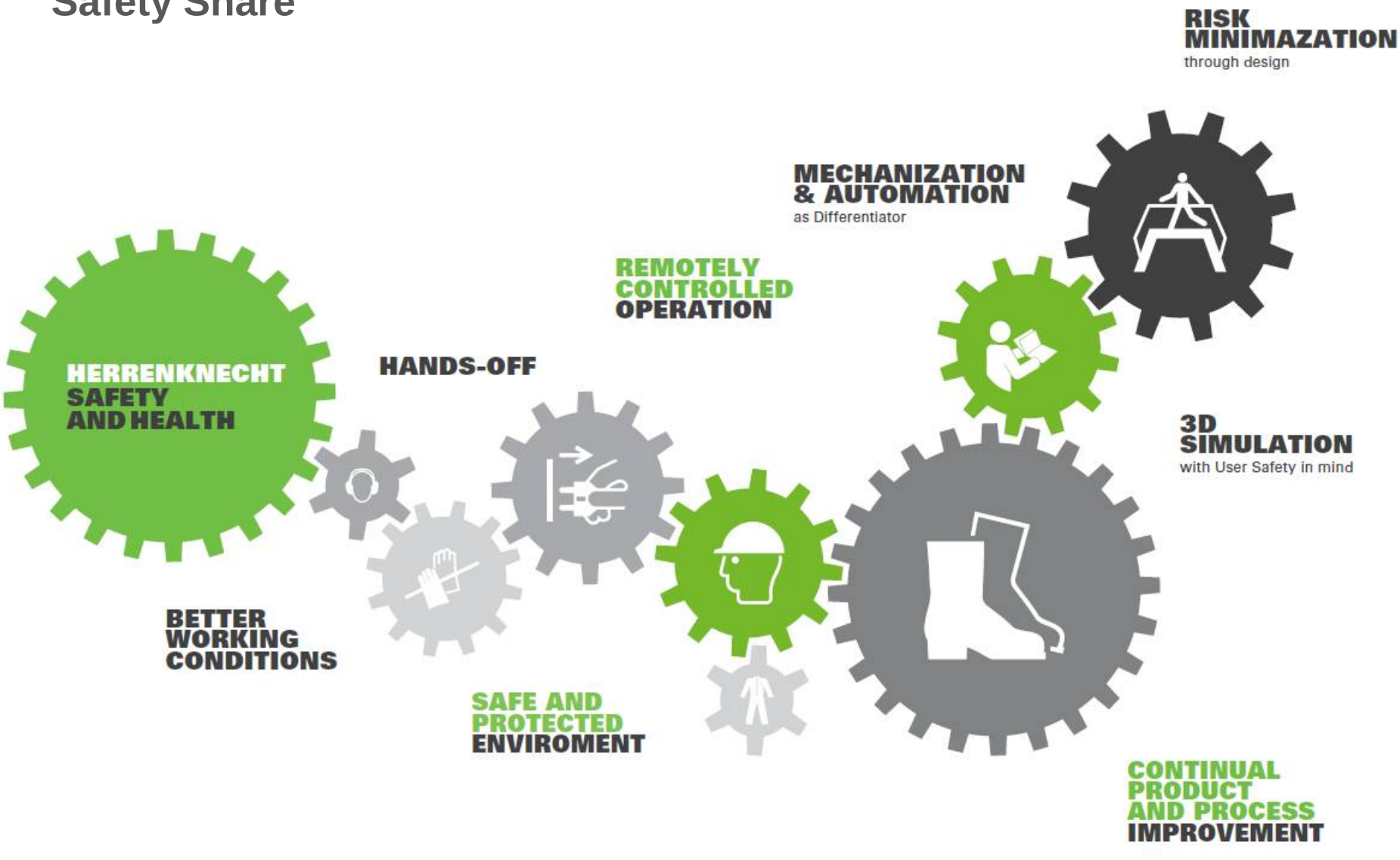
Herrenknecht Mining | Pioneering Underground Technologies

Mechanized Shaft & Raise Excavation Webinar

22nd January, 2020 – Patrick Rennkamp & Danny Harquail

Safety Share



- Introduction Herrenknecht and Mining
- Overview of Shaft Boring Machines and references
- Boxhole Back Reaming Developments
- Questions?

HERRENKNECHT IN SCHWANAU

- Founded in 1977
- Site area: 199,800 m²
- 18 Assembly workshops for different product applications
- Today around 4,600 employees worldwide, 2,000 in Schwanau & around 200 young people in training

