MINERALS COUNCIL
SOUTH AFRICA

Mud Rush
Day of Learning

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Mud rushes and inrushes

Lessons from investigations and the evolution of inrush risk management

Cullinan Diamond Mine

srk consulting

2026/09/03

Contents

01

Major mud rushes

Major mud rushes

Mine	Country	Date	Volume (m³)	Run-out distance	Source/Cause	Mining method	Fatalities	Reference
Grasberg	Indonesia	8 Sep 2025	800,000	Extraction level, panel drift, vent raises, ore passes, drainage ways, service level	External wet material from pit through unrecognised pathway (official record)	Block Cave	7	Jakubec (2026), news articles
Mufilira	Zambia	25 Sep 1970	450,000	Multiple levels	TSF material flowed through cave subsidence into active workings . Overdraw along contact?	Block and Sub Level Cave	89	Mufilira report, (1970) Butcher et. al (2000)
Mir	Russia	4 Aug 2017	300,000	Multiple levels, rim tunnel, drainage gallery, ore passes and ventilation raise to levels below	Failed pit drainage, Water and loam used for liner, erosion pipe/chimney failure of crown pillar	Drift and fill	8	Investigation following accident
Rovic	South Africa	27 Nov 1996	Many 1,000s?	Multiple levels	Water, weathered shale & mud in pit, overdraw, crown pillar failure (chimney?)	Chambering, Shrinkage	20	Rovic report, Butcher et. al (2000)
O'Kiep	South Africa	1980s?	100,000	Flowed through bulkhead, two levels engulfed, main ramp system for 5 levels	Liquefaction of backfill (blasting and seismicity, groundwater, variable backfill strengths)? Bulkhead failure.	Vertical Crater Retreat (VCR) stoping and backfill	4	Butcher et. al (2000), Inquiry
Bultfontein	South Africa	7 May 2018	38,000	3 levels engulfed	Overdraw and isolated draw creating rathole, which potentially reached pit lake	Sub Level Cave below Block Cave	None Shift change	Investigation following accident, Ross & Marsden (2024)
Argyle	Australia	4 Feb 2020	18,000	Engulfed >5,000 m² of extraction level	160 mm of rain over four hours. Through existing ratholes. Collapse of hang ups.	Block Cave	None **TARP**	Saepulloh, Hassell & Albrecht (2022)
Du Toitspan	South Africa	17 Feb 2026	9,000 (rock/mud), 50,000 (water)	450m of tunnels	Water inrush carrying rocks with small amount of mud through ring blast	Block Cave	5	Marsden (2026), Mud rush day of learning

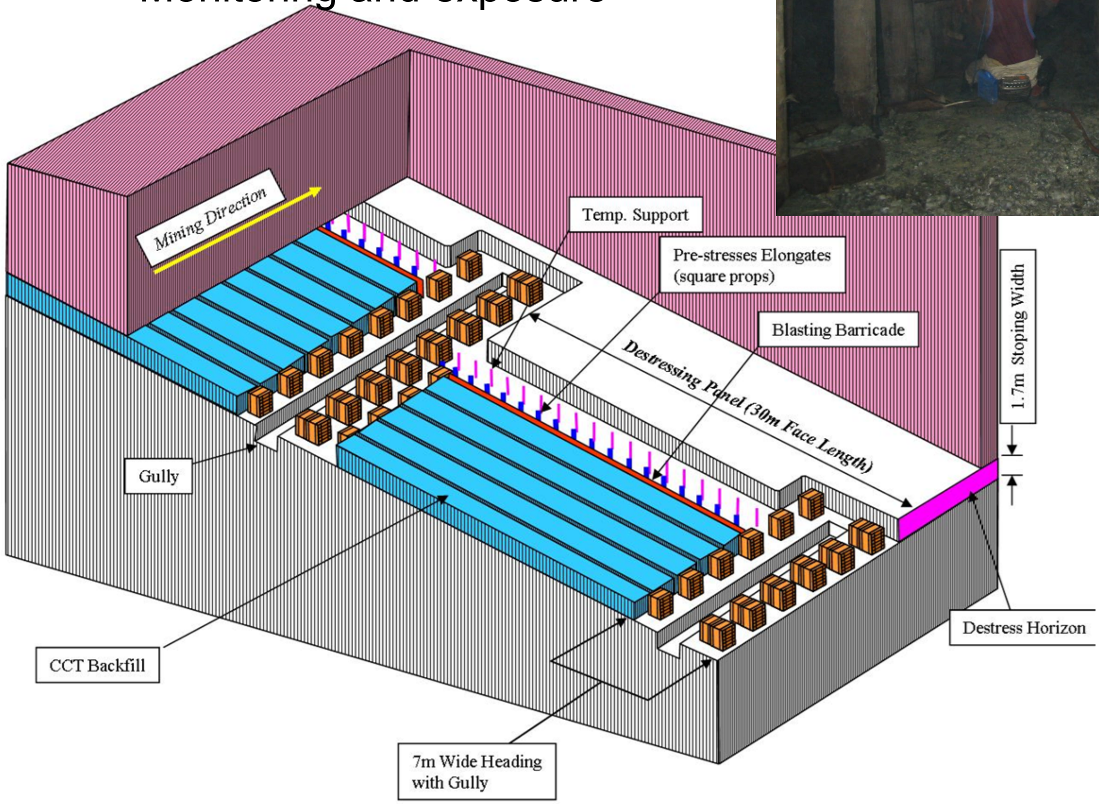
02

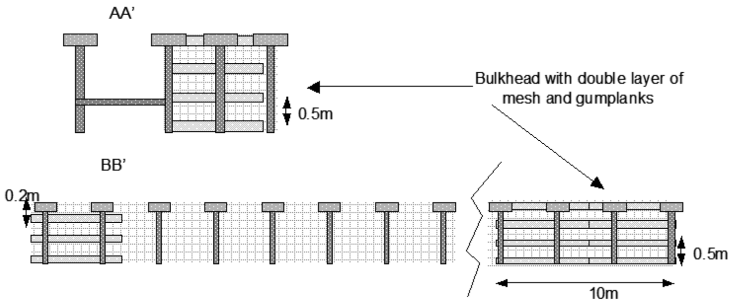
Backfill mud rush prevention

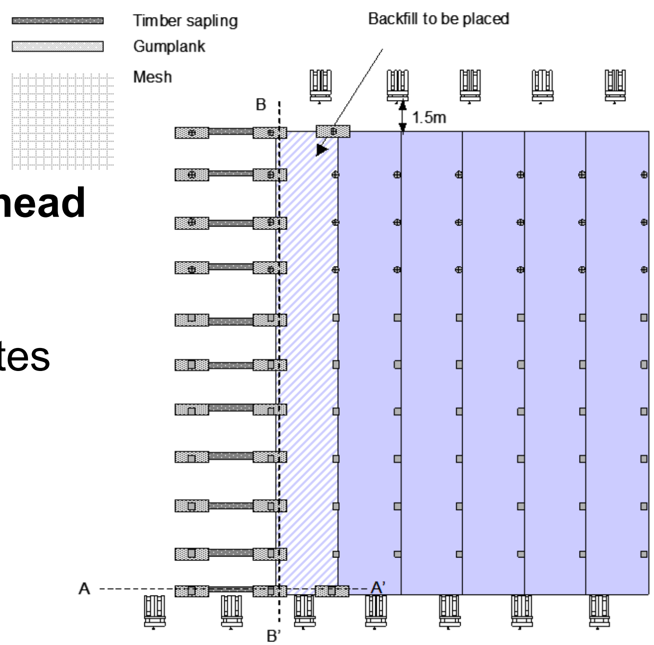
Narrow tabular stope backfill

Paddock failures and mud rushes

- Hydraulic fill
  - Density, Cement and admixtures?, Fines (<10μm particles)?
- Steep dip or faults (head)
- Monitoring and exposure







Paddock & Bulkhead

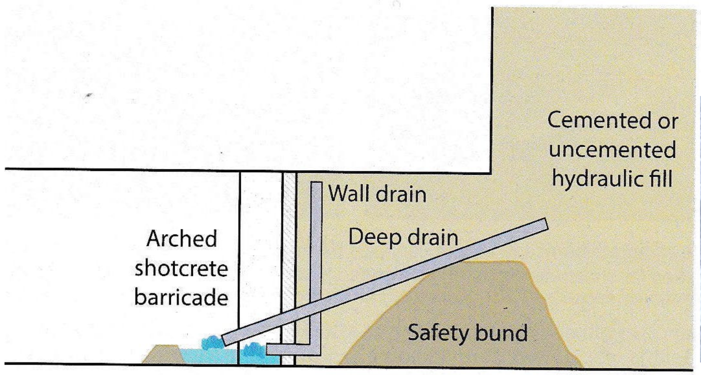
- Geotextile
- Wire mesh
- Timber elongates
- Packs
- Gum planks

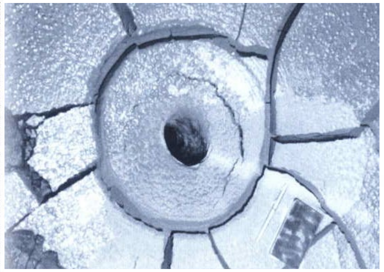
Spills end up in ore passes

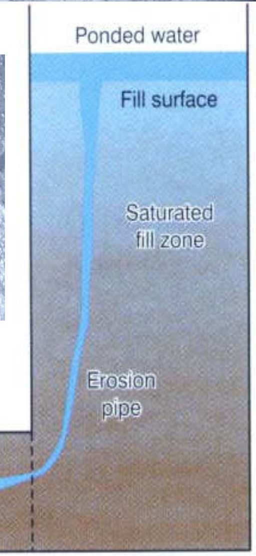
Longhole Open Stoping

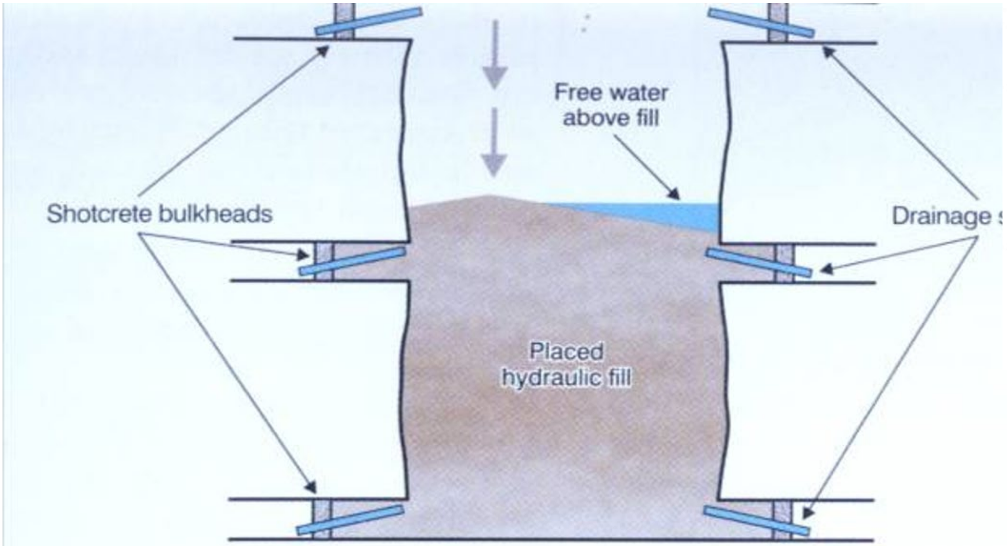
Bulkhead failures and mud rushes

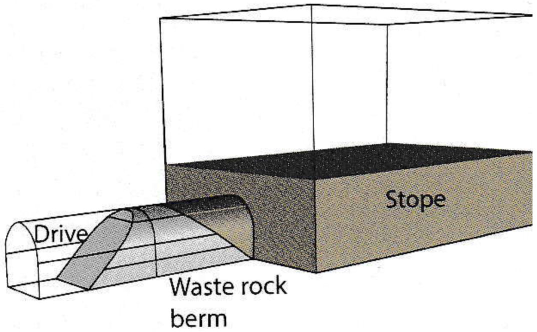
- Hydraulic fill
  - density, cement and admixtures?, fines (<10μm particles)?, drainage design, Fill rate etc
- Paste fill (liquefaction & curing)
- Bulkhead design & construction
- Monitoring & exposure











Potvin, Y, Thomas, E & Fourie, A 2008. Handbook on Mine Fill. *Australian Centre for Geomechanics www.acg.uwa.edu.au*

*Potvin, Y, Veenstra, R . 2025. Comprehensive H*andbook on Mine Fill. *Australian Centre for Geomechanics www.acg.uwa.edu.au*

03

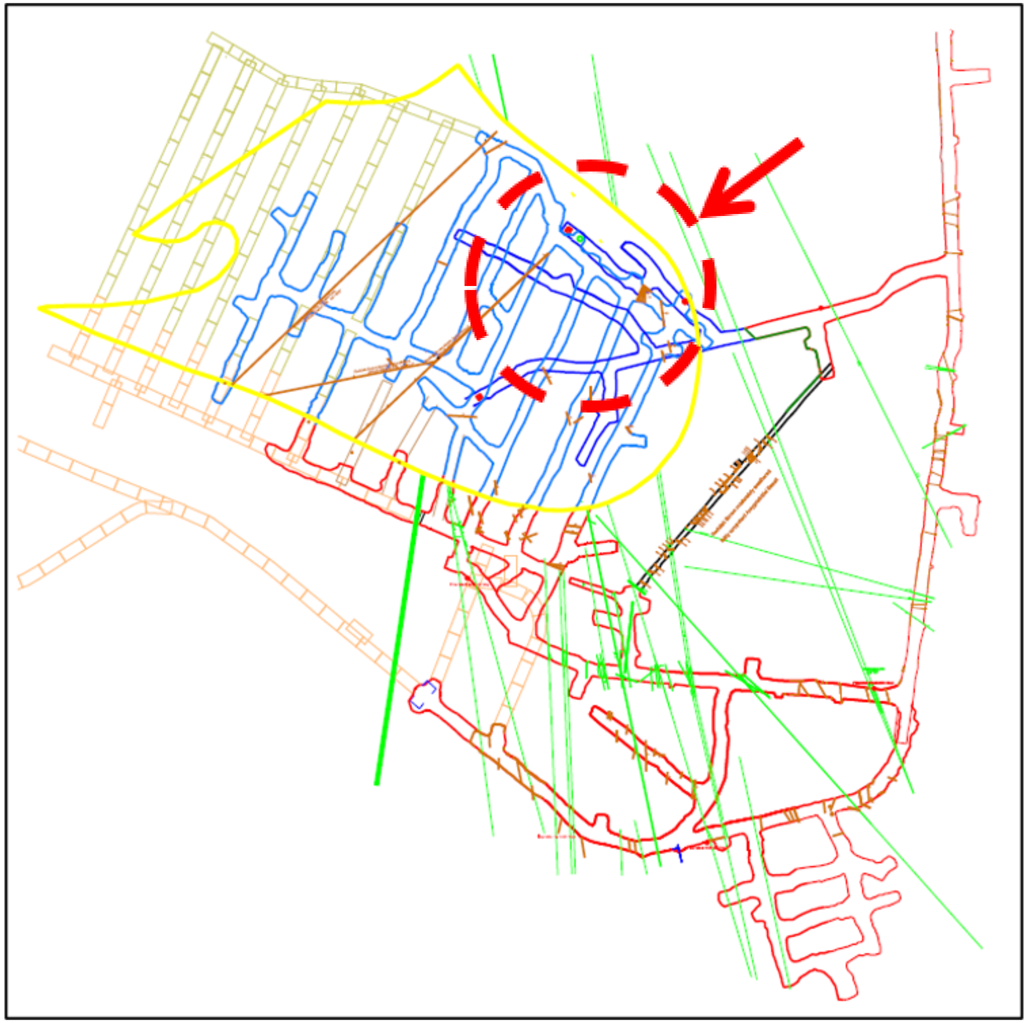
Caving case studies

Ghaghoo – Nov 2015 crown pillar failure, sand inrush & air blast (Botswana)

