Structural logging and modelling for use in simulation of inflows in underground hard rock mines

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Abstract

African mines are predominately located in hard rock. Inflows to the underground or surface workings are typically along geological structures. Often the matrix permeability of the country rock is very low, individual water bearing structures provide some 80% of the inflows. It is therefore very important to map geological structures and plot the sources of water flowing into the mine.

Fractured rock aquifers have very distinct anisotropy and in Southern Africa, North – South striking structures are usually tensional, carrying most of the water into a mine. East-West structures tend to be compressional because of the plate tectonic regime and can be barriers to groundwater flow.

Permeability is proportional to aperture cubed, therefore, the width, vertical and lateral extent of the apertures in the water bearing geological structures are important to know for use in inflow calculations.

Accurate logging of core and underground or in-pit structural mapping is essential to understand the direction and risks of inflows to mine workings in both the short term and for life of mine. This paper describes the occurrence of fracture-controlled flow in mines, methods of mapping, logging and use in mine inflow simulations.

Keywords: Structural mapping, inflows, dewatering, faults, boundaries, compartments

Introduction

African mines are predominately located in hard (well lithified) rock where inflows to the underground or surface workings are typically along geological structures. Often the matrix permeability of the country rock is very low. Individual water bearing structures can provide some 80% of the inflows to the mine. To intercept the water, it is very important to map the structures carrying or diverting the water and plot with the sources of water to understand the risks to the mine.

Fractured rock aquifers often have very distinct anisotropy and in Southern Africa North – South structures are typically tensional and carry most of the water into a mine. In contrast, East – West structures tend to be compressional because of plate tectonic regimes, and therefore can be barriers to groundwater flow.

Permeability is proportional to aperture cubed therefore knowledge of the width and lateral extent of the apertures in the water bearing structures is important for use in calculations of inflow for life of mine and for specific sectors.

Individual structures such as faults can be both open and closed along strike and down dip. Accurate logging of core and underground structural mapping is essential to understand the direction and risks of inflows to mine workings in both the short term, for each mine sector and for life of mine.

Experience

The authors work on African mines. The rock successions comprising the African continent are predominantly composed of well lithified and often metamorphically altered successions that comprise the cationic cores of the continent, of the intervening, heavily deformed mobile belt successions. It is the combination of the thermal and tectonic history of these sequences that underpins the existence of most the continent's economic mineral deposits. Even coal bearing cover

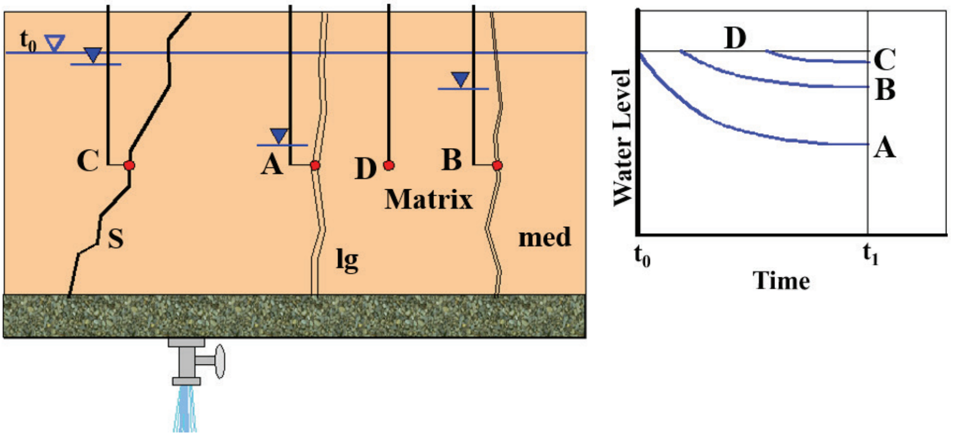

Figure 2 Speed of drainage from different types of water bearing structures (Morton et al *2008 after Atkinson 2007).*

sequences such as the Karoo Supergroup strata that are relatively undeformed and unmetamorphosed are well lithified. Because of the antiquity of the rocks as well as their complex thermal and tectonic history Africa tends to have some of hardest and least permeable rock types encountered.

