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DEVELOPMENT, MINING, AND HANDLING OF ORE IN FOLDED AND FAULTED AREAS, RED IRON ORE MINES, BIRMINGHAM DISTRICT, ALABAMA

BY

W. R. CRANE

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DEVELOPMENT, MINING, AND HANDLING OF ORE IN FOLDED AND FAULTED AREAS, RED IRON-ORE MINES, BIRMINGHAM DISTRICT, ALA.

By W. R. Crane

INTRODUCTION

Early underground mining of iron ore in the Birmingham district did not involve any particularly difficult problems until the workings had penetrated some distance from the outcrop. Extending the slopes beyond faults encountered in the steeper parts of the ore bed probably constituted the most difficult problem, and local disturbances of the ore bed that made necessary modifications in the methods of developing and working the deposits were troublesome. The handling of ore and the types of surface structures adopted control the choice of methods of development and mining. The change from car to skip haulage and the adoption of mechanical loaders have been responsible for most of the underground and surface changes. (See figs. 1 and 2.)

At various distances from the outcrop, on the average about 2,500 feet, the dip of the ore bed usually changes decidedly; in some
places the average dip of 20° is reduced enough to give the effect of "flats" and "pitches," while the presence of folds causes many of the main haulage slopes to end in parts of the bed that lie horizontally, or nearly so, and the continuation of the bed has a reverse dip. (See fig. 3.) In general, the ore bed dips to the southeast for an average distance of 3,800 feet, although the bed is more or less broken by minor folds and many faults. The occurrence of folds and accompanying reversals of dip complicate the conditions to be overcome in mining.

The methods for developing, mining, and handling the ore have already been described in detail;¹ the present paper deals more speci-

![Figure 2.—Type of ore tipple used in skip haulage](image)

fically with the development and handling of ore as affected by folds and faults in the ore bed, and considers changes that may be desirable or necessary in future mining practice. Modifications of current practice and certain radical changes in virtually all methods of working may and probably will be required because of the increasing depth of cover and the necessity of more adequate support, the larger amounts of water that must be pumped from the mines, and the need of extracting a higher proportion of the ore. The suggested

changes in methods are based largely on the trend of present practice, which embodies methods found necessary or desirable with respect to economical operation, particularly in handling ore, and which anticipates more extensive improvements in all phases of mining.

That the discussion of methods may be thoroughly understood and their relation to existing conditions clarified, a brief description is given of the ore deposits and the mining methods employed from the time when the deposits were first worked to the present. Brief statements also set forth the reasons for those changes in practice that may be desirable in the future.

Furthermore, the possibility of utilizing the low-grade high-silica ores that may be rendered available through beneficiation may help to bring about changes in practice. The mining of high-silica ores would affect the larger part of the district now being mined and would require radical changes in development, mining, and handling that especially involve drainage and the support of workings.

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**OCCURRENCE OF ORE**

The red iron ore of the Birmingham district lies in a bed that has an average thickness of 20 feet and is divided into two benches by a shale parting that ranges in thickness from a mere separation to about 30 inches. The upper bench is continuous throughout the district and maintains an average thickness of 10 feet; lower-bench ore is ordinarily higher in silica than upper-bench ore and averages 10 feet in thickness to a point midway in the field, where it thins to about 4 feet of ore, the remainder being ferruginous sandstone and slate interstratified. The Big Seam is generally understood to mean the upper bench alone, from a point midway in the district to the southward.

The outcrop of the bed runs northeast-southwest and dips southeast at an average angle of 20°. Because of the warping of the bed, the part immediately beyond the outcrop lies at a much higher angle in the southern part of the field; the range in dip from the north to the south is 12° to 35°.

The warped and faulted surface of the Big Seam is shown to advantage in Figure 4, in which the lay of the ore bed is given for 12 miles along the outcrop on the dip and to the limits of development in 1925.

