Hard rock cutting technologies – Overview and Progress

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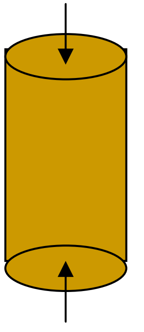
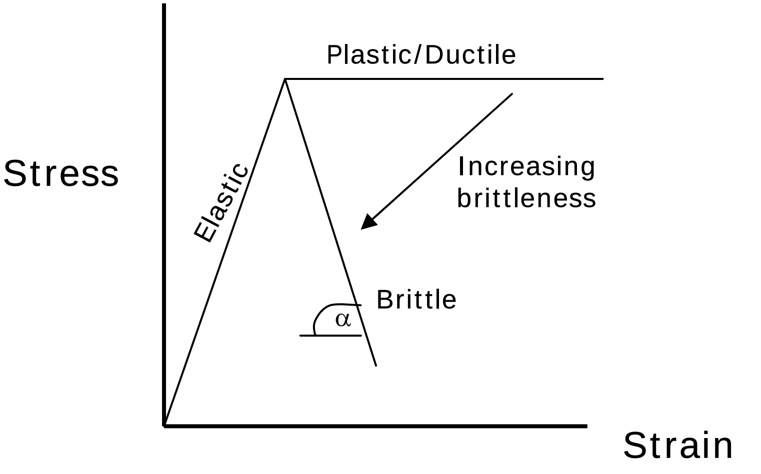
Behaviour of rock as a material

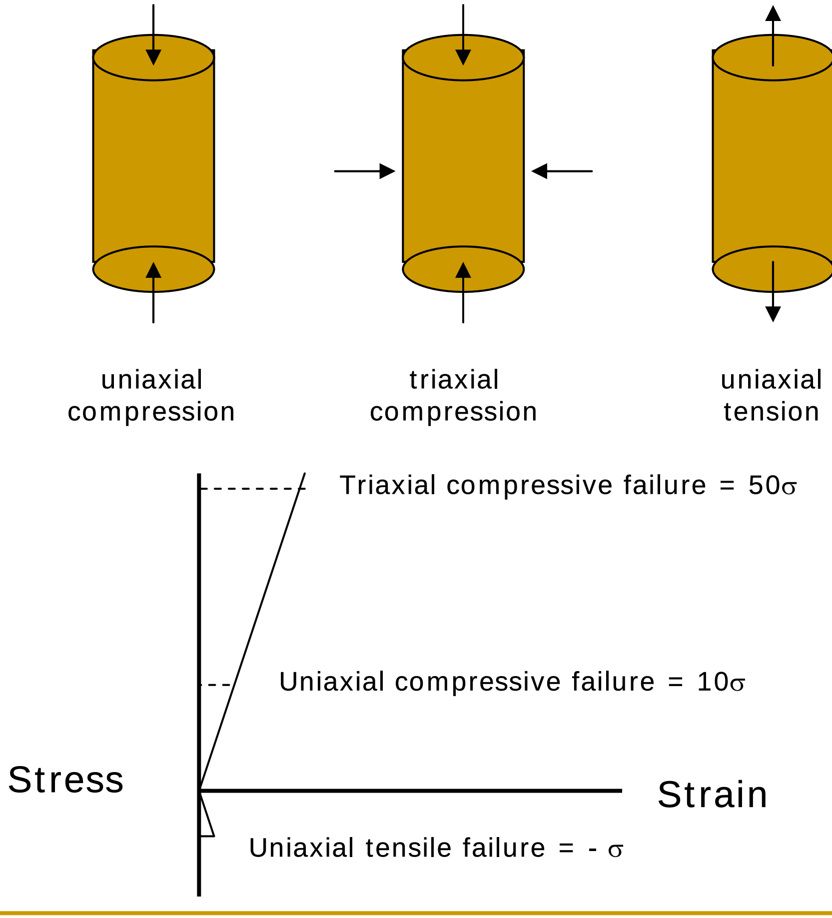


- Most rocks respond to load in an elastic-brittle manner
- Slope of unloading curve defines the extent of brittleness



