Mechanizing Extraterrestrial Excavation
- Transfer Potentials from the TBM Industry -

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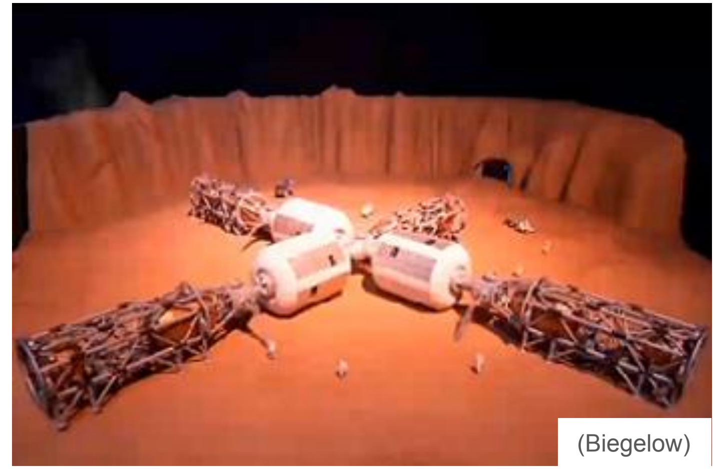
Space Resources Round Table 2016

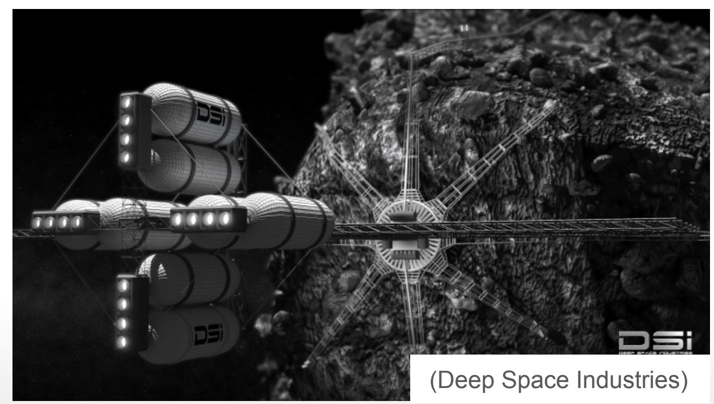
Content

Why We Need To Excavate Beyond Regolith


(Exploration Architecture Corporation)


(Biegelow)

- Access to / creation of underground cavities
- Cut obstacles for extension of existing structures
- Cut ore bodies to transport / processing size
- Advanced construction and exploration


(Deep Space Industries)

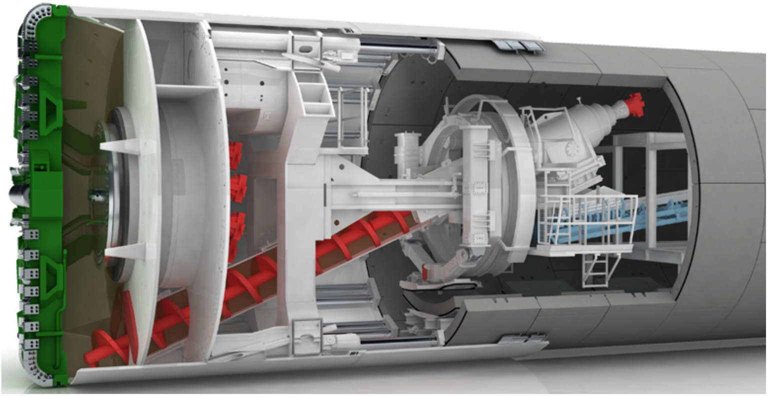
Controlling The Environment vs. Adapting to Environment

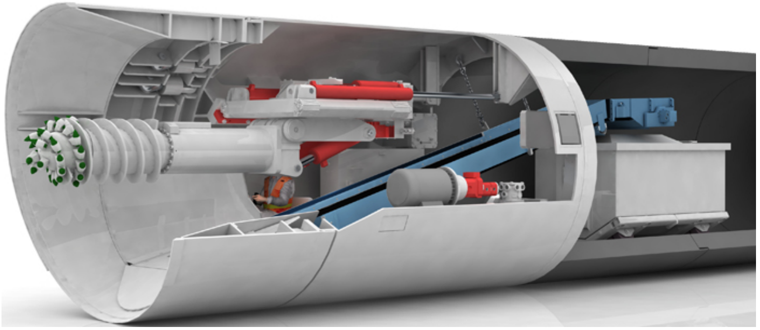
Early 1900

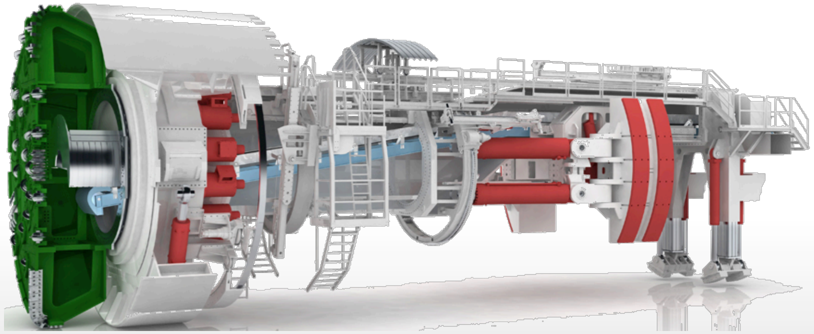
Today

TBM Operating Principles

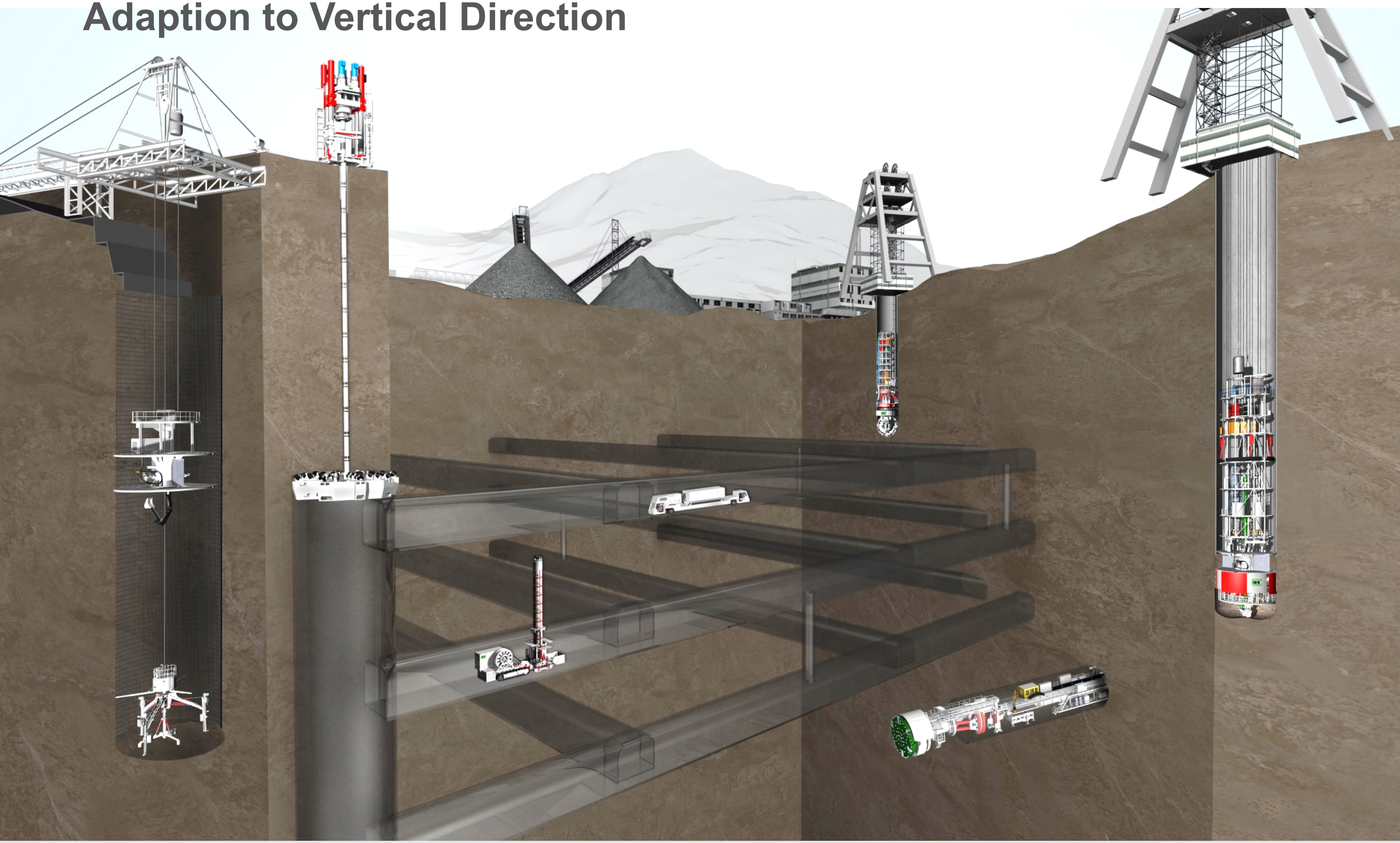
- Self propelled from ground or finished lining
- Flexible excavation methods
- Pressure insulation
- Integrated muck handling
- 90% of human work in protected space
- High amount of standardized work activities
- Balance of Ground Pressure