Herrenknecht | Global

– 76 Locations: represented on all continents

– 4,100 Projects worldwide

Herrenknecht | Business Units

TRAFFIC TUNNELLING

- Roads
- Railroad
- Metro
- Water
- Sewage
- Hydropower
- Electricity

UTILITY TUNNELLING

- Communication
- Water
- Sewage
- Hydropower
- Electricity
- Oil gas
- Shafts

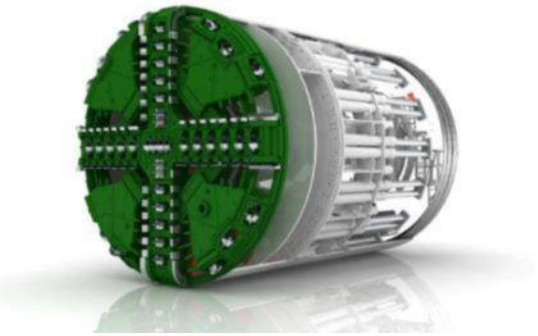
EXPLORATION

- Onshore
- Offshore
- Geothermal energy

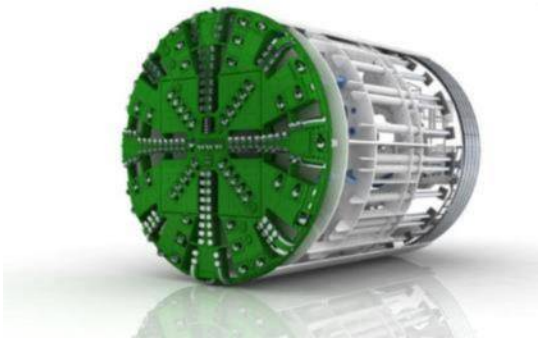
MINING

- Exploration
- Production

All Around Tunneling Solutions | Core Products for Traffic Tunneling

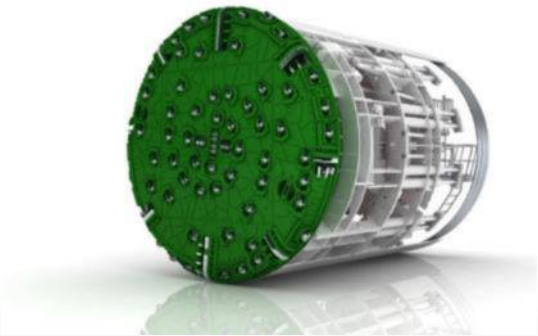


- EPB Shield



- Mixshield

- Gripper TBM



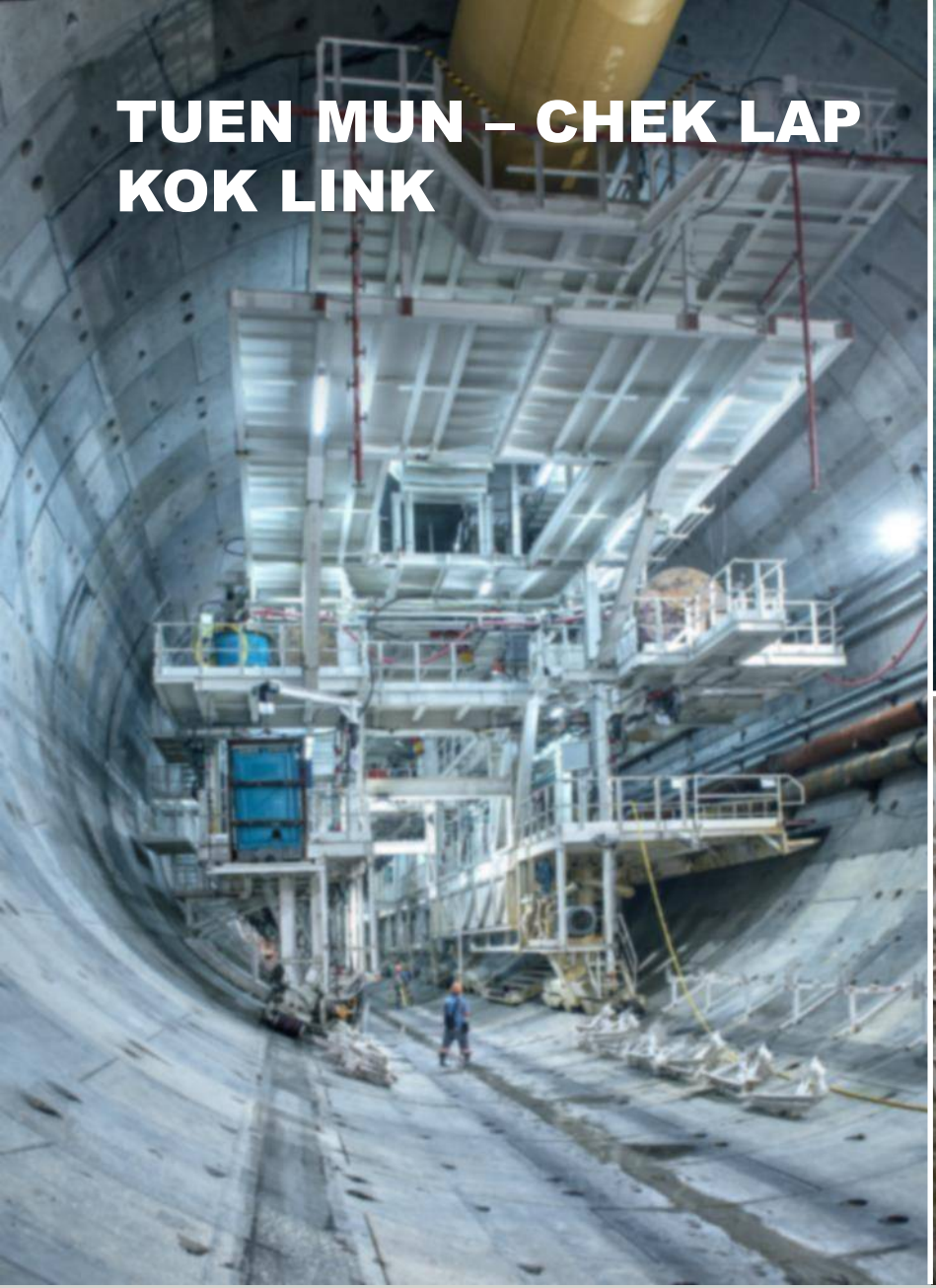
- Single Shield TBM

- Double Shield TBM

THE BRENNER BASE TUNNEL

Lot 2-3 Mauls / Mules

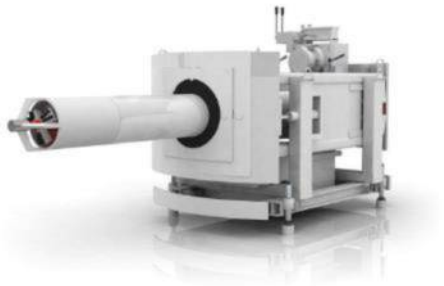
TUEN MUN – CHEK LAP KOK LINK



All Around Tunneling Solutions | Core Products for Utility Tunnelling

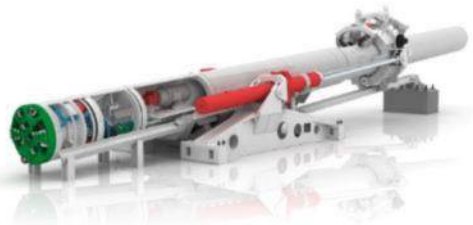
- AVN Machine

- Partial-face Excavation Machine

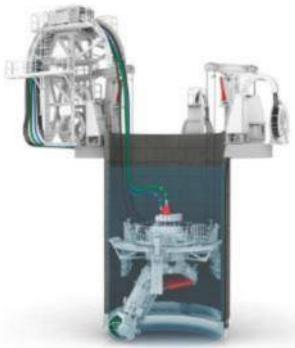


- Auger Boring Machine

- HDD Rig



- Direct Pipe®

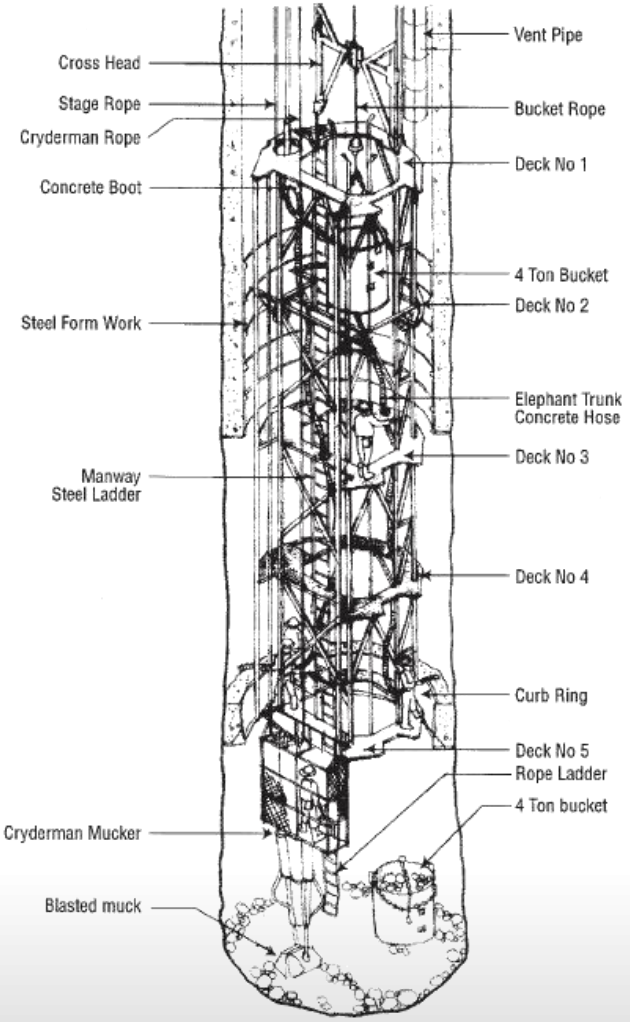


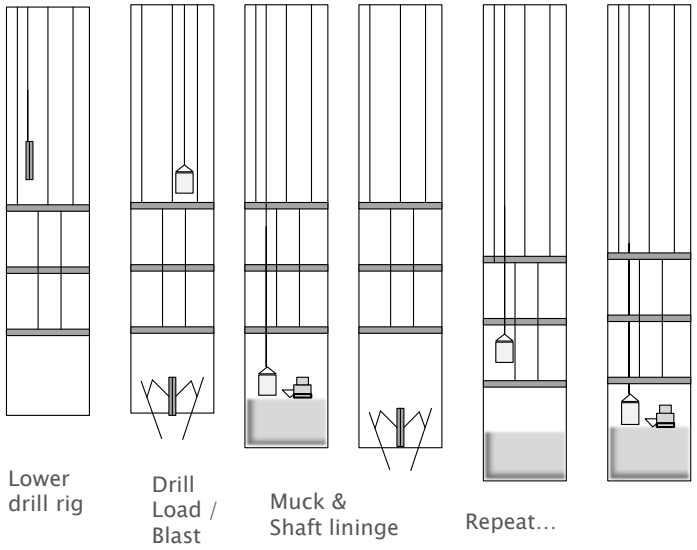
- Shaft Sinking Machine

Herrenknecht Mining

Product Portfolio

Conventional D&B Shaft Sinking





https://www.youtube.com/watch?v=xpehTws0nUc

Herrenknecht Mining | Mechanical Shaft Boring Systems vs. Conventional Drill & Blast

	Mechanized	Drill & Blast
Excavation	Cutting Tools	Explosives
Mucking	Pneumatic / Slurry	Cactus Grab
Advance Rate	3-4 meter/day	1-2 meter/day
Process	Continuous	Cyclic
Lining	Shotcrete/Cast in Place/Tubbing	Shotcrete/Cast in Place/Tubbing
Hoisting	Bucket	Bucket

Mechnical Cutting

- The basic rock cutting tools for mechanical excavation include:
  - Drag Cutter
  - Picks
  - Disc Cutters
  - Roller Cutters
  - Button Cutters

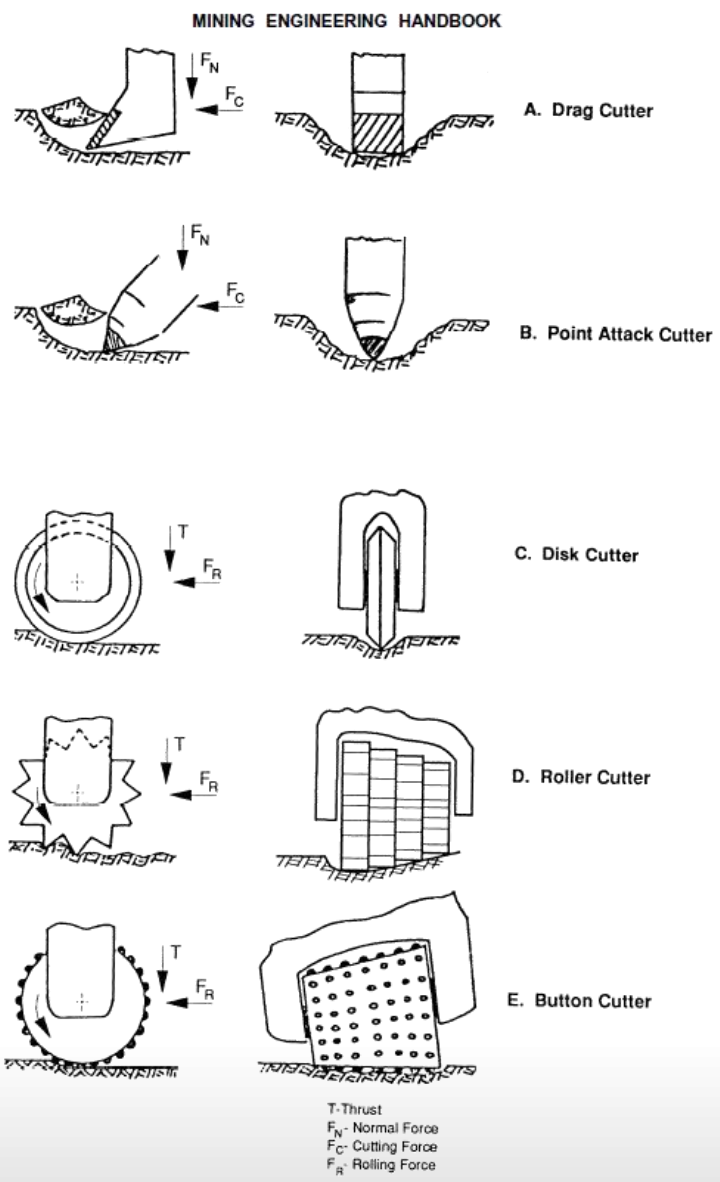
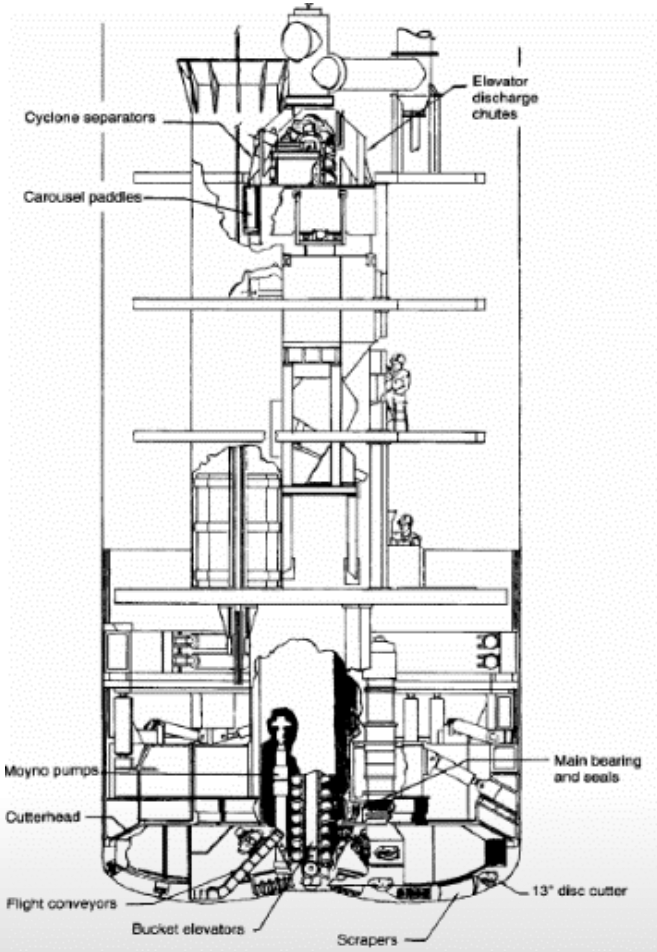
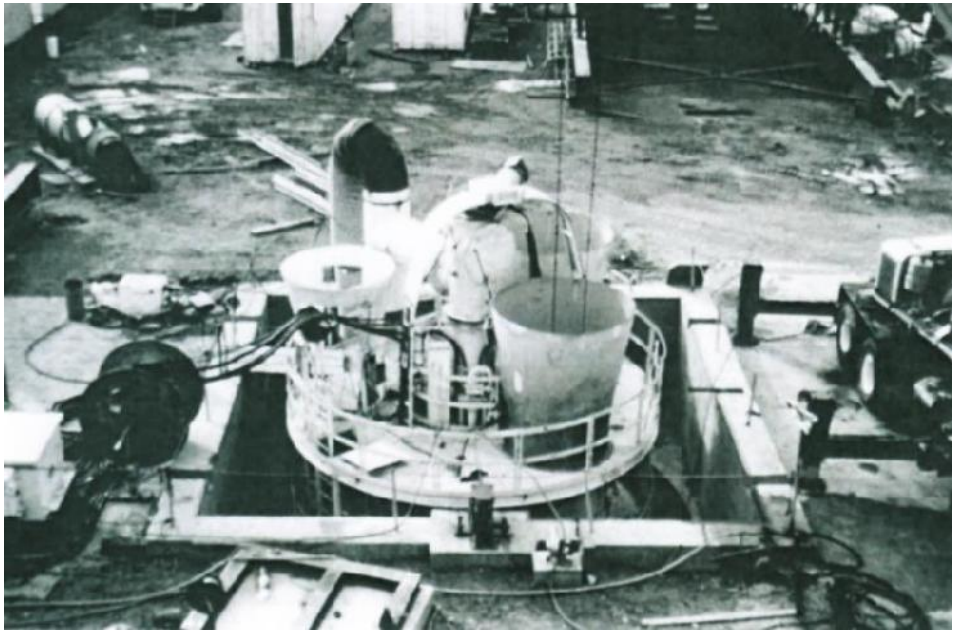


