Surface and underground drilling techniques used in exploration drilling

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SYNOPSIS

The diamond-drilling machine has for many years been the most important exploration tool in the search for and subsequent evaluation of Witwatersrand-type ore deposits. With a view to increasing the range of services that can be provided and, at the same time, counteracting rising drilling costs, new techniques are continuously being developed. Many of these techniques have equal application in surface and in underground exploration.

This paper reviews drilling techniques such as non-coring pilot holes and deep wire-line drilling, as well as the design of core-barrels and drilling bits to cater for the specific nature of the job on hand. Special drilling fluids and aluminium rods to assist in normal drilling operations are also discussed.

Special mention is made of a borehole's natural tendency to deviate in a certain direction. The factors that cause deviation are used to the advantage of controlled drilling techniques.

SAMEVATTING

Die diamantboormasjien is reeds vir baie jare die belangrikste nasporingswerktuig in die soektog na en daaropvolgende evaluering van Witwatersrand tipe ertsneerslae. Met die oog op die uitbreiding van die reeks dienste wat verskaf kan word, en terselfdertyd stygende boorkoste teen te werk, word nuwe tegnieke voortdurend ontwikkel. Baie van hierdie tegnieke beskik oor gelykwaardige toepassing in bogrondse en in ondergrondse nasporingsomgewings.

Hierdie verhandeling hersien boortegnieke soos geen kerngitsgate en diep kabelkernboorwerk, sowel as die ontwerp van kernbuise en boorpunte om vir die spesifieke aard van die werk ophande voorsiening te maak. Spesiale boorvloeistowwe en aluminiumstawe om normale boorwerksaamhede te steun, word ook bespreek.

Spesiale melding word gemaak van 'n boorgat se natuurlike neiging om in 'n sekere rigting af te wyk. Die faktore wat afwyking veroorsaak word tot die voordeel van beheerde boortegnieke aangewend.

Introduction

The drilling of pilot holes for deep surface boreholes is a concept that has been used in recent years with great success. The most important aspect of these pilot holes is the large amount of time saved and, to a lesser extent, the saving in cost that can occur. For additional time and cost savings in boreholes, wire-line drilling has been used in the past decade. This is a concept that was first introduced in the 1940s, but it has proved successful only in recent years.

Additional techniques are continuously being investigated and improved in an attempt to lower drilling costs and improve performance. Some of the more recent innovations, like special drilling fluids, specific core barrels and bits, aluminium rods, and controlled long deflections are discussed briefly in this paper.

Long inclined underground boreholes of more than, say, 500 m in depth have become popular during the past decade. Locally these boreholes are known as long controlled boreholes, the operator's idea being to keep them on a predetermined path by making use of the conventional wedge or the borehole's natural tendency to deviate in a certain direction. The latter is probably the most important aspect in that the success of any controlled drilling operation depends entirely on the degree of natural deviation that occurs.

The term *deviation* is used to signify only unwarranted wandering of the course of the borehole, and the term *deflection* refers to a planned change in direction of a borehole. Because natural deviation is so important in controlled drilling, a detailed discussion of its causes is warranted. Various techniques have been developed to assist with natural deviation and planned deflections.

Surface Drilling

Pilot Holes

The drilling of non-coring pilot holes to a depth and then continuing with a diamond drill hole can result in considerable savings in time and cost. The Schramm-type rotary drill can reach depths of more than 1000 m in less than a week, while a diamond drill hole of the same depth would take approximately three months. A non-coring pilot hole of 500 m would take no more than two days to drill, while a diamond drill hole of 500 m would require more than a month. The time saving is thus clearly discernible, and no further elaboration is necessary.

The saving in cost is more complicated. While the costs of diamond drilling are always higher than those of non-core drilling, various other factors have to be considered in the final costing of a hole. An in-depth study in which all the factors were taken into account (casings being the dominant factor) has shown that non-core pilot holes are always less expensive than diamond drill holes when drilled in soft rock (e.g. Karoo strata). When the drilling takes place in hard rock, where casings are not necessary, diamond drilling is less expensive.