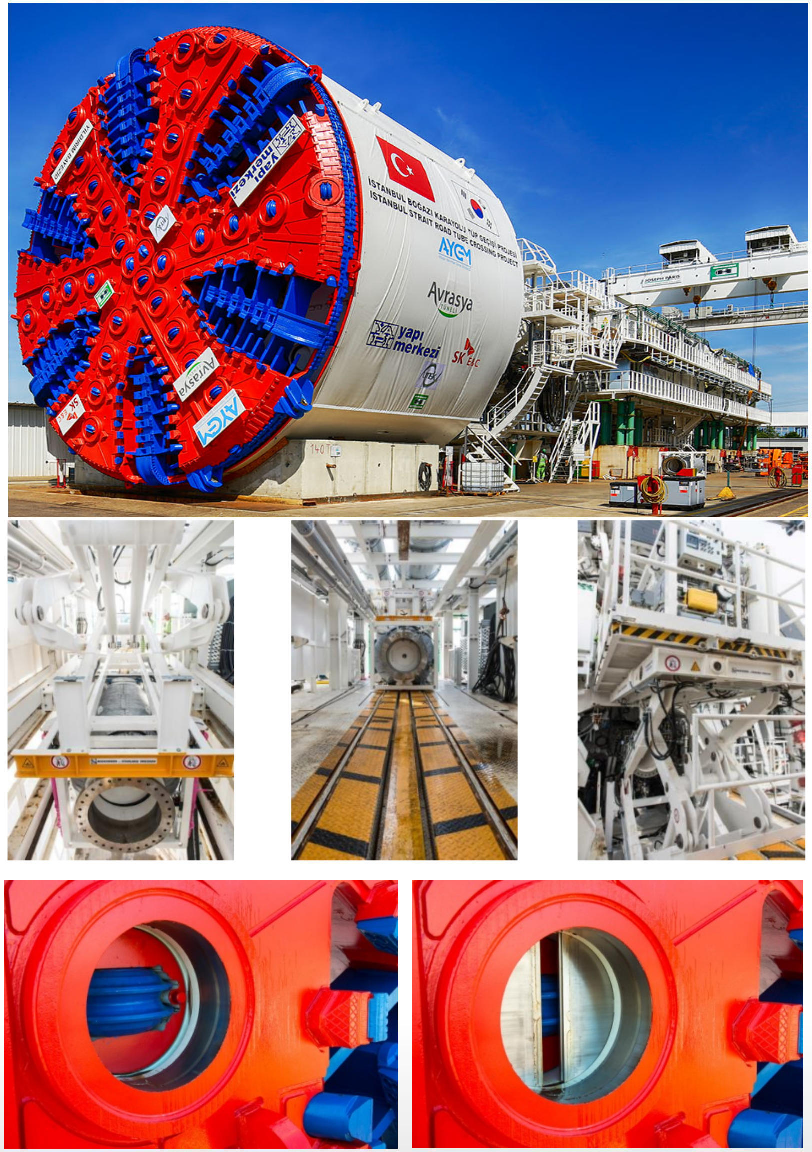


Adaption to Vertical Direction



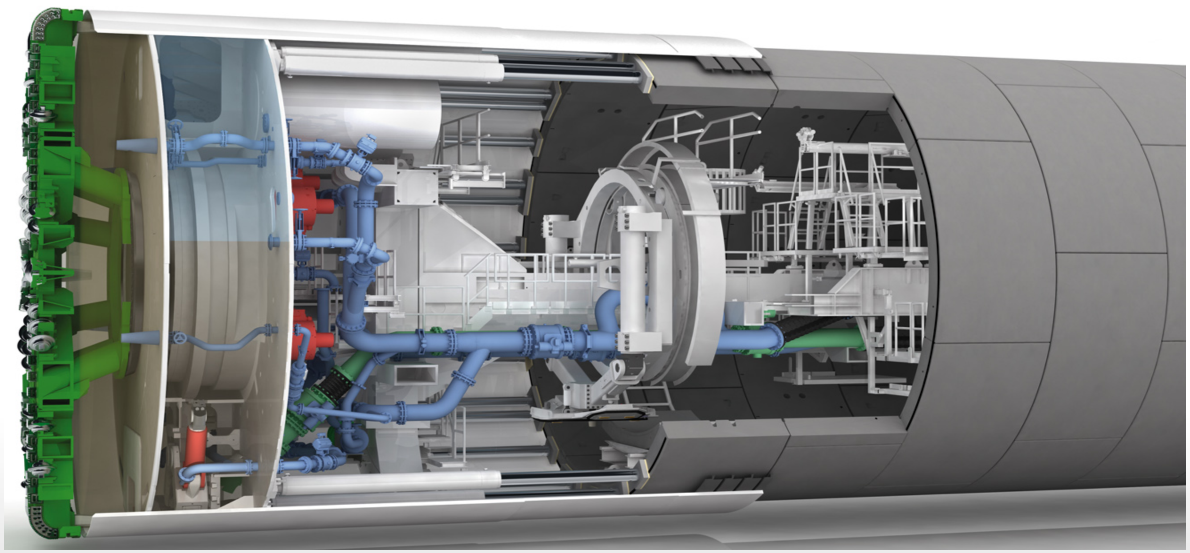
State of the Art

- Large Diameter up to 19m
- Max 100MNm Torque
- Max. 200Mn Thrust
- Long Distances (Survivability)
- High Temperatures
- High pressures (max. 17bar)
- Saturation Diving Maintenance
- Atmospheric Lock Tools
- Geophysical Advance Exploration
- Sensor Controlled Cutting
- Wear and Abrasion Monitoring and Resistance
- Variable Operation Modes



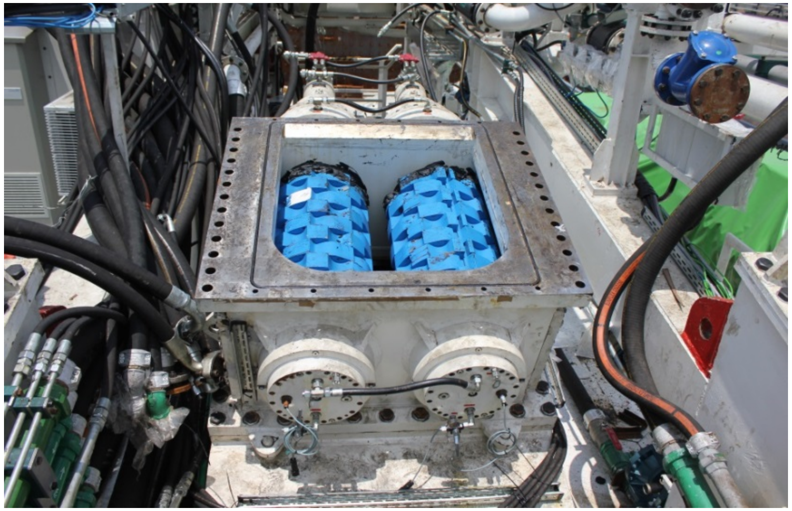
Concurrent Excavation and Lining Construction