Aquifers are mostly hard, fractured rock aquifers with inflows to mines occurring along open and often vertical structures that connect sources of water to both open pit or underground workings. Figure 1 illustrates the types of structures carrying water in hard rock mines.

Understanding the types and location of structures for use in a dewatering design is essential because each type of structure drains at different speeds into the mine workings. Figure 2 illustrates the speed of drainage.

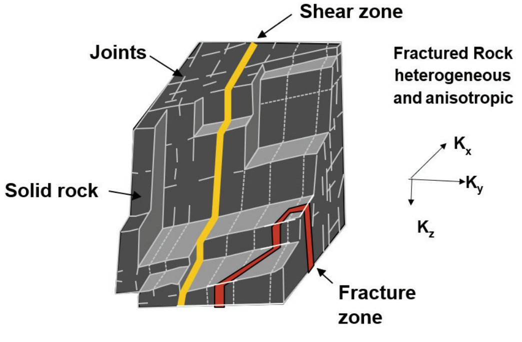

Figure 1 Types of structures carrying water in hard rock mines. (Atkinson 2007

Types of geological structures that carry water into mines

Geological structures affecting the rock mass of a mine can be tectonically derived, sedimentary or man-made.

Pre-mining geological structures.

There are numerous tectonically derived geological structures that may be potentially identified within a rock sequence. However, not all are equally capable of transmitting water. Some like axial pane cleavage are closed when unexposed to weathering and/or decompression at surface, as they are in fact simply planes of weakness within the rock fabric, not discontinuities.

Similarly gneissic foliation and many bedding planes represent a change of rock type of mineral composition and are not originally open voids in the rock. Other structures (e.g., jointing) have, by definition very small aperture dimensions of up to several millimetres and tend to be closed or transmit small (i.e., nuisance) amounts of water within mines.

Faults are major water carrying structures. This can be true of either the central fault core zone (i.e., the zone of slippage), or the enclosing, fractured fault damage zone (Figure 3).

Faults may be “open” to water transport along their strike in extensional tectonic regimes, “closed” in compressional regimes, or be a combination of both depending on

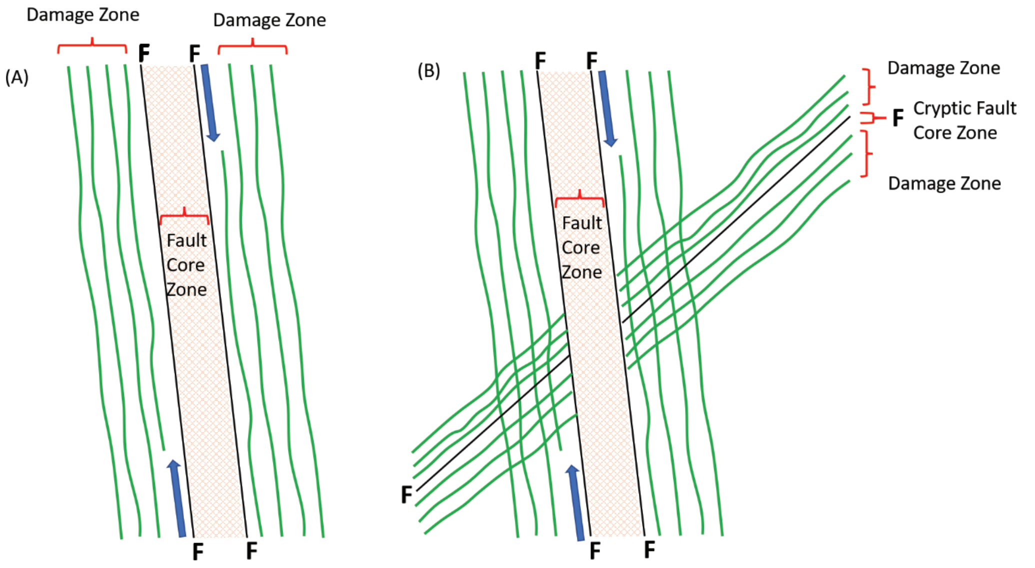

Figure 3 *Schematic cross-section diagrams of faults and associated increased permeability. and may cause older closed structures to become open (see Figure 4).*

the orientation of a fault segment relative to the extant tectonic regime in curved faults (Figure 4).

