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PREVENTIVE TECHNIQUES FOR CONTROLLING ACID WATER IN UNDERGROUND MINES BY FLOODING

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ABSTRACT

This paper is concerned with the preventive and corrective measures for controlling water pollution in abandoned mine workings. The preventive techniques include flooding of mine workings which is based on the concept of isolation of pyrite minerals coming in direct contact with air, thus retarding the oxidation process. In practice, preventive measures, which include the application of various types of stoppings, are required to isolate abandoned and flooded workings. The techniques of sealing off mines are discussed, together with the alternative designs of dams. Various corrective techniques using flooding with neutralisation agents and reduction of water intake into the mine are also described.

INTRODUCTION

The objective of preventive techniques is to prevent the formation of acid effluent in an abandoned mine. In contrast, corrective techniques are those which treat acid water in mines in such a way that they cease to be a threat to the environment. When planning to abandon a mine, it is better to give priority to preventive techniques when possible. The use of corrective techniques are only justified in abandoned mine where no prior consideration has been given to the formation of acid mine water, which can present a serious threat to the environment (Reed 1984, Atkins and Singh, 1982).

PREVENTIVE TECHNIQUES FOR UNDERGROUND MINES

The preventive techniques act on any one of the three factors which must be present in order that the acid water forms i.e. oxygen,

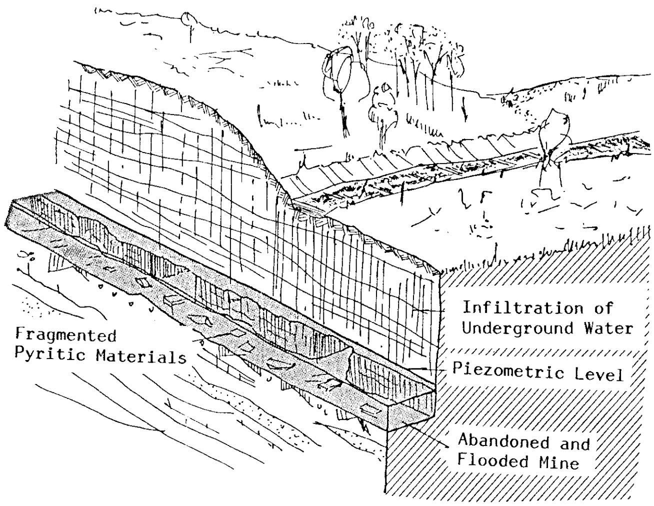

Figure 1. An example of a flooded mine.

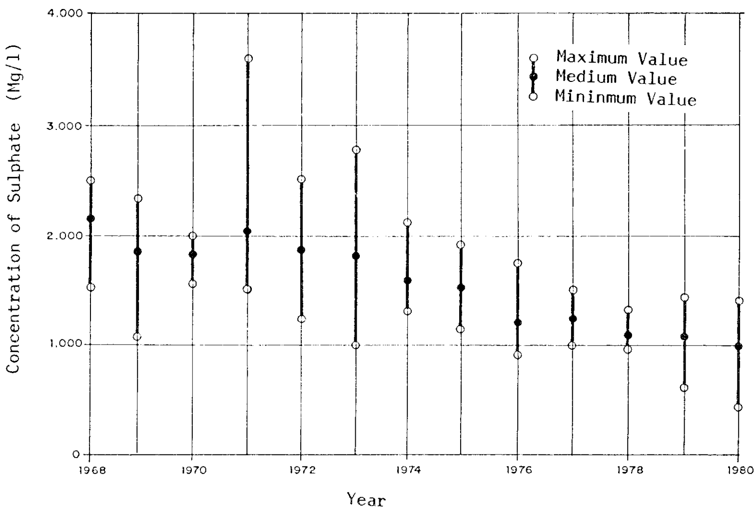

Figure 2. Reduction of sulphate content in abandoned mine water.

water and the presence of **Thiobacillus ferro-oxidians** bacteria. It must be understood that this reaction does not take place if elemental sulphur is present in the rock mass. The Techniques utilising oxidation in the presence of **Thiobacillus ferro-oxidians** have only recently been discovered and put into practice and until the present time have only been used in open pit mines. It may be noted that a great difference exists between the preventive measures which can be used in underground mines and those which can be used in open pit mines. Two types of preventive techniques are used in underground mines as follows:-

(i) Those which try to reduce the level of oxygen in the mine to a minimum so that the oxidation of the sulphur cannot take place (for example by flooding the mine,) and

(ii) Those which limit the quantity of water existing in the mine in such a way that even if sulphur oxidation does take place, the acidic water level cannot give rise to environmental problems. These are hydrological techniques of increasing impermeability and insulation of ground.