For the saving of time and money, it would be ideal to drill a non-coring pilot hole to the base of the soft rock that has to be cased, and to diamond drill the hard rock. However, if money is of little consequence and time is the overriding factor, it would be advantageous to dril al pilot hole to the maximum depth before commencing with diamond drilling.

A good record of the rock-type can be kept during the drilling of pilot holes. As the chips from the drill are constantly being expelled from the hole by air pressure, a

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representative sample of the rock-type can be collected at any depth.

Wire-line drilling

In wire-line drilling, the drill rods are left in the borehole while only the core tube is extracted from the hole by means of a winch and wire cable. The core tube is replaced in the same way after it has been emptied. This method obviously results in a substantial saving in time since the rod string is removed from the hole only once the bit has to be replaced. There is no direct cost saving from this method: the drilling cost is the same but, because of the increased drilling tempo, the hole is completed in less time, resulting in an indirect cost saving.

The only disadvantage of wire-line drilling is that abnormal deviation tends to occur in the hole. A borehole drilled by this method can deflect by more than 40° from the vertical for a 1500 m hole. With careful planning, if the dip and strike of the strata in an exploration area are known, this abnormal deviation can be turned into an advantage.

Special Drilling Fluids

A large variety of drill fluids is available on the market, including Bentonite, CMC, mica flakes, etc., and with the necessary expertise these can be used to great advantage and cost saving in some boreholes.

When there are problems like caving ground, water loss, swelling shales, or abnormal deviation, drilling operators who are experts at solving such problems should be called in for the necessary advice on suitable drill fluids. The use of the correct drill fluid can prevent problems before they occur, and this obviously results in a large saving of time and money. Claims have also been made that the use of drill fluids can lengthen the life of bits, resulting in a saving for the drilling company.

Core Barrels and Bits

Specific core barrels are designed to cater for special jobs. A large variety of core barrels is available with single, double, and triple tubes and in lengths from 1,5 to 18 m. The double- and triple-tube core barrels are designed in such a way that the inner tube stays stable while the outer tube rotates independently of the inner barrel. The use of a short, rigid barrel can reduce the vibration of the rods on the core barrel to a minimum. Very good core recovery can thus be obtained in extremely friable strata, and by use of the correct core barrel 100 per cent recovery can be obtained over certain requisite zones. Unnecessary deflections over reef zones can thus be eliminated, which can obviously represent a large saving in time and money.

Research on drilling bits is a continuous process, and new and better bits are being tested and manufactured regularly. The new diamond impregnable bits used in wire-line drilling can be designed to suit specific formations, and may have a life span of more than 60 m when drilling in such formations. Side-track bits and other special non-coring bits can be used when adverse ground conditions are encountered in unimportant strata. Although no core is obtained when this method is used, the advance is speedier. The pros and cons of drilling with non-coring bits must thus be considered for each individual borehole before drilling starts.

Aluminium Rods

Drill rods manufactured from aluminium alloy are a rather recent innovation. These rods, which are much lighter than the normal steel rods, have been used successfully in a number of boreholes. The lighter rods now enable a small machine to drill to a much greater depth than was previously possible.

The use of these rods effects an indirect saving in costs, especially in underground drilling, when excavations for a big machine may not be necessary and the same job can be done with a small machine and aluminium rods. These rods also come in handy in surface drilling when large machines are not available or the inaccessibility of the terrain makes the transportation of large machines virtually impossible.

Wedges

Although wedging procedures are generally applied when deflections are drilled on various reefs or for stratigraphic reasons, wedges are sometimes used in the original hole in an attempt to keep the hole straight or to deflect the hole in a certain direction. Directional wedges are set on certain bearings to deflect a borehole in a required direction.

For the maximum control of a long deflection, it is firstly imperative that the wedges should be set on the correct bearing. (The addendum describes wedge-setting procedures.) Many different drilling bits have been designed to enhance the deflection of a borehole.