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**Figure 4.**—Block sketch showing lay of Big Seam in Shades Valley: ab, Outcrop; cd, sea level; surface lines at e and intermediate points represent slopes in ore. See Figure 7 for scale of dimensions, but note that scale for line ab is one-half that of af and fg, which tends to foreshorten and distort sections, faults, etc.
FOLDING OF ORE BED

The ore bed and associated strata have been warped and flexed into folds, which in many places are accompanied by faults. The largest anticlinal fold that affects the position of the ore bed is represented by Red Mountain, which forms its southern and eastern limb. Beyond the flank of this anticlinal fold are other minor folds with axes forming angles more or less acute with that of the main fold. The distribution and extent of folds in the territory south and east of Red Mountain are not well known, as there has been little exploratory drilling, yet the folds probably are small as compared with the fold represented by Red Mountain. Folding and counterfolding have, however, seriously disturbed the ore bed, and when accompanied by faulting have complicated the development and normal mining of the ore. Figures 5 and 6 give examples of the folding of the ore bed; the first shows the bed standing almost vertical, the second the turn of a close fold.

Figures 4 and 7 show the position and extent of folds and the bearing of their axes. Figure 4 gives the trend of the folds, and Figure 7 their position with respect to the outcrop and the elevations of troughs and crests.

Joints are well developed in the ore bed and associated overlying and underlying rocks; cross-bedding is common in the rocks of the Clinton formation. Jointing and cross-bedding affect decidedly all phases of mining. The assumption that the flexing of the ore beds and their associated formations is responsible for the prominent jointing seems hardly tenable, as jointing is equally prominent where flexing is at a maximum or minimum. The bearing of the more prominent joint planes, however, often approximately parallels that of the larger faults that cut and displace the ore beds, although it can not be said definitely that there is any connection between the trend of faults and that of joints.

FAULTING OF ORE BED

Numerous faults cut the ore bed and as a rule roughly parallel the outcrop which forms the crest of Red Mountain, although a small number intersect the ridge and are responsible for gaps in it.

The majority of the faults are normal or downthrow, although there are a number of reverse or upthrow faults.

Figures 4 and 7 show the position of faults with respect to Red Mountain. The occurrence of normal and reversed faults and the hade of the faults are shown in the sections along slopes. The occurrence of faults in one section of the district is shown to advantage in Figure 8, although the displacement, except that of the main fault, is not large.
Rotatory or so-called "scissor" faults are not known as such in the iron-ore mines, but they may occur as the tailing out of a fault, and the appearance of another with increasing displacement in approximately the same line may represent rotational faulting. Moreover, the common occurrence of rotatory faults in the neighboring coal fields strengthens the belief that they occur also in the iron-ore district.

![Figure 5.—Ore bed dipping steeply because of local disturbance](image)

The displacement of the faults is usually less than 60 feet, but ranges from 8 or 10 to as much as 450 or 500 feet. Although a number of faults have been traced for 2 or 3 miles most of them terminate rather abruptly; many originate in minor folds and disturbances and terminate in the same way. Many faults of small displacement cut the flanks of anticlinal folds and are bothersome, although they cause no serious trouble. (See figs. 7 and 8.)
hade of the faults is both with and against the dip of the ore bed, the greater number probably being with the dip; the angle of hade is usually rather high, although some of the larger faults have low angles; the average angle of hade is probably about 45°. (See fig. 9.)

Faults of moderate to large displacement hinder or prevent the regular layout of mine workings, yet a problem that probably is
more difficult confronts the engineer when a number of faults of small displacement but relatively close together break the ore bed into long narrow strips that require special methods of development and working.

**STRIKE AND DIP OF ORE BED**

The strike and particularly the dip of the ore bed, although they are direct results of folding and faulting, are factors that are usually considered apart. Beds of uniform dip are comparatively easy to develop and work, but variable dips often require radical changes in method, particularly in mining and handling the ore. Flats and pitches in an ore bed, with changes in the grade of tracks at each, reduce the speed of hoisting, particularly when the excessive cost of driving and maintaining slopes makes impracticable the use of a uniform grade. Variations in strike, usually due to changes in direction of the axis of a fold or the presence of a counterfold, affect the working of a bed by necessitating a
change in the direction of haulage ways. Changes in strike and dip have marked effects in the iron-ore mines and necessitate changes in methods.

