MINEFILL SERVICES

State of Industry Practices in Mine Backfilling

Expert Witness Testimony

by

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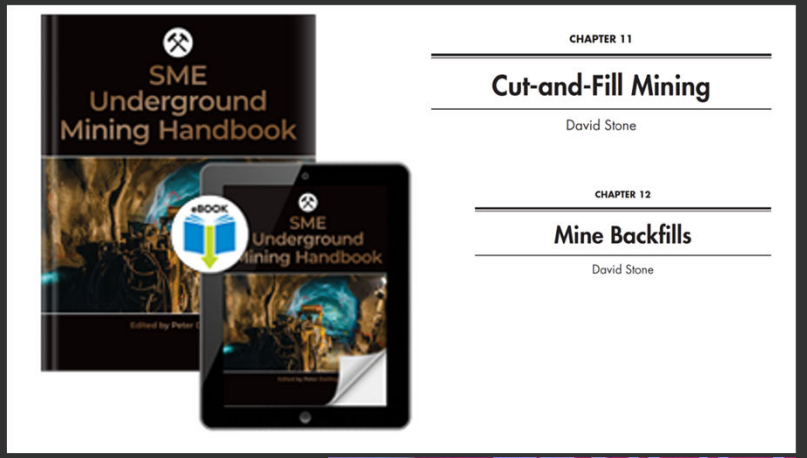
Dr David Stone – Backfill Expertise

- Graduate of Queens University in Canada, 1985. PhD dissertation in mine backfills
- 40 years consulting expertise to the metal mining industry
- Author of two chapters in 2023 publication of SME Underground Mining Handbook
- Frequent author, presenter and keynote speaker at mine backfill and tailings workshops
- Chairman of 2001 and 2019 Minefill Conferences



Agenda

- What is Mine Backfilling
- An Overview of Underground Mining
- The Role of Backfills in Underground Mines
- Design Considerations
- Closing Comments

What is Mine Backfillng

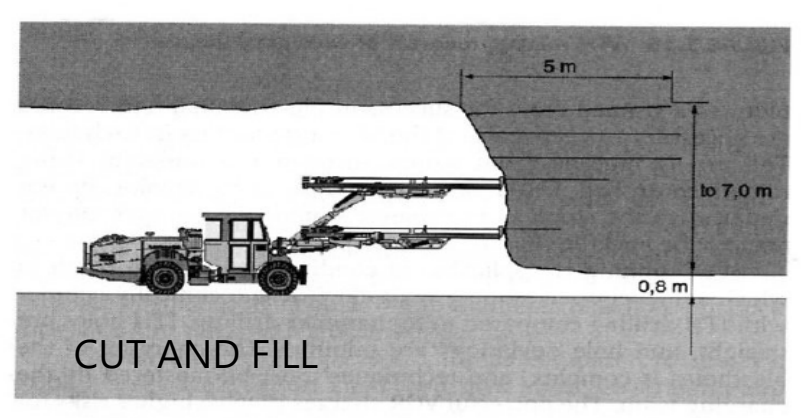
- Mine backfilling is an essential element of most modern underground metal mines.
  - Maximize resource extraction – removal of pillars
  - Improved safety for miners and equipment
  - Allows mining in weak and unstable rock masses
  - Underground disposal of mine wastes (rock or tailings) is now mandated by most stakeholders