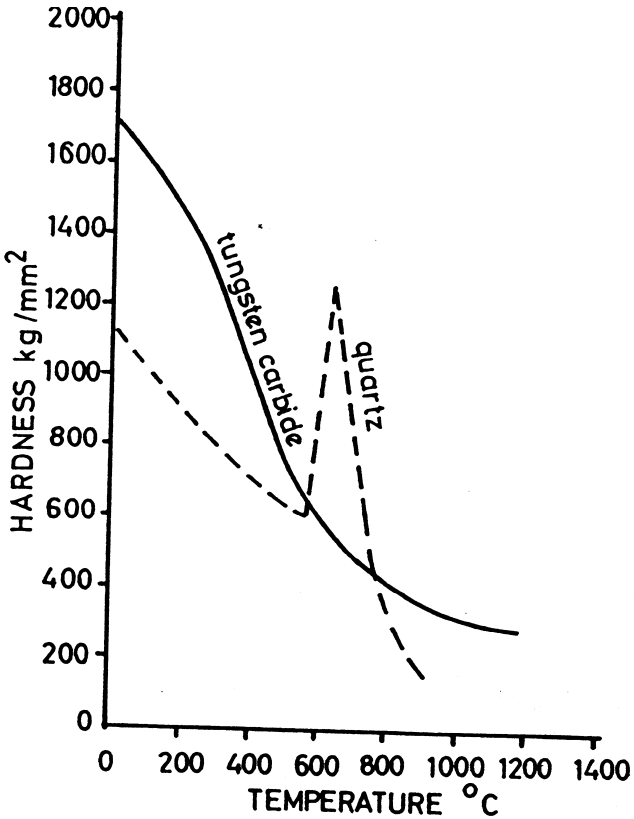
Characteristics of Brittle Materials

- Brittle materials are:
  - Strong in compression
  - Very strong in confined compression
  - Weak in tension
- Strength ratio 50:1
- Brittle materials fail in tension
- Ductile materials fail in shear



Characteristics of rock

- Most igneous and metamor-phic rocks are strong
  - Uniaxial compressive strengths = 200-400 MPa
  - Triaxial compressive strengths ~ 1 GPa
- And often highly abrasive
  - Room temperature hardness of quartz = 11 GPa
  - But hardness falls rapidly with temperature
  - Many minerals harder than quartz, eg topaz = 22 GPa; corundum = 44 GPa; diamond = 150 GPa



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Lessons for rock breakage

- **Don’t** try and break rock in triaxial compression
- **Always** try to break rock in tension
- Heating of rocks will reduce strength and soften them
  - Unfortunately heating reduces the strength and hardness of the cutting tools too
- Very important to keep the cutting tools cool during the cutting operation

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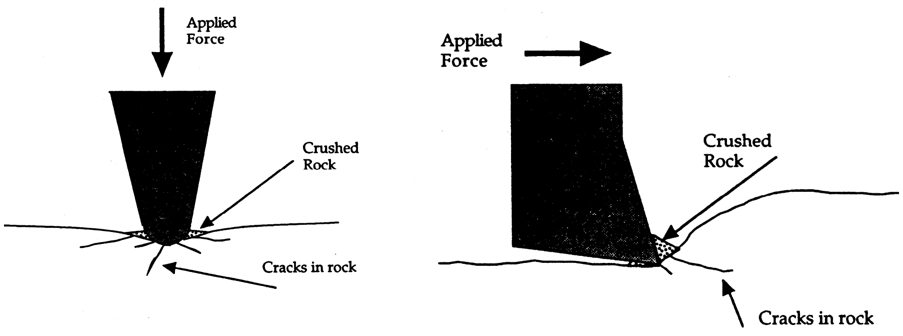
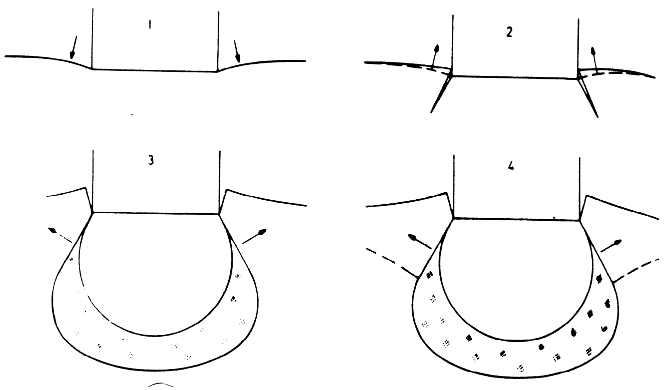
Fundamentals of rock breakage using mechanical cutting tools

- Two types of cutting tool
  - Indenters
  - Drag bits
- Both tools cause rock failure by inducing tensile cracking
- However, drag bits induce these tensile cracks more directly than indenters
- Indenters load the rock in triaxial compression
  - Hydrostatic loading immediately below indenter – no failure
  - Crushing and dilatation around this zone





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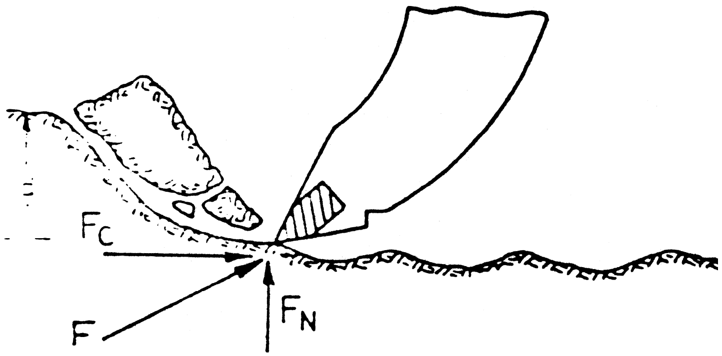
Why not use drag bits everywhere?
More efficient than drag bits

- Unfortunately cutting tools are also made out of brittle materials
  - Weak in tension
- The cutting action of drag bits induces bending (tensile) stresses in the bits
  - With high forces, ie when cutting in strong rock, this causes premature bit failure
- Also the sliding frictional contact between a drag bit and the rock induces high temperatures in the bits
  - Leads to tool softening and rapid wear



