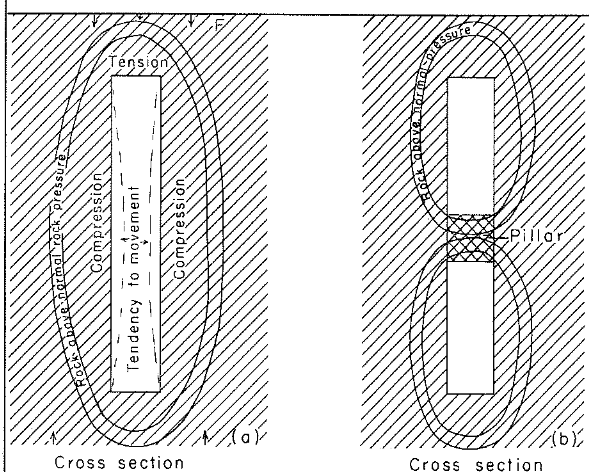
These pressure effects aid in the system of cave mining. To prepare a block of ore for caving, the block is undercut (D, a). Pressure effects cause the ore in the top or back to break and fall into the opening (D, b; E, a). Because solid rock increases in volume when broken, the opening is soon filled with broken ore (E, b). This broken ore supports the back and stops the caving action. When the broken rock is pulled away from the back (F, a), caving starts again.



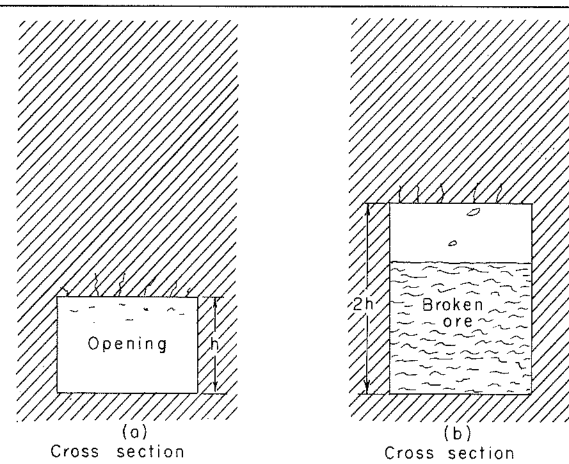
A. (a) Force effects on a solid block of material. (b) Force effects of a tube filled with fluid.



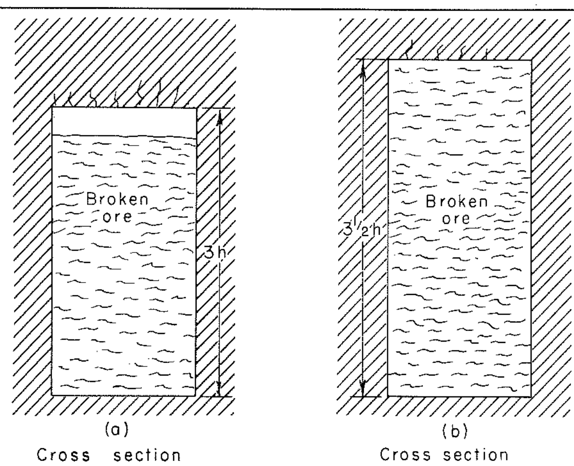
B. Effects of one-direction force on a square opening in solid rock.



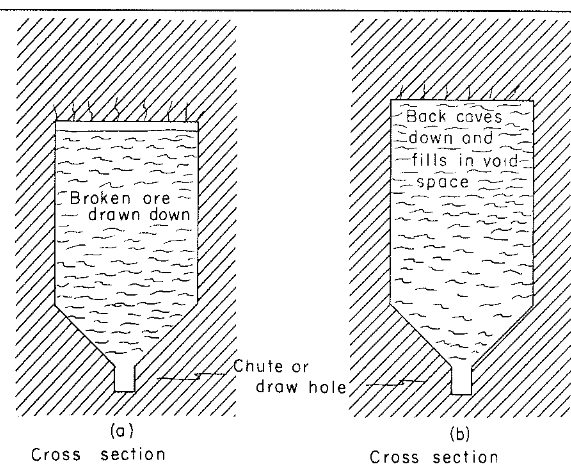
C. (a) Effects of one-direction force on a tabular opening in rock. (b) Change of pressure effects caused by pillar or support in the stope.



D. Opening in solid rock filled by caving material. Broken material increases in volume.



E. (a) Further development of caving. (b) Broken rock completely fills the void and gives support to the back.



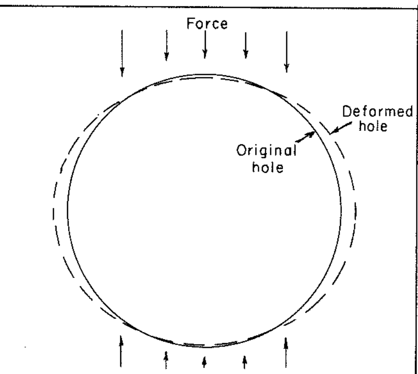
F. (a) Drawing down or removing broken ore causes the back to cave again. (b) The void fills again.

SUPPORT

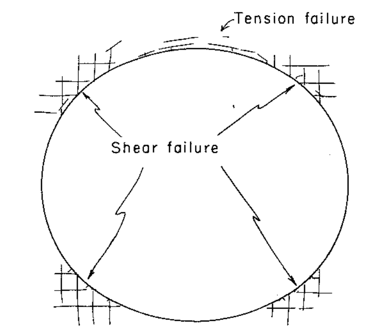
Plate 11A, B shows the distortion of a circular opening in solid rock under a vertical force. This distortion causes the rock to break by tension overhead or in the back and by shear at other points (B). This is a theoretical concept; actual distortion is difficult to observe because the walls are not smooth, and some distortion probably takes place as soon as the solid rock is broken.

To support the broken rock, several methods are in use. The old standby is timber; C and D show the cross section and long section of a timbered level set. A development in the last 20 years is the use of rock bolts. E shows a haulageway supported by rock bolts. The bolts are anchored into the solid rock and the nut is pulled tight against the rock. Tightening the nut on the bolt tends to pull the rock back in place, thereby providing support to the opening. Another method of support used where permanence is required is concrete (F).

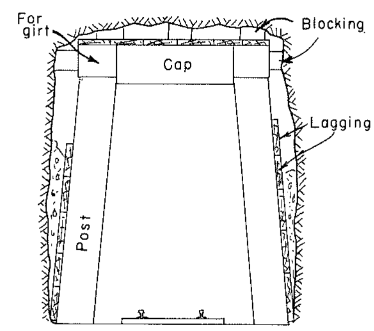
Stopes need not be kept open as long as development headings. After a stope is mined out, it is allowed to cave. In large stopes the pressure effects may cause the stope to collapse. Supports in stopes tend to keep the pressure effects at a safe level (Pl. 10C). If the ore occurs in a narrow vein, timber stulls can be used for support (G). If the ore is not high grade, parts of it may be left as pillars to help support the walls (H), but if the ore is too good to leave, the mined-out section may be supported by filling it with broken mine waste or sand fill (I, J). Square-set timber is used in high-grade stopes where the ore is weak (K). L is an isometric view of a stope timber set labeled to show the various parts.



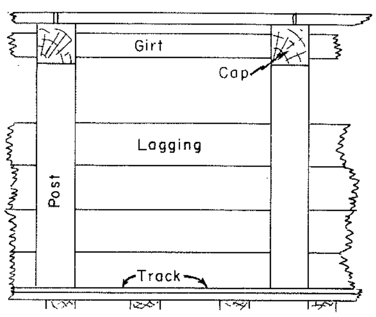
A. Deformation of a round hole by vertical pressure of force.



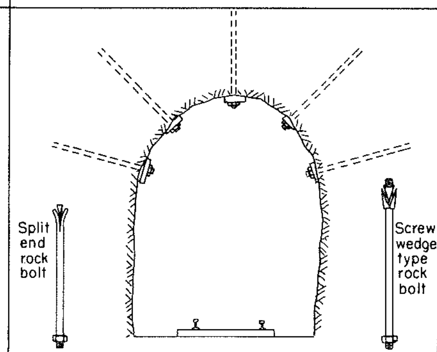
B. Typical rock failure about an opening as a result of vertical force.



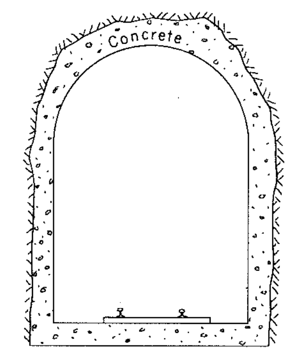
C. Cross section of a timbered drift set.



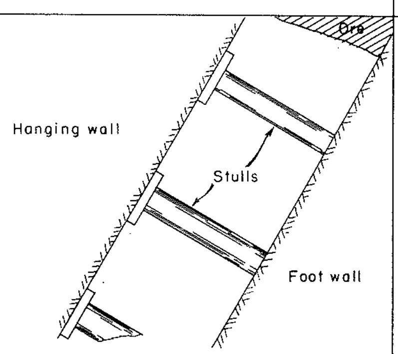
D. Long section of a timbered drift.



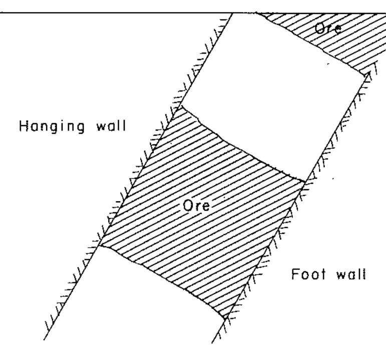
E. Cross section of haulageway supported by rock bolts.



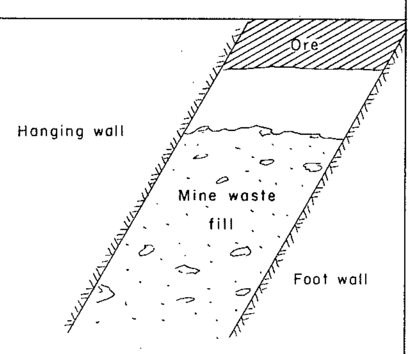
F. Cross section of haulageway supported by concrete.



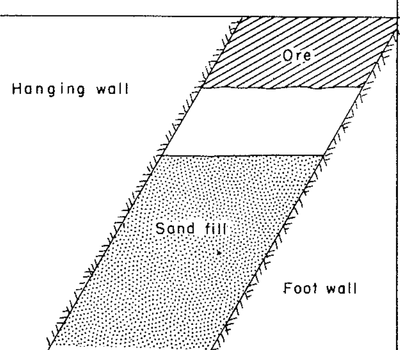
G. Cross section of a stope with stull support.



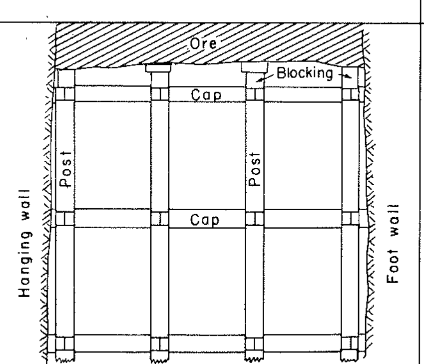
H. Cross section of a stope with ore pillar for support.



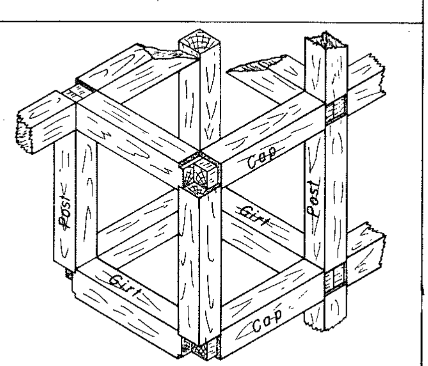
I. Cross section of a stope with mine waste fill for support.



J. Cross section of a stope with sand fill for support.



K. Cross section of a stope with square-set timber for support.



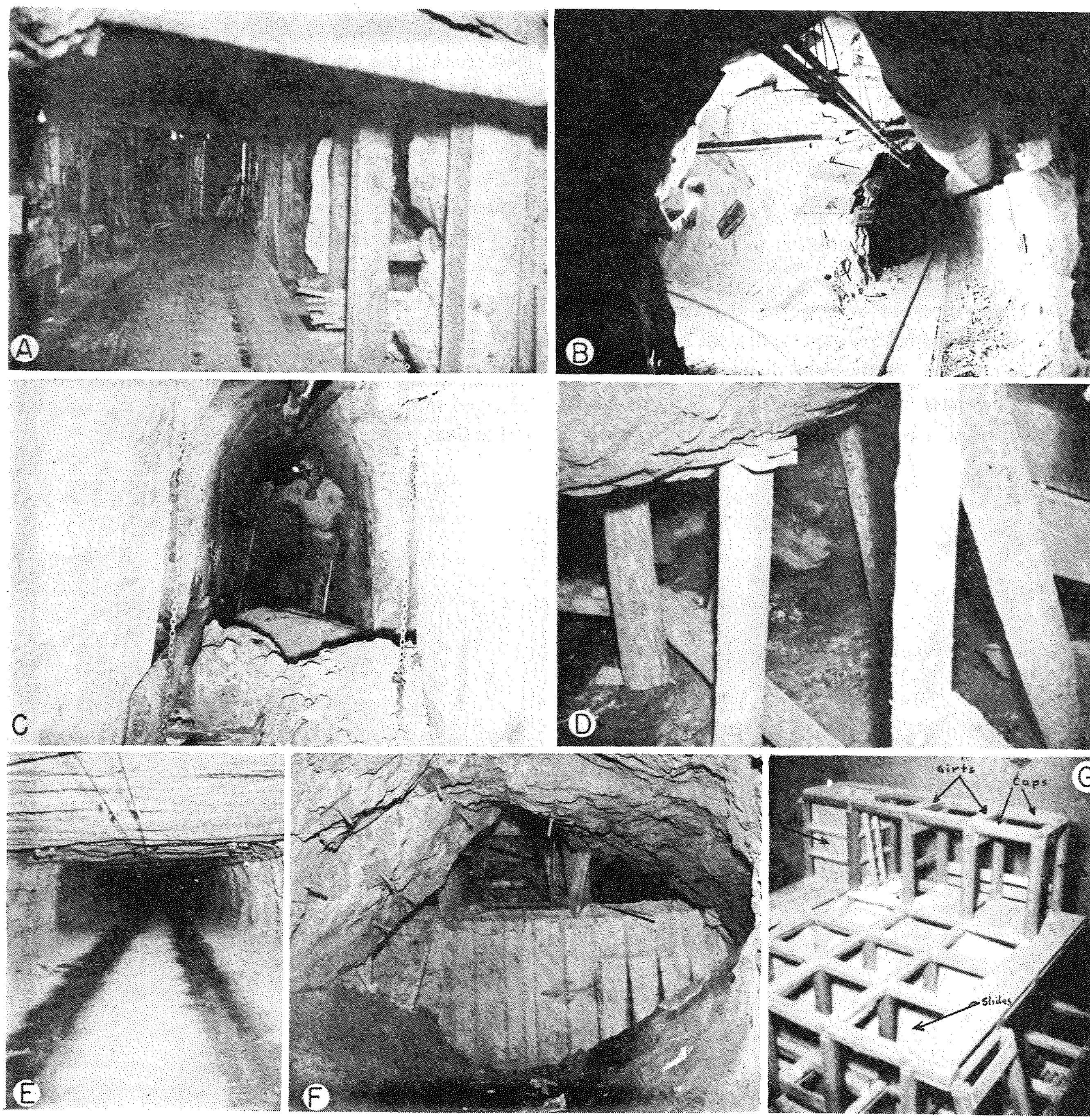
L. Isometric view of a timber square set.

Plate 12 shows various types of supports used underground. A is an underground station at the shaft in a small mine in Montana. The support is timber of square cross sections. B shows the start of a curve in an underground haulageway supported by rock bolts. Note that wood headboards are used on these bolts to hold more ground in place. C is a drift section concreted where the ground is extremely heavy and ground support is a difficult problem.

Materials commonly used to support stopes are natural pillars, sand or mine waste fill, and timber. D shows a stull-supported stope. Each individual stull is cut to length to fit into a particular spot and is wedged tightly in place. Note the wedges at the top of the post.

Natural pillars are left for support in most coal mines and other room-and-pillar mines. E shows a haulageway in a room-and-pillar mine. Rock has been left in place along each side. Mine waste and sand may be used to support mined-out portions of a vein. F shows a sand-filled stope ready to be filled with sand to close to the back of ore. Notice that the back is supported by rock bolts.

For support of heavy or weak ground, the square-set system of timber is most commonly used. G shows (in a model) square-set timber as constructed in the mined-out portion of a vein. The spaces within the timber set may be filled with mine waste rock or sand fill at some later time.



A. Mine station with square timber for support. **B.** Underground drift intersection supported by rock bolts inserted in wooden headboards. *(Courtesy Anaconda Co.)* **C.** Grizzly drift in a cave mine; concrete is used for support. *(Courtesy Anaconda Co.)* **D.** Stope in which round timber posts are used for support. **E.** Room-and-pillar mine, natural ore material in place is used for support. **F.** Cut-and-fill stope; fine-grained sand is used for support. The sand is mixed with water and brought in by a pipe line *(Courtesy Anaconda Co.)* **G.** Mine model showing labeled timber sets.

REMOVING ORE AND LOADING CARS

Loading and transporting ore is the last major operation to be discussed in this section. Methods of removing ore other than the ones shown on this plate are included in the part on mining methods.

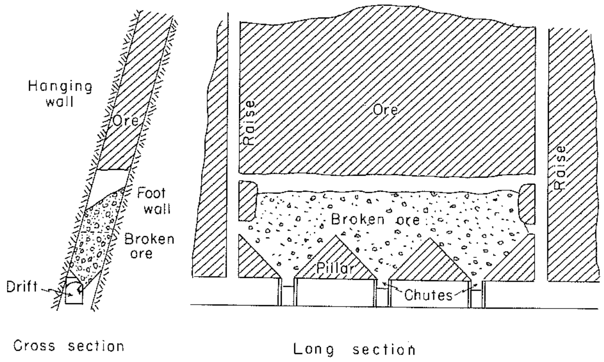
A shows a common method of development by shrinkage or open types of stopes. The zone above the chutes is funneled so that the broken ore is directed toward one of the chutes at the bottom of the stope. E shows a car in position to be loaded from the chute.

In some types of stopes, the ore cannot pass through the mined-out portion, so it must be directed toward ore passes. B shows a slusher dragging the ore to an ore pass in one such system. The ore pass leads to a chute where the cars can be loaded.

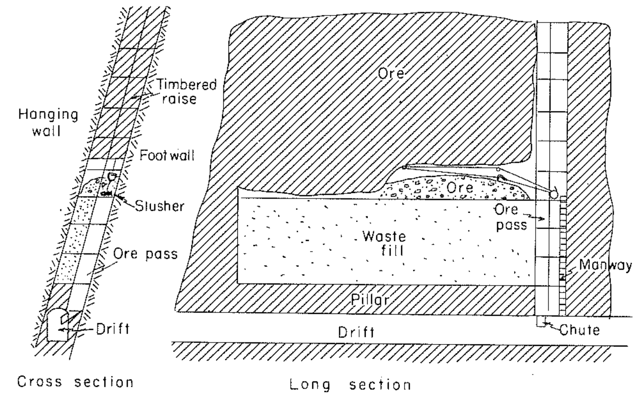
Another system used in shrinkage or sublevel stopes is the slusher or scram drift. C shows this system under a type of open stope. Chutes may be a bottleneck if the ore contains large boulders; this system is designed to load directly into cars (G).

If the dip of the vein is so flat that the ore will not run down the stope by itself, it is necessary to scrape or slush the ore from the mining face. A system may use a scraper and slusher both to run the ore down the stope and to load the cars (D).

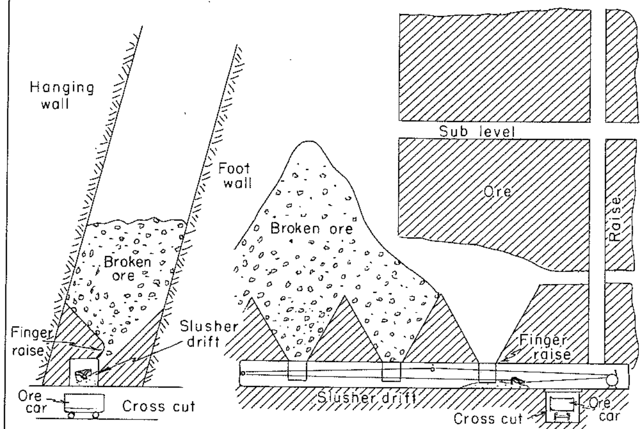
If chutes cannot be used because of boulders of ore, and if the physical layout is such that the installation of a slushing system is impractical, a mucking-machine and draw-point system may be used. The bottom of the stope is belled out, but the ore is discharged into a small crosscut (F). The mucking machine then loads the cars directly.



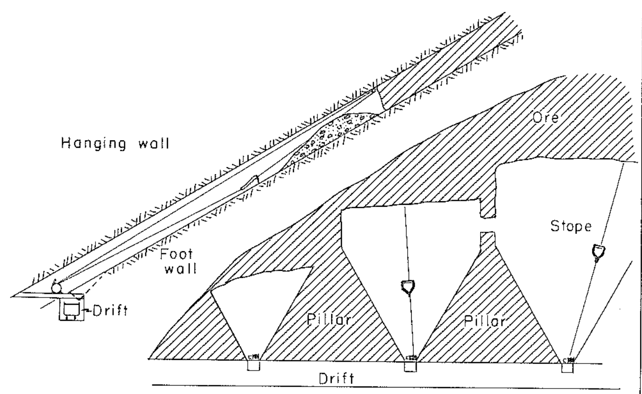
A. Removing ore from a shrink-type stope by a system of chutes.



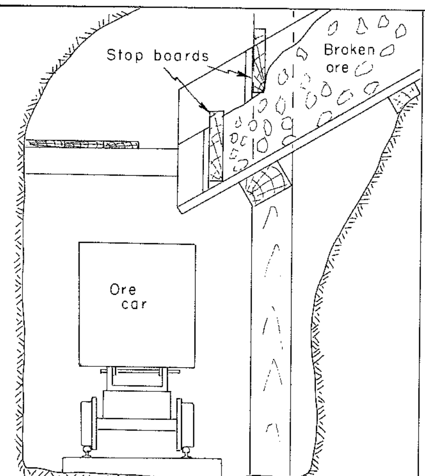
B. Removing ore from a cut-and-fill stope by a slusher pulling ore to an ore pass.



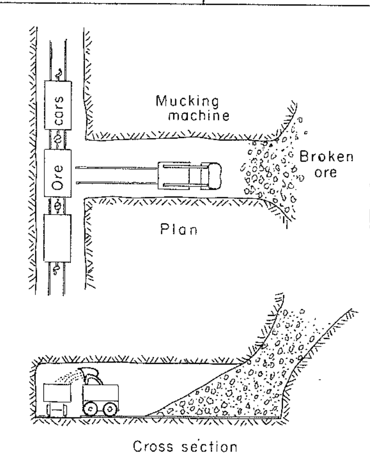
C. Removing ore from a large sublevel stope by a slusher drift and slusher loading directly into cars.



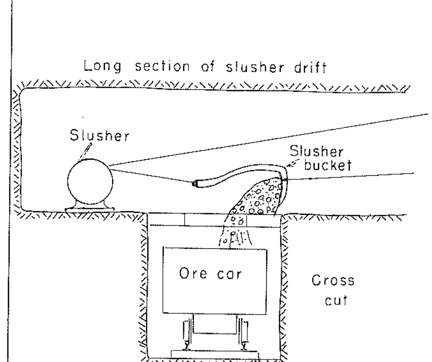
D. Removing ore from a flat-lying stope by slushers pulling ore to a chute.



E. Chute loading into an ore car. (Cross section of a stop-board chute)



F. Loading ore from a stope by a mucking machine.



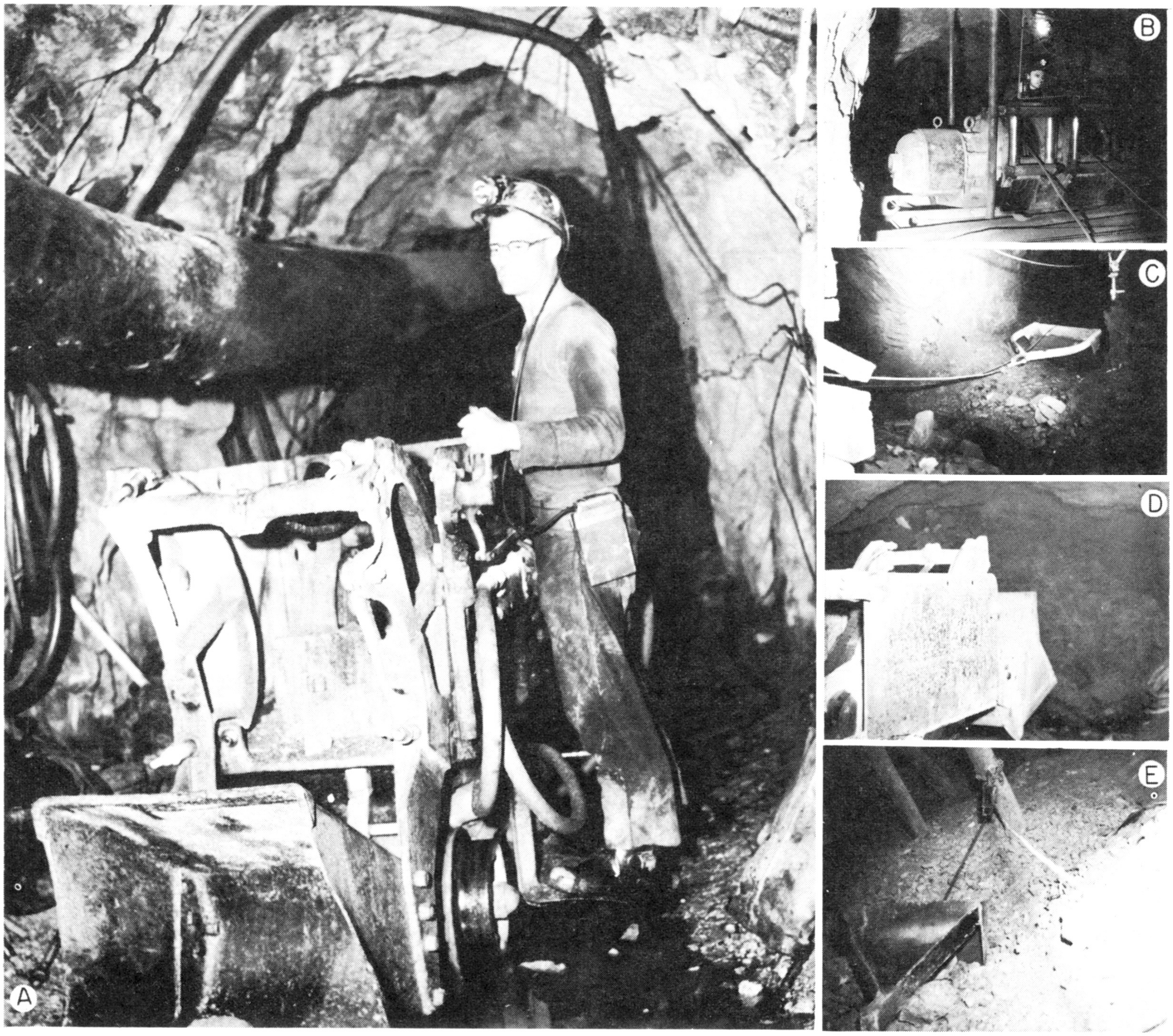
G. Direct loading of ore car by a slusher in a slusher drift.

MUCKERS AND SLUSHERS

Loading or moving ore by means of a hand-held shovel must be kept to a minimum. The two kinds of machines most used underground to load and move waste and ore are the mucking machine and the slusher-scraper combination.

A is the front view of a mucking machine in a drift. The bucket is in the down position ready for loading. The whole machine moves forward and as the bucket is driven into the ore pile (muck) it is raised and pushed forward at the same time so that the bucket will be filled. The filled bucket is raised over the top of the machine and throws the muck into a car attached behind (Pl. 19B). D is a rear side view of a mucking machine used in a stope loading operation as shown in Plate 13F. Mucking machines may be operated by compressed air or electricity, but air operation is more common in Montana.

A slusher is essentially a double-drum hoist. Slushers may have either electric or compressed-air motors of 5 to 125 horsepower. A 50-horsepower electric slusher is shown in B. One cable of the slusher is attached to the front of the scraper so that it can be pulled toward the slusher. The other cable goes around a block securely fastened in the far end of the slusher drift and is attached to the back of the scraper (E). Pulling this cable brings the bucket toward the end of the drift for another load. As the scraper or bucket (C) is dragged across the muck pile, the ore is pulled into an ore pass (the dark hole in front of the scraper in C) or into a car (Pl. 13G).