- Dust blown out through Lvl 0 and Portal
- Sand immediately reported to Lvl 1 draw points in Tunnels BT1 & BT2

(from Ghaghoo Mine Surface Subsidence Incident Report, Dec 2015)

Ghaghoo – Nov 2015 crown pillar failure, sand inrush & air blast (Botswana)



- Large sinkhole volume suggests large underground void, due to overdraw on Lvl 0 and Lvl 1
- Note: Internal structure / pipe contact intersection coincidently aligns with sinkhole funnel
- Lvl 0 extraction:
  - 55% actual vs. 60% planned
- Lvl 1 extraction:
  - 95% actual vs. 75% planned
- Overdraw created large void below crown pillar, crown pillar not adequately supported, and collapsed

Importantly: Precursor collapse and 1st air blast 2 weeks earlier, with crater facies material reported on ROM stockpile

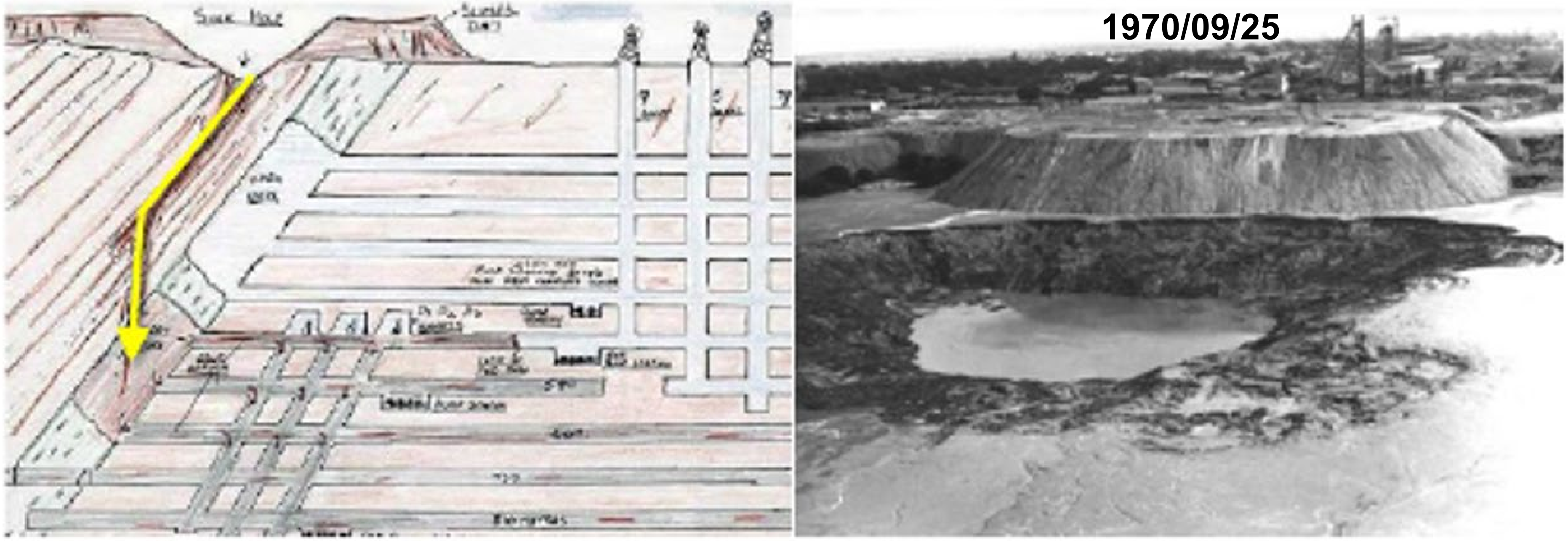
(from Ghaghoo Mine Surface Subsidence Incident Report, Dec 2015)

Sandy, JD, Piésold DDA, Fleischer, VD & Forbes, PJ 1976, ‘Failure and subsequent stabilization of no. 3 dump a Mufulira mine, Zambia’, Transactions of the Institution of Mining and Metallurgy., Section A, vol. 85, pp. A144–A162.

Clarke, N & Jakubec, J 2026, 'Backfilling with filtered tailings above an active cave mine: a conceptual study', in A van As, D Cumming-Potvin & J Wesseloo (eds), Caving 2026: Proceedings of the Sixth International Conference on Block and Sublevel Caving, Australian Centre for Geomechanics, Perth, pp. 1-16, https://doi.org/10.36487/ACG_repo/2645_604.

Mufilira mine disaster

SLC



(a) (b)

Figure 2 **Mufulira mine disaster. (a) Mine section showing tailings entry route; (b) Sinkhole in no. 3 dump**

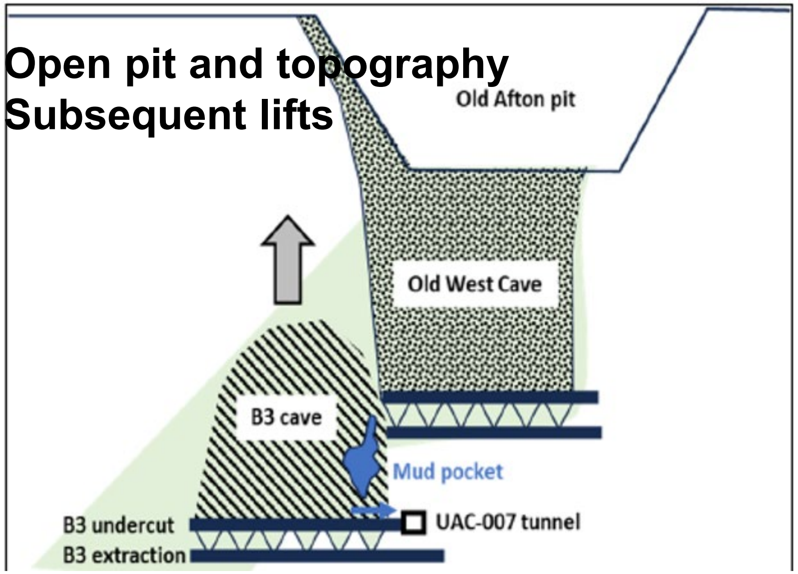
Information

- 3.9 Mt of slime deposited in sinkholes to start TSF
- TSF additional 20 Mt
- 450 000 m^3 entered mine 700 m below surface
- 500 m^3/s in 15 minutes
- 89 fatalities

Cave evolution and mud rush potential

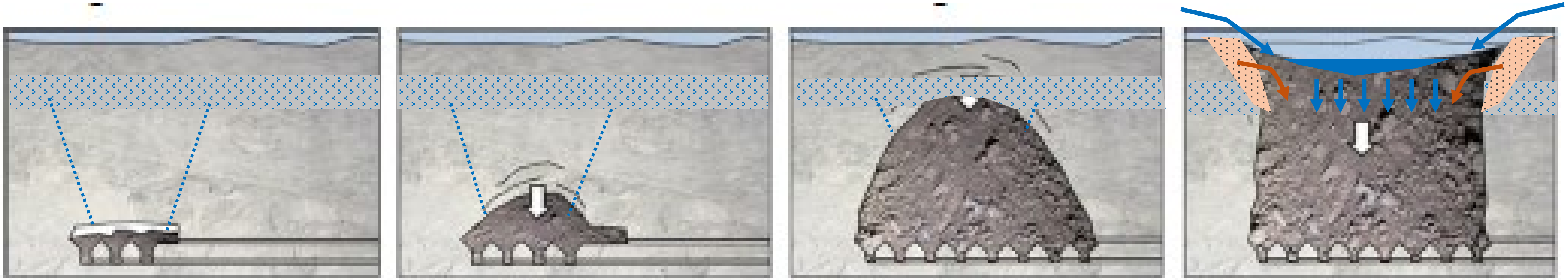
Mud forming materials (silt and clay)
- Soil on surface
- Weathering of near surface material
- Slope failures
- Mudslides
- Comminution and weathering of ore

Open pit and topography
Subsequent lifts



Tropical Storm

Groundwater

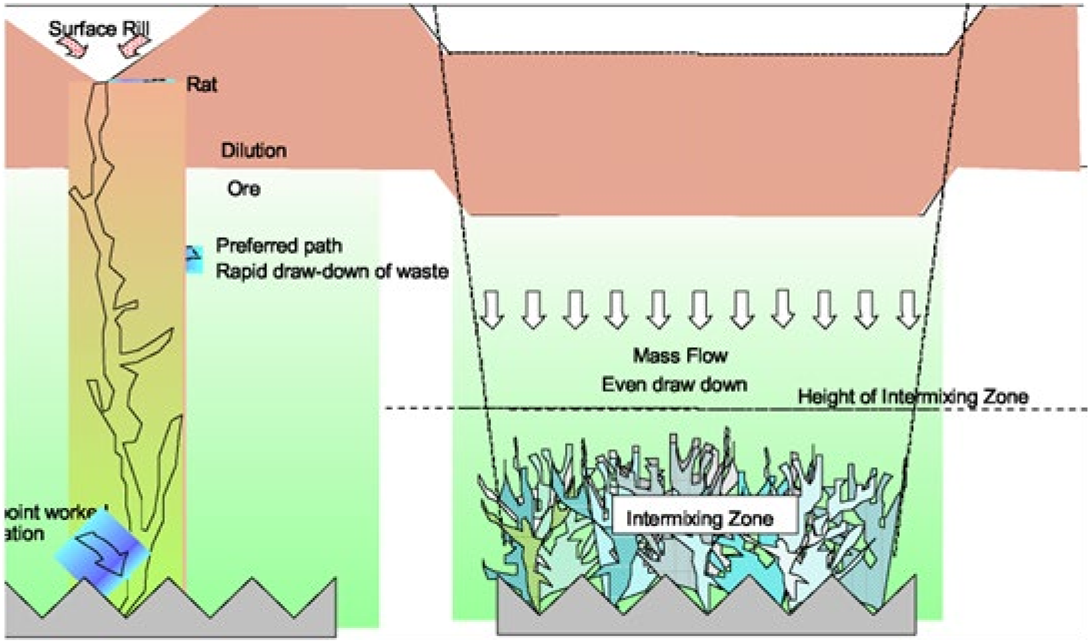


1 – Undercutting initiation | 2 – HR is reached, and cave starts propagate | 3 – Whole footprint is reached | 4 – Cave breached surface and forms crater

Jakubec

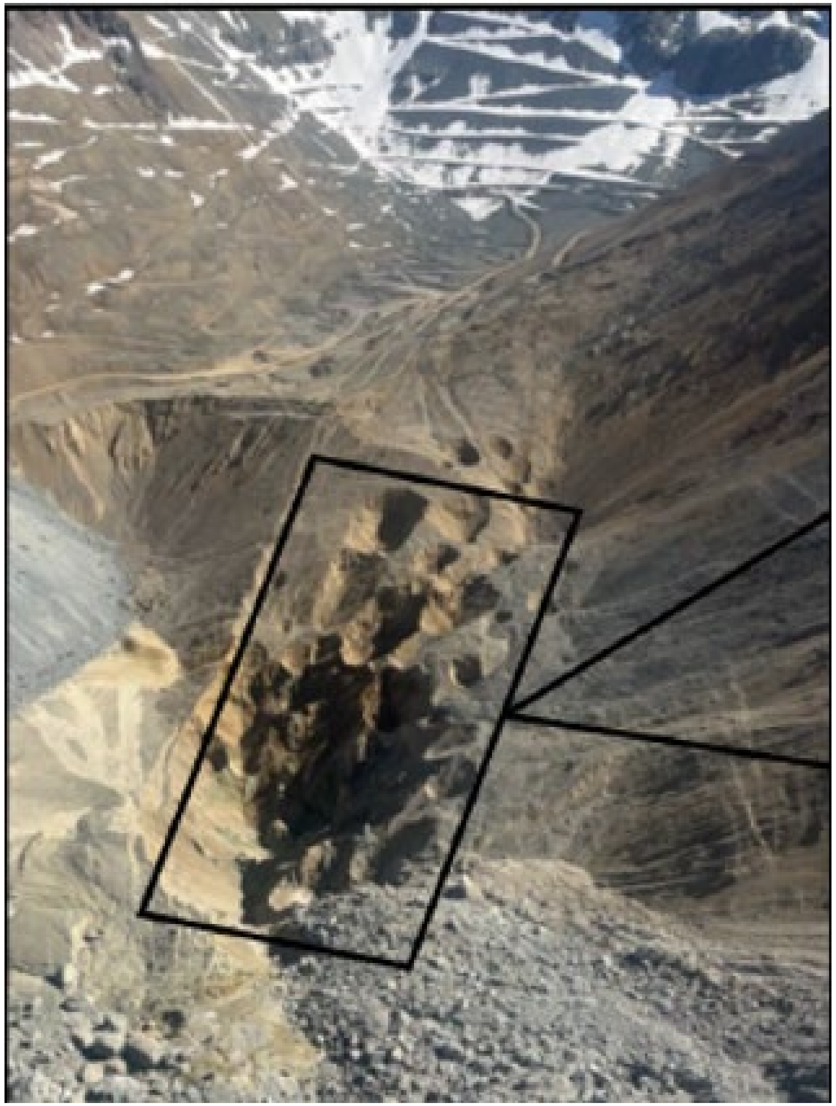
Draw control

Isolated draw **Interactive draw**



Laubscher, D H, 2000. *Block Caving Manual*. Prepared for International Caving Study. JKMRC and Itasca Consulting Group, Inc: Brisbane.