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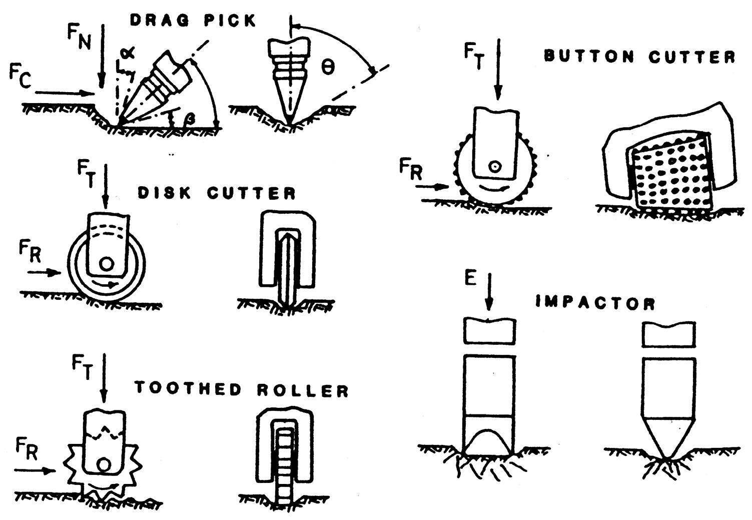
Advantages of indenters

- The tool as well as the rock is loaded in compression
- Often mounted on a rotating shaft so that sliding contact (heat loading) is minimised AND individual indenters have a chance to cool – **very important**
- BUT, rock is loaded in its strongest configuration – triaxial compression



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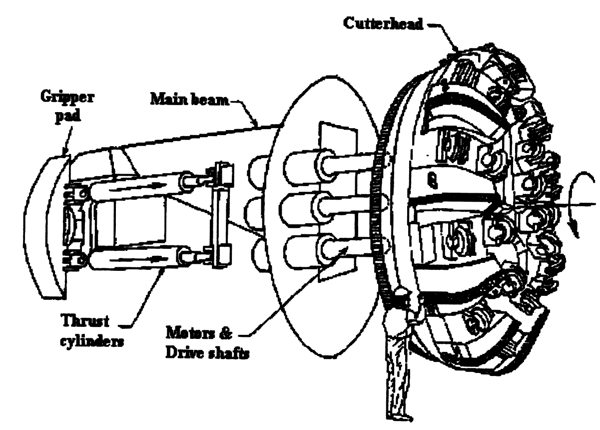
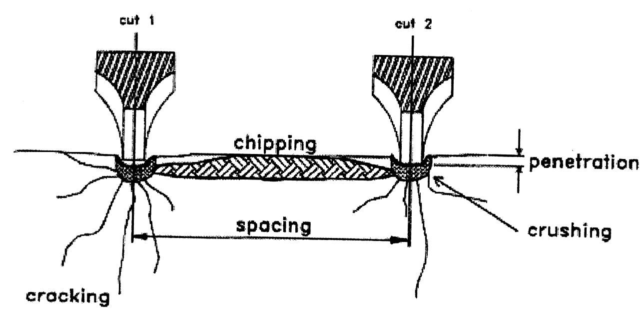
Disc cutters work together

- On a cutterhead disc cutters work together
- Cut a series of parallel grooves
- Rock excavation occurs because of tensile cracking between adjacent grooves
- Cutter geometry today, constant cross section – not wedge





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Specific Energy

- Is the energy required to fragment a unit volume (or mass) of rock
- Critically dependent of size of rock fragments
- Goal is to minimise the SE
- Depends on cutter spacing to cut depth ratio
- Does not decrease with groove deepening