- Permanent Protection for Personnell
- Lining with Additive Manufacturing Type Layers (Shotcrete, etc)
- Prefabricated Lining Assembly (Concrete / Steel Segments)
- Low gravity leads to reduced lining requirements



Integrated Material Handling and Processing

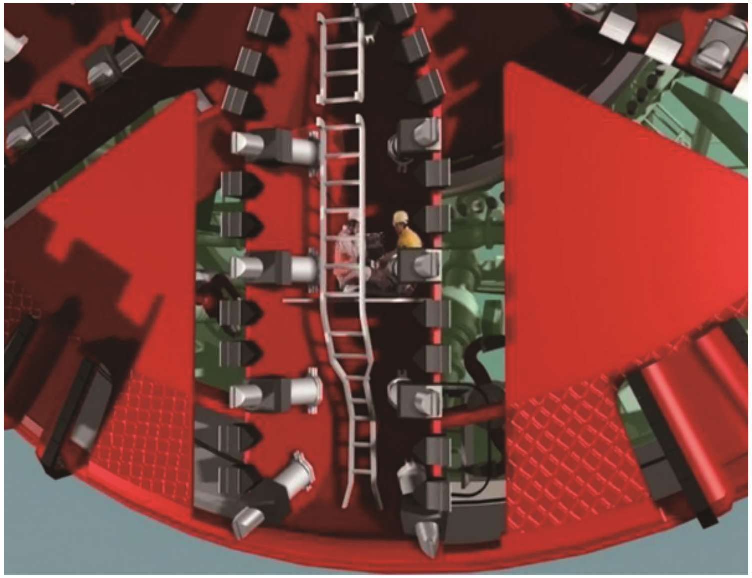
- Understanding of performance and wear of material handling and processing systems
- Rock crushing without gravity is challenging!
- Limited analytical design methods mean that extensive testing is required

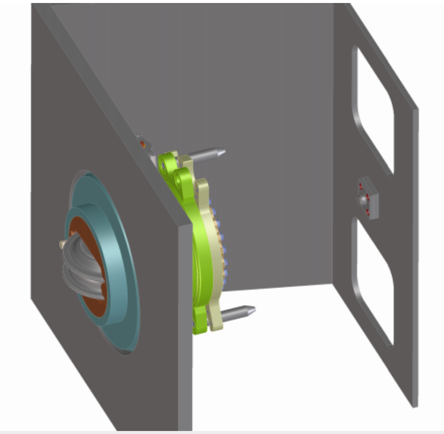


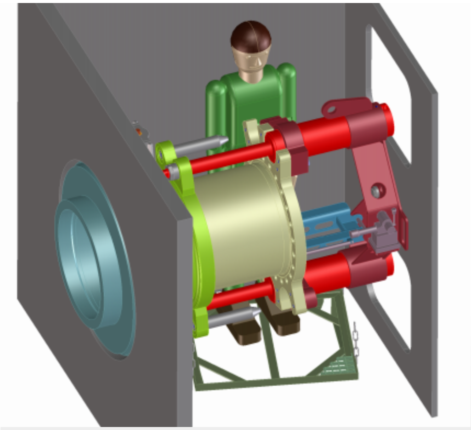
Mechanical Excavation of any Geology

Atmospheric / Robotic Toolchange

- Airlock housed tools
- Tool mounting adapted to robotic exchangeability
- Reduced operator exposure
- Wear / deformation tolerant design

