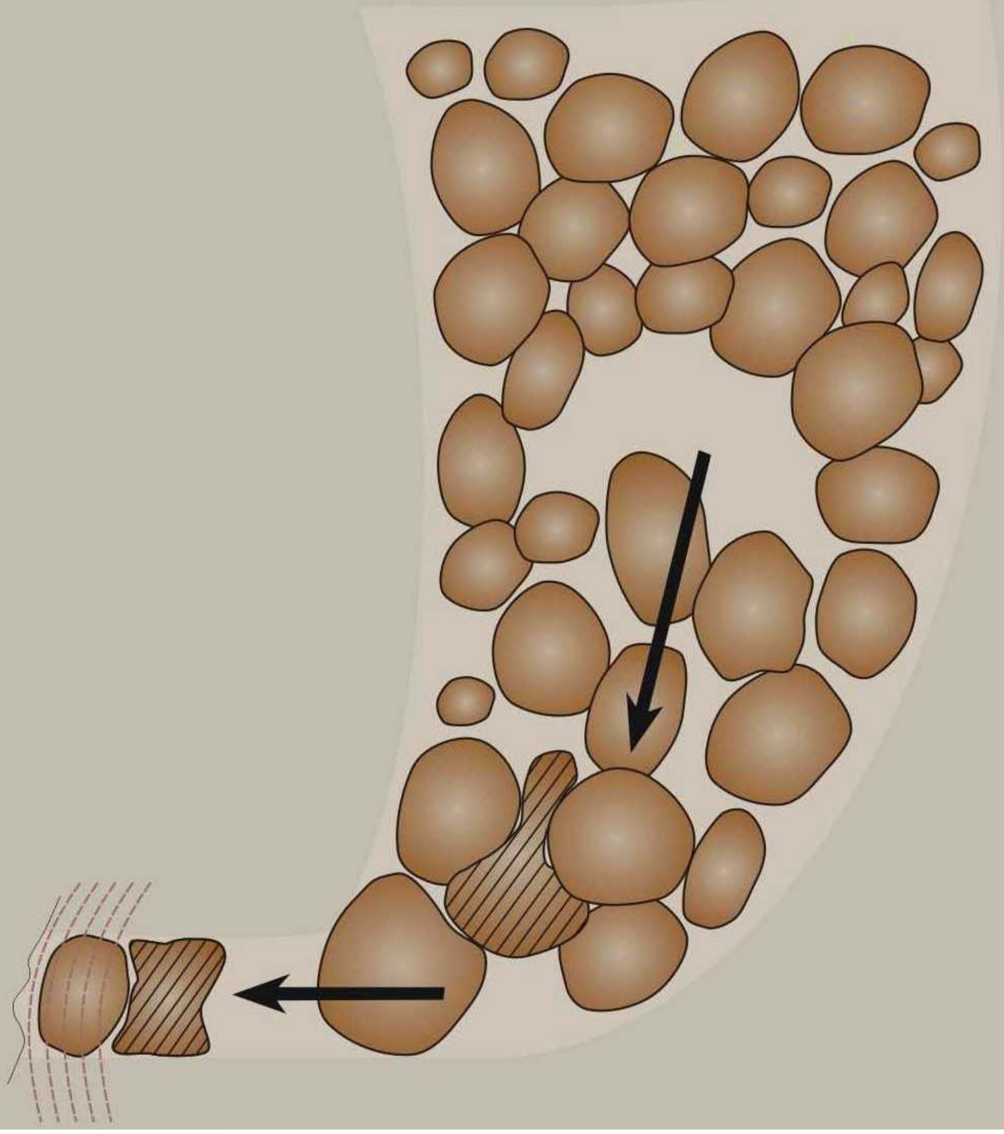
A BOOKLET ON

METHODS OF COMBATING MUDRUSHES IN DIAMOND AND BASE METAL MINES

R Butcher, W Joughin and T R Stacey
SRK Consulting



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METHODS OF COMBATING MUDRUSHES

IN DIAMOND AND BASE METAL MINES

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1 INTRODUCTION

Mudrushes can and have posed a major hazard to safety in underground mining. In South Africa, at least 24 fatalities due to mudrushes in diamond and base metal mines have occurred in the past 10 years.

Mudrushes are sudden inflows of mud from drawpoints or other underground openings. The rapidity of the mud inflow is such that escape of personnel in its path is most unlikely, with terrible consequences for safety. Mudrushes are also directly responsible for severe damage to infrastructure. Considerable violence, in the form of an airblast, is often associated with a mudrush. Such an airblast event can be the cause of accidents and severe damage to mine infrastructure.

This booklet, dealing with recommended measures for combating mudrushes, has been prepared as an output of the SIMRAC OTH601 Project. It is aimed at technical staff on operating mines, such as the planning engineer, the rock mechanics engineer, the draw control officer, etc. Further information on the background and details of the research carried out can be found in the OTH601 final report.

2 SOURCES OF MUD, AND ENVIRONMENT FOR MUDRUSH OCCURRENCE

From a review of literature and mudrush accident reports, sources of mud which has been involved in mudrush occurrences are the following:

- readily weatherable materials such as shale and kimberlite, which occur in the ore and country rocks;
- tailings impoundments which are located on surface above or adjacent to mine workings;

- backfill placed in underground stopes for support or disposal purposes;
- in the case of boxholes and passes, any fines, from whatever source, which can form "sticky" material.

Four elements are required for a mud rush to occur:

- potential mud-forming materials must be present;
- water must be present;
- a disturbance of the mud, in the form of drawing or other mining activity, must occur;
- discharge points must be present through which the mud can enter the mine workings.

Evidence from mudrush occurrences suggests that all four elements must be present at once for a mud rush to occur. This is illustrated by the conceptual **Mudrush Diamond** diagram given in Figure 1.

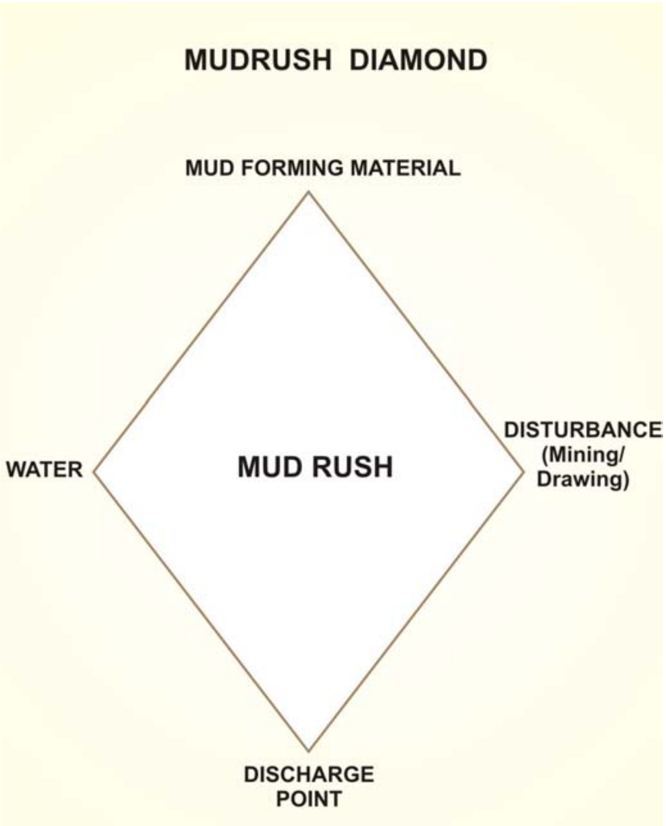


Figure 1 Elements of a mudrush

3 MUDRUSH MECHANISMS

There is no single mechanism for the occurrence of mudrushes in mines. Mudrushes can be classified as external mudrushes or internal mudrushes, as shown in Figure 2.

- External mudrushes result from mud generated externally by the deposition of tailings and by the production of mine backfills from metallurgical plants. Inrushes of material from slope failures are also classified under this heading. External mudrushes are those in which the mud is produced externally to the physical underground environment.
- Internal mudrushes involve mud produced by the comminution of shale or other clay-forming country rocks, and clay mineral rich ores, within the cave muckpile. Fines which accumulate as a result of the mining process are also involved in the internal process. Mixed mud forming materials are also grouped in this category - even though some material is formed outside the underground environment, owing to drawdown, this material mixes with internal mud.

External mudrushes

External mudrushes are produced from three main sources:

- Inrush of tailings or slimes: the inflow of tailings or slimes can occur directly, as illustrated in Figure 3, or indirectly as a result of dam wall rupture, from which the material can flow unaided towards a shaft, adit or open bench, resulting in an inrush of tailings underground.
- Failure of placed backfill in underground massive stopes: this type of failure could occur due to the placement of poor quality backfill, during the filling if a drawpoint bulkhead ruptures, and once the fill has been placed. The mechanisms of stope backfill mudrushes are shown in Figures 4 and 5.