A. Mechanical air-operated mucking machine. *(Courtesy Anaconda Co.)* **B.** 50-horsepower electric slusher in use underground. **C.** Bucket 5 feet wide used with the slusher pictured in B. **D.** Mucking machine in a drawhole loading point. **E.** Slusher bucket in use in a flat-lying stull-supported stope.

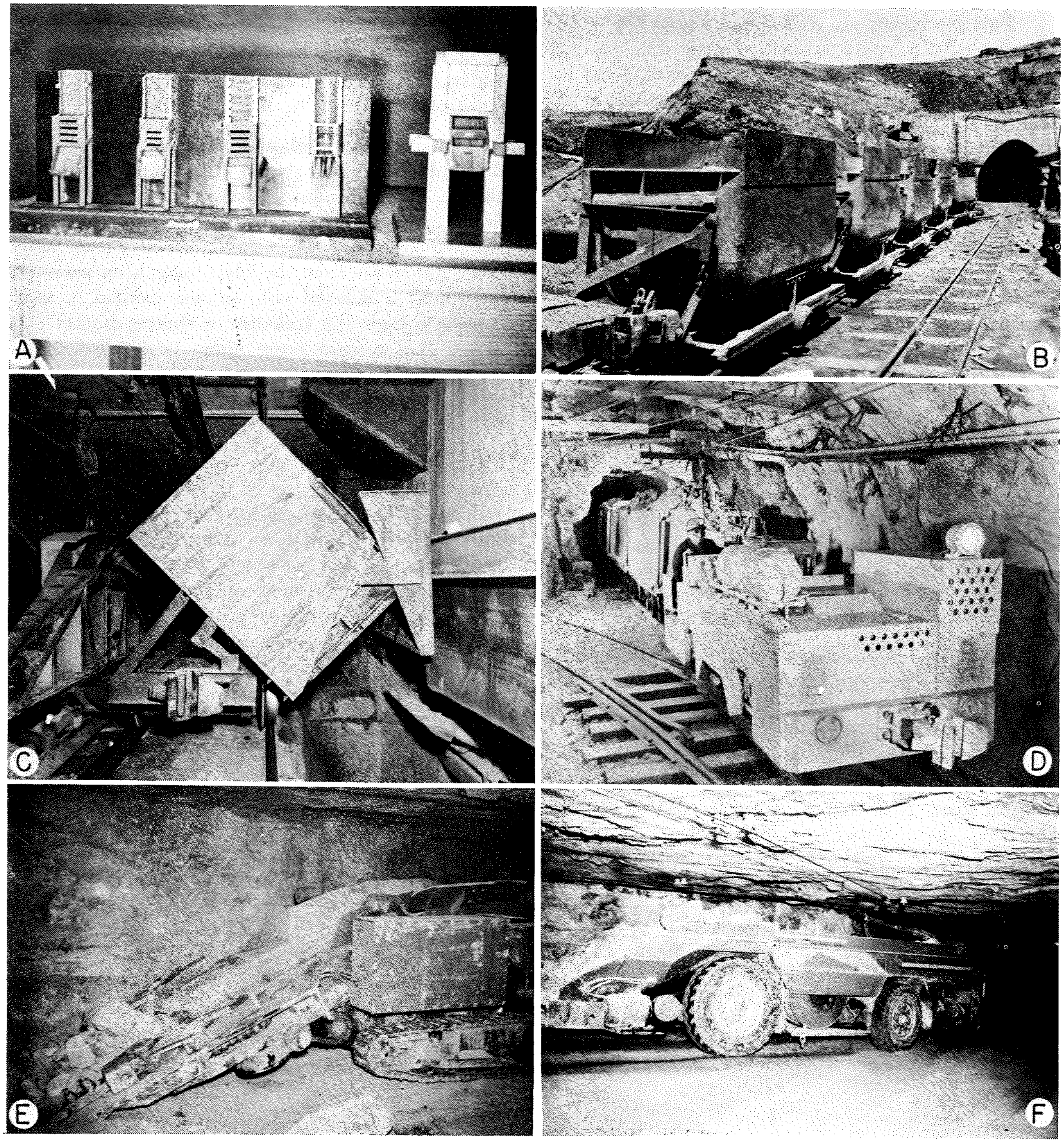
UNDERGROUND LOADING AND TRANSPORTATION

Numerous styles of chutes are in use. Plate 15A is a picture of a composite model showing four different styles of chute mouths and gate arrangements. Gates are used to control the flow of ore from the chutes into the ore cars. The gate on the far left is an arc type that swings up from underneath the mouth to shut off the ore flow. Second from left is an overhead type of arc gate, which swings down from above to cut off the ore flow. Third from left is a straight swing gate similar to the overhead gate. The gate fourth from left is not strictly a gate but has heavy hanging bars or chains to slow the falling muck. The gate on the right is the stop-board type shown in more detail in Plate 13E.

Most ore is transferred underground in ore cars. The cars shown in B are 5-ton capacity, side-dump cars. A side-dump car (of different make) is shown (C) in dumping position. Ore cars used underground range from ½-ton to 30-ton capacity, but 1-ton, 3-ton, and 5-ton are most common.

Cars are pulled by underground locomotives powered by electricity, diesel engine, or compressed air. Plate 15D shows a large underground trolley-type electric locomotive pulling a train of cars; electricity is supplied to the motor through the overhead trolley wire. Electric locomotives that carry their own batteries for electric power are termed battery locomotives.

In many flat-lying mines, electric- or diesel-powered trucks called shuttle cars are used to transport material. The one shown in F hauls approximately 15 tons of material per trip. Loading machines provided with raking arms and a conveyor system (E) are used to load the shuttle cars. These machines find widespread use in mining coal and bedded nonmetallic minerals such as gypsum.



A. Model showing various types of chute mouths. **B.** Train of cars used for underground ore haulage. *(Courtesy Anaconda Co.)* **C.** Car in dumping position at an underground dump. *(Courtesy Anaconda Co.)* **D.** An underground trolley-type electric locomotive pulling a train of ore cars. *(Courtesy Anaconda Co.)* **E.** An underground loader using a raking and conveying action to load shuttle cars. **F.** Underground ore hauler known as a shuttle car.

PART 4—DEVELOPMENT

Few ore bodies are so situated within the earth that mining can be started immediately. The deposit must be prepared for mining or developed. Even in open-pit mines, some of the overburden or waste must first be removed; this work may be classified as development, although it may not be called that. The U.S. Bureau of Mines classifies development as "work done in a mine to open up ore bodies, as sinking shafts and driving levels." This, of course, refers to underground workings. Raises are often classed as development headings. This section describes the general methods and procedures in use in Montana for driving development headings, but the minute details are omitted.

The descriptions in this section will start at various steps in the cycle of operations, but the cycle is generally planned so that the blast is made at the end of a shift to allow time for the smoke, fumes, and dust to clear out of the heading before the next shift reports for work. If possible a blast is made every shift, but in sinking shafts or driving large timbered raises, blasting every shift may be impractical if not impossible.

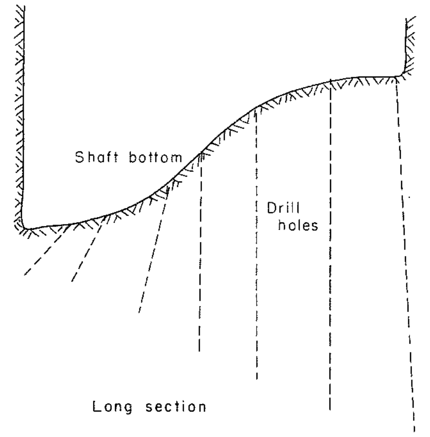
SHAFT-SINKING SEQUENCE

Shafts are of various sizes and shapes. The horizontal cross section can be square, rectangular, circular, elliptical, or some special shape. For small mines, the timbered rectangular shaft is the most popular. The shaft may be inclined or vertical. Plate 16A shows a bench or sump type of blasting round in a vertical shaft. Note that the holes are slanted so that they will break toward a free face. The sump round is popular because it provides a low place in the shaft for water to collect so that the drill holes can be started or collared in the high rock bench above the water level. Thus mud and dirt are kept out of the shot holes.

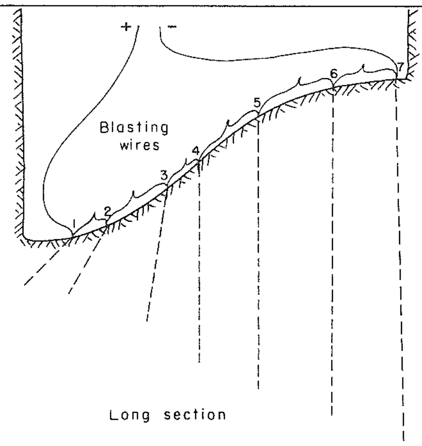
Because electric blasting provides greater safety, the explosives in wet shaft bottoms are detonated by electric blasting caps. B shows the shaft bottom drilled, loaded, wired, and ready for blasting. The blast usually piles the broken rock as shown in C. After the fumes from the blast have been removed, the round is mucked out. In one method, a small clamshell loads the rock into a sinking bucket (D). Notice that a small sump pump is installed in the lowest part of the shaft to remove the water so that it will not interfere with operations.

Supporting the shaft is the next problem. After the round is mucked out, or even before it is all mucked out, the next set of timber is installed. The wall plates (horizontal pieces along the long sides of the shaft) are brought down and suspended by hanger bolts from the shaft set above (E). The other pieces to the set are then lowered and put in their respective places; the whole timber set is aligned or plumbed and then blocked or wedged into position (F). After the timber is in position, drilling is resumed and the cycle is repeated. A hand-held sinker drill is shown in F drilling the cut holes for the next sump round.

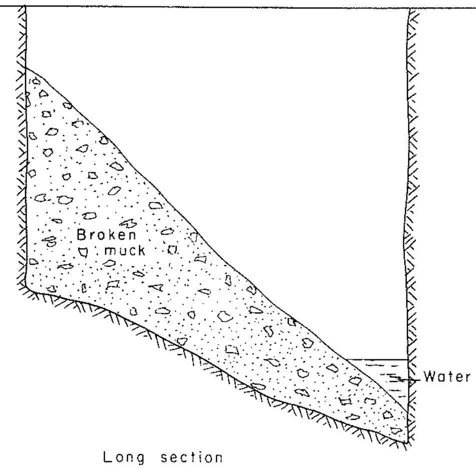
Not all operators use the sump type of round when sinking shafts. The whole bottom may be drilled with a V-cut or burn-cut type of round (Pl. 8G).



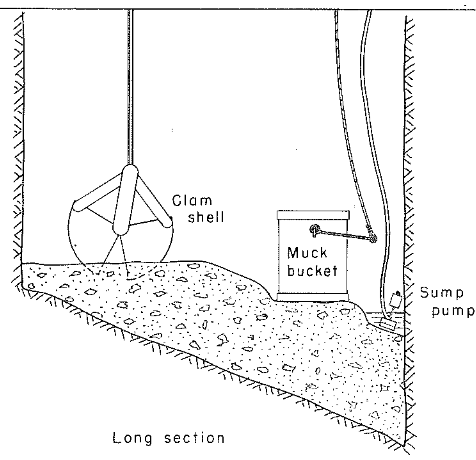
A. Shaft bottom drilled out with a sump or bench type of round.



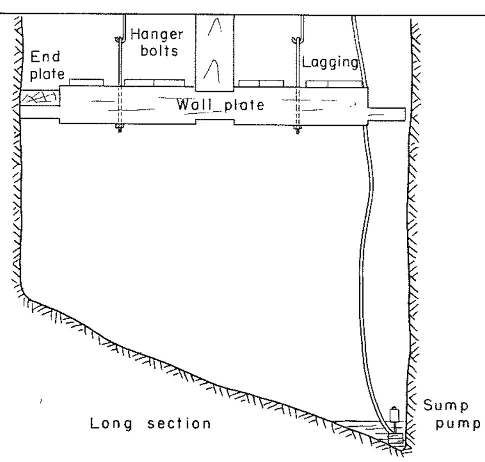
B. Shaft bottom loaded with explosive and electric blasting caps. (numbering sequence shows order of detonation)



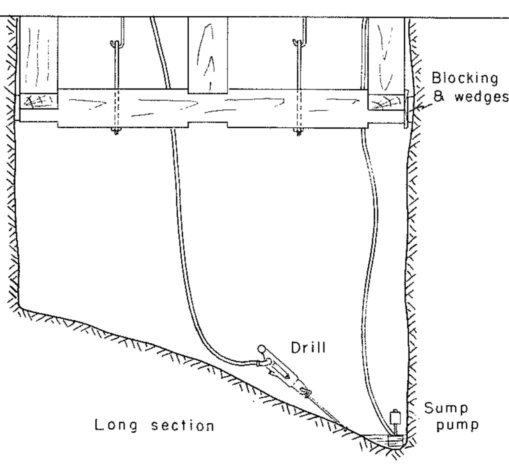
C. Round after blasting, showing muck piled up at one end of the shaft.



D. Mucking in the shaft with a clamshell bucket.



E. Timbering in shaft. Wall plate is suspended from timber set above.



F. Timber set blocked, ready for the start of another drill round.

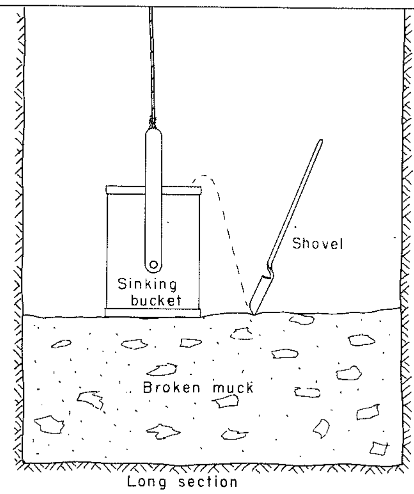
MUCKING AND CONCRETING SHAFTS

Hand mucking is still practiced extensively in sinking shafts at small mines because mechanical shaft-mucking equipment is costly to purchase, expensive to operate, and inefficient in cramped quarters. To use mechanical shaft muckers effectively, the supporting equipment such as sinking buckets and surface facilities must be designed to handle the large amount of muck that the mechanical equipment is capable of moving. Most small mines are not thus equipped, nor is money available to purchase such equipment.

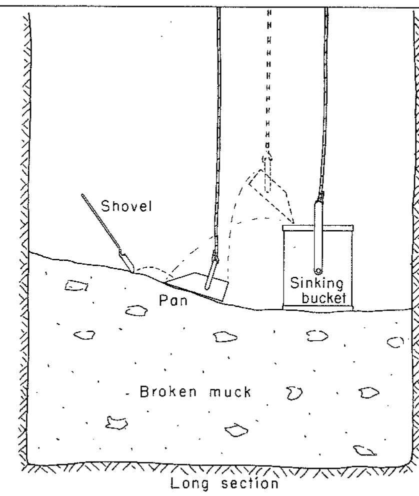
Two methods of hand mucking are in general use. One is direct loading of the bucket (A); the other consists of first filling a low container called a sinking pan, which is then hoisted and dumped into the bucket. Shoveling into a low pan is easier than shoveling into a high bucket. The sinking pan is popular, although it may require a separate hoist.

The two mechanical shaft muckers most commonly used in Montana are the Riddell and the Cryderman muckers. The Riddell (C) uses an ordinary cable-actuated clamshell bucket. The two hoists necessary for operation of the clam are mounted on a traveling carriage, which runs back and forth in the shaft on a specially designed track suspended in the shaft. The dotted position in C shows the clamshell in the dumping position. The Cryderman (D) also uses a clamshell bucket, but the bucket is closed and opened by air cylinders rather than cables. The clam is attached to a telescoping air-operated arm, which is positioned in the shaft by air cylinders attached to the cage. The dotted line in D shows the bucket in the dumping position.

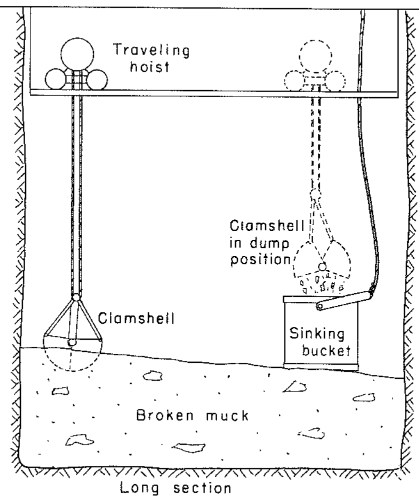
Concrete is now a popular shaft support because of its strength, permanence, and fire resistance. Forms are needed to hold the wet concrete in the desired shape until it hardens, but they must not interfere with or restrict the other shaft-sinking operations. Therefore steel forms of the desired shaft cross section and as much as 20 feet in vertical length are commonly used. They are lowered into position and may rest on the broken muck. After the forms are carefully aligned and blocked into position, wet concrete is brought down by bucket or pipe line to fill the space behind the forms, which are left in place while the concrete hardens and shaft sinking continues. They are lowered when needed again.



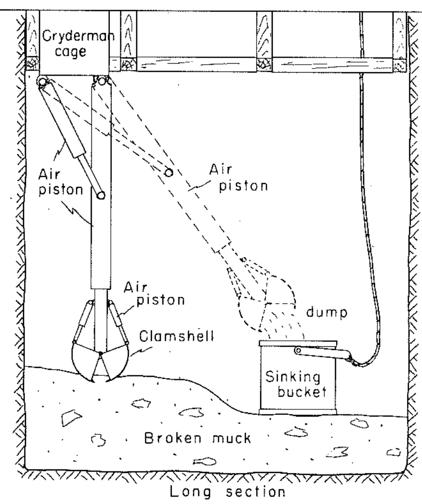
A. Shaft bottom mucking by shoveling directly into sinking bucket.



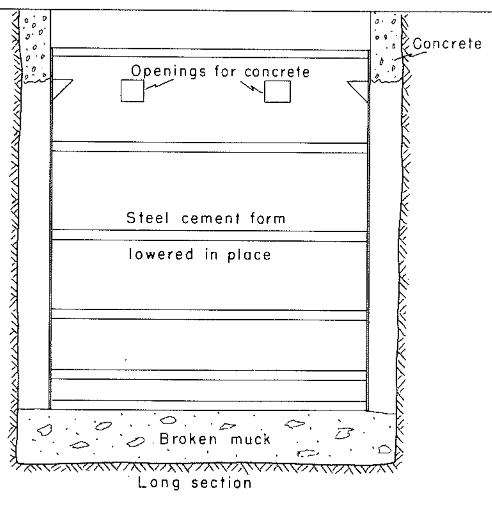
B. Sinking pan used in a shaft bottom to fill the sinking bucket.



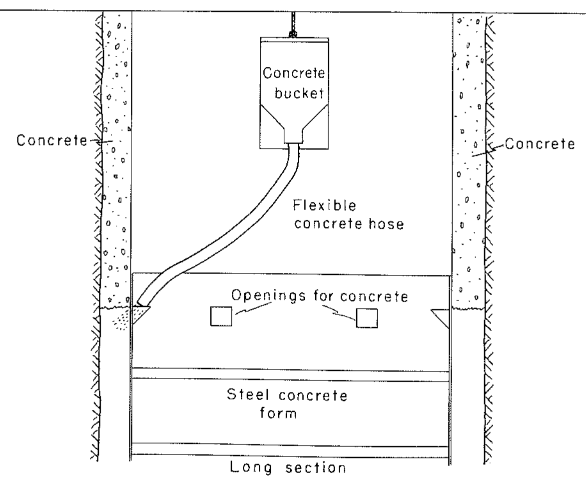
C. A Riddell shaft-mucking machine mucking into a sinking bucket.



D. A Cryderman air-operated shaft mucking machine in use in a timbered shaft.



E. Steel form for concrete in position in a shaft bottom.



F. Concrete bucket in shaft supplying wet concrete to steel forms.

SHAFT-SINKING EQUIPMENT

In Plate 17 the use of mechanical shaft sinking equipment was explained; this plate illustrates some of the equipment. Because of the small space underground, the full view of a large piece of equipment may be impossible to obtain.

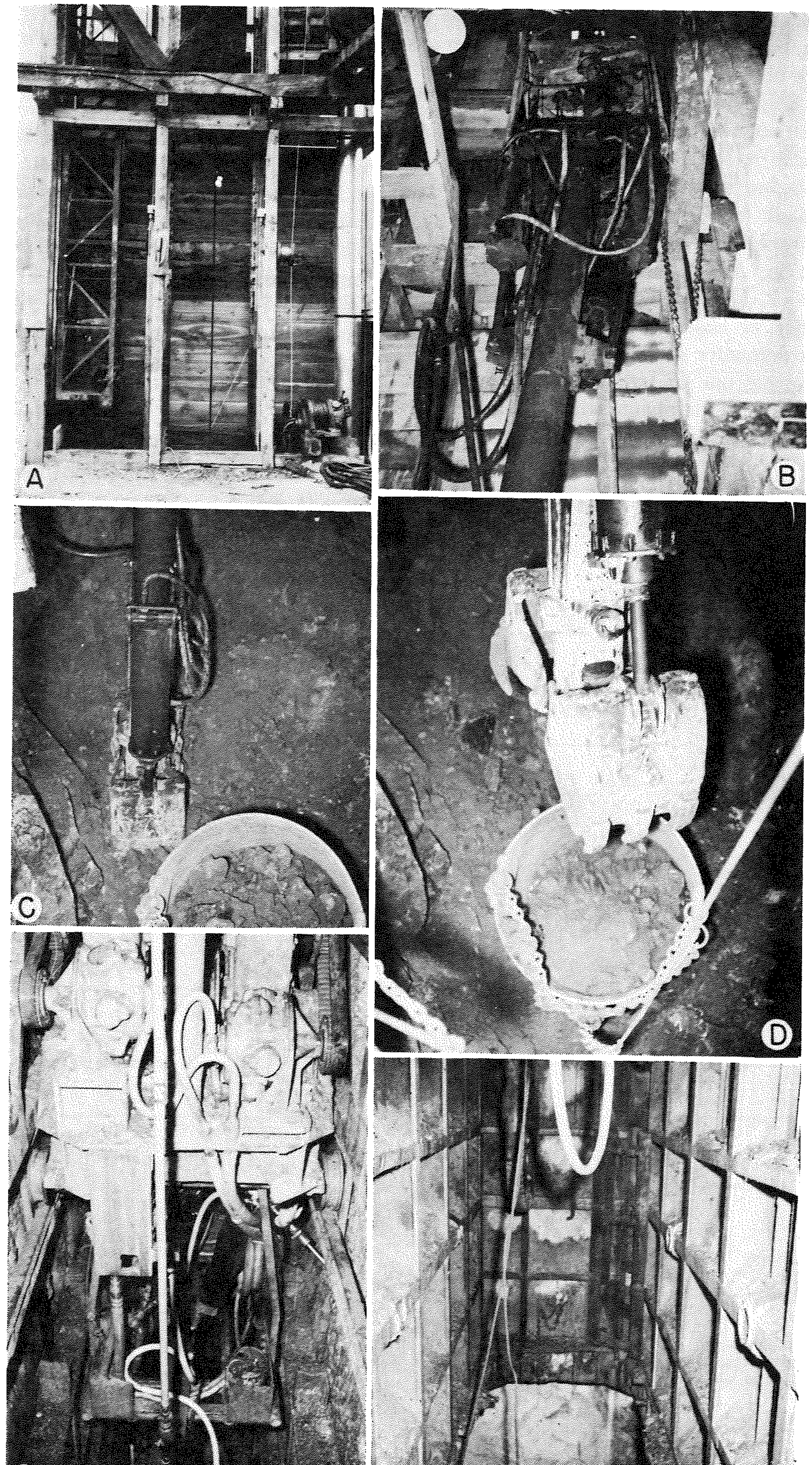
The cage or supporting frame of a Cryderman mucker is shown in A. The whole machine is raised and lowered in the shaft. The telescoping air leg and positioning cylinders attached to the bottom of the supporting frame are seen from below in B. (This machine is not the one shown in A.) The bucket end of the telescoping air leg is seen in C, which shows the bucket digging and filling at the shaft bottom. The Cryderman bucket is dumping into the sinking bucket in D. Note that the air cylinders have opened the Cryderman bucket in this view.

When the sinking buckets are hoisted to the surface for dumping, they tend to swing back and forth in the shaft. To overcome this, the buckets slide into a crosshead, which guides them up and down the shaft and prevents swinging.

The carriage and hoists of a Riddell shaft mucker are shown in F. Note the carriage wheels, which run on the track positioned so that the whole carriage can move across the long section of the shaft. Because the carriage can move in the shaft, the bucket can dig or dump in almost any position in the shaft. (Pl. 17C shows a long-section sketch of this machine.)

Steel forms for concrete are shown in F. The bracing on the forms gives them strength so that they will stay in alignment while the concrete is being poured into place. The open space within the forms allows the sinking buckets to go past the forms freely, so that the sinking cycle is not delayed. A section of the forms can be removed to decrease the perimeter distance and allow the form to come loose from the hardened concrete so that it can be lowered to a new position. The concrete used underground is high early strength, which means that it takes its initial set within a few hours after placement.

A. Supporting frame for a Cryderman shaft-mucking machine. The frame is in the left compartment **B.** Cryderman machine viewed from below. *(Courtesy Anaconda Co.)* **C.** Cryderman clam bucket picking up a load of broken rock. *(Courtesy Anaconda Co.)* **D.** Cryderman clam dumping into sinking bucket. *(Courtesy Anaconda Co.)* **E.** Riddell shaft mucker showing the traveling carriage. *(Courtesy Anaconda Co.)* **F.** Steel forms hung in shaft ready for concrete. *(Courtesy Anaconda Co.)*

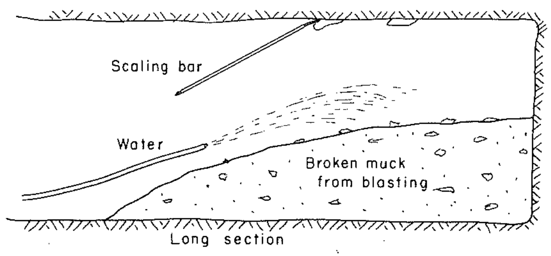

A
B
C
D
E
F

DRIFT CYCLE

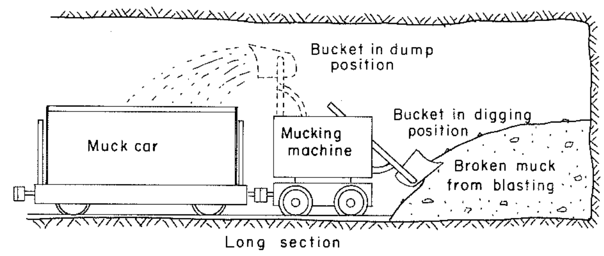
In a freshly blasted heading, the first thing to be done is to scale or bar down loose rocks, then water the walls and muck pile to control dust (A). Mucking the blasted round comes next; B shows the mucking machine filling the car. After all of the muck is removed, the heading is rock bolted (C, D) or timbered. If the ground needs no support, then drilling of the round is next. An air-leg driil is shown being used for drilling (E); jumbo drills (Pl. 9C, D) may be used in this operation. A burn-cut round for breaking the rocks is shown (F, G). Loading the round comes next. The first stick of explosive that goes into the hole should be the detonator stick, which contains the cap and fuse. (Putting one or two sticks of powder into the hole ahead of the detonator stick is regarded as poor practice.) The rest of the hole is then filled with explosive.

Ammonium nitrate, like that used for fertilizer, if treated with ordinary diesel fuel can be used as an explosive with great success, both in open-pit and underground mines. The nitrate is in bulk form and can either be poured into a vertical hole or blown into a horizontal hole or up with a compressed-air nozzle.

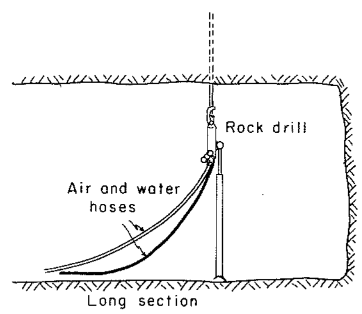
Fuses should originally all be of the same length. Fuse burns at a fairly constant rate, so the timing of the blasting sequence of the holes is set by the length of the fuse. After the round is loaded, the fuse to the hole that is to be shot first should be shortened most. The fuse for the next hole has a smaller length of fuse cut from it, and so on until the round is timed. Assume all fuses are originally 12 feet in length and that the fuse burns at a rate of 1 foot in 30 seconds. If a 4-foot length were cut off the 12-foot fuse, leaving 8 feet, it would take 4 minutes after lighting until the explosion. If the next fuse is shortened by 3½ feet, it would take 4 minutes 15 seconds for the next hole, and so on (J, K).



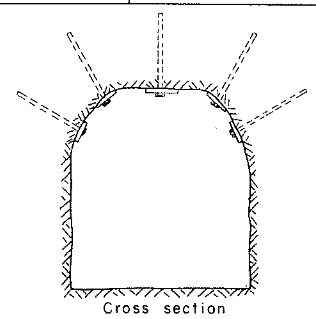
A. Entering blasted drift. (Scaling or barring loose rock and wetting of muck pile required for safety of operations).