Past evidence has shown that some domestic services of drinking water have been contaminated by water from underground mines. The simplest solution in these cases which are neither preventive nor corrective is to take uncontaminated water from the deeper part of the mine. (Evans and Ciezlik, 1984; Hoffman, 1984). Whichever technique is chosen to combat acidic mine water, it is necessary to make a detailed hydrological study including the following aspects (Ladwig, 1985) :-

- The exact situation of the recharge areas and flow lines towards the mine,
- Identifications of mine districts which produce acidic water and
- The estimation of water quantities circulating through the mine.

FLOODING OF MINES

Flooding and Results

A reservoir of underground water is formed when a mine is flooded. Air cannot reach the galleries and mine shafts when they are waterlogged, so there can be no oxidation of pyrites and consequently no acidic water is produced. Figure 1 is an example of a flooded mine. It must be taken into account that the walls of any underground excavation contain pyrites and during mining operations this comes in direct contact with air and water to promote oxidation. The products of oxidation are sulphuric acid and soluble metallic sulphates which form a precipitate of vivid colours on the walls of mining excavations. This precipitate penetrates deeply into the rock through fractures in the rock minerals and when the mine is flooded, the products formed in oxidation may cause the water stored in the mine to acidify and mineralise.

The quality of the water in the mines improves slowly because stored water takes several years to be replaced by underground water. Ladwig, 1985, described the evolution of the quality of water in an abandoned coal mine complex in Pennsylvania, where the quality of mine water has significantly improved over the past fifteen years (Figure 2). At some points where water was discharged from the mine, the sulphate content has been reduced by 49% and at all points of discharge the pH has risen to a point where the water is now neutral.

The water retained in an abandoned mine forms different layers, (Ladwig, 1985). The water at the top layer is the best quality, whereas the water at the bottom is contaminated. Figure 3 shows the qualititive distribution of water in an abandoned coal mine complex in Pennsylvania. Since the drainages of mines are near the surface, this tends to lengthen the time period in which the effluents are effected.

A possible solution to shorten the process of improving the quality of water is to discharge water from the lower levels (Ladwig, 1985). However, poor quality water will be present for many years and it may become necessary to install some kind of neutralisation plant. Therefore, the flow of water discharge should be controlled because it is dangerous to force the hydrological system by draining more water than the amount of recharge. If this happens the level of water will drop and permit the entry of oxygen from the atmosphere causing further oxidation of sulphur.

In some flooded mines drainage is produced through the lowest part of the mine which contains water of poor quality giving rise to toxic effluents. This problem can be solved by creating a discharge system which extracts water from the top level, leaving the worst quality water confined in the mine. A case example of this type is concerned with the River Girvan (N.C.B. Report 1984, Scotland).

The efficiency of underground mine flooding is subject to whether the water can be retained inside the mine, but cannot always be guaranteed on a long term basis. In many cases, their Hermetic seal will leak with the passage of time (Kim et al 1982). Conversely, cracks which form due to subsidence may frequently reach the surface, thus permitting the entrance of air into the mine forming acidic water. In such a case, it is necessary to seal all highly permeable zones at the surface. The usual technique consists of localising the subsidence cracks, filling them with clay and so making the section compact. This technique has two limitations as follows :-

- o It is essential to localise the subsidence cracks, and
- o It is also essential that no new cracks are formed once the mine has been sealed and this can rarely be guaranteed.

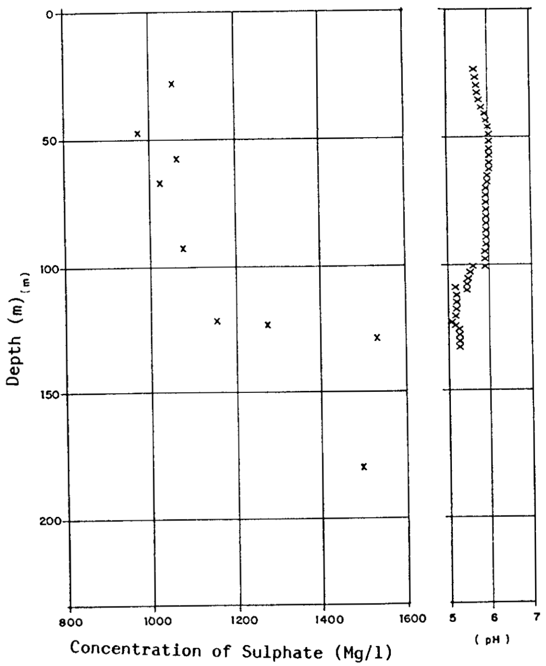

Figure 3. Change of sulphate content and acidity with depth.