GENERAL CONSIDERATIONS

The simple methods employed in the early development of the mines of the district have been modified from time to time until virtually all procedures, with the possible exception of the general plan of development, have been radically changed; in particular the methods of mining and handling the ore have been greatly modified. The trend in present practice in handling ore and the need of more adequate support for the roof and the extraction of a higher percentage of the ore indicate the necessity of adopting more radical and extensive changes in future.

The simultaneous driving of a slope and two manways, one on either side, was found to be fairly satisfactory for the first 1,000 feet from the outcrop, or until areas were reached where the ore bed was folded and faulted. Then operators felt the need for definite information regarding the lay of the ore before they drove slopes, in order that they might properly and adequately plan development at reasonable cost and in some instances to safeguard the workings.

The first attempt to obtain, in advance of development, information on the occurrence of the ore was by the use of drill holes, and a
rather extensive drilling program was started. Holes were placed in line with and in advance of the slopes at distances of 800 to 2,000 feet, but the numerous folds and faults at irregular intervals made the information obtained insufficient as a guide to preliminary exploration. In consequence, the present system of development was evolved, in which one of the manways is used as a pilot passage. The right manway is usually driven two to three heading intervals in advance of the left manway; the latter is carried in advance of the main slope by at least one heading interval.

The advantage of this procedure is twofold. Information is obtained early regarding the occurrence and grade of the ore, and safety in advancing the main slopes is insured. This method of advancing the manways and slopes through new territory has proved eminently satisfactory and has largely eliminated the risks that formerly attended the development of the mines.

![Figure 10.—Bottom of synclinal basin; ore bed horizontal](image)

**EARLY MINING METHODS**

**DEVELOPMENT**

The general plan of developing and working the Big Seam is similar in many respects to that employed in near-by coal mines; the chief exception is that in the past no provision was made for ventilation. Slopes and manways driven on, or approximately on, the dip of the ore bed and spaced along the outcrop at suitable intervals for economical handling of the ore between slopes, and headings driven from the slopes to subdivide the bed horizontally in areas convenient for working show the striking similarity between ore and coal mining methods. Beyond development the similarity between ore and coal mining methods disappears; in the ore stopes are developed in conjunction with the headings and rooms are not driven off headings, as in coal mining.
Cheaper handling of ore has been and is the main reason for the change in methods, and as development is more expensive than actual mining an increase of the distance between headings, or longer intervals, has served as a means of obtaining the desired results. However, the dip of the ore bed controls the spacing of headings and the operation of systems of handling ore in the stopes. (See figs. 10 and 11.)

High dips to a large extent limit the handling of ore by mechanical means and limit the length of the stopes; low dips are unfavorable to gravity or mechanical handling and also limit the size of stopes; medium dips, 15 to 20°, no doubt present the most favorable conditions for economical handling of ore by mechanical scrapers, and also permit both the length and width of stopes to be developed to the maximum.

Other factors that help to determine the optimum increase in the size of stopes are a high percentage of extraction and the support of the roof. The latter favors stopes of moderate size, the former favors relatively large stopes, that is, long intervals between headings.

Heading intervals of 55 to 65 feet were common in early mining practice and are still employed in certain localities; in fact, where the ore is loaded by hand or mucked the 65-foot heading interval may be considered standard.

Dips high enough to move the ore from the stope face to the heading track are essential; any increase in the width of stopes adds to the difficulty of handling the ore, and any reduction in dip requires narrower stopes or the use of mechanical conveyers for delivering the ore to the track at the foot of the stope. Varying dips in the
ore bed, and low dips in particular, require the use of scrapers, and these permit the stopes to be carried wider.