Bits

The side-tracking bit, which was mentioned earlier, accentuates the deflection to a large degree, especially if a B-size rod is coupled directly behind this bit. It must be mentioned that these special bits are effective only in certain types of rock, and not in any type of ground condition. It would be advisable to seek expert advice before long deflections are attempted. The only disadvantages of the side-tracking bit are its high cost and the fact that it is a non-coring bit. However, the cost is negated by the use of fewer wedges than normal in such a deflection, which results in a big saving in time.

A second type of bit that is currently being used with great success is the new BX to B wedging bit. Its use eliminates the necessity to bullnose after the insertion of a wedge. The tapered head of this bit ensures that the bit drills in the facet of the wedge and does not 'climb over' the wedge. The maximum deflection can thus be expected. If a swivel head and B rods are used directly behind this bit, the deflection can be accentuated and increased. It must be stressed once again that this procedure is not equally successful in all conditions. Once again, fewer wedges are used, and the elimination of the bullnosing procedure increases the time saving obtained. As there is no extra cost involved, the cost saving on wedges is self-explanatory.

Underground Drilling

Borehole Deviations

Various forces and ground conditions tend to cause deviation, and the following factors must be taken into consideration:

(1) worn drill rods that are smaller than the drill hole,
(2) stratified (layered) formations through which the drill hole passes,
(3) alternating hard and soft layers within the rock formation through which the drill hole passes, and
(4) the type of crowns, rate of feed, and crown (bit) load and their influence on hole deviation.

The worst causes of deviation are (2) and (3) above, (2) being the most difficult to control. Before these factors can be discussed, an explanation of natural deviation in a borehole is called for.

Natural deviation is the tendency for a borehole to deviate in a certain direction without any planned change of direction on the part of the operator. Stratified formations with alternating hard and soft layers have an influence on the degree of deviation and, for the success of a controlled drilling programme, it is essential that the natural deviation should be used to its full advantage.

In an investigation of the natural deviation in any given area, it must be remembered that all boreholes deeper than 500 m have a tendency to turn perpendicular to the strata (Fig. 1). It has been shown that, with steeper

