[No. 3264

MINES DRAINAGE

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Introduction.—In a recent paper* given before one of the Federated Institutes, mine water and the factors affecting it were dealt with at some length. Reference to that paper is invited for greater detail than is here given on that aspect of mines drainage.

It is proposed to deal here with the practical side of the question of the effect of the water in the mine.

ENTRY OF WATER TO MINE WORKINGS.

A clear picture of the mode of passage of water through the strata is best obtained by imagining these to be replaced by a series of pipes, arranged like those in an organ, but with lateral connexions at intervals. Imagine first that the pipes are all open at the top, but closed at the bottom and ends, with the exception of one end of the uppermost lateral connexion (Fig. 1). If water is allowed to enter the open tops of the pipes these will fill up until the water begins to flow out of the single open end.

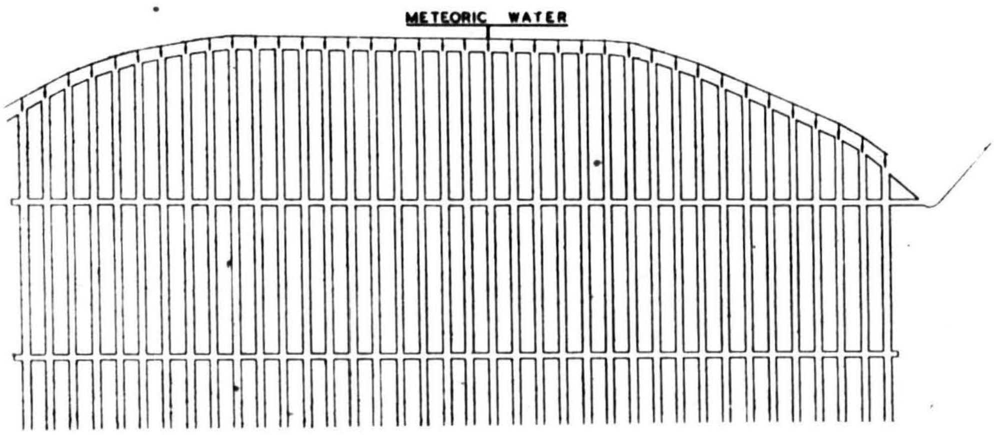

Fig. 1.—Percolation through Breaks and Bedding-planes. The Tube Analogy.

Assuming the water to enter all the pipes at the same rate, it will stand at any instant at the same level in all, until the lateral is reached. Once lateral flow commences, however, due to the friction in the lateral passage, water must stand at an increasingly higher level with increasing distance from the open lateral end, and, indeed, if the rate of entry of water is high enough, or alternatively, the size of the lateral small enough, the vertical tubes most remote from the open end may overflow at their upper ends. Thus, a line drawn through the water surface in the various tubes will slope downwards to the open lateral end (Fig. 2).

If the tops of the tubes be considered to be the surface of the earth and the open lateral the lowest point of a valley, then the line joining the tube water surfaces represents the "rest level" of ground water, or "water-table," while the angle of its slope from the horizontal is the "hydraulic gradient." The hydraulic gradient will depend upon the diameter and number of the vertical tubes, the diameter of the lateral, and the quantity of water available to them, or, translated

* "Mine Water," H. Saul, *Trans. Inst. Min. E.*, 1947-8, **107**, 294.

into practice, the porosity, frequency of occurrence of breaks and bedding-planes in the rocks, and the rainfall preceding the period in question.

Let it now be imagined that a pumping-shaft is sunk, down to the first lateral, at some distance from the open end. Clearly, the level of water will fall in the vicinity of the shaft in a manner similar to that at the open lateral end, except that in this case it will occur equally in all directions from the shaft, assuming similar ground conditions. The level of the water in the shaft is then known as the "depressed" or "pumping-water" level, and the plane joining the water-level

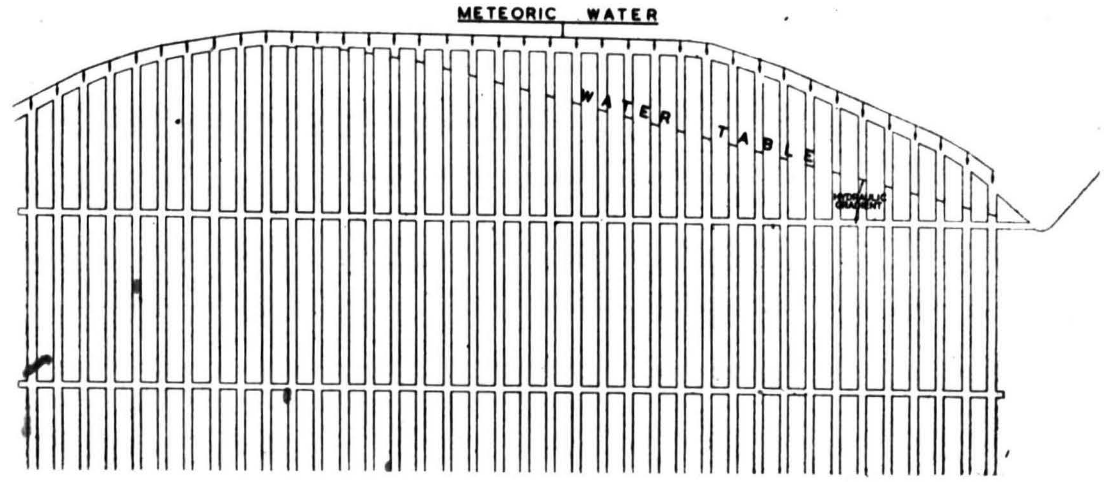

FIG. 2.—DRAINAGE OF GROUND WATER TO A VALLEY BOTTOM.