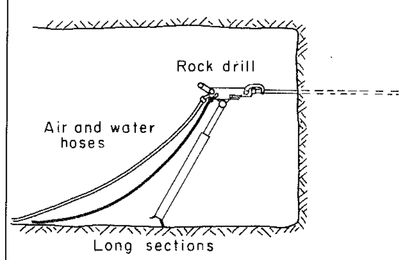
B. Mucking broken rock into a mine car with an overcast mechanical loader.



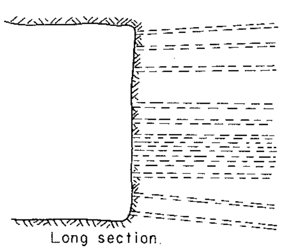
C. Drilling holes in back of drift for installation of rock bolts.



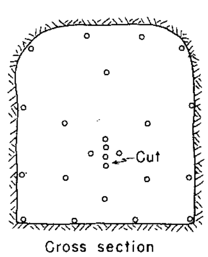
D. Rock bolts installed in section of drift.



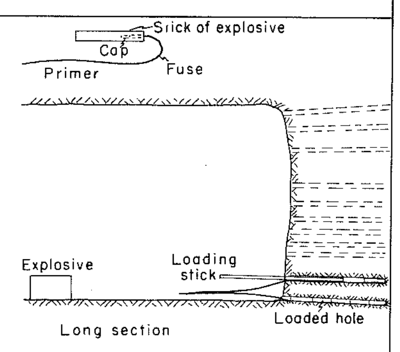
E. Drill set up to drill holes, preparatory to blasting.



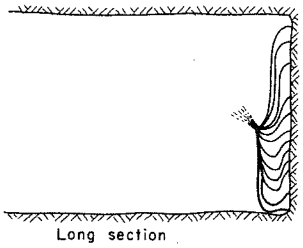
F. Pattern of drill holes in a drift heading.



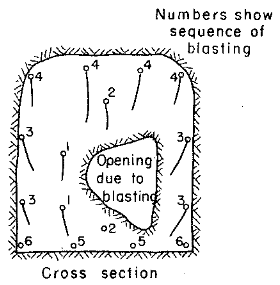
G. Front view of drill holes in a drift heading. (burn cut round).



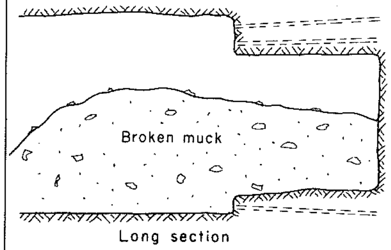
H. Loading the drill round with explosives.



I. Lighting the fuses. (Fuse and caps are used here instead of electric detonators).



J. Front view of round after the cut and two relievers have been detonated.



K. View of round after all holes are detonated except the back holes and lifters.

RAISE CYCLE

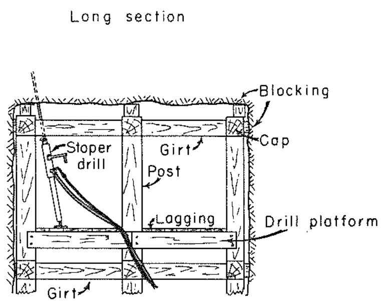
The top of a 6-post timbered raise, as prepared for the drilling sequence, is shown in A. (Only three posts can be seen in this long-section sketch, but there are three more posts behind the three shown, hence the term 6-post raise.) A stoper drill is commonly used for drilling in a raise. In timbered raises, the V-cut type of round is popular (B), whereas the burn cut is often used in untimbered raises.

Before blasting the round, the timber must be protected and the blasted rocks must be directed into the ore pass or chute. A common method of directing the ore is the use of slides (C), which also keep broken rock from dropping down the manway. The timbers that will be directly exposed to the blast should be covered with lagging. The round is then loaded and blasted.

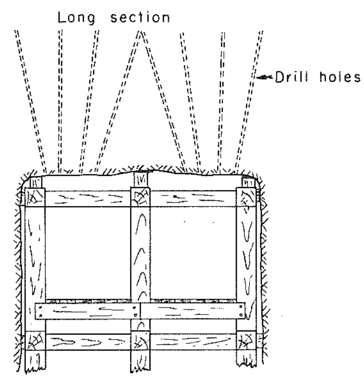
After the blast, it is necessary to clean up loose broken rock that may have fallen into the manway and to water the whole area to reduce dust. The loose broken rock on the back and sides must be scaled down (D), usually starting from one corner.

After the raise has been made safe, the manway slide is removed, a floor is built on top of the timber set, and the timber for the next set is hoisted and set in place (E), then aligned and blocked tightly in position (F). The cycle is then ready to start again.

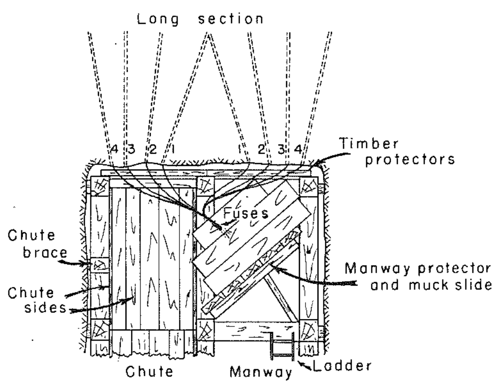
Jobs that must be done as the raise is being driven include raising the chute side and installing ladders, lengths of ventilation hose or bag, and air and water pipes. These necessary miscellaneous jobs are performed whenever the miners can get them done during the cycle.



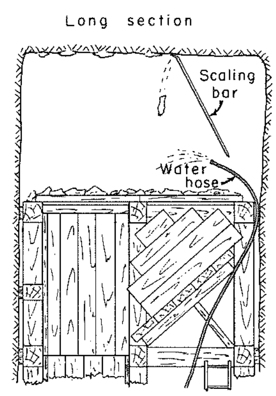
A. View of a 6-post timber raise. (being drilled with a stoper-type drill).



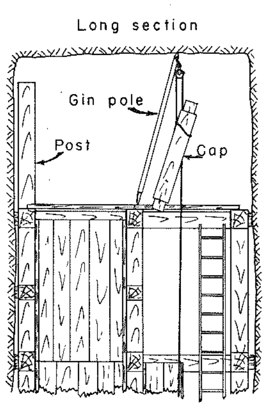
B. Long-section of a V-cut type of raise round.



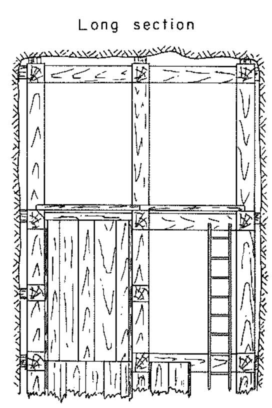
C. Raise prepared for blasting; chutes, slides, and timber protectors are in place.



D. Raise after blasting; scaling or barring down, and wetting entire area.



E. Hoisting timber in scaled-down raise.



F. Next floor of timber in place in raise. (Cycle is ready to start again).

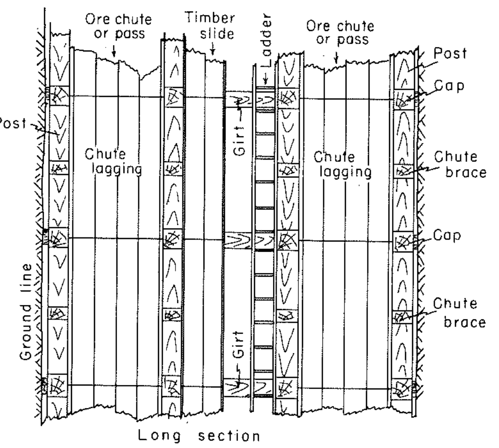
TYPES OF RAISES

The raise illustrated in Plate 20 is a 6-post timbered raise containing one ore-pass or chute compartment and one manway compartment. Another popular style of timbered raise is the 8-post raise (Pl. 21A), which has two ore-pass or chute compartments and one manway compartment. The advantage of an 8-post raise is that stopes can be mined from both sides of the raise at the same time more conveniently than with a 6-post raise.

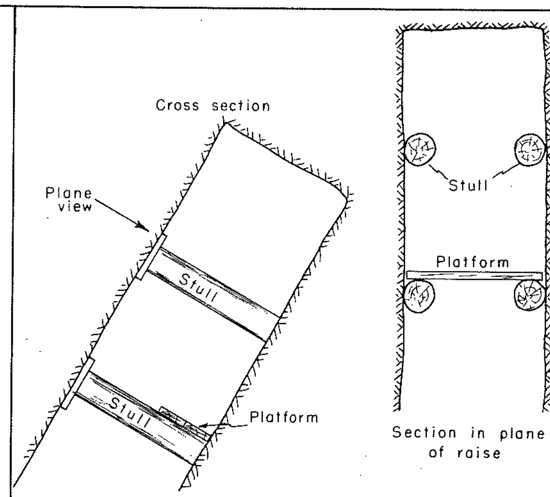
Timbered raises are used where the ground is heavy or where the timbered raise is an integral part of the mining system. Untimbered raises are driven, however, and the sketches in Plate 21 show some types. Stulls are used in many one-compartment raises (B). The stulls give support to the back and also provide a base for a drilling platform. If the ground does not need support, then stulls may be horizontal (C) as steps and drill platform. The perpendicular stull system (B) may be used in steeply dipping raises, but the horizontal system (C) is used only in moderately inclined raises.

In hard ground, stulls may be broken or knocked out by the blast. Two systems are designed to overcome this. The pin raise (D) requires steel pins about 14 inches long. A short sinker type of drill is used to drill holes in the footwall so the pins can be installed. Mud from drilling is usually enough to cement the pins in place firmly. They provide means of support when climbing the raise. Alternatively, anchor pins are inserted in holes in the side of the raise (E) to support the drill platform and the chain, rope, or chain ladder.

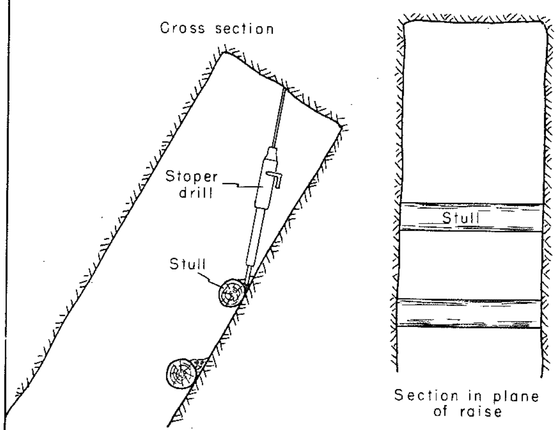
A recent development in raise driving is the mechanical raise-climbing machine, which runs on a track fastened to the sides of the raise (F). It includes a drilling platform and a means of hauling supplies up the raise.



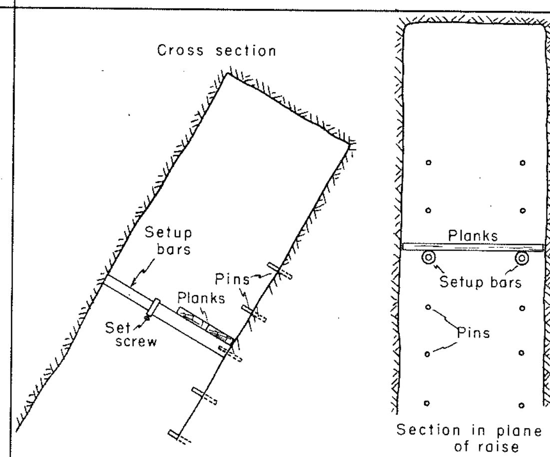
A. Eight-post raise with ore passes or chutes on each side of the manway.



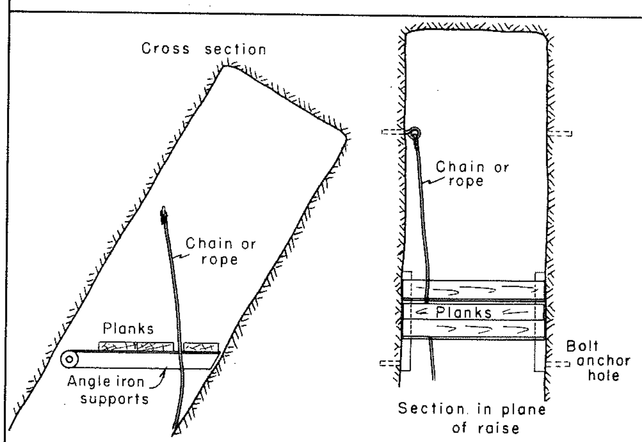
B. Stull type of raise, single compartment with stulls perpendicular.



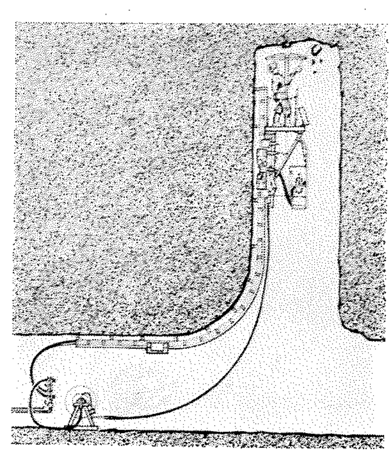
C. Stull type of raise, single compartment with stulls horizontal.



D. Pin type of raise, single compartment showing setup bars and drill planks.



E. Single-compartment raise with chain, rope, or chain ladder for access.



F. Sketch of raise-climbing machine.
(Courtesy Anaconda Company).

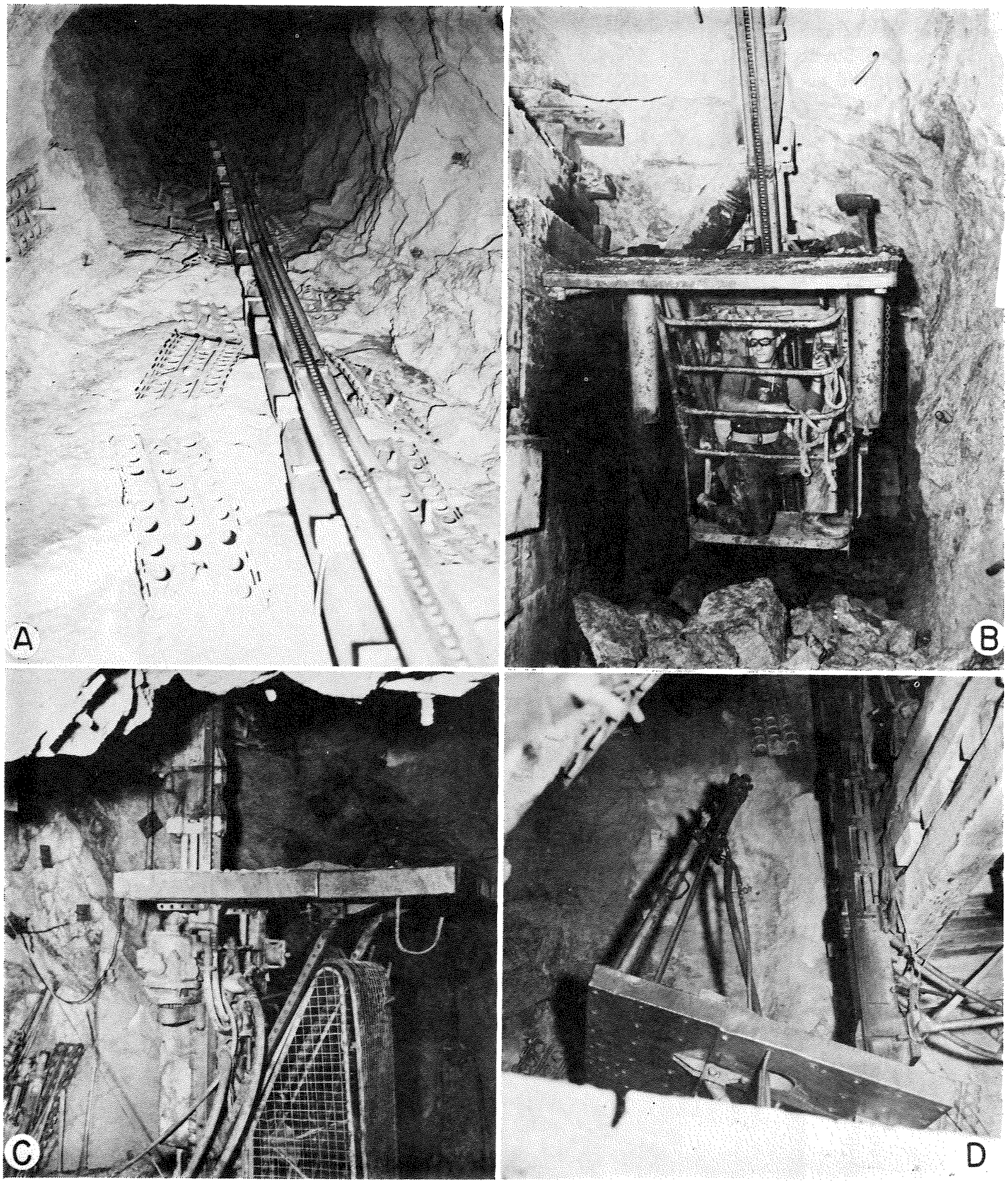
RAISES AND RAISE MACHINES

Pin raises were sketched on Plate 21. The major disadvantage of such a raise is that everything including the machine must be carried up the raise. A block and cable may be carried up for hoisting the equipment, but this practice is generally regarded as impractical.

The raise climber was also sketched on Plate 21. The machine runs on a track, which is securely fastened to the wall of the raise by rock bolts (A). On this track is a row of teeth, which meshes with the gear on the raise climber. Turning the gear directs the climber up or down the raise. The climber is driven by compressed air. The miners can ride up and down the raise in the man carrier just below the platform (B, C). When the climber gets to the top of the raise, the miners climb onto the deck, scale down the loose rock, and are ready to drill (D). When drilling is finished, another section of track is installed and the climber is run down the raise so the explosives can be brought up and the round loaded. The track sections contain the air and water lines, and a ventilation tube can be installed behind the track, which protects it from the blast. This machine has greatly increased the rate of raise driving.

A. Track and pipe assembly on which a raise climber runs. *(Courtesy Anaconda Co.)* **B.** Raise climber starting to climb the raise. *(Courtesy Anaconda Co.)* **C.** Raise climber viewed from the side; the drilling platform is at top. *(Courtesy Anaconda Co.)* **D.** A drill on the raise-climber platform. *(Courtesy Anaconda Co.)*

PLATE 22 — RAISES AND RAISE MACHINES



DRILLING IN DEVELOPMENT HEADINGS

Pictures of drilling in raises are few, not only because of the difficulty of getting the camera in a suitable position, but also because the miners working in a raise are paid an incentive bonus and they do not want to waste time posing for pictures.

Plate 23A shows the operation of a stoper-type drill in a raise. Water is used in drilling to control dust, and a spray of water can be seen issuing from the hole where the steel is rotating. The compressed air exhaust forms a fog behind the machine.

Plate 23B shows an air-leg type machine in a drift heading. The machine is pivoted so that the angle between the leg and the machine can be adjusted. The dark streak below the hole is caused by water running down the side of the drift. The large hose carries compressed air to the machine, and the smaller hose carries water.

A. Drilling in a raise with a stoper type drill. *(Courtesy Gardner-Denver Co.)* **B.** Drilling in a drift with an air-leg pusher drill. *(Courtesy Gardner-Denver Co.)*

PART 5—SURFACE MINING

The lure of placer gold brought thousands of miners into Montana who strongly colored its early history. Although the easily obtained placer gold has long since been removed, some areas in Montana are still being worked by placer methods—panning, sluicing, hydraulicking, mechanical washing plants, and dredges. These methods are discussed briefly in this section.

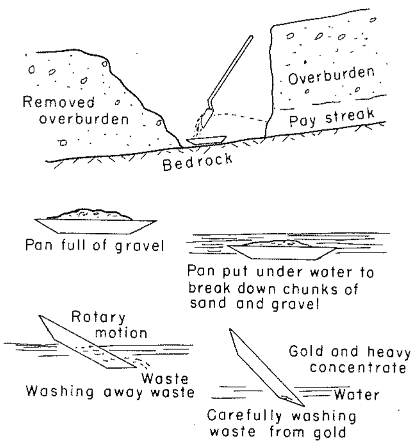
The rapidly increasing cost of underground mining, the improvements in milling and processing, and the efficiency of surface-mining equipment, have combined to make open-pit mining and stripping the preferred mining method throughout the world. Open-pit and stripping methods are also discussed briefly in this section.

PLACER MINING METHODS

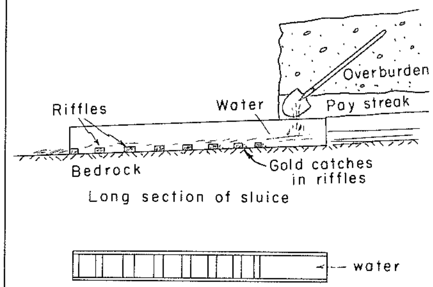
The gold pan is seldom used in placer mining, because it has very small capacity, but it is used extensively in testing potential placer ground. The pan is filled with gravel (A) and immersed in water, the clay broken by hand, and the large rocks removed. The pan is then rotated under water to settle the gold and heavy minerals to the bottom, then titlted and gyrated so that the lighter material is washed away. The pan should be jarred occasionally to settle the gold. As the quantity of material decreases, the washing rate must be reduced to avoid washing away the gold.

A sluice box (B) will wash much more gravel than a pan, but an ample supply of water must be available for sluicing. If water is scarce, a rocker may be used (C). The washing action is provided by rocking the rocker back and forth. The coarse gravel is caught in the screen and periodically dumped, so that only fine material goes to the riffles. Although the rocker has less capacity than a sluice, it is faster than a pan.

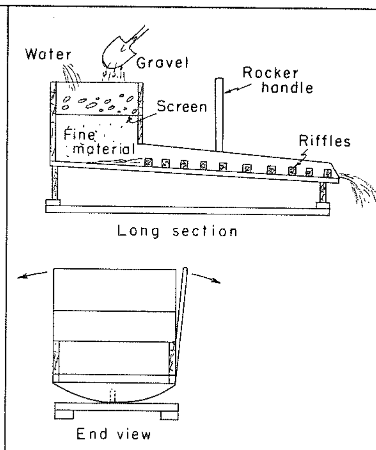
If water is plentiful and if disposal of tailings is not a problem, the hydraulic giant or ground-sluice method may be used. The hydraulic giant is a pivotable water nozzle attached to the end of a large pipe. If the water comes from an elevation much higher than the nozzle, water issues from the nozzle with tremendous force and will wash boulders and gravel through the sluice box (D). In the ground-sluice method, the force of a stream of water directed into the cut washes the gravel into the sluice (E). In ground sluicing, the water upstream is dammed and a large volume of water is released at one time. The ground that the water is to wash may be loosened by blasting. Mechanical washing plants are also popular (F). The gravel is fed into the hopper by a power shovel, dragline, scraper, or other device. The operation of the plant is described in the next section. Abundant water is essential, and many operators catch the used water in a pond downstream and pump it back to the plant.



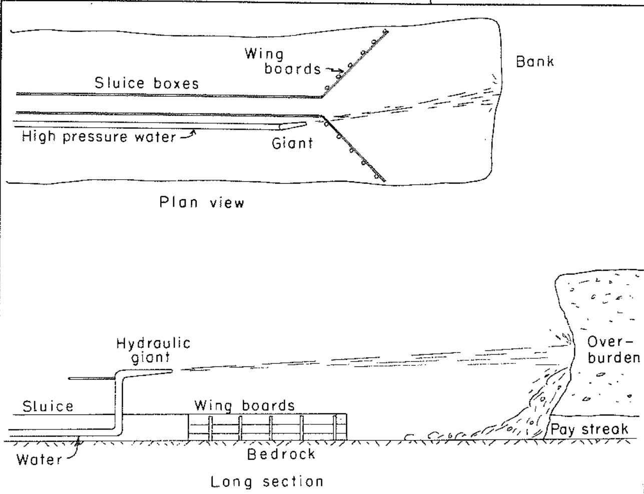
A. Steps in gold panning.



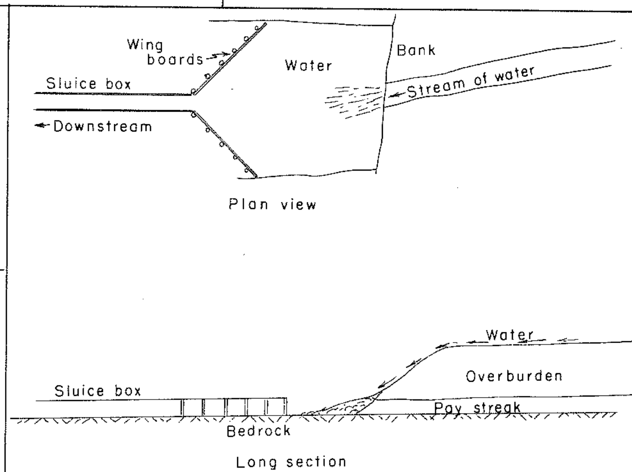
B. Washing gravel in a sluice box filled by hand shoveling.



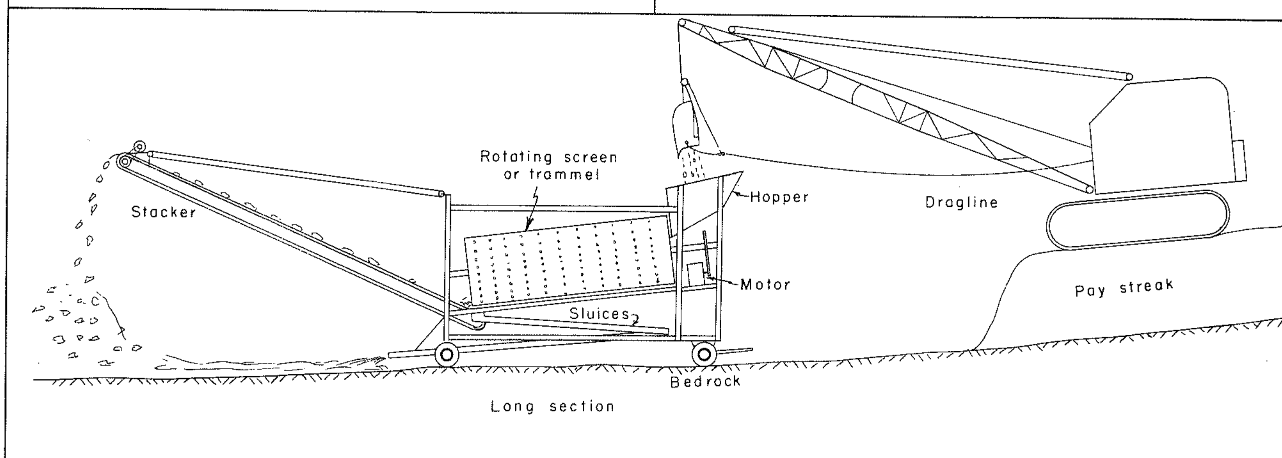
C. Washing gravel in a rocker.



D. Views of placer mining by hydraulic giant.



E. Views of placer mining by the ground-sluice method.



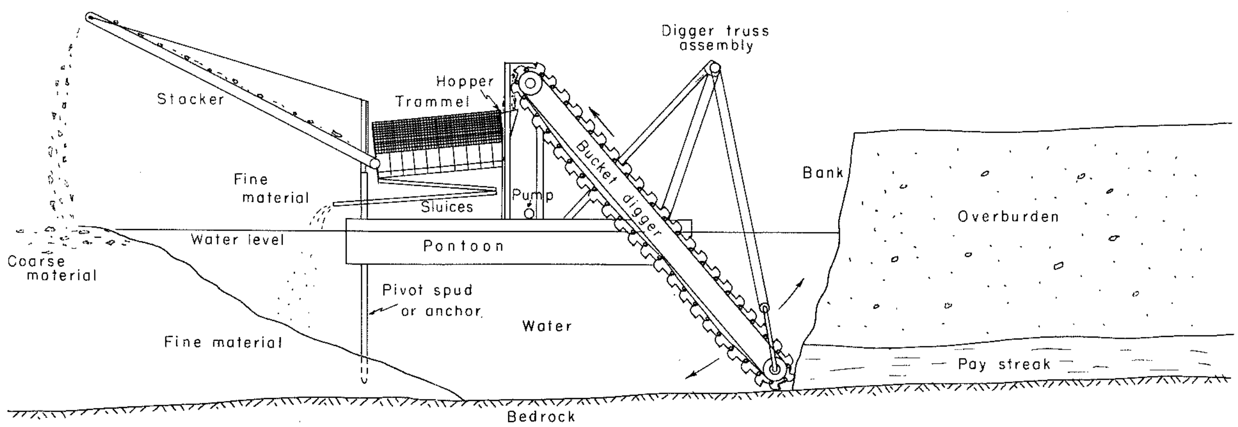
F. Sketch of a dry-land dredge or washing plant. A dragline or power shovel fills the hopper with gravel. The rotating trommel separates the coarse and fine gravel; only the fine gravel is sluiced. Water must be brought to the plant.