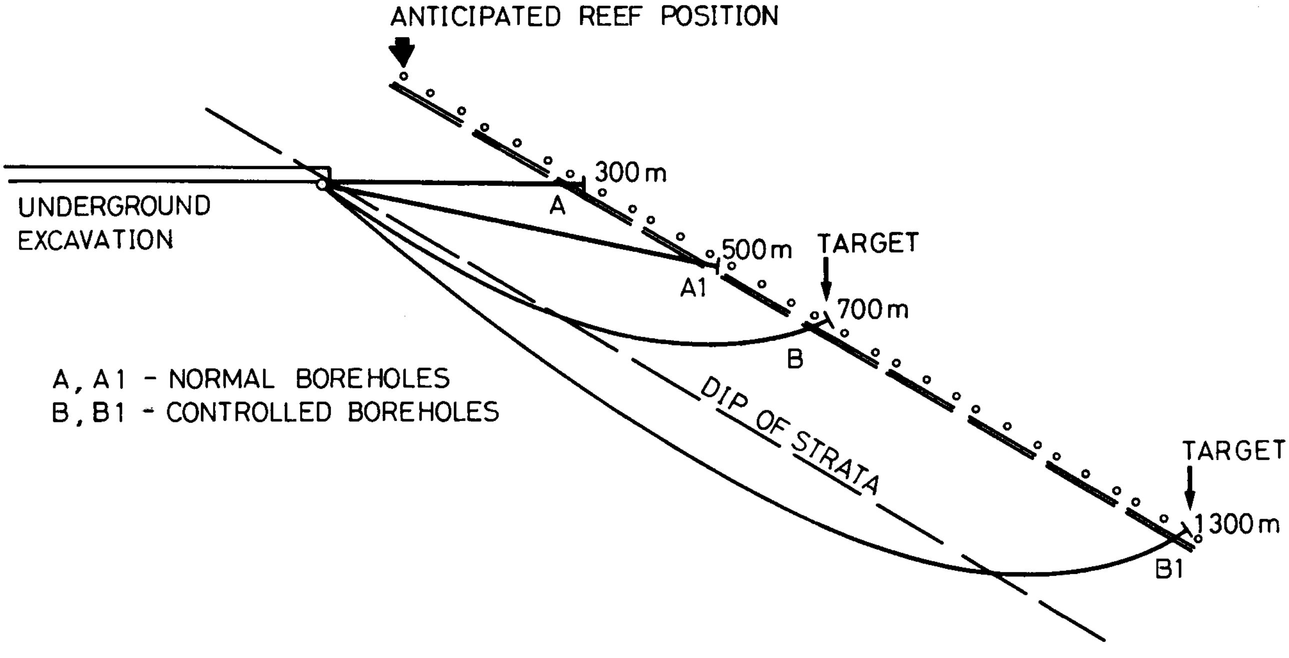

Fig. 1—Diagram to show that a borehole exceeding, say, 500 m in depth should be collared at an angle greater than the dip of the strata to allow for the natural deviation when the borehole is directed towards a target

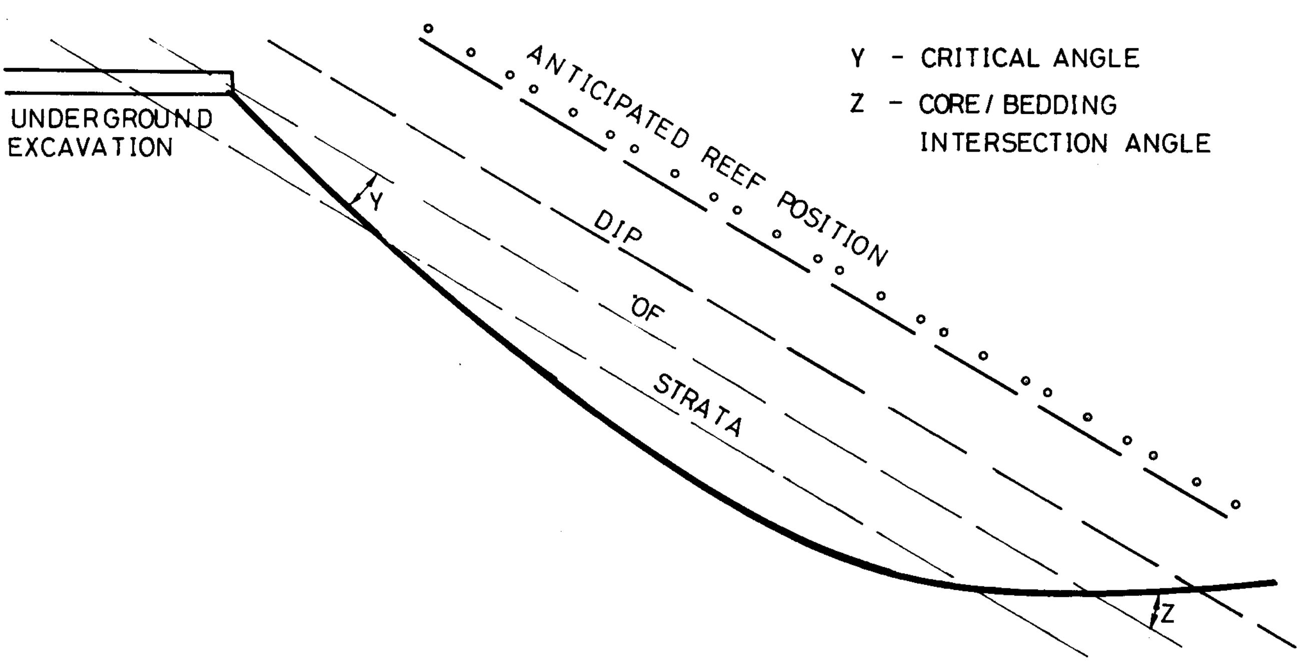

Fig. 2—The critical angle and the attitude of the controlled borehole at depth

strata dips, the angle between the core and the bedding intersection is larger, causing the borehole to turn more into the strata. This angle at which the borehole penetrates the strata is known as the angle of penetration.