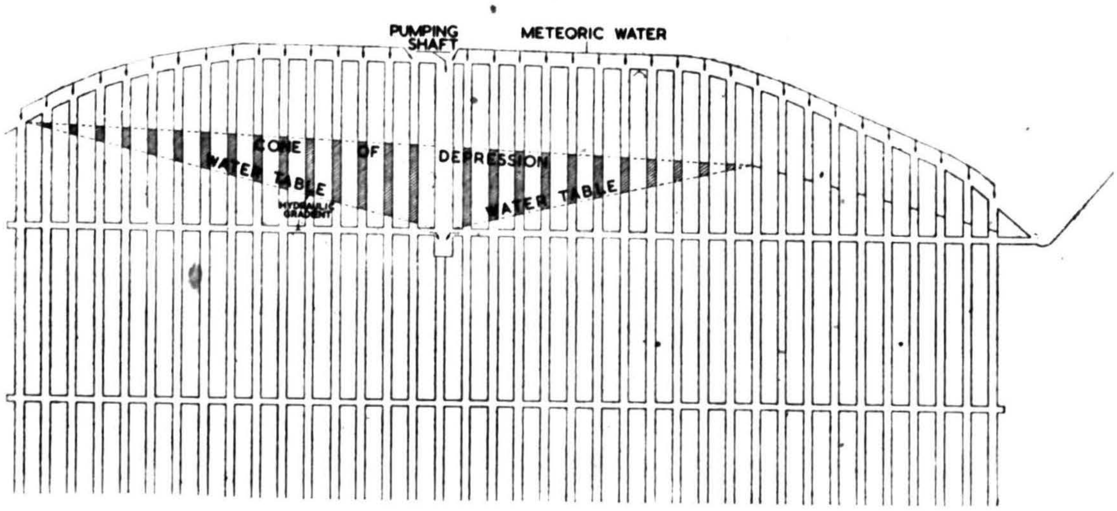

FIG. 3.—EFFECT OF SHAFT-SINKING UPON GROUND WATER.

in the ground around it is referred to as the "cone of depression." Again, the easier the lateral flow in the ground the less the angle from the horizontal of the cone of depression (hydraulic gradient), and the farther distant from the shaft the circle on which the water remains at its former level (Fig. 3).

If the shaft be now plugged with concrete or alternatively be given a watertight lining, or again, if the lateral be located and sealed with cement or an ice plug, lateral flow will cease, and sooner or later the ground will fill up again to its former level, placing a static-water pressure upon the shaft at the end of the lateral equal to the height of the water-table above it. It will be borne in mind that should the lateral be opened subsequently there will be available the feeder pumped immediately before sealing, together with an additional feeder due to the water between the cone of depression at that time and the rest water-level.

Let the sinking be continued until another lateral is encountered. Here again, there will be a renewed flow of water, with a repetition of the former experience in some degree. If the depth between the two laterals is small, or if the ground is very open such as in the extreme case in limestone or Triassic uncemented sandstones, the conditions will be identical. If, on the other hand, the vertical distance is considerable, or the ground is almost impervious, then, because of friction in vertical and lateral passage of the water, the quantity available will be less, and the cone of depression formed at the surface will be shallower and less extensive (Fig. 4).

Following on, it will be appreciated that a depth will be reached, greater or less according to the permeability or otherwise of the ground, at which entry from a lateral break or bedding-plane will be almost negligible. This may be described as the base of the "zone of meteoric water," and coal workings below it will be dry unless open subsidence fractures reach up into permeable ground within the zone. Here again, it must be remembered that such a break will form its own

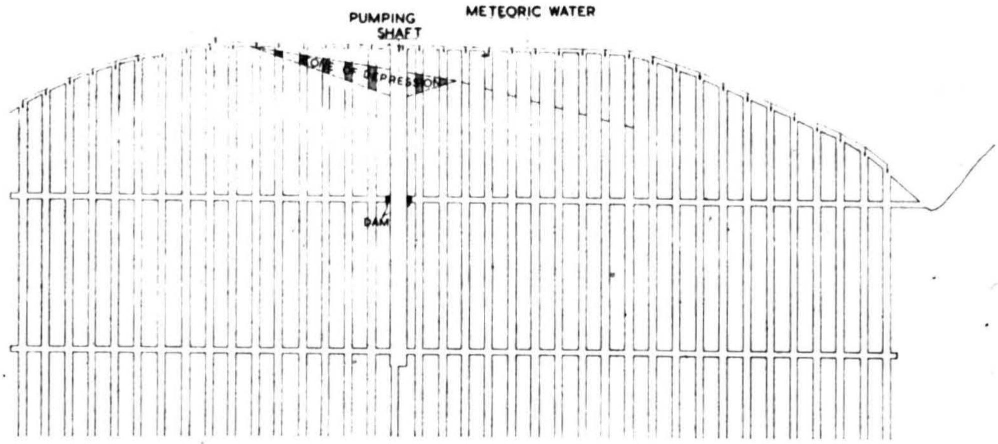

FIG. 4.—EFFECT OF RENEWED SHAFT FEEDERS AFTER INITIAL SEALING.

cone of depression, and until this formation is complete there may be an initial flow of water much in excess of the permanent flow after equilibrium has been established.