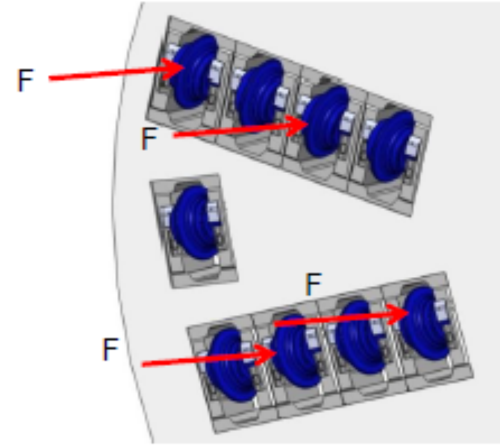


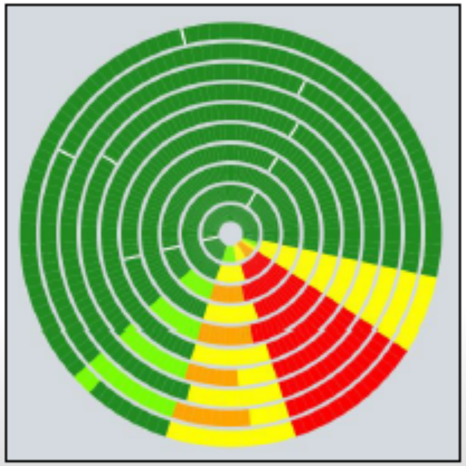




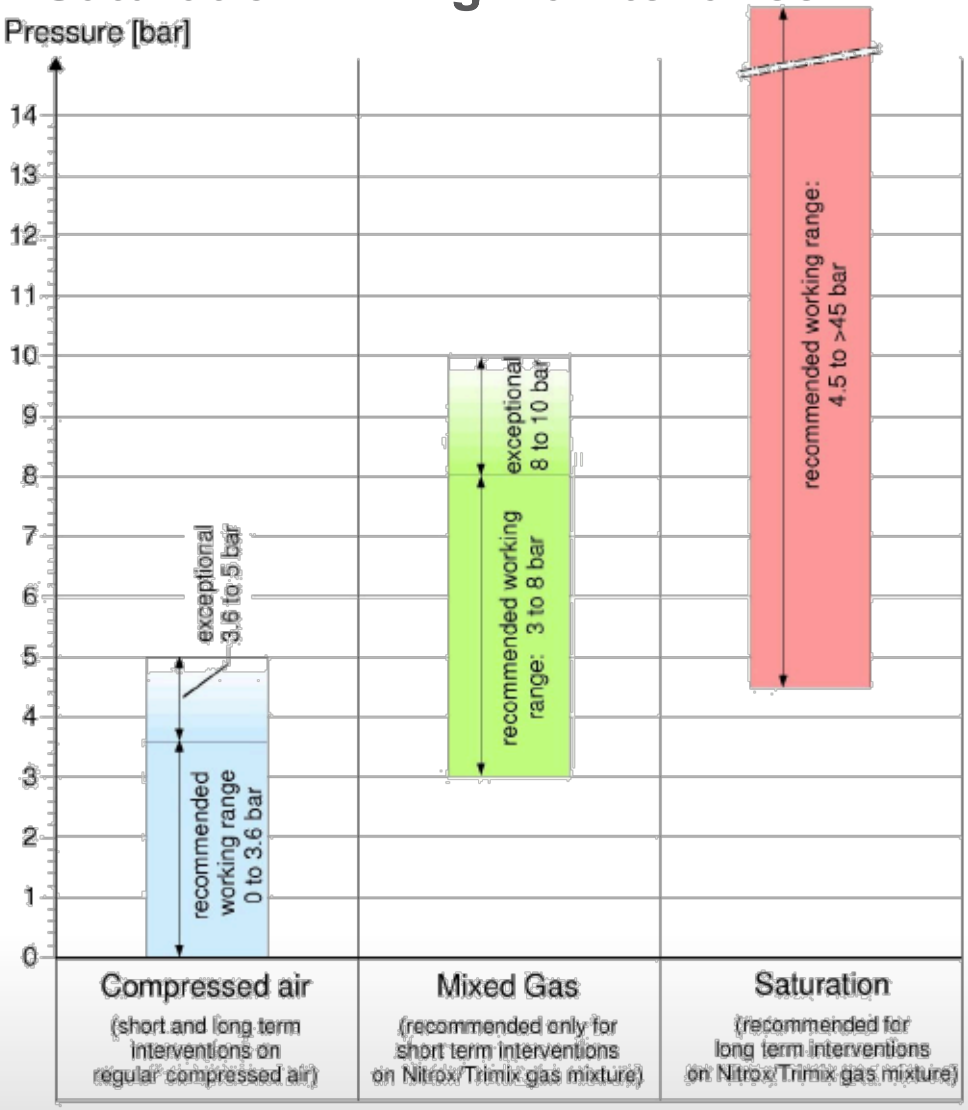
Sensors in Cutting

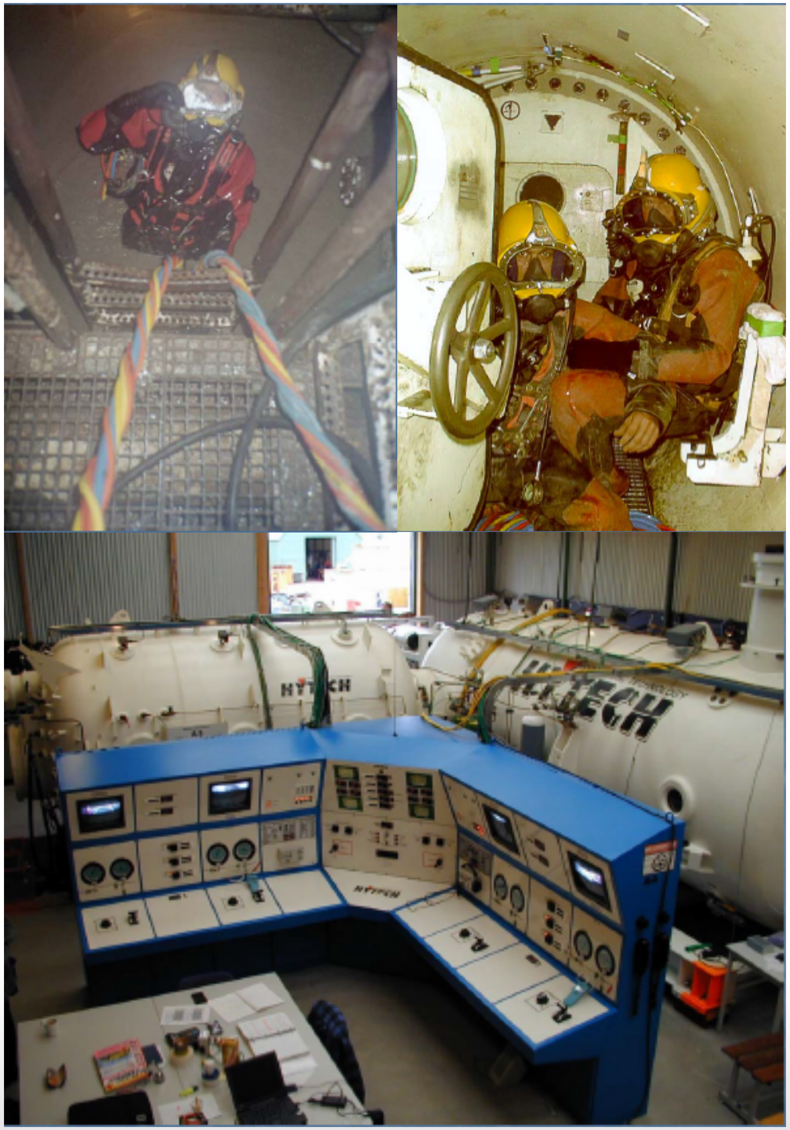
- Real Time Monitoring of key Data:
  - Rotation
  - Load
  - Wear



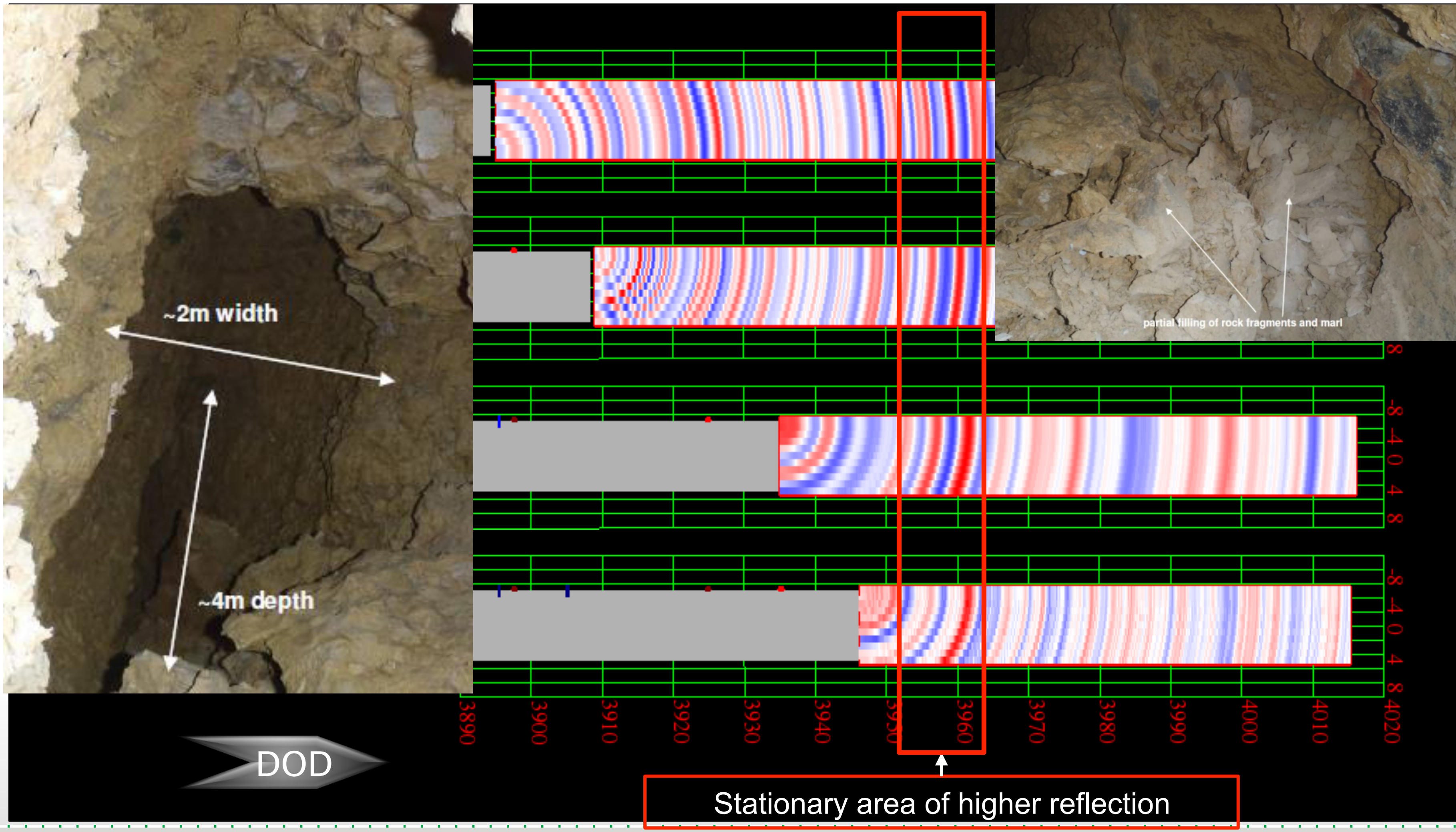


Saturation Diving Maintenance





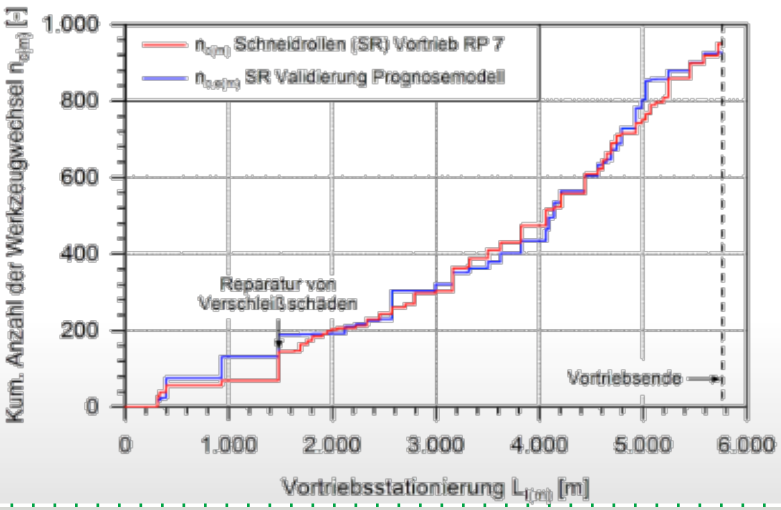
Geophysical Exploration (Cavities, Rocks, Fracture Zone)