As is to be expected, practice in the handling of ore varies widely even in adjacent mines of a company or in the same mine. Handwork or mucking is still in rather extensive use, particularly in narrow stopes and in those sections of the mines where mechanical scrapers have not been installed or can not be operated to advantage. Some time will elapse before mucking is abandoned, and whether it will ever be entirely replaced by machine work is doubtful; consequently the former plan of development, by short intervals between headings, will continue in small properties and in disturbed areas where mechanical loaders can not be used advantageously.

![Figure 12.—Cross-heading connection with main-heading track](image)

The adopted modifications of the earlier and simpler methods of development and working were made possible by the use of stationary and shaking chutes, of gravity and engine planes, and at present the adoption of mechanical loaders or scrapers. The use of these devices and the necessary modifications in the arrangement of workings have resulted in the present practice of development.

**MINING AND HANDLING**

As a result of the longer intervals between headings, stopes are developed from relatively narrow headings and run approximately at right angles to them, that is, parallel with the dip. In stopes spaced at relatively short intervals the longer dimension parallels the strike of the ore bed; where longer intervals are used, the longer dimension
Figure 13.—Plan of foot of main slope and anticlinal fold, showing usual method of development, and suggested plan with rock tunnels or slopes and ore chutes.
Figure 14.—Sketches showing plan and vertical section of method of developing anticlinal fold by rock tunnel or slope; manways not shown
of the stope parallels the dip. Consequently, in any discussion of development and mining, one must bear in mind, in speaking of width and length of stopes, the method employed or confusion will result. Where handwork or mucking is done the stopes and headings are driven together and the length of the stope is the length of the heading; but where mechanical loaders are used the stopes are driven to the rise; their length is at right angles to the headings.

An interesting modification of former practice is the use of crossheadings—passages driven through pillars and connecting with the headings below by lines of track extending diagonally across the stopes. Cross headings are employed in robbing pillars, in taking up the bottoms of worked-out stopes, and often in the first and second stopes above their starting point. The chief advantages in the use of cross headings are applicability to a wide range of dips, ready access of cars to the working face, and economy of construction and operation. (See fig. 12.)

PRESENT PRACTICE

DEVELOPMENT

In the development of their mines most of the companies have adopted the policy of keeping in view permanence and a larger production and have applied this policy to the mines as a whole rather than to particular phases of mining. In fact, aside from previously noted changes in heading intervals and width of headings, there is slight room for changing former practice.

The most important changes have been made in development and have affected in large measure the main and auxiliary slopes and the correlation of slopes. Extending the main slopes in such manner as to serve a greater territory at depth is of great importance, particularly where minor folds crowd close upon the flank of the major fold or where faults are relatively close to the outcrop. Of hardly less importance is the connecting of the main slope with one or more auxiliary slopes close to each other; this is accomplished by rock tunnels.

Present as distinguished from past practice shows a marked tendency toward maintaining the grade of main slopes by driving rock slopes and tunnels, thereby extending the use of these slopes beyond areas where the ore bed is folded or faulted. Former practice is illustrated by Figure 13, where the main slope terminates in a trough or basin and the main haulage way is continued over the fold by reversed and normal slopes. In present practice at many mines the troughs or basins on either side of the fold are connected by rock tunnels or slopes, as shown in Figure 14. By either method the ore
is handled in a similar way, but the advantage of the rock slopes or tunnels in getting the most service out of the main slope is evident.

Better methods of handling ore in headings and slopes have also received much attention, as is evidenced by the gradual change from the hand loading of cars to the large-scale employment of mechanical loaders, which has in turn brought about numerous changes in the arrangement of workings and the development of the mines.