Fault core zones may be open or closed depending upon the presence or absence of fault gouge or mylonite that can act as a sealant. These sealants may also be inconsistently present along a fault. In terms of lateral transport of water across fault planes they can also act as aquicludes or aquitards in more porous rock materials. The emplacement of younger, cross cutting structures can also affect the water bearing abilities of that part of an older structure that is crosscut by a younger structure (Figure 5).

The intrusion processes of Kimberlite bodies results in them having circular, unbonded contacts around the pipe that connect upper and lower aquifers in the country rock allowing rapid movement of water into workings (Morton 2008).

Geological structures that may have originally been "open" can become closed due to post formation infilling with minerals such as quartz or calcite. While structures that may have originally been "closed" may become "open", due to changes in the extant compressional regime, rock movements due to mining activities, the development of younger cross cutting geological structures (e.g., faults) etc or a combination of multiple factors.

For the implementation of appropriate mine dewatering strategies to be put in place the anisotropy in the rock mass that acts as the structural aquifers must be characterised in terms of its capacity to connect areas of recharge to the mine, to act as aquifers and to determine where that water is transported to. Geological and Geotechnical logging assist with plotting the anisotropy.

Manmade structures

On surface a zone of relaxation (ZOR) occurs around and within a pit. Figure 6 and Figure 7 show the ZOR in plan and section. This rapidly transmits surface and ground water into the workings.

Similarly, the entire network of voids in an underground mine creates a 3D interconnected zone of preferential groundwater flow. This 3D network of interconnected voids and fractures both store and transmit water throughout the mine. When the open pit overlies the underground workings the ZOR can be connected to structures associated with the ore body and the crown pillar.