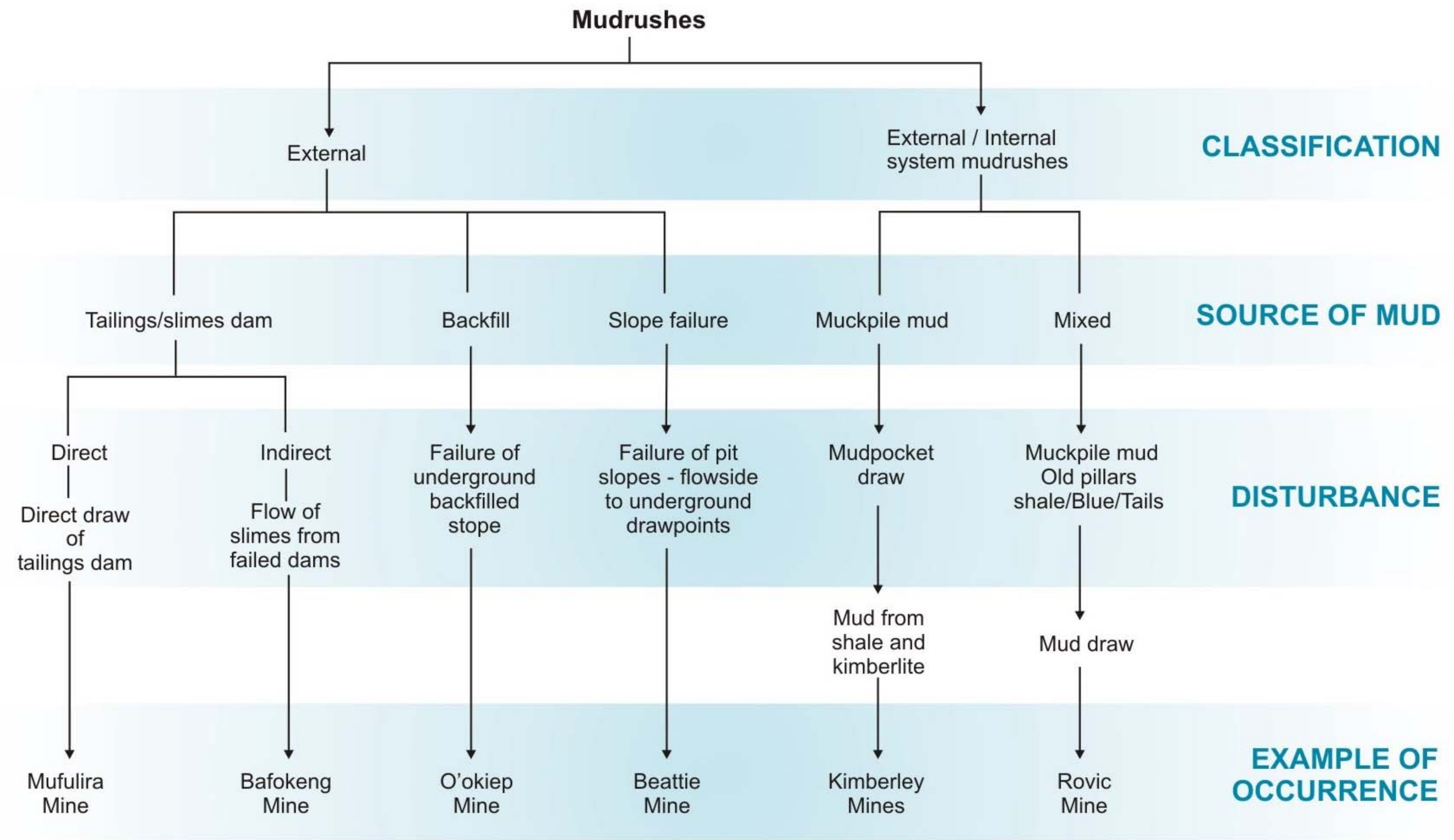


Figure 2 Classification of mudrushes

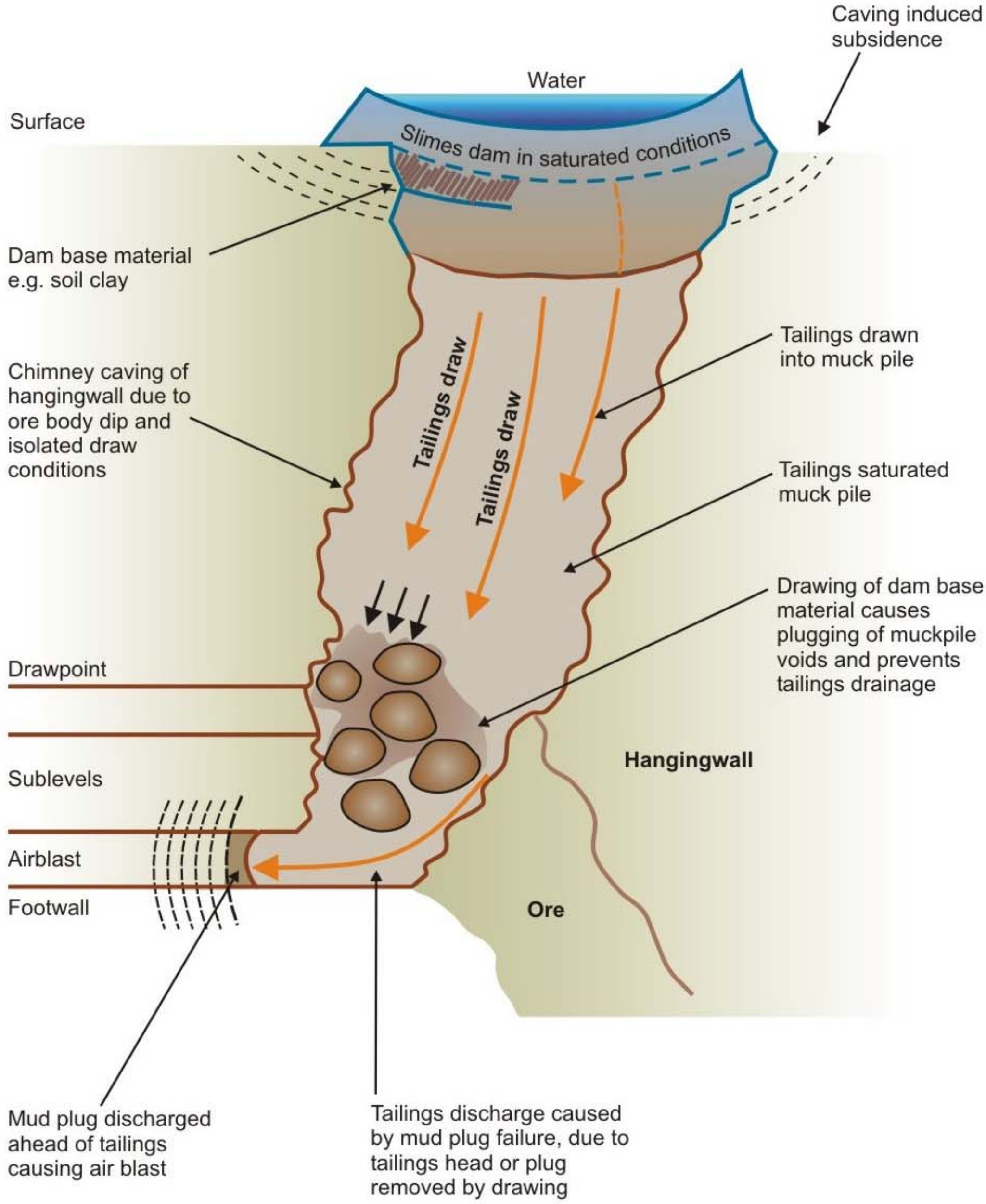


Figure 3 Direct draw of mud and tailings

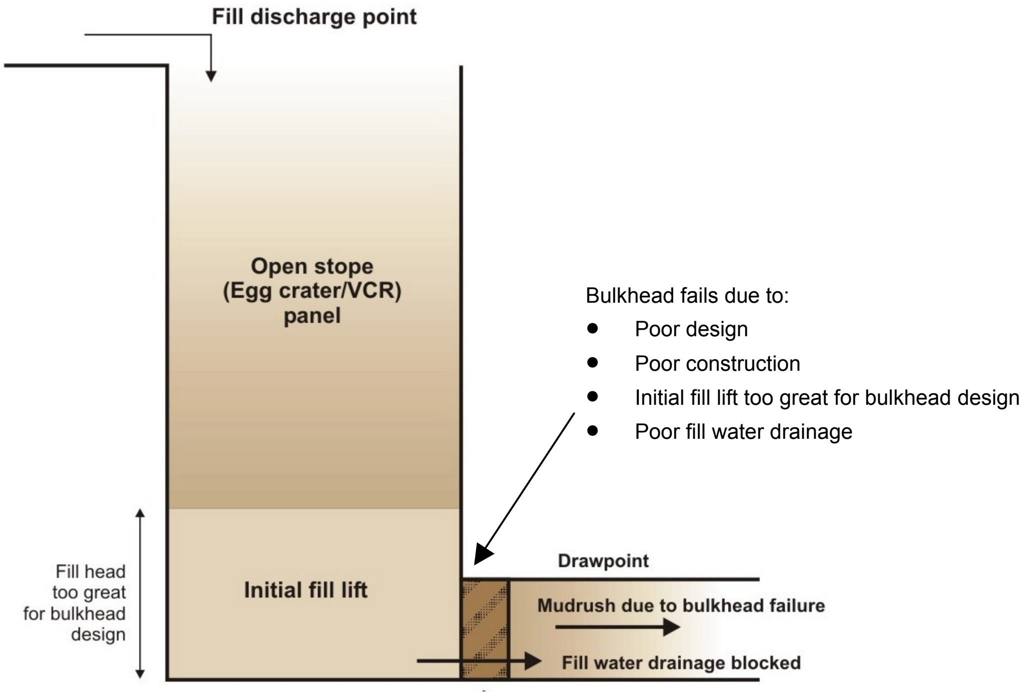


Figure 4 Failure of backfill bulkhead resulting in localised mudrushes

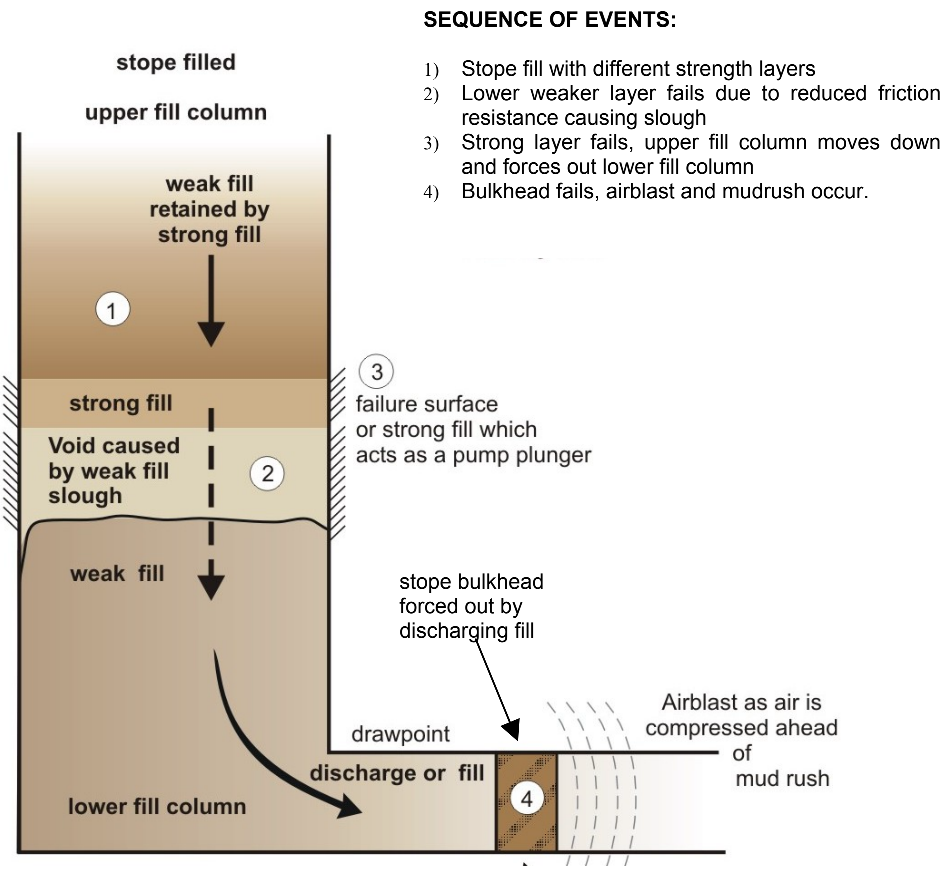


Figure 5 Post backfill failure causing mudrush

- Mud rushes due to open pit slope failures: in cases in which underground mining of an orebody has been preceded by open pit mining, the influx of mud into the workings is due to the failure of an open cut slope directly above open stope, open bench or fissure mine drawpoints, resulting in the inrush of slope material to the underground workings via the drawpoints. Figures 6 and 7 show this mechanism.

Internal mudrushes

Internal mudrushes have been experienced for approximately 100 years at Kimberley mines. The mud is formed internally during drawdown of the waste capping above the orebody. Mixed mud rushes are included in this classification, due to the mixing of internally and externally generated mud materials within the muckpile. The proposed internal mudrush mechanisms are given below.

- Muckpile/waste. capping mudrushes: the proposed mechanism for a diamond mine, in which initial open pit mining was succeeded by underground cave mining, is shown in Figure 8. Although this mechanism is illustrated for a diamond operation, it is conceptually applicable to other operations as well.
- Secondary waste capping/muckpile mudrush mechanisms: the above mechanism may be regarded as a "major" mechanism. However, there are two other secondary internal mudrush mechanisms. These are, firstly, rapid muckpile compaction, illustrated in Figure 9, which can be seen as the mechanism responsible for mud pocket discharge; and reduced muckpile/waste capping drainage, the mechanism of which is shown in Figure 10.

Mixed mudrushes can be ascribed to the creation of mud from a combination of sources namely;