Diego Garcés a,*, Sebastián Rejas a, Joaquin Bernier a, Matías Ferrada. Reactivating mud-affected drawpoints at El Teniente mine. Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds) © 2026 Australian Centre for Geomechanics, Perth, ISBN 978-1-7636842-3-2 Caving 2026, Ulaanbaatar, Mongolia doi:10.36487/ACG_repo/2645_88



Ratholes in subsidence crater (El Teniente, Chile)

Muckpile mud rush mechanism

The moisture content of mud changes over time. It increases when it comes into contact with water and decreases through drainage and evaporation. Disturbances (draw, agitation, seismicity) enable mixing and liquefaction.

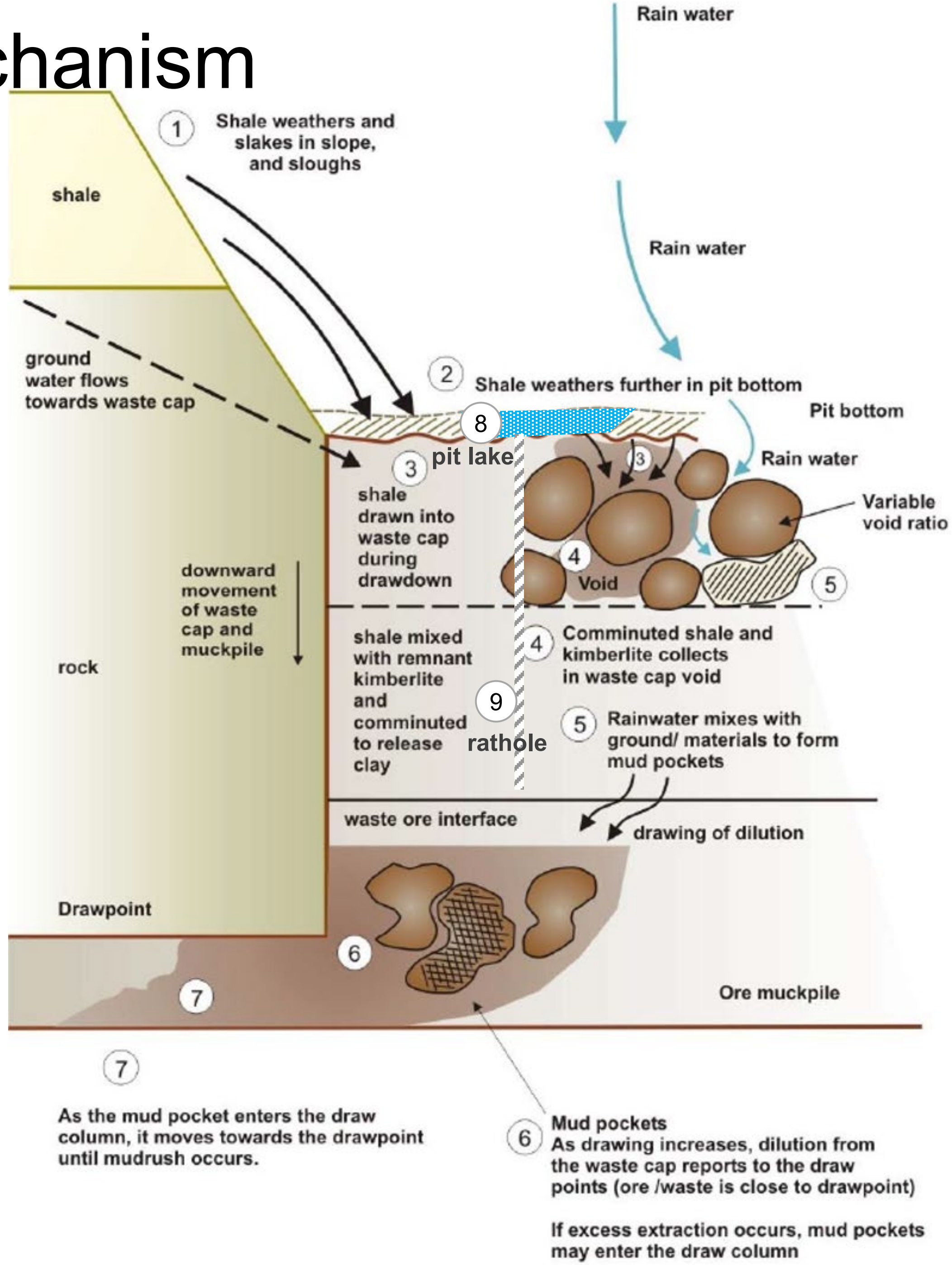
The properties also change over time.

- Aquiclude - provides a barrier and enables accumulation of water
- Arching in muck pile to create voids underneath
- Hard plastic mud which is extremely difficult to handle
- Mud push - slow plastic flow (<1m/day to walking speed)
- Mud rush - rapid flow of mud (m/s)

Based on experience at Kimberley mines

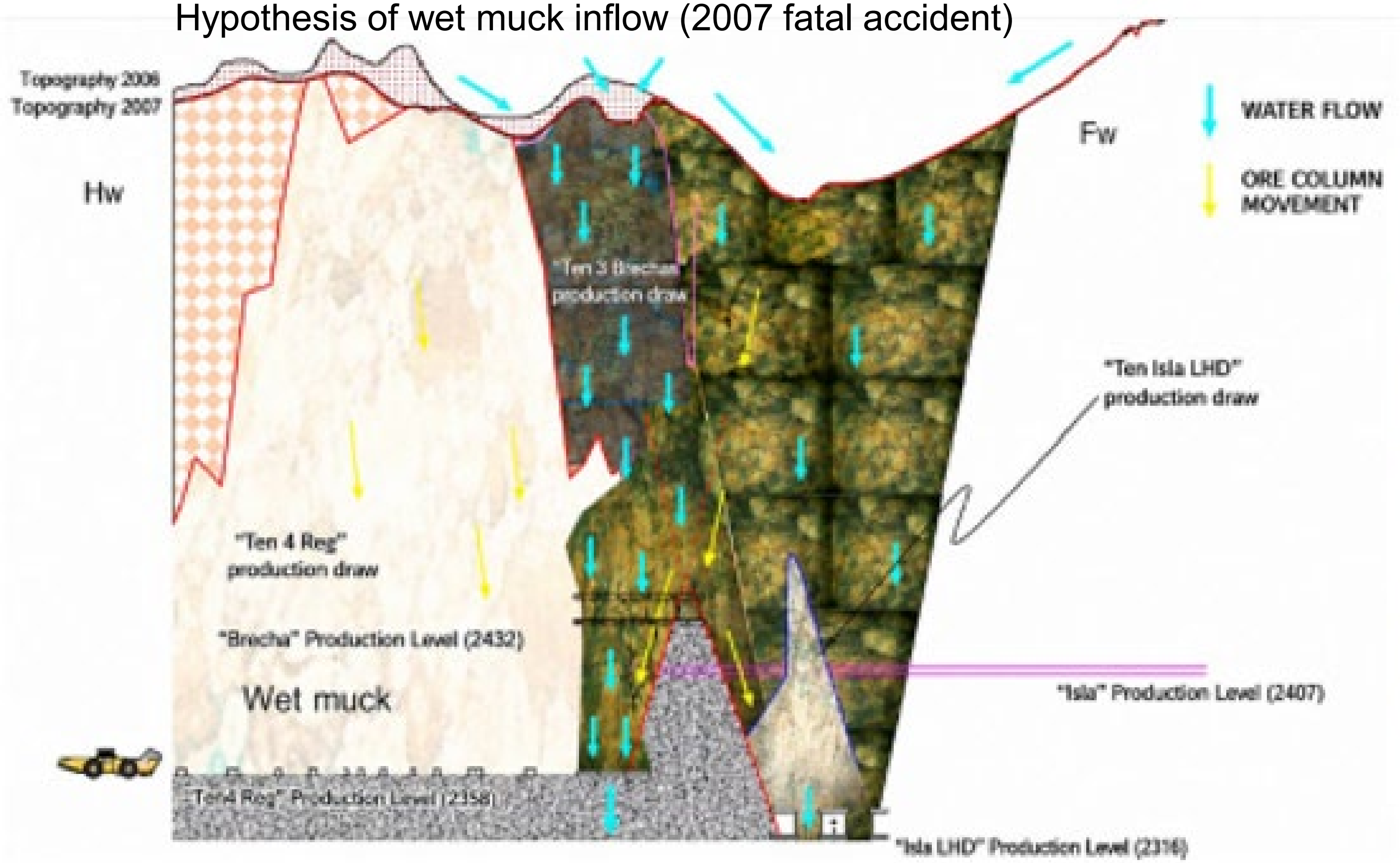
Butcher, RJ, Stacey, TR & Joughin, WC 2005, 'Mud rushes and methods of combating them', Journal of the Southern African Institute of Mining and Metallurgy, vol. 105, pp. 817–824.

Butcher, R., Joughin, W., & Stacey, T. R. (2000). Methods of combating mud rushes on diamond and base metal mines, South Africa. SRK Consulting, from a publication to The Safety in Mines Research Advisory Committee (SIMRAC).



El Teniente mud rushes (Chile)

Hypothesis of wet muck inflow (2007 fatal accident)



Surface water accumulation above cave footprint

Kenji Basaure-Matsumoto, Andrés Latorre, Patricio Miranda Evolution of wet muck inflow risk management at El Teniente: lessons learned and current practices Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds)
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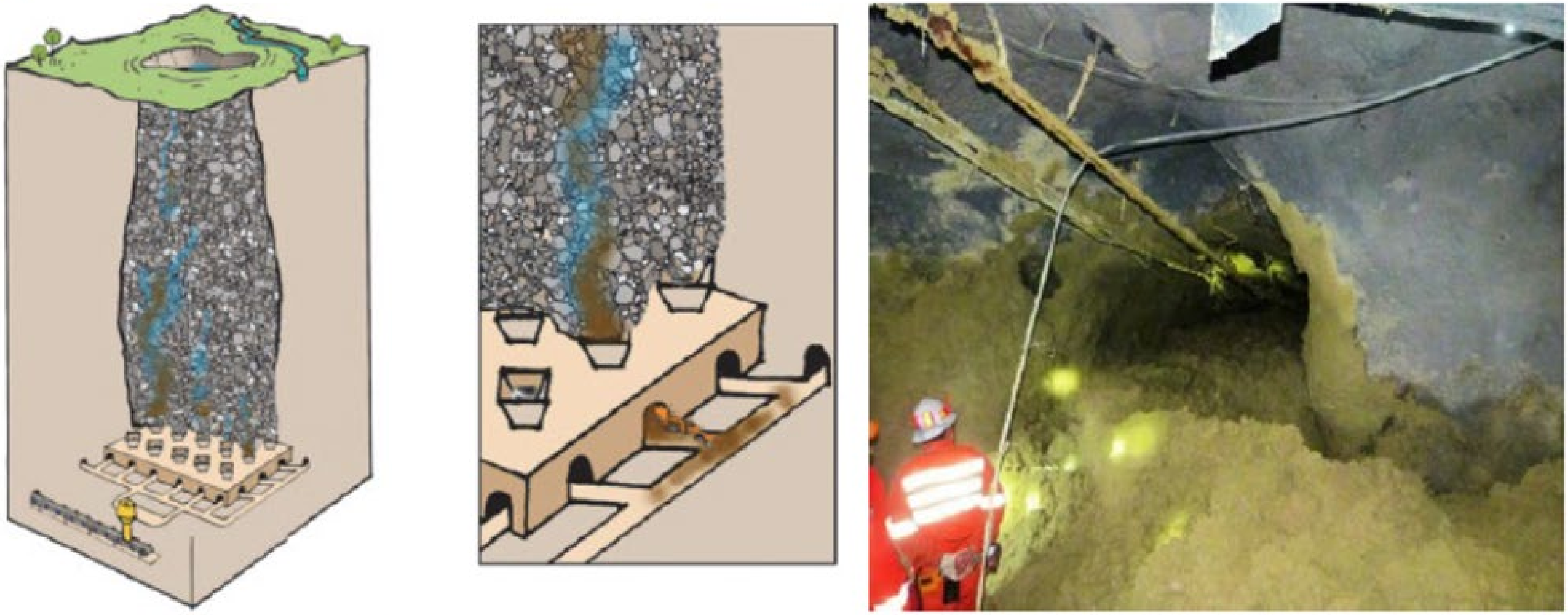
doi:10.36487/ACG_repo/2645_77

El Teniente mud rushes (Chile)

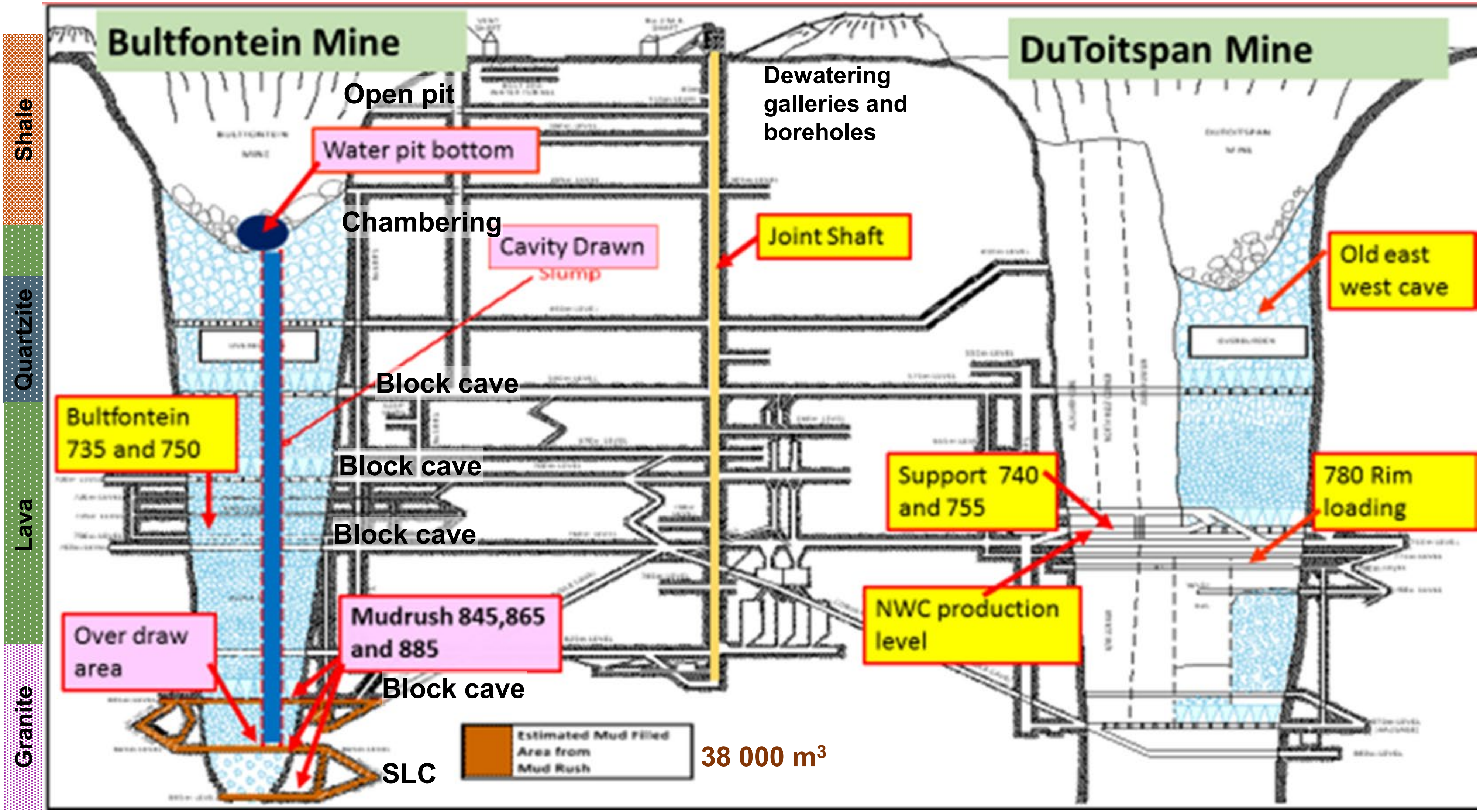


(a) (b)