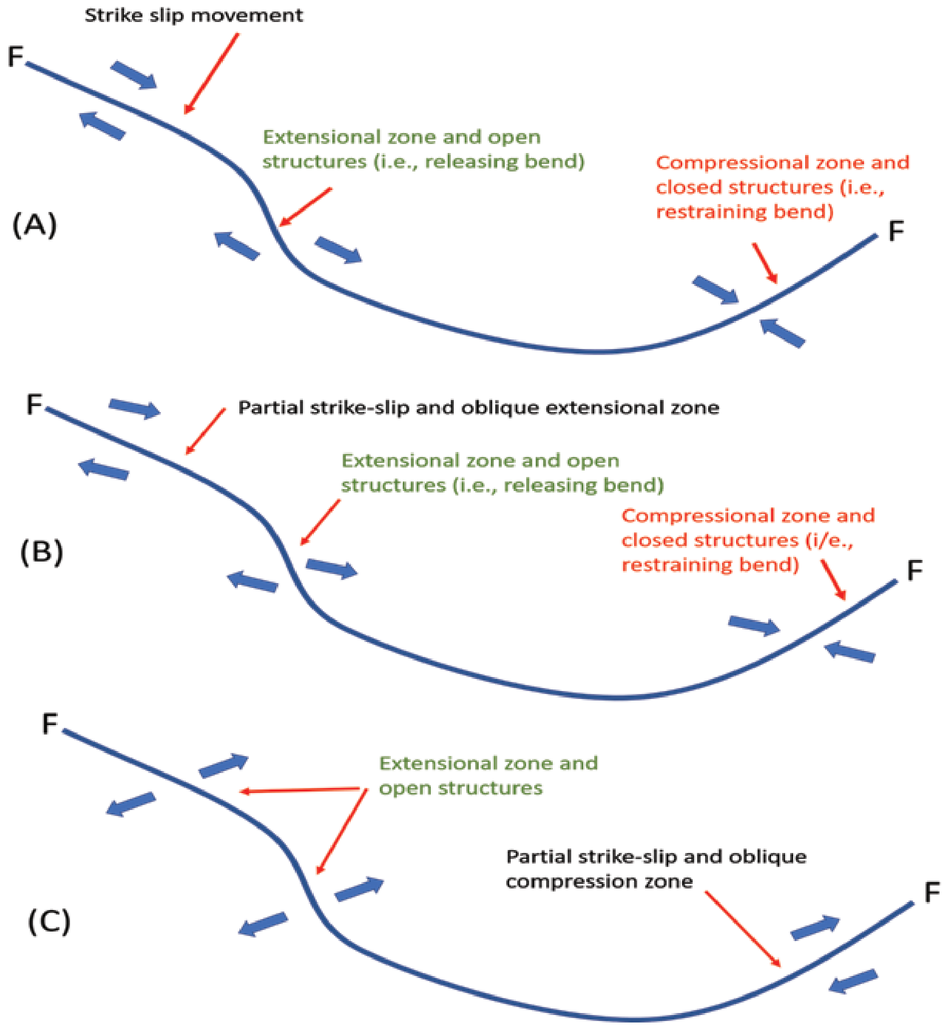

Figure 4 *Schematic plan views diagram of the same curved strike slip fault showing the sense of movement of the rocks either side of the fault in three different compressional/extensional regime orientations.*

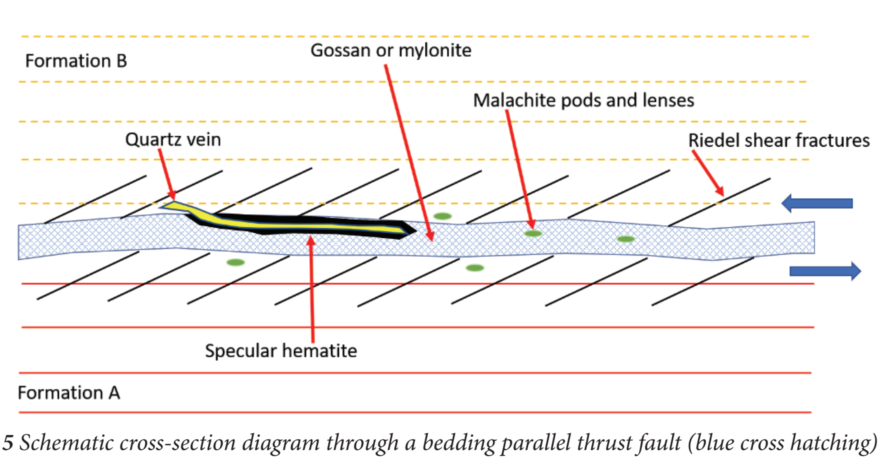

Figure 5 *Schematic cross-section diagram through a bedding parallel thrust fault (blue cross hatching)*

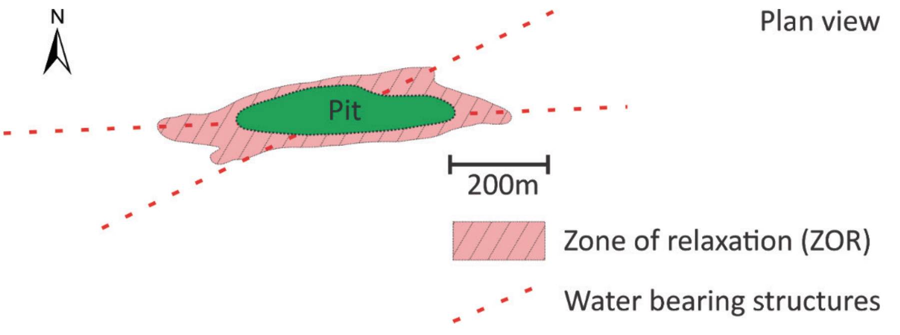

Figure 6 *Plan view of structural influence on the zone of relaxation (ZOR)*

Risk map

Once all the main water bearing structures and underground voids have been mapped, they can be combined with measurements of groundwater gradient, sources of water (both on surface and underground) then used to produce a risk map. The map can be used in combination with a mine planning tool such as Deswik® to inform production crews of water risk and enable planning for nimble dewatering systems. Figure 8 shows an example of a risk matrix for an underground mine.

Use in numerical modelling

Important structures can be incorporated into finite element numerical models such as FEFLOW to simulate inflows to specific mine sectors and provide more realistic inflow estimates. Using measurements of groundwater gradients, targets for reducing water pressures in and around a mine can be set and achieved by draining the main water bearing structures in advance of mining.