If a break reaches ground in conditions similar to that described at the first lateral, then the cone of depression will be appreciable, and the flow of water into the mine will be seasonal. If, on the other hand, it reaches ground at some depth, or separated from the surface by less permeable strata, the seasonal variation will be less.

In the early days of mining, when the only means available for pumping large quantities of water was the expensive steam pumping-engine, it was the practice to drive a road in the coal-seam rising at about 1 in 500 from the lowest surface point near the mine, corresponding to the lateral first described, and indeed, sometimes the level was lowered still further by use of a tunnel to a lower point still more distant. To facilitate dry work at depths below this lateral, a second water-level was driven from a pumping-shaft on a line estimated to be the approximate contact of the seam with the base of the zone of meteoric water.

The higher water-level took out large quantities of water, with heavy seasonal variation, by gravity. The lower water-level carried to the pumps smaller quantities which would practically account for the remaining water available to the mine, and provided that a solid pillar of coal 15 to 30 yds. in width was left on the lower side of each level, any small quantities occurring at greater depths could readily be dealt with by small pumps driven by horses or gears from the haulage-rope.

Due to the introduction of electricity and compressed air, and the reduction of pumping installation and running costs to a minor proportion of mining expenditure, this elaborate but economical lay-out for mines drainage had fallen almost into disuse since the turn of the century, except in very heavily-watered shallow mines. Fortunately, the introduction of locomotive haulage forms an excellent opportunity for the reintroduction of the system, and the recovery of its former advantages by the superimposition of only a little extra care and work upon a locomotive-haulage system. Under present conditions, the system can be used with much more flexibility, due to the fact that the level may be removed from the shaft to any point convenient for other purposes and be served by an electric pumping-station, always provided that its depth below the zone of meteoric water is not so great as to put on unnecessary pumping lift.

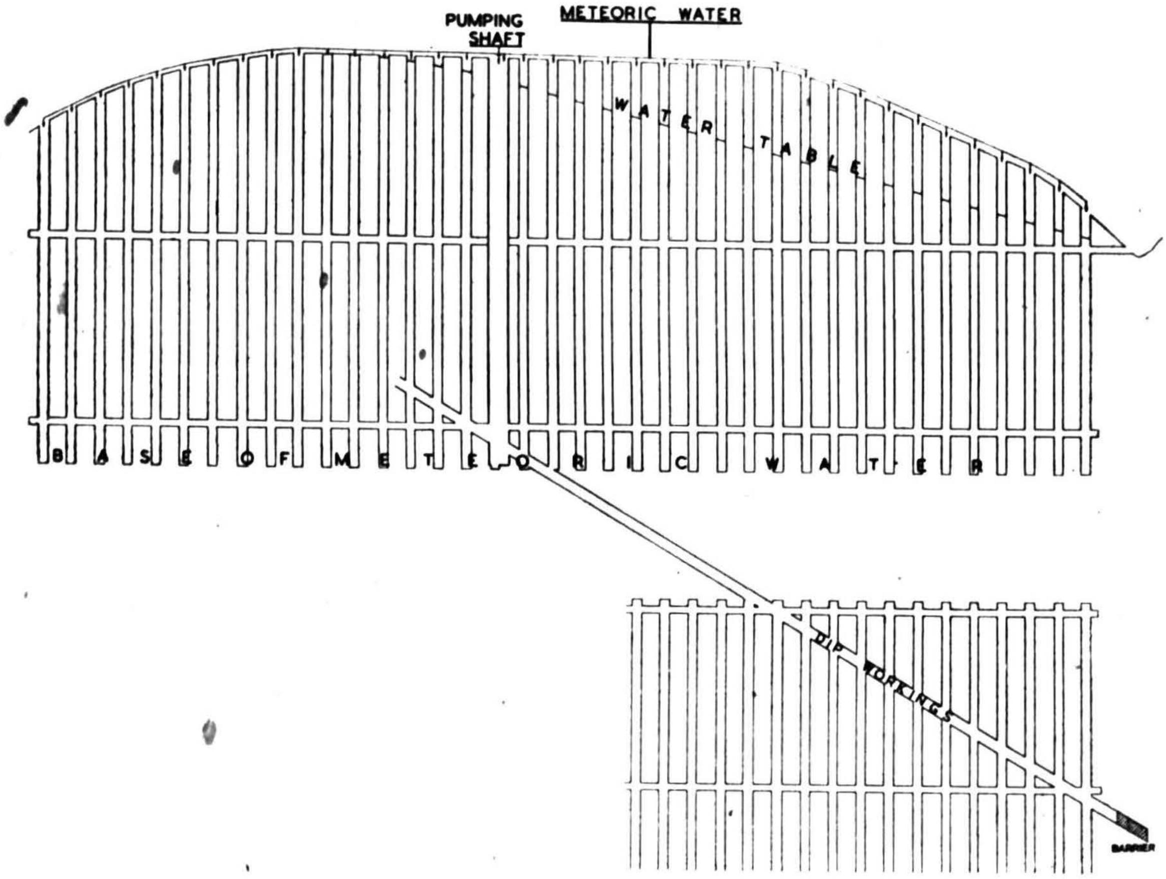

FIG. 5.—SECONDARY WATER-TABLE AT FLOODED DIP WORKINGS.