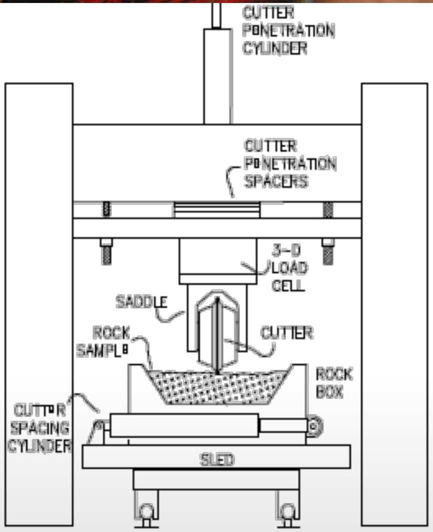


Empirical Wear Models for Specific Applications

Dependency of radial cutter ring wear:

- Radial wear of the cutter ring is a linear function of the rolling distance.
- Radial wear of the cutter ring is directly proportional to rock abrasivity.
- Example of radial wear measurements:

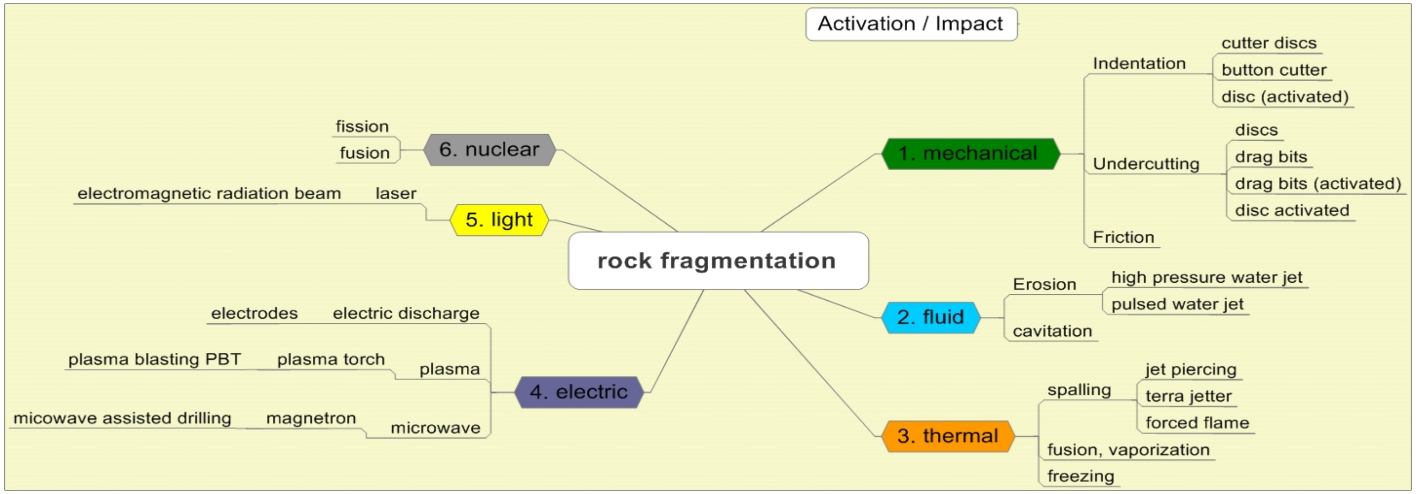




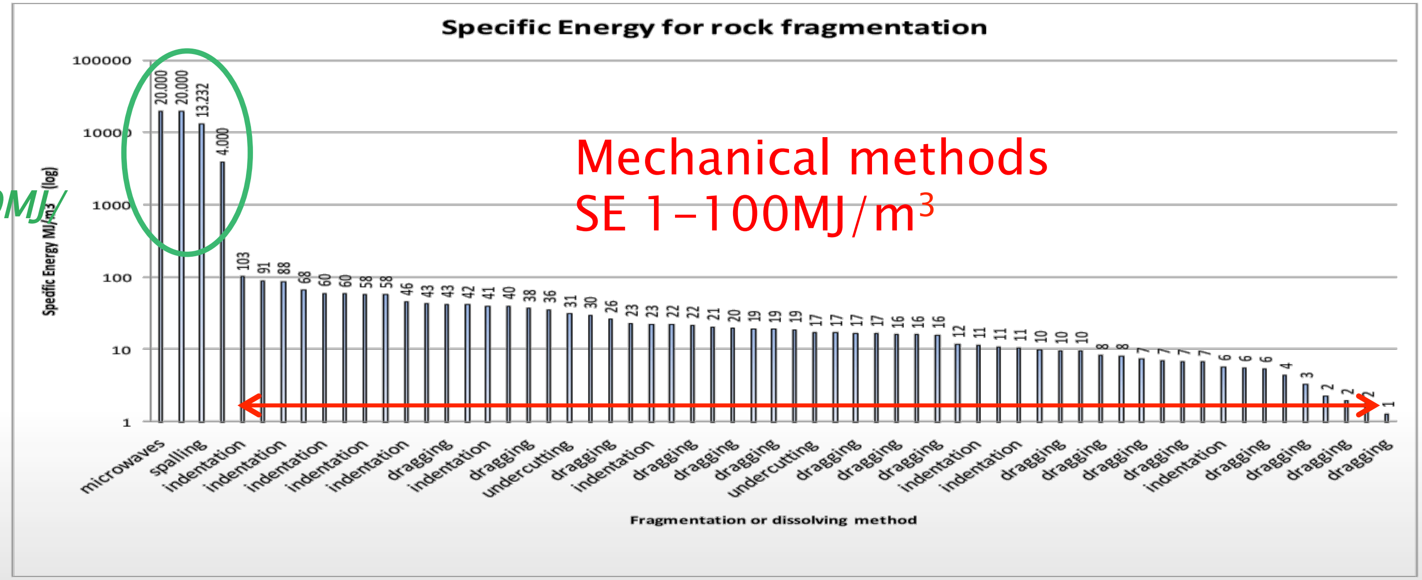
Towards Extraterrestrial Excavation Tools

- Boundaries set by mass, force, energy, power limitations
- Manage wear, tool exchanges, reliability, mixed geology conditions
- Adapt conventional technology to extreme conditions (tribology, dust, sealings, actuators etc.)
- Evaluate „exotic“ technologies with little experience on earth
- Transfer of specialized technology into flexible, platform independent tools