Figure 1 (a) Schematic representation of water inflow into the broken ore columns and the occurrence of a mudrush (Flores-Gonzalez 2019); (b) Occurrence of a mud rush at a drawpoint in the extraction level during mine operation in El Teniente mine (Codelco 2016)

Diego Garcés a,*, Sebastián Rejas a, Joaquin Bernier a, Matías Ferrada. Reactivating mud-affected drawpoints at El Teniente mine. Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds) 2026 Australian Centre for Geomechanics, Perth, ISBN 978-1-7636842-3-2 Caving 2026, Ulaanbaatar, Mongolia 1 doi:10.36487/ACG_repo/2645_88

Bultfontein mud rush



Ross & Marsden (2024)

Bultfontein mud rush

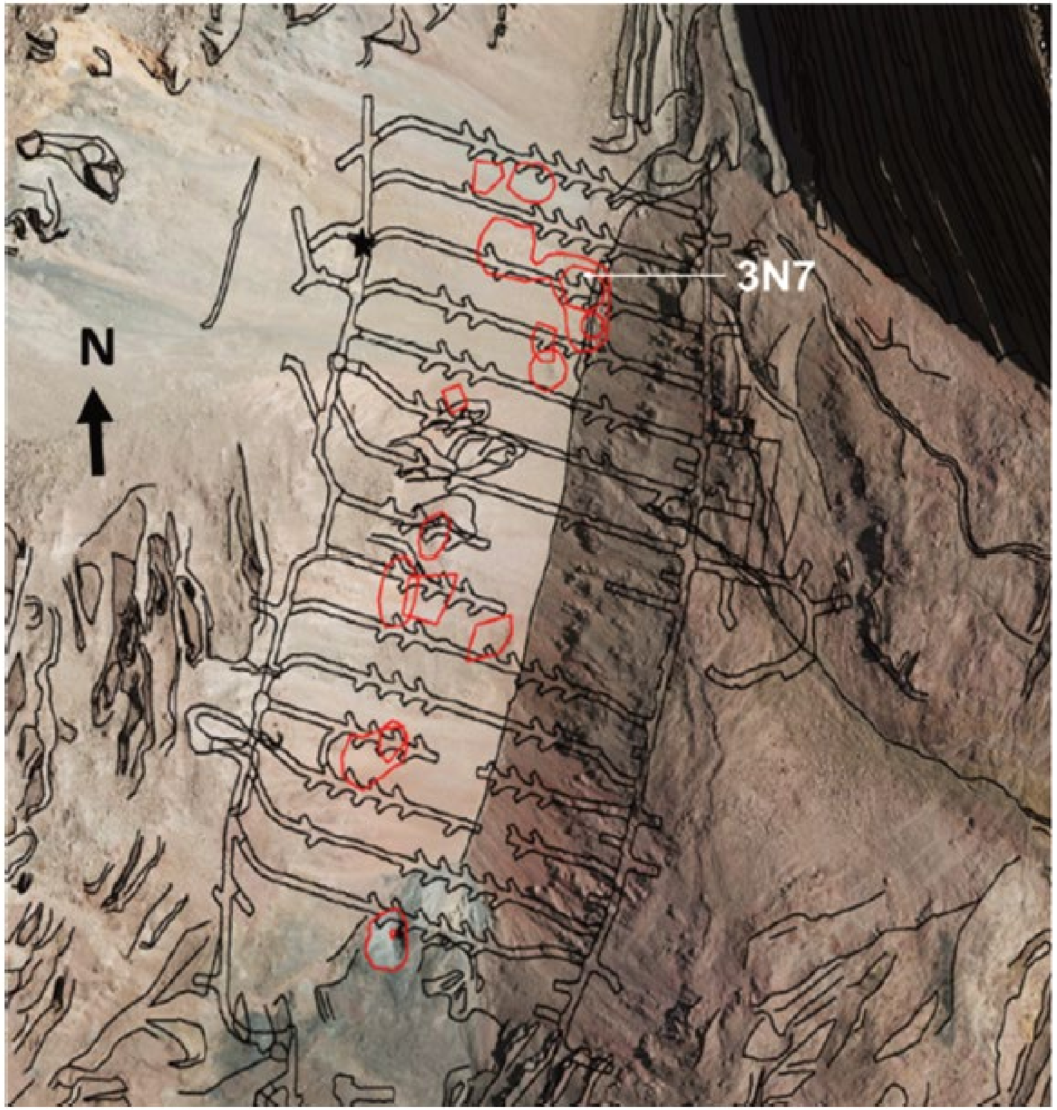
26 April 2018 Fly over

08 May 2018 – Day after event

Occam's razor – simplest explanation is usually the best one

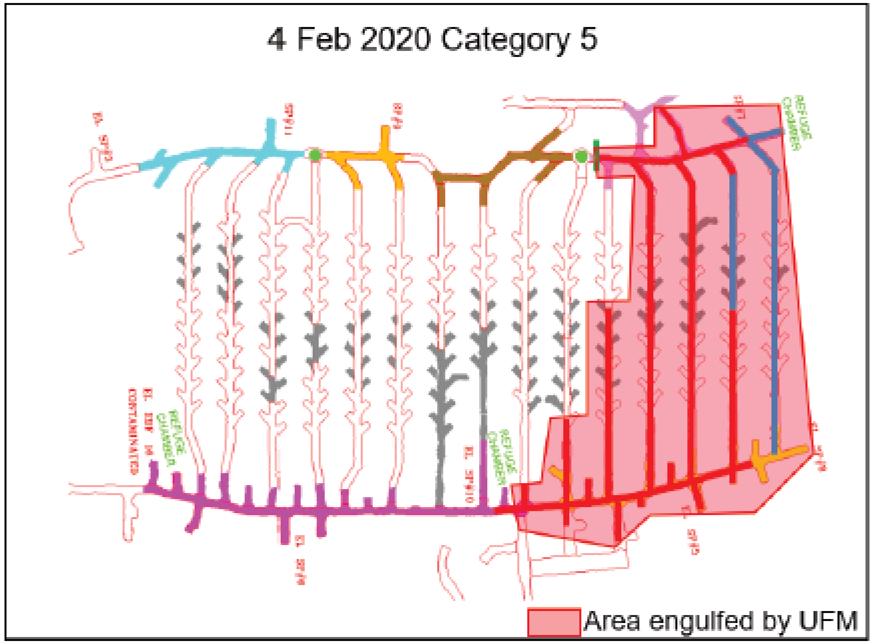
Ross, I & Marsden, H 2024, 'Analysis of a mud rush event', in D Johansson & H Schunnesson (eds), MassMin 2024: Proceedings of the 9th International Conference & Exhibition on Mass Mining, Luleå University of Technology, Luleå, pp. 1333-1345, https://doi.org/10.36487/ACG_repo/2435_O-08

Argyle mud rush

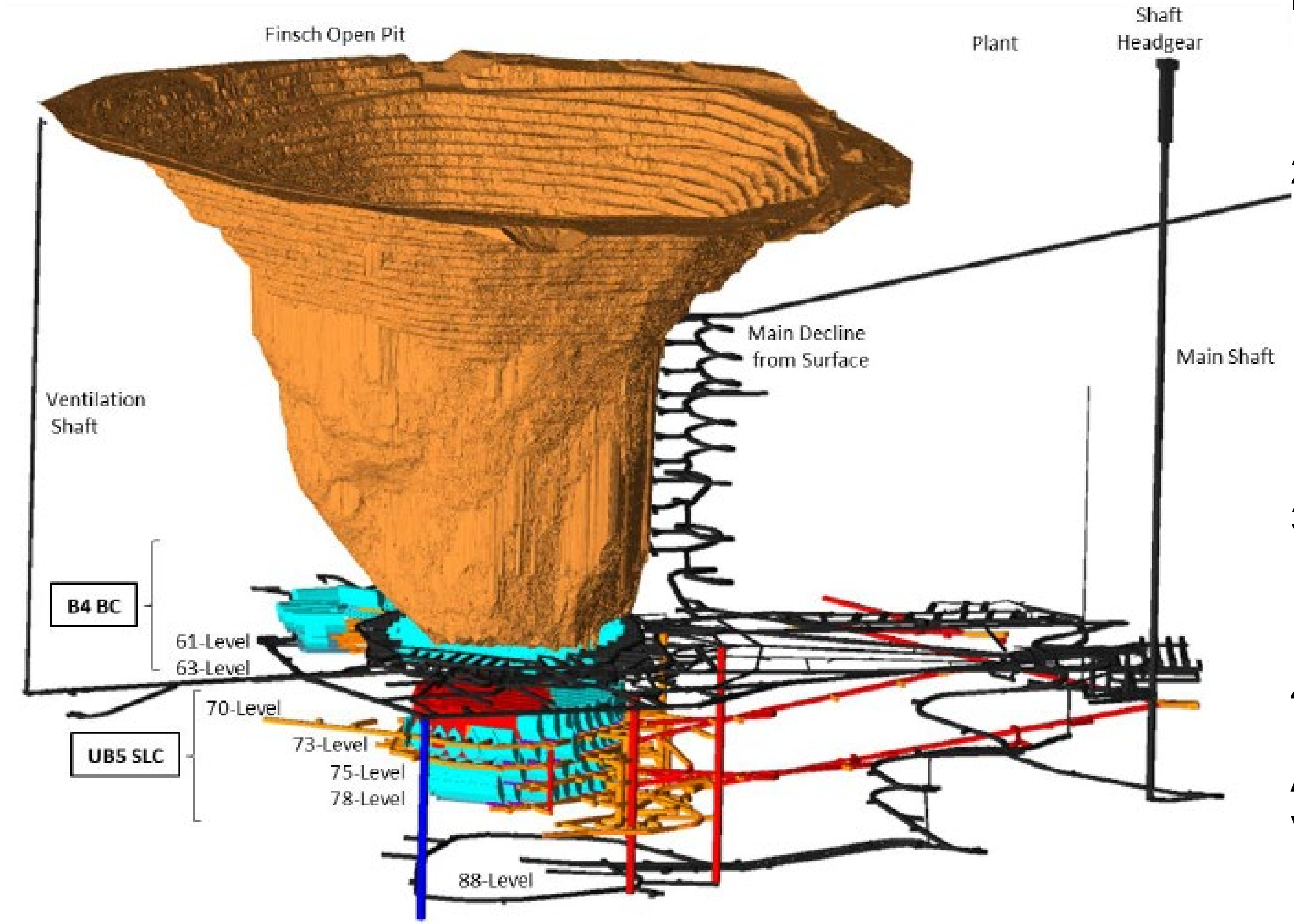


Ratholes in pit 2019

- 4 February 2020.
- 18,000 m3 (35,000 t) material from the draw points into the extraction drives
- Covered an area of more than 5,000 m^2
- The event was triggered by a significant rainfall event of 161 mm over four hours. Above the one in 100-year flood
- Sudden collapse of hang-ups in the draw points
- TARP activated four hours prior to mud rush



Finsch – Feb / Mar 2021: Flooding / water inrush



Mud rush risk assessment:

1. Waste rock non-fines generating (Banded Ironstone underlain by Dolomite).
2. Kimberlite in previous mining blocks mined to 'blue sky' i.e., no ore left behind (even 63L pillars on B4 BC production level, mined on retreat as gap filler) >> no kimberlite left to comminute in muck pile and form fines.
3. Caved kimberlite material low in fines content, relatively free draining >> no build-up of water in the muck pile.
4. No history of mud rushes!

All agree: Finsch is a mine with a very low risk of mud rushes.

Finsch – Feb / Mar 2021: Flooding / water inrush

- Early 2021 - Unseasonally high rainfall
- In-pit runoff inundated rim tunnels and production drives in the Upper Block 5 SLC, on 70 to 78 Lvl
- Cause: Inter-level drain holes too small / under-designed, clogged up, could not transfer flood water to 88 to 90 Lvl
- No injuries / fatalities – significant impact on production!

Kimberlite footwalls in production drives turned to mud!