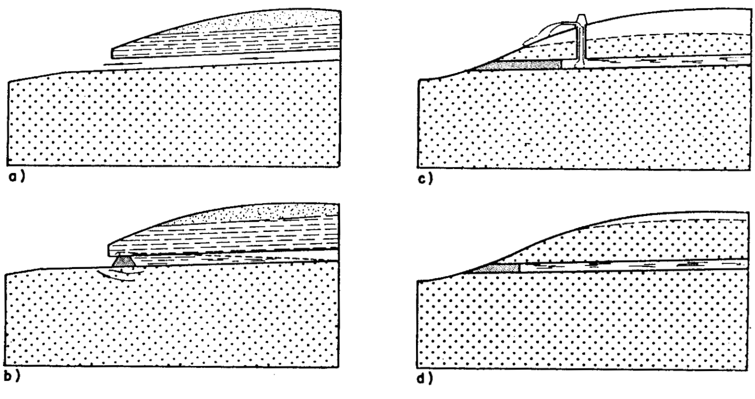

Figure 4. Types of Drainages in abondoned mines.

Possibilities of Flooding an Abandoned Mine

It is essential to differentiate between mine workings situated below the general drainage level of the area and those situated above (Kim et al., 1982).

In the first example all levels in the mine below the general drainage level will be flooded eventually. The working levels situated below the regional piezometric surface, and which extend to the outcrops, can be flooded spontaneously, if the mining is carried out by a shaft, leaving a protective barrier along the whole length of the outcrop (Figure 4, Parizek and Tarr, 1972). This undoubtedly increases the mining cost because water must be pumped to extract minerals through the shaft but it reduces greatly cost of abandonment. If mining was done by adits involving gravity drainage, it will be essential to install a dam before abandoning which will have to withstand hydraulic pressure of the water coloumn of the mine. This method is very costly and never achieves total impermeability.

When trying to flood mines or part of mines situated above the regional piezometric surface it is essential to seal all potentially flooded workings to exclude bleeding of air. This requires the installation of stoppings which could be of two types.

(i) Hermetic stopping against air and water, and

(ii) Hermatic dams against water only.

If the mines rely on gravity drainage during mining it will be necessary to seal the mine so as to ensure flooding (Figure 4a and 4b). Flooding will be spontaneuos in examples shown in Figure 4c and 4d (Parizek and Tarr 1972). The first type of stoppings are installed to prevent the mine discharging water through them and second types allow mine water to freely flow through them. The details of their use and the limitations are discussed in the following paragraphs.

Sometimes mines which are dewatered by gravity drainage can not be flooded because the surrounding ground makes a leak proof stopping impossible. Often a feature in mountainous areas is the occurence of many old abandoned mine workings which may be partially collapsed and are impossible to seal. When this happens, one may have to depend on the techniques described elsewhere.

Figure 5 shows a simplified section of a large lead and zinc mine at Bunker Hill in Idaho, U.S.A. This mine consists of two very different parts, one lower which will flood after being abandoned and the other upper part with gravity drainage and many small workings which are unlikely to flood. (Riley et. al. 1984).

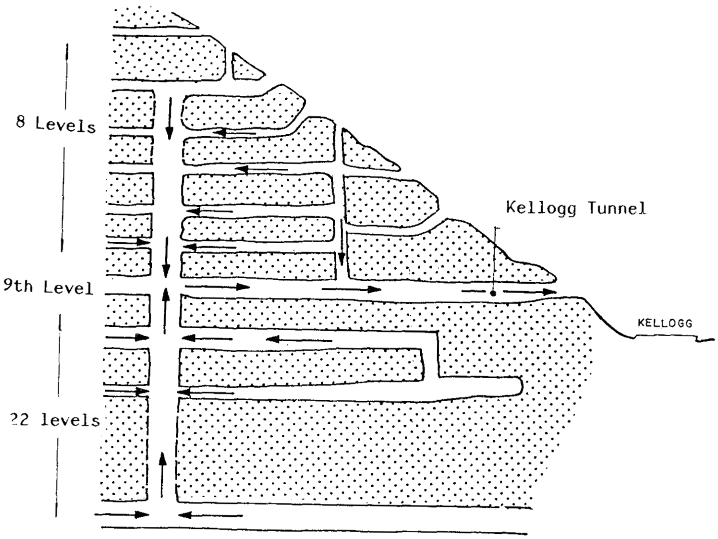

Figure 5. Section of Lead/Zinc Mine of Bunker Hill, Idaho.