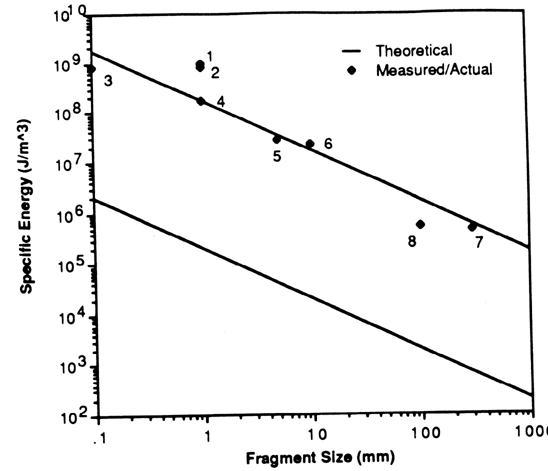
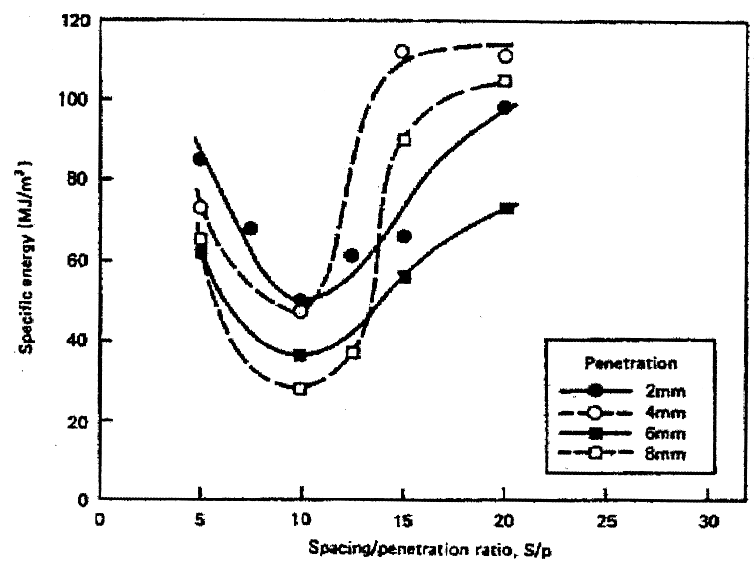
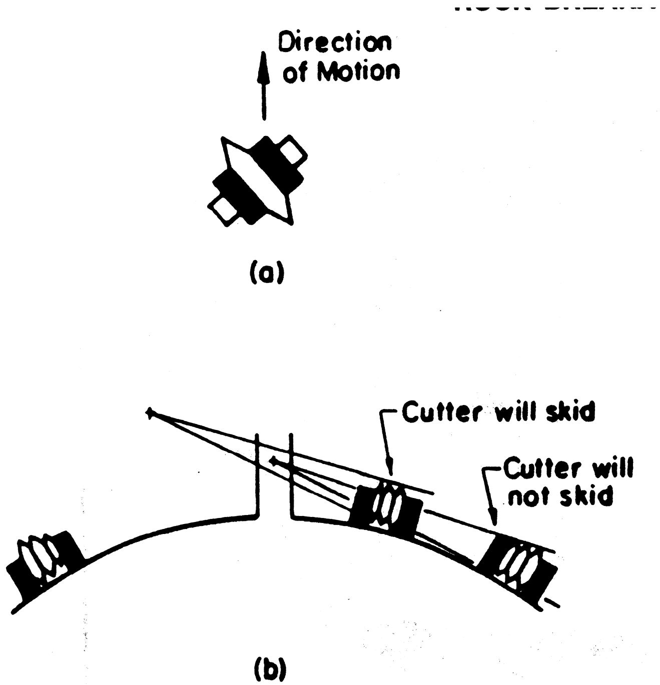


Fig. 9.1.66. Specific energy as a function of nominal particle size. The data points are for different methods of breaking strong (C_0 = 200 MPa) quartzite (after Cook and Joughin, 1970). (1) Flame-jet piercing, (2) high-pressure water jet, (3) diamond cutting or drilling, (4) percussive drilling, (5) drag bit cutting, (6) rolling cutters/boring, (7) impact-driven wedge, (8) explosive blasting.