Fig. 22.1.1. Rock cutting techniques (after Roxborough and Rispin, 1973).

History of Mechanized Shaft Sinking |

The Full Face Blind Shaft Borer 1978, Robbins

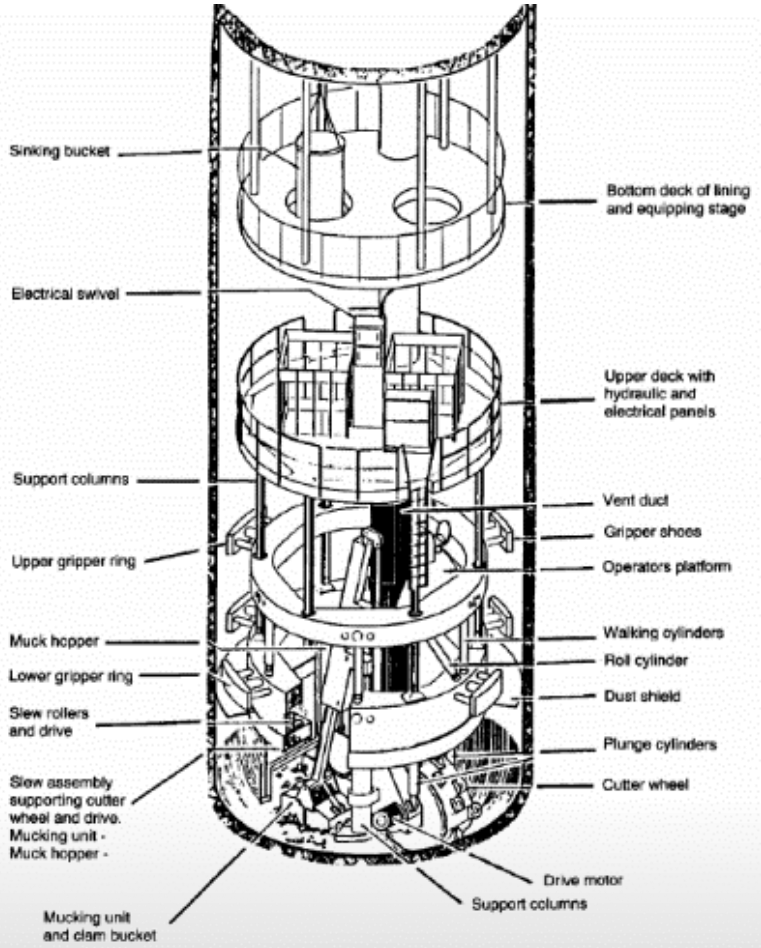


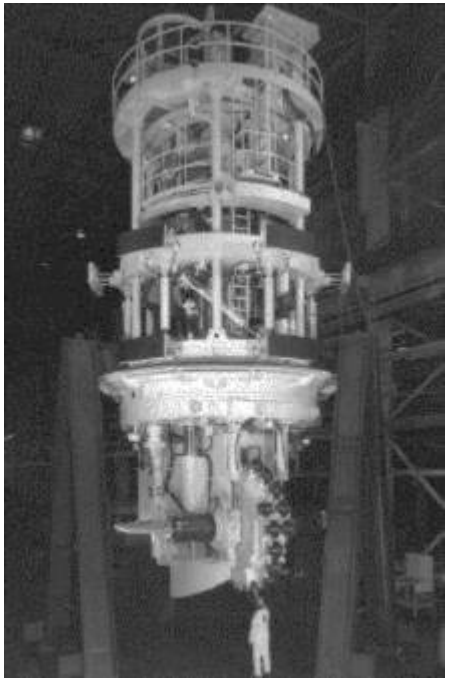


- Self supporting machine (gripper systems)
- Full face excavation with disc cutterhead
- Chain and bucket conveyors as primary mucking system

History of Mechanized Shaft Sinking |

Shaft Boring Machine, Robbins 1984

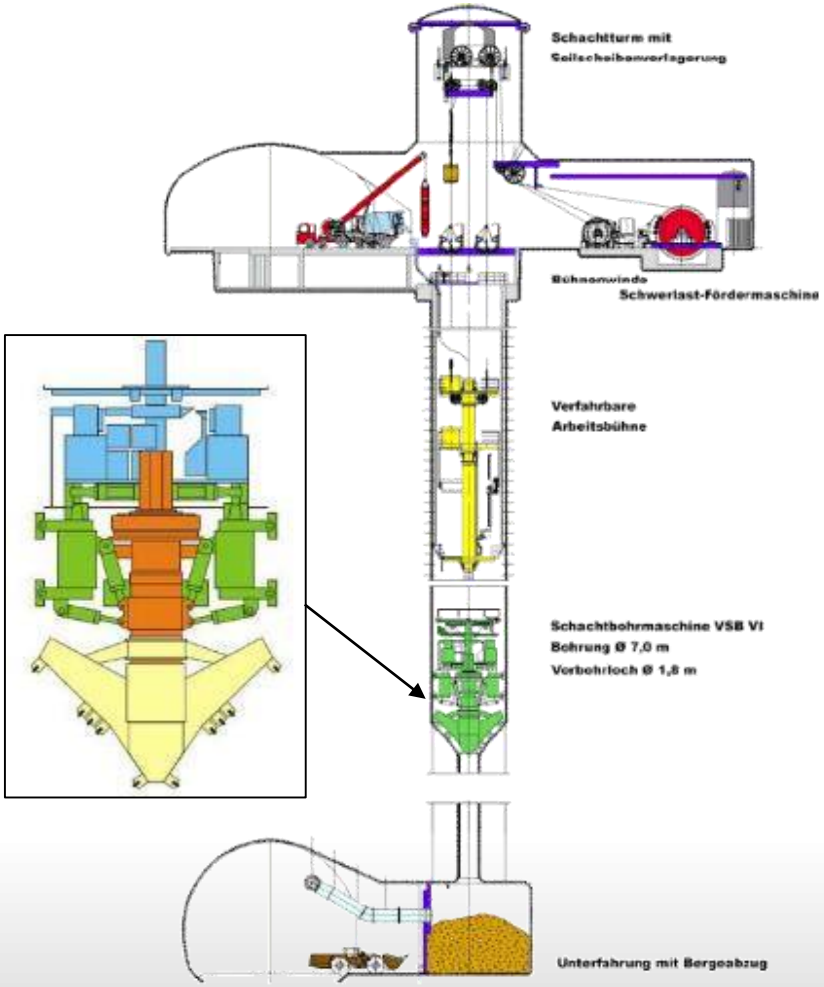




- Self supporting machine (gripper systems)
- Partial face excavation with disc cutter drum
- Clam bucket as primary mucking system