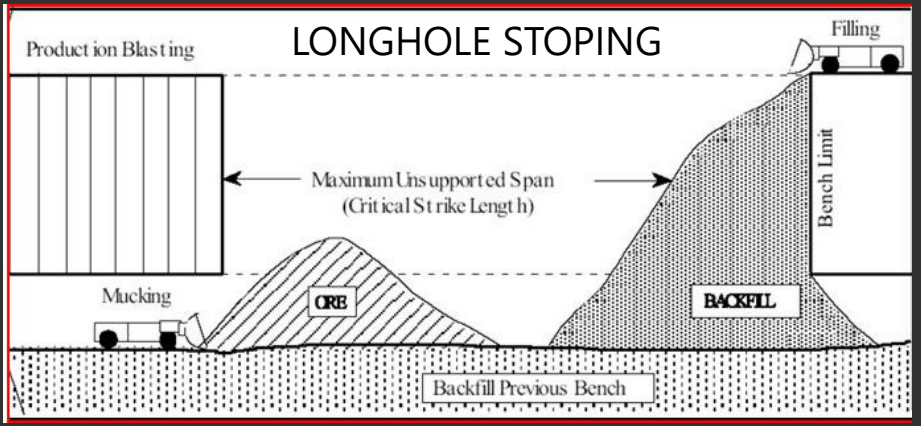
Underground Mining Methods

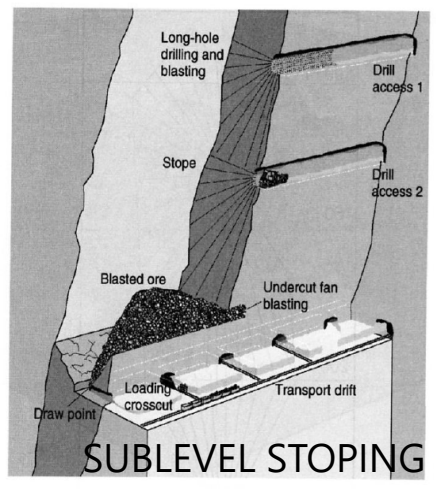
- Underground mining methods can be broken down into 3 categories:
  - Self-supported methods – e.g. room and pillar
  - Artificially supported methods – e.g. cut and fill mines – backfilled mines
  - Caving methods – e.g. block caving, sublevel caving

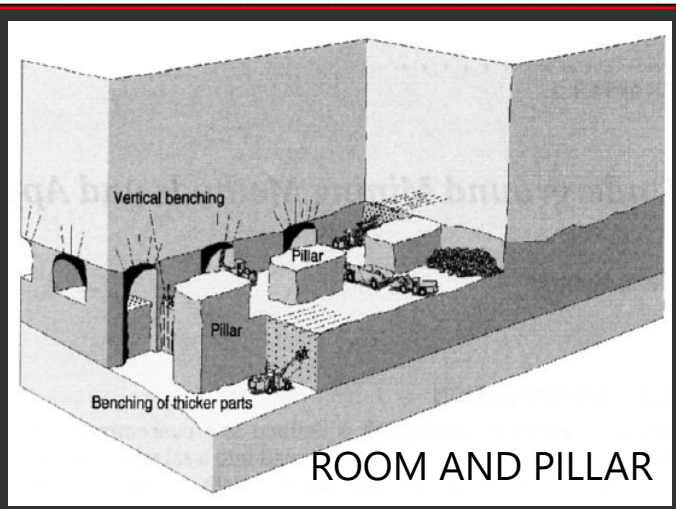
- Mines that rely on Backfilling
  - Cut and Fill (CAF)
  - Drift and Fill (DAF)
  - Longhole Open Stoping (LHOS)
  - Sublevel Open Stoping (SLOS)
  - Blasthole Open Stoping (BHOS)
  - AVOCA or Bench Stoping