Figure 15 shows the development of an ore bed displaced by normal and thrust faults, the former condition at A, the latter at B. When the faults are normal rock slopes can be used, but when thrust faults occur, the overthrust portions of the bed are usually worked by gravity planes.
Ore in anticlinal folds or "hills" is extracted by driving headings at the proper grade and the desired or necessary distance apart, as indicated in Figure 13. Figure 16 shows a top heading, the pillar to the left being at the top of the fold, and Figure 17 shows an intermediate heading in which the ore bed makes an abrupt turn downward.

Examination of Figure 13 shows that the ore is raised by engine plane on the side of the fold opposite the main slope and lowered by gravity on the other side, its descent being controlled by the same engine that raises the cars to the crest of the fold. Figure 18 shows the junction of the two systems at the top of the fold; the ore is raised in the haulage way that extends over the fold and lowered on the gravity-plane side as shown in Figure 13.

Large, electrically driven hoisting engines are placed at the head of auxiliary slopes underground and form an intermediate step in the movement of ore from the lower headings to the foot of the main slopes. (See fig. 19.)

The adoption of mechanical loaders or scrapers has been responsible also for the great increase in the size of stopes, an increase that, in fact, has probably exceeded at certain localities the safe working limit; numerous falls of top rock where there are large areas of unsupported or inadequately supported roof indicate that
there is a limit to the size of stopes, and practice favors those that are moderately large rather than very large. However, the great advantages of mechanical loaders over hand loading or mucking—ease and economy of operation and large output—insure the continued use of loaders and the adoption of methods particularly suited to their best and most efficient operation.
When mechanical loaders are used the headings are driven narrow and the stopes are turned off to the rise by driving small openings through the pillars, leaving stubs between them; the stopes are carried upward to the headings above, but are separated from them by other small stub pillars. Adjacent stopes are separated by long, narrow, unmined strips of ground or pillars. The number of openings into each stope both above and below ranges from one to three, according to the size of the stope. Posts, placed singly and in rows, and other temporary supports are employed, the most satisfactory form being small pillars of ore or rock formed at points most advantageously situated. The long pillars left between stopes are often broken through and mined out at the middle before the stopes are abandoned.

Stopes 150 feet long and 100 feet wide are not uncommon and in many localities are standing well with temporary supports alone, but in other localities top rock has caved when relatively small areas of roof are exposed. Lack of definite knowledge of roof conditions is largely responsible for the uncertainty as to safe working limits; experience is the sole index.

Most of the ore is brought from the face in 2½-ton wooden and metal cars. However, more recent practice favors large cars, particularly when mechanical loaders are employed, and 5-ton all-metal cars hauled by motors are now being used. Furthermore, sloping-top all-metal skips are being replaced by those of the rectangular box type. (See figs. 20 and 21.)
TREND IN PRESENT PRACTICE

DEVELOPMENT

As previously indicated, the handling of ore is the factor that has most influence on development and working, particularly where the ore bed is badly disturbed by folds and faults. Mines that have reached that stage of development where the ore must be handled a number of times before delivery to the railroad cars are nearing the limit of economic handling and will have to make radical changes in order to continue to compete with other mines where conditions are more favorable or where mining is done more advantageously.
and economically. It is needless to say that the conditions under which mining must be conducted are fully recognized, and in the majority of mines changes that will allow most efficient operation under these conditions have already been put in effect. However, to change practice in order to improve bad conditions is only a step in the right direction; a more desirable procedure is to take full advantage of the latest methods that are applicable rather than to change methods that have limited application or have become obsolete.

Formerly little rockwork was done in the mines, except to connect the surface with the ore bed for convenience in placing surface works and to connect those parts of the bed that are separated or displaced by faults. Now it is becoming established practice to connect folded and faulted areas by rock slopes and tunnels, thus simplifying development by eliminating the steep and varying grades that would result from following the ore bed, and also extending the use of the slopes to greater distances and thus reducing costs of operation.

The practice has been to terminate main slopes where folds cause reverse dips in the ore bed. Rock cuts, slopes, or tunnels are now usually employed to connect the lower parts of the folded ore bed, the ore from elevated parts being delivered to the rock slopes or tunnels by engine or gravity planes, on which it is handled by skips or electric motors. (See figs. 22 and 23.)