History of Mechanized Shaft Sinking |

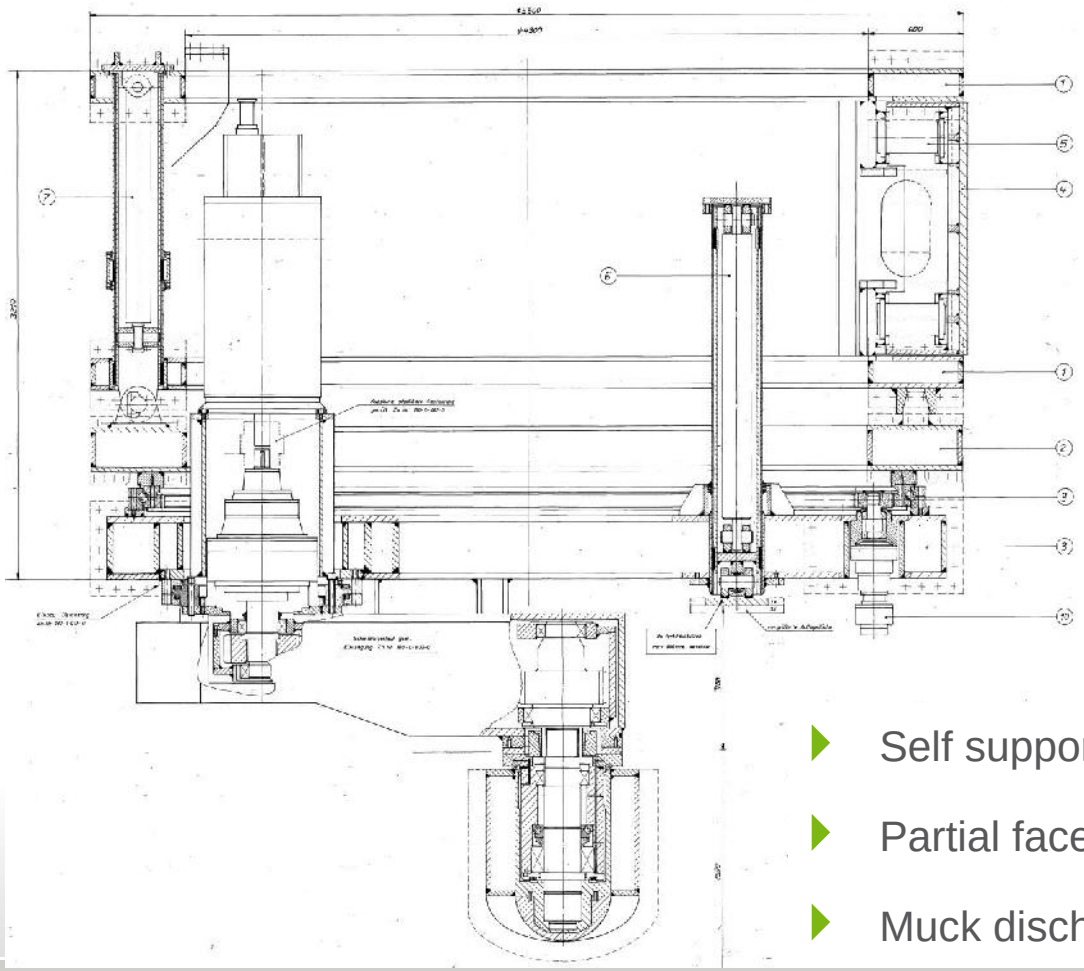
V-MOLE, WIRTH



- Shaft enlargement works
- Self supporting machine (gripper systems)
- Full face excavation with disc cutterhead
- Muck discharge through pre shaft

History of Mechanized Shaft Sinking |

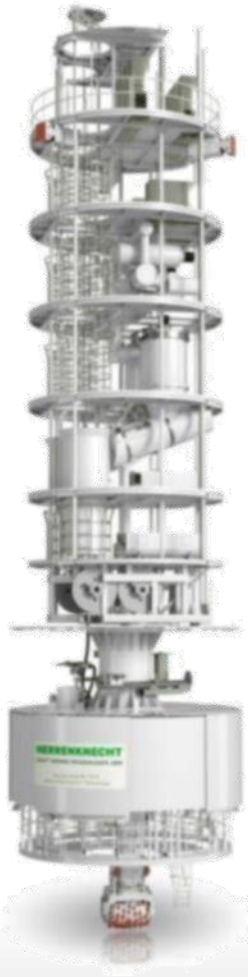
Herrenknecht Shaft Sinking Machine 1986



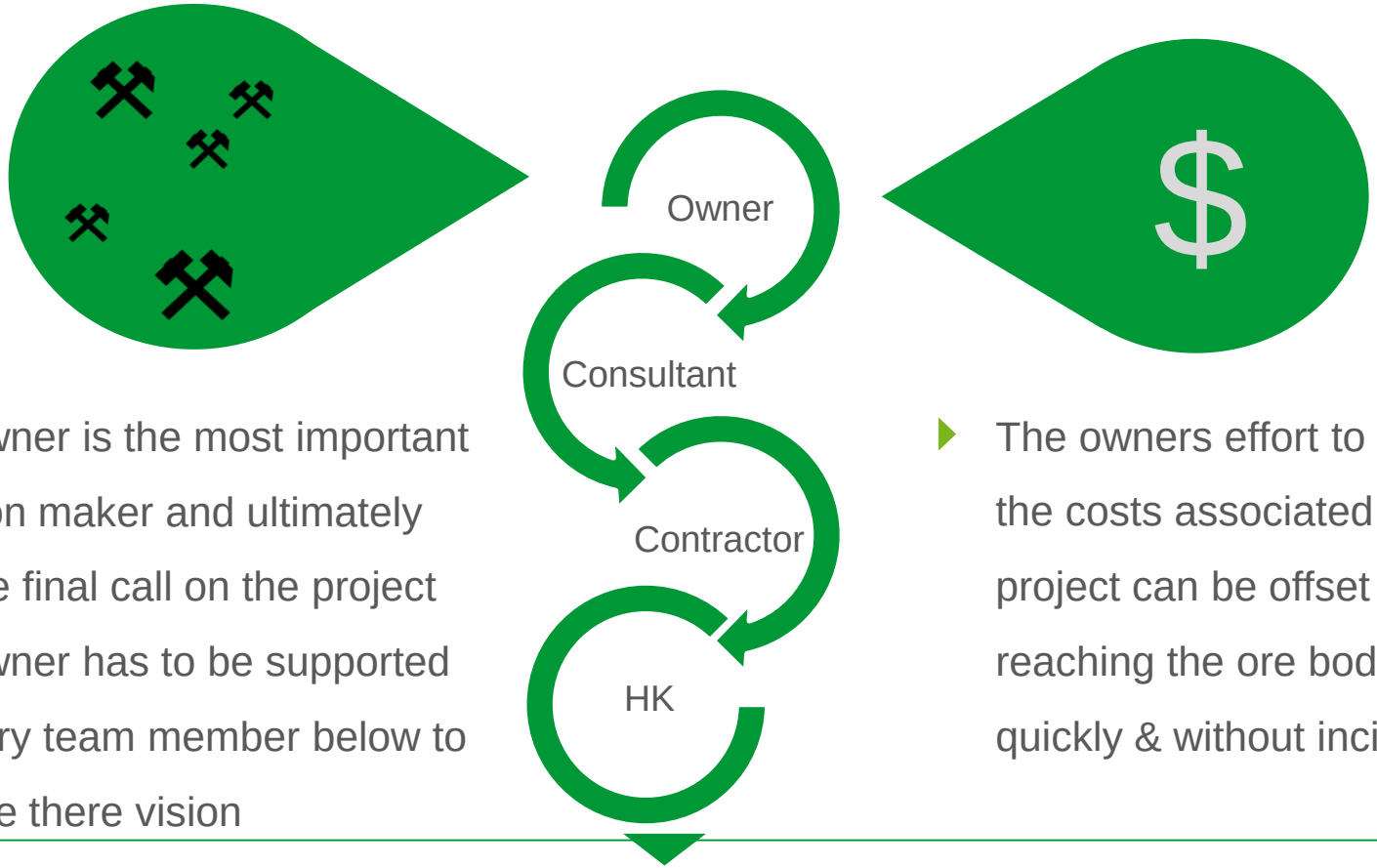
- Self supporting machine (gripper systems)
- Partial face excavation with roadheader boom
- Muck discharge through pre-shaft

Reasons for a Mechanized Approach | General

- Increased level of **Health & Safety**
- **Mechanical excavation** systems provide greater advantages compared to drill & blast methods for the shaft design
- Cleaner, improved and modern **working environment**
- An increased level of **digital automation**
- Generates **real-time data acquisition** and ready reporting analysis – for full transparency
- Higher logistical efficiency due to greater accuracy in excavation parameters
- Opportunity for **concurrent work activities**



Process and Involvment for Sucessful Shaft Sinking Projects



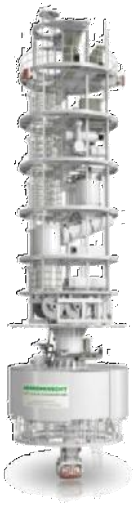
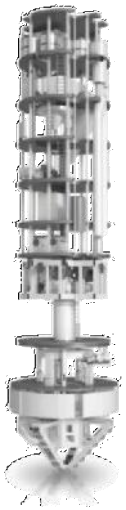
- The owner is the most important decision maker and ultimately has the final call on the project
- The owner has to be supported by every team member below to achieve there vision

- The owners effort to be balance the costs associated with a project can be offset by reaching the ore body more quickly & without incident

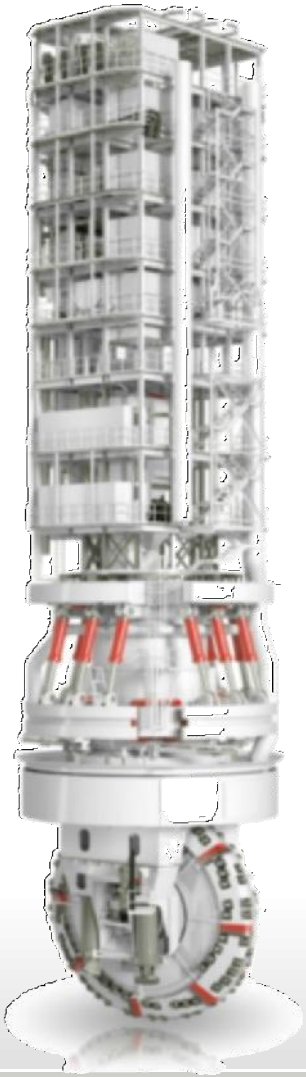
Buy in by the owner required

- Introduction Herrenknecht and Mining
- Overview of Shaft Boring Machines and references
- Boxhole Back Reaming Developments
- Questions?