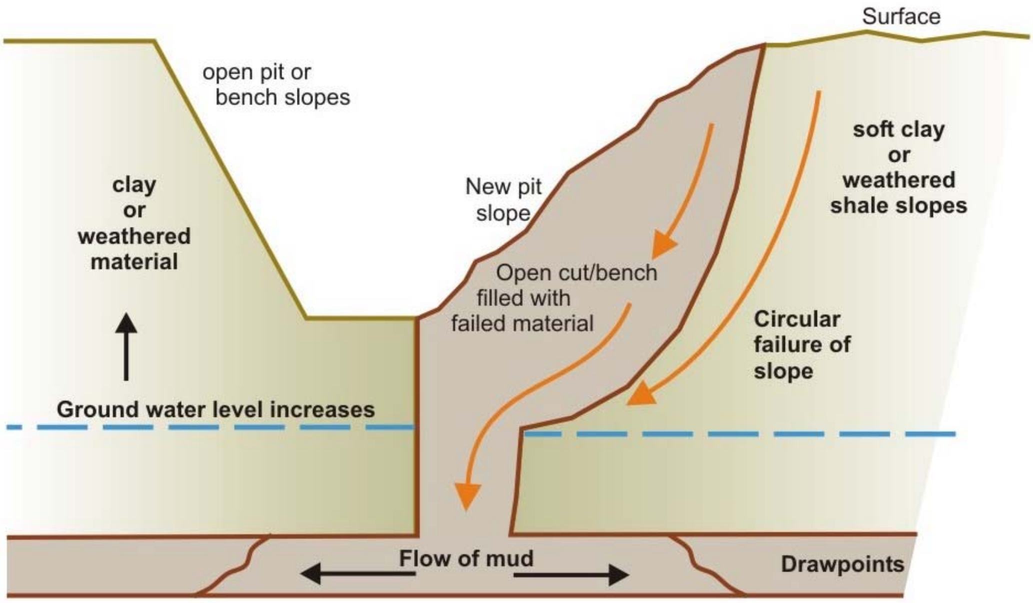


Figure 6 Mudrush resulting from slope failure of soft material

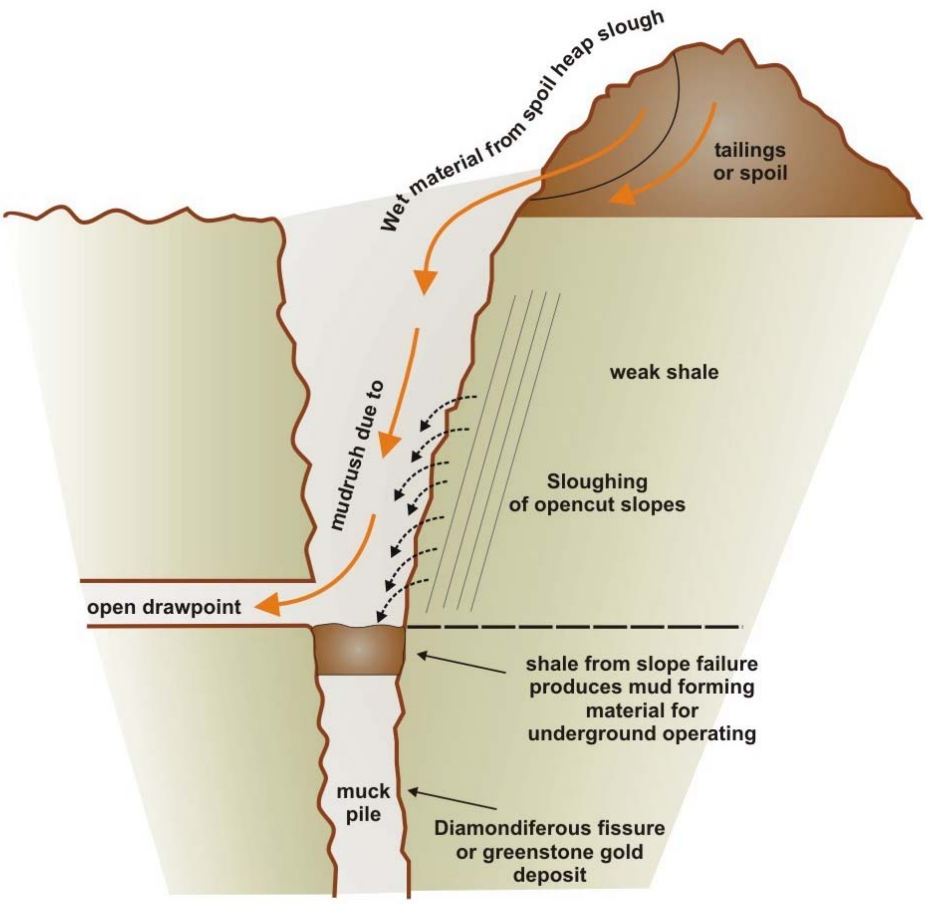


Figure 7 Indirect role of slope failure in mudrushes

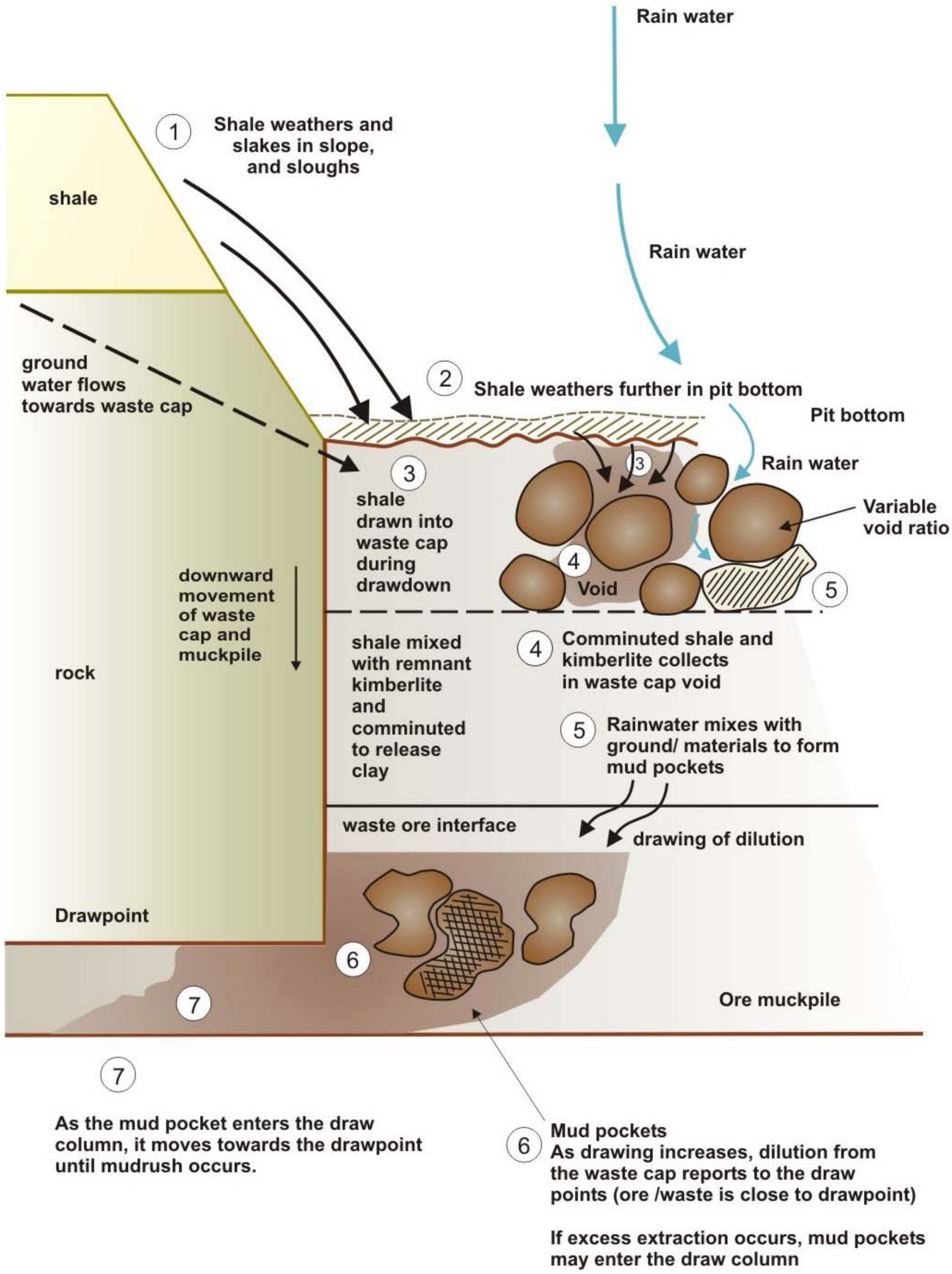


Figure 8 Muckpile mudrush

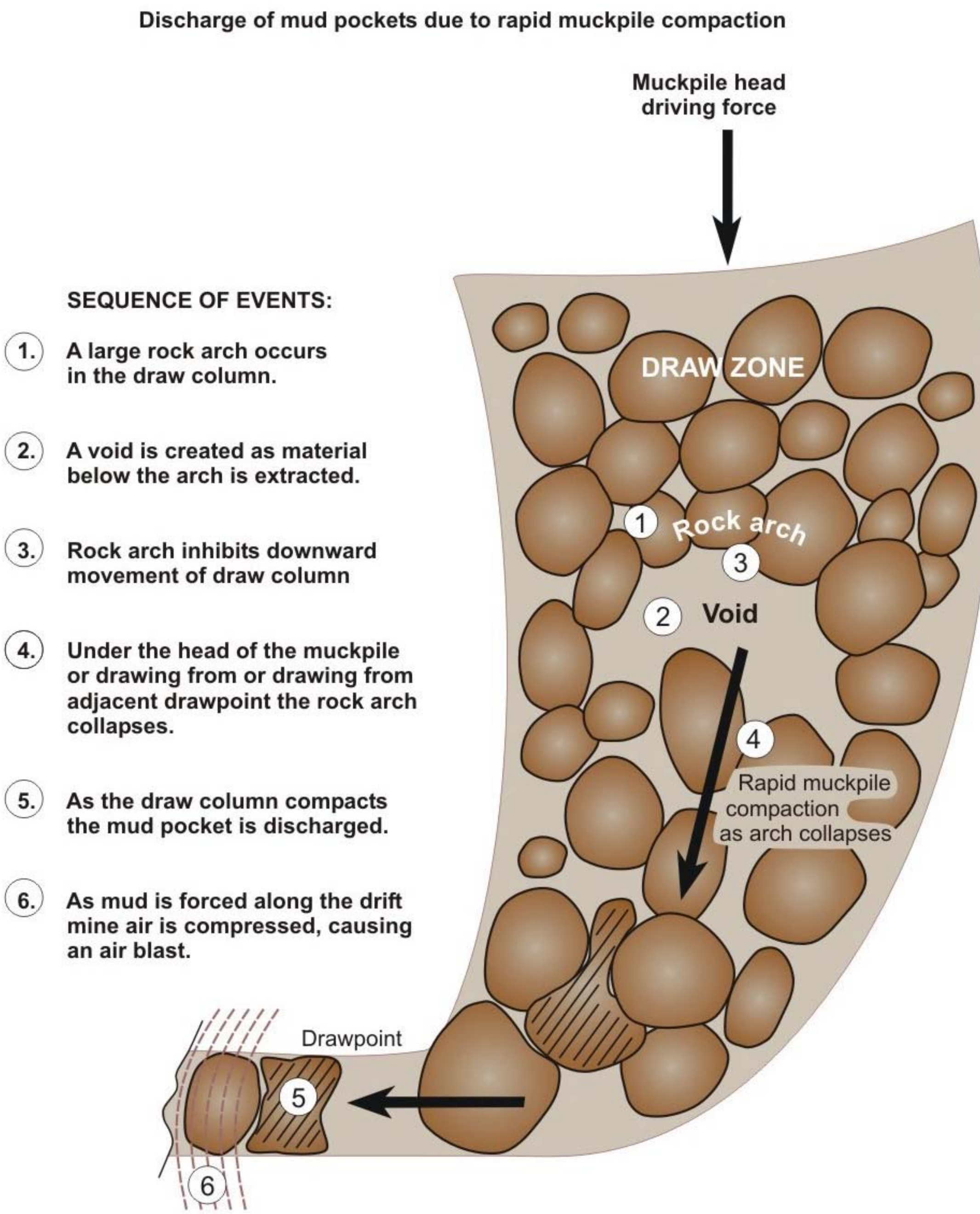
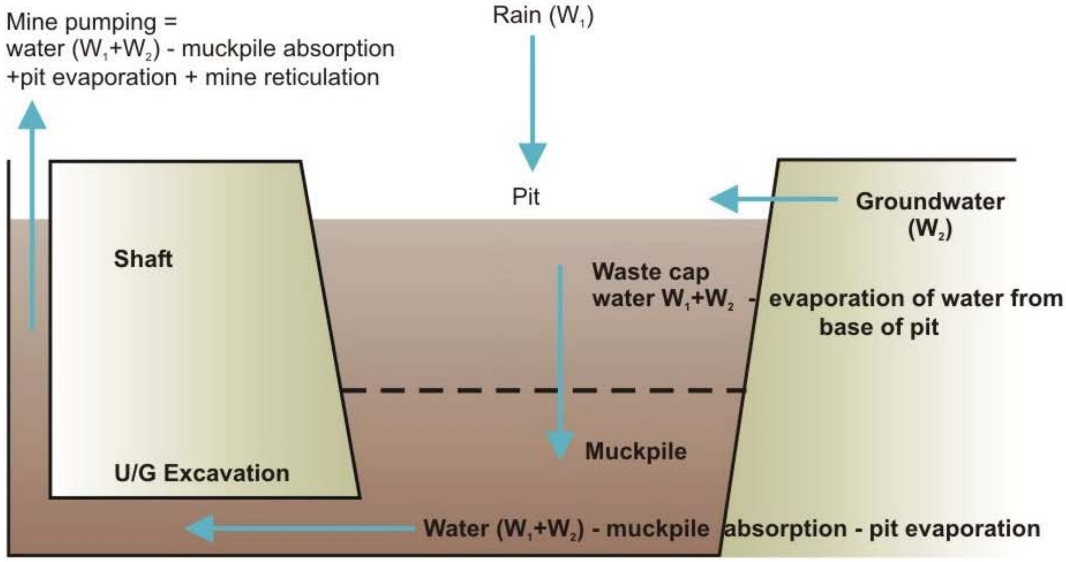