The outstanding features of modern practice in the ore mines are as follows:

1. In development, slopes are placed in the footwall but are connected directly with the ore bed either by headings opening into the top of slopes or by rock tunnels and slopes that join the tops, bottoms, or intermediate parts of folded areas with the main haulage system or connect auxiliary slopes with the main slopes.

2. In mining and handling ore, long narrow stopes are carried to the rise directly or at angles that permit economical handling of ore and the use of mechanical loaders.

The advantages of driving slopes and tunnels in the foot or hanging walls include greater safety in support and the establishment and maintenance of grades that permit more economical handling of ore. In many places the use of main and auxiliary slopes is extended in this way much farther than in former practice.

**MINING AND HANDLING**

The change from narrow stopes and short heading intervals to the reverse has, on the whole, reduced the cost of development. It has been brought about largely by the desire to extract a higher proportion of the ore and to provide increased protection to the
haulage ways. However, the numerous falls of top rock, where there are large areas of unsupported roof in the large stopes, have brought about a rather unfavorable reaction among operators, and the present tendency is to reduce the heading intervals and consequently the size of the stopes.

As long as mechanical loaders are used narrow headings will be standard because of the advantage of using relatively short chutes to connect the stopes with the ore cars. Where mechanical loaders are used large stopes will be both necessary and desirable, the factor that will limit width being proper and adequate support for the roof.

FIGURE 22.—Small auxiliary hoist for slope.

SUGGESTED CHANGES IN PRACTICE

DEVELOPMENT

As a whole, the ore mines of the Birmingham district have been efficiently and economically opened and worked under the methods employed, which were those reasonable and logical in the first stage of operation. In many mines the handling and rehandling of ore has reached the economical limit, and it is reasonable to assume that these mines have attained this first stage in development and operation. In certain mines ore is handled in from three to five up to nine or more separate steps before it is loaded into railroad cars at the tipple.

In an ore bed that has a fairly uniform dip and is not disturbed by folds and faults the rock slopes might be extended almost indefi-
nately if advantage is taken of the natural breaking of the top rock as an aid in the support of the haulage ways and other openings necessary in development. In the mines of the Birmingham district, however, the ore is disturbed by both folding and faulting; thus the use of slopes in or adjacent to the ore bed is restricted to a comparatively narrow area along Red Mountain and auxiliary development passages, such as rock slopes and tunnels, must be used. It may be said then that the first stage in the development and mining of the ore has probably been reached or passed, and new practice must be adopted if mining is to be continued in an efficient and economical manner.

The suggestions offered do not involve any radical changes in procedure but follow present practices that have proved satisfactory;

![Electric-motor haulage in rock tunnel](image)

The use of vertical shafts in Shades Valley offers very decided advantages in efficient and economical operation as compared with slopes. The opening of new workings would be simplified; the number of operations in handling ore from the stopes to the surface would be reduced to a minimum; drainage would be facilitated by the exclusion of water from the workings; ventilation would be greatly improved by an adequate supply of fresh air under complete control; and the use of standardized equipment (including hoisting
engines, traction motors, mechanical loaders, and other devices) in workings systematically laid out would insure the best possible operating conditions.

Methods of developing folded areas are suggested for three sets of conditions which range from one extreme to another and may represent conditions that are not attained but are approximated. A low fold that is wide in comparison with its height is shown in Figure 24, a high fold that is narrow in comparison to its height is given in Figure 25, and intermediate conditions (moderate folding) are shown in Figure 26.
Figure 25.—Sketches showing suggested method of developing a high anticlinal fold by rock tunnels and ore chutes, and the position of a vertical shaft if employed. Position of headings indicated by broken lines; manways not shown.
LOW FOLD