Types of Underground Mines



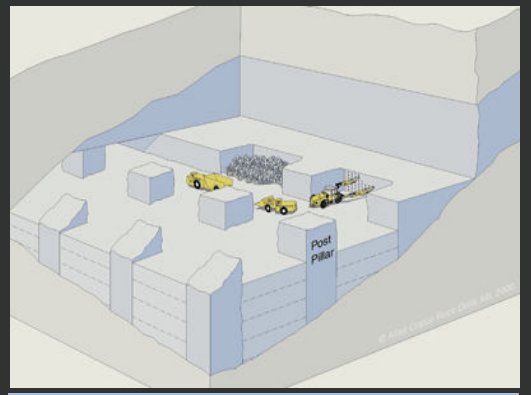


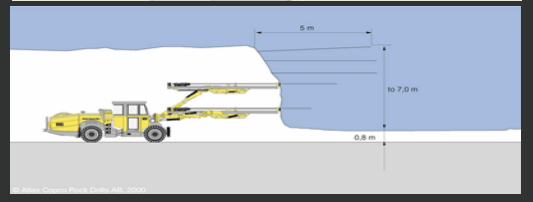




Role of Mine Backfills - Backfilling of Voids

- In many instances backfill is simply used for filling voids, e.g. room and pillar mining without pillar recovery, overhand cut and fill mining
- Reduce size of surface impoundments
- Control surface subsidence
- Easier project permitting
- Lower water treatment costs
- Reduced closure costs and liabilities
- Can selectively place high sulfur or acid tailings underground
- Fill generally does not carry much load – only provides a working floor





Role of Mine Backfills - Fill for Pillar Recovery

- Most mines use backfill for increased ore recovery
- Works best in primary stopes in open stoping operations (e.g. large blasthole stopes, longhole, vertical crater retreat, sub-level stoping etc)
- Cement must be added to provide stable vertical faces during exposure of fills
- Uncemented fills in secondaries unless plan to undercut
- Typical strengths > 0.5 MPa
- Can encompass all types of fills: rockfills, paste and hydraulic fills
- Fills generally not designed to carry external loads (other than self-weight)

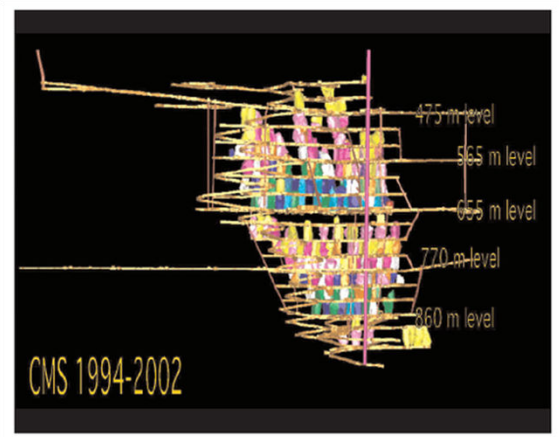
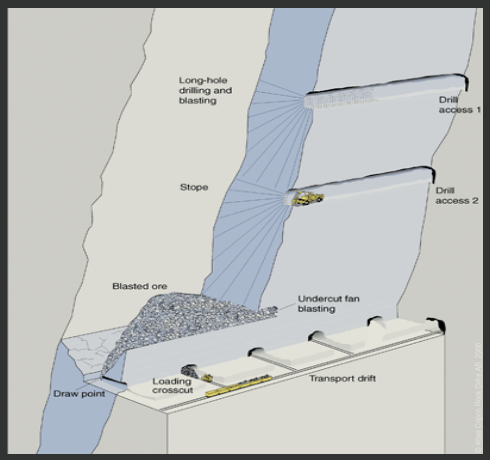
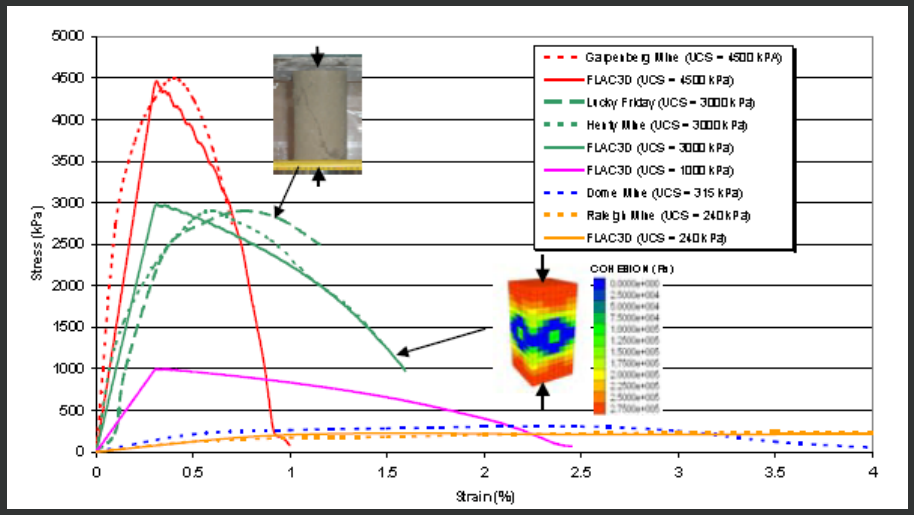