Secondary Water-table.

It is to be assumed that any seams below the one previously in question would under normal circumstances be worked dry. If, however, the upper workings had been allowed to fill with water, conditons similar to those obtaining at the surface would be reproduced, and a new water zone created, which might extend the availability of water 200 to 400 ft. vertically below where nature had it. The old workings represent a lateral passage frequently very much more conductive to water than any stratum previously existing, however. Thus the occurrence of a water-carrying break might not be a question of short-term heavy pumping to produce a local cone of depression, but of the de-watering of the old workings.

Reversed Water-table.

There has been considered, so far, only the EXTENSION of the surface water-table by old workings. Extensive workings to the dip, however, may have passed a considerable distance below the zone of meteoric water. On these filling with water, not only would a secondary water-table be formed below them but also conditions above them would resemble the case of open-ended vertical and lateral tubes up to a height equal to the static head of water available (Fig. 5). This is most important when considering the question of dams and barriers, which are too often the subject of opinions which ought properly only to be applied to a specific case.

DAMS AND BARRIERS.

The strata above or below a barrier, or in the case of a dam the stratum containing it in addition, may be represented by tubes of greater or less diameter according to the permeability of the stratum in question. If there is a large diameter lateral connexion at such a distance from the waterlogged working that the friction in the vertical tube is small, then water will pass over or under the barrier, or around the dam, with relative ease. If the vertical or horizontal distance to the easy passage is such that frictional resistance against the mine water is great, then little or no water will pass, and "the barrier is sound." Be it remembered that the vertical and lateral tubes may be only the bedding-planes, joints, and pores of the strata *in situ*, or may be, in addition, subsidence breaks due to the mine working. If it is intended to leave a barrier, or place a dam, it is desirable first to compute the position of a break which would reach permeable strata either at such a height as to be above the accumulated water, or at such a distance as to guarantee an adequate vertical and lateral friction against water passage, and then to see that workings are not carried beyond a line forming such a break. If this cannot be arranged, a barrier is unlikely to be of use, except in the restriction to a steady flow of water from old workings subject to heavy seasonal variations. In the case of the dam, on the other hand, cementation may rectify the position.

Width of Barriers.

So far as I am aware, there is no case on record of the bursting of a barrier, failure being always by leakage. Computation of shearing strength will show that the actual strength to resist bursting is normally given by a width of barrier much less than that required to resist leakage. It is suggested that the following are the major considerations:

1. Liability to error due to surveying or to close approach before notifying the surveying department. It is the safer course to allow 1 chain width for this factor alone in excess of that considered essential, in order to ensure that an error of this type shall not render valueless an otherwise excellent barrier of great length, left at considerable expense.

2. Nature of the seam. It is often found that barriers leak along dirt-partings, or, in faulty or steep ground, along cleavage exaggerated by earth movement. In thicker seams, subsidence being greater than in thinner seams, breaks in the vicinity of the barrier are usually of greater significance, and furthermore, the coal is usually broken and useless for 2 or 3 yds. on each side.

3. Nature of roof and floor. As already indicated, the more open or broken the nature of the adjacent strata, the less the frictional resistance against water per unit length of passage. The remedy for such conditions is to increase the length of the passage. It has therefore been found necessary, in some cases, to fix a greater width of barrier in one seam than I considered necessary to fix in another at considerably greater depth, having an almost impervious roof and floor.

4. The possibility of future work in other seams. Where several seams are to be worked under a barrier in an upper seam, it is often thought that a vertical section through the barrier should be wedge-shaped in order to avoid spoiling the topmost barrier. I am not in invariable agreement with this policy. It may conceivably be more economical to leave the upper barrier of greater width so that, in fact, breaks from lower seams may pass along it and inside it, without damage because the frictional path over or under the barrier is still of sufficient length to be effective in preventing serious leakage.

For example, it is often found that under most favourable conditions, a barrier 2 chains in width is completely effective, and it is not suggested that a less width should be left because of consideration (1) above. If a seam 300 yds. deeper were to be worked, in order to ensure no interference with the barrier, it would be necessary to leave a supporting pillar under average circumstances of the order of 7 chains in width. If, on the other hand, a 4-chain barrier were to be left in the upper seam it might be possible to withdraw support completely in the lower seam, a point worthy of consideration in the first instance.

Construction of Dams.

The same considerations as to length of leakage path just applied to barriers should be applied to the siting of a dam. It is of little value to cement the natural breaks within 100 ft. of a dam if at 120 ft. distance similar breaks are still available to connect workings 90 ft. apart. If possible, roads to be dammed should be in solid coal for a length comparable with the width of a barrier to be left under like circumstances.

Apart from temporary or emergency dams, which may conveniently be constructed of tapered wood blocks, if necessary repeated with clay separation, a most generally useful form of dam is that of mass concrete. Good service has been given by comparatively thin reinforced-concrete dams, but these are subject to the drawbacks of a tendency to leak along their reinforcement, and the necessity for very extensive excavation. It will be appreciated that a concrete dam is very much stronger than an equal thickness of the strata containing it. The governing factor, therefore, is normally the length of the shear-plane in the strata containing the dam, which must be made of adequate length either by deep excavation in the strata or by great length along the road. The appropriate calculation is that of multiplying the static pressure on the water side of the dam by the area of the face exposed to it and equating this with the shearing strength of a square inch of strata, multiplied by the shearing surface area and an appropriate factor of safety.

