Inflow Prevention
GENERAL REPORT

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Abstract

A review, from the point of view of a groundwater geologist, is made of the factors influencing inflow to mines, and measures to control it.

A report is made on four papers contributed to the Conference.

INTRODUCTION

In reviewing the papers in this section, I hasten to admit that my experience in dealing with inflow into mines is limited. I can however lay claim to a good many years experience in dealing with water in fractured rocks, and the main spring of my comments is from the point of view of a groundwater geologist.

SURFACE FEATURES

Attempts to understand and control inflow must ideally begin in the planning stages of a mine. The site having been chosen by the natural occurrence of the mineral, the surface conditions come first to mind. The climate and particularly the variability of the rainfall constitutes a risk to underground or open pit workings. The proximity of rivers or channels that sometimes carry water is important. Records of surface flooding, tsunamis or tidal seiches also carry a warning, and enable suitable protective bunds to be built into the design of the mine's surface works.

In these days of postulated climatic change, a possible progressive change in sea level should not be ignored.

GEOLOGY

Geological features next come into consideration. The unindurated aquifers are sands and gravels, and are capable of carrying great quantities of free-running water. Mining history is full of accounts of mines that have intersected 'gravel wash' with subsequent disastrous flooding and loss of life. Tunnelling as for instance under the Thames was seriously impeded by the same problem.

Clays of themselves do not form aquifers, but they control the flow of water in adjacent aquifers, and therefore their location is of significance.

The indurated rocks, those hard enough to require drilling and blasting for their removal are more commonly the country rock of mining. In our study we do not need to distinguish the different rocks except to identify them as intergranular or fracture aquifers. The first are those where water is transmitted between the grains of the rock and the second where water flows mainly or entirely through the natural fractures in the rock. Most mathematical treatments of groundwater dynamics are based on intergranular aquifers as these are susceptible to more or less realistic analysis, but in the real world, and I take it in mining, fracture flow is much commoner.

Two rock types must be mentioned as they stand aside from the bulk of hard rocks in their hydraulic properties. They are limestones and evaporites, such as salt or anhydrite. They are different because they are soluble in water, so that as it flows through, it slowly removes the rock resulting in enlarged channels. The effect that this has is so profound that it totally changes the water regime.

STRUCTURE

Besides the hydraulic nature of the rock, its structure is influential. The rock may possess weathering zones which penetrate into the fresh rock and carry water into the mine. The rock if sedimentary may be bedded and this will usually carry with it a hydraulic anisotropy. The beds themselves may be folded, so that directions of high transmissivity may swing round with dip. The feature which distinguishes these aquifers, their fracturing, is a structural property, and will change from place to place in accordance with the imposed stress regimes. It will also result in the major discontinuities that we call faults, which so commonly carry large quantities of water.

Cleavage, the tendency to split along a particular direction, which is imposed by past stress regimes, also controls fracturing and hence possible directions of water flow. Lastly, and perhaps most important, the state of stress or conversely the relaxation state of the rock is that condition which determines whether the discontinuities discussed are sufficiently open for water to be able to flow. To a groundwater geologist the experience of walking about underneath a highly productive aquifer is a novel one, particularly at some depth where the stress state is sufficient to close the normally relaxed fractures and to provide a reasonably dry mine.

EVENTS

Besides the given rock types and their state of deformation, fracture, and stress, we must attempt to predict the risk of geological and other events producing more or less catastrophic inflow. Surface collapse of clay gravel or sand roof is an obvious hazard to be avoided by an adequate knowledge of the geological history of the mine area. Surface events such as landslides, earthquakes, or volcanic eruption are able to suddenly and radically change surface drainage, and to a less extent produce subsurface changes, and these too can be revealed by an adequate geological history.

In these days of wars and rumours of wars sabotage or industrial action can easily disrupt the workings of a mining operation, and what better way than by altering the flow of water, but this is not a geological consideration and I shall leave it there.

HYDROGEOLOGY

Next we must consider some features of groundwater dynamics. This science is based on flow in intergranular aquifers and these are only poorly approximated by fracture aquifers. A borehole drawing water from a fracture aquifer is strongly marked by site specificity. Variability between boreholes is high and yields are subject to 'chance' intersections of particular fractures. Such boreholes are marked by low permeability, low transmissivity, but particularly by high variability and therefore unpredictability.

Mines must be regarded in groundwater terms as large bores, or alternately as large interconnected fracture systems. Inflows although an expensive and troublesome problem, are not as large as groundwater studies would lead us to believe. This is because yields from fractured rocks are normally low, and at the depth of most mines rocks are under considerable compression and fractures are normally tightly closed. Exceptions to this observation are afforded by basalts, limestones and major fractures or faults.

INFLOW CONTROL

There are several ways in which the natural surroundings of the mine may be modified. Dewatering the whole area by means of relief wells is a possibility and means that no further water inflow will occur. On a small scale freezing is used as a temporary measure, and normally requires backing up by some more permanent work, and finally one has the choice of grouting, using cement chemicals or clay.