DREDGING

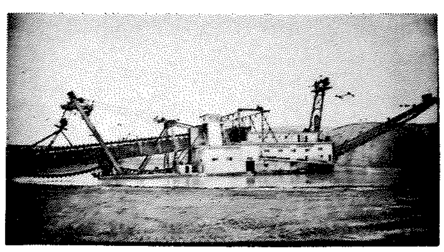
A dredge floats in water and digs the gravel by an endless string of buckets (A, B). The gravel is deposited in a hopper that feeds it to the washing plant, which is similar to that of a dry-land dredge (Pl. 24F, Pl. 26C, D). The material from the hopper flows into a rotating screen. The hole size in the screen ranges from ¼ inch to ⅝ inch. Water is sprayed into the screen to break up clay and wash large rocks. The coarse material from the screen falls on a conveyor belt called a stacker, which transports it away from the dredge. The fine material passes through the screen and into a series of sluices equipped with riffles where the gold is recovered. The fine material coming out of the sluices is deposited at the back of the boat and forms a dam to retain water in the pond. The large quantities of water needed are pumped from the pond that contains the dredge. Although the water may be dirty, the dirt has no effect on gold recovery.

On some dredges, other devices in addition to sluices are used to recover gold or other valuable material. A copper plate covered with mercury makes a good trap for fine gold. Jigs, which are concentrating devices used in many mills, may be used to recover gold and other heavy minerals.

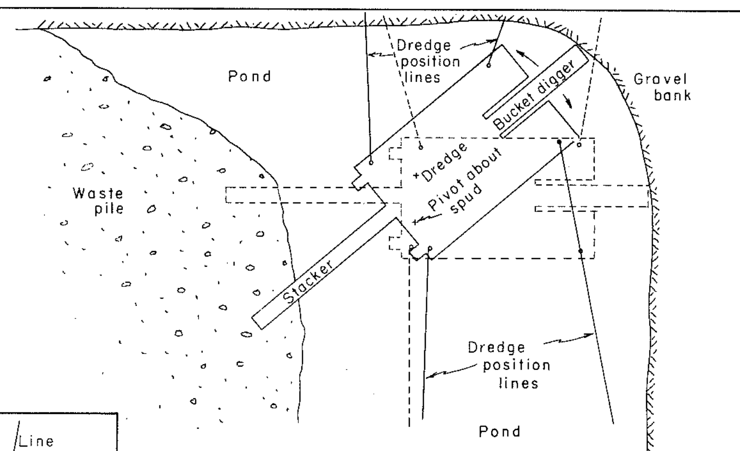
To make a floating dredge dig effectively, it must be held in position. This is done by cables attached to winches on the boat and to anchors on the bank (D, E). By proper placement of the anchors and proper tension on the cables, the boat can be held at any place in the pond. To aid in digging into the corners of the pond, pivots or spuds are driven into the bottom of the pond so that the boat can rotate about them as an anchor (C). The series of sketches (C, D, E) shows how the boat moves across the pond.



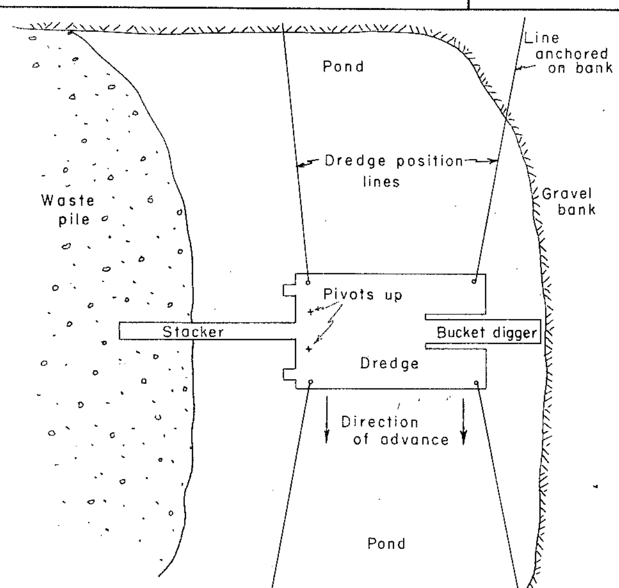
A. Long section of bucket-type floating dredge and dredge pond. (only essential features of digging, washing, and stacking parts of dredge are shown.



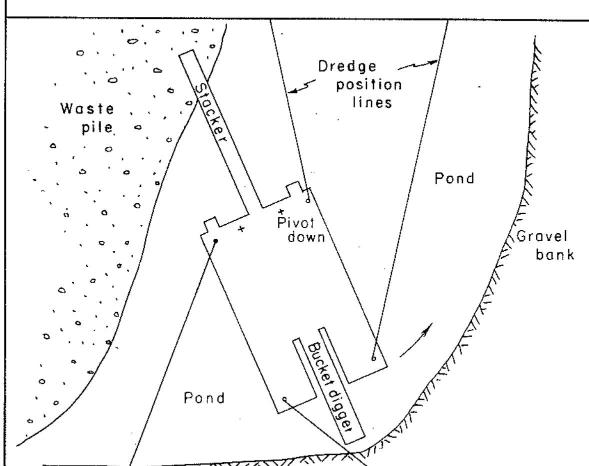
B. Floating dredge.



C. Plan view of dredge digging against corner of pond. Solid and dotted positions show how dredge swings about pivot.



D. Plan view of dredge traversing or moving across the pond.



E. Plan view of dredge at other corner of dredge pond.

PLACER MINING EQUIPMENT

The ordinary hand placer equipment is shown in A and B. An assembled rocker (A, upper) includes the screen (right) and the riffles (left). The sluice box (A, middle) is actually a model of a box showing many different riffle arrangements that can be used. Almost every prospector chooses his own particular type of riffle that he feels is the best for gold recovery. A gold pan (A, lower right) is shown with a prospector's pick (B) for size comparison. The pick is about the same length as a hammer.

A dry-land washing plant (C) includes the hopper at the left, the rotary screen or trommel to the right of the hopper, and the sluice underneath the trommel. The back view of the plant (D) shows the stacker. To provide water for the plant, a dam is installed downstream (E), and water is pumped back to the washing plant. As this mine was in a wooded area, it was necessary to clear off the brush by bulldozer (F) before the dragline could strip off the overburden lying above the pay streak, which is near bedrock. The unproductive overburden can be stripped off and piled to one side, whereas a dredge (Plate 26) must wash everything, including the overburden, with rare exceptions.

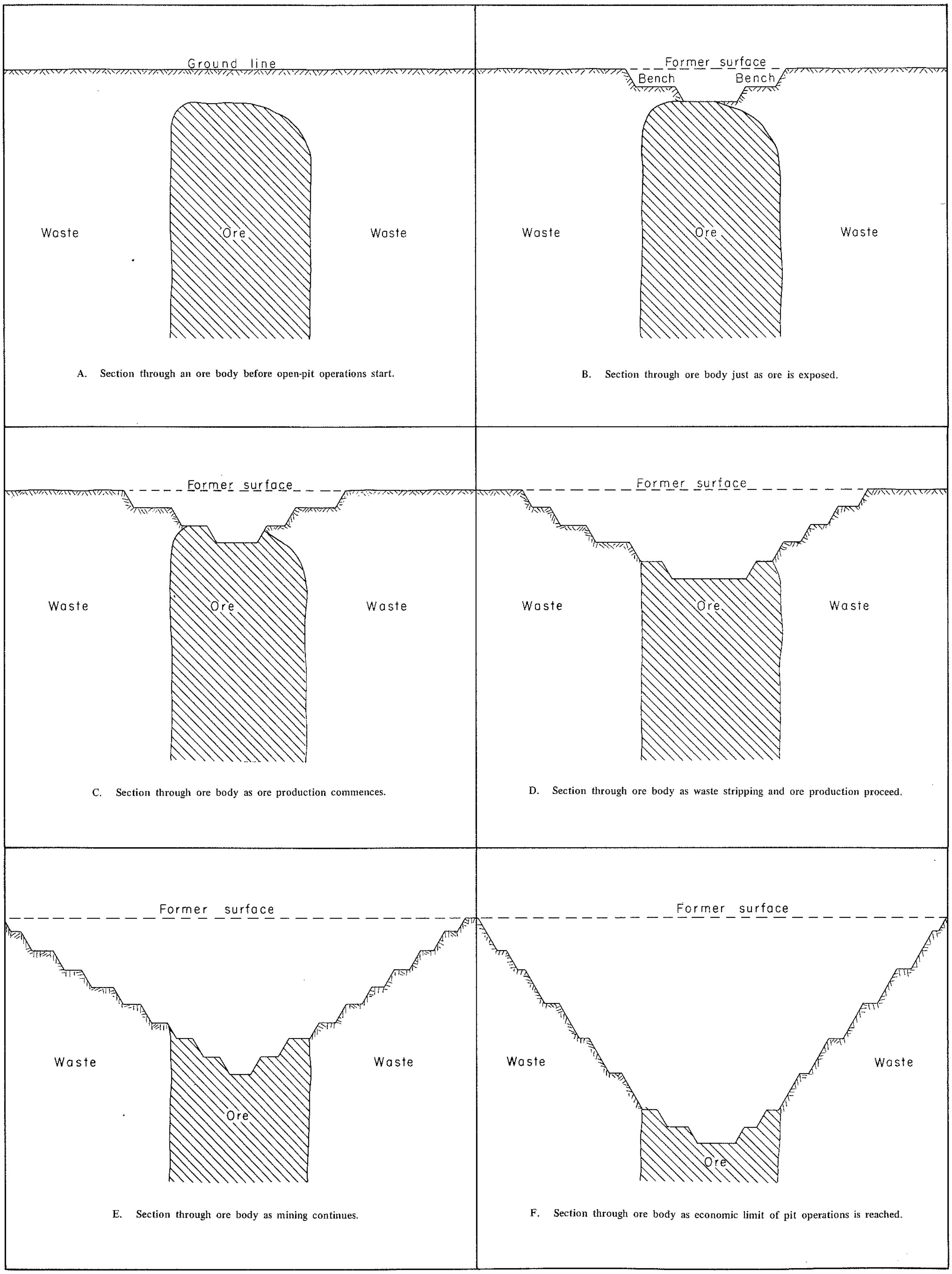
A. Rocker, in background, sluice box with various styles of riffles, in middle, and gold pan, in front. **B.** Gold pan partly filled with gravel. **C.** Side view of a dry-land dredge or gold-washing outfit. Loading hopper on left, rotating screen in middle, and sluice on lower right. **D.** The same washing plant viewed from the rear. **E.** Pump and pond that supply water to the washing plant. **F.** Clearing brush and stripping overburden preparatory to mining.

OPEN-PIT MINING SEQUENCE

Before an ore body (A) can be mined, it is necessary to expose the ore by stripping off the overburden (B). As this is waste material, it is dumped far enough from the mining area so that it will not interfere with future operations. A system of benches is used (B through F). Bench height ranges from 25 to 60 feet, depending on the depth that holes can be drilled and the convenient bank height that a power shovel or other loading device can work. The width of the bench depends on the size of the equipment used to haul the ore and on the room needed to load the equipment with the shovel. Waste stripping continues after ore production has started (C).

In order that the sides do not become too steep, it is necessary to continue to strip back the waste as the pit is deepened and ore is produced (D). Mining and stripping continue at the same time (E). In an open-pit operation a time finally comes when the economic limit is reached; for each foot of depth several thousand cubic yards of waste must be stripped and carried away (F). The usual stripping ratio for waste to ore for most copper and iron mines is about 2 to 1; i. e., two tons of waste can be removed for each ton of ore removed, but this ratio depends on the value of the ore.

If the walls could be steepened, more ore could be removed. Judging the maximum safe steepness of open-pit walls, sides, or slopes is one of the biggest problems facing operators of open pits, because a difference of a few degrees can mean the recovery of many thousands or even millions of tons of additional ore. Unfortunately, the answer is not easy, but much work is being done on the problem by mining companies, colleges and universities, and government agencies to attempt to arrive at the maximum safe angle at which a given pit wall will stand.



A. Section through an ore body before open-pit operations start.

B. Section through ore body just as ore is exposed.

C. Section through ore body as ore production commences.

D. Section through ore body as waste stripping and ore production proceed.

E. Section through ore body as mining continues.

F. Section through ore body as economic limit of pit operations is reached.

THE BERKELEY PIT

The largest open-pit copper mine in Montana is at Butte. All pictures in this plate are published through the courtesy of the Communication Department of The Anaconda Company.

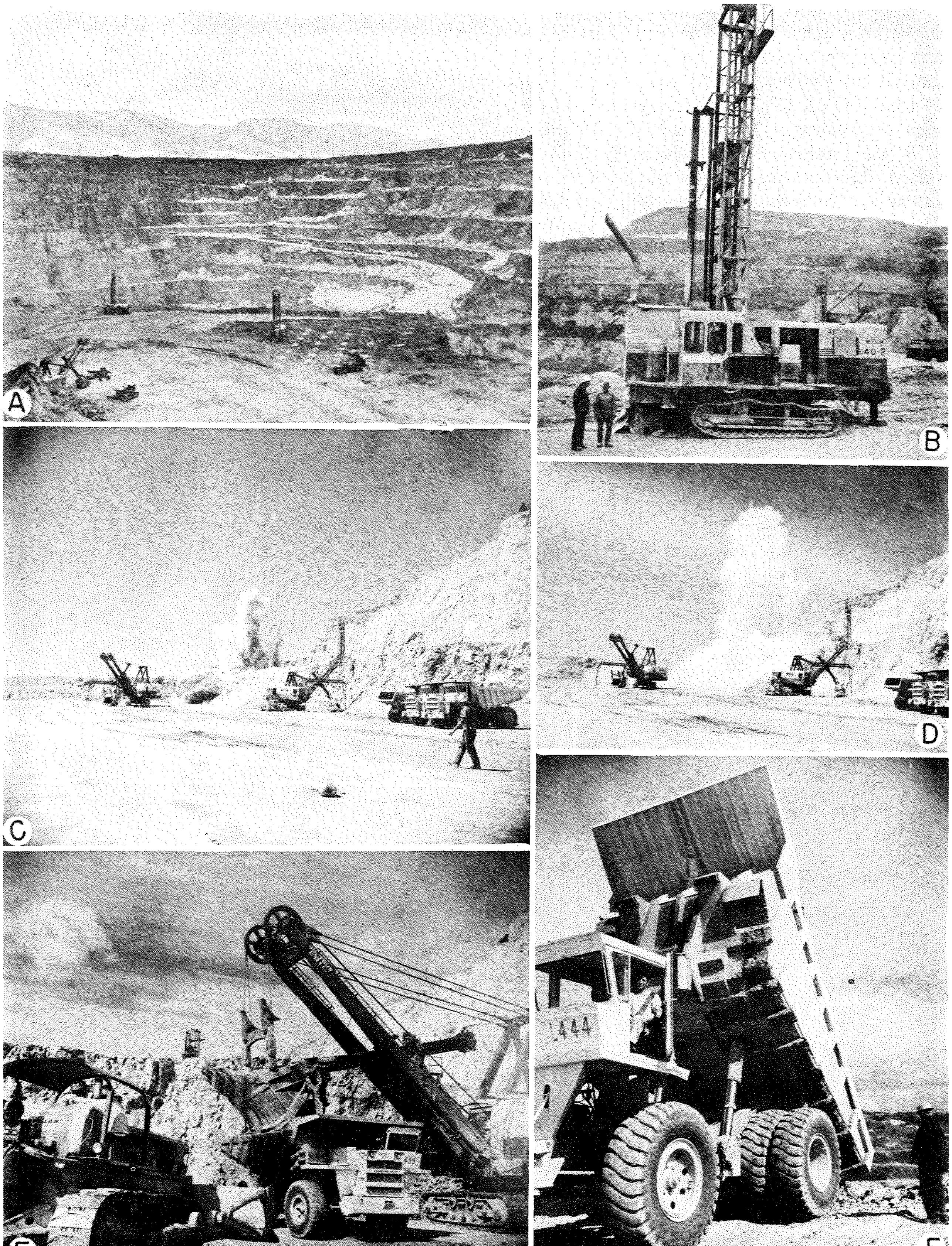
A general view of the pit (A) shows benches and haul roads. A power shovel, trucks, and drills are shown in the foreground. The white piles in the lower center, between the truck and the drill, are sacks of explosives, which will be loaded into the drill holes.

The large electric-powered rotary drills (B) drill holes of 9-inch diameter as much as 42 feet deep in just a few minutes. The first part of a blast is shown in C; D was taken just a fraction of a second later. A blast is not designed to throw broken rock into the air, but rather to break the rock just enough that the power shovels can move it. The white cloud in these pictures is mostly dust. The shovels (C) are 6-cubic-yard electric shovels.

A 13-cubic-yard electric-driven power shovel loads a 65-ton-capacity diesel truck (E). The bucket on this shovel could hold an ordinary automobile and will load the truck with three or four scoops in a couple of minutes. The bulldozer in the foreground is used to clean up loose spilled rock around the shovel so that the tires on the trucks will not be damaged.

Most rock from the pit is hauled to an area well away from the ore deposit and dumped over the bank (F) by 65-ton-capacity trucks.

A. The Berkeley pit in Butte showing haulage roads, benches, and equipment. **B.** Rotary type blast-hole drill used in the Berkeley pit. **C.** Blast at the Berkeley pit. **D.** The same blast a fraction of a second later. **E.** Power shovel loading a 60-ton-capacity truck. The bulldozer cleans up around the shovel. **F.** Waste from the pit is dumped over the end of the waste pile.


A
B
C
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LOADING IN OPEN PITS

Not all operators use equipment as large as that in the Berkeley pit (Pl. 28). Power shovels are used in most large production pits. A 6-yard electric shovel is suitable for loading blasted rock into a 35-ton diesel truck (A). A 2½-yard diesel-powered shovel is adequate for loading an 18-ton truck (B). The pick-up truck in the foreground is a service truck for the shovel. A diesel-powered shovel (C) is effective in remote areas. Truck-mounted shovels have relatively small capacity (D). On the next bench above the shovel a tractor loader is loading a truck.

Another type of loader (E) has the same action as an underground loader. This machine does not have to turn around like most tractor loaders, but throws the load directly up and over the back of the machine into a truck (F).

Tractor loaders are popular in small open pits because they are versatile, can operate in small areas, and they are readily available. When a pit starts large-scale production, however, power shovels usually give the best service.

A. A 6-yard electric shovel loading a 30-ton truck in the Berkeley pit. *(Courtesy Anaconda Co.)* **B.** A 2½-cu. yd. diesel shovel loading 18-ton truck. **C.** A diesel shovel loading waste rock at tungsten mine in southwestern Montana. **D.** A small truck-mounted shovel loading barite in a pit in southwestern Montana. **E.** An overcast tractor loader removing waste rock at the tungsten mine shown in C. **F.** A tractor loader loading tungsten ore at the mine shown in C.

PLATE 29 — LOADING IN OPEN PITS

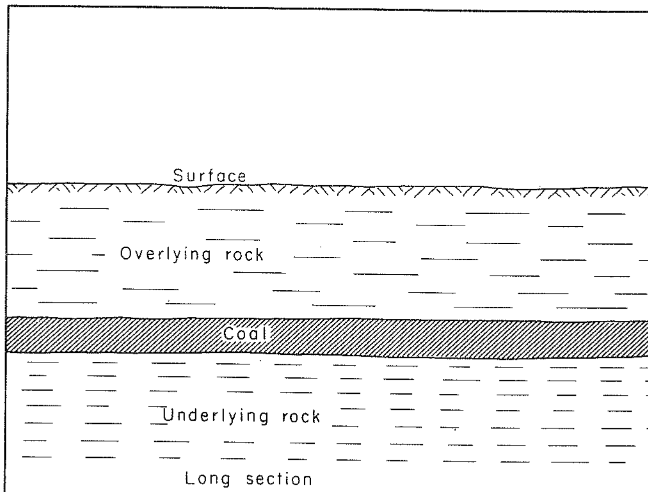
OPEN-CUT STRIPPING

Most bedded deposits lying within a reasonable distance below the surface are recovered by stripping operations. The overlying rock or waste material is first blasted and removed. The valuable mineral thus exposed is then mined. Much coal at Colstrip, Montana, has been mined in this manner, as are some placer deposits, i. e., the worthless overburden is thrown off to the side and only the paydirt is sluiced.

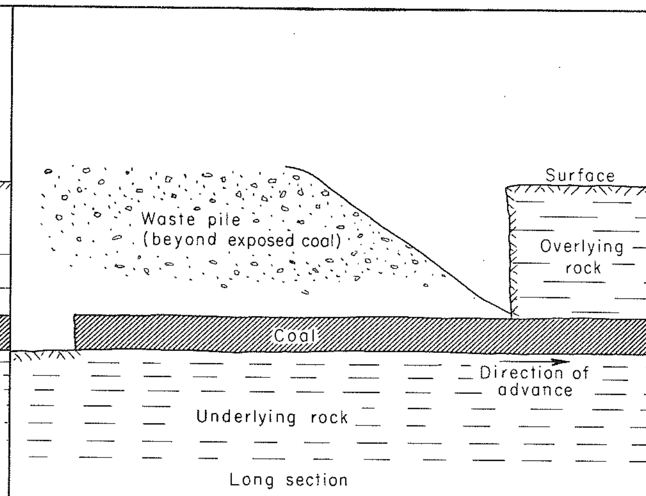
A long section of a bedded deposit is shown in A; B shows this same bedded deposit after part of the waste is removed and cast to the side. (The waste pile is beyond the exposed coal; compare with E.)

Cross sections of the cut show the overburden removed (C) and the coal removed (D). This sequence is shown in more detail in E. The waste rock is cast to the side by the stripping shovel, usually into the area that has already been mined. Draglines may be used instead of stripping shovels to remove the waste rock. As a rule, a dragline has a longer reach than a stripping shovel, and hence can pile the waste higher.

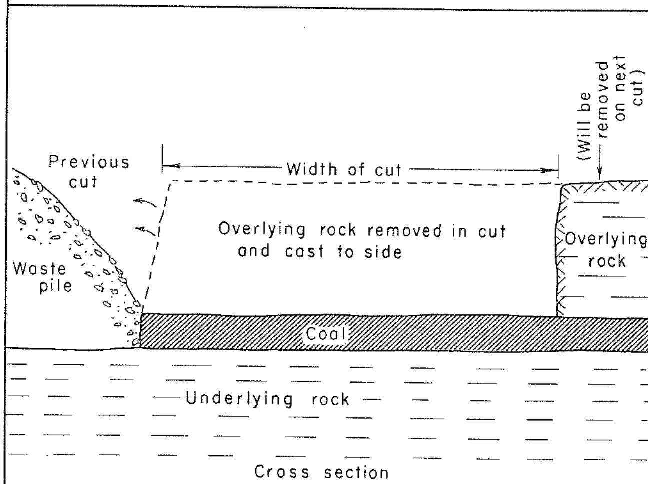
The sequence of stripping operation is shown in F. The stripping shovel started at the left end of the picture and is moving toward the right, casting the waste toward the upper side of the sketch. It is followed by the loading shovel mining the coal. Whenever the shovel turns a corner, a problem arises as to where to cast the waste. It cannot be cast into the mined-out portion until the loading shovel has mined out the coal. On corners it may be necessary to bring in a dragline to move some of the waste out of the way of both the stripping shovel and the loading shovel. After the corner is turned, the going is good—as far as the next corner. Different layouts or arrangements of strip mining are used, depending upon the size and shape of the property, the size and type of excavation equipment, and the type of haulage equipment. Trucks and railroad cars are used for haulage.



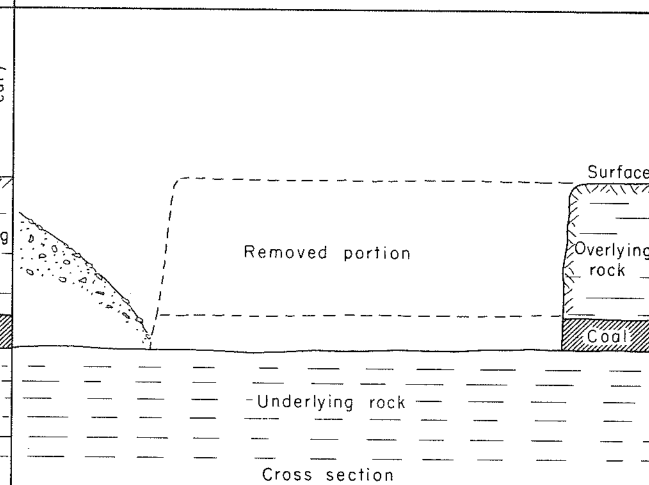
A. Coal seam lying close enough to the surface for stripping operations.



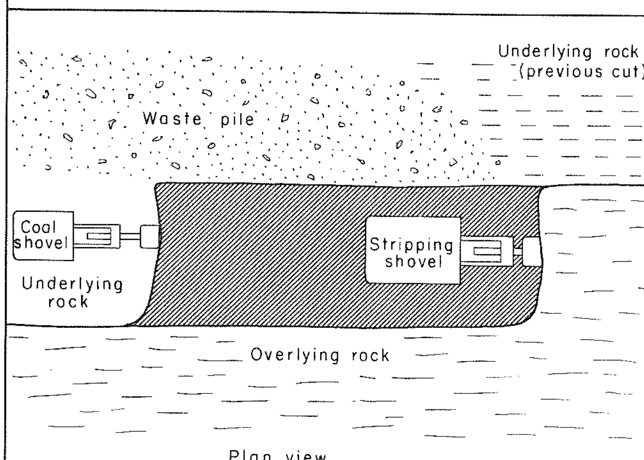
B. Overlying rock is stripped off and cast to one side. Exposed coal is then loaded.



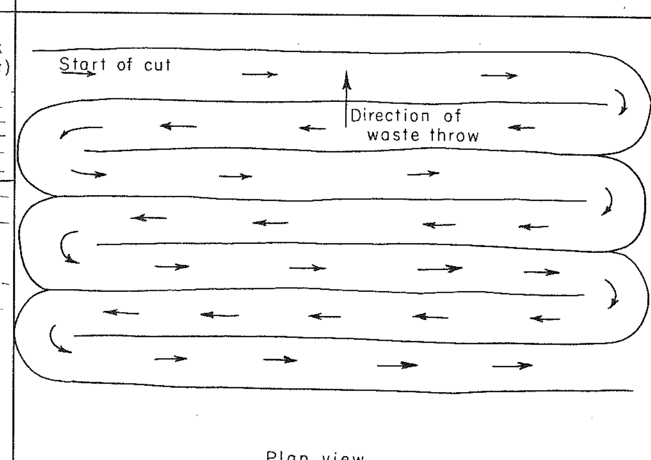
C. Coal seam exposed after overlying rock has been removed.



D. Cut after the coal has been removed.



E. Plan of cut showing stripping shovel working to expose coal seam.



F. Plan of cut sequence to work out a tract of coal land.

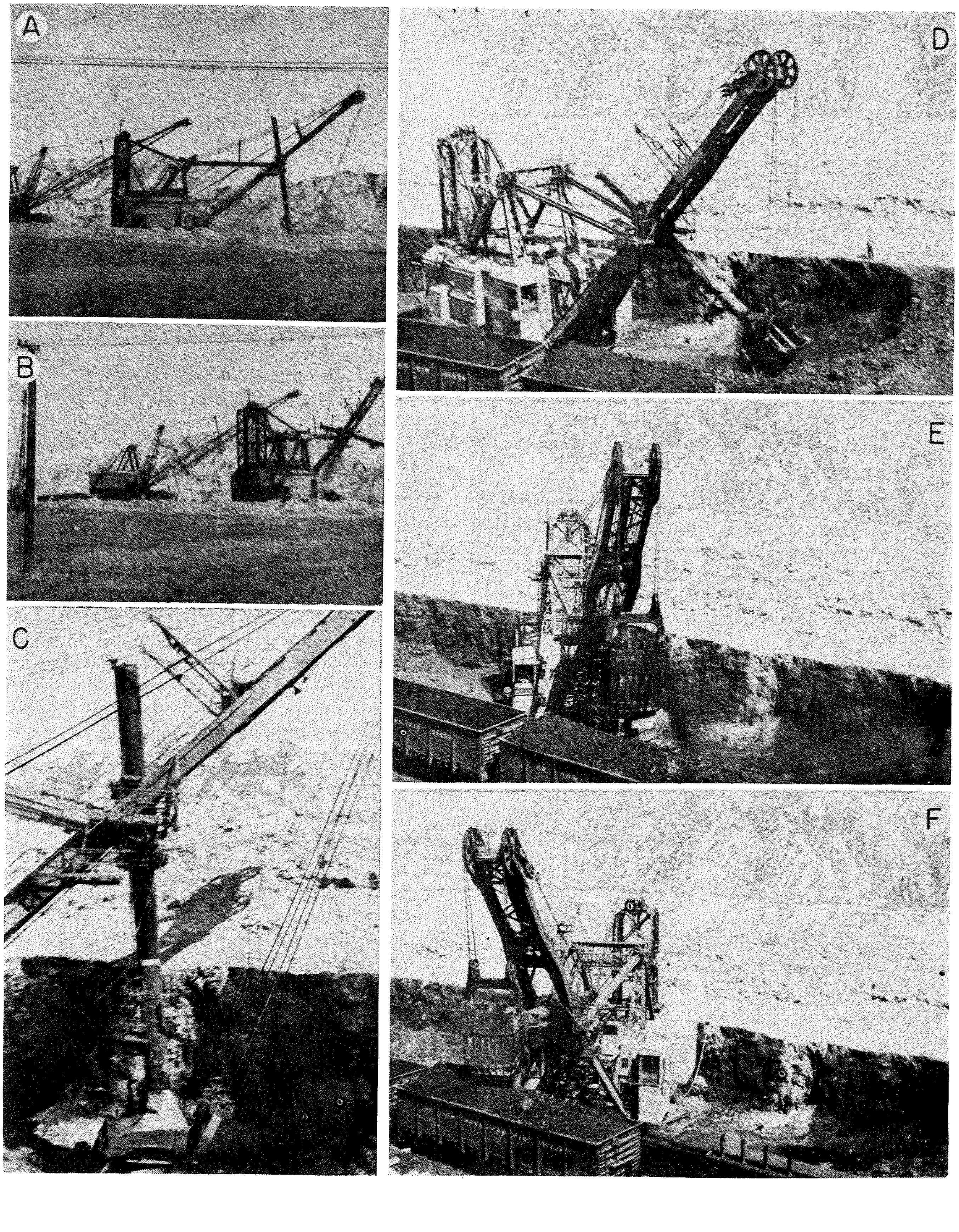
COAL STRIPPING

The pictures in Plate 31 were taken several years ago at Colstrip, Montana. The equipment is large and has tremendous capacity. A 20-cubic-yard stripping shovel is shown in the foreground and a 25-cubic-yard dragline in the left background (A). The shovel is casting a load of waste on the waste pile (B). The machine just to the left of the telephone post is a churn drill, which was used to drill blast holes into the overlying waste rock.