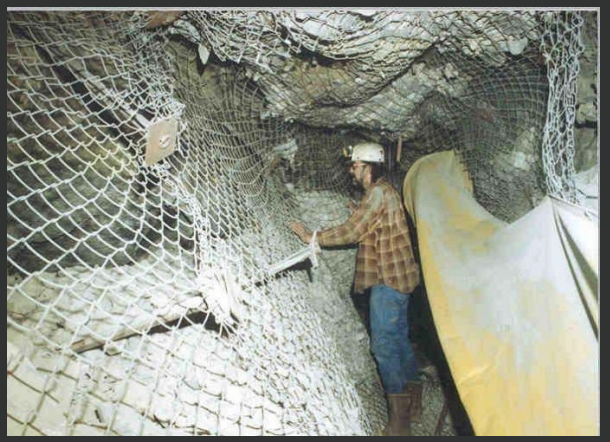
Fig. 3. The main sill pillar at the 655 m level.



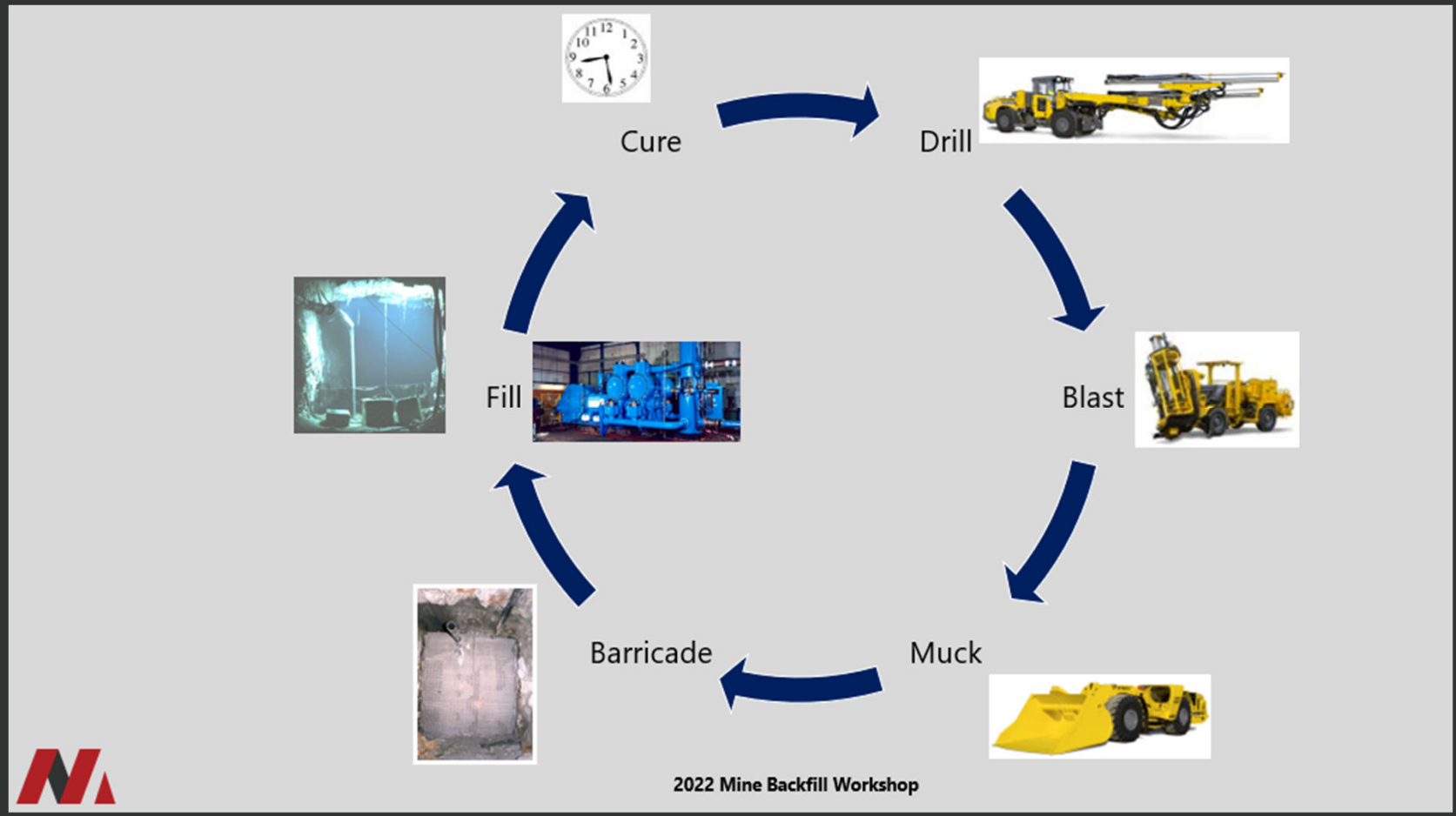
Role of Mine Backfills - High Stress Ground