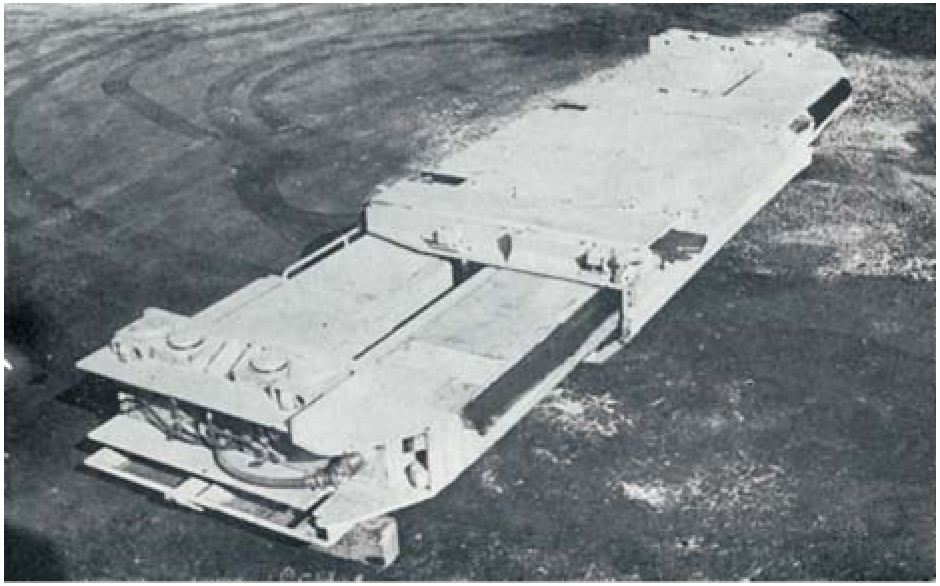


Cutter disposition on head

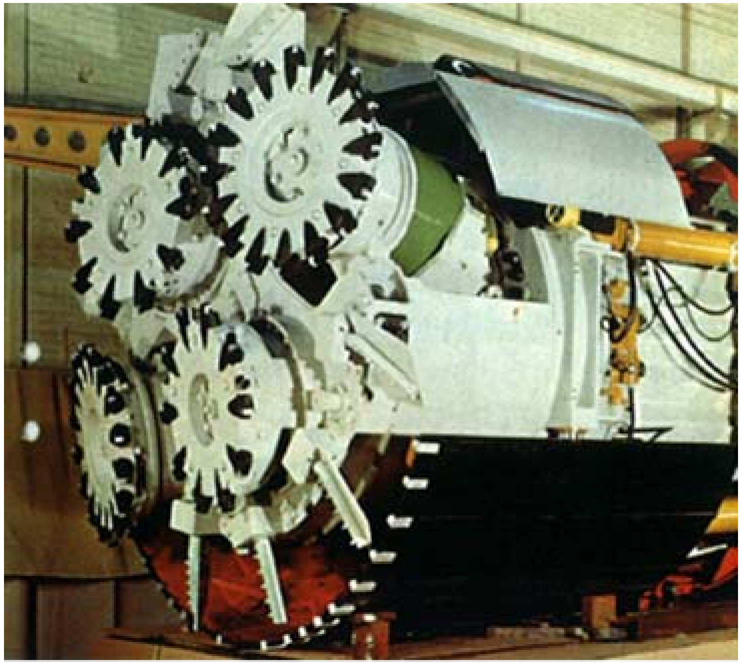
- Heat loading (wear) is critically dependent on cutters rolling true
- Difficult to achieve if all cutters are same diameter
  - Cutters near axis tend to skid (a)
- If multiple discs are mounted on same shaft then some can spin (b)



Many attempts over many years



South African reef slotter circa 1973



Atlas Copco TBM, circa 1978

Both these machines uses picks (drag bits) to cut the rock
Although picks are more efficient than indenters also more susceptible to thermal damage and wear. **Neither machine succeeded**; found a market

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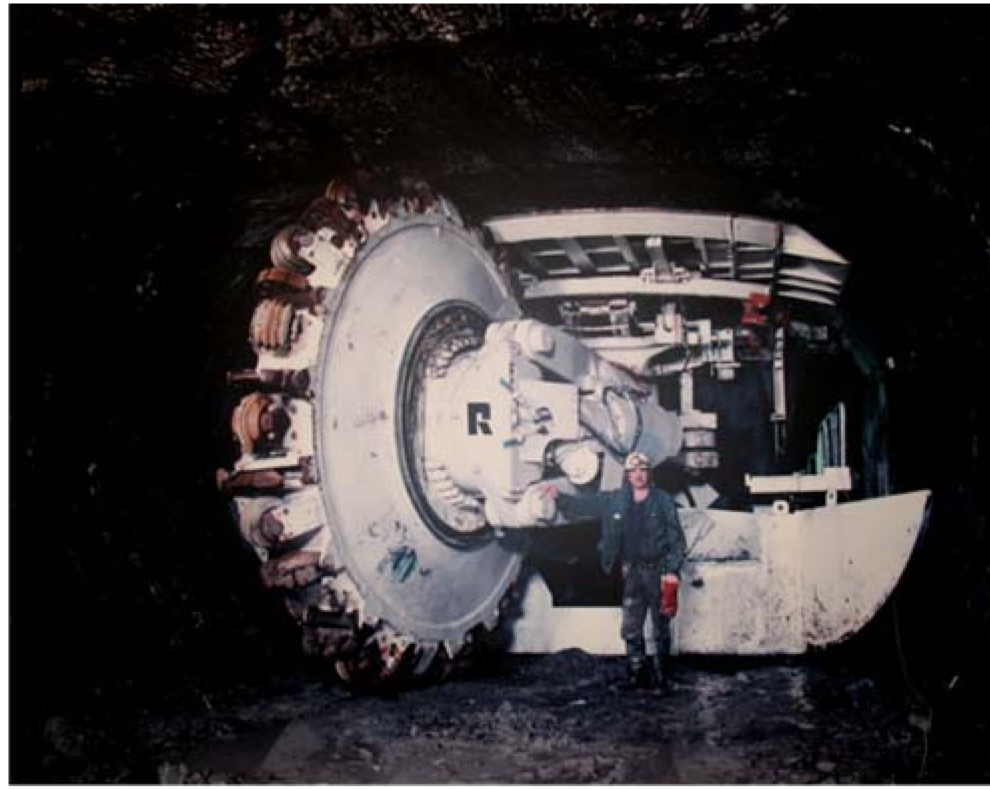
Disc Cutting Mobile Miner

- Three models of this machine
  - Model 1 tested at Mt Isa Mines
  - Model 2 tested at Broken Hill mine
  - Model 3 tested in Japan
- Created a beautiful excavation
- Fundamental problem was excessive cutter wear
- Problem caused by cutters not tracking in same groove – highly inefficient cutting mechanism
- Development abandoned early 1990s



Robbins Mobile Miner (Mt Isa, Broken Hill) circa 1987

Attempt to combine advantages of discs and picks

Wirth-HDRK, CMM, circa 1990

Sandvik's ARM 1100 reef miner, circa 2008

Undercutting discs break rock like picks but rotate to distribute thermal load
More robust than picks

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New Developments Rio Tinto + OEMs

Rio partnership with Atlas Copco on rapid tunnelling machine AND with Herrenknecht on mechanised shaft sinking

Interesting both machines resemble the Robbins Mobile Miner But without the flaw in the cutting mechanism