The next four pictures show the loading sequence of the 13-cubic-yard loading shovel. The bucket is digging into coal (C, D), the bucket full of coal is swinging to the railroad car (E), and the load is being dumped into the car (F). It required only three to four scoops of the coal-loading shovel to fill a railroad car completely full.

These shovels and draglines are driven by electric motors of impressive size.

A. Large stripping shovel and dragline used to uncover a coal deposit. The dragline bucket capacity is 25 cu. yd. and the shovel 20 cu. yd. **B.** The shovel casting overburden to the side. A churn drill used for drilling blast holes is at left of pole. **C.** A 31-cu. yd. shovel digging into a coal seam. **D.** The shovel preparing to dig into coal. **E.** Swinging a scoop of coal toward a railroad car. **F.** Dumping coal into the car.


A
B
C
D
E
F

PART 6—UNDERGROUND MINING METHODS

Underground mining methods are usually classified or distinguished from one another by the type of support required in the stope. Supports required may range from almost nothing to heavy timbers supported by sand or mine waste rock. Even in the strongest rock, large underground openings will cave eventually. If the ore is weak and caves readily, a system of stoping is sometimes used that takes advantage of this weakness. Mining methods usually fall into one or more of the following five systems:

1. Open stopes—gophering, glory hole, room and pillar, and sublevel.
2. Cut and fill—horizontal or flat back, rill, resuing, and timbered.
3. Shrinkage.
4. Timber—square set and stull.
5. Caving—topslice, sublevel cave, longwall, and block cave.

There is some overlap. For example, in a room-and-pillar system, timber or stulls may be required to support weak areas. A stope may be started as cut and fill but as the ground gets heavy or weak, timber may be required. Conversely, the timber method may be changed to cut and fill if the workings enter stronger ground.

The general systems will be described in order in this section, except that the longwall system is described after the room-and-pillar system because, in some mines, one may be substituted for the other. Some of the systems described are not presently in use in Montana but some ore bodies may be effectively mined by such methods. For example, in a mine where square-set timber seems to be required, the less costly top slice method or sublevel cave system may be substituted under certain conditions.

Gophering, much used in Montana, is really not a method, but consists of following the high-grade ore wherever it goes. The miner uses only what support is necessary. It is most difficult to picture this system.

The glory-hole system has been almost completely replaced by the sublevel long-hole or the open-pit type of mining.

SYSTEMATIC ROOM-AND-PILLAR METHOD

Coal and other minerals occurring in flat-lying deposits are mined by the room-and-pillar method. It may be necessary to sink a shaft or drive an incline to the deposit (Pl. 5B).

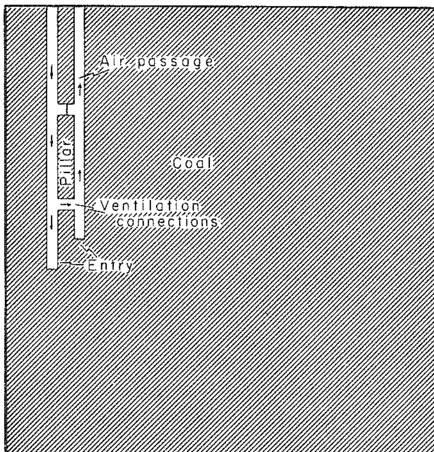
A double entry (entries side by side) driven in the seam (A) provides two passages for ventilation air. In mining coal, large amounts of air are required to dilute below explosive concentration any gases that may be released from the mined coal. Connections are made every so far to direct the air (arrows in A, B, C, and D).

To outline a block of coal, side entries are driven (B). Rooms are started in sequence (B, C) from the side entry, which is extended to prepare more coal for mining. The block is mined as shown in D. Pillars are left between the rooms to support the roof or back.

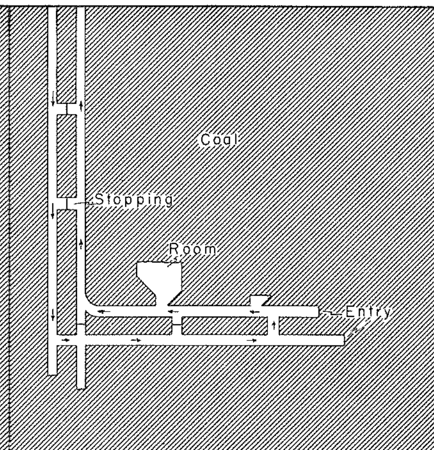
In the room-and-pillar method, 30 to 60 percent of the coal or other mineral remains in the pillars after the rooms are mined. To recover the pillars (E), a pillar (a) is mined by using timber for temporary support and then allowing the area to cave. Then pillars b, b are mined and the ground is allowed to cave. As pillar robbing progresses, the whole mined-out block of ground caves (F). This procedure is called retreating mining because after the pillar recovery starts, no attempt is made to go back into the block. It is allowed to cave and is abandoned.

A model of a coal mine (G) shows a complete picture of the development of a coal mine. The model of a large zinc and lead mine (H) shows a variation of the room-and-pillar system. (This mine is not in Montana.)

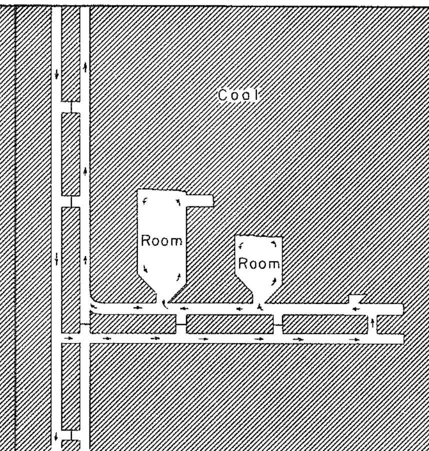
Unless the roof or back stands well, the room-and-pillar system cannot be used. This system produces ore at low cost per ton and is in general use under the proper conditions. The equipment shown in Plate 15D, E is used extensively in this system of mining.



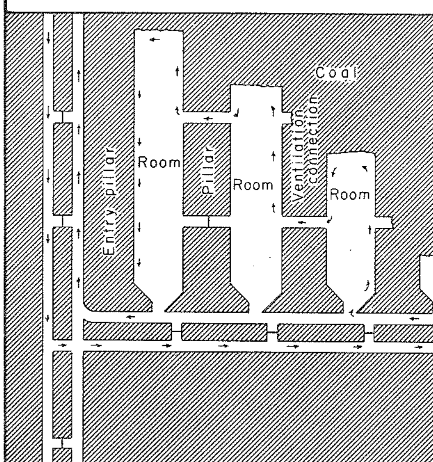
A. Initial development of a horizontal coal seam consists of driving the main entries.



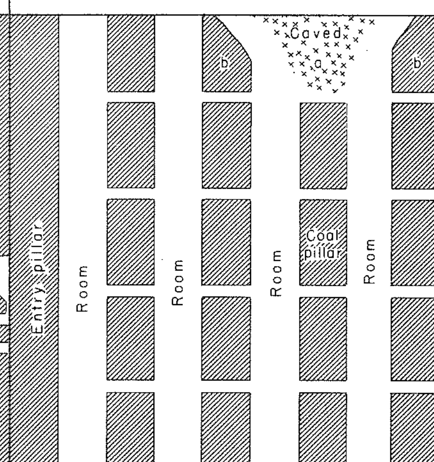
B. Development of a block of coal involves driving entries for mining block.



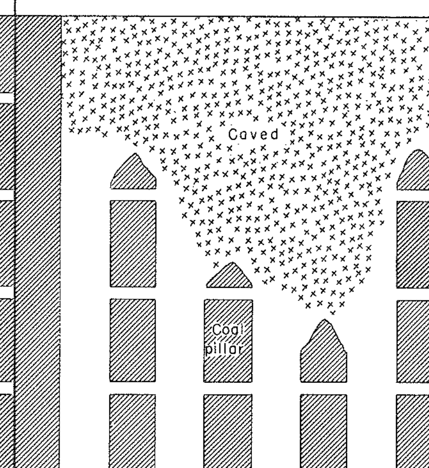
C. A series of rooms is started in the block of coal.



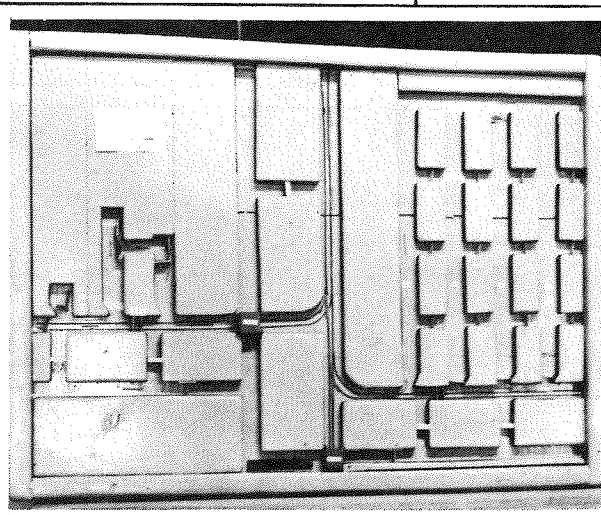
D. Mining the block of coal by driving rooms and leaving pillars for support.



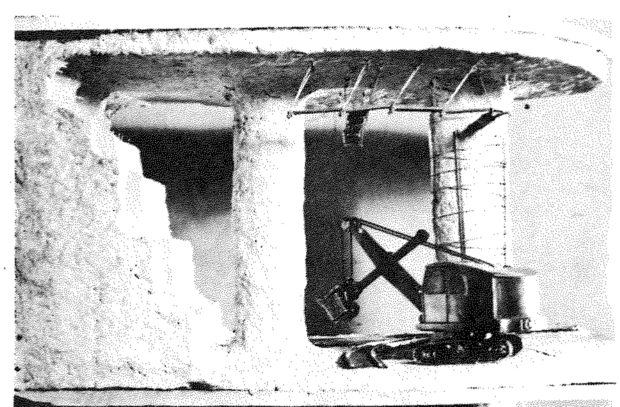
E. The block is mined out by room and pillar. Recovery of pillars is started.



F. Retreating method of pillar recovery. Area caves behind mined pillars.



G. Model of a coal mine showing development and mining of a coal seam.



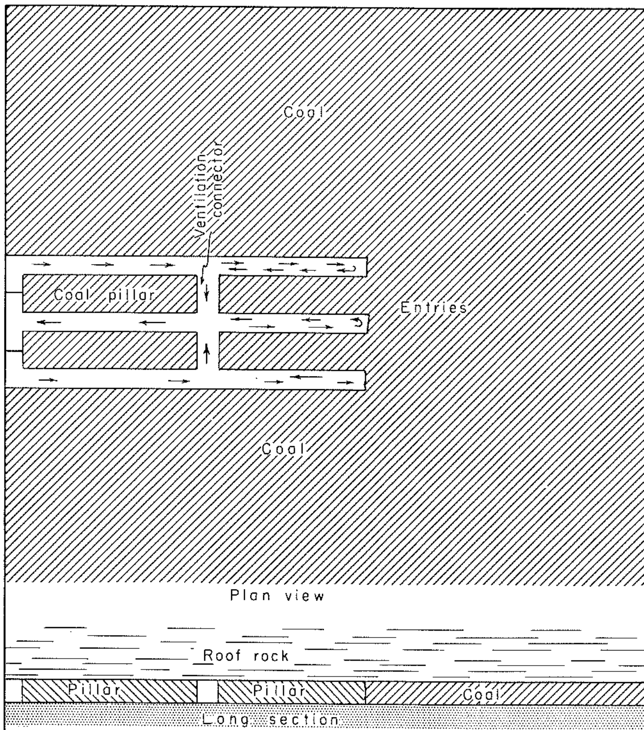
H. Model of a lead mine showing a different system of pillars in a thick ore zone.

LONGWALL CAVING SYSTEM

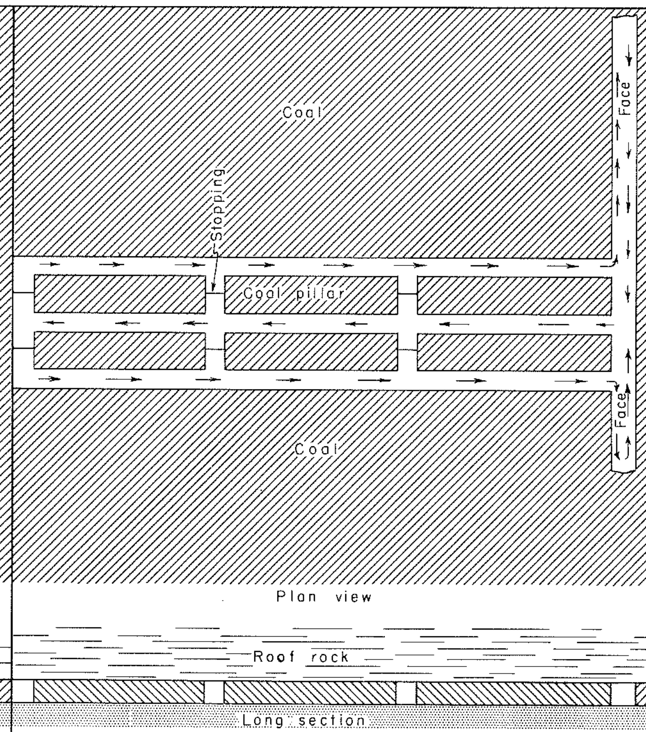
As mentioned in the section on the room-and-pillar system, only 40 to 70 percent of the coal is recovered on the first mining by that method; that is, before the pillars are robbed. To recover almost all of the coal in a single operation, the longwall system was developed. Although this system is not used in Montana, it may find use in the future for mining coal or other flat-lying mineral deposits.

Entries are driven in the seam (A) from the shaft or incline. The deposit is similar to the one shown in Plate 5B. This is a triple entry heading, popular where mining faces are to be driven both ways. The entries are driven to the limit of the block and then longwall side entries are driven in both directions (B). Note both the plan and long-section views in these sketches. The longwall side entries are driven wider, progressing to the left in the sketch (C), which produces a longwall face. The open ground is supported by wooden timbers called props. As the face progresses to the left, the roof in the mined-out area caves. The mining face is protected by the props or other support and by the unmined face (long sections, C, D). This method mines almost all of the coal in the first mining. As a rule, explosive cost is less in this system than in the room-and-pillar system, because the caving action causes some breakage of the solid coal. Equipment used is similar to that used in the room-and-pillar system, but slushers and scrapers can be used to pull the coal from the face. Plate 14B, C, D shows a slusher and bucket in operation.

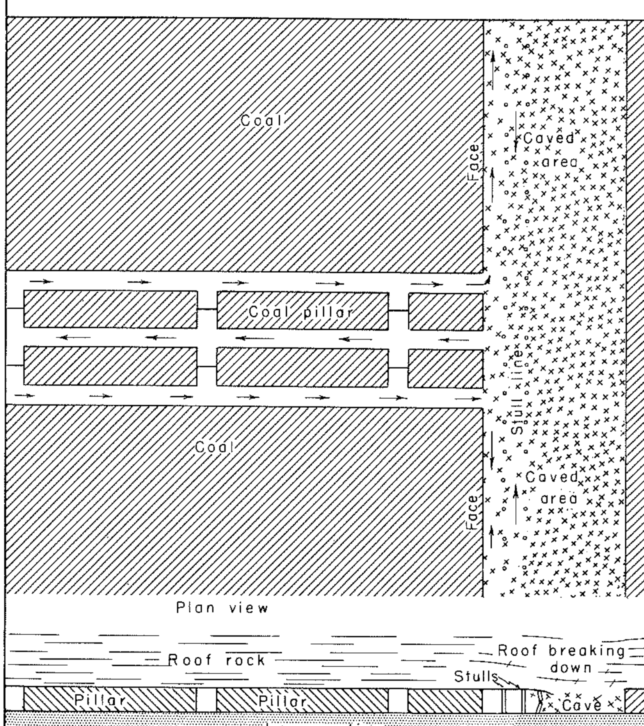
Coal is now being mined in some parts of the country, though not in Montana, with continuous coal miners, which cut, break, and load the coal in one operation, whereas the room-and-pillar and longwall systems generally require that the coal or mineral be blasted. Numerous changes in layout have been made to accommodate these high-production machines.



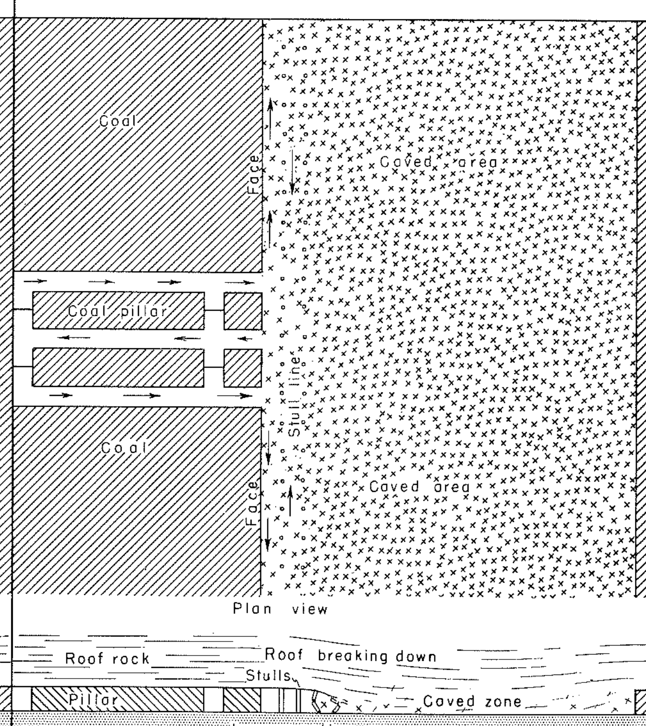
A. Developing a longwall block by driving a triple entry.



B. Developing the end of the block by driving two single entries so a longwall face can be started.



C. The longwall face retreating from the limit of the block. Caving of the roof rock has started.



D. Further progress of the retreating longwall face. The mined-out zone is allowed to cave.

SUBLEVEL LONG-HOLE STOPES

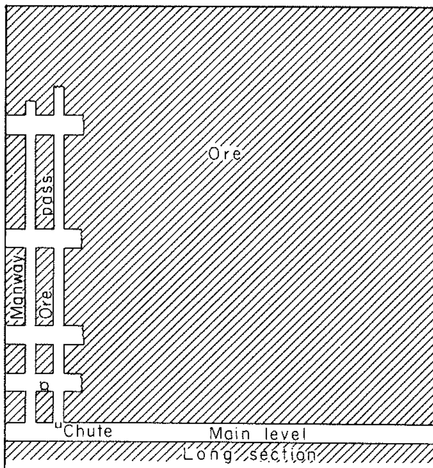
A system resembling room-and-pillar mining can be used in dipping veins (Pl. 5A, E). For steeply dipping veins (50° to 90°), the sublevel long-hole system is popular. The ground, both walls and ore, must be strong enough to stand unsupported over large spans.

A typical development for a sublevel stope is illustrated. A double raise is driven (A); connections are driven between raises, and short levels are driven toward the stope at sublevel intervals. When the raise is completed (B), the slusher drift and lowest sublevel are driven, and the next sublevel and the opening raise are started. The sublevel stope is completely developed (C) when all of the finger raises are belled or funneled out to catch the ore. This method requires much development, but once the stope is developed, mining can proceed rapidly. A three-dimension view of a model of the stope is shown in I.

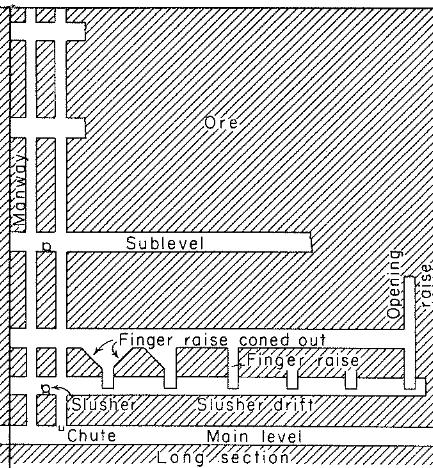
To start mining, it is first necessary to cut a slot across the ore, from footwall to hanging wall. This is usually done by drilling and blasting the walls of the opening raise (C). Once this raise is open from footwall to hanging wall, mining can progress rapidly. The open raise provides a free face for blasting, and lines of parallel holes (F) or rings (G) can be drilled. The blast throws the rocks into the open stope. The whole mining face is advanced toward the manway raise (D, E). Broken ore can be removed from the stope as needed. Should the wall begin to fail, a pillar can be left (E).

A drill (H) is used to drill long holes (F), which may be as much as 60 feet in length.

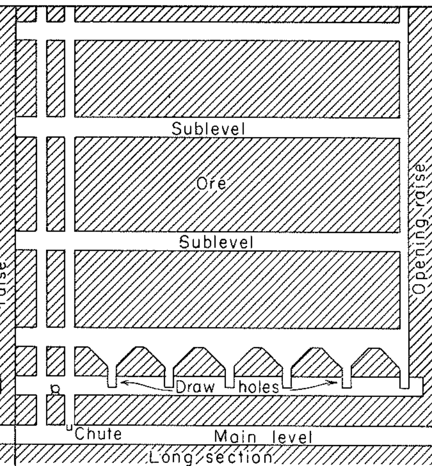
The ore can be removed from the stope in any of several ways. The slusher drift and scraper is shown in this plate, but any of the systems shown in Plate 13A, C, F could be used.



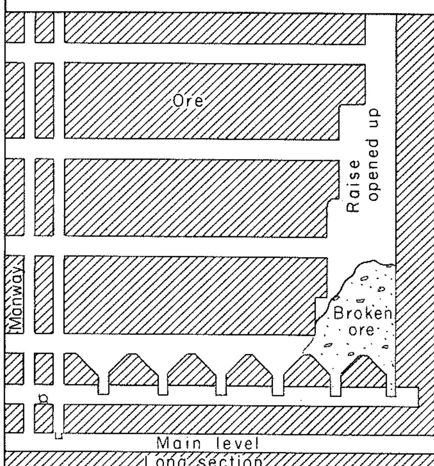
A. Initial development of a sublevel stope consists of driving raises to level above.



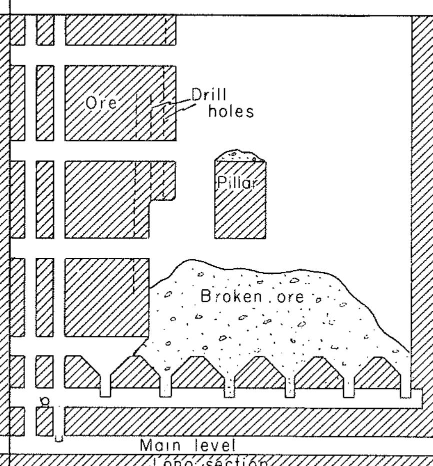
B. Raises are completed. Slusher drift, raises, and sublevel drifts are being driven.



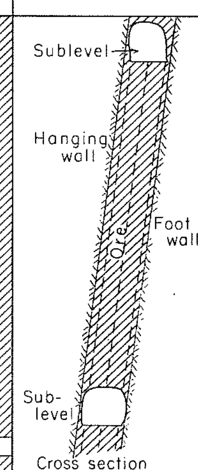
C. Stope completely developed. Opening raise is extended from foot to hanging wall.



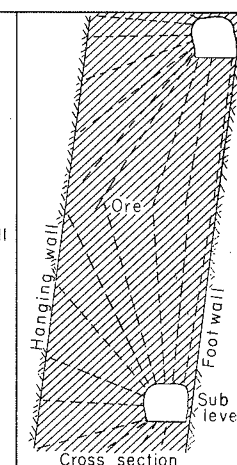
D. Mining in the stope progresses from opening raise toward manway.



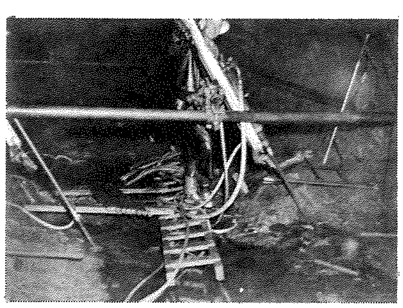
E. Stope being mined. Pillar is left as support for hanging wall.



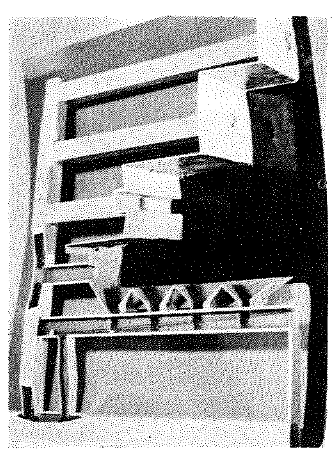
F. Long drill-hole pattern in narrow stope.



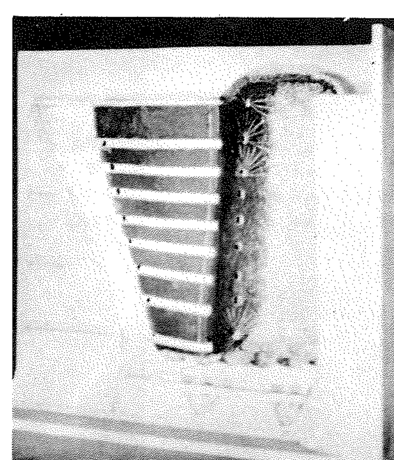
G. Ring drill-hole pattern in wide stope.



H. Long-hole drill in a sublevel stope.



I. Model of a sublevel stope.



J. Model of a sublevel stope showing ore by dark color.

DRILLING IN SUBLEVEL STOPES

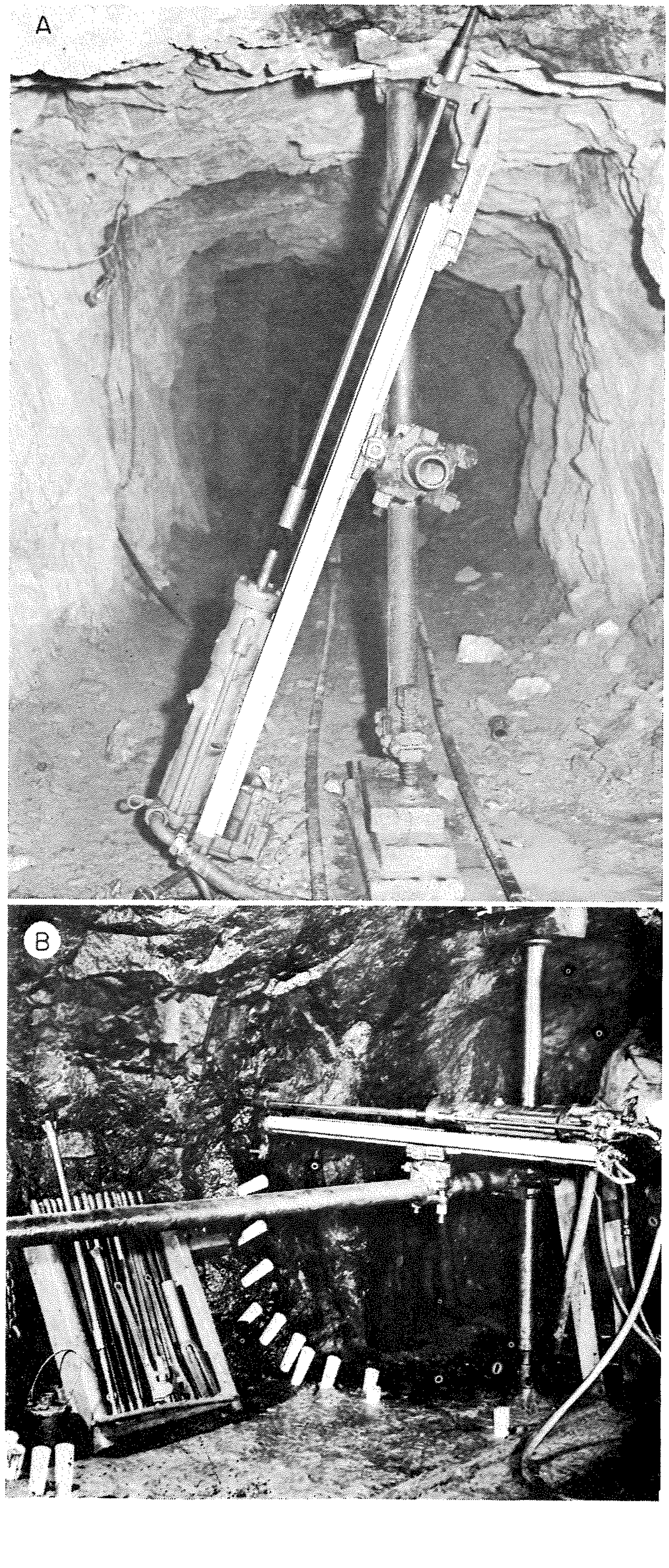
Some ore bodies are pipes (Pl. 5D). In the model (A) of a sublevel stope designed for an ore body of this type, the dark color represents the ore and the white horizontal lines are sublevels. Because the ore body is so wide, it is necessary to use two sets of sublevel drifts.