In a mass concrete dam, only the loose material is removed from floor, roof, and sides, giving a final cross-section of say $W \times H$ sq. ft., and a total pressure on the face of the dam of $P \times W \times H$. The shearing surface is twice W plus twice H multiplied by length L (required to be ascertained), giving a simple equation. The mass concrete is commonly contained between two brick end walls, and these are cut into floor, roof, and sides to such a depth as will intercept all major breaks. This depth varies in practice from 2 ft. to, in the worst case in my experience, 30 ft. (in the roof).

The mass concrete is inserted either as such, as dry brick packing subsequently injected with cement, or as "Colcrete," and the dam is completed by sealing the contact planes and strata breaks by cement injection. It will be realized that but for the intersection of these by the brick end walls, sealing would be difficult, or at least expensive.

ROOF AND FLOOR WATER.

A clear understanding of the principles already emphasized will often help to reduce the magnitude of coal-face water problems. The cost of mine drainage is often considered in terms of pumping cost only, whereas quite frequently that is not so great as the indirect cost consequent upon having wet faces. It often seems possible to ease or obstruct the water path through the strata in order to direct water from the coal-face to some point at which it can be dealt with more easily and more cheaply.

Thus, water in roof measures may lie against a fault or some point of local high resistance until a subsidence break taps it into a coal-face, with unpleasant consequences. Again, faces advancing to the dip may do so in dry conditions until they reach the level to which the water-table has been reduced by drainage elsewhere. Thereafter, further advance is a miserable matter of wet faces and uneconomic face pumps dealing with small quantities "on snore." There may also be the added discomfort of roof drippers.

The following examples of experiences in recent years typify devices which may be adopted to minimize such trouble:

(1) A small colliery had profitable workings to the rise from a level roadway which was normally just above the water-table. It was found almost impossible to

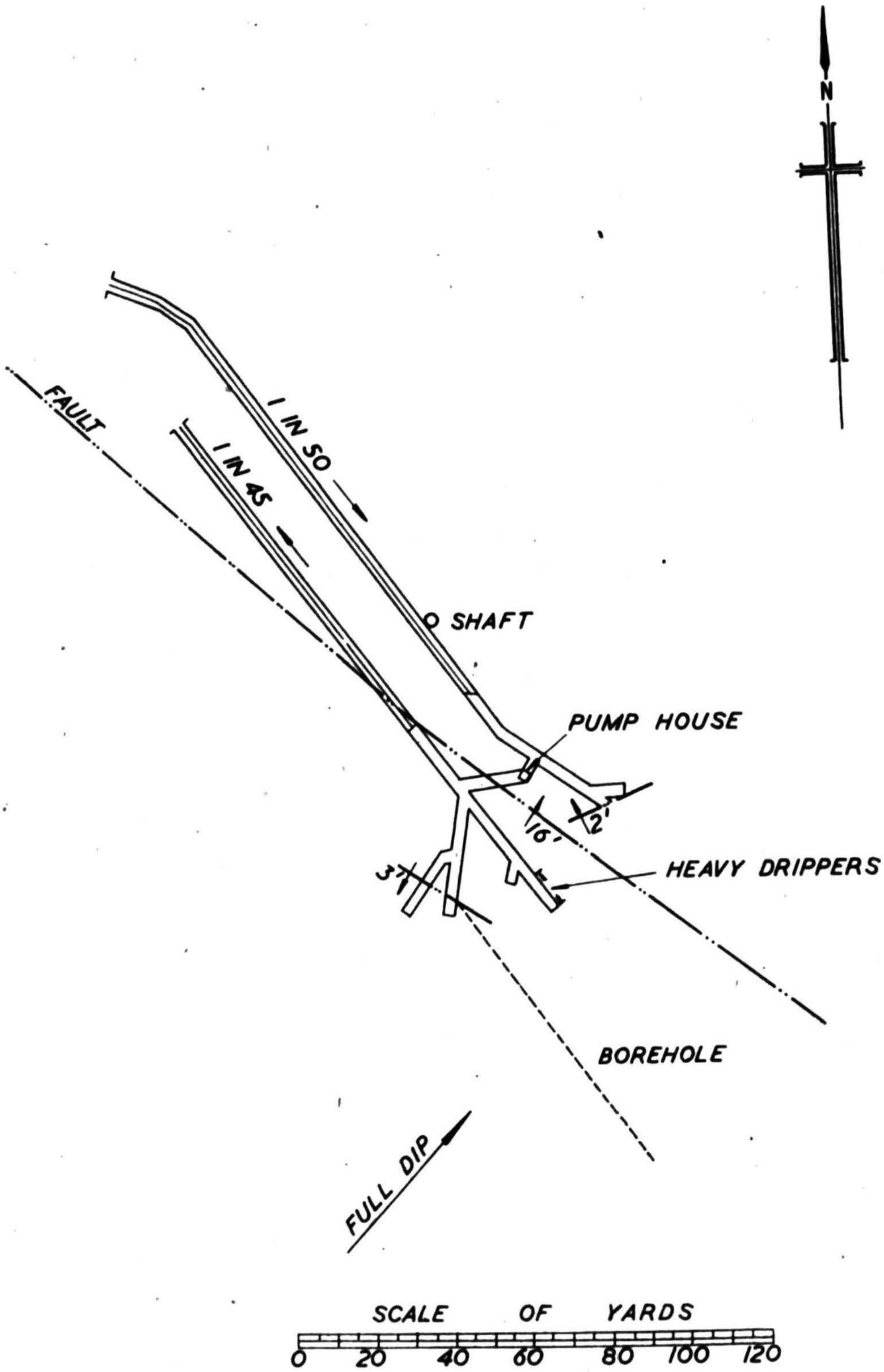

FIG. 6.—ELIMINATION OF ROOF DRIPPERS BY HORIZONTAL BORING.