Figure 9 Secondary mudrush mechanism

Beginning of mine life



Reduced muckpile / waste cap drainage

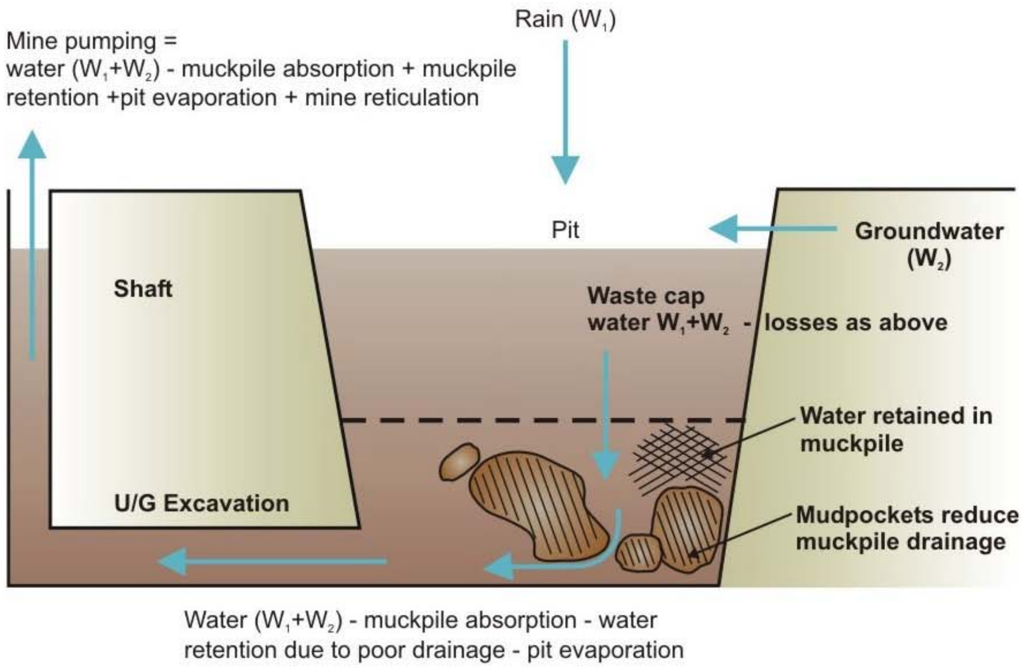


Figure 10 Reduced drainage from muckpile/waste capping

- the deposition of tailings above the mine waste cap;
- sloughing of open cut sidewalls;
- comminution of muckpile remnant ores and wastes.