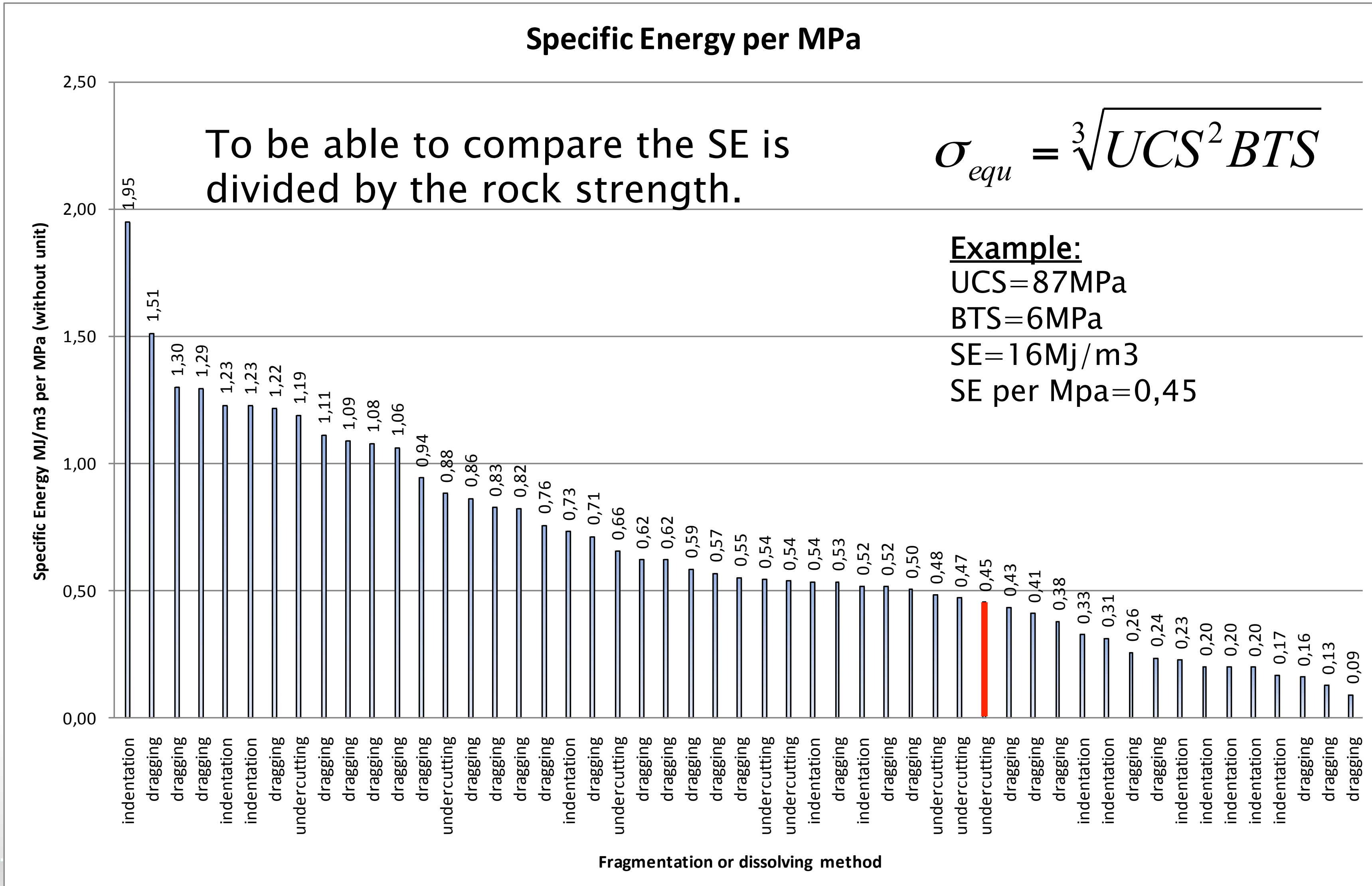
Specific Energy for Rock Fragmentation



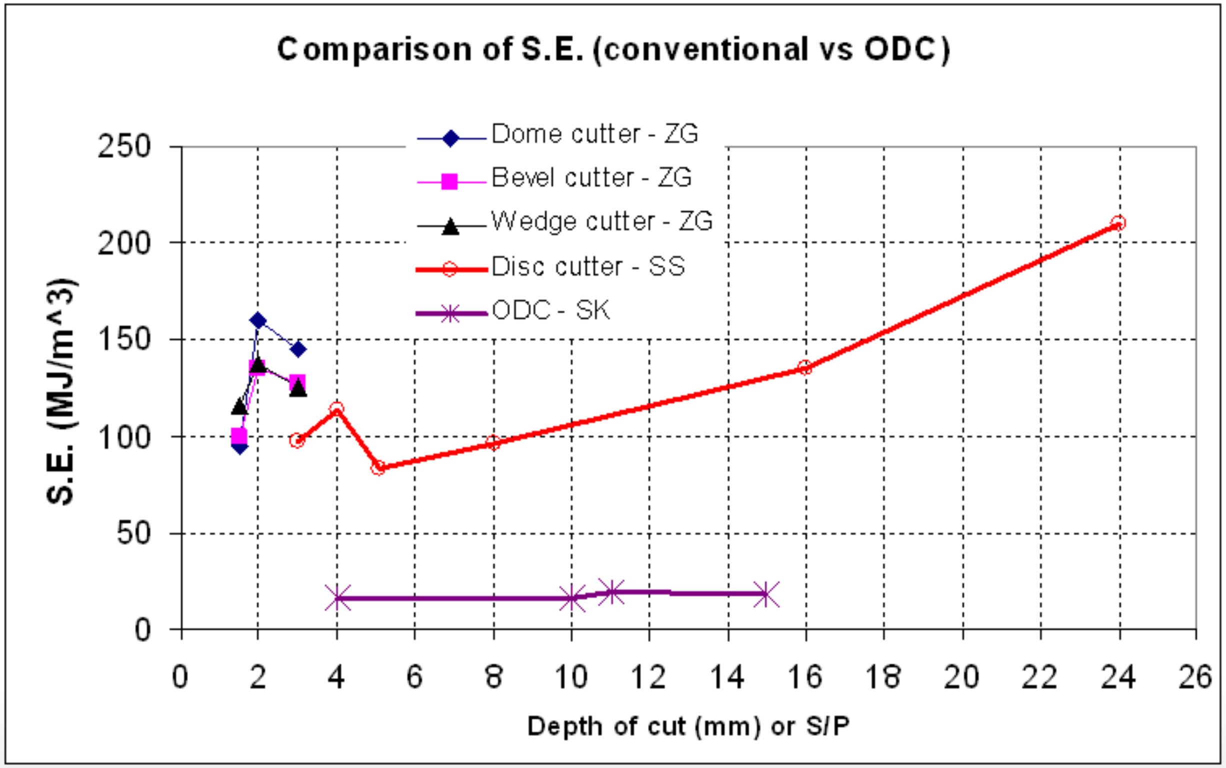
Microwave
Termal spalling
Water jet
SE 4000-20.000MJ/m³

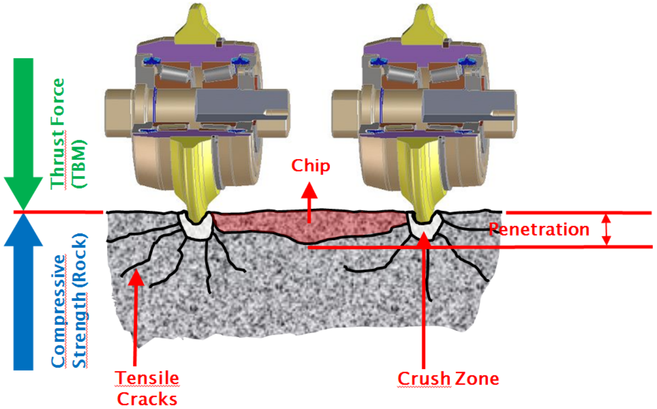


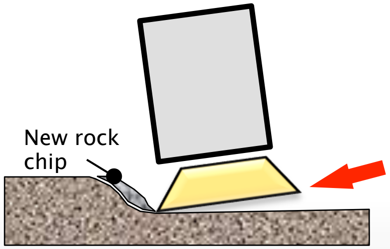
Specific Energy by Mpa (for mechanical methods)