Herrenknecht Shaft Sinking Machines | Overview

Type	**SBM** | Shaft Boring Machine	**SBR** | Shaft Boring Roadheader	**SBC** | Shaft Boring Cutterhead	**SBE** | Extension Shaft Boring Machine
				
Geology	Hard rock	Soft/medium hard rock	Hard rock	Hard rock
Shaft diameter	10 – 12 m	8 – 12 m	8.1 – 8.6 m	7,5 – 9,5m
Shaft depth	~ 2000 m	~ 1000 m	~ 1000 m	~ 3000 m
Machine height	60 m	40 m	35 m	20 m
Machine weight	3000 t	350 t	350 t	350 t
Mucking method	Mechanical	Slurry / Pneumatic	Slurry	Pilot hole

SBM - Shaft Boring Machine



Geology	hard rock (~280 MPa)
Shaft diameters / depth	10 - 12m / ~ 2000 m
Machine height / weight	60m / 3000t
Suspension	gripping system
Mucking method	mechanical
Rock Support/Lining	rock bolts, shotcrete
Net excavation	~10.5 m/d

*Developped with Rio Tinto – Mine of the Future™

Target of Rio Tinto

- “Civil Technology” with high mechanization level to be combined with “Mine Development Technology”, which has a lower mechanization level

HK Approach

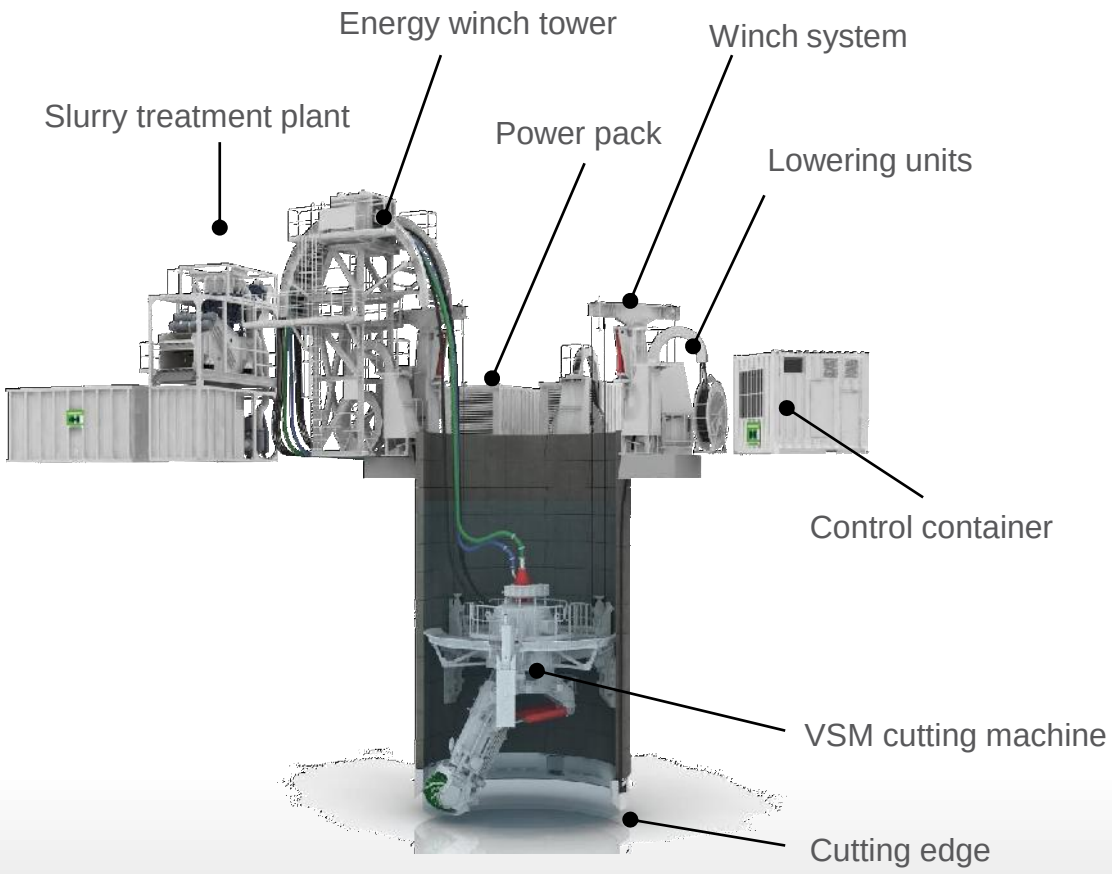
- Excavation System: Combination of full-face cutter head and cutting drum
- Primary Mucking System: Bucket Wheel and Continuous Vertical Conveyor
- Support and Thrust System: Single Gripper and Support Shield
- Rock Support: Permanently Installed Rock Bolters and Shotcrete Robot
- Pre-Excavation Drilling: Permanently installed rock drill (L≈3 m)

SBM | Basic Assemby Units

1. Cutterhead
2. Dust shield
3. Rock bolters
4. Gripper system
5. Vertical conveyor

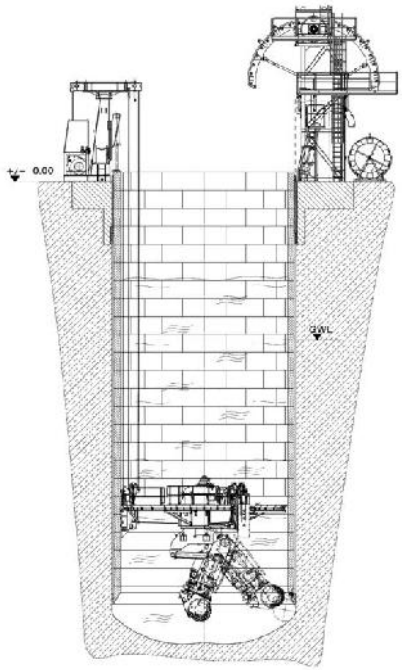
https://www.herrenknecht.com/de/produkte/productdetail/shaft-boring-machine-sbm/

VSM - Vertical Shaft Sinking Machine | System Overview

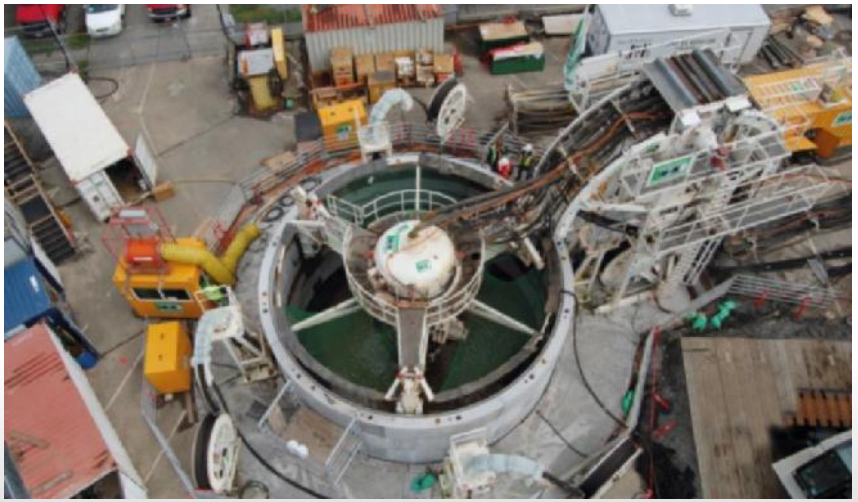


- Shallow shafts (~ 120 m)
- Shaft Ø 4,5 – 16m
- Blind sinking method
- Soft rock
- Water bearing soils
- Heterogeneous geological conditions
- Hydraulic mucking system
- Pre-cast liner system
- Submerged operation
- Remote controlled
- High shaft accuracy

VSM reference | Ballard Siphon Replacement Project



- 45 meter-deep launch shaft for microtunnelling
- Advance rates of up to 2.6 meters per shift
- High level of worker safety, low noise emission and reduced construction time compared to conventional methods
- Shaft sinking below groundwater possible

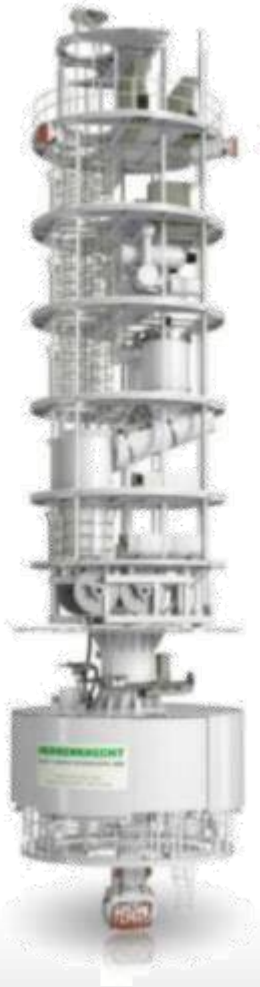


Herrenknecht VSM Development | From Submerged to Dry Excavation

	2004 - Kuwait	**2004 - Indonesia**	**2006 - Israel**
Shaft depth	30 m	100 m	160 m
Shaft diameter	8 m	2,5 m	6,9 – 9,3 m
Max. excavation rate	3,5 m/shift	2 m/shift	5 m/shift
Material transport	pneumatic	rope excavator	pilot hole

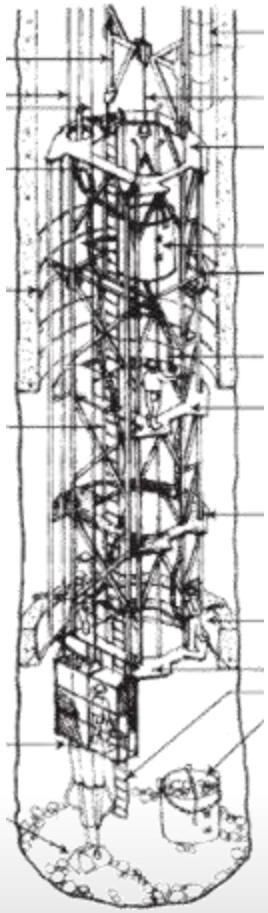
SBR - Shaft Boring Roadheader

Geology	soft/medium hard rock (~120 MPa)
Shaft diameters / depth	8 - 12m / ~1600 m
Machine height / weight	40 - 70m / ~400t
Suspension	Headframe / ropes
Mucking method	slurry, pneumatic
Rock Support/Lining	per requirement
Net excavation	~3 m/d