carry development headings to the full dip by reason of the large quantity of water which had to be dealt with at the face. Furthermore, during abnormally heavy weather, the water-table rose into the main level and created a major pumping problem. It had been thought that the water appeared from waterlogged workings in a deeper seam through vertical breaks in the strata. Extensive cementation in the floor was in progress. In fact, however, the water arrives naturally via a thick bed of rock below the seam from its exposure at the surface, and development has been made possible by a series of vertical boreholes in the floor of the main level, carried down 30 ft. to a depth below the proposed second level. These holes have been sealed and connected to a receiver, to which is attached the suction of the main pump. Steady pumping is gradually lowering the water-table.

(2) Level development headings in a shallow seam 6 ft. in thickness encountered roof drippers so numerous that oilskins were necessary. A 2½-in. dia. horizontal borehole in the seam, 83 yds. in length, parallel to the heading and 5 yds. distant, produced a feeder of 24 gal. of water/min., the roof drippers ceasing entirely within 24 hours (Fig. 6).

(3) A level stone heading in Bunter sandstone had such heavy roof drippers for 20 yds. back from the face as to drench workmen in a few seconds. Two holes drilled in the roof from the commencement of the wet section, inclined upwards at 45° towards the face, removed the drippers in two weeks, although they had been running previously for several years.

An application of the same principle in a converse direction, varying from the placing of a concrete sill in the floor of a dip road to a zone of cementation, may prevent rise water from following down a dip heading or drift. Particularly is this remedy valuable where a fault is crossed, for the construction of a sump and automatic pumping arrangements, coupled with such water-proofing measures, may well dispose completely of the water problem.

LAY-OUT OF PUMPING ARRANGEMENTS.

Cases have not been unknown in the past where the haulage system of an old mine has been found to consist of a series of haulages put in one after the other, as each reached the limit of its rope capacity. Similarly, there are still to be found cases where the answer to the appearance of a feeder of water is the installation of a pump at that spot, when, perhaps, earlier planning in accordance with the principles here discussed, followed by periodic review of the whole situation might result in a completely different arrangement.

In order to eliminate labour on maintenance, pumping should be organized as far as possible to take place from properly prepared sumps, allowing for steady running-on water free from sediment.

To eliminate pump attendants, automatic gear should be used. Such gear can be made safe by the use of flameproof motors, having thermostats on stator and bearings of both pump and motor, and in the roof of the pump-house, together with under-load relays to prevent running on snore, in addition to the normal protective gear.

Nevertheless, because of the dependence of the effectiveness of most of these measures upon their adequate maintenance, it is desirable that such automatic installations should be placed at a shaft-bottom or at a permanent station, where fireproofness and good ventilation are permanent and unquestioned. For this reason, careful lay-out to secure the direction of main feeders of water towards such points is necessary, and the development of the practice of putting down boreholes for strategically placed pumps. The development of the submersible motor is also to be encouraged, because quite apart from any other advantage it is fireproof when used with a properly designed and adjusted underload relay, and offers the most promising lead towards safe automatic inbye pumping in the future.

Mr. H. McVicar (Pontypridd): Some of us have had a great deal to do with the handling of water in mines in past years and it is undoubtedly one of the most costly jobs with which mining engineers have to contend today.

I was very interested to hear what happened in Yorkshire where one particular company provided sufficient money to drive adequate water-levels. I am reminded in particular of the workings on the north crop of the coalfield where, many years ago when the old iron-mines were worked, the levels were driven at a gradient to provide free drainage into the river at the bottom of the valleys, and even today where these levels have been looked after there has been a tremendous advantage in the working of the seams of coal below the ironstone planes, particularly as regards the cost of pumping. Examples of this can be seen at the top end of the Rhymney, Tredegar, and Blaenavon valleys, where the water-levels have been well maintained.

Another point which interested me was the working of seams which were very wet and by the simple measure of boring holes to drain the water away from the face of the workings, conditions were greatly improved.

I should like to express thanks to Mr. Saul for his most instructive and interesting paper.

Mr. C. S. Ball (Hengoed): Many of us undoubtedly have thought that we knew quite a lot about the water problems in this Division, and that we had the answers to many of the problems, but after listening to Mr. Saul I realize how little I do know about the subject. As for the answers to water problems in this coalfield I am afraid they must be reoriented in the light of what Mr. Saul has said. I shall have to reconsider many of the peculiarities we have observed in the behaviour of water in many places. I congratulate Mr. Saul on his most instructive paper.

Mr. P. Cornick (Nantyglo): The author referred to the examination of the outcrops in order to ascertain their permeability and porosity. This examination may give a false impression. If the outcrop has undergone any degree of weathering one must be careful to ascertain the horizon of that particular outcrop and its true correlation with the bed or section of bed one is examining in the earth's crust. The deeper the strata the more compact the rocks become and the less their permeability and porosity.