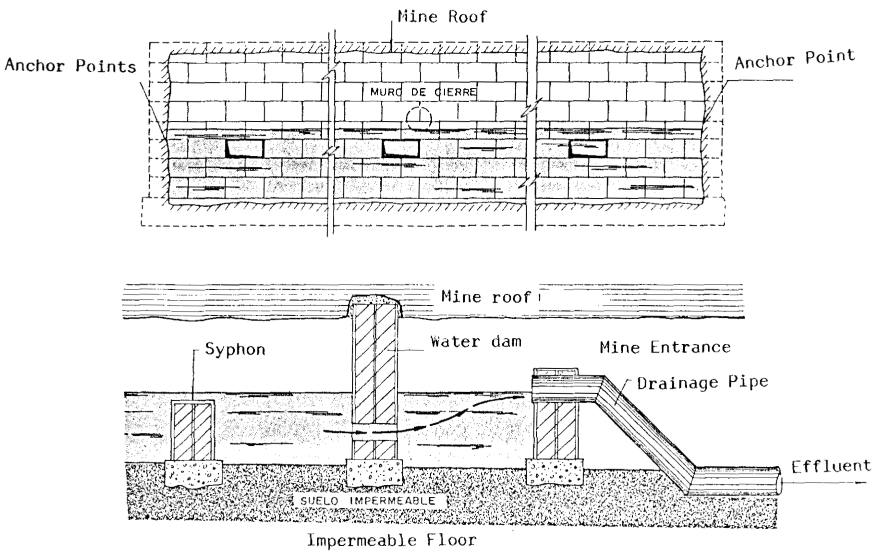

Figure 6. Types of water dams to abandon a mine.

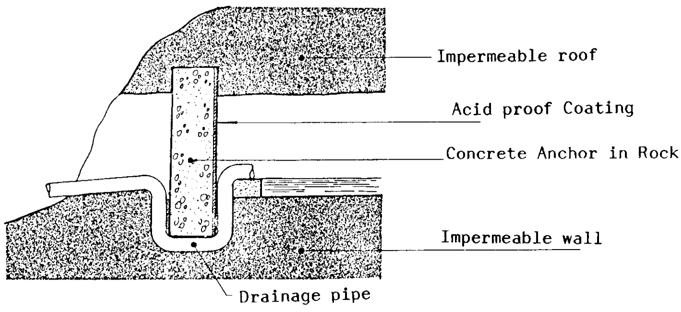

Figure 7. Water dam to abandon a mine.

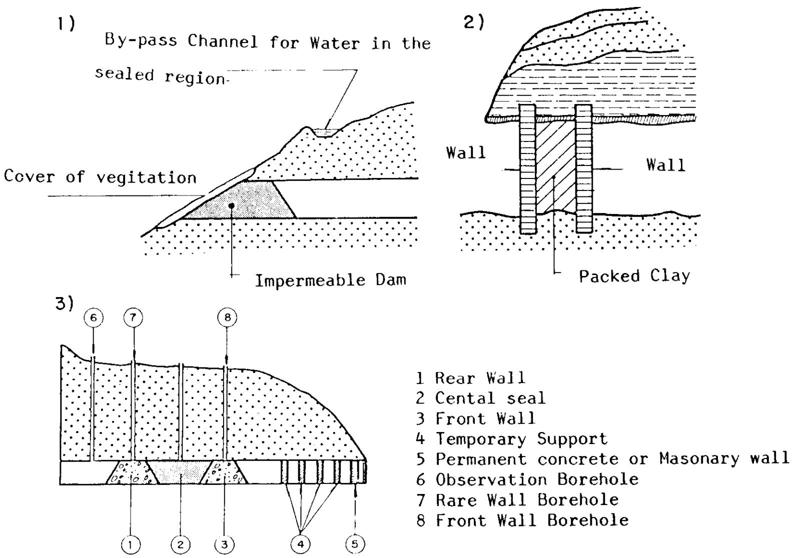

Figure 8. Leak-proof water dams.