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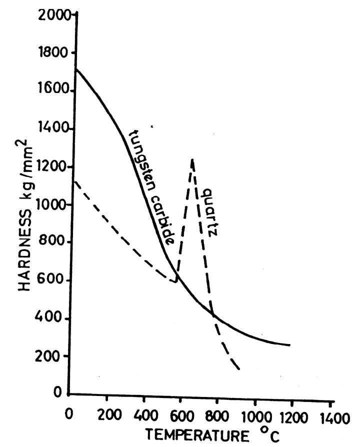
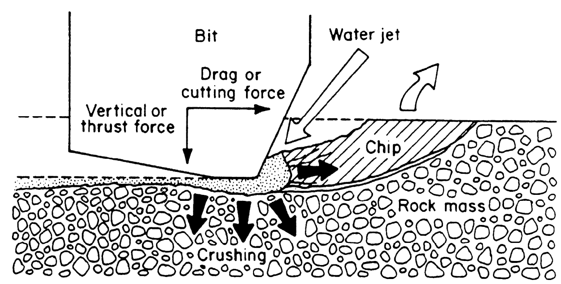
Water Jet Assisted Cutting

- The principal cause of cutter wear is heat, causing tool softening
- Jet assisted cutting seeks to remove the heat from the point where it is generated – the cutter-rock interface
- Pressure in the crushed rock zone underneath the cutter is very high – GPa
- Jet pressure also needs to be high, but because of compliance in the machine, can be MPa – but kPa doesn't work





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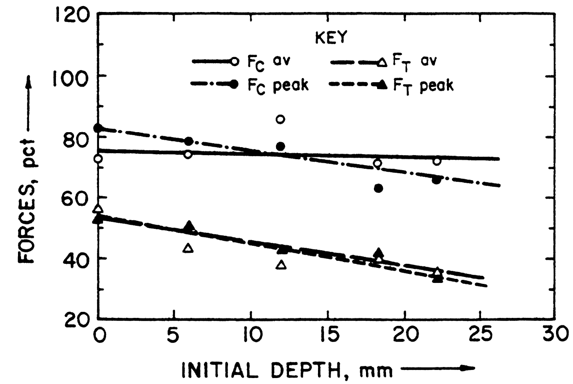
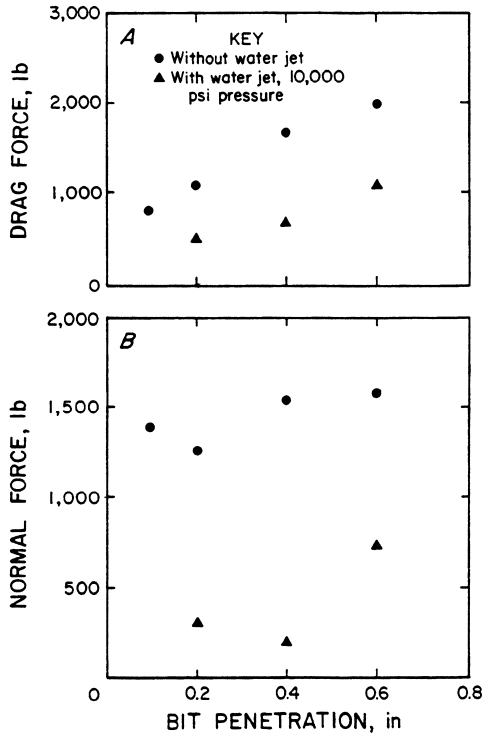
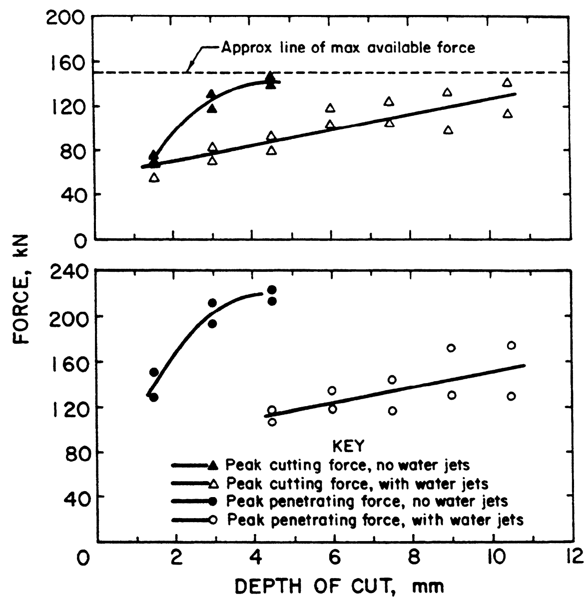
Force reduction

- The surprising feature of jet assisted cutting is that the jets serve also to significantly reduce the cutter forces!