- Paste works well in high stress ground because it is not as stiff as rockfill.
- Paste fills not brittle – even at 4 MPa compressive strength the yield strain is ~ 3.0% -- equivalent to a closure strain of 300 mm in a 10 m span
- Paste fills can absorb more strain than rockfills.
- Design is complicated – need to build numerical models in FLAC3D.





Backfill in the Mining Cycle



Design Considerations – Selection Criteria

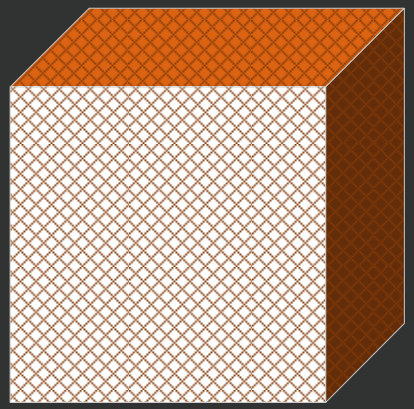
- The mining method which will determine the geomechanical requirements of the fill, stope volumes and geometry
- Available materials – quantity, proximity, quality, cost
- The impact on the mine plan – e.g. limited stope sizes
- The impact on the mining schedule – e.g. stope turnaround time
- The project economics
- Impact on logistics and mine services – e.g. ventilation, extra traffic on the ramp, dust
- Permitting issues – e.g. subsidence criteria
- Availability of water – salinity
- Impact on drainage water in the mine – water quality
- Long term chemical stability of backfills

Design Considerations

- Mass Balance – not all tailings can be placed underground
- Production Rate – needs to be balanced against mine production, mill availability and mine schedule
- Geomechanics – strength and stiffness of the backfill
- Binder optimization – binder is 60-80% of cost of the fill
- Cost optimization – alternative binders, pre-cycloning tailings to remove slimes etc.