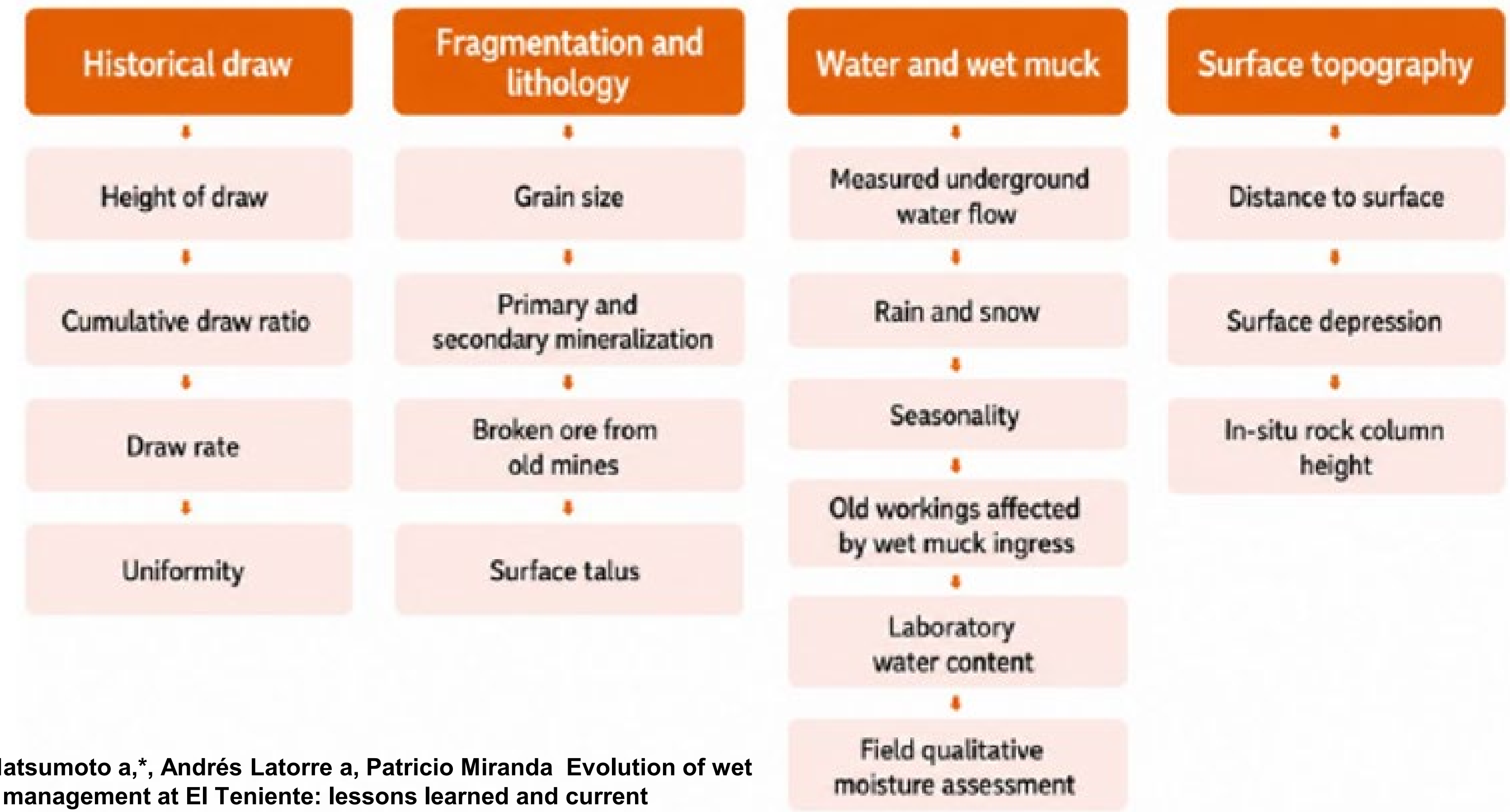
Kimberlite footwalls in production drives turned to mud!

Muddy water almost knee deep in rim tunnels (see mud marks on gum boots)

04

Potential sources of inrushes

Mudrush – contributing factors



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doi:10.36487/ACG_repo/2645_77

Potential Sources of Inrushes

On surface

- Failure, breach or overtopping of tailings storage facilities, slimes dams, FRDs and CRDs
- Breach, overtopping or emergency release from stormwater / return water dams and reservoirs
- Surface runoff and flooding of rivers, streams, lakes and pans exceeding flood controls
- Undermining of, or sinkhole formation below, any of the above

Loose surface materials

- Thick soft or loose overburden cover (e.g. 80–100 m of Kalahari sands)
- Liquefaction of waterlogged soils and highly weathered rock
- Surface materials eroded and deposited into the pit
- Avalanche, glacial lake collapse or snow-melt runoff inundating the mine

In the open pit

- Direct rainfall on the pit footprint and stormwater runoff from adjacent areas
- Groundwater seepage into the pit
- Pit lakes and pit-bottom sumps reliant on dewatering infrastructure
- Coarse / fine tailings deposition and backfill fines placed in the pit
- Erosion of non-durable highwall material and highwall failure / breakback

Muck column, muck pile and stopes

- Water and mud ingress from surface runoff, the open pit or connected old workings
- Groundwater seepage
- Weathering of non-durable materials in the muck column
- Fines generated by comminution of caved material, ore and waste

Undercut, production and development levels

- Ingress via draw points, orebody and geological contacts, faults and shears
- Ingress via old workings, declines, travelling ways, ore passes and shafts
- Excavations intersecting water-bearing fissures; inadequate fissure grouting
- Rapid unravelling of wide shears and sheared contacts; liquefaction of saturated cave material

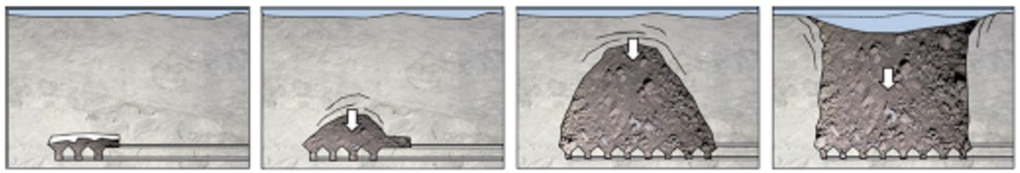
Underground workings and other triggers

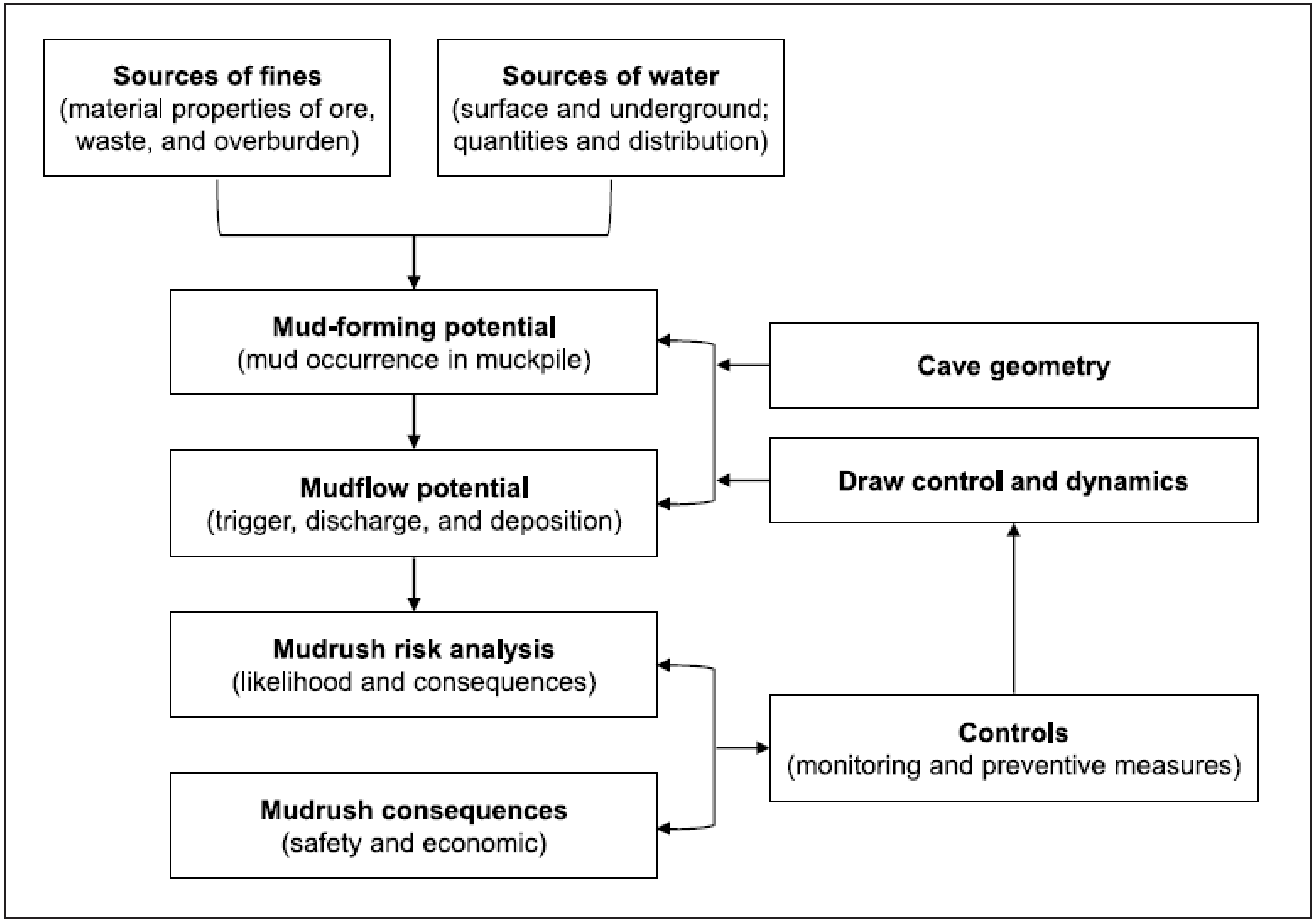
- Crown pillar, plug, bulkhead, ventilation wall and backfill barricade failures
- Breach into abandoned flooded workings; piping failure through erodible or soluble rock
- Inrush when opening blocked ore passes or clearing silo / bin hang-ups
- Pathways to surface: shafts, portals, cracks, sinkholes and the zone of subsidence
- Dewatering pump, pipeline or power failure; off-plan mining into water or mud

05

Risk Assessment and Management

Mudrush Risk Evaluation





Jakubec, J., Clayton, R. Guest, A. 2016. Mudrush risk evaluation. CIM Journal | Vol. 7, no. 1.

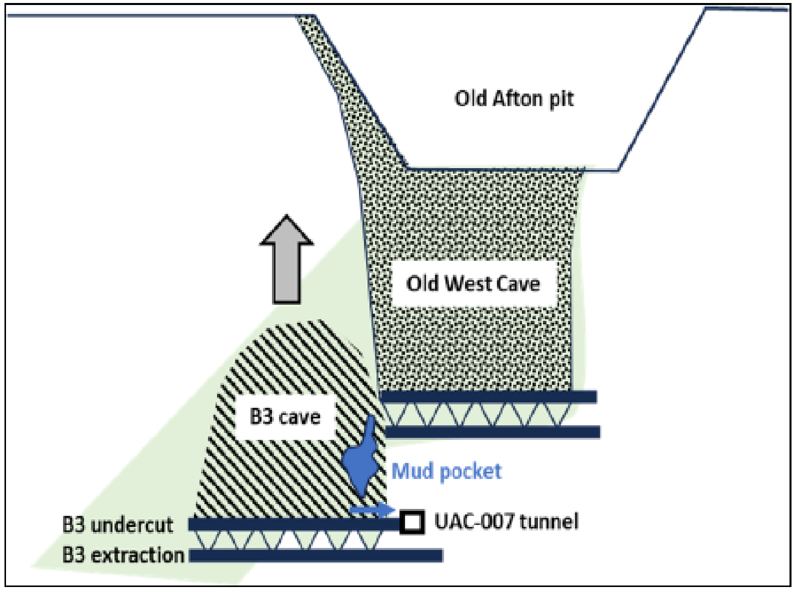
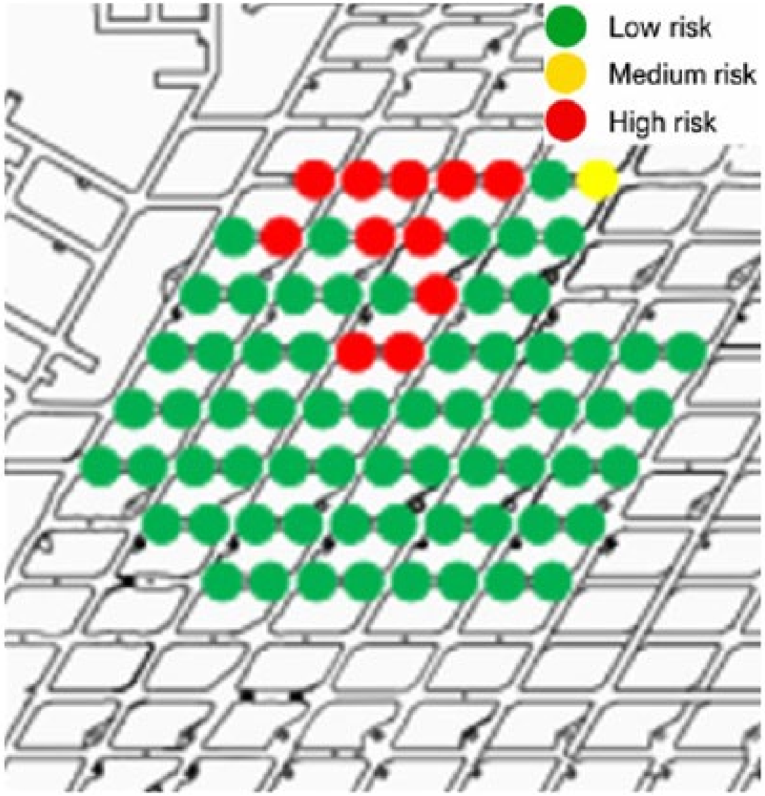
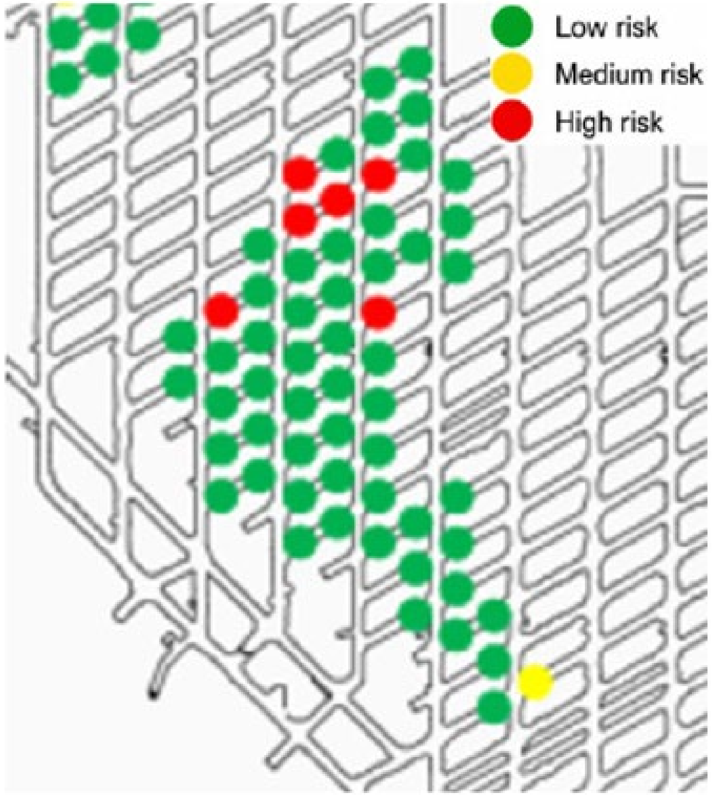


Figure 1 Schematic section through the New Afton Mine.