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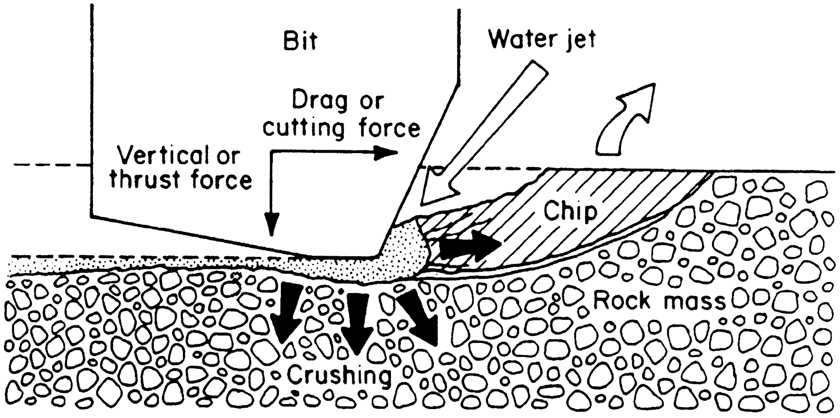
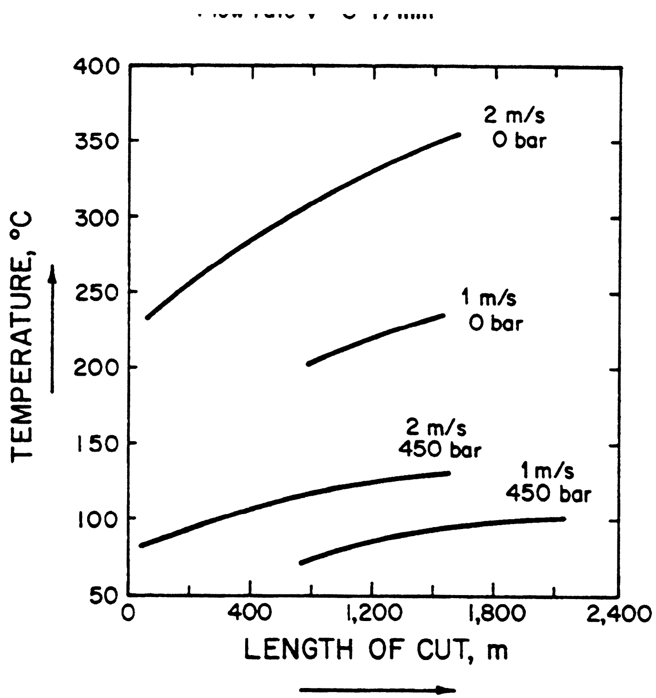
Why force reduction?

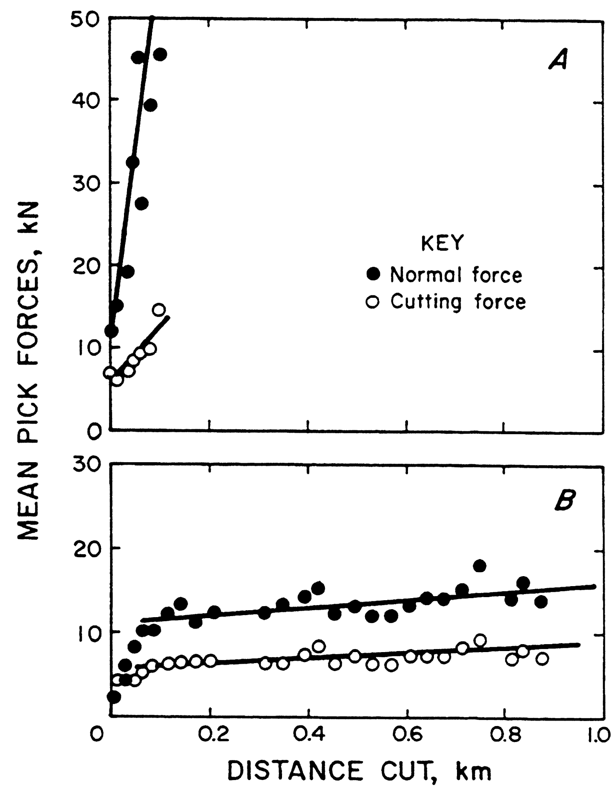
- Purpose of applying force to a cutter is to generate a tensile stress in the rock > rock tensile strength
- Cutter rides on a cushion of crushed material which distributes the cutter force over a large area
- Jets serve to continually flush away crushed rock allowing tool to interact directly with intact rock
  - Generates rock tensile stresses more directly
  - Ie with lower cutter forces