Special long-hole drills (B) are used to drill the deep holes necessary for this system. Designed to drill with sectional steel, this drill can drill a hole 4 feet deep as it travels up the track. When the drill reaches the upper end of the track, the coupling is unscrewed and another 4-foot length of steel is inserted in the machine. Alternatively, the 4-foot length is unscrewed and an 8-foot length inserted. These machines can drill as much as 100 feet.

Ring drilling is shown in C. The finished holes are plugged. The distance between the rings of holes is called the burden on the holes; it is the distance between the explosive and the free face. The machine is of slightly different construction than the one shown in B.

Sublevel mining, where applicable, has the advantage of producing ore at low cost, and the safety features of the system are good. Holes can be drilled and blasted as the ore is needed.

A. A special long-hole drill used for ring drilling. Note sectional steel and connectors. **B.** Ring drilling in a sublevel stope. The drilled holes are plugged to keep them clean.


A
B

OPEN-STOPE MINING IN GENTLY DIPPING VEINS

Some bedded ore does not dip steeply enough to permit mining by sublevel methods because the broken ore will not run down the footwall. Therefore, it is necessary to scrape the ore down the stope.

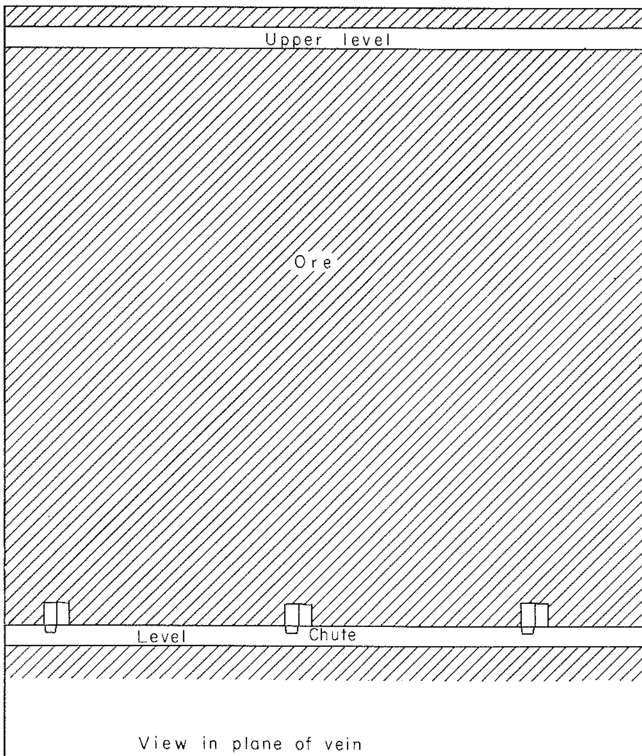
The haulage level may be driven in the footwall just below the ore (D). Chute cutouts are made at intervals (A). After the chutes are installed, the short raises are widened to full stoping width (B). The stopes advance in stairstep fashion (C) to reduce the effects of ground pressure in the stope faces.

As these headings are blind, i. e., not open to the level above, it is necessary to break into the neighboring stope for ventilation (C). Air is circulated through the stopes by fans in these connections.

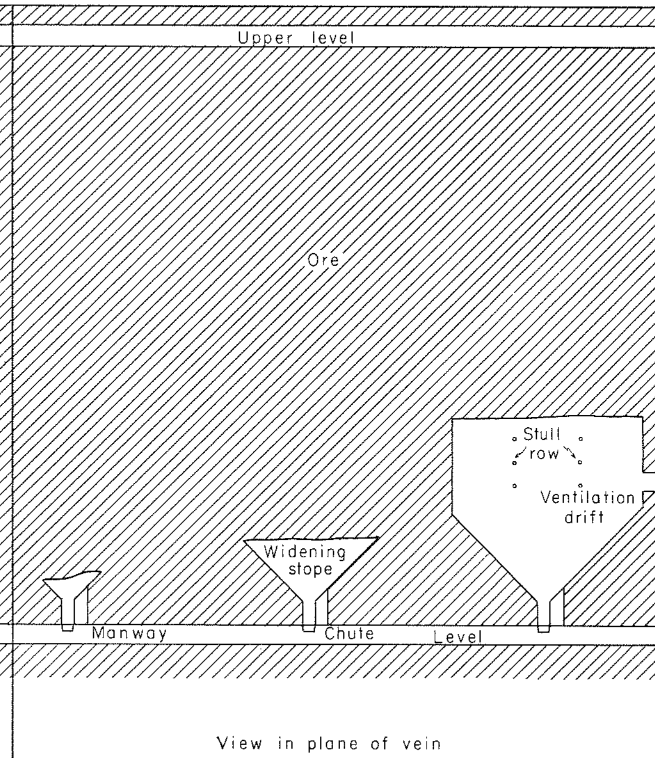
The system shown is actually a combination of timber and pillar methods. Narrow pillars separate the stopes, which would be called rooms if the deposit were horizontal, but two or three rows of timber stulls in the stope help to support the center until the stope is mined (B, C). These stope faces can be 70 feet or more in width, depending on the strength of the ground.

A question may arise as to how steep the stope must be for the ore to run by itself. Theoretically, ore will run if the slope is steeper than the angle of repose of the broken rock. The angle of repose is the angle (measured from the horizontal) that the sides of a pile of the material assume naturally. For broken rock this angle is close to 40°. Therefore, if the ore is hard, it should run of its own accord at angles exceeding 40°, but if it contains much clay, it may require a steeper angle.

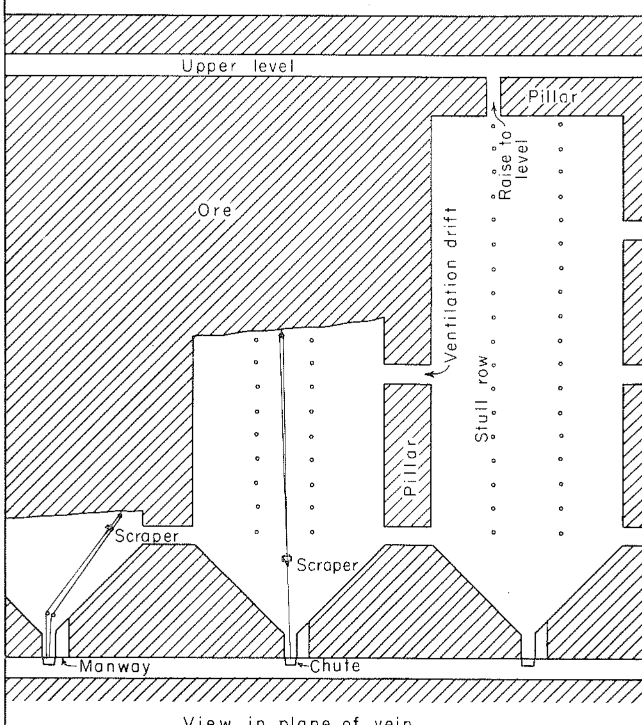
Production rates per man shift compare favorably with those of other underground mining systems; this is regarded as a low-cost underground method. The basic requirement is firm strong walls, which will stand unsupported over large spans.



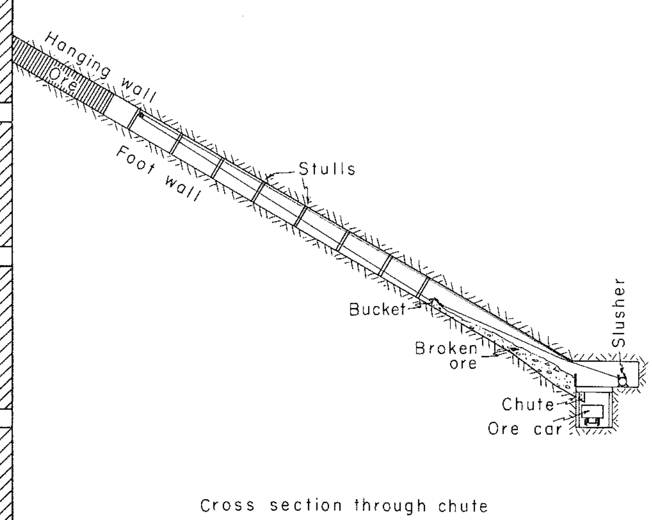
A. Initial development of a block of ore in a gently dipping vein.



B. Starting a sequence of stopes in the block of ore. Stulls provide support.



C. The stope on the right has been mined out. Ore is removed from stopes by scrapers.



D. Slusher and scraper system as used in gently dipping veins.

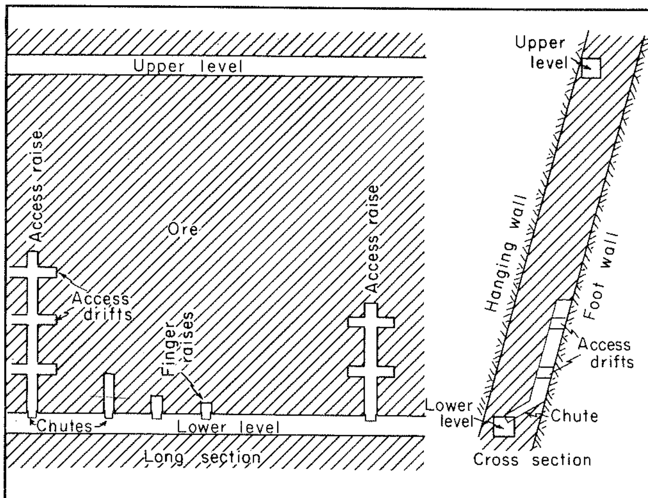
SHRINKAGE STOPES

The shrinkage method can be employed in steeply dipping veins if the ore and walls are strong and self supporting. Broken ore is left in the stope to provide a working platform for the miners. Because breaking the ore increases its volume by 40 percent or more, some ore must be pulled out of the stope as mining progresses, otherwise the broken ore would choke the stope.

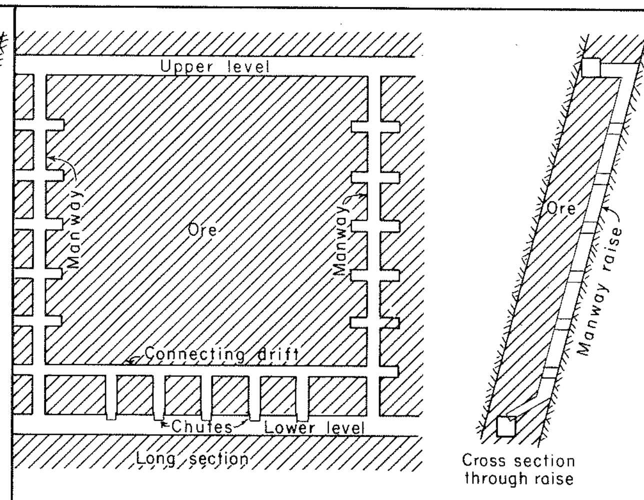
At each end of the planned stope, raises are driven through to the level above (A), and small drifts are driven at about 20-foot intervals to provide access to the stope as mining progresses upward. This stope is being developed with chutes at the mouth of draw holes. Not all shrink stopes are developed in this fashion. Timbered or cribbed raises at each end of the stope may be used instead of unsupported raises, and the short drifts are not driven. To gain access to the stope, the sides of the raise are removed. If raises are not driven through first, they must be carried up with the stope. The stope shown in B is fully developed except that the chute raises are not yet coned or funneled out.

After the chute raises are funneled out, mining is started (C) and progresses back and forth across the stope (D). Air-leg drills are commonly used in these stopes, and a bench as much as 15 feet in length can be drilled and blasted in one shift. The series of benches across the stope makes one vertical cut in the stope. In pulling broken ore away from the solid ore face to provide working room, caution must be exercised not to pull too much, or the miners cannot reach the working face. When the stope is completely mined out (E), it is full of broken ore, which is then removed (F). Commonly a pillar is left near each level so that the drift will not be destroyed. The stope may be filled with waste at some later time. The pillars may or may not be recovered.

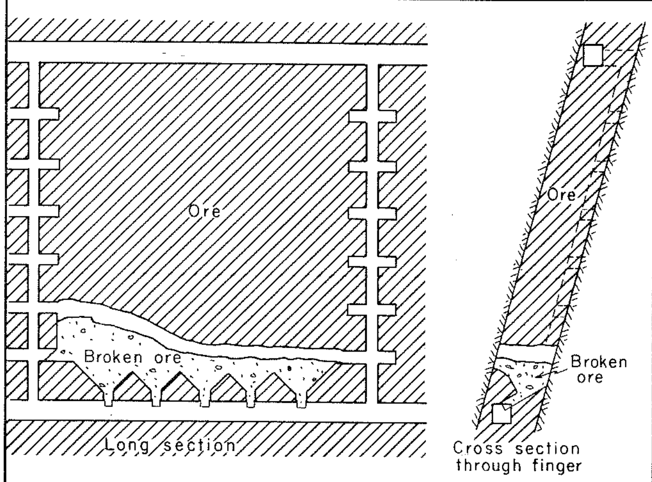
The shrinkage method gives a large production per man shift because scaling, drilling, and blasting are the main operations. The stope must be carefully mined to avoid losing time by under pulling or over pulling. A big disadvantage is that a large amount of mined ore must remain in the stope until mining is completed.



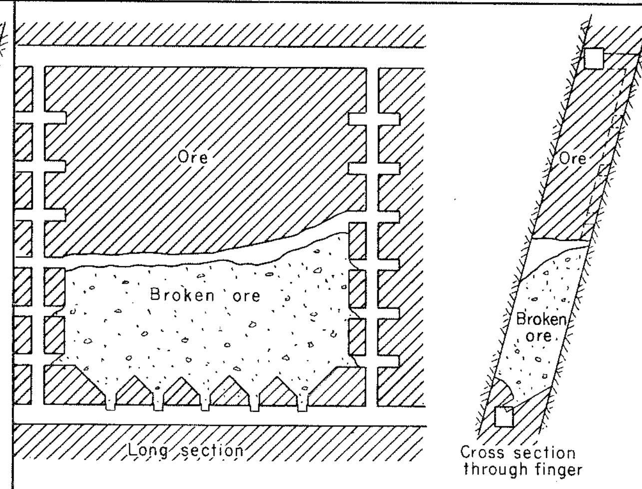
A. Driving raises and fingers to prepare a shrink stope for mining.



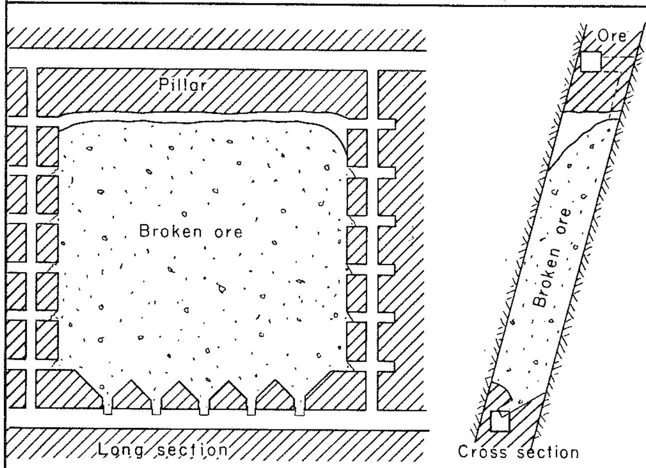
B. Stope developed and ready to be mined.



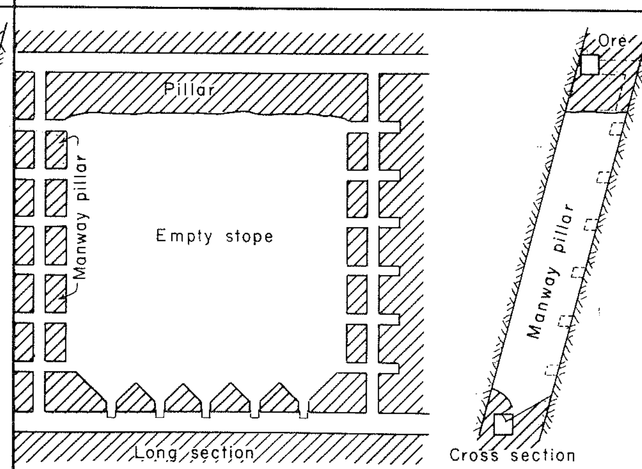
C. Finger raises are belled out and mining has started.



D. Mining progresses in the shrink stope.



E. Mining is completed but the stope is still full of broken ore.



F. All broken ore pulled from stope; mining of this stope is completed.

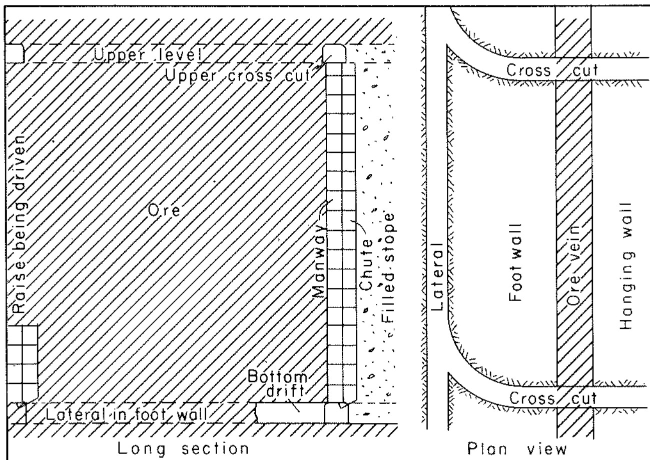
HORIZONTAL CUT-AND-FILL STOPES

In a cut-and-fill stope, a cut of ore is mined and waste is brought in to support the walls of the mined-out portion of the stope. Plate 38 shows this method developed by a lateral driven in the footwall and crosscuts driven into the ore zone at intervals (A). From the crosscuts, raises are driven in ore to the level above. A drift is driven in the ore to connect two crosscuts at the bottom haulage level. When the drift connecting the two crosscuts is completed (B), mining is started, and the mined-out portion is filled with waste. A series of benches is drilled and blasted across the stope (C) from one raise to the other, which completes a cut. The broken ore is left in the stope after each blast unless some of it must be removed to make room for drilling. After the cut across the stope has been completed, the broken ore is scraped out of the stope to the ore pass on the left side of the sketch (D). After the ore has been scraped out, waste rock is dumped down the raise on the right from the level above. The waste is scraped into the mined-out portion by the slusher (E). The waste is not piled completely to the back, as room is needed for the expansion of blasted ore. Mining of the stope progresses upward (F).

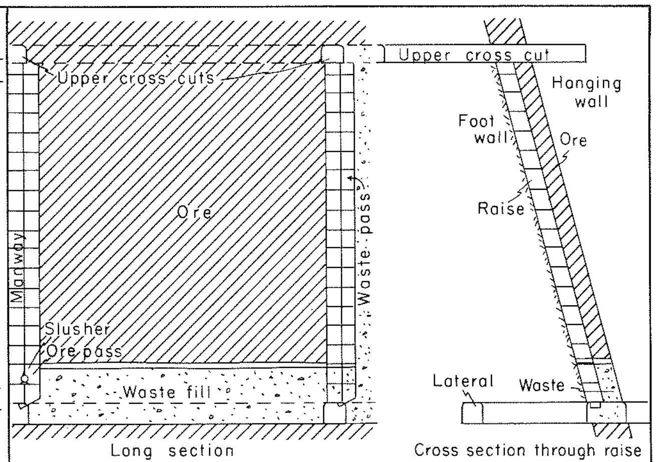
The cut-and-fill method can be used only if the ore is fairly firm and the walls will stand unsupported until waste fill is brought in.

Sand is now commonly used instead of waste for support in cut-and-fill stopes. Sand can be brought into the stope as a water slurry in a pipeline. This reduces the scraping required in the stope. The sand fills all voids and forms a tight compact support after the water has drained away. Stopes of this type are shown in Plate 40C, D.

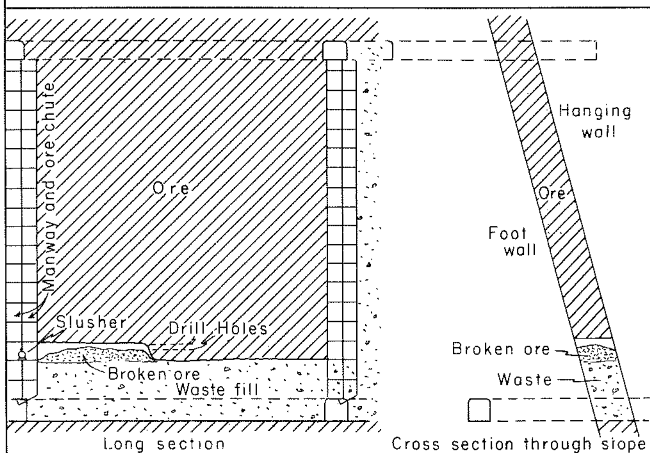
As a general rule, a floor is not built on top of the waste fill to keep the ore and waste separated. Repeated building and removing of a floor would cost more than the value of any ore lost in the waste fill.



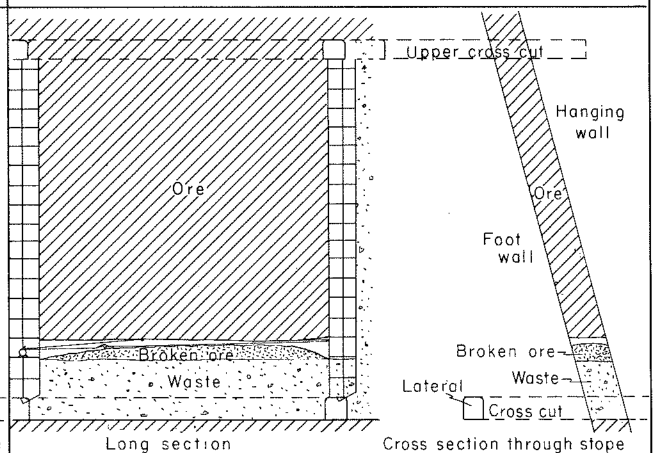
A. Initial development of a cut-and-waste-fill stope involves driving 6-post raise and bottom drift of stope.



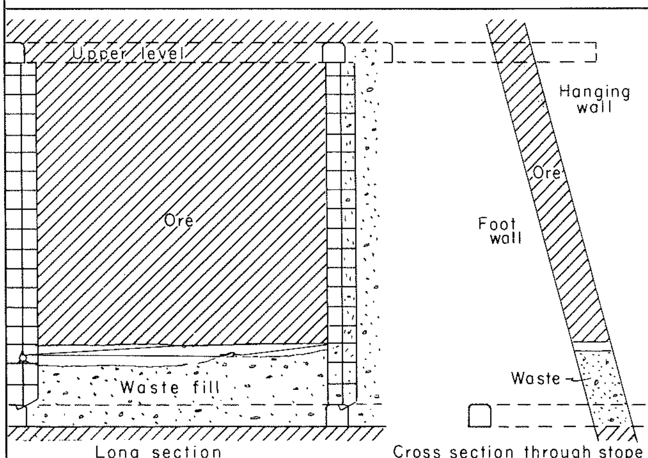
B. Stope during mining cycle. Sill and bottom two floors of stope are filled with waste.



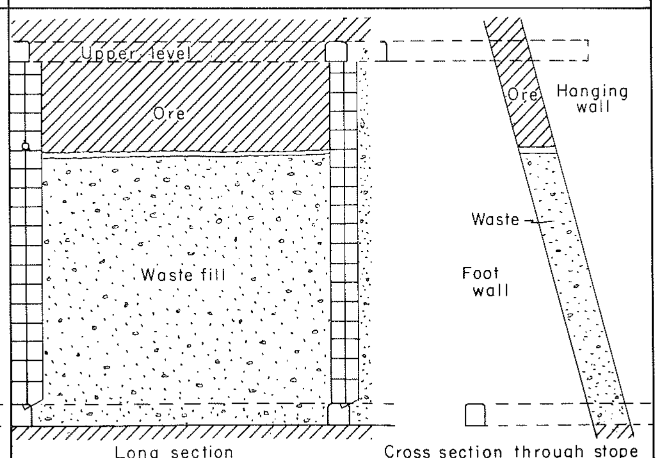
C. Breaking another cut across the stope. Only enough broken ore is removed to give working space for drilling.



D. Breaking cut completed across stope. All of the broken ore is next removed.



E. After all broken ore has been removed from the cut, waste rock is slushed in to fill the open space.



F. Stope cut filled with waste and ready for next cut. This view shows work much higher in the stope than E; several cuts have been made.

RILL OR INCLINED CUT-AND-FILL STOPES

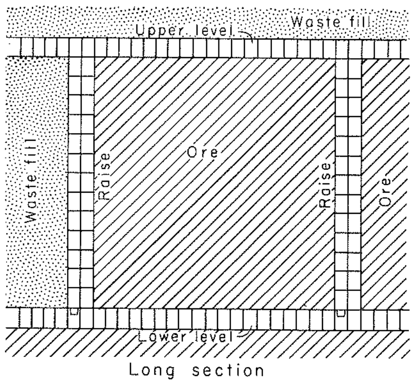
Efficiency in a cut-and-fill stope requires a slusher and scraper. Before the widespread use of slushers and scrapers, the rill stope was devised to use gravity to move the ore and to emplace the supporting waste fill. This system is seldom used today, but in special situations in a small mine this system could be used efficiently. Mining equipment may be at a premium in a small operation, and slushers and scrapers may not be available.

The rill stope is developed either by driving a raise at each end or by utilizing the raise of the previous stope (A) and driving a raise at the other end. The lower corners of the stope are mined, and waste is brought down from the level above to fill the corners (B). The waste flows in and stops at its angle of repose. When the ore is broken, it slides down the top of the waste pile into the drift or into a chute (F).

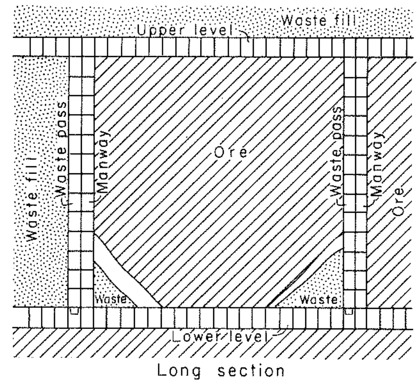
In this system, a center 8-post raise is required, but it is usually brought up as the stope is mined (C). A cut is started in ore and is taken up from the center raise (D). The ore is held in place by timber stops placed against the timbers of the raise. The miners work from the pile of broken ore. After the cut is completed (left side, D), the ore stops in the center raise are pulled out and the ore slides into the ore pass. When all of the ore has been removed, the stops are permanently placed against the center raise and waste is run into the stope from the level above (E).

Common practice is to mine in one side of the stope while the other side is being emptied of ore and filled with waste (D, E). After one side has been filled with waste, mining will start on that side, while the other side is being drawn of ore and filled with waste.

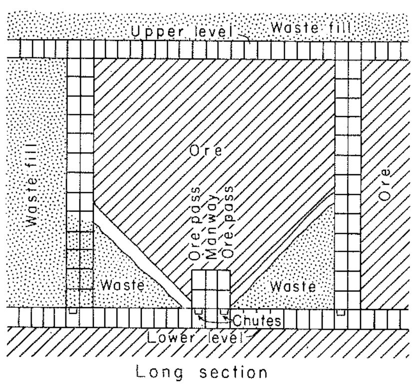
The ore must be strong enough to support itself over the long opening. The walls should stand over the unsupported height until fill can be placed. The ore should run well at the angle of repose and should be free of sticky clay.