Paste Backfill Mass Balance

SOLID ROCK

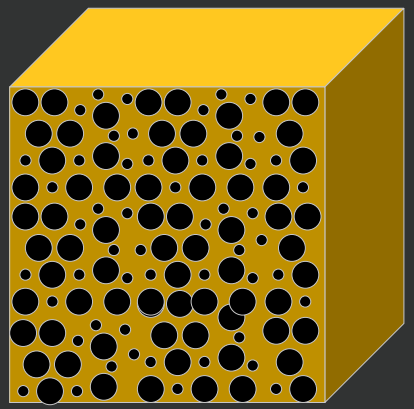


SG = 3.0
3,000 kg rock
No Voids
No Water

1 m^3

49% replacement

PASTE BACKFILL



SG = 2.06
1,489 kg tailings
100 kg cement
473 kg water
(47.3% Water)

Paste in the Laboratory – Example

Low Solids Paste

Pumpable

SG = 1.74

54% Water by Volume

High Solids Paste

Not Pumpable

SG = 1.85

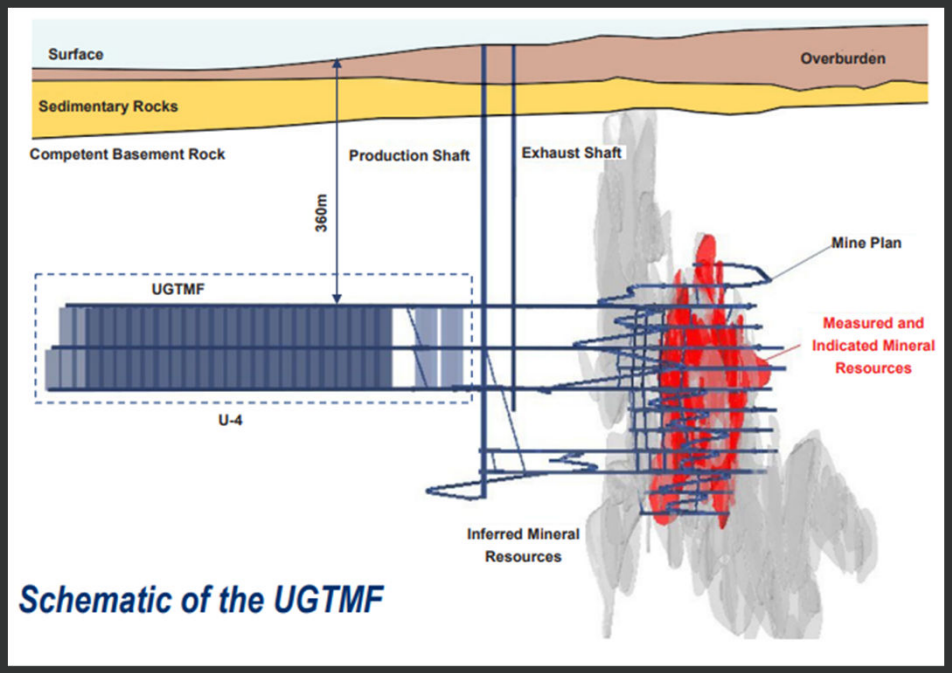
48% Water by Volume

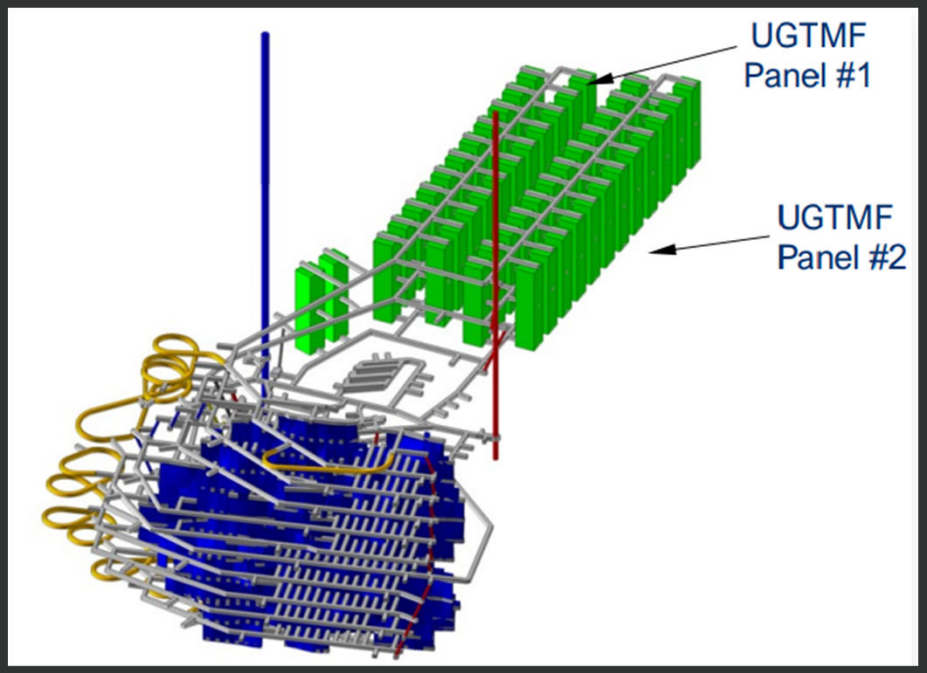
Tailings as a Saleable Product

- Generally, tailings cannot be converted into a saleable product, especially on a large scale, but some have tried making bricks, selling as fertilizer etc.
- Most metal mine tailings are too fine to be usable as a replacement for sand in concrete or use a filler product. Even when inert (no sulphides).
- Transport and logistics to get tailings to market generally renders the option uneconomic. Far cheaper to purchase local sand.
- Volumes of tailings available generally far exceeds demand.
- Economic viability of project can be impacted without a binding letter of intent or off-take agreement. Project must be viable without, otherwise project is put at risk.

Underground Tailings Management Facility (UGTMF)

- Intentional excavation of caverns in low grade ore or waste in order to create space (volume) for storing mine tailings underground.





NexGen Energy

- The UGTMF concept has never been attempted by any operating mine globally. NexGen propose this solution because it would be complex and expensive to permit a surface tailings impoundment to contain uranium tailings.
- NexGen is not an operating mine and they do not have a permit to operate. The project must complete both a Provincial Environmental Review as well as a Federal review since it involves mining uranium. It is in the early stages of this process (draft Environmental Review).
- NexGen list permitting of the UGTMF concept as a moderate risk since no one has permitted one previously and the regulators may not accept the concept.