The processes involved in this type of mud rush are summarised in Figure 11.

Mudrush mechanisms from boxholes and passes are straightforward. The "sticky" material formed from the fines and water adheres to the sides of the boxhole or pass, and to the box or chute structure. This restriction impedes the flow of material and causes further agglomeration and ultimately a blockage. In addition, sticky material particles may adhere together to form, effectively, much larger particles. These may be large enough to lead to hang-ups in boxholes and passes. Once a blockage or hang-up has occurred, rock, further fines and water accumulate above the restriction, providing a driving force for a mudrush, which occurs when the chute is opened.

4 TRIGGER MECHANISMS AND WARNING SIGNS

As shown in Figure 1, only two possible mudrush triggers exist – disturbance and water. This is because these two factors control the discharge process of the mudrush. **Disturbance** creates the conditions necessary to allow free mud discharge, and **water** acts as a mobilizing force for the mud, either by changing the material properties of the mud, or by applying a pressure, due to an increasing head of water.

4.1 Disturbance

Disturbance as a mud rush trigger can take several forms:

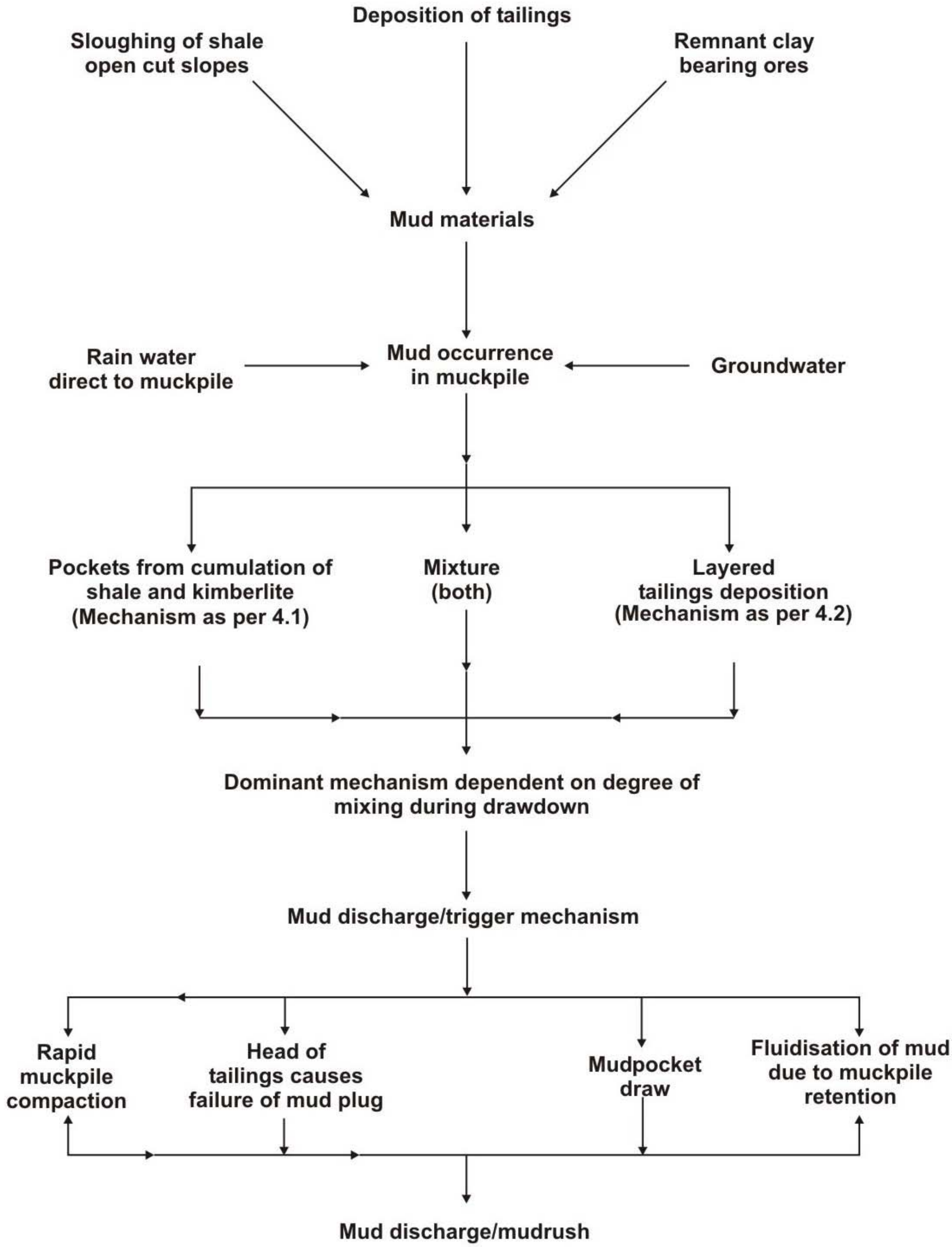


Figure 11 The process of mixed mudrushes

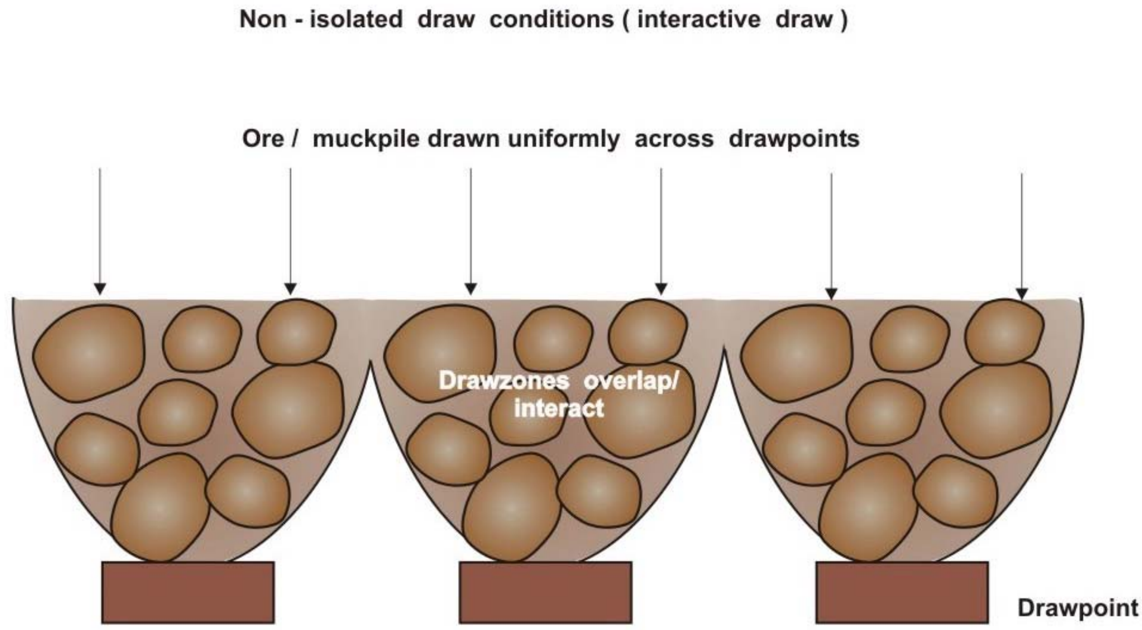
Excavation of slopes or stopes in mud forming materials: this is self explanatory in that, if unstable slopes or stopes are developed in weak and/or weathered rocks and soils, which, in the presence of water, can flow or fail, then a mudrush can occur. In the case of slopes, the following are considered as potential warning signs for mud ingresses:

- incorrect or no design of slope angles in weak/weathered materials;
- poor slope drainage, resulting in a sudden rise in the phreatic surface;
- lack of maintenance of slope drainage measures, resulting in increases in water quantity and water pressure in the slope;
- the alteration of the mine pit geometry, resulting in a change of slope confining stresses and an increase in ravelling;
- removal of a slope ore protection pillar in an open benching system, resulting in the exposure of weak zones in the slope;
- the undercutting of the slope toe, resulting In an unstable slope geometry.

In the case of underground stopes, the following are considered to be warning signs for mud rushes:

- the poor design of stope, back, crown pillars and sidewalls;
- the collapse of open stope rib pillars leading to back/crown pillar failure and surface subsidence;
- the ingress of groundwater into the stope, weakening the rock mass.

Disturbance due to drawdown of the cave muckpile: there is a correlation between isolated draw (illustrated in Figure 12) and mudrush occurrence. The main danger associated with isolated draw is the high rates of extraction from drawpoints. This results in an increased possibility of mud rushes due to the fact that dilution from the mud-bearing waste cap enters the draw column sooner. Also, larger quantities of waste can be drawn from diluted drawpoints



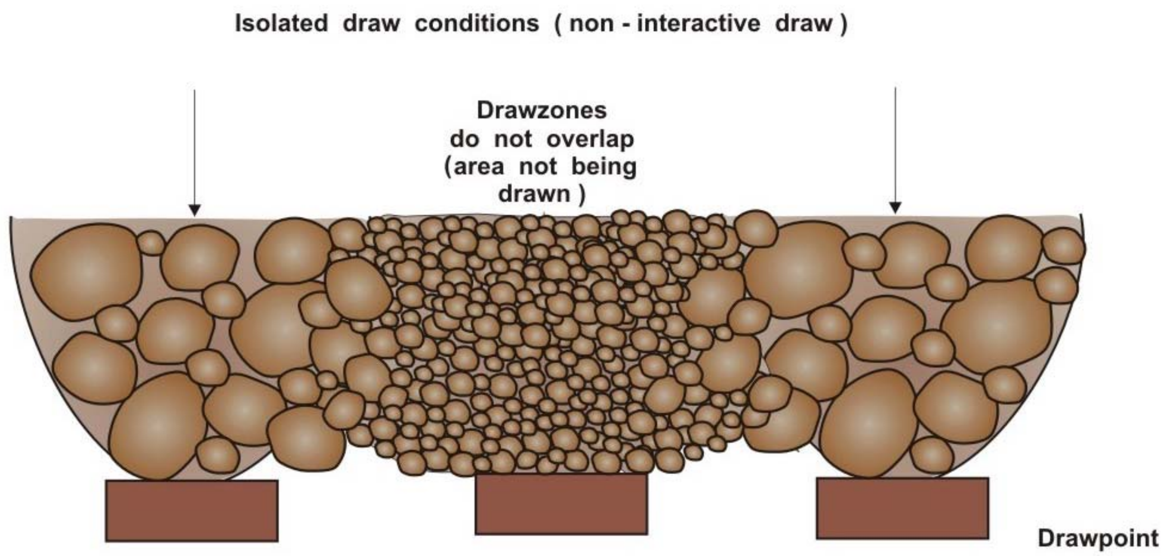


Figure 12 Non-isolated and isolated draw conditions

before they are closed, resulting in dilution cut-off of reserves from adjacent drawpoints. In essence, these heavily extracted drawpoints act as mud pocket pathways to the operation levels. As draw rates increase, the fines are normally extracted from the draw column first, leaving a honeycomb of rock arches and an increased possibility of mud pocket discharge due to rapid draw column compaction. With regard to draw trigger mechanisms, the following conditions must be fulfilled:

- a condition of isolated draw must exist on operational levels;
- 30% of drawpoints must be overdrawn (beyond the allocated drawpoint reserves);
- operational drawpoints must have draw rates much higher than common practice (typically 1.5m/day). For example, sublevel cave draw rates of 8m/day are favourable for mud ingress.

It should be noted that these draw rates are probably only applicable to SLC mining. In block cave mining, due to the fragmentation requirement, draw rates in the region of 200mm/day are considered normal. However, isolated draw conditions can still occur in block caving and the danger of mud ingress due to excessive over extraction still exists.

From the above discussion it is apparent that, for mud ingress to occur, isolated drawpoints must be extracted in excess of the allocated reserves. It therefore follows that non-interactive draw conditions are a warning sign of mudrushes in caving operations. Isolated draw conditions can occur due to poor draw discipline (drawpoints deliberately over pulled), or due to poor layout design. Even though instances of poor draw discipline do occur at most operations, experience indicates that uniform drawdown is generally achieved at most profitable caves, unless waste cap mining is economic.

Figure 13 shows the process which results in isolated draw conditions occurring in a SLC or block cave. Non-interactive draw normally begins when drawpoints or drifts are lost due to the following:

- ground control problems requiring drift repairs;
- ground control problems due to excessive action blasting (blasting for drawpoint hang-up clearance);
- the formation of crown pillars, bridges or banks due to poor blast design and practice. This is non-extraction of the full fan profile, which results in remnant pillars remaining in the fan blast geometry;
- destruction of drifts by point loading due to poor action work;
- destruction of drifts or drawpoints due to stress loading from remnants left on previously mined levels;
- drawpoints lost due to non-mining of areas where there has been a mud occurrence or where mud pockets are suspected.

The result of the initial loss of drawpoints or drifts is that, if the level or block tonnage (call) is not reduced, then the remaining drifts and drawpoints will be extracted above their natural capacity. The usual result is that ore fragmentation size reporting to drawpoints increases. Consequently, the frequency with which action blasting of drawpoints (to clear hang-ups) is conducted also increases. This causes additional drawpoints to be lost due to blast damage. Again, if the call is maintained, the remaining drawpoints are extracted above their natural capacity and the process is repeated until excessive dilution of ore reserves occurs or the block is lost due to mud ingress.

Boxholes and passes: in the case of boxholes and passes, the disturbance is the opening of the chute.

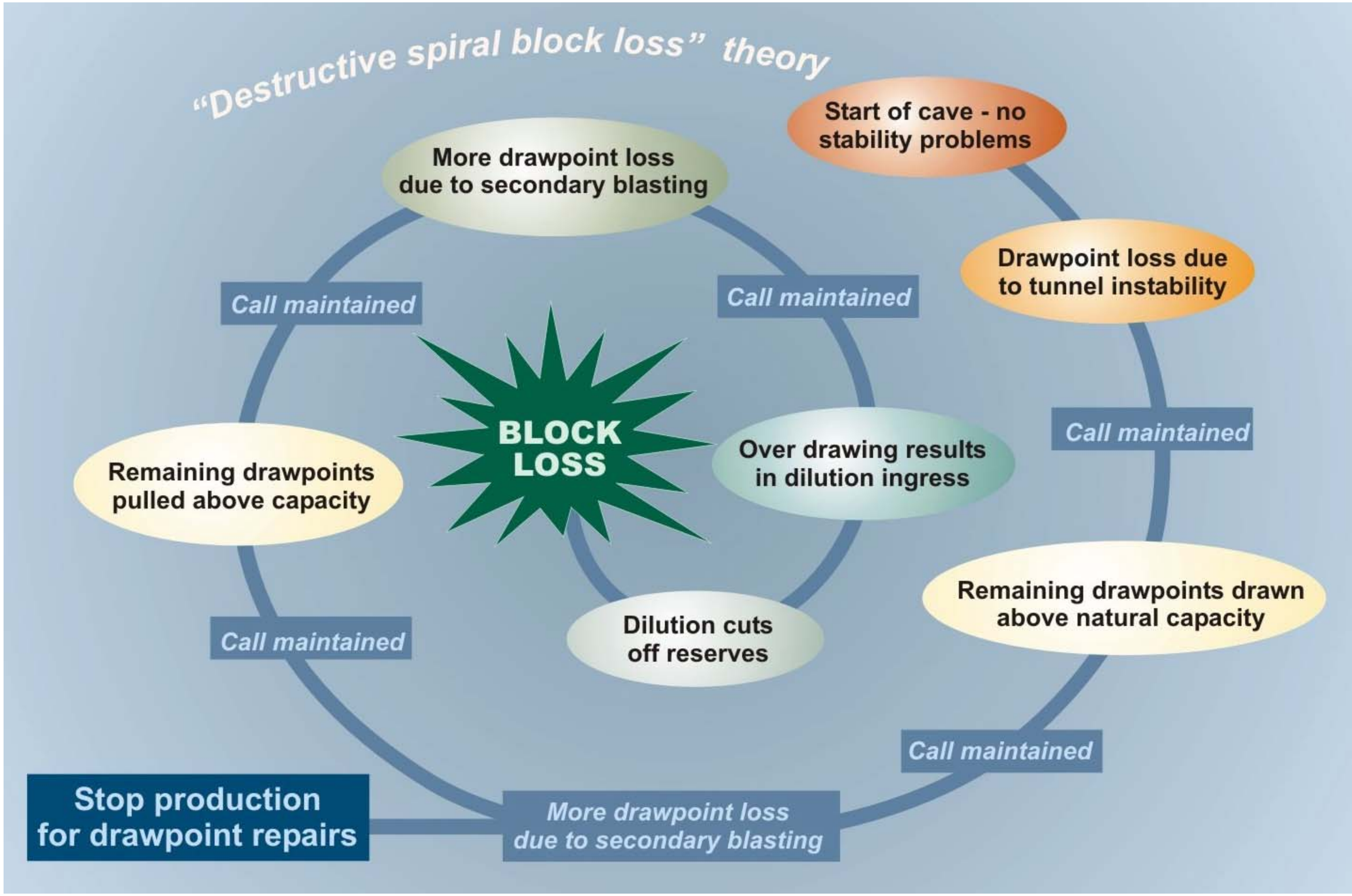


Figure 13 Spiral of isolated draw

4.2 Water

It is clear that water has had a role in mud formation and the inrush triggering process. The following are considered as possible mud rush warning signs:

- Lack of a correctly designed mine drainage system;
- poor maintenance of the mine drainage system. In this respect, particular note must be taken of the following:
  - if the mine drainage system consists of a network of drainage galleries: the collapse of these tunnels, the calcification and blockage of drain holes and underground drains;
  - if mine dewatering is achieved by the use of borehole pumps: the vandalism and theft of pumps, and the collapse of dewatering boreholes;
  - blockage of surface drainage trenches by undergrowth, and their collapse;
  - surface ponding;
- decreasing mine pumping rates over time, but with a theoretical increase in mine water. Figure 14 shows a theoretical model depicting muckpile water retention which can be used as a warning;
- small underground floods and mudrushes;
- the increased presence of water underground.

With regard to boxholes and passes which contain material and in which there is water entry, a warning sign will be the absence of water draining from the chute or box front. The implication is that a blockage has occurred allowing water and material to build up behind it.