In the light of all these factors, surface and subsurface, the miner is confronted by a dilemma, unless of course he can use gravity drainage. The choice is whether to pump or grout in order to dispose of incoming water. Two properties of the water are of first interest, its volume and its pressure, and these are related. If the incoming volume is small then the problem is solved. If the volume is enough to cause difficulties, then inflow may be at a relatively low pressure because of the high resistance of the rock fissures. This good feature will be lost if attempts are made to impede the flow for the pressure will then build up. Rather than cope with the high pressures an appreciable inflow may well be acceptable.

FLOW MEASUREMENTS

Groundwater geologists use pump-out tests in order to determine aquifer properties, while in dam foundation work prior to grouting, pump-in or Lugeon tests are used. The former are well adapted to determining aquifer properties over a large area, but are of limited use in most fractured rocks. The Lugeon test deals with a smaller radius of observation and gives more local information, as well as being designed to predict grout takes. Houlsby (1976) is a clear account of the Lugeon Test as modified for use in routine modern practice, as well as giving a good philosophy and interpretation.

Aquifer testing is a conservative field but advances have been made over a decade or more by the introduction of techniques from petroleum reservoir engineering. We have an example of these new techniques amongst our contributions. The techniques depend on the measurement of pressure changes after flow from an aquifer begins or is cut off. They are dynamic pressure/volume tests.

These drill stem methods have the advantage over the Lugeon test in that they measure the properties of the surrounding rocks to a greater distance than is possible with static pressure/volume tests.

A paper in the literature dealing directly with inflow in a fractured rock area is Schmidt (1985) where a dewatering decision was taken, supported by a groundwater model. Jones (1986) gives an Australian coal mining general account of means and methods, while on the broader scene Baker (1982) edits the proceeding of a grouting conference. It has to be said that the vast majority of grouting literature is involved with dam construction. Mining gets an occasional mention, but miners do not often write about this technique.

REPORTS

Contributions to this conference on the prediction and control of inflow, however, all take the grouting or freezing solution to the problem.

Kipko gives an example from the Donetz Basin where pumping was considered, but out of consideration for the groundwater resource which might have been adversely affected by new or old mining, grout covers into major faults were employed.

His example from Yakutia is unusual in that both permafrost and brines complicate the problem, but by using clays and process slimes with suitable additives, a solution four times cheaper than dewatering was achieved.

Brines in karst in the Western Ukraine where the inrush caused subsidence and endangered the mine, specialised grouting again solved the problem. The methods used are obviously well advanced and one would like to have more details.

Two contributions are from China. Zhang relates how a cheap, controllable single liquid grout has been developed, and that considerable flexibility of properties has been achieved. A grout suitable for most applications can be tailor-made.

In a shaft sinking application at Yunjaoling, water in fractured sandstones with pressure water was cover-grouted successfully without excessive grout consumption. At Pucheng, an inrush from sand and gravel was successfully reduced and at Heyang a shaft section required a three stage grouting procedure to reduce the flow to manageable magnitude.

As an outsider, it seems to me that there must be a great deal left unsaid in any paper about grouting. We are often left with a sense of mystery about the operation, rather like that surrounding a good cook!

The second paper, from Wang, Yang, and Wang deals with a potentially catastrophic inrush of water from an interface against limestone, again in a coal mine. The Ordovician limestone was fissured "without rules' and the fissures were often filled with soft mudstone. The situation was complicated by faulting, although whether the faults carried water is not clear.

Time was short if the colliery was to be opened on schedule. Three sections of the main incline were cover grouted in 20-30m lengths as indicated by the inflow volume as far as possible as indicated by the observed fissuring and caves.

Details are given of the grouting equipment, pressures, and concentrations, and both cement and chemical grouts were used. Grouting began with the most difficult parts, with the floor before the upper holes, and with the sides before the middle. In this way the water was controlled as quickly as possible and with added safety. The whole task took nine months and entailed some 4000m of drilling and used 1200t of cement.

The whole paper seems to describe an heroic piece of grouting with a successful outcome, and I compliment the authors on the work and on their account of it.

The last paper by Daw Fear, Jeffery and Pollard describes hydrological measurements using drill stem methods, and then the subsequent design and use of freezing to control inflow in the sinking of coal mine shafts.

The Triassic mudstones, sandstones and breccias overlying the Coal Measures in the English Midlands have always caused large inflow problems, and freezing has often been used before, but drill stem tests are a welcome advance on the conventional methods. 26 of these tests were used in the sinking of two shafts, and conventional petroleum engineering equipment was used. The tests were successful at lower permeabilities, but at higher permeabilities both high flow rates and short measurement times restricted the effectiveness of the tests.

The results obtained indicated that grouting would be unsuitable and that ground freezing was preferable.

When sinking resumed after freezing, drilling ahead allowed pressure recovery tests to be made. These are analogous to the drill stem tests, but on a small scale and much closer to the aquifer.

Prediction of aquifer inflow based upon these two sets of tests were good and enabled the two shafts to be sunk without incident.

This paper is important as it introduces a new set of tests to the conservative groundwater field which are well suited to the depths and high pressures encountered in mining practice. The shallow depth, conventional methods are shown to be inadequate and are being superseded.

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