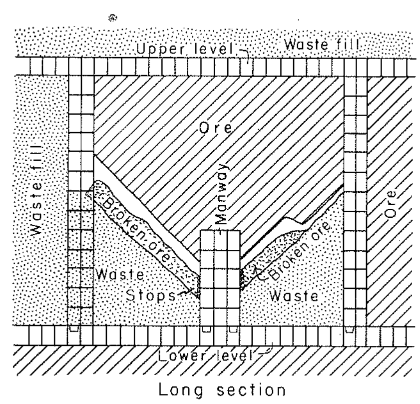
A. Rill-type stope developed with raises at each end.



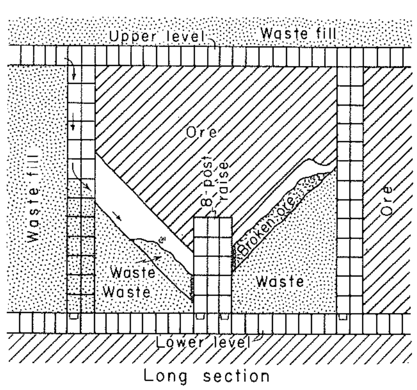
B. End cuts are being made and the mined portion filled with waste.



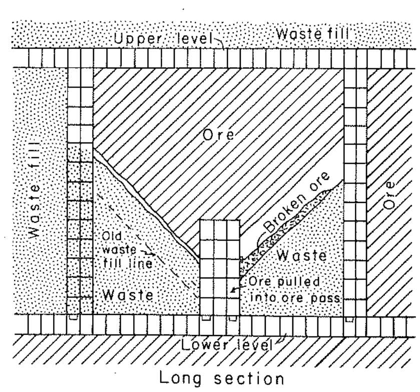
C. End cuts have progressed far enough that the 8-post center raise is started.



D. Stope in mining cycle showing the ore-breaking process.



E. In cut on left the ore has been removed and waste fill is being introduced.



F. Cut on left has been filled with waste, and ore is being removed from cut on right.

MINE MODELS

Picturing a mining method in two dimensions may be difficult unless a model of the system is made.

The models pictured in A show a very wide cut-and-fill stope. Ore passes at certain intervals in the stope are shown on the left side as light-colored semi-circular openings. The fill is below the horizontal opening or cut, and the ore is above this opening. Waste pass raises, one of which is shown, are driven to the level above. The model on the right in A shows a timbered system, which is used when the stope approaches the upper level. The ore must be very strong if this system is to be successful.

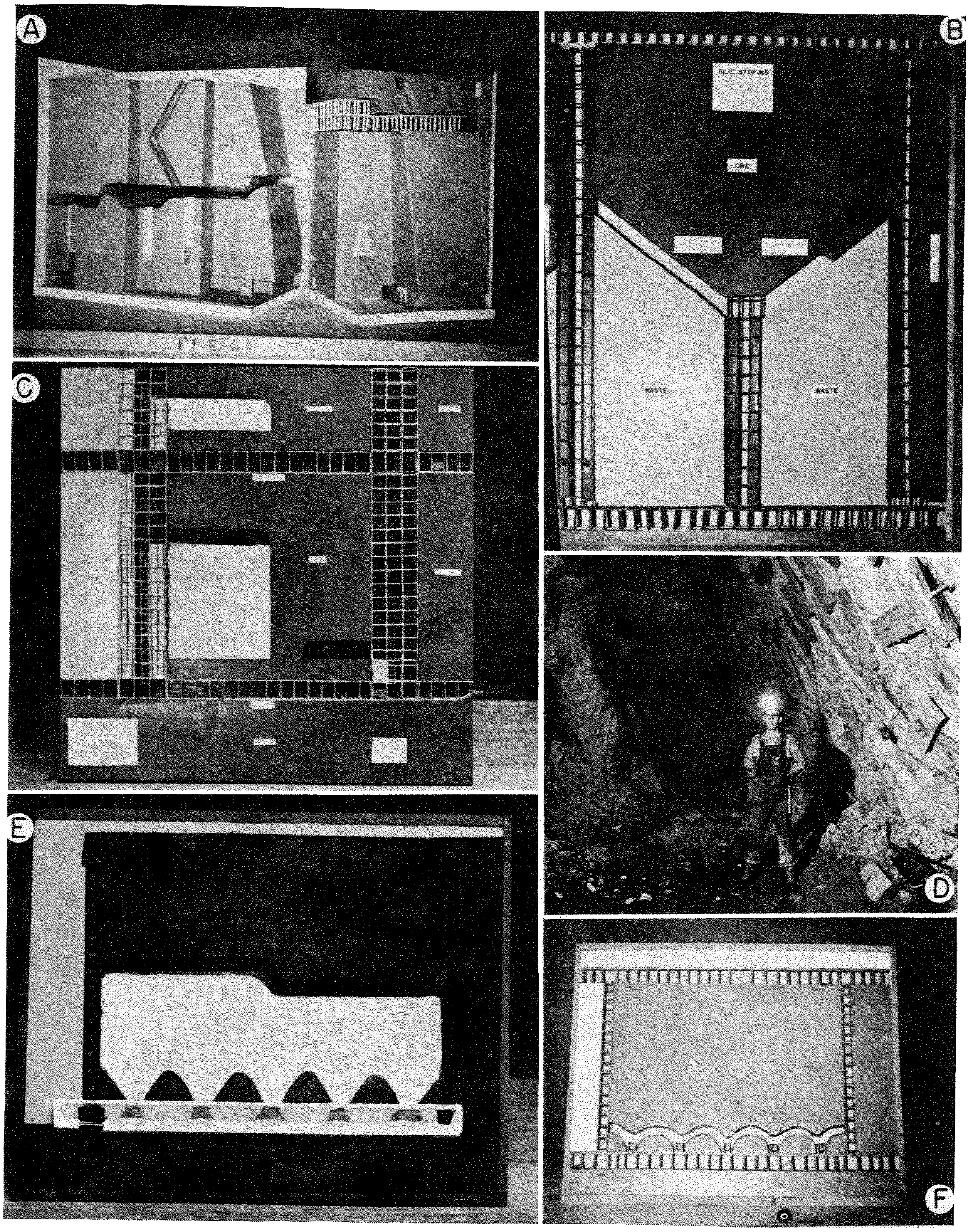
The model pictured in B is a rill stope system, which is the system explained in Plate 39.

The model pictured in C is a cut-and-hydraulic-emplaced-fill system showing several stopes. The white portion represents fill and the dark part is ore. The stope on the lower left is ready for fill; the stope in the upper left has been filled and is again ready for mining. The first cut in the preparation of a stope is shown in the lower right. When the sand fill is emplaced, it sets almost like concrete, and therefore the ore is mined horizontally in the first cut toward and to the waste already emplaced in the stope on the lower left.

The picture (D) shows how the stope looks when all of the ore is removed and the stope is prepared for filling. Note the rock bolts and headboards supporting the ore back and the hanging wall. The manner in which the raise is prepared in order to stop the sand from flowing down the raise is shown in Plate 12F.

A slusher drift to drain ore out of the stope is shown in E. The white represents broken ore, and the dark represents unbroken ore, which is to be mined. A shrinkage stope prepared with chutes through which the broken ore is drawn out is shown in F. The chutes are belled out, the raises are completed, and the stope is ready for mining.

A. Models showing cut-and-fill stope method used in wide veins. Model on right shows conversion to timber. **B.** Model of rill stope. **C.** Model showing hydraulic stope fill; stopes in different stages of operation. **D.** Cut-and-hydraulic-filled stope in Butte. *(Courtesy Anaconda Co.)* **E.** Model of shrink stope. As mining progresses, ore is removed from this stope through slusher drift. **F.** Model of shrink stope just as it is ready for mining.


A
B
RILL STOPING
ORE
WASTE
WASTE
C
D
E
F

RESUING METHOD

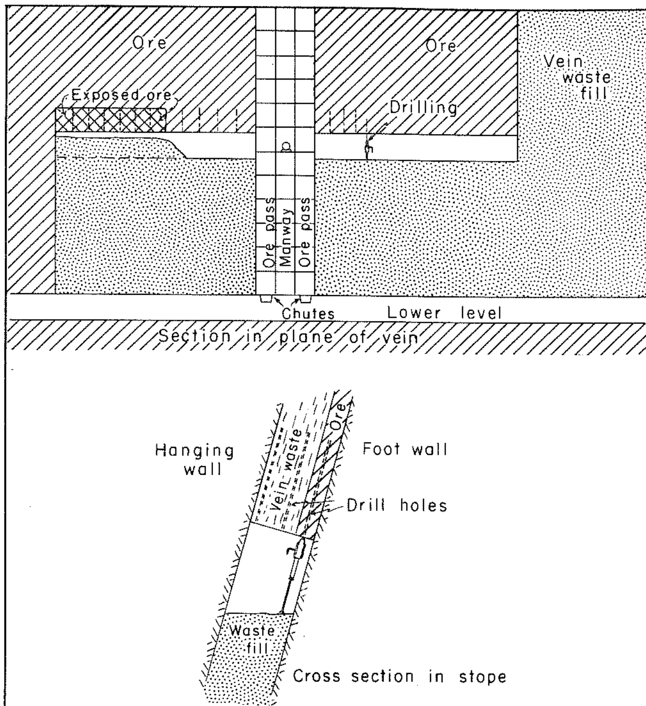
Much high-grade ore occurs in narrow veins, but to mine the ore it is necessary to have sufficient mining room. The high-grade ore is not rich enough to pay for hauling waste to the smelter or mill, and hand sorting the waste from the ore is ineffective, tedious, and expensive. The resuing method is an attempt to keep the ore and waste separated during mining.

The sequence of operations is shown in Plate 41. When the stope has been started (A), the ore and waste are drilled (cross section). The waste is loaded and blasted first (cross section, B). The waste is leveled off and if the ore is high grade, a wooden floor may be laid on the waste. The ore is then blasted down and scraped out of the stope (C). After the ore is blasted down, the stope is ready to be drilled again (cross section, D).

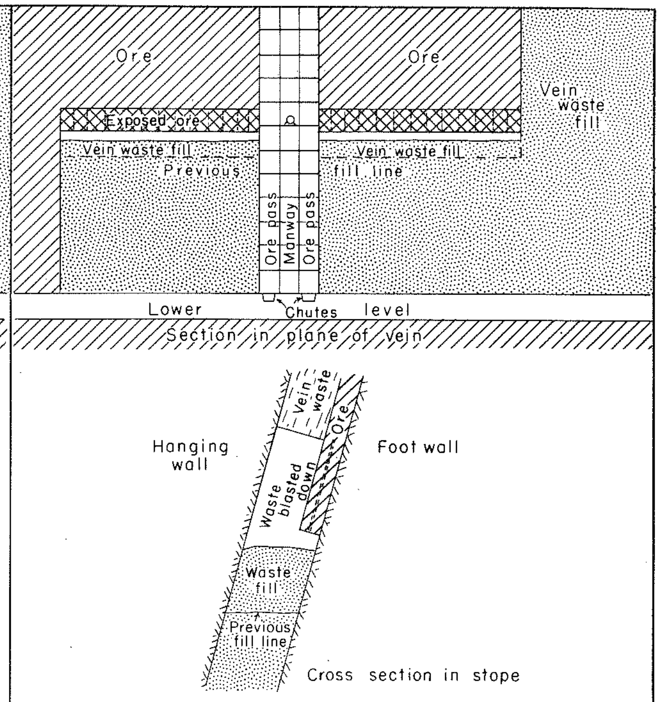
Production per man shift by this method is low, but the ore is not diluted with waste. The walls and the ore must stand very well, or stulls may be required. Keeping the ore from breaking with the waste may present a problem.

Sometimes the ore is blasted and removed before the waste is blasted down. Usually a trial-and-error approach must be used to determine whether the ore or waste should be blasted first.

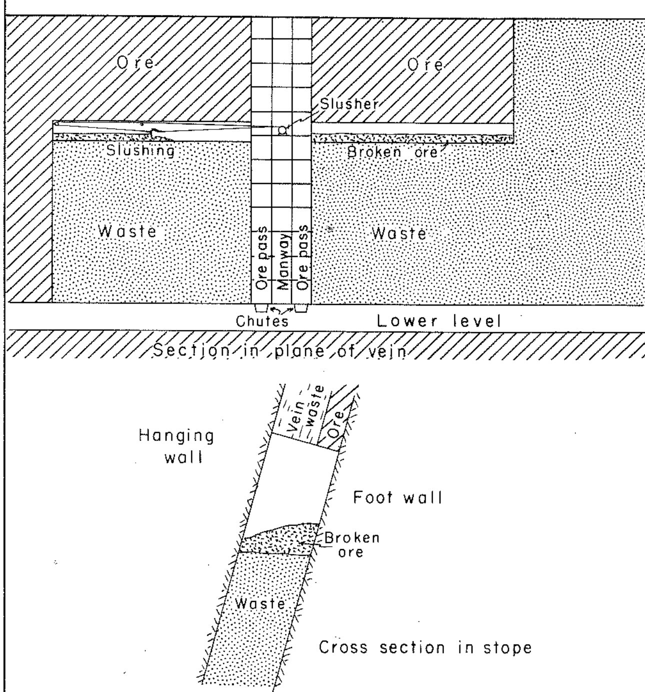
If the waste is insufficient to fill the mined-out portion, a raise may be driven in the hanging wall to provide additional waste for fill. Another plan of a resuing stope is shown in the picture of a model, Plate 48E.



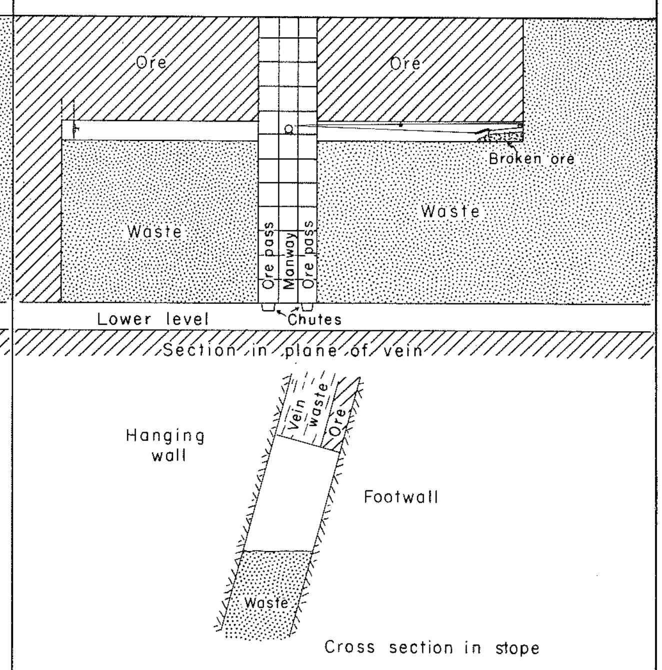
A. View of resuing type stope showing drilling operation.



B. View of same stope after vein waste is blasted into stope and levelled.



C. View of same stope after ore is blasted down on waste filling.



D. Ore scraped out; drilling cycle can start again.

SLOT TIMBERED METHOD

The slot method of mining is a systematic way of mining and filling wide stopes. A raise must be driven from one level to the next. This raise extends from the footwall to the hanging wall of the vein and is termed a slot raise. The entire width of the vein is mined. Usually only three sets of timber are advanced along the strike of the vein in each stope. During mining, it is necessary to maintain a waste pass from the level above and an ore pass to the level below.

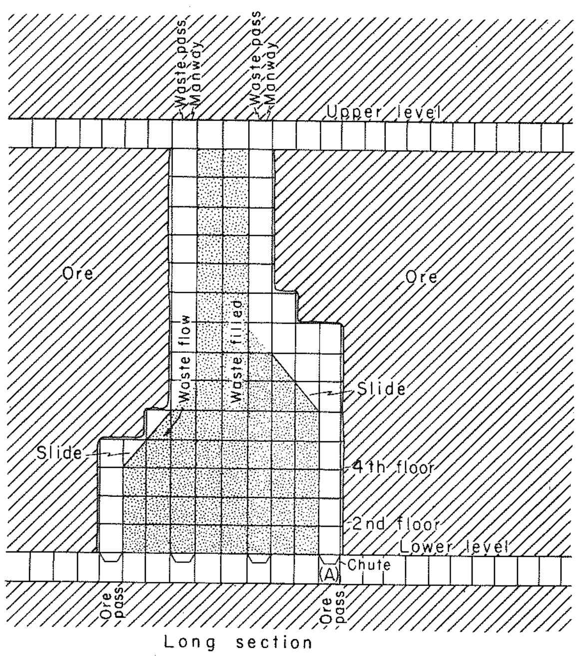
The sequence of operations is depicted in Plate 42. In A, one slot stope has been mined through and two more stopes are being driven from this initial mined-out and filled stope.

In the stope on the left side, the slides direct the broken ore to the ore pass. After the slides are raised, waste is dropped down the waste pass from the level above to fill in under the slides. Mining in the stope on the right is progressing upward. After two or three floors are mined out, the slides must be raised.

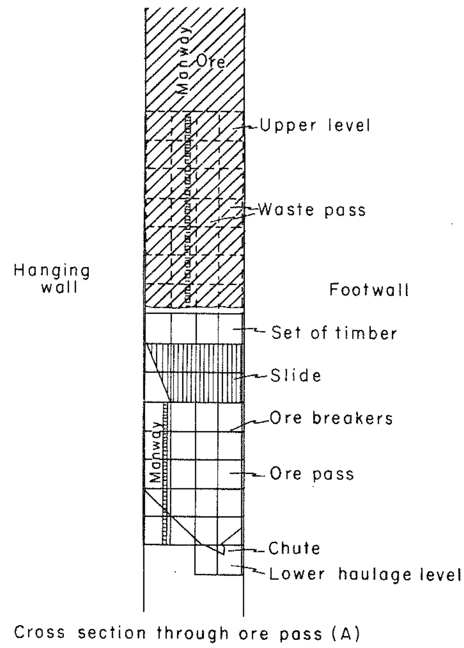
Progress in the stopes is shown in C and D. This sequence is practiced until both stopes reach the upper level. Then new stopes are started in the ore next to the bottom of the mined-out stopes.

A cross section through an ore pass is shown in B. Ore breakers of heavy timber on alternate timbered sets tend to reduce the velocity of the broken ore as it falls, thereby reducing the damage to timber in the raise. Alternatively, one compartment may be lined with lagging on all four sides to provide a narrow ore pass.

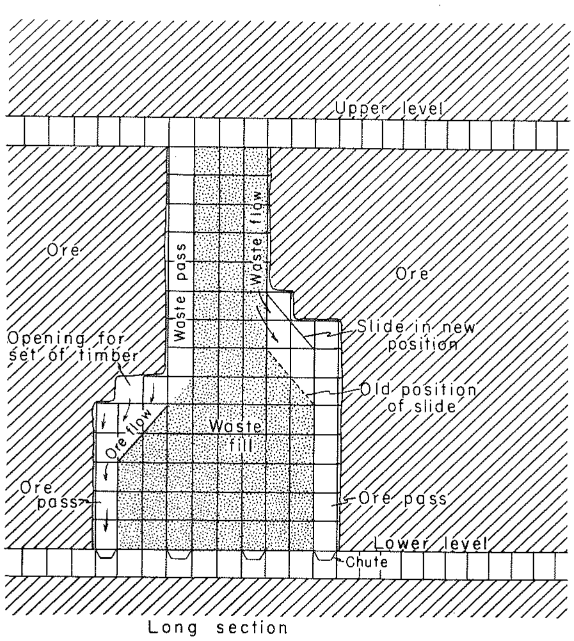
Timber methods are used in weak ground that requires continual support. These methods are slow and costly, therefore the ore must be reasonably high grade.



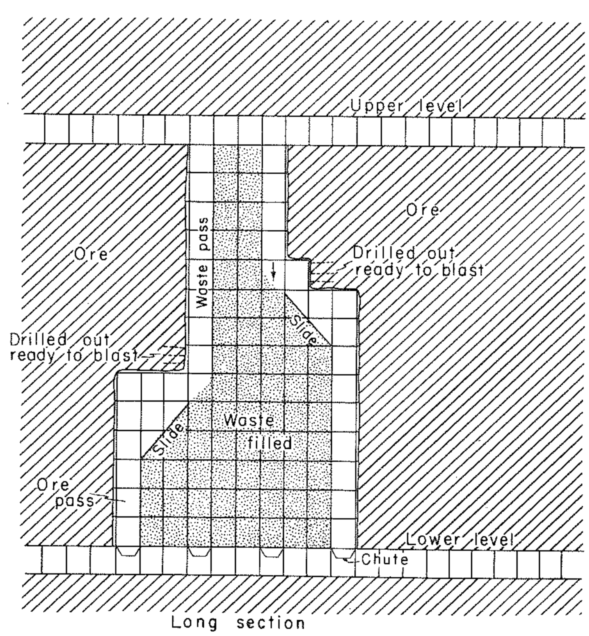
A. Timbered slot type stopes progressing in both directions.



B. Cross-section of a slot stope four sets wide.



C. Another view of the stope shown in A but each cycle more advanced. Mining is proceeding in the left side; the slide is being moved on the right.



D. One more set of timber is to be installed on left side before raising slides; several more sets are to be installed on right side before raising slides.

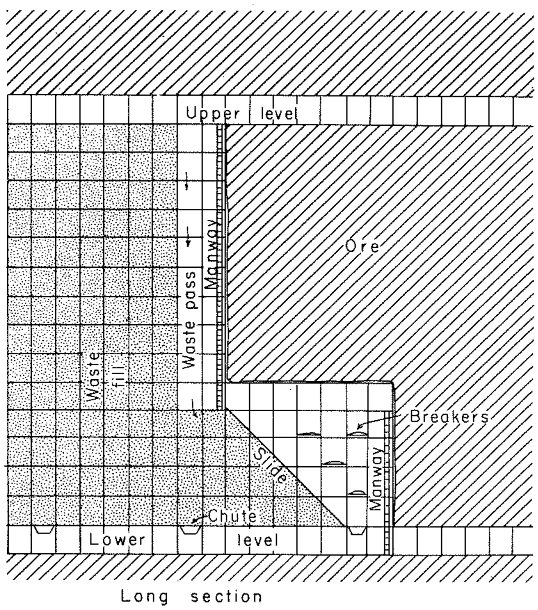
SLICE TIMBERED STOPE

A narrow vein, about one set wide, can be mined by the slice system (cross section, B). A stope is started from the lower level by mining three or four floors up and dropping the ore to the level below, where it can be loaded with a mucking machine. A slide may be installed (A) and waste fill dropped down from the level above to fill in under the slide. Breakers in alternate sets protect the timber in the stope from breakage by falling rock. Progress in the stope is shown in views B and C.

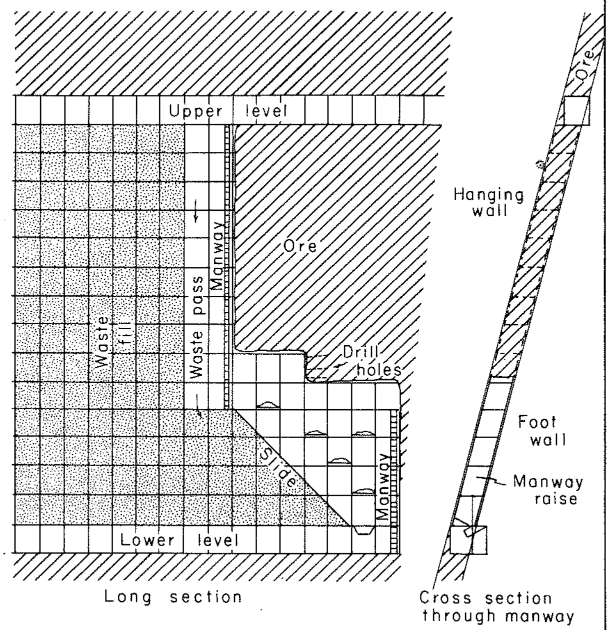
When the stope has progressed to a certain point (C), the slides must be raised because of heavy ground. Waste fill is introduced below the slide, and mining continues in the stope (D). Note the manway, on the right side in these stopes, which must be maintained for the next stope. Maintaining both manways as the stope is mined provides two means of exit from the stope.

In the benching method of drilling (B), space for only one set of timber is drilled and blasted at one time. The entire back or cut may be drilled and blasted at one time (D) unless the ground is so weak that caving would start. Drilling and blasting the whole cut gives better production rates if caving does not occur.

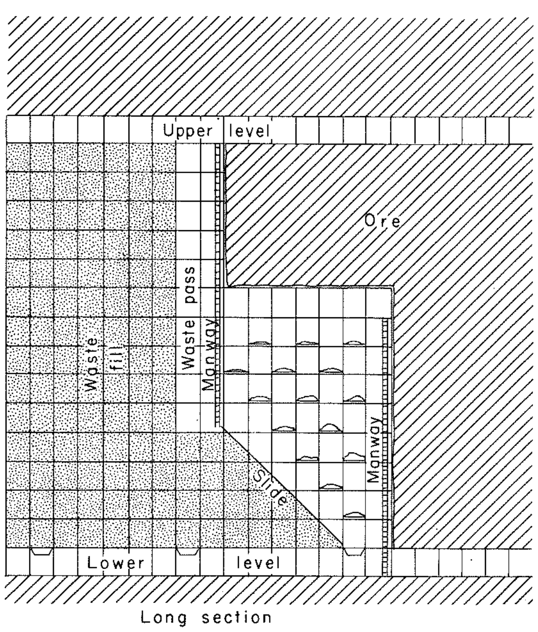
If the ground is not too weak, the slide may not have to be installed until the stope is completely mined. Waste is not introduced until the stope is completed. A model illustrating such a method is shown in Plate 44D.



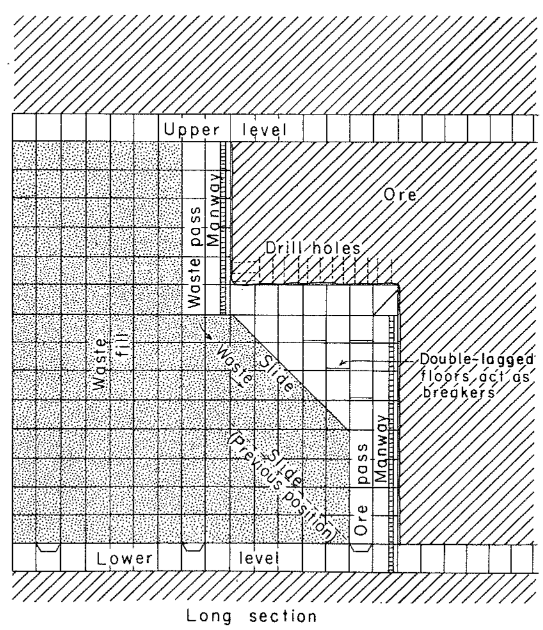
A. Slice type of timbered stope. Ore flow is interrupted by breakers in stope.



B. Another floor is being mined, one set of timber at a time.



C. Stope after several floors have been mined out. It is necessary to clean the breakers and raise the slides.



D. After the slide has been raised, waste can be introduced below the slide. Entire back of stope has been drilled.

MODELS OF TIMBERED STOPES

Two views of a model (A, E) illustrate a slot stope. The ore is at the left in A. That part of the model is removed in E to give a view of the ore pass.

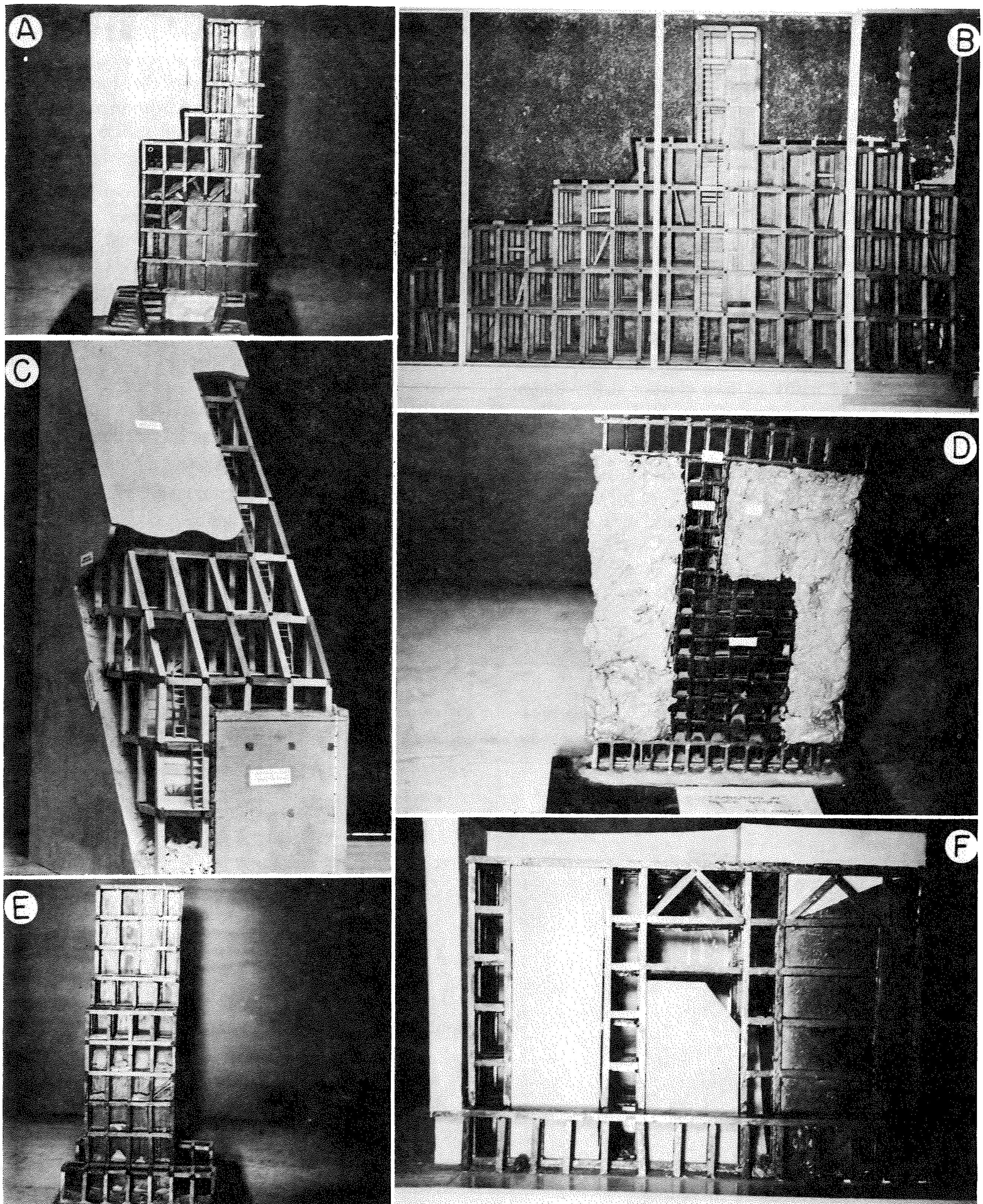
The slot system as used in a dipping vein (C) requires special arrangement of the timber. When sand instead of mined-out waste is used for fill, the sand is dumped down the raise from the level above and flows into the stope by gravity. Sand not only makes a tighter fill and gives better support than waste rock but also reduces the loss of ventilation air.