Thomas. A., Joughin. W. and Jakubec.J. Inrush and air blast barricades for caving mines. MassMin 2024

Draw point risk ratings





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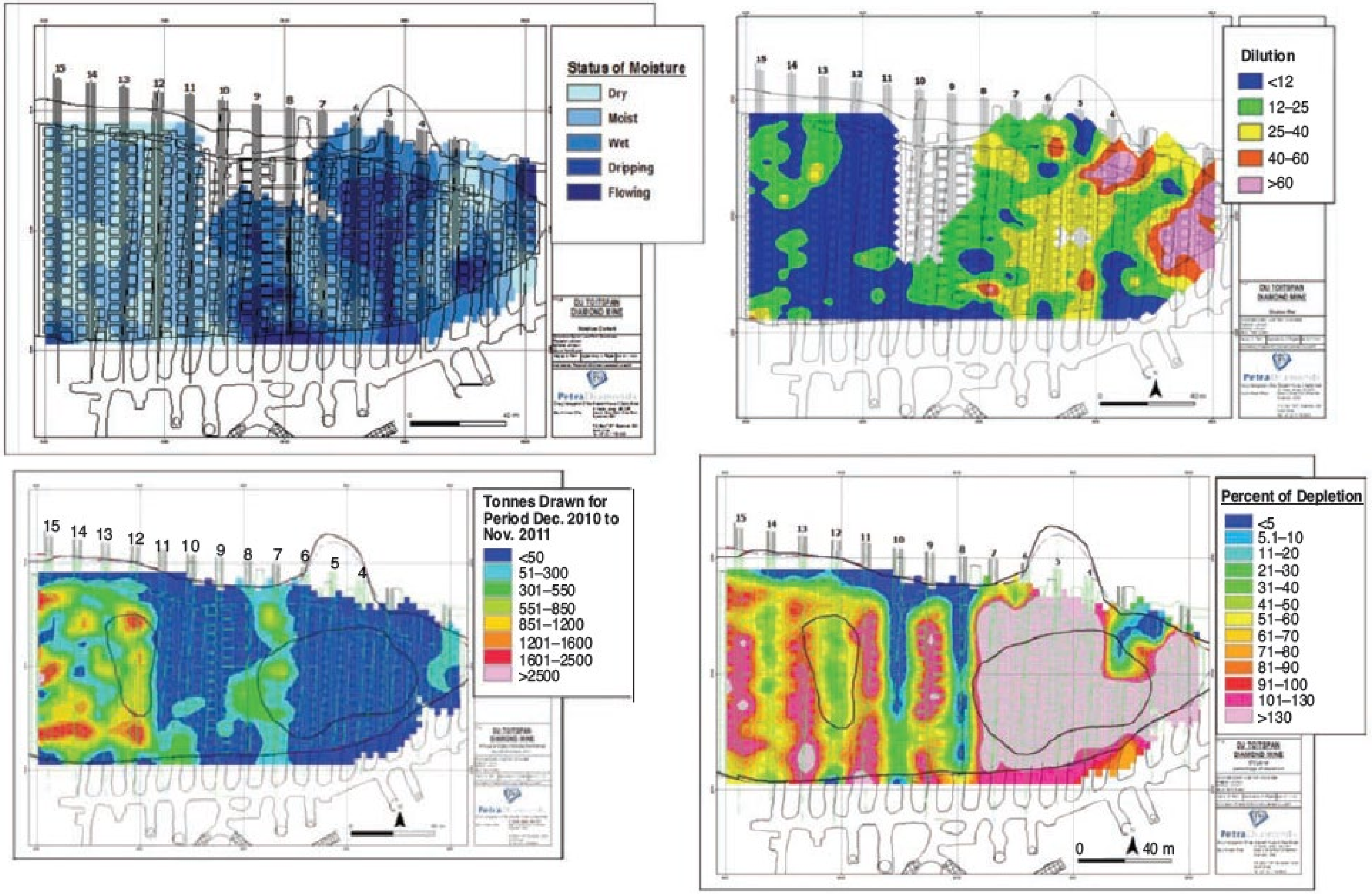
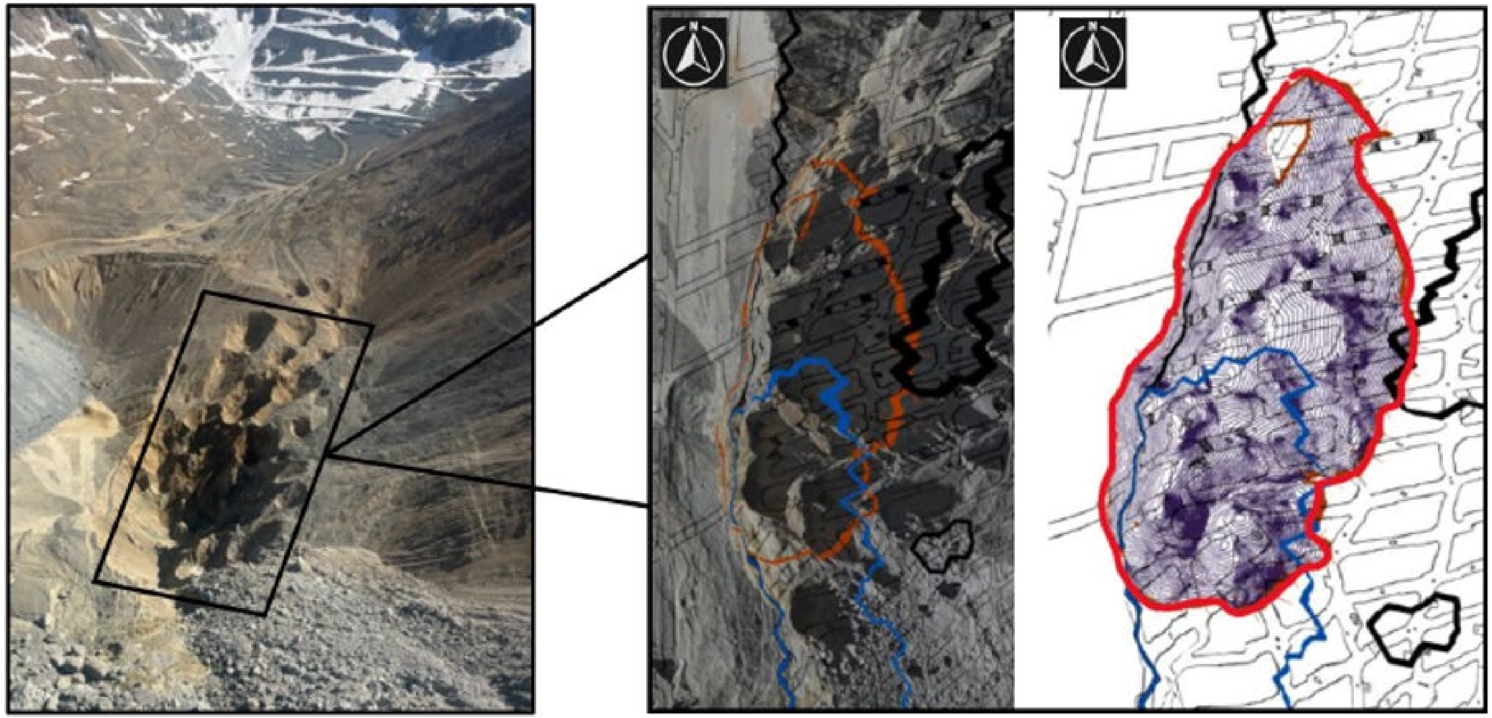
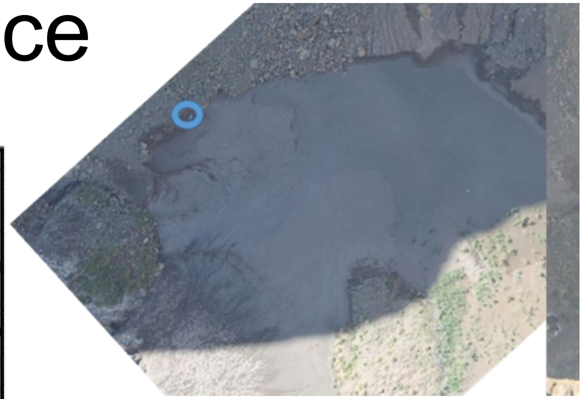
Draw point risk ratings – draw point data



A. Holder, A.J. Rogers, P.J. Bartlett, and G.J. Keyter 2013. Review of mud rush mitigation on Kimberley's old scraper drift block caves. The Journal of The Southern African Institute of Mining and Metallurgy Vol 113no.7

Draw point risk rating – surface influence





- Rainfall
- Groundwater
- Dewatering/storm water management
- Mud & mud forming materials
- Topography
- What else?

Diego Garcés a,*, Sebastián Rejas a, Joaquin Bernier a, Matías Ferrada. Reactivating mud-affected drawpoints at El Teniente mine. Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds) © 2026 Australian Centre for Geomechanics, Perth, ISBN 978-1-7636842-3-2 Caving 2026, Ulaanbaatar, Mongolia 1 doi:10.36487/ACG_repo/2645_88

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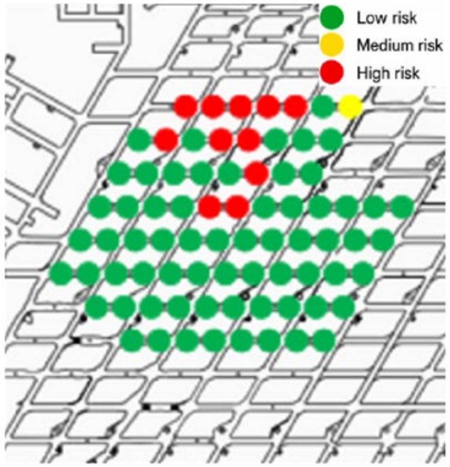
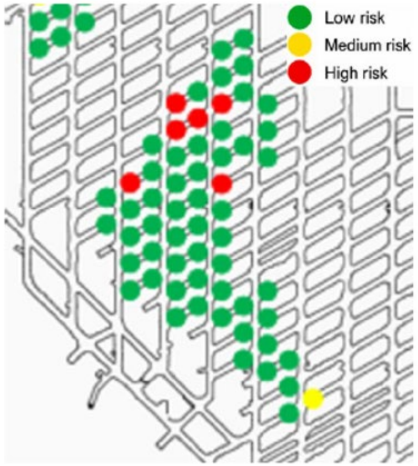
Draw point risk ratings - misinterpretation

Uncertainty

- Composition of muckpile
  - Coarse rocks
  - Mud
  - Silts & clays
  - Water
  - Arching
  - Historical ratholes (not visible on surface, draw history?)
- External
  - Climate change and extreme events
    - Tropical storms
    - Mud slides
- Time to move through muck pile

Lack of belief in rating system





Confusion matrix

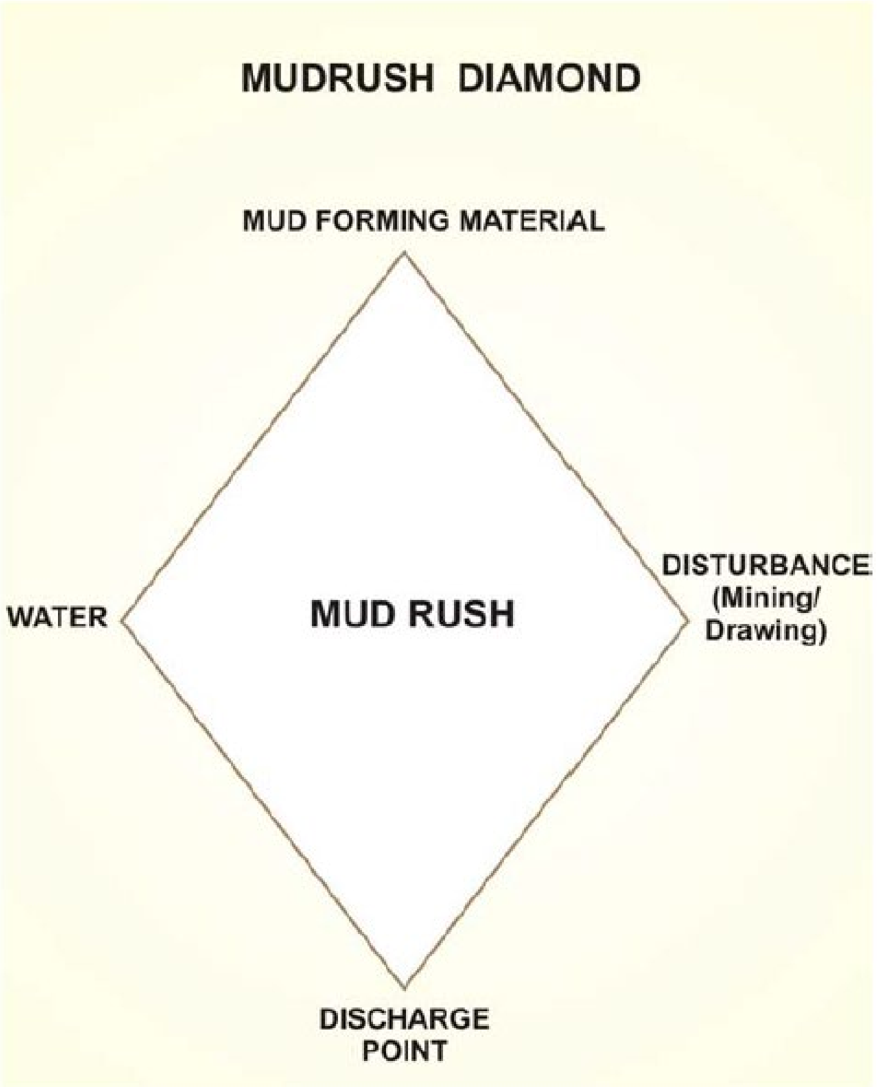
	Pred. Yes	Pred. No
Actual Yes	TP	FN
Actual No	FP	TN

Time between warning and event?