Conclusions

It is essential for hard rock mines to plot and understand the major structures that carry water into the mine. The anisotropy needs to be understood to be able to give numerical models better predictive capabilities. Structures can be used in a risk map to guide dewatering in advance of mining.

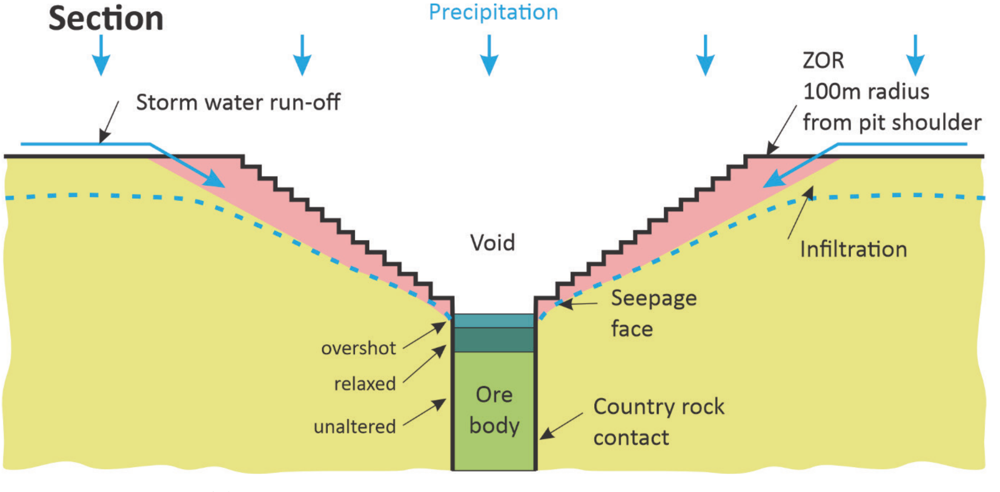

Figure 7 *Section view of the ZOR*

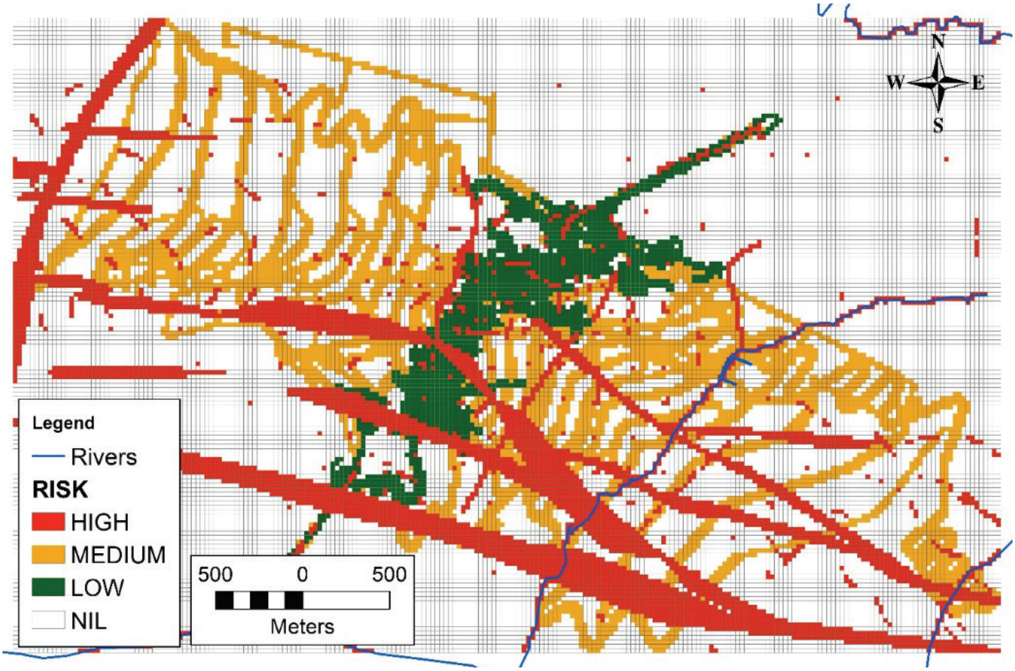

Figure 8 Risk matrix for an underground mine

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