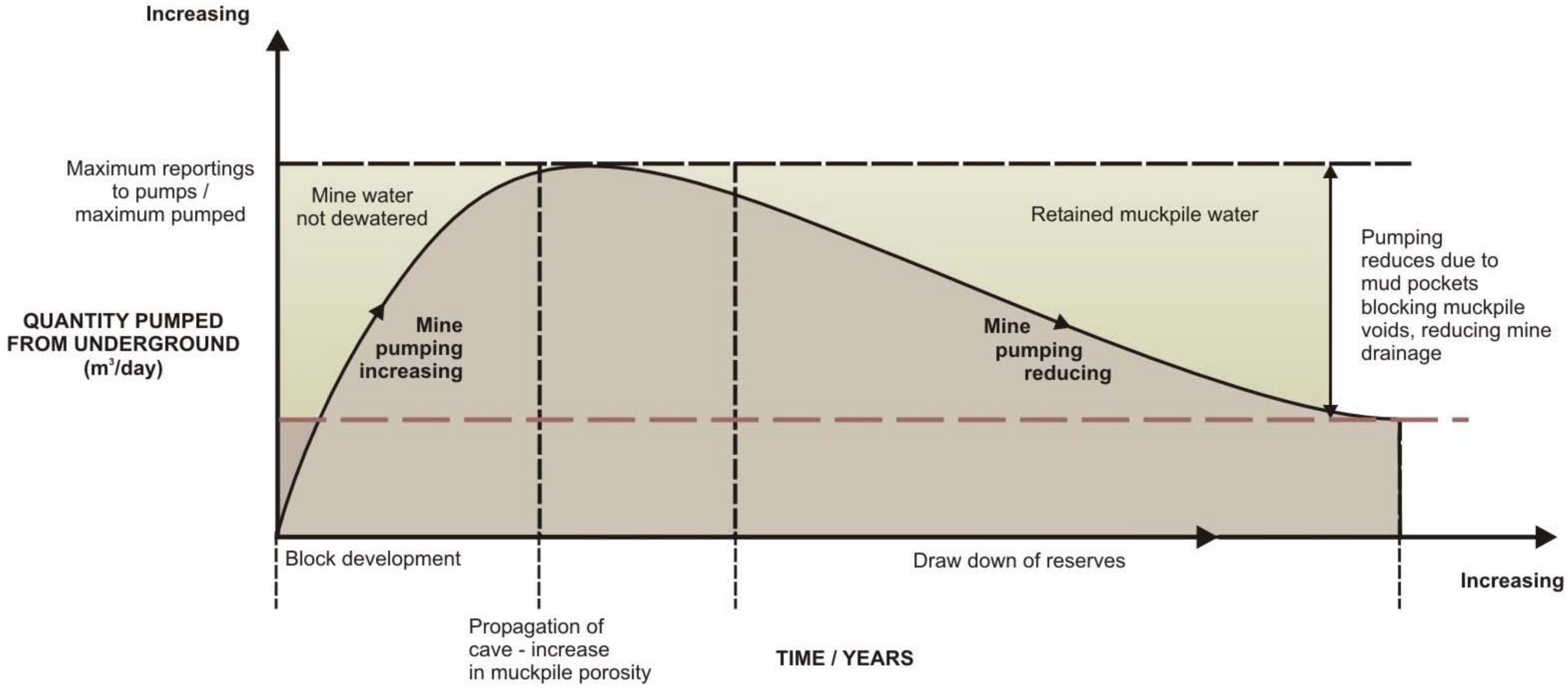


Figure 14 **Mine pumping history, showing muckpile water retention, assuming constant quality of water reporting to underground pumps**

5 RISK ASSESSMENT

As part of their requirement to identify hazards in terms of the Mine Health and Safety Act, mines must address the potential for mudrushes. The primary risks in the occurrence of mudrushes are:

- the accumulation of water;
- the accumulation of mud forming minerals, both internally and externally;
- the proximity of the mud to the drawpoint or discharge point; and
- the freedom for the mud to discharge.

If such a risk assessment identifies that a significant mud rush hazard exists, the mine should be classified as a mud rush prone mine.

A mudrush prone mine is defined as a mining operation which has a previous history of mudrushes, or one in which risk assessment techniques have determined that there is a significant probability of occurrence of mud ingress. A suggested conservative value for this significant probability is 0,01%. This definition applies for major mudrushes and does not include the consideration of boxhole or pass mudrushes.

6 PREVENTATIVE MEASURES

Implementation of preventative measures will reduce the risks of mudrushes.

6.1 General preventative measures

Design and siting of tailings dams: the incorrect design and siting of tailings dams has been seen as a major cause of inrushes. The following restrictions should therefore be imposed:

- the disposal of tailings, slimes or any other waste which could behave as a fluid should not be conducted above active mining operations, or where, should the impoundment fail, there is a direct flow path to underground workings;
- the disposal of tailings should be prohibited in areas that may undergo subsidence due to caving or failure of mine structures (eg failure of crown pillars); .
- the disposal of tailings. slimes or any other waste that may behave as a fluid, into open cast mines or open cuts which are situated above current operations, should be forbidden;
- tailings and slimes dams, and their foundations must be correctly designed taking cognisance of material geotechnical properties, hydrogeological and hydrological regimes, potential seismic loading and differing disposal techniques. The importance of correct darn construction and management is also highlighted.

Open pit slopes: correct excavation of open pit bench slopes in mud forming soils or weak soft rock is critical to the prevention of mudrushes. The following measures should be imposed:

- slopes should be designed according to established current geotechnical best practice;
- the effects of variations in rainfall and groundwater regimes, mining sequences and blasting practices must be taken into account for slope-induced mudrush prevention purposes.

Backfilling of underground stopes: in mining operations in which backfill is used as regional support (cut and fill, open/VCR stoping, post filling and post pillar mining operations), fill quality is vital:

- backfill should be designed according to best current practice;
- a backfill quality control programme must be implemented, where acceptability of fill strength is judged according to established concrete

practice statistical analysis techniques (ie 98% of backfill strengths being above the required low strength value);

- a mine dewatering system and other measures must be implemented to prevent the ingress of groundwater into filled stopes. All mines using backfilling must have a system of preventing fill decantation water from accumulating in stopes and other workings;
- stope bulkheads should be designed with a sufficient factor of safety to account for the possibility of a backfill runaway.

Blockages and hang-ups in boxholes and passes: the hazards associated with these should be prevented by the following:

- minimising the quantity of water that flows into these excavations;
- correct design of chute fronts and chute operating systems;
- draining of water from behind boxfront structures;
- regular removal of pagging from the surface of the boxhole and pass, and from the surfaces of the box or chute front structure;
- regular drawing of material to ensure that the rock column is kept moving and does not consolidate.

The design of chute and box fronts is not well covered in the literature, and it appears that most mines have designed their own chute and box fronts in-house. Problems associated with chutes were dealt with as part of SIMRAC Project OTH303, and the booklet which resulted from that project contained pointers regarding chute design and operational aspects.

At all mudrush prone mines, methods should be in place for the sealing of old workings and abandoned drawpoints from where mud discharge could occur. Methods of slowing or preventing the flow of mud to other operational levels via mud transport excavations, such as shafts, boxholes, passes, haulages etc, must be determined and implemented. Special note should be taken of the need to ability secure those passes and shafts which may facilitate mud flow to operational workings.

6.2 Mud ingress prevention through the implementation of the 3 D's principle (Distance, Drain, Draw)

Figure 1 shows that, *for* a mudrush to occur, four elements must be present mud-forming material, water, disturbance and a discharge point through which the mud can enter the workings. The 3 **D's principle** is focused on three aspects:

- keeping the mud material away from the mining operation (**D**istance);
- prevention of water ingress into muckpiles, filled stopes or workings, boxholes and passes (**D**rain) to stop the fluidization of mud forming materials;
- correct drawdown of ore reserves to prevent the discharge of mud pockets and layers (**D**raw).

Distance

Mud must be kept distant *from* the mining operation. Therefore, tailings dams must be sited such that there is no risk of such material flowing underground; open pit slopes must be designed to ensure that weatherable material will not accumulate in an area where it has the potential to flow underground.

Sublevel caving methods are more risky with regard to mudrushes, since any mud in the waste capping is closer to the extraction location than it is *for* block, panel or front caving methods. The latter methods maintain the mud at a greater distance. However, it is important to correlate the percentage extraction with the possible occurrence of mud. As a general guideline *for* mudrush prone mines, only 120% of the allocated drawpoint reserve should be extracted, despite the economic viability of waste cap mining.

Drain

These measures are aimed the prevention of water (groundwater or rainwater) from fluidizing mud-forming materials. The following are recommended for mudrush prone mines:

- the hydrological and hydrogeological regime should be defined, with a mine water balance being determined;
- mines must have correctly designed surface and underground drainage systems, to prevent groundwater and rain water from entering slopes, muckpiles, filled stopes and open cuts.
- mines must have a correctly designed underground water reticulation system, which is maintained regularly to prevent leakage;
- a system of groundwater monitoring must be established to detect variations in the phreatic surface surrounding the mine. This is to monitor the efficiency of mine drainage measures;
- in the case of underground drainage, records of quantities pumped from underground must be kept. These records must be correlated with rainfall over time;
- in areas where mine dewatering is carried out using borehole pumps, records must be kept of quantities pumped. This is to check on the efficiencies of these measures;
- adequate security measures must be provided to protect boreholes, pumps, water tunnels and other dewatering systems from the effects of theft and vandalism;
- if mine drainage is achieved by a system of water drainage tunnels, these excavations must be maintained. Underground drains and dewatering drainage holes must be kept clear. Drainage holes must be redrilled should calcification or blockage occur;
- if surface runoff into open cuts or pits is prevented by a system of surface trenches, these trenches must be kept free from obstruction;
- an audit of the mine drainage measures should be conducted by a qualified hydrogeologist at least annually.

Draw

Overdrawing and isolated draw conditions are trigger mechanisms for mudrushes. The following are advocated at every mine where caving or mining involving the drawdown of a muckpile or shrink pile is being conducted:

- at all operations a draw control system must be implemented. The key components of such a system are:
  - one competent person must be appointed to be responsible for drawcontrol;
  - a mine draw reserve must be determined, with tonnages allocated to each ring or drawpoint/loading place. The draw reserve must correlate with the ore reserve to within 5% and a record must be kept of all suspect remnant ore tonnages left from upper blocks. An ore reserve statement must be kept of all dilution tonnages or other suspected mud-forming materials;
  - a tally sheet system must be implemented showing the drawpoint/loading place reserves, progressive extraction status and daily/monthly calls;
  - all decisions to overdraw (ie for drift repair, bridge removal, crown pillar removal) must be noted in the remarks column of all tally sheets and monthly depletion status reports;
  - documentation showing the monthly depletion of drawpoint reserves, block reserves, quantities of dilution present, extraction levels for drawpoints and blocks must be completed;
  - drawn tonnages and hoisted tonnages must be reconciled, to indicate inaccuracies of drawcontrol and reporting;
  - a monthly report concerning all aspects of draw control must be compiled;
  - a set of extraction level contour plans showing contours of extraction, dilution and draw rate should be kept. This is required to indicate the possible presence of chimney caving or rat holing into the waste capping.