06

Monitoring & Controls

Mud rush diamond



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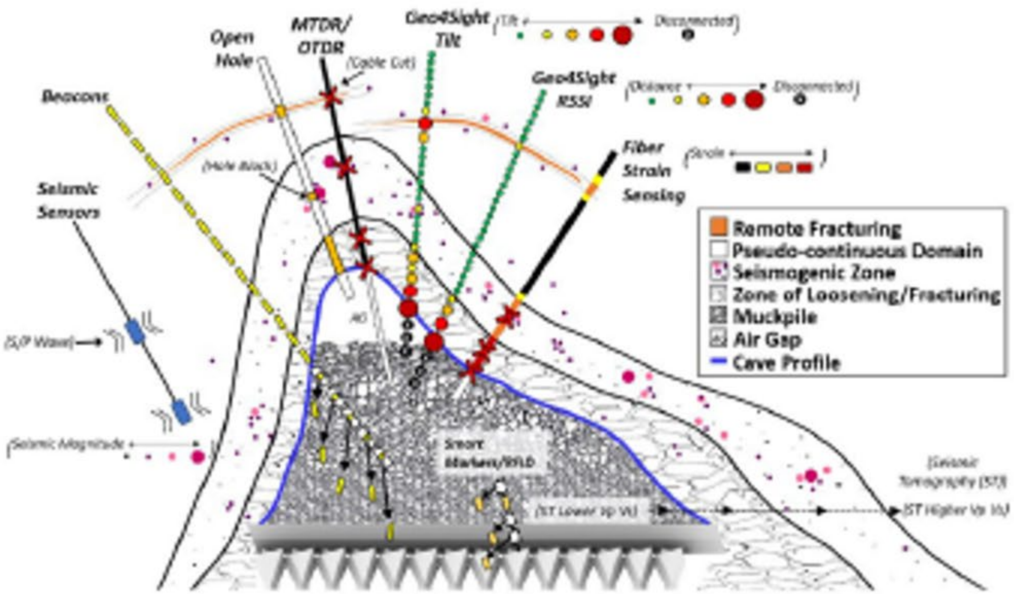
Monitoring - complexity

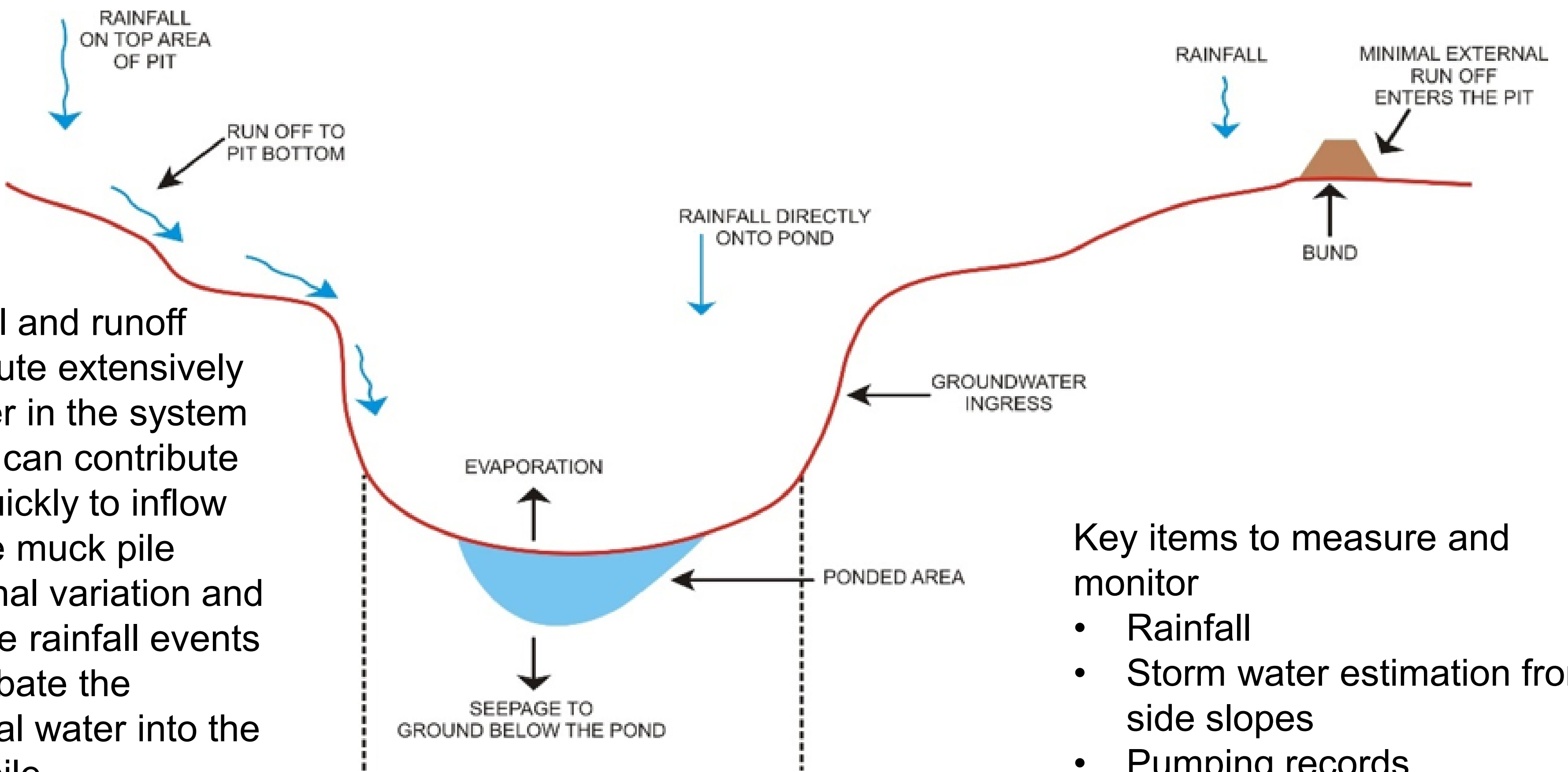


(Kamp et al., 2024)

Monsalve, J, Vanegas, C, Lemas-Pesqueira, C, Hilt, G, Ferguson, S & Shea, N 2026, 'Integrating multi-source data through a geomechanical digital twin: advancing risk management in cave mining', in A van As, D Cumming-Potvin & J Wesseloo (eds), *Caving 2026: Proceedings of the Sixth International Conference on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 1-16, https://doi.org/10.36487/ACG_repo/2645_12

Each monitoring device only tells you one part of the story

Water monitoring and management



- Rainfall and runoff contribute extensively to water in the system
- Runoff can contribute very quickly to inflow into the muck pile
- Seasonal variation and extreme rainfall events exacerbate the potential water into the muck pile
- Runoff from the sides will collect silt in large amounts

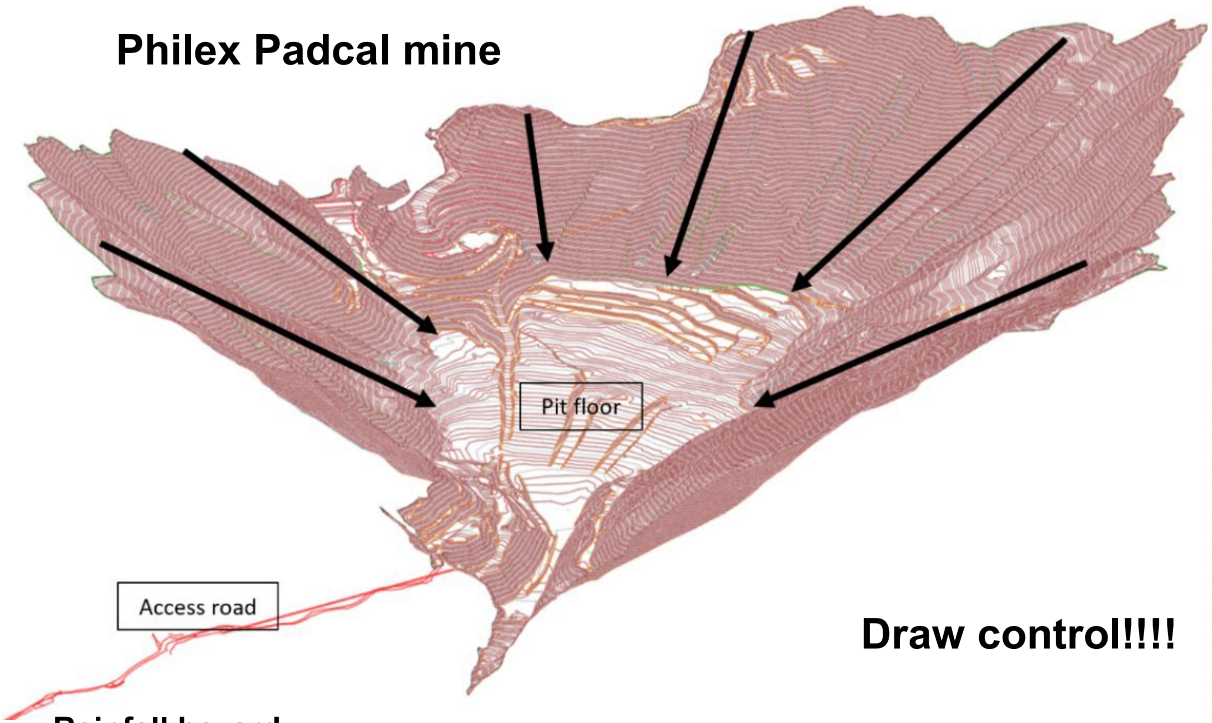
Key items to measure and monitor

- Rainfall
- Storm water estimation from side slopes
- Pumping records
- Flow meters
- Muck pile characteristics

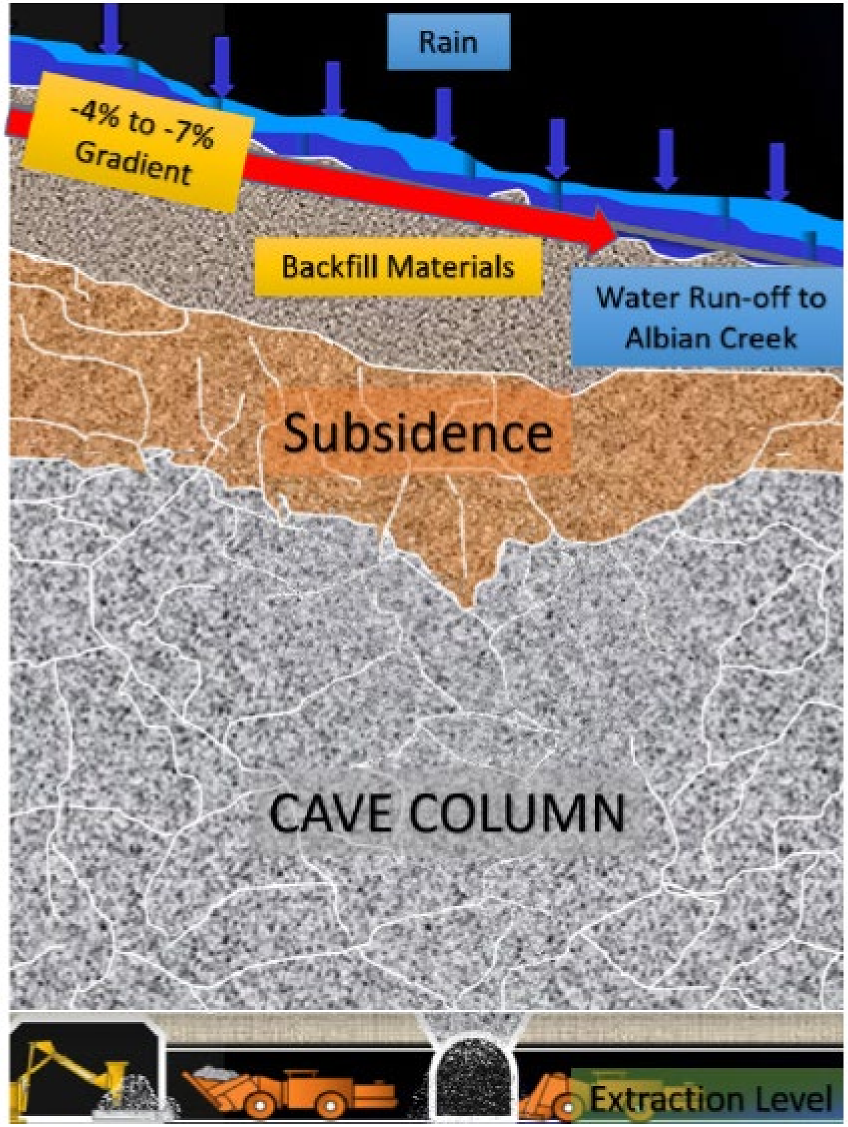
Some management measures just don't work

Backfilling of crater/pit

Philex Padcal mine



Draw control!!!!



Rainfall hazard

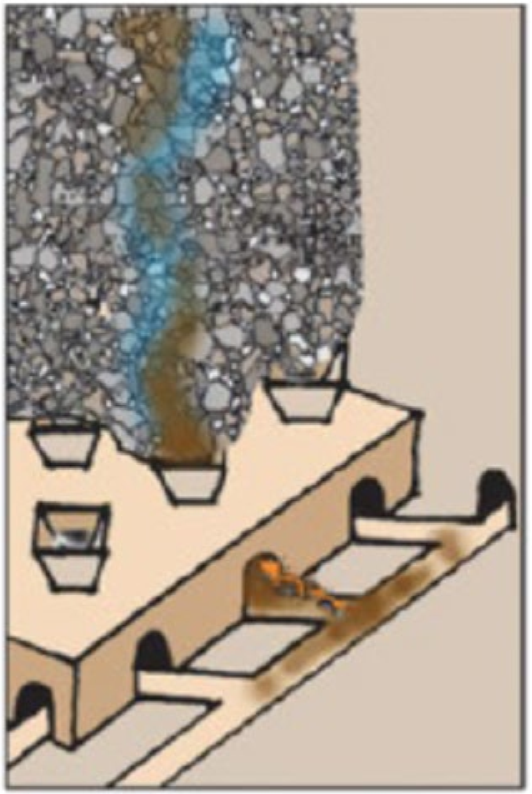
- 20 typhoons per year originating from the Pacific typhoon belt.
- Annual precipitation routinely exceeding 3,000–4,000 mm

Management

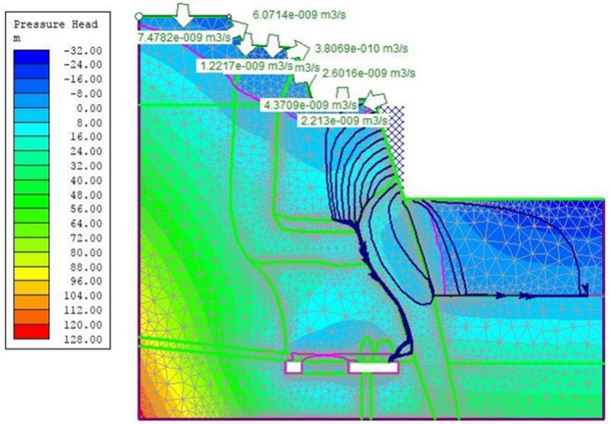
- Strategic infill of the subsidence zone effectively extends the lag time of inflow events and reduces their peak severity.
- Spreading and compaction of backfill
- Prevented catastrophic mud rush events experienced in the mine's earlier history.