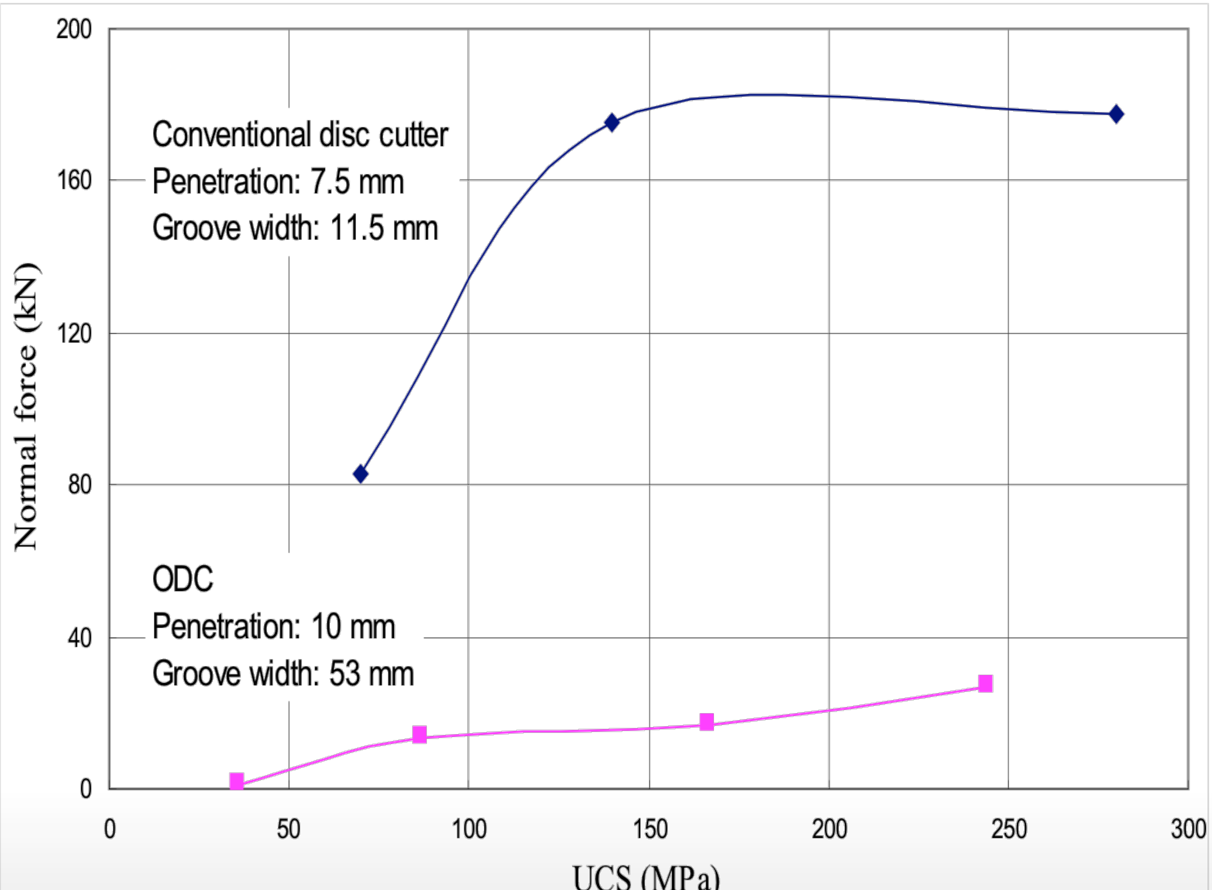
Energy Reduction Conventional vs. Activated Undercutting



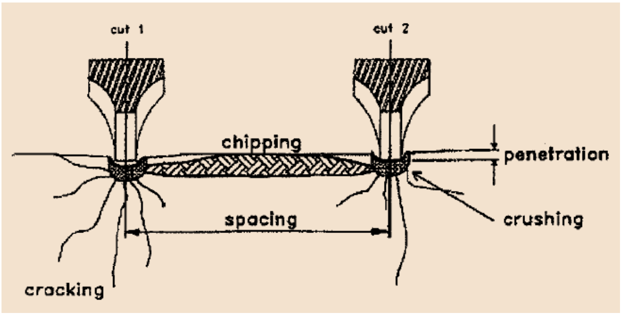


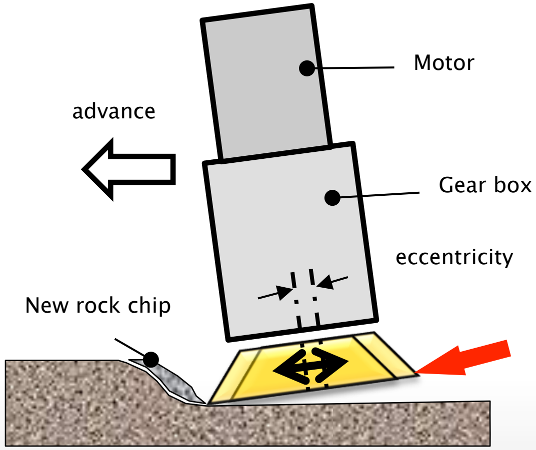


Force Reduction Conventional vs. Activated Undercutting



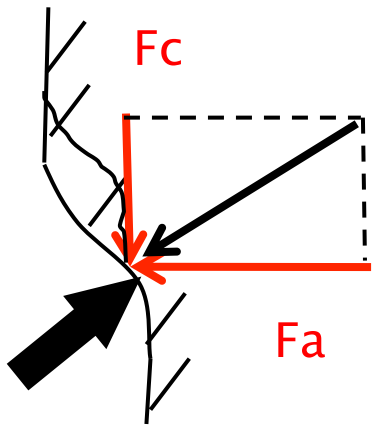
Source: CRC-Mining, 2000



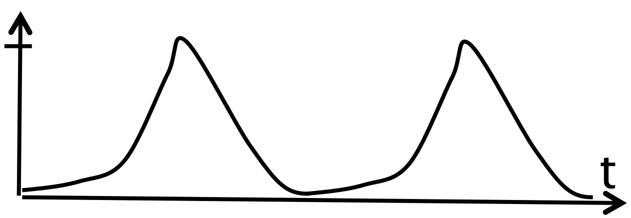


Lower Loads on the Machine

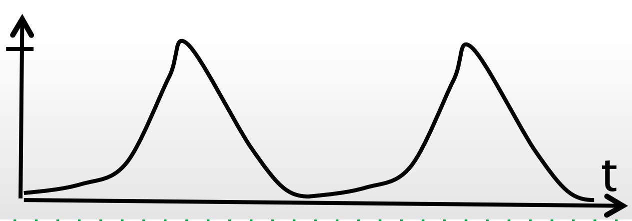
static cutting



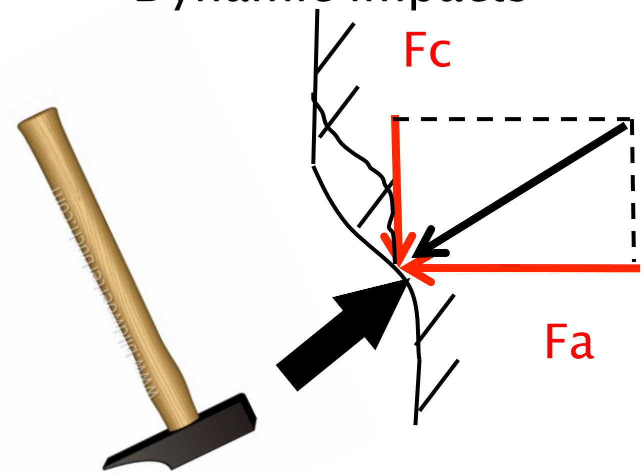
Force on the rock



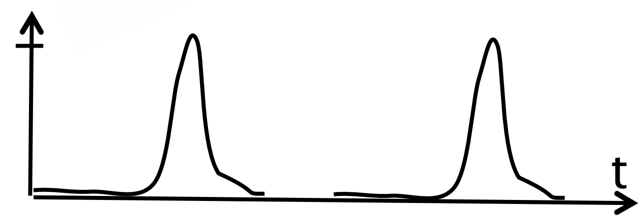
Load on the machine



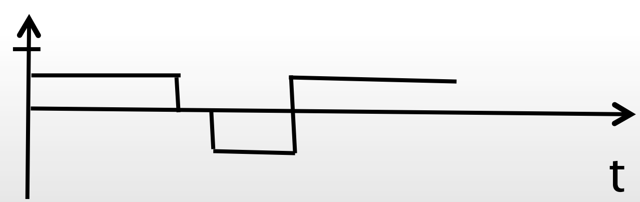
Dynamic impacts



Force on the rock



Load on the machine



State of The Art Undercutting

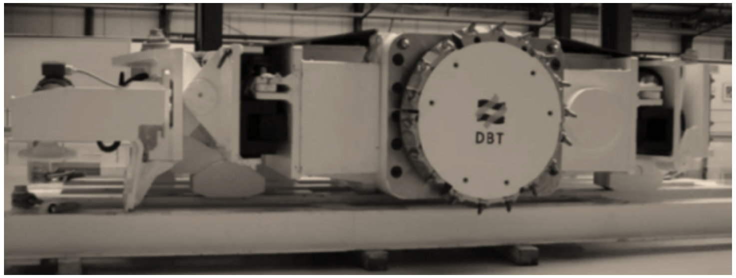
Wirth

Field tests

Discs

Undercutting

PASSIV



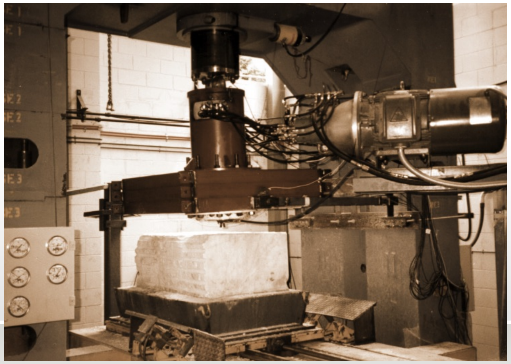
Bucyrus (DBT)