Should not such examinations be accepted with a certain amount of reserve?

Mr. Lister Walker (Hengoed): The author stated that the shear-stresses of rocks in the vicinity of dams is never more than 25 p.s.i. Is this true of strong sandstone?

Suggested methods of working under water-bearing strata have not been mentioned, and I should be glad if the author would indicate maximum safe widths of excavations under Magnesian limestone or Permian sandstones.

Mr. C. H. Davis (Hengoed): Mr. Saul has just given an example of the boring of a hole upwards to prove a seam waterlogged above. Does he know of an example of boring a hole upwards definitely to de-water a seam from a silting-up point of view?

Mr. R. Richards (Pengam): I shall be glad to have further information on dams and barriers. The author has accepted 15 p.s.i. as the resistance between the sides of the dam and the surrounding strata, or the equivalent of 2,160 p.s.ft. Would he recommend this value for all kinds of strata, particularly as several kinds of shale, etc., found in the Coal Measure sequence are so prone to incipient fissures and disintegration, etc.?

Is it not an engineering consideration, in the case of concrete constructions, that the weight of the dam plays an important part in resisting the load? The concrete dam cannot be considered as an integral part of the surrounding strata, hence in addition to a very variable shear resistance the weight of the dam cannot be ignored.

Regarding the width of coal-barriers, bold is the individual who would suggest that a 2-chain width would suffice for all cases. Even the WATER DANGERS COMMITTEE was loth to express an opinion on the matter having regard to the varying factors and conditions involved in the problem. The cleat of English coals differs considerably from the "slips" which are characteristic of Welsh coals. Such slips are prone to slide away from the seam and thus weaken the barrier, and particularly so when the line of the coal-barrier is coincident with the line of slips in the coal.

As regards coal-pillars left in lower seams to prevent ground movement surrounding a dam in upper seams, such pillars should progressively increase in their dimensions with increasing depth. The suggestion that pillars should diminish in size with depth is in opposition to our experience and knowledge of roof movement and pressures with increasing depth. Would the author advocate that the shaft-pillars in successive seams should diminish in size with depth? The protection of a shaft is on a par with the protection of a dam or any other structure, and pillars left for the support of a dam should, in seams situated below the dam, be increased in size on some recognized angle of draw of the strata.

The problem of water in Coal Measure strata is purely geological. Shales and other rocks of an argillaceous nature are impervious and present a natural barrier to the entry of water from an upper or lower water-bearing bed, such as sandstones. In South Wales the main water-bearing beds occur in the Pennant sandstones, which overlie the No. 2 Rhondda coal, and the amount of ground-water diminishes with depth until the level of the Two Feet Nine coal-seam is reached. Below this seam the great mass of shales and coal-seams of the Lower Coal Measures occur, and on account of the very impervious nature of the shales the workings in zones of strata below the Two Feet Nine are dry. In fact, water for fire-fighting and infusion services is drawn from shafts at levels from the Two Feet Nine Seam upwards.

An additional feature connected with water liable to interfere with mining operations in South Wales is its entry in large supply from below the lowest workable coal-seam, namely, the Gellideg or Old Coal. These large supplies of water are pent up in the Millstone Grit and in certain parts of the coalfield the layers of shale and other rocks are relatively thin, and when dislocations occur in such areas, such as small faults, inrushes of water from below into the workings above have at times been sudden and alarming.

The water resources liable to impede mining operations in South Wales are therefore confined to two horizons, namely, from the Two Feet Nine Seam upwards and from the Gellideg and Old Coal downwards, and the problem, in so far as the belt of strata in which are found our principal coal-seams is concerned, is not a serious one provided reasonable precautions are observed to isolate, as far as possible, water confined to strata above the Two Feet Nine from entering the lower productive shale series. Water difficulties encountered in mining operations could in most cases be forecast by a geological study of the strata sunk through, as the problem primarily is a geological one, the question of drainage and the most economical way of arranging the scheme being mechanical.

Professor J. Sinclair (University College, Cardiff): I should like to know what Mr. Saul would suggest should be done where exploratory boreholes have been put down from the surface through water-bearing strata, or from an upper seam which afterwards becomes waterlogged, when these boreholes are approached in lower seams and it is not known and cannot be checked whether these holes have been filled up by concrete or not. I am sure Mr. Saul must have come across these problems many times in his wide experience.

With regard to the cutting of rickets on the side of main haulage-roads, I was down a Dutch pit about a year ago and it would appear that they have more or less abandoned this system for pumps and pipes. In the deeper mines, the presence of an open ricket at the side of the road may lead to increased humidity of air through pick-up of moisture. I think that in such cases closed pipe-lines would be preferable.

Mr. H. Saul (Crofton): I appreciate the remarks of Mr. McVicar and Mr. Ball, and have realized from what I have seen and heard during the past two days that the problem in this coalfield is of even greater magnitude than I have supposed from my study at a distance.

I agree entirely with Mr. Cornick's remarks, but would remind him that in most Coal Measure rocks permeability at depth is more by means of breaks and bedding-planes than by porosity. Conclusions must be relative and not absolute; that is to say, one compares the outcrop under examination with the outcrop of other rocks which are being used as standards. The allowance for variation with depth is thus more or less automatic, since it applies equally to the sample and the standard.