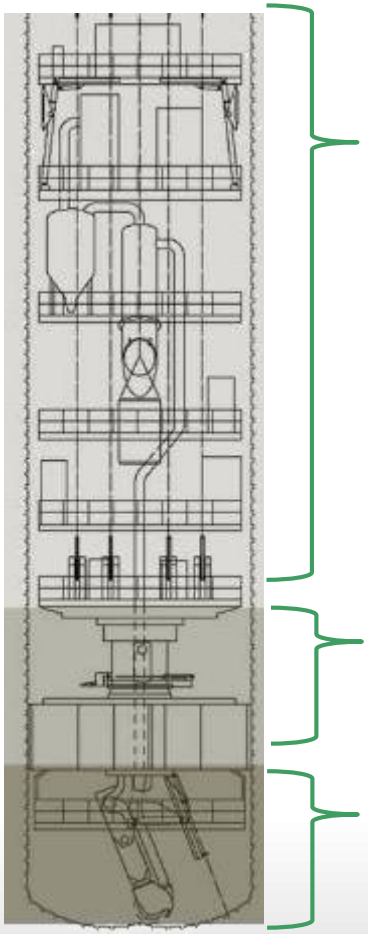


SBR | Built-In Safety

Before…



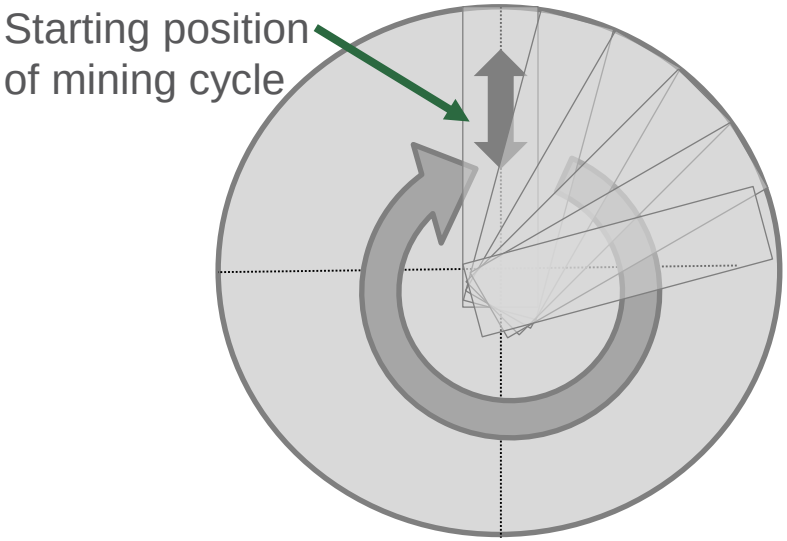
…after Jansen

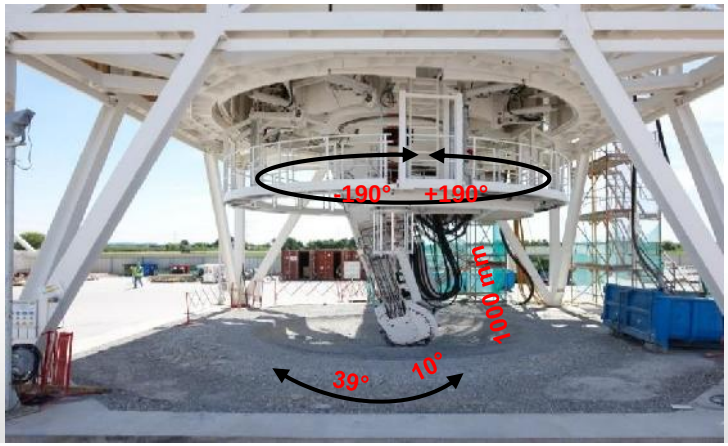


Location of workplaces and equipment on the SBR

- **Work Decks**
  - Infrastructural components
  - Control cabin
  - Permanent work places
  - **P**neumatic **M**ucking **S**ystem (PNM)
  - Position of sheaves
  - Personal and material logistic
- **Rock support area**
  - Shotcrete application and rock bolting unit
- **Excavation chamber**
  - Boom with cutting drum and muck intake hopper
  - Access during maintenance time only

SBR | Excavation and Mining Cycle





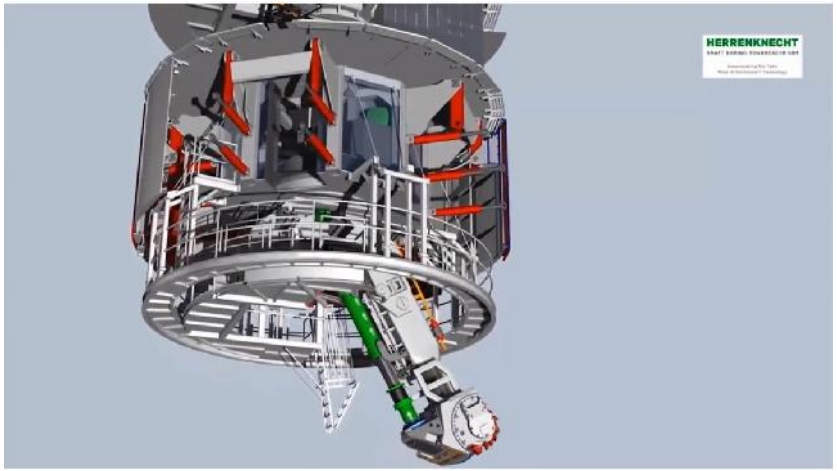
https://www.herrenknecht.com/de/produkte/productdetail/shaft-boring-roadheader-sbr/

- Steps of Mining Cycle:

1. Cut trench in 12o´clock
2. Move boom to center position
3. Slew a few degrees clockwise
4. Cut next trench
5. Repeat until in 12o´clock position
6. Extension of the boom
7. Re-start of the cutting cycle
8. When 1m of the bench is cut,
   the SBR will be lowered 1m and the mining cycle starts again…

SBR | Pneumatic Mucking System

- Air Flow per. Blower: 7800 m³/h
- Tank Capacity: 4.5 - 7m³
- Vertical Distance: 25 m
- Number of Blowers: 1 - 3



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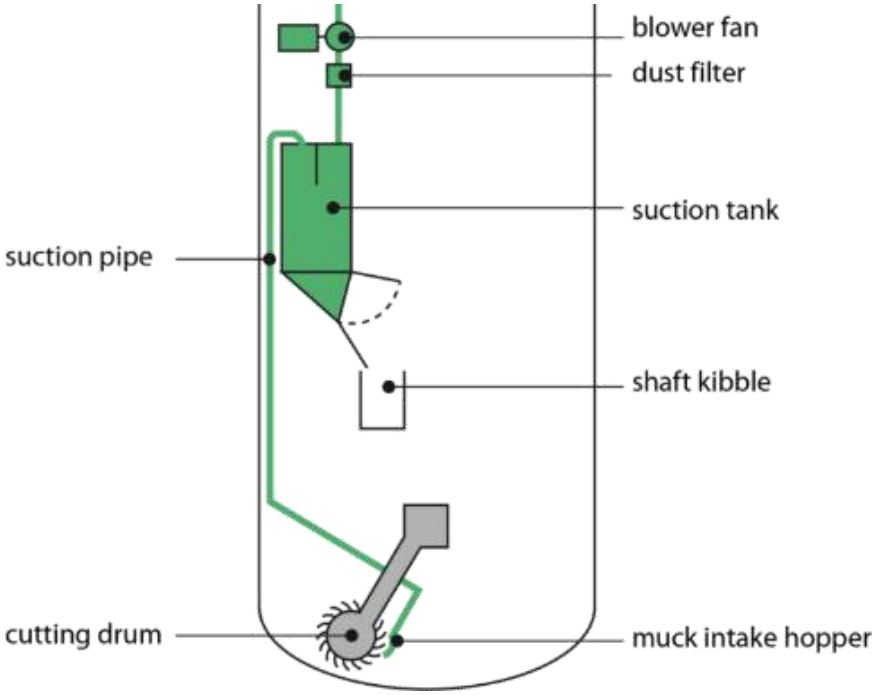


SBR| References

MI-003 & MI-004

BHP Jansen Project Overview

- Potash mine in Canada
- DMC contractor
- Blind shafts for Service and Production
- Shaft depth up to 1,005m,
- Diameter between 8-12m
- Lining: shotcrete, cast in place and bolt & mesh
- 2 x SBR
- Geology: medium hard rock (~120 MPa)
- Frozen ground up to 700m depth

SBR | Jansen | Rock Support / Lining

- **Initially planned rock support:** Screen mesh support in combination with shotcrete

https://www.herrenknecht.com/de/produkte/productdetail/shaft-boring-roadheader-sbr/

SBR | Jansen | Rock Support / Lining

- **Actual rock support:** Fibre reinforced concrete cast in place using shaft forms

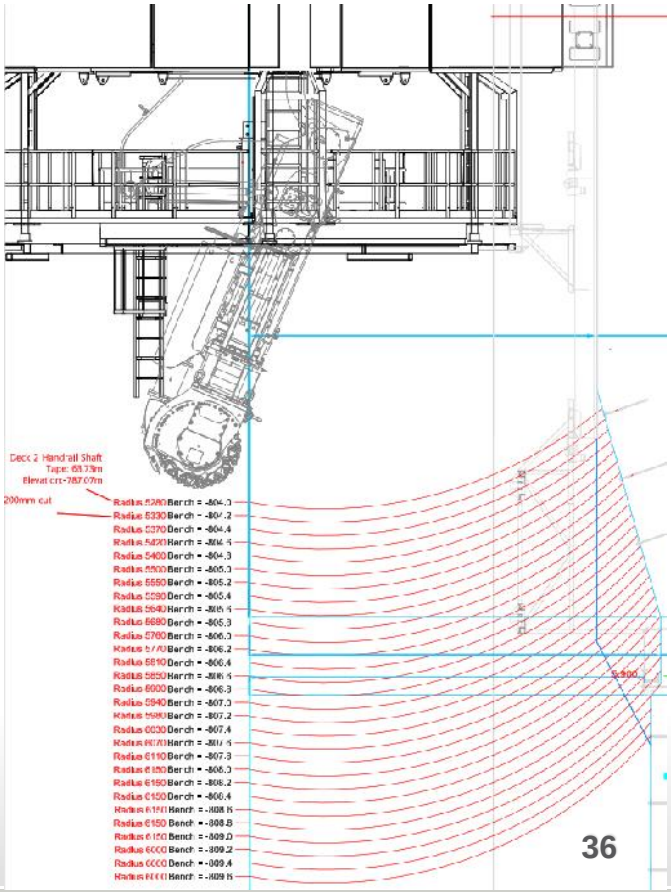
- **Rock support in the Blairmore layer (-430 to -480m):** Segmental steel lining rings installed with Blairmore Ring Erector.
- **Rock support below -828 m:** PET, geo grid and split set bolts.