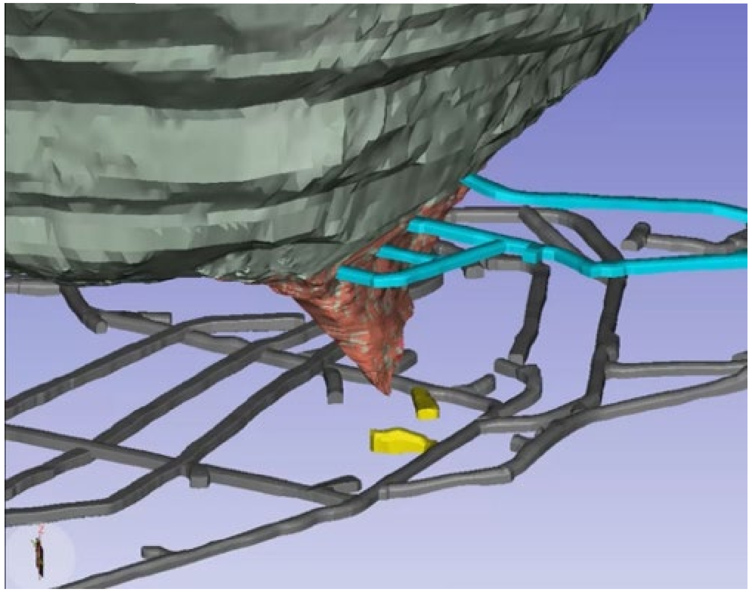
Monis, JA 2026, 'Subsidence backfilling operation of Padcal: A unique case in block caving ', in A van As, D Cumming-Potvin & J Wesseloo (eds), *Caving 2026: Proceedings of the Sixth International Conference on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 1-15, https://doi.org/10.36487/ACG_repo/2645_59

Discharge points



Draw points
(draw and collapse of
hang ups)



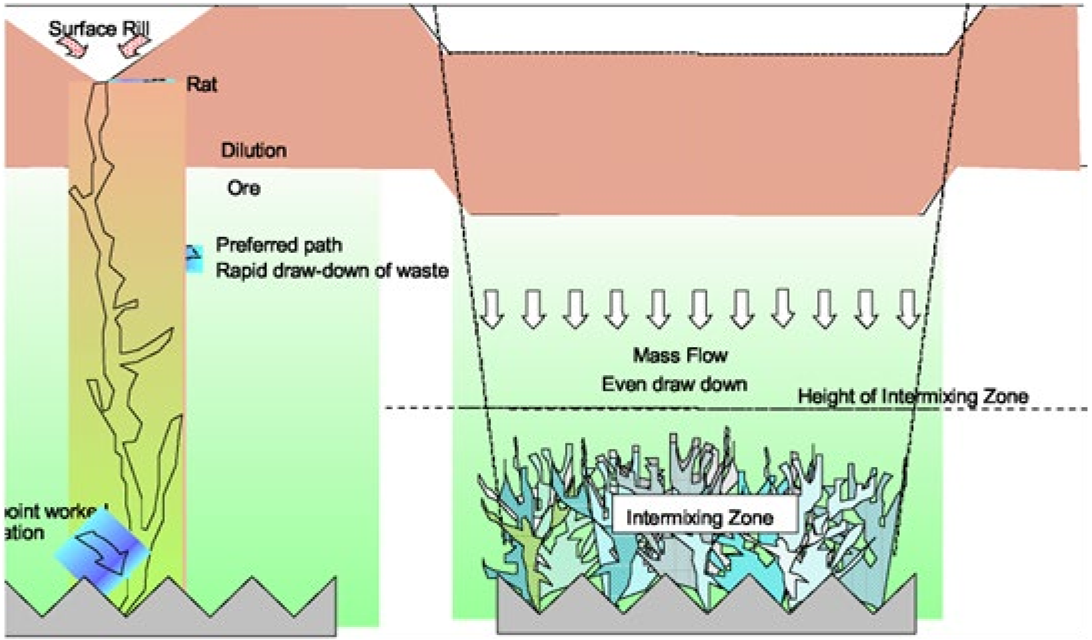


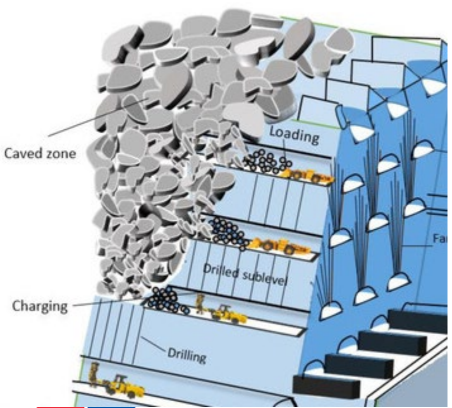
Erosion piping
Chimney failures

Failed backfill bulkheads

Draw control

Isolated draw **Interactive draw**



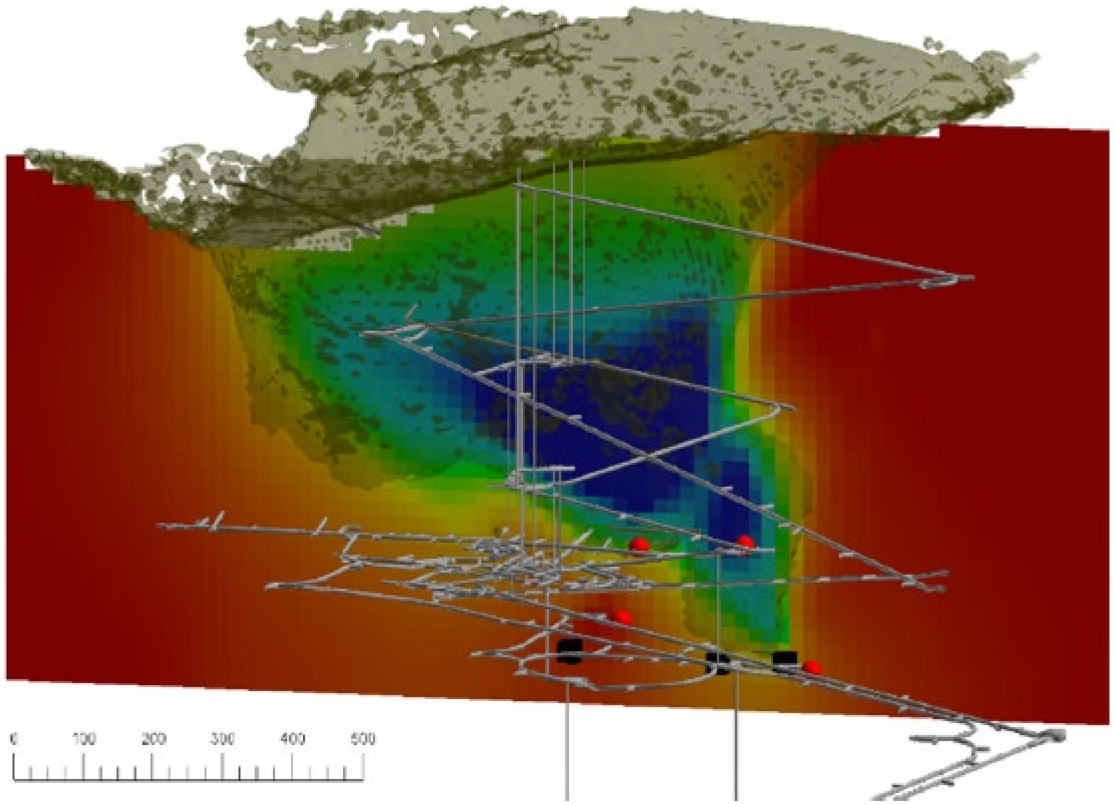


Sub Level Cave

Factors influencing draw control

- High production targets
- Block Cave
  - Easiest drawpoints pulled most
  - Drawpoint damage/wear and repairs
  - Hang ups
  - Slusher block caves require opening and closing of drawpoints
  - Poor controls
- Sub Level Cave
  - Draw up to sub level height per ring
  - Ore blanket between waste and draw point (plan <100% of ring)?
  - No flexibility due to retreat mining
  - Rim loading?
- Planning and controls
  - Detailed production and risk based planning
  - Tracking of tonnage from each drawpoint (automated?)
  - Contingency plans when things go wrong

Monitoring - Muon tomography – the future?

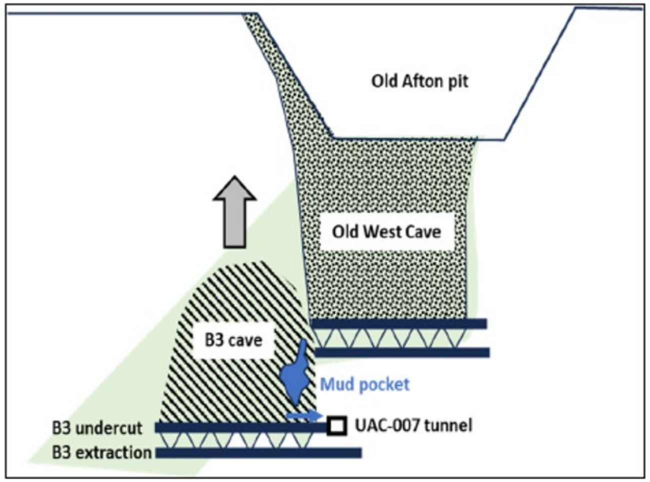


Schouten, D, Phillips, N & Merrill, R 2024, 'Cosmic-ray muon tomography', in D Johansson & H Schunnesson (eds), *MassMin 2024: Proceedings of the 9th International Conference & Exhibition on Mass Mining*, Luleå University of Technology, Luleå, pp. 1576-1583, https://doi.org/10.36487/ACG_repo/2435_R-05

Water retaining plugs and mud rush barricades

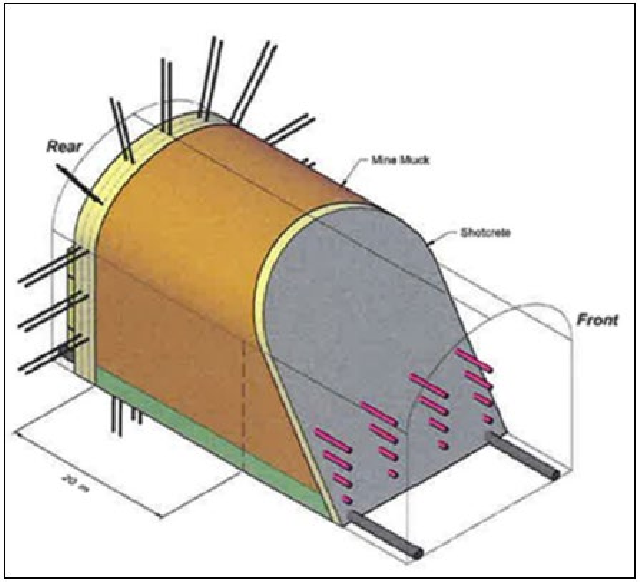
Debris flow barrier

Thomas. A., Joughin. W. and Jakubec.J. Inrush and air blast barricades for caving mines. MassMin 2024



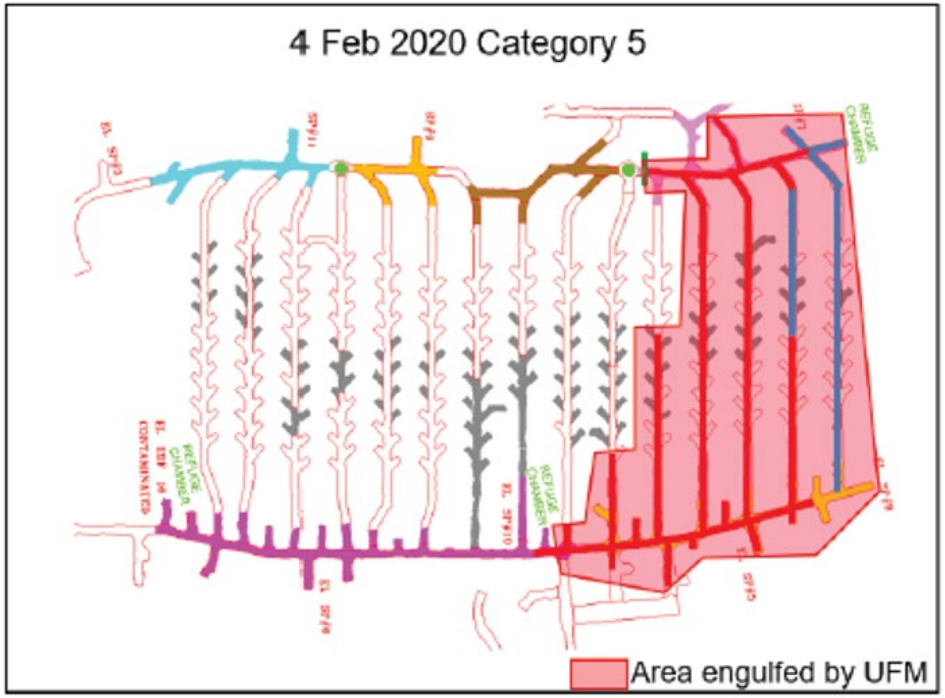
Strategic placement of controls

Concrete water retaining plugs



Mud rush barricade

Exposure management



Affected area and exclusion zones

- Depends on volume of mud and flow rate (run-out distance)
  - Run out distance from a single draw point (relatively small volumes)
  - Large inrushes may affect a large portion of the footprint
  - Extreme events fill entire level or multiple levels
- Remote equipment
  - LHD (draw is highest risk)√
  - Drilling, charging, other activities?
  - Inspections (drones)?
- Timing
  - Warning of increased risk of occurrence√
  - Warning time to event?

07

Way Forward

Way Forward

Development of an International Guideline

- Establishment of an international committee
  - Mining companies
  - Consultants
  - Academics
  - Regulatory authorities
- Collation of best practice
- Uncertainties
  - Research
  - Management of uncertainty and decisions
  - Identification of extreme events and management thereof
- Risk management and decision making

MINERALS COUNCIL
SOUTH AFRICA

Mining Regulation Advisory Committee (MRAC)

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | The University of Western Australia | Joint Venture

Thank You

Presented by:

William Joughin

Gerhard Keyter

srk consulting