In the planning of a controlled borehole, the angle of penetration must be considered separately for the initial and the final stages of the drilling programme. During the initial stage, the borehole should be drilled as straight as possible, deeper into the footwall of the orebody and cutting the bedding planes at an angle. All precautions should be taken that the borehole does not deviate up to a depth of, say, 500 to 600 m. During the final stage, the borehole should be left to deviate. The borehole will now 'lift' as it has the tendency to become more normal to the bedding.

The angle at which the borehole cuts the bedding planes during the initial stage of the drilling programme is very important (Fig. 2). If the angle is too small the borehole may deviate too soon and 'lift', resulting in a much shorter hole that does not reach the target. If the angle is too large, the hole may deviate in a direction opposite to that originally planned, resulting in a borehole that does not intersect the target.

Because of its importance, the angle of penetration is referred to locally as the critical angle (Fig. 2). Unfortunately, this angle cannot be calculated and varies from area to area depending on the dip of the strata in that area. Information from previously drilled holes has indicated that an angle of between 16 and 20° can be used with success in the Orange Free State Goldfields.

Therefore, to achieve the optimum success in a controlled drilling programme, the borehole should be collared at an angle between 16 and 20° greater than the strata dips, and should be drilled initially into the footwall of the orebody. The hole should be straight and not deviate for approximately 600 m, and thereafter should be allowed to deviate to intersect the target as planned.

The worst cause of deviation is the presence of hard and soft layers within stratified formations. Figs. 3 and 4 show that the hole tends to steepen in hard rocks as pivoting takes place at the lowest point of the drilling bit with maximum wear along the upper portion of the hole. Figs. 3 and 4 also indicate that the opposite happens, i.e. the hole 'lifts' during drilling in soft rocks. In addition to the soft layers present in a formation, soft material occurs on the bedding planes and assists in the deviation into the bedding.

The load or pressure on a drilling bit can have a major influence on the natural deviation of a borehole. With additional pressure, the borehole is usually forced into its natural trend, i.e. it turns perpendicular to the strata. When it is desirable for a borehole not to deviate, no additional load should be applied. Natural deviation and load must be considered simultaneously, and the load is the only aspect that can be strictly controlled to ensure that a drilling programme continues as planned.

Borehole Deflections

During the planning and drilling operations of a controlled borehole, more emphasis is usually placed on natural deviation than on planned deflection. In planned deflections, the operator can use the conventional wedge as well as the factors that cause deviation to guide the hole towards a target.

The use of the conventional wedge to change the direction of a hole is by far the most commonly used deflection technique. Normally, a wedge has a maximum deflection of 1° 30″ and, in order to obtain greater angles, a set of wedges placed close to each other is used. In addition to the re-alignment of holes that have deviated, wedges are used intentionally to deflect a hole from its original course. The latter application is used where secondary holes are deflected from the mother hole to obtain multiple intersections of the orebody.

Wedging is expensive and, with metal in the hole, there is a possibility of losing the hole. Because of this, it is suggested that, where possible, wedging should be limited and more use made of the natural deviation of a hole.

The secret of borehole deflections in controlled drilling lies in the control of the load on the bit. It is most important that the load should be strictly controlled to ensure that there is not excessive load on the bit. Excessive weight on the bit causes excessive deviation, which could result in failure to intersect the target. However, load can be used to advantage when additional 'lifting' is required. It is common practice for operators to use additional load on the bit in order to force the borehole in the direction of deviation if this is required.

Borehole Surveys

During any diamond-drilling programme, boreholes deviate and they are intentionally deflected in certain directions. To obtain the optimum information regarding their behaviour, borehole surveys are carried out.

Various survey instruments are used today, and the information required is the inclination from the vertical and magnetic bearing (direction). This information, together with the horizontal and vertical location at the survey station, is used in the extrapolation of any other points on the course of the borehole. This can be done mathematically, graphically, or by the use of computer programs.