I admit that the shear-stress of a strong sandstone may exceed 25 p.s.i., and it might be possible in exceptional cases to use a higher figure. On the other hand, a strong sandstone commonly has wider and more extensive fissures, and is more difficult to seal. A greater allowable stress would result in a shorter dam, and it is questionable whether the saving in mass in the dam might not be lost by trouble in cementing, due to the shorter length plugged against injection.

My own view with regard to working under Permian rocks is that nothing should be taken for granted. There will be little risk in approaching to a vertical distance of, say, 80-100 yds. below potential water-bearing strata. If this thickness were composed of bind and shale there would appear to be little risk in complete extraction. If, on the other hand, there were some thick sandstone, it would be desirable to adopt such widths of excavation as would be used in the same seam to prevent surface damage from a like depth.

Within 100 yds. of the potential water-bearing strata I consider that development should be by narrow work, with boreholes vertically upwards at intervals. If and when water is tapped a test run should be taken from one borehole, the result upon a pressure-gauge at a nearby borehole being observed meanwhile. If a moderate feeder drawn off leads to a rapid fall in pressure, the risk of a flood would not appear to be great, particularly if similar tests at various points yield like results. If, however, there is no fall in pressure when water is drawn off for a long period, great caution in working would be required.

Perhaps it is not out of place to give a reminder that any hole put up to test for water should be subjected to a pressure test after drilling only a few feet beyond the stand-pipe.

In reply to Mr. Davis, I have not had any serious trouble with the silting of a hole drilled vertically upwards, although I have had experience on inclined boreholes which required re-drilling at intervals of 6 months. I understand that in this coalfield, owing to the peculiar nature of the coal, it is desirable to drill holes parallel to the seam in the roof just above it, but I can offer no general suggestion with regard to vertical holes other than the normal precautions of attempting to drill to a known roadway some distance back from the face.

In the case of a borehole vertically downwards, from which the water must be pumped, silting is a serious threat, and in two such cases I have been fortunate enough to be able to prepare a concrete-lined roadway at the bottom of the hole, leaving 30–40 yds. open to the dip, to accommodate the initial silt when water was turned through the workings to the borehole.

Just as I must concede Mr. Walker's point on strong sandstone, so, as Mr. Richards suggests, there may be cases where a figure less than 15 p.s.i. must be used. I have examined proposed sites where such a concession would have had to be made, but surely the answer is to find another site for the dam, if possible. Fissures are dealt with in any case, of course, by cementation of the strata surrounding the dam. I am not quite clear why a concrete dam which is cemented under pressure, in ground also cemented, cannot be considered as integral with, even if stronger than, the surrounding strata, and it is always a pleasure to reflect that the weight of the dam is in favour of strength.

I agree entirely that the individual would be bold who would suggest a 2-chain barrier for all cases. I suggest in the paper that this width is effective under the *most favourable conditions*, and should be a minimum. I am conversant with the report of the Water Dangers Committee, but unfortunately when one is called to a specific problem one must express an opinion. The paragraph on the width of barriers was written as an indication of the factors which I normally take into consideration in such cases. I appreciate the point with regard to the slips characteristic of Welsh coals, and indeed examples were brought to my notice yesterday in which they had apparently rendered a barrier valueless. On the other hand, Mr. Richards will bear in mind that the weight of the barrier acts in the same way as the weight of a dam.

I hoped that I had made clear in the paper that I recognized the need for an increase in the width of barrier in successive seams with depth in normal cases, and entirely agree with Mr. Richard's arguments in that connexion. It will be appreciated, however, that a barrier is normally left as an alternative to pumping out the accumulation and feeders on its rise side. It is, therefore, a prime necessity that the alternative must not be more expensive than the disease. In many cases it has been found that the total value of a wedge-shaped series of barriers would cover alternative pumping costs for many years. I therefore suggest that if an upper seam is most seriously affected by water, the barrier in that seam should, in appropriate circumstances, be of a much greater width than appears to be required from consideration of that seam alone. Deeper seams may then be worked even to such an extent as to cause breaks along, but within, the upper seam barrier, without causing appreciable leakage through it. With seams very close to one another, of course, the barriers could increase in width with depth, without being excessive in total width in the deepest seam, and in that case I would not suggest other than the orthodox procedure.

I am grateful for the local particulars which Mr. Richards kindly adds.

With old boreholes which may not be sealed, I would advise putting advance holes from the approaching heading, inclined upwards, so that if there is any water-pressure it may be readily possible to drain the hole through the strata, if that is not achieved in any case by drippers into the advancing heading. Extravagant precautions would only be necessary where the hole may have passed through a seam now waterlogged, or through a heavily water-bearing horizon, in which case it will be necessary to keep well clear of the suggested position of the hole, then leaving a permanent pillar or adopting repetitive boring until the hole is encountered. In the latter event, it is necessary to seal each unsuccessful hole for some distance in order to ensure that control of the water is not lost by the hole, finally successful, having passed near to one of its predecessors. I know of a similar case in which the pillar finally left was reduced to small dimensions by advancing the face in steps, protected by intersecting boreholes.

I should agree entirely with the abandonment of the ricket system for closed pipe-lines, provided there were no intermediate feeders. On the other hand, a concrete-lined drain with loose concrete covers prevents any serious evaporation, avoids filling with debris, and provides ready access for intermediate feeders and cleaning.