The general plan of development shown in Figure 24 is suitable for a low fold and is similar to present practice in the use of skips to the bottom of the first trough or basin; manways are omitted from the plan. A rock slope connects the two basins and thus the main slope extends beyond the foot of the large anticlinal fold to the left. A rock tunnel is driven from the bottom of the first basin to facilitate the handling of ore from the part of the bed that overlies it and is opened up by the main slope. Auxiliary rock tunnels and slopes are driven at given and convenient intervals, as shown in the plan, Figure 13, so that the ore bed is subdivided into areas of proper size for working to the best advantage. Tunnels and slopes are connected with the headings in the ore bed above by chutes driven in the footwall. Where large areas are to be worked ore pockets should be provided to permit mining to continue when there are temporary delays in motor haulage or in hoisting.

Suitable locations for vertical shafts are indicated, as well as the position of pump rooms, sumps, and ore pockets. (See figs. 24, 25, and 26.)

HIGH FOLD

Figure 25 shows the development of a larger and higher fold; the main ore bed to the left also has a higher angle of dip than in Figure 24. The only difference in plan and section is that rock tunnels or slopes and secondary rock tunnels are used as sublevels in the upper part of the fold. Chutes are driven in the ore bed, as shown on the right side of the fold, and other chutes in the footwall at the crest. The number of sublevels invariably depends upon the height of the fold and the length of the chutes; as a precaution against choking sublevels are to be preferred to very long chutes, although branched chutes will largely obviate choking. (See left side of sections, figs. 25 and 26, for use of branched chutes.)

MODERATE FOLD

Figure 26 presents a method applicable to mining ore in a fold intermediate in size between those shown in Figures 24 and 25; the method is only a modification of the methods described above.

Figure 15, B, showed a method of mining ore in a close fold or overthrust by a fault, and is similar in every respect to the methods already described for folds of different degrees of width and height.

MINING AND HANDLING

These suggestions relative to the mining of folded and faulted ore beds are made, first, for working the upper bench alone and
second, for working both benches or the entire thickness of the Big Seam where it is of suitable grade. In the northern part of the district both benches or virtually all of the Big Seam is "ore," although under present conditions the upper bench is the chief source; in the southern part of the district the lower bench is largely waste material at present and may never be mined.

When a process is developed that will render possible the economical production of a concentrate suitable for making iron the question of how all available ores can be mined will need to be answered, otherwise irretrievable loss will result. That such a decision may have to be made relatively soon seems probable, therefore it is desirable to anticipate events and suggest possible methods of mining and utilizing low-grade ores.

No attempt is made here to do more than to suggest methods. Details of application are essentially the result of much and varied experience, but a general method of procedure can be outlined and adapted to given conditions. The basis for the choice of a method is its previous application to ore with approximately similar conditions of occurrence.

The methods of opening a bed and of mining it ordinarily depend largely upon how the ore is handled; this, in turn, is controlled by the characteristics of the bed—that is, its dip, its thickness, and so on. When ore is mined by hand, the stopes have their longer dimensions parallel with the strike unless cross headings are employed. When mechanical loaders are used the reverse is true, the length of the stope being parallel with the dip. Although the first operation of breaking ore may by similar in both instances, the second mining, or robbing, is different, particularly when mining is by hand. For hand loading the working face parallels the dip, and for machine loading the face parallels the strike. The choice between overhand and underhand mining depends upon the dip of the ore bed; that is, upon the ease with which the broken ore moves from the working face to the loading level, a condition that obviously has little or no effect upon mechanical handling of the ore. There are, however, limits to the dip on which mechanical scrapers can work efficiently—between 15 and 20°.

Incidentally, conditions that affect the support of the roof, such as the occurrence of jointing or slip planes, limit the use of mechanical loaders because they largely determine the size of stopes. To maintain stopes with long working faces parallel with the jointing is much more difficult than to maintain faces at an angle with the jointing, because pillars fail under roof pressure.