Temperature and Cutter Wear

- Jets cool the tools and greatly prolong cutter life





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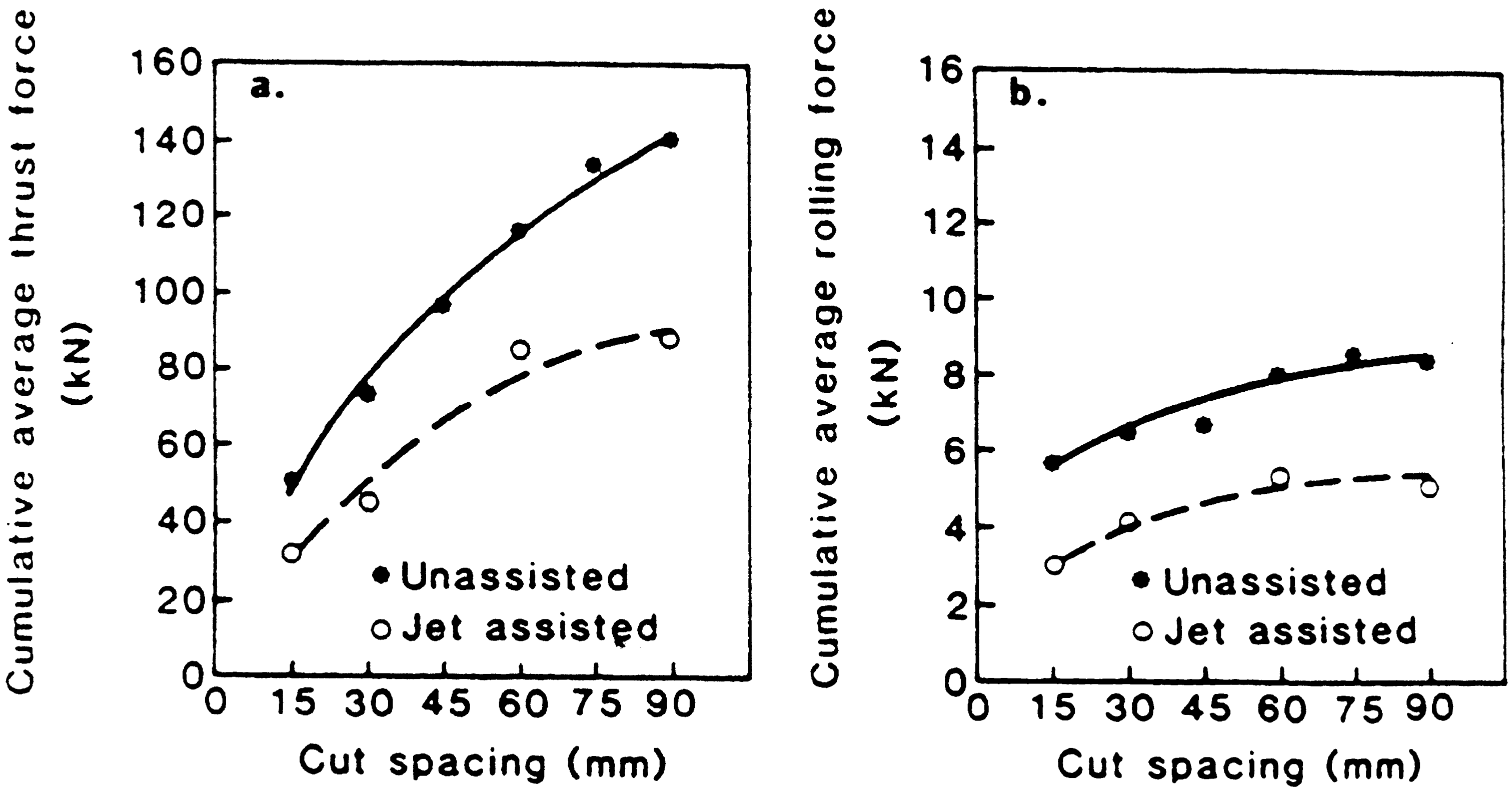
Jet Assisted Disc Cutting



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Using Jets to pre-weaken rock

- Work has been conducted on using jets to cut grooves in the face ahead of TBM cutters
- Very energy intensive. Requires jets of 400 MPa in hard rock
- Jet assisted cutting more attractive

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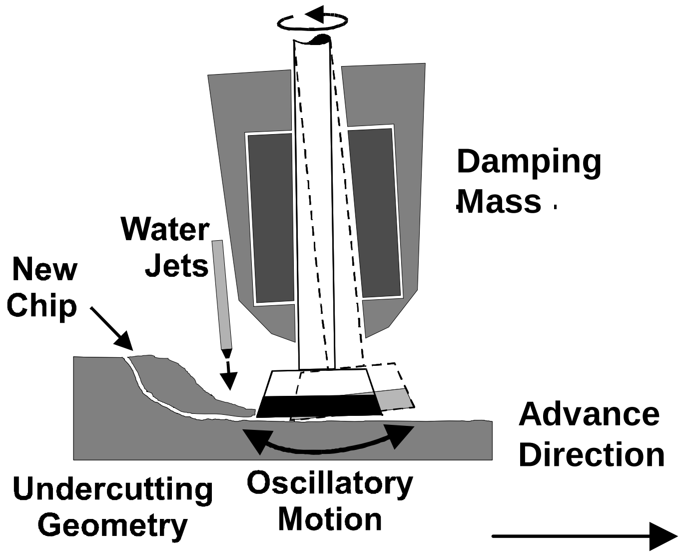
Oscillating Disc Cutting



- Uses robust disc cutter to break rock in tension!
- Also uses high pressure water jets to cool tool and reduce forces
- AND oscillates cutter to cause rock to fail in fatigue

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Field Trials

- Successfully demonstrated ODC technology in a quarry
- Same low forces as lab
- Licensed a major US manufacturer to develop ODC mining system for underground mining and initially for S African platinum mines
- Licensed Herrenknecht for field of civil engineering

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Thank You