SBR | Jansen | Rock Support / Lining

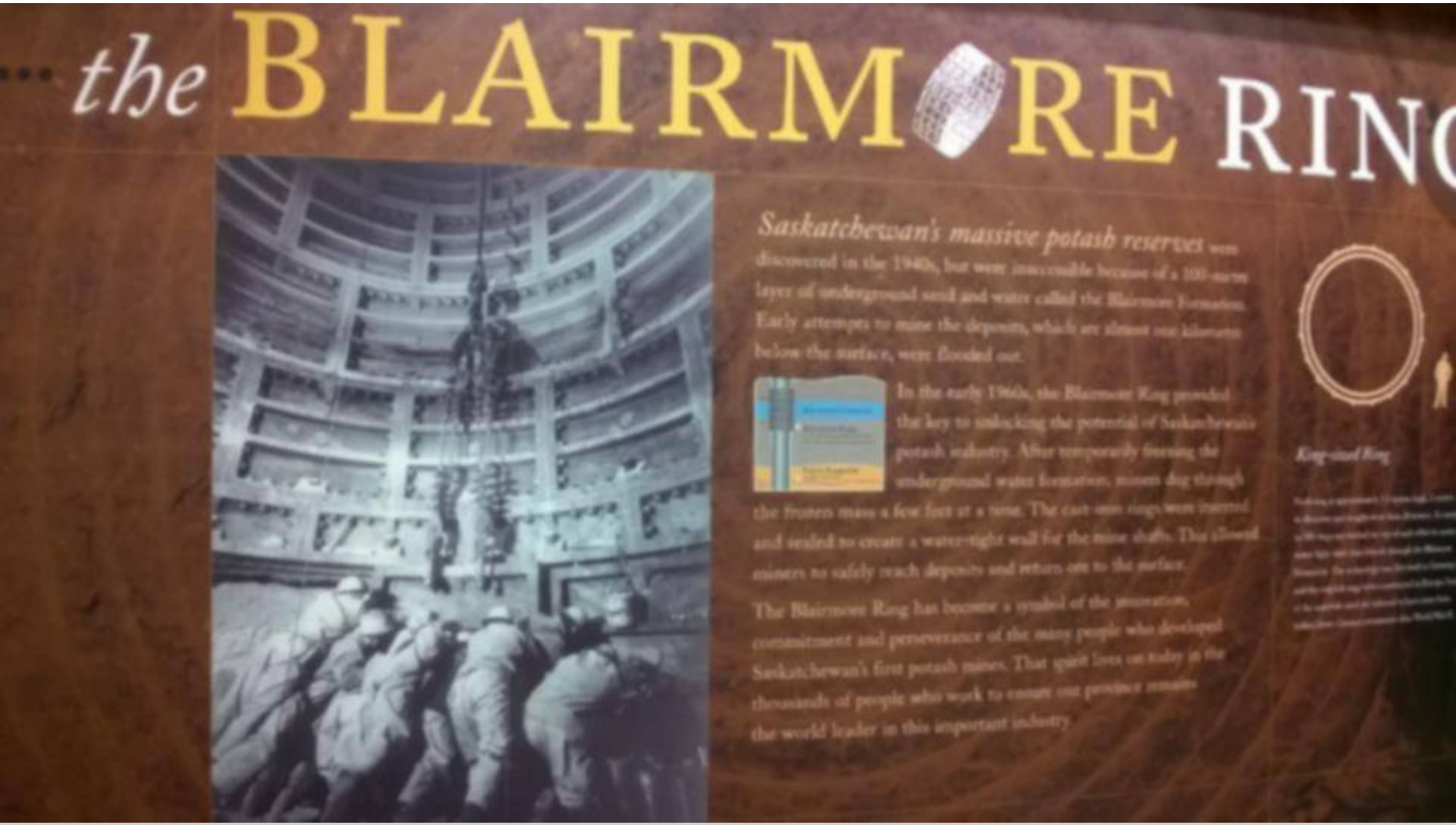
Bolt and Mesh

SBR | Jansen | Rock Support / Hitches

Thanks to the machines´ ability to excavate variable diameters, large/mini hitches were excavated into the shaft wall throughout the length of the shafts to improve liner friction.



The Famous Blairmore Layer of Saskatchewan



SBR | Jansen | Rock support / Blairmore Ring Erector

- Lower Cretaceous Blaimore formation extends over the whole of Southern Saskatchewan
- Innovative Blairmore Ring Erector technology allowed for a fully mechanized installation of 8,35 m ID rings with minimal open wall exposure.
- 16 pieces of tubbing weighing 2 tonne each forming one ring
- Doubled the expected performance for ring installation as planned

SBR | Jansen | Reaching Shaft Bottom

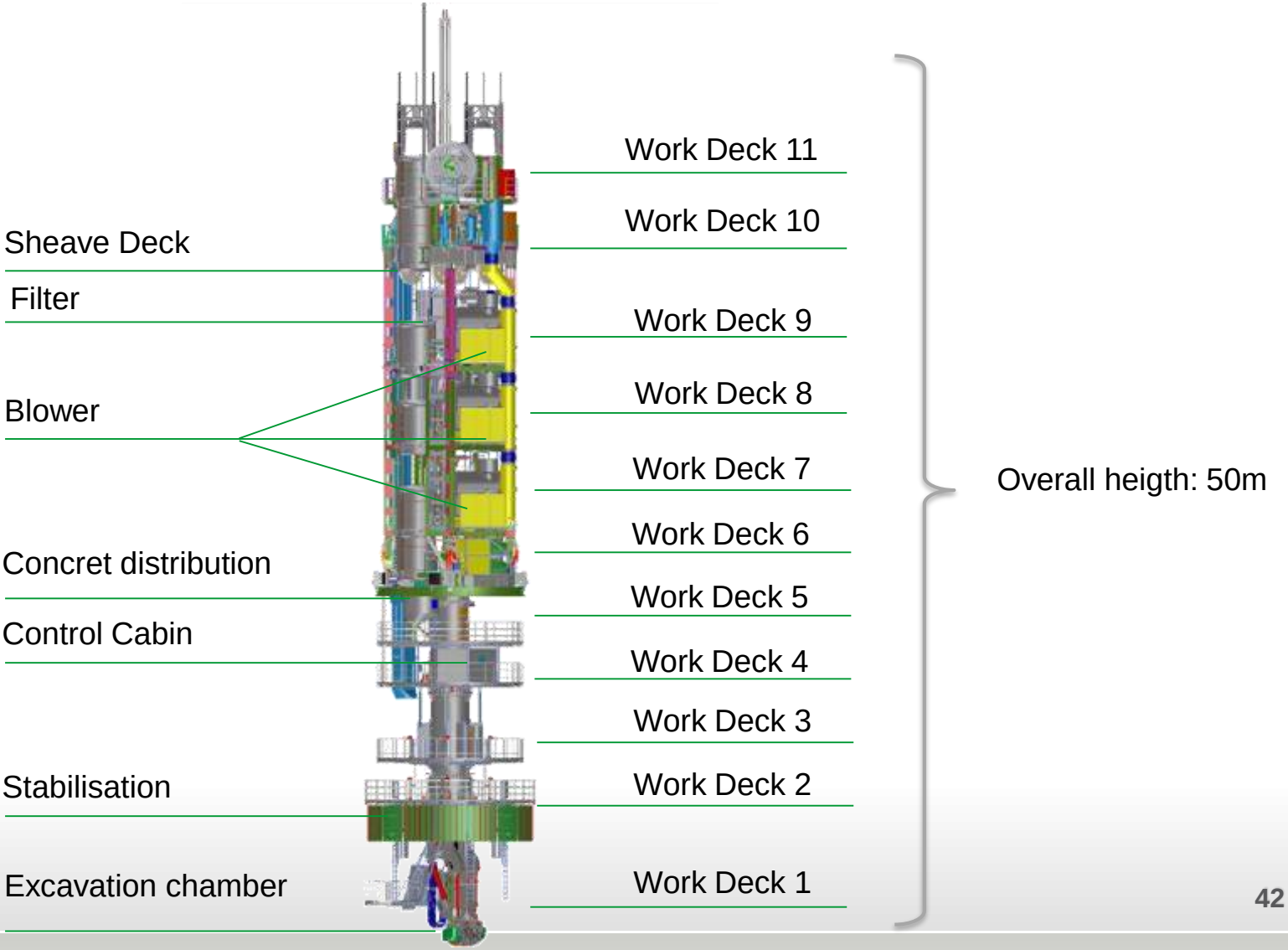
SBR | Jansen | SBR Removal

- Excavation chamber equipment removed and replaced by a support platform
- SBR brought up to the sub-collar
- SBR´s support platform connected to the sub-collar with Ø82,5 mm structural strands
- With SBR fully supported by the structural strands and using stabilizers at three elevations, the winch ropes removed from the SBR
- The machine removed from the shaft in five major lifts ranging from 35 t to 90 t.