Stratometric surveys are an important aspect of any exploration drilling programme, and involve the determination of the attitude of dip and strike of bedding planes and faults.

Normal borehole and stratometric surveys should be carried out at regular intervals during controlled drilling programmes. The attitude of strata dips and the borehole's behaviour at any given point should be known because it could have an effect on the natural deviation at that point. The inclination of the borehole and the dip of the strata can be obtained, and the degree of natural deviation calculated. With this information, any decision regarding the control of the borehole can be taken.

Conclusion

In conclusion, it can be stated that, of the various methods and techniques that can be applied to increase the performance and decrease the cost of surface and underground boreholes, the most important factor is the preplanning of the holes and a knowledge of the ground formations. Different techniques should be applied in different environments. In underground controlled holes,

TABLE I

GUIDE TO THE SETTING OF WEDGES IN LONGHOLE DRILLING FROM SURFACE

Category of hole	Required result	Recommended wedge setting
0,0 to 7,50° off vertical	To flatten hole and maintain azimuth	On magnetic bearing of hole
	To steepen hole and maintain azimuth	Magnetic bearing of hole +180°
	To flatten hole and change azimuth	Magnetic bearing of hole +90° maximum. N.B. Optimum turn is achieved in the clockwise direction
	To steepen or maintain inclination of hole and change azimuth	Magnetic bearing of hole +120 to 135°. N.B. Optimum turn is achieved in the clockwise direction
7,50 to 12,50° off vertical	To flatten hole and maintain azimuth	On magnetic bearing of hole
	To steepen hole and maintain azimuth	Magnetic bearing of hole −(135 to 180°). Risk hanging wedge. N.B. Very little or no turn will be achieved in the anti-clockwise direction
	To steepen hole and change azimuth	Magnetic bearing of hole +(111 to 135°), i.e. for (7,5° and 12,5° respectively). N.B. Optimum turn will be achieved in the clockwise direction
	To flatten hole and change azimuth	Magnetic bearing of hole +(70 to 110°). N.B. Very little directional change will be achieved in the anti-clockwise direction
12,50 to 20° off vertical	To flatten hole and maintain azimuth	On magnetic bearing of hole
	To flatten hole and change azimuth	Magnetic bearing ± (90 to 120°). N.B. Optimum turn will be achieved in the clockwise direction
	To steepen hole and change azimuth	Magnetic bearing + (121 to 140°). N.B. Only very little turn will be achieved.
12,50 to 20°	To steepen hole and maintain azimuth	Magnetic bearing (135 to 180°). High risk hanging wedge
>20° off vertical	To flatten hole and maintain azimuth	On magnetic bearing of hole
	To steepen hole and maintain azimuth	Magnetic bearing of hole ±(135 to 180°). Very high risk hanging wedge
	To flatten hole and change azimuth	This exercise is virtually impossible. The direction cannot be changed unless the hole is steepened first
		Wedge setting of magnetic bearing of hole +140° can be attempted but very little results should be expected

natural deviation is the key to success and must always be considered before use is made of wedges, which are costly and may present problems during drilling operations.

Reference

Cumming, J. D. *Diamond drill handbook.* Hunter Ross Co. Ltd, 1951.

Addendum: Directional Wedges in Surface Boreholes

Over the years, a great number of directional wedges have been employed in deep exploration boreholes. Operators have used wedges to obtain optimum separation between reef samples for evaluation purposes or to negotiate problems of a structural or sedimentological nature.

The efficiency of the wedging operation has varied enormously from situation to situation, and Table I was compiled to simplify decision-making regarding the setting of wedges in the exploration of Witwatersrand-type orebodies. It must be pointed out that not all the relevant factors have been taken into account. For example, the attitude and physical nature of the rock being drilled can contribute to the behaviour of boreholes. The investigation of all these effects has not yet been possible.

The actual changes in inclination and azimuth brought about by the emplacement of a series of directional wedges in rapid succession can be enhanced in a number of different ways. One of these techniques is termed *side-tracking* (to be used when the borehole is more than 10° off the vertical).