The thickness of the ore bed worked affects, if it does not determine, the methods of development, mining, and handling employed;
Figure 28.—Sketches showing suggested method of developing a medium-high anticlinal fold by rock slope, rock tunnel, and ore chutes, and the position of a vertical shaft if employed. Position of headings indicated by broken lines; manways not shown.

46918°—27. (Face p. 24.)
if the entire thickness of the Big Seam is worked, a somewhat radical change will have to be made in every phase of practice if high-percentage extraction is to be attained. That stopes of large area with a height the full thickness of the Big Seam will stand open long enough to permit the percentage extraction of ore desired is highly improbable, particularly in areas where the dip of the ore bed is moderate to steep.

CAVING SYSTEM FOR BIG SEAM

A careful survey of the whole field of mining practice in those places throughout the country where the conditions of occurrence of the ore are approximately similar to those in this district indicates that a caving system would give the greatest promise of success in respect to the development, mining, and handling of the ore and probably in providing adequate support for the workings.

A caving system adapted to a 10 or 20 foot bed of ore with inclinations of 15 to 35° could undoubtedly be used with success; it would involve working in panels, carrying the preliminary advance work narrow, and retreating in a broad face by caving. The preliminary work in the lower part of the bed should be done like that in the lower bench, the upper part or bench serving as a strong back for support; the retreating work, which would comprise the major part of work and produce the bulk of the ore, would involve breaking down the back of ore by pressure of the overlying formations when support was removed. (See fig. 27.) Breaking the back of ore would be accomplished by undermining through removal of the ore in the pillars between adjacent preliminary openings or stopes. One-half of each adjacent pillar would be broken and handled through the preliminary openings or stopes, and the back of ore would be temporarily supported by props until the pillars were removed.

In hand loading or mucking the ore would be loaded directly into cars under the protection of the back of ore, which might extend 15 to 25 feet beyond the retreating face of ore or the face of the pillars. If mechanical loaders were used the scrapers would have to be operated (1) either across the end of the pillars and adjacent to the bank of caving ore that would advance toward the scrapers with the breaking or caving of the back, or (2) in the stopes, terminating at or slightly in advance of the ends of the pillars that taper to points, forming wedges of ore, whose failure under increasing pressure of roof would permit the back of ore to break and retreat with the pillars. As previously indicated, the method of mining would resolve itself into a method of handling and of supporting or controlling caving ore and rock, which in turn would be largely influenced by the angle at which the ore bed dips.
MINING RED IRON ORE IN FOLDED AND FAULTED AREAS, ALA.

CONCLUSIONS

Changes in future methods of working the Big Seam may prove desirable and even necessary because of economical mining and handling of ore, occurrence of folds and faults, inadequate support and ventilation, the presence of large quantities of water through breaking top rock, ground movement, and other factors. The methods suggested herein are intended to cover these conditions in a general way, at least, and although they are probably inadequate in some respects they indicate possible solutions.

The use of rock slopes and tunnels in conjunction with chutes driven in the footwall would materially assist the handling of ore by reducing the number of operations now necessary between the working face and the surface; in mining the more extended use of water drills and mechanical loaders would almost certainly effect economy of operation.

The use of a caving method for mining the upper bench alone or the entire thickness of the Big Seam would seem to be the logical solution of the problem of support, which will become difficult if not serious in the future. The percentage of extraction of ore would also be increased.

Although drainage of the mines is not a particularly serious problem at present, it promises to become increasingly important as overlying formations fracture and settle when old workings cave. Al-
though only a little can be done to remedy the caving that has already occurred, further extensive caving can be limited, and by the use of vertical shafts in the development of new areas the water that now enters the mines can be excluded from those areas.

Moreover, by the use of vertical shafts and an efficient ventilating system, ventilation of workings, which is now inadequate, could be radically bettered.

Ground movement in the top rock above the old and present workings may or may not become of consequence, but it is not unlikely that there will ultimately be extensive movement of top rock above the more steeply dipping parts of the ore bed, particularly in folded and faulted areas.