- all draw records must be kept for the life of the mine, as they form the extraction history of the operation and show areas of high dilution ingress (possible mud ingress areas) and ore reserve loss;
- a dilution influx model must be determined for drawpoints;
- in mines in which mudrushes have occurred, a record of all inrushes should be kept. The following information must form part of this record:
  - date and time of inrush;
  - location of mudrush (indicated on a plan);
  - how far the mud pushed and the quantities discharged;
  - the percentage extraction for the discharge drift and drawpoint;
  - mine pumping and rainfall records. These records should be reviewed annually to quantify the extent of the mudrush problem and the effectiveness of mudrush prevention measures;
- in mines where there has been a history of mudrushes, the maximum drawpoint extraction percentage should be stated as a shut off limit to prevent mud ingress. A justification for this extraction level must be given.

6.3 Procedural measures for the prevention of mudrushes

The first procedural step is to classify mines as mudrush prone or non-mudrush prone operations, based on a risk assessment as indicated in Section 5 above. Should a mine be classified as a mudrush prone mine, the following measures should be implemented:

- the compilation of a mandatory Code of Practice for the prevention of mudrushes, as provided for by the Mine Health and Safety Act. This Code of Practice should be reviewed independently on an annual basis;
- a set of underground mudrush precautions should be compiled;
- the appointment of a competent person to be responsible for mudrush control;
- mudrush incidents should-be recorded in the SAMRASS database.

6.4 Compilation of a mandatory Code of Practice for mudrush prone mines

A mandatory Code of Practice for the prevention of mudrushes should be prepared by all mudrush prone mines. This requirement should be implemented under the guidance of the Mining Regulation Advisory Committee as provided for in the Mine Health and Safety Act. Guidelines providing information on the recommended content of the Code of Practice are given in the Appendix.

The Code of Practice for a mudrush prone mine should be reviewed annually by an external party and updated as required from this review. This party should be an external reviewer in possession of the experience and qualifications given in the section below. It is important that the reviewer has experience with mine mud rush incidents, investigations or research projects.

6.5 Appointment of competent persons for mudrush prone mines

A competent person responsible for mudrush control should be appointed by the mine manager in terms of the Code of Practice for the prevention of mudrushes. Owing to the complexity associated with mud ingress, it is recommended that, in large scale operations, this person be in possession of an appropriate qualification as determined by the Mining Qualifications Authority (MQA). It is recommended that an appropriate qualification would be a tertiary qualification in one of the following disciplines: mining engineering, geology, engineering geology, geotechnical engineering, and hydrogeology. It is suggested that a person who holds a Chamber of Mines rock mechanics certificate may also qualify for this position, provided that this person has at least 2 years of experience in that particular mining environment. It is important that the appointed person has at least 4 years experience in the mining industry.

In the case of small scale operations, it is suggested that the appointed person should have extensive experience in that type of mining, and experience with draw control and mine drainage. For these smaller operations, a review must be carried out on a quarterly basis by an independent party in possession of the qualifications and experience as stated above.

6.6 Compilation of underground mudrush precautions

At every mine where a historical major mudrush hazard or potential mudrush hazard exists as determined by a risk assessment, a set of underground mudrush precautions should be compiled. These precautions should be focussed on the evacuation and identification of workers in a mudrush hazard area. The following must be included:

- a record book or other means of recording the number and names of personnel working in the hazard area. This book must be kept in a prominent position at the entrance and exit of each area. It must be signed by all personnel entering, working in, visiting and leaving the area. The position should be identified by a flashing light and signs;
- a mud rush warning system, consisting of sirens or alarms, should be installed in the hazard area. These alarms must be sounded in the event of a mudrush;
- an evacuation procedure, showing the means of escape from the affected area and the further actions to be taken if deemed prudent;
- a notification procedure to ensure that the responsible officials are informed of the inrush as quickly as possible;
- a closure procedure for any mine services that may hamper rescue efforts.

Copies of the precautions must be placed at the entrance and exit of all potential inrush areas. These procedures should be communicated to all personnel concerned on a monthly basis, at the working place.

6.7 Recording of mudrush incidents

Mudrush incidents should be included in the list of reportable incidents. They should be reported to the Department of Minerals and Energy, and recorded in the SAMRASS database of accidents and incidents. The following information should be forwarded to the Department of Minerals and Energy for inclusion in the SAMRASS database:

- date and time of inrush;
- location of mud rush (location indicated on a plan);
- how far the mud pushed and the quantities discharged;
- percentage extraction for the discharge drift and the drawpoint;
- mine pumping and rainfall records.

APPENDIX

GUIDELINES INDICATING THE RECOMMENDED CONTENT OF A CODE OF PRACTICE FOR THE PREVENTION OF MUDRUSHES

The following guidelines, providing information on the recommended content of a Code of Practice, are divided into two sections:

- a description of the mudrush or potential mudrush environment, and
- the strategies for prevention of mudrush occurrence.

Mudrush environment

This section should describe the global mining environment and its relationship to the factors contributing to mudrushes - mud-forming materials, water, disturbance, and discharge points.

Mining methods: the current and previous mining methods must be described. A justification should be included for the selection of the mining method as well as reason for changing from past methods. For mines with a history of mudrushes, correlation between the frequency occurrence of mudrushes and the corresponding mining method must be stated.

Layouts and dimensions of all excavations must be given for the current operational levels. In the case of mud discharge points, the size of these excavations must be justified. A plan should be given showing all potential routes of mud inflows and a list of all mud transport excavations.

Sections should also be included showing the potential flow of mud to lower levels and a list of all shaft and pass mud transport excavations.

A plan should be included showing all potential mud discharge points and mud transport excavations of all abandoned workings, and the relationship of these to current operational levels.

Surface layouts: plans should also be given showing the positions of tailings dams, lagoons, spoil heaps, swamps, marsh drainage channels and unconsolidated material. These positions should be related to subsidence/potential subsidence areas, slope break back zones, adits, shaft collars, open bench drawpoint mouths and open cuts. Potential surface mud flow paths should be indicated on this plan.

Mudrush history: on mines which have a history of mud ingress, a record should be compiled showing, where possible, for each mudrush occurrence, the date, time, location, quantities discharged, and mining method used. The record should show the frequency of mudrush events over time. Details of the number persons killed, injured or trapped should also be stated. Comments should be made regarding increasing or decreasing trends. In this database, mudrush records from sister and adjacent mines should be included if possible.

Mud-forming materials: geological sections must be included showing the geological succession through the mine. Geotechnical parameters and a full geological/mineralogical description of each geologic unit must be given. Comments must be included regarding the mud-forming properties of each unit.

In terms of mining wastes (tailings, slimes) a full geotechnical description of these materials must be given, with special reference to their liquefaction susceptibility.

Water: the hydrological and hydrogeological regime of the mine must be fully defined. Special importance must be placed on water-bearing geological structures, surface accumulation of water, and run off patterns in relation to the mine workings.

A mine pumping history must be given for at least 20 years, if possible. The relationship between mine pumping and rainfall must also be given.

Seismicity: a detailed seismic history of the area should be given. Special attention should be given to the presence of tremor and rockburst damage.

Draw: in the case of caving mines or mines which conduct operations under a muckpile, a complete extraction history of the operation should be given. This history should include block tonnages, extraction and ore loss per mining area, dilution percentages and types, a drawpoint dilution influx model for the current operation, and historical mining drawdown rates for current and previous blocks mined. Copies of the contour plans showing levels of extraction, dilution and draw rates for current operational blocks should be included. Where remnant draw recovery operations (such as SLC rim loading) are being practised, an ore reserve justification must be included. In addition, a depletion schedule for the blocks currently being mined should be included.

Strategies for the prevention of the occurrence of mudrushes

The following are advocated as prevention strategies:

- **Mining waste disposal:** a tailings, slimes and other waste disposal strategy should be included. This section must highlight the rationale for the siting and design of all slimes and tailings impoundments. A comprehensive design rationale for dams must be included, showing all necessary stability calculations. The effects of rain and construction material variation on dam stability must be stated. The disposal strategy must include information on dam construction and management;
- **Mine drainage:** a mine drainage strategy must be incorporated, stating the global process for mine drainage, the positions of all drainage facilities, water monitoring arrangements, the abilities of mine pumps to cope with sudden influxes of water associated with mudrushes, dewatering system security and maintenance measures. A section should be included showing that adequate financial provision has been made for the above;

- **Mine flooding and mud ingress:** procedures should be given stating the measures taken to secure the mine in the case of a flood. This may take the form of plugging of old workings, water stulls to retard mudrush flood water, additional pumping capacity and water-tight doors. Where the mine has installed plugs, reserve drains and water-tight doors, design calculations should also be attached;
- **Tunnel and stope stability:** in order to prevent the occurrence of isolated draw conditions and crown pillar failure, a geotechnical design rationale for all excavations must be included. In addition, drift rehabilitation procedures must also be given. Stand up time graphs for all tunnels in the different geotechnical units must also be prepared. Mine support quality control installation standards and a graph showing spending on support over time must be given;
- **Slope design:** where applicable, slope design calculations should be enclosed. In the case of dormant pits, a copy of the slope monitoring and management strategy must be included;
- **Backfilling:** if fill is used as a mine support, then details of the mine filling standards must be attached. These should include fill material design (ie required target strengths, material grading, required moisture content etc), a flow chart of the fill manufacturing, transport and deposition processes, fill quality control process, paddock and bulkhead construction and design specifications, and procedures in the event of bulkhead failures;
- **Draw control:** all caving operations or mines that operate under a muckpile must have a draw control system, and a strategy for the uniform drawdown of reserves and the prevention of isolated draw conditions and mud ingress. A draw reserve should also be compiled showing extraction, dilution and ore loss for the different blocks mined over the operational history. The section should also include the design rationale for drawpoint dimensions and layout spacings for interactive draw conditions. For every block, drawdown rates should be kept. A dilution influx model for drawpoints should be constructed. The shut off limit for dilution ingress for drawpoint and blocks must be given. The method under which draw control data are recorded and stored must be stated.

Compilation and responsibility

It is important that a competent person is appointed as head of draw and mud ingress control. The code of practice should be compiled of a committee consisting of this person, a geotechnical engineer, rock engineer, hydrogeologist, geologist, metallurgical engineer and a mining engineer. This code should be reviewed annually.