Field tests

Bits

Undercutting

ACTIVATED



CRC-Mining

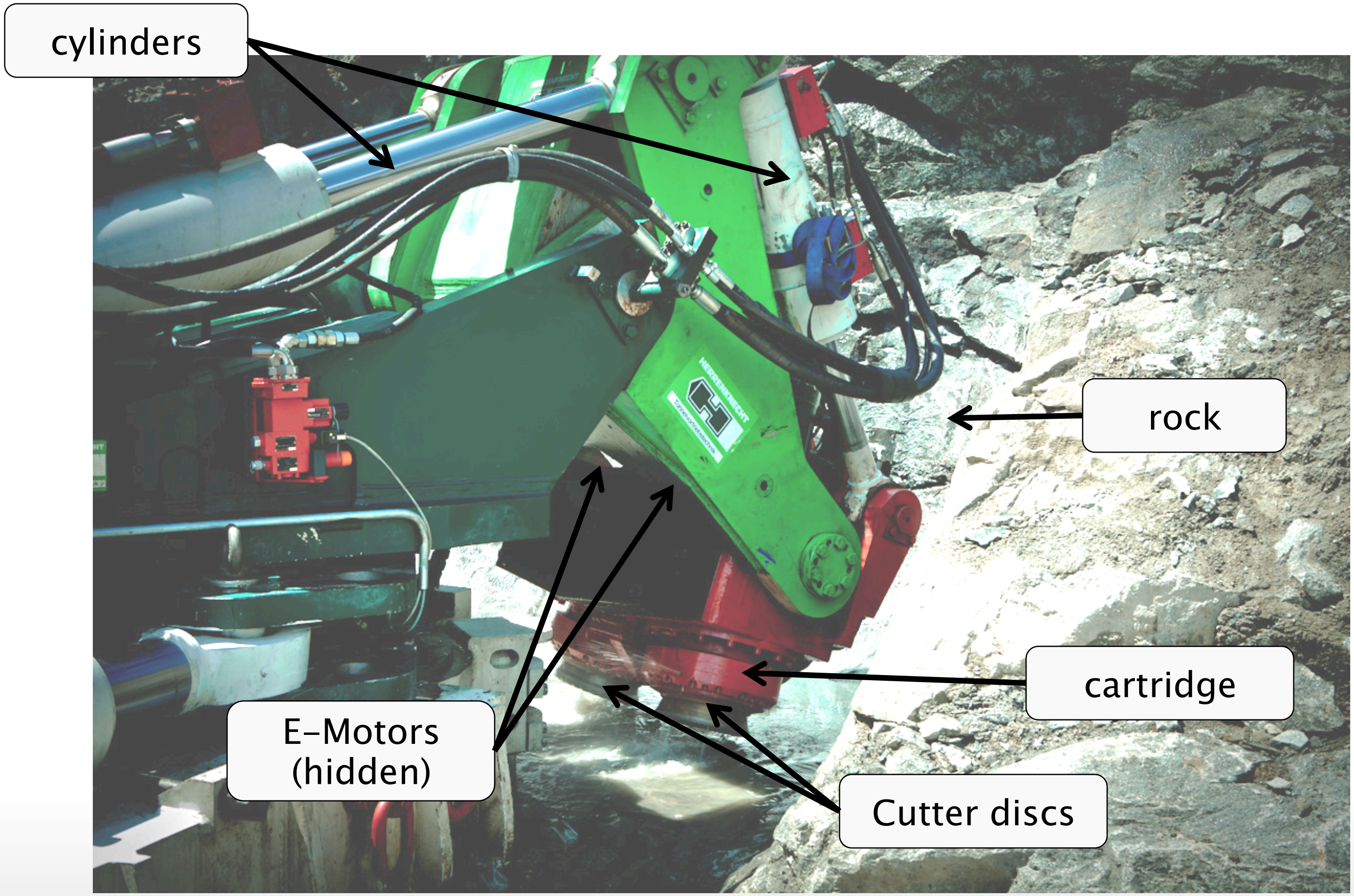
Labor tests
+
Field tests

Discs

Undercutting

ACTIVATED

Oscillating Disc Cutter Prototype



Possible Application

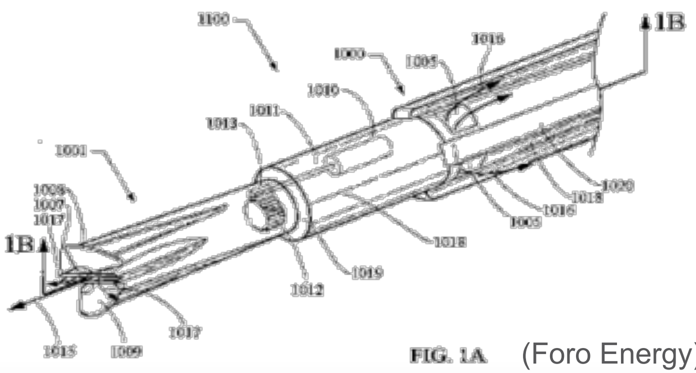


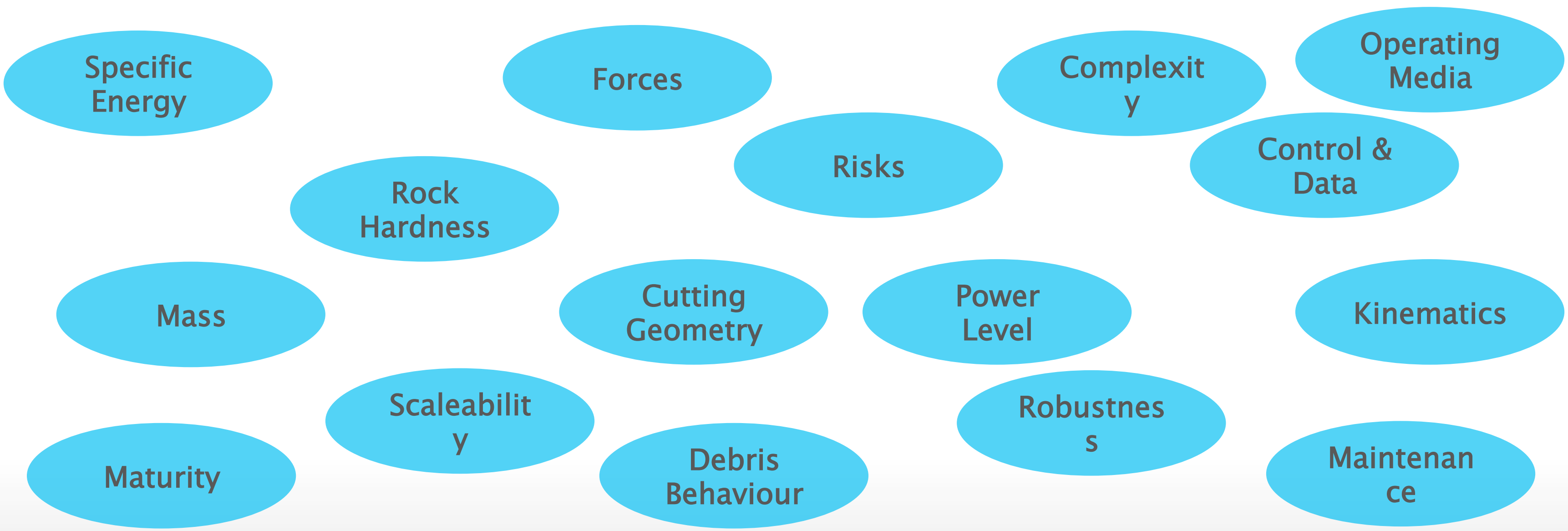
FIG. 1A (Foro Energy)

- Platform independent tool with scaleable operation principle

(Nasa-Lance)

Outlook

- Transfer of wear and failure models from mining & construction to soil collection rovers
- Development of requirement framework for practical cutting technology which is matched to space mechanism capabilities



Thank You