The slice stope (D) is used in narrow veins. The operation of this stope is illustrated in Plate 43.

Fill is not used in some applications of the square-set timbered method, or if fill is used, it may not be introduced as systematically as in the slot or slice method. The model pictured in B shows a square-set stope with the raise in the center of the stope. Ore is usually blasted down on a timber floor and scraped to the ore pass.

Another variation of the timber method is the Mitchell top-slice stope (F). Two slot raises (extending from foot to hanging wall) 15 to 20 feet apart are driven from one level to the next. The pillar between is mined from the top down. As the ore is removed, long heavy timbers are used to connect the timber in the raises to keep them from collapsing. As mining progresses downward, waste fill is brought in to fill the mined-out area from above, and to support the walls of the mined-out portion. As a rule, underhand systems such as this are used only in exceptional circumstances.

A. Side of slot-stope model. Block of ore is at left. **B.** Model showing square-set stope. Waste fill need not be introduced until the stope is empty. **C.** Model showing slot stope adapted for dipping vein. Sand is used for fill. **D.** Model of slice stope in vertical vein. **E.** End view of model shown in A with ore removed to show breakers and slides, which direct flow of broken ore. **F.** Model showing Mitchell slot-stope method. Ore is mined underhand, progressing downward.


A
B
C
D
E
F

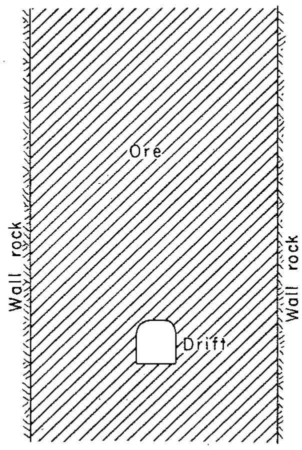
BLOCK CAVING

Some ore caves readily, and if the ore body contains enough tonnage, the block-caving method may be used. After the stope is developed, the ore breaks of its own accord; it does not have to be drilled and blasted. Caving is a large-production low-cost method. If an opening is large enough, it will eventually cave, even in the firmest and strongest rock, but a caving system of mining requires that the ore or rock will cave over a small unsupported area.

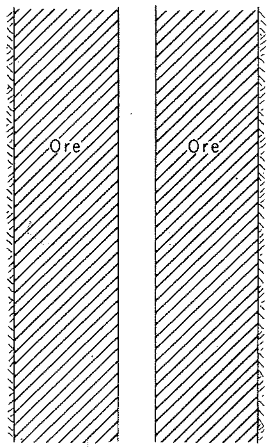
A common method of developing a block of ore for mining consists of first driving a slusher drift in the ore (A, B). Slusher drifts are spaced at suitable intervals in the block to produce efficient caving above the fingers and are usually spaced so that two or three cars in the ore train can be loaded at the same time. There may be as many as five slusher drifts under each block. Slusher loading of cars is shown in Plate 13C, G.

From the slusher drift, finger raises are driven to the undercut level (C, D). The tops of the finger raises are connected by crosscuts and drifts (E, F). The crosshatched portion in F represents the supporting pillars, which keep the overlying ore from caving. The tops of the finger raises are drilled and blasted to a funnel shape (G, H). The supporting pillars are either drilled and blasted when the raises are enlarged or immediately afterward in sequence (H, 1 to 11). As blasting of the raises and pillars progresses, the stope begins to cave (cross sections, I, J).

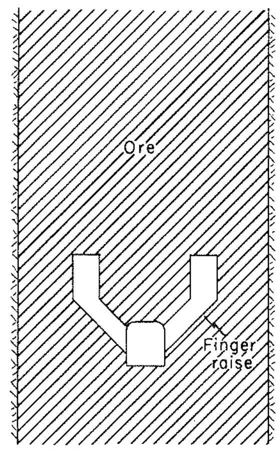
When the broken ore is pulled from the back of the stope by drawing ore from the raises, cracks form and the ore still in place tends to break by its own weight and fall to the pile of broken ore. Because the ore increases in volume when broken, the broken ore will soon fill up to the back, which in turn gives support to the back and thus stops the caving. The more rapid the rate of draw the more rapid the caving action. Too rapid a draw of one finger may cause overlying waste to come through the stope and into a finger. Therefore, all of the fingers must be carefully drawn to insure even caving action and to prevent overlying waste from coming through the fingers before all of the ore is pulled out.



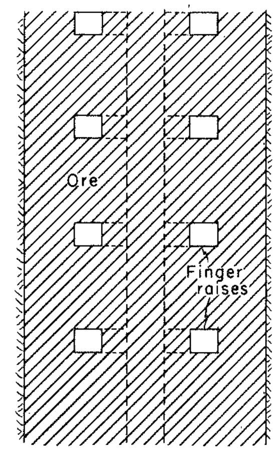
A. Cross-section of slusher drift in ore body to prepare for caving.



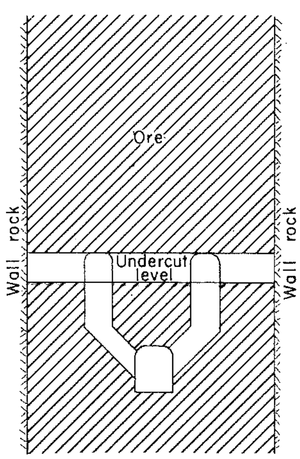
B. Plan of slusher drift in ore body to prepare for caving.



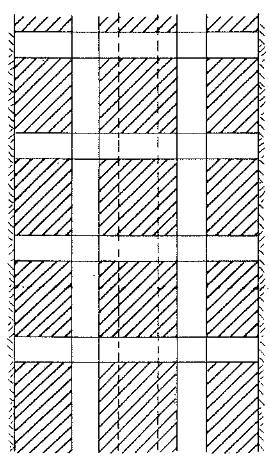
C. Cross-section of finger raises from slusher drift.



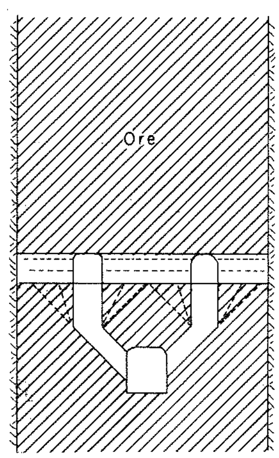
D. Plan of finger raises from slusher drift. (dotted lines outline lower workings)



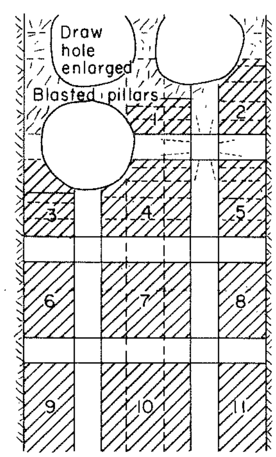
E. Cross-section of undercut level to prepare for caving.



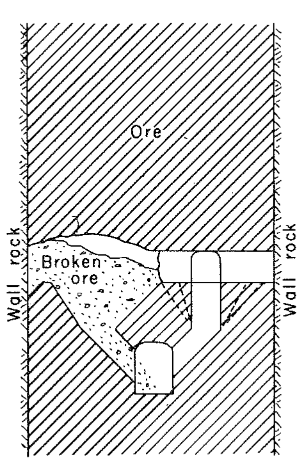
F. Plan of undercut level.



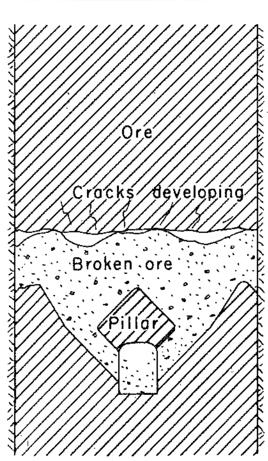
G. Cross-section showing drill pattern to enlarge fingers and start caving.



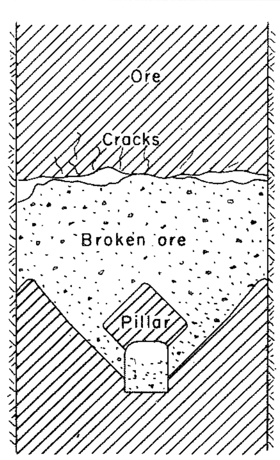
H. Plan view of undercut level showing pillar-blasting sequence.



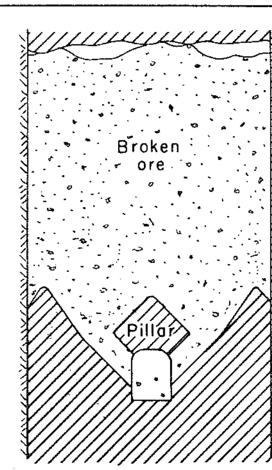
I. Cross-section of undercut level after part of ore has started to cave.



J. Cross-section of cave stope after undercut level has been blasted.



K. Cross-section showing development of cave.



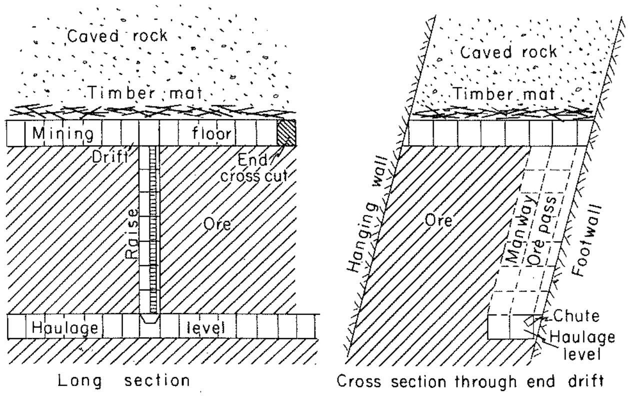
L. Cross section showing progress of cave.

TOP-SLICE STOPING

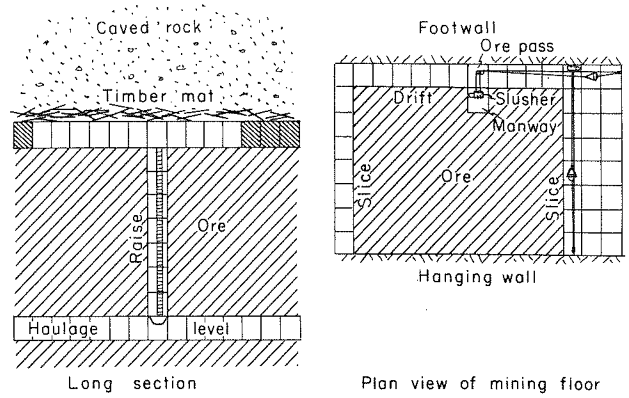
The top-slice method yields greater production per man shift than the square-set timbered method. The supporting timber in a top slice is only temporary, therefore a cheaper grade can be used, and only that for the first stage of development need be framed. This method is classified as a cave system because the overhead waste rock caves downward. The ore does not cave, however; it must be drilled and blasted. Caving of overlying rock will cause the surface of the ground to cave, therefore this method cannot be used where the surface property is valuable. Almost all caving methods destroy the surface, however.

From the haulage level, a two- or three-compartment raise is driven to the overlying rock, sometimes called cap rock, or to the previous mat. From this raise a drift is driven under the cap rock or mat near and parallel to the footwall (long sections, A, B, and plan, B). The drift extends to each end of the block. From the ends of the drift, crosscuts are driven to the hanging wall (cross section, A, and plan, B). These crosscuts are then mined out to a width of several sets of timber, and mining progresses toward the raise (plan, B). The small crosshatched areas in the long sections on the mining floor represent slices that have been mined out but not yet caved.

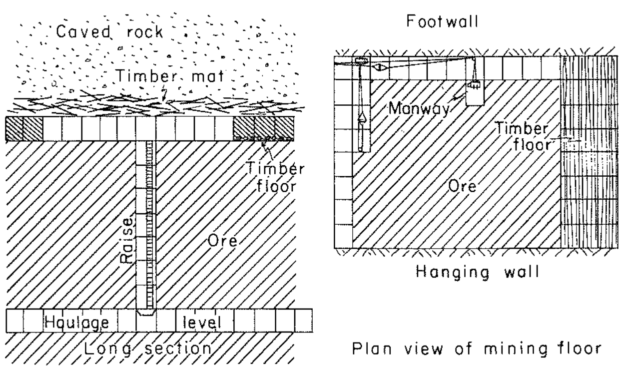
After the slice has become wide enough, usually three or more sets wide, a floor of timber, chicken wire, scrap lumber, etc., called a mat, is laid on the bottom of the workings (C). After the floor is laid, the supporting timber posts are blasted to allow the overlying rock to cave (D). The mat keeps the ore and rock separated. The ore is scraped from the slice to the drift and from the drift to the ore pass. The ore is mined toward the raise, and the worked-out areas are allowed to cave (E, F). A new floor is prepared for mining by driving a drift along the footwall directly under the timber mat (F), and the sequence is repeated. Stulls or props used for support of the mat while mining, and which are blasted as mining progresses, become part of the mat that descends to form the next mining floor.



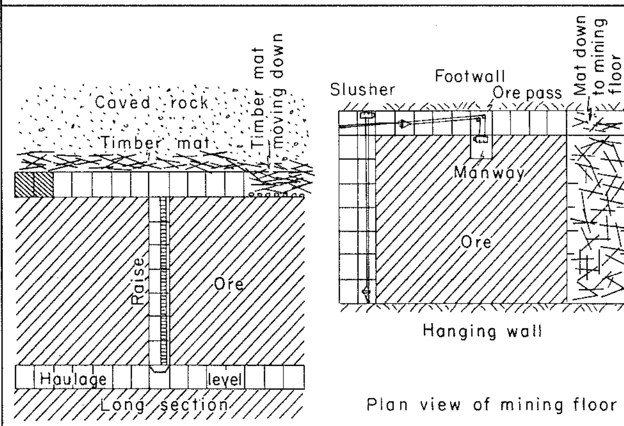
A. Long and cross sections of top-slice caving stope. Initial development of mining floor.



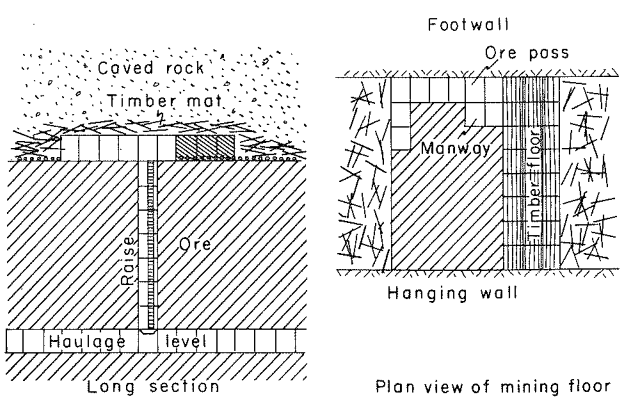
B. Long section and plan view of top-slice stope as mining progresses.



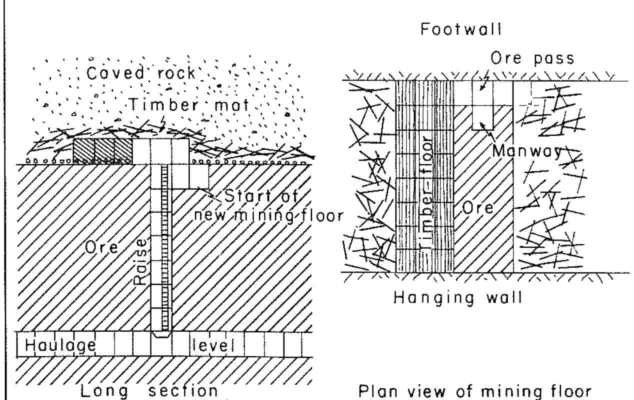
C. View of stope as part of mining floor is prepared for caving.



D. View of stope after supporting timber has been blasted and overlying mat and rock allowed to cave.



E. View of stope as mining progresses on both sides of the raise.



F. View of stope as most of floor is mined out and new mining floor is started.

SUBLEVEL CAVING

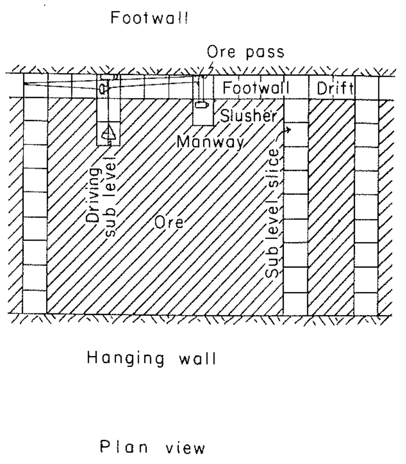
Sublevel caving resermbles top slicing except that the mining floors are spaced farther apart in the sublevel system, and not only the overlying cap rock but part of the ore is also caved. The cap rock and ore must be weak enough to cave readily. Production per man shift in sublevel caving is greater than in top slice, and the cost of explosives and timber is likely to be less.

Sublevel caving should not be confused with sublevel longhole stoping. The sublevel longhole system requires strong rock and is not a caving method.

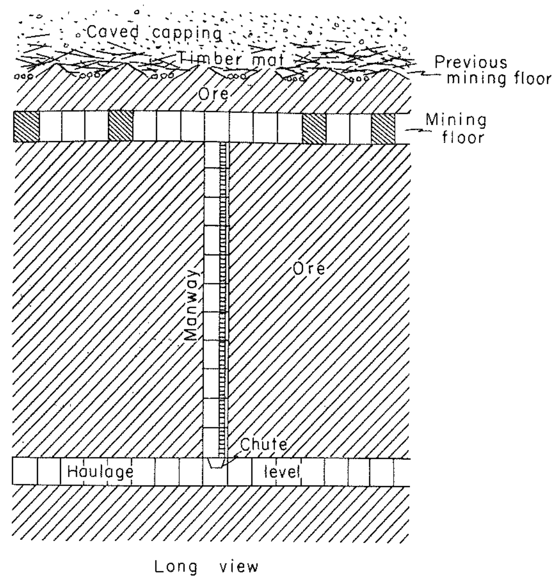
The initial stage of a sublevel cave stope is similar to the top slice, i. e., a raise is driven up to the cap rock or the overlying mat. A drift is driven along the footwall as in a top-slice stope except that some ore is between the mat and the drift (B). The crosscuts or sublevel slices are spaced a certain distance apart (A, C). Sublevel caving normally requires framed timber for ordinary drift sets in the slices.

After the slices are driven (A, C), the lagging on the side of the slices is removed and the ore is allowed to cave into the sides of the slice. The ore is scraped through the slice to the drift and from there it is scraped to the manway. If the ore does not cave readily, drilling and blasting of the ore may be necessary to start caving action. As the ore caves (C), the mat caves down, and when all the ore is mined the mat reaches the mining floor. The slices are floored with timber to keep the waste from mixing with the ore on the next lower mining floor.

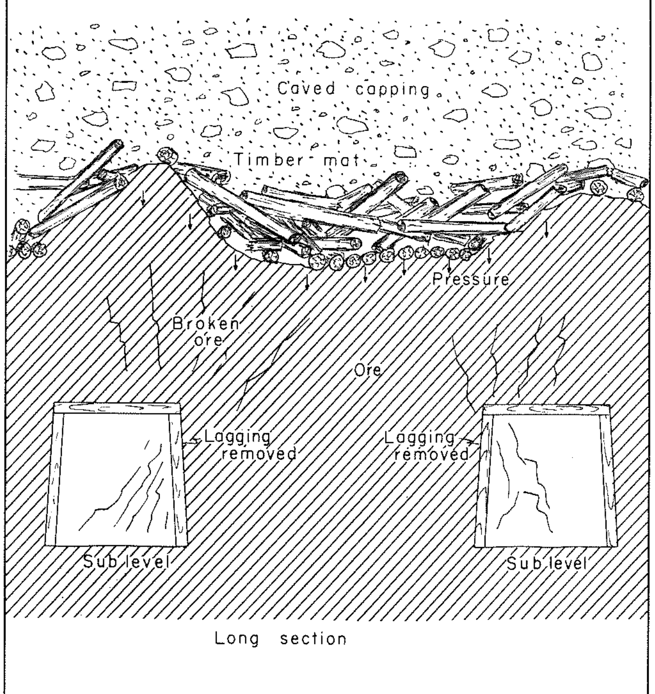
On the next mining floor (D), notice that the slices are not directly below the previous slices but are offset between the upper slices. The upper slice positions in D are indicated by round timbered ends. By this arrangement the mat will eventually be evenly distributed between the ore and waste.



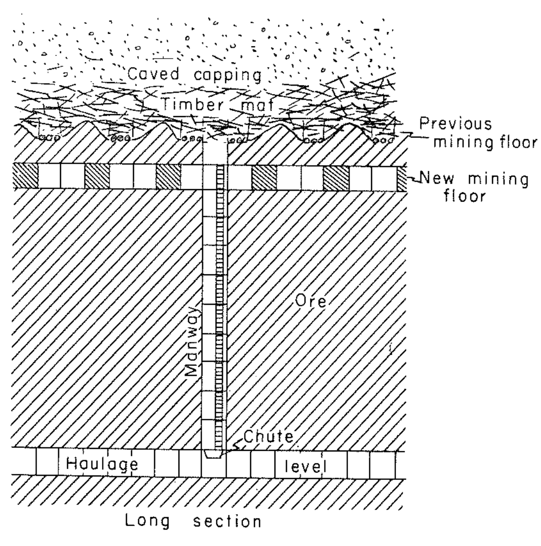
A. Plan view of sublevel cave stope.



B. Long view of sublevel cave stope showing overlying mat and caved capping.



C. Close view of caving action around sublevels.



D. View of sublevel cave stope showing next lower development level.

MINE MODELS (CAVING)

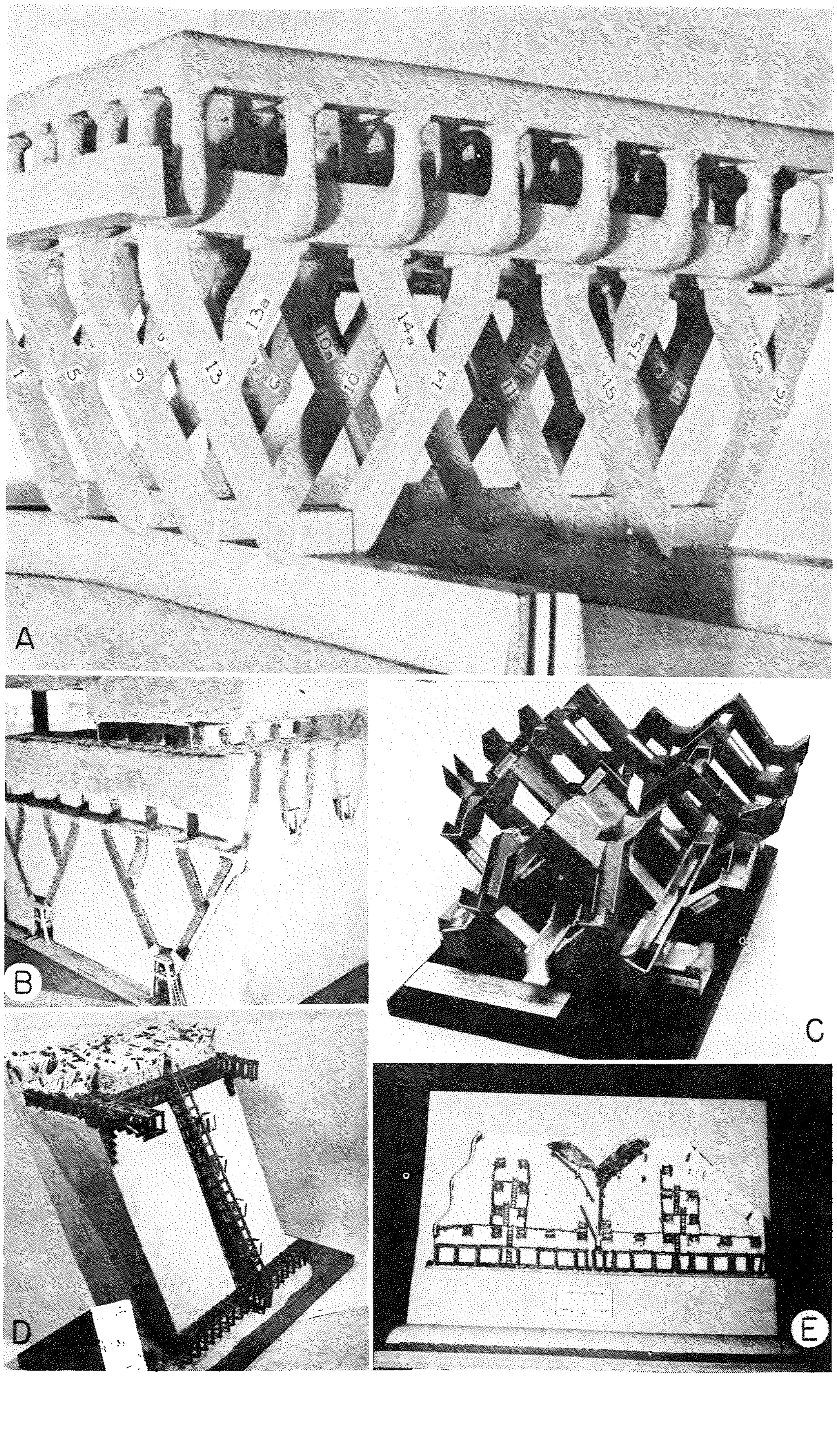
To better illustrate the block-caving method, models of the system are pictured. In the early caving system used in Butte (A, B), raises were driven from the lower haulage drifts to the grizzly level. From the grizzly level, finger raises were driven to the undercut level. The undercut level was developed as explained in Plate 45. The grizzly level was used to break large boulders and to pull old timber out of the ore. Parts of the area caved in Butte had previously been mined by square-set timber methods. Two styles of models of the same system are shown in A and B. In A the solid represents the actual openings underground, whereas in B the openings are shown as they actually occur underground.

The system has been modified in Butte to the operation described in Plate 45. Ore can be scraped directly into cars from slusher drifts (C). The fingers are driven as explained in Plate 45. The undercut level is much more complicated in this model because the system is designed to leave larger pillars over the slusher drifts and haulage levels. Pillars over the development headings are shown in Plate 45. The system depicted in the model (C) is not in use in Montana, but the picture is included to present a modification of the block-caving system.

The model shown in D depicts a sublevel cave system. The mining floor can be seen at the top of the model, and the mat overlies the model. The small side sets on the side of the raise show where the other mining floors will be driven. The drift in this model is in the center of the stope rather than on the footwall as shown in Plate 47. Any system can be modified to suit the peculiar conditions at a mine.

The model in E shows a resuing stope rather than a caving system. Resuing was described in Plate 41. This model shows a system designed to take advantage of gravity in moving ore, somewhat similar to the rill system, rather than using a slusher and scraper as shown in Plate 41.

A. Model of block-caving stope in which all openings are represented by solid material. **B.** Model of block-caving stope depicting the same system as A, but in this model the openings correspond to actual openings in the ground. **C.** Model of block-caving stope in which a sloping type of undercut level is used. **D.** Model of sublevel cave stope showing arrangement of raises, drifts, and caving crosscuts. **E.** Model of resuing stope.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