SBR | Jansen Summary

- The Jansen Potash project has been a proof of the SBR concept and showed that shaft sinking using purely mechanical excavation can safely and efficiently accomplish the BHP vision.
- With a high degree of accuracy and top-level planning, the two shafts at the Jansen Mine demonstrate that mechanical excavation of deep shafts is possible and brings several benefits not achievable by conventional means.
- Using the success and lessons learnt from Jansen, the next generation of SBRs are already active and producing at a high level of efficiency with more on their way.

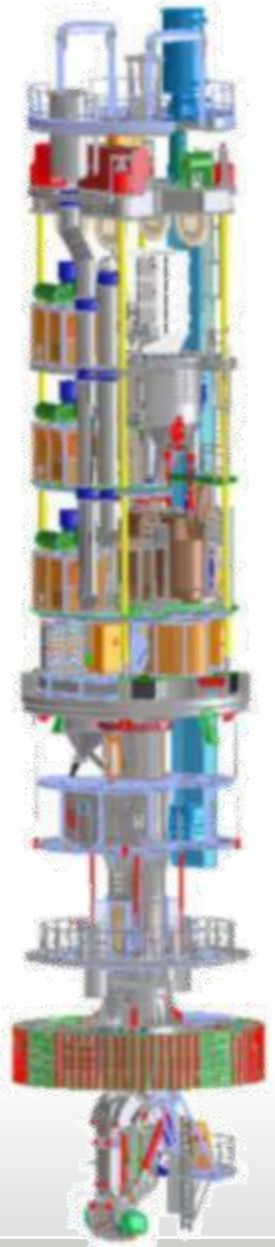
SBR | Second Generation



Shaft Boring Roadheader | References

Slavkaliy ordered two SBRs: MI-029/30

- Delivery time 11/12 months after workshop commissioning
- Client: Deilmann-Haniel Dortmund (Redpath group)
- Potash Plant in Nezhinsky, Belarus
- Production of 2 Mio. Tpd of potash in 2024
- Sinking of two shafts with two SBR machines (725m & 698m)

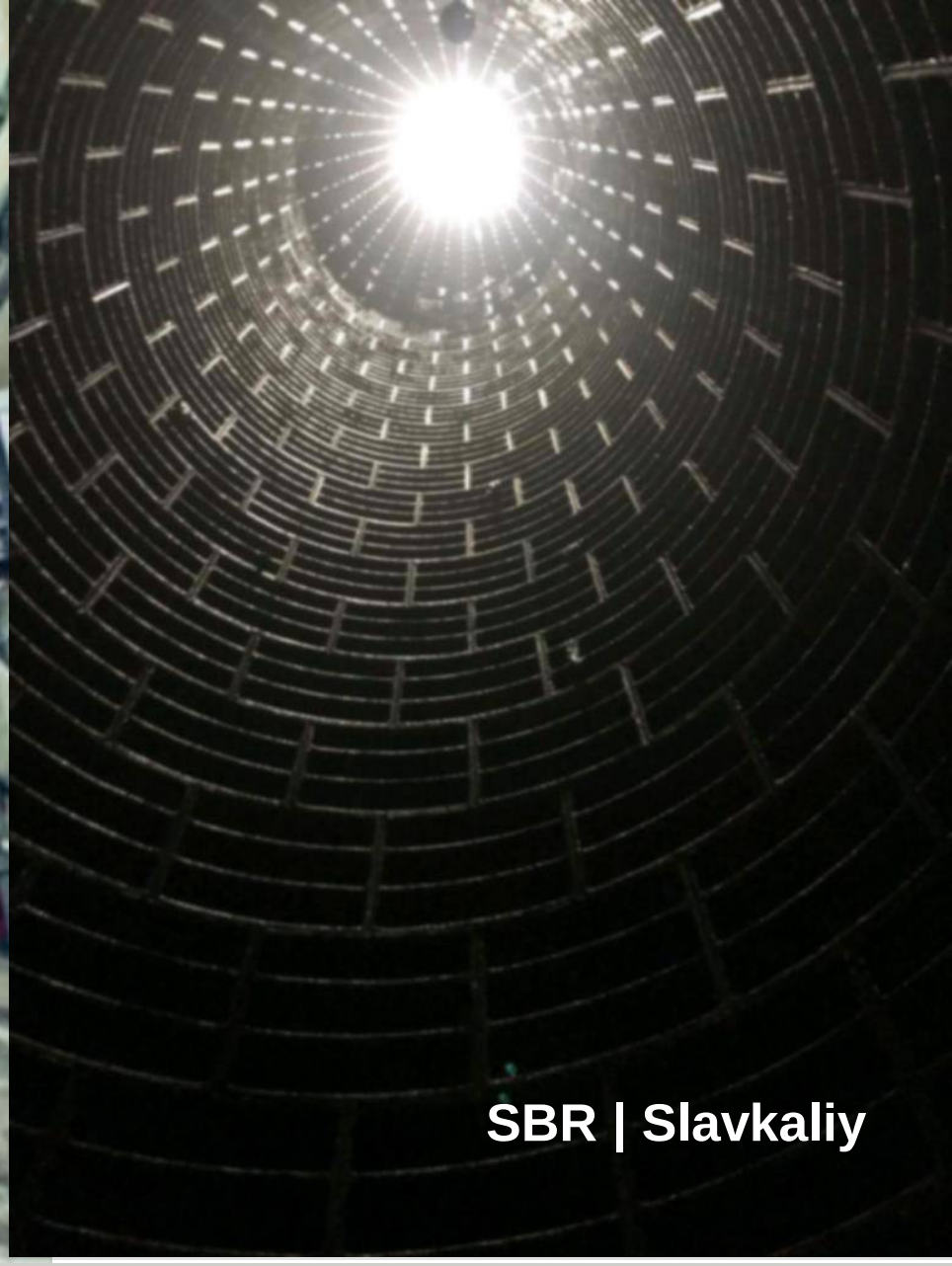


SBR | Slavkaliy | Overview

First cut, December 11th, 2018

SBR | Slavkaliy | Belarus shaft sinking record.


SBR | Slavkaliy



SBR | Slavkaliy

Shaft Boring Roadheader | References

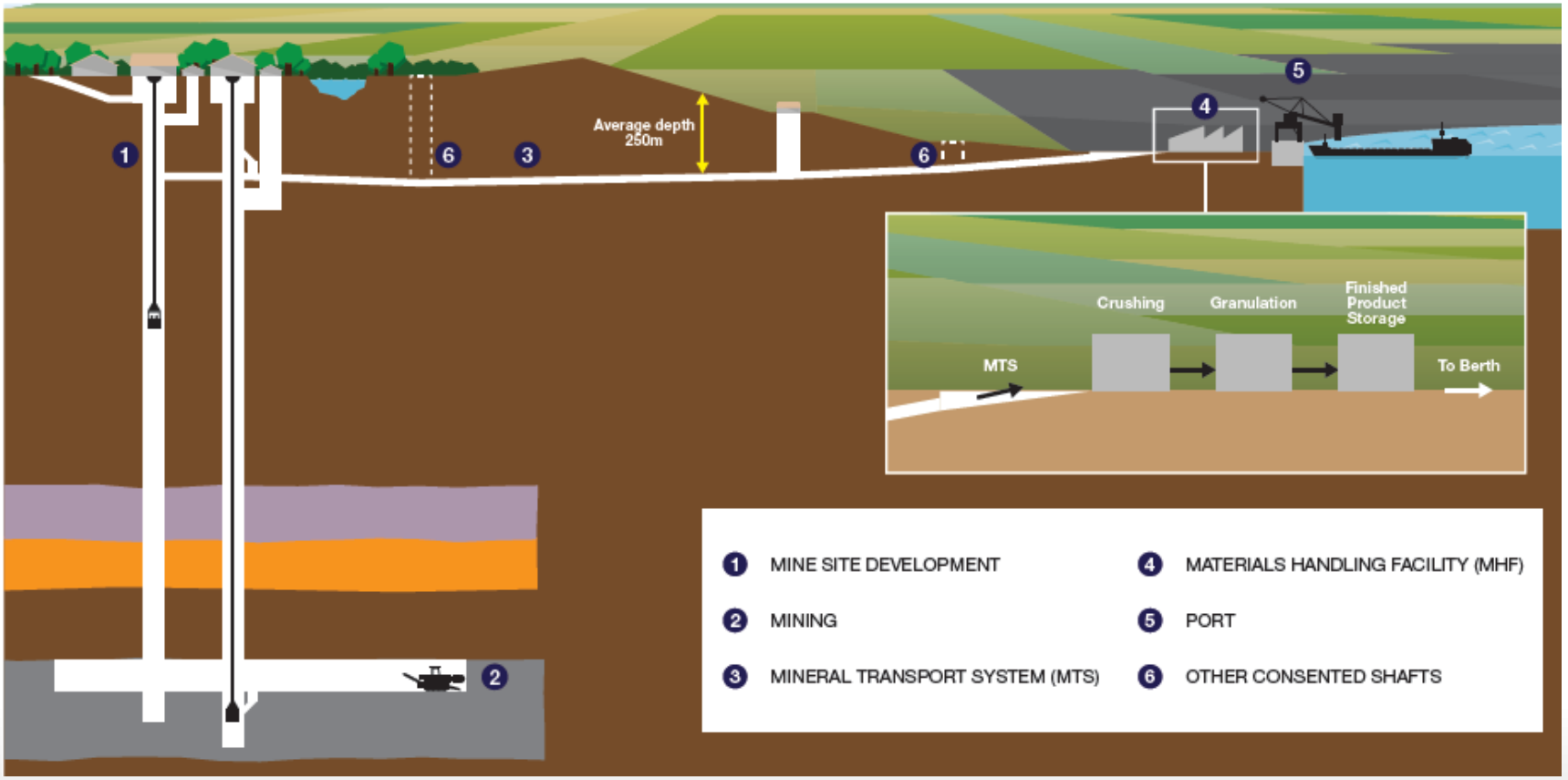
MI-035 & MI-036

DMC UK ordered two SBR
for the North Yorkshire Polyhalite Project

- Owner: SIRIUS MINERALS
- Contractor: DMC UK
- Two shafts with two machines
- 1600m depth

YORKPOTASH
A Sirius Minerals Project

SBR | Sirius | Project overview