- The concept produces large volumes of waste rock -- 97 stopes of 37,500 m^3 for a total of 3.64 Mm^3. These stopes will be filled with low strength/low binder paste backfill.
- Operating costs include additional mine development (ramps and drifts), excavation of stope voids, hauling waste to surface, and backfilling stopes with paste. Operating costs are estimated at CAD$31 per tonne of ore or about 9% of the annual mine operating cost, emphasizing the extreme economic pressures imposed by this scheme.

Sale of Armorstone

- Arctic Mineral Resources (AMR) propose a scheme similar to the NexGen UGTMF concept but in this case they propose to sell the excavated waste as Armorstone.
- These types of concepts have been proposed before but eventually they fail because the costs are not sustainable. AMR quote a cost of US$15/tonne for mining Armorstone but this must compete with local surface quarries that can produce this material for about US$2.50/tonne. The AMR cost does not include the logistics and cost of transport of the product to the market.
- As with the tailings the concept is only viable if you can secure a long-term supply contract with a credible buyer. Otherwise the cost of excavating and disposing of the Armorstone is just an added cost to the mine.

Closing Comments

- Mine backfilling is very common in underground base metal and precious metal mines globally, and this practice is growing due to stakeholder pressures related to recent failures of surface tailings storage facilities.
- The reality is that physics do not allow the placement of more than a maximum of about 50-60% of the mined solids back underground. Exceeding this limit requires alternative void spaces such as historic workings, backfilling of unused development drifts etc. The remainder must then be placed on surface in a mined-out open pit, dry stacking, or placement in a conventional TSF.
- No operating mine has ever attempted to build a UGTMF – in all cases it would be considered cost prohibitive compared to the alternatives. Note that NexGen Energy is not a permitted mine – it is only at the draft EIS stage.

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