Mine Dams or Stoppings

Figures 6 and 7 show two types of dams, which allow water to flow freely but prevent air from entering. This is ensured in both cases by incorporationg a syphon in the construction of the dam. The syphon needs regular maintenance because of the following reasons:-

o The formation of a ferric hydroxide $Fe(OH)_3$ which causes the outlets of water to become obstructed (Kim et al 1982). and

o It is essential that during the dry season the level of water stored in the mine does not fall below the syphon because in this situation, water in the syphon may evaporate and permit the entry of oxygen in the mine through the syphon.

Figure 8 shows mine stoppings or dams which prevent water from leaving the mine. The stoppings usually consist of masonary, keyed and sealed firmly in the foundations on the floor, sides and roof of the gallery. However, there are many other materials which can be used in their construction such as compacted claystone, cement blocks and cement cast in situ (Atkins and Singh 1982).

The U.S. Bureau of Mines (Kim et al 1982) are studying new methods of constructing a mine dam. This consists of packing crushed limestone under pressure in between two masonary walls at the time of sealing the mine. These dams have the following advantages over the conventional dams as follwos:-

(i) It is essential in a well built dam to ensure that the stopping is adequately keyed and sealed to floor, sides and roof of the gallery. This is often impossible with the conventional stoppings due to the existance of fissures in the weak strata surrounding a stoppping. Pneumatic packing of crushed limestone ensures a highly compacted stopping. Also any strata movement in the vicinity of a stopping only causes this to become more compacted and secure. If cement blocks and other similar materials are added to the limestone construction an even more solid stopping will be achieved.

(ii) If necessary the limestone stoppings can be so constructed as to allow a flow of water from the mine. If water is slightly acidic it will become neutral as it flows through the dam material. This is a definite adavantage over leaving stagnant water inside the mine.

Tests have been carried out using this method of packing limestone under pressure which resulted in obtaining a safe construction and safe dam with highly satisfactory cost advantages.

If flooding of a mine is to be efficient in controlling the formation of acidic water , it is essential to seal off all mine workings in the exploited strata, through which acidic water could filter (Parizek and Tarr 1972). Earlier studies have been made of this problem by the U.S. Bureau of Mines and the following conclusions have been reached regarding sealing of mine stoppings.

(i) They have to be thick enough to prevent water from leaking.

(ii) They must be solid enough to withstand hydraulic pressure without collapsing.

(iii) They must be keyed into stable surrounding rock.

(iv) In many cases they must be so constructed as to allow water to escape from the mine and in doing so relieve pressure.

Sealing of Abandoned Boreholes

When an underground mine is flooded, water of poor quality accumulates in old workings. Under these conditions any exploratory borehole or well drilled through the strata will act as waterways, allowing contaminated water to infiltrate other sources of water under low hydraulic head (Riley 1984 amd Kim et al 1982).

Hoonanian and Somes 1984, described a problem that confronted them in the Tar Creek Superfund site, Oklahoma, where contaminated water retained in the mine workings circulated through exploratory boreholes. This seriously contaminated a water source at a deeper level which was a principal source of water supplying the surrounding area. It can be seen that before flooding a mine, it is essential to seal all the boreholes interconnected with the mine workings. Recently drilled boreholes do not present any problems as they can be located easily. However, the problem lies with earlier boreholes and consequently:

(i) It is essential to find them, and

(ii) It is also necessary to clean them of any obstructions at depths.

The cost of borehole closure has been analysed by Hoonanian and Somes, 1984 as follows :-

- o Cleaning cost of the borehole, which can vary according to the depth and hardness of the obstruction, and
- o The independent cleaning costs, which are more or less the same for different boreholes.