The side-tracking technique involves the following procedures.

(1) Set wedge on required magnetic bearing.

(2) Bullnose 1 m only so as to leave at least 0,5 m of the facet of the wedge still exposed. (This encourages the initial kick-off of the wedge.)

(3) Drill past the wedge, using specially flattened *non-coring* side-track bits, turning the rods at low revolutions and applying high pressure.

Recent experience has shown that ground conditions favourable to the use of the side-tracking technique include the following:

(a) robust, polymictic conglomerates, e.g. the boulder beds in the Elsburg (when the borehole is less than 10° off the vertical, the risk of changing the azimuth is very high),

(b) hard siliceous quartzite with intercalated soft argillaceous quartzite or shale bands — the hard quartzites must predominate,

(c) lava or intrusives, especially when penetrating alternating intrusives and sediments,

(d) any formation that changes often from hard to soft — hard must dominate.

Ground conditions unfavourable to this technique include

(i) shales, e.g. USM or Jeppe Upper Shale, where the shale bands are predominant and the intercalated siltstones are very soft,

(ii) even-textured, even-grained, hard, siliceous quartzite or soft, argillaceous quartzite with no break in monotony, e.g. MF 4 quartzites and VUS.

A second method is drilling with a recently designed *tapered wedging crown*. Although the authors have not had any experience of drilling with these crowns, reports have been received of excellent results in boreholes. One advantage of this technique is that coring takes place and that the bullnosing process is completely eliminated.

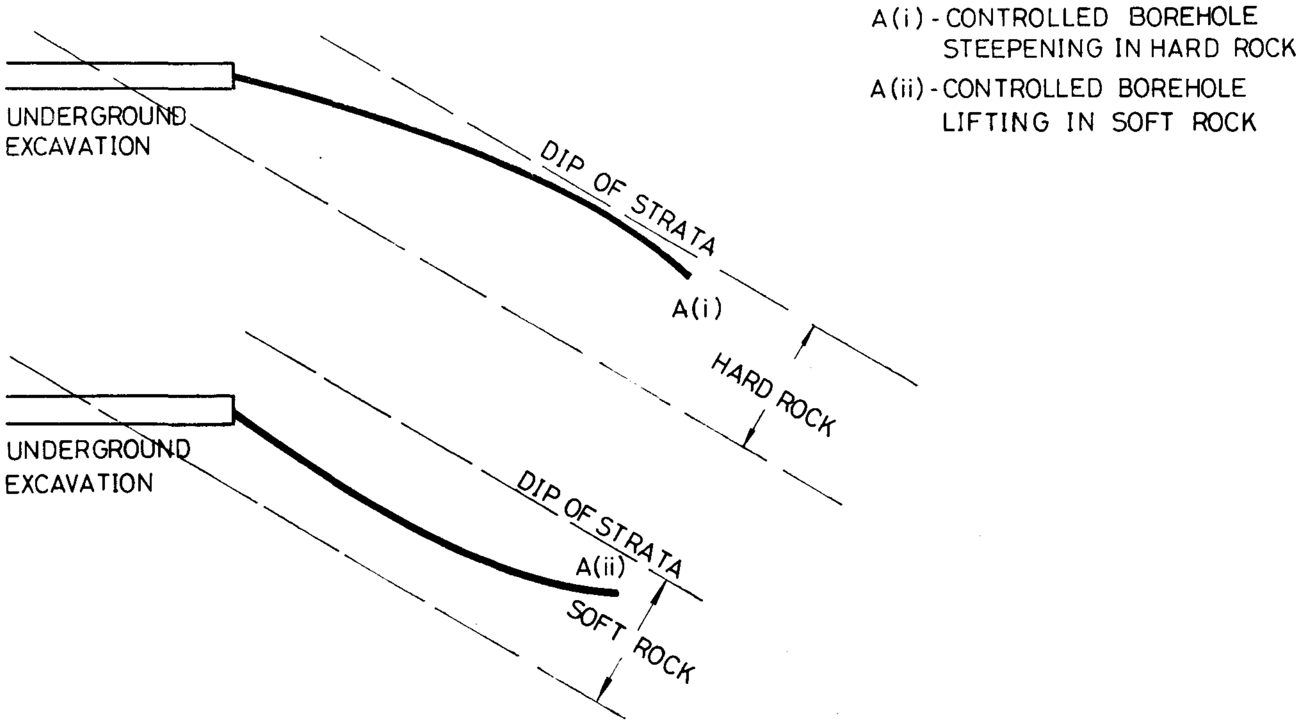

Fig. 3—The behaviour of a borehole in hard and soft rock

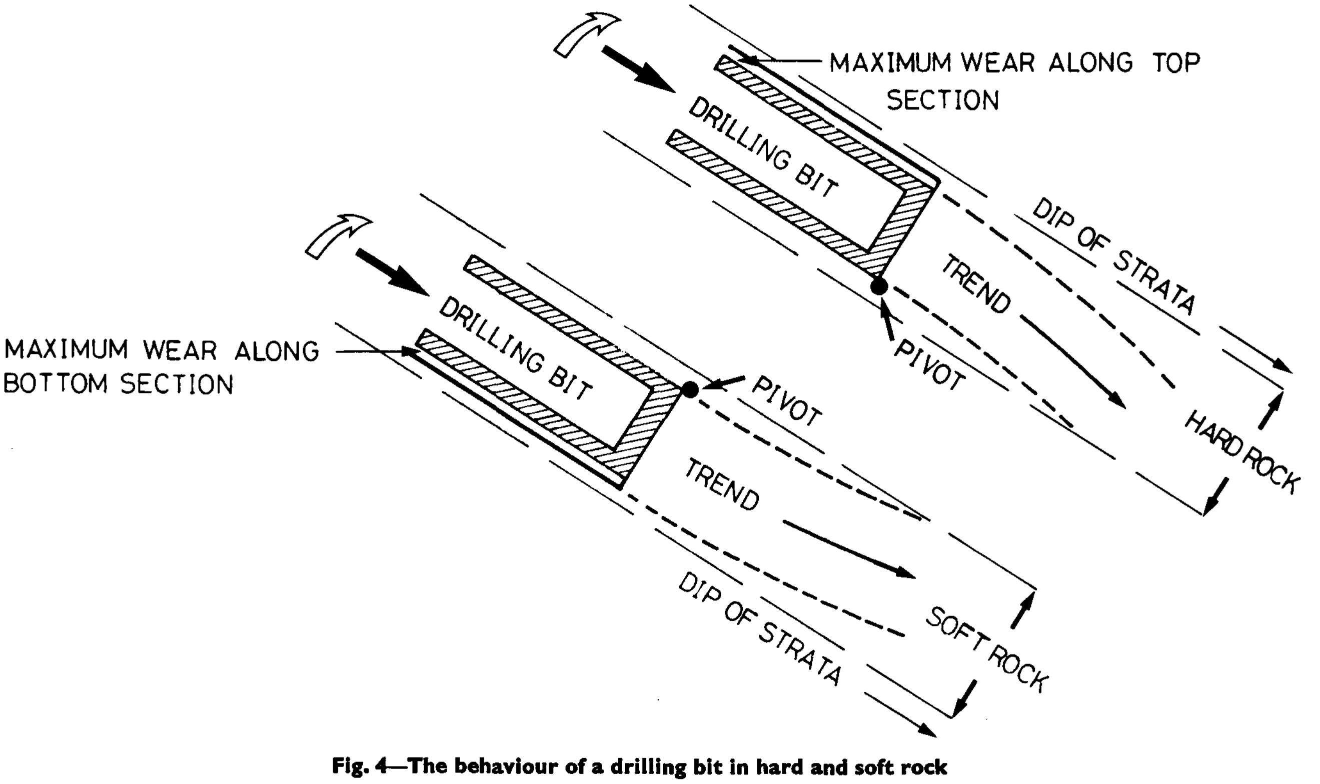

Fig. 4—The behaviour of a drilling bit in hard and soft rock