Well and borehole sealing is absolutely essential when mines have to be abandoned. Figure 9 Shows conventional technique of sealing a borehole. In both cases the water source is insulated from the mine. The object of this is to prevent acidic water stored in the mine from mixing

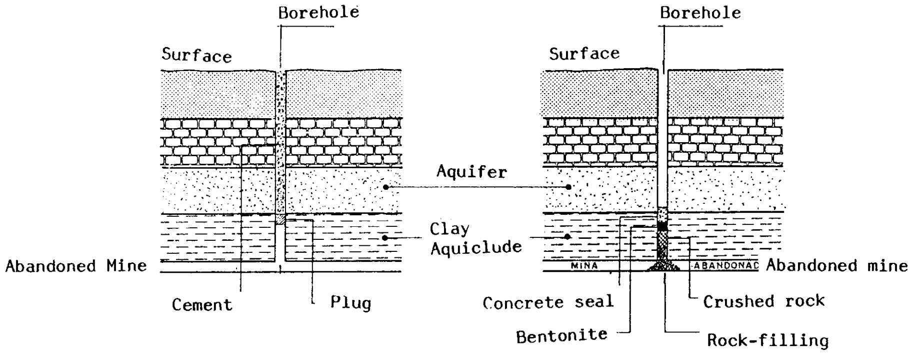

Figure 9. Techniques of sealing boreholes.

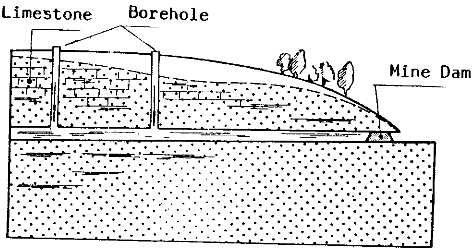

Figure 10. Natural neutralisation of water in an abandoned mine.

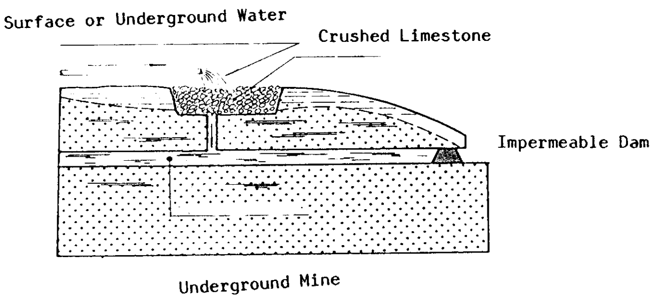

Figure 11 Crushed limestone to neutralise acidic mine water.

with a water source which lies directly above it. Wells and instrumentation in the boreholes can be sealed from the surface or the interior of the mine. In general, the latter is preferable, but it does not mean that even when the mine is active no thoughts be given to its future abandonment.

FLOOODING WITH NATURAL NEUTRALIZATION AGENTS

Parzek and Tarr 1972, have analysed different hydrological situations in which acidic water contained in a mine could be neutralised in a natural way with alkaline water enaminating from limestone formations. Figure 10 shows a sealed and flooded mine, above which are limestone areas. Through boreholes perforating from the surface to the mine it is possible to force alkaline water to the mine and also through flooded mine workings.

Figure 11 shows a similar system in which crushed alkali producing limestone is deposited artificially on the surface. In both cases, alkaline water reaching the mine, dilute the acidic water contained within the mine. Water rich in calcium carbonate and magnesium in natural conditions has a pH level sllghtly higher than 8. If the alkaline flow is sufficient it will produce a significant rise in the pH level of the water inside the mine. The consequent precipitation of iron hydroxide will have a double effect as follows:-

(i) De-mineralize the mine water and so improving its quality.

(ii) Form a skin around the sulphur grains, thus preventing further oxidation.

Parizek and Tarr do not comment on the success or otherwise of this technique.

REDUCTION OF INTAKE WATER INTO THE MINE

In some cases, it is possible to reduce substantially the intake of water in the mine. In this way it is possible to reduce the quantity of acidic water formations without hermetically sealing the mine. The techniques described elsewhere were concerned with limiting the air in the mine. The following is concerned with limiting the water in the mine, because it is not always possible to entirely stop the entrance of water into a mine and so oxidation will continue indefinitely in the abandoned workings. These techniques, however frequently reduce the flow of acidic water effluent and so the problem can be reduced. It must be appreciated that water can enter an abandoned mine in many different ways as follows (Kim et al 1982) :-

- Water entering through springs
- Water infiltrating from the surface.

- o Water filtering through cracks, fissures and borehole Connections.
- o Water migrating from an active mine to the abandoned mine nearby.

If water is infiltrating from springs above or below the mine or from the surface, attempts could be made to seal the rock mass surrounding the affected gallery by cement grouting. If hydrogeological conditions are favourable, an efficient solution to the problem could be provided by gravity drainage of the water source or spring or a by-pass beteween one upper water source and a lower source (Parizek and Tarr 1972).

If the principal intake of water into the mine is from superficial water, the most efficient remedy is to by-pass the water before it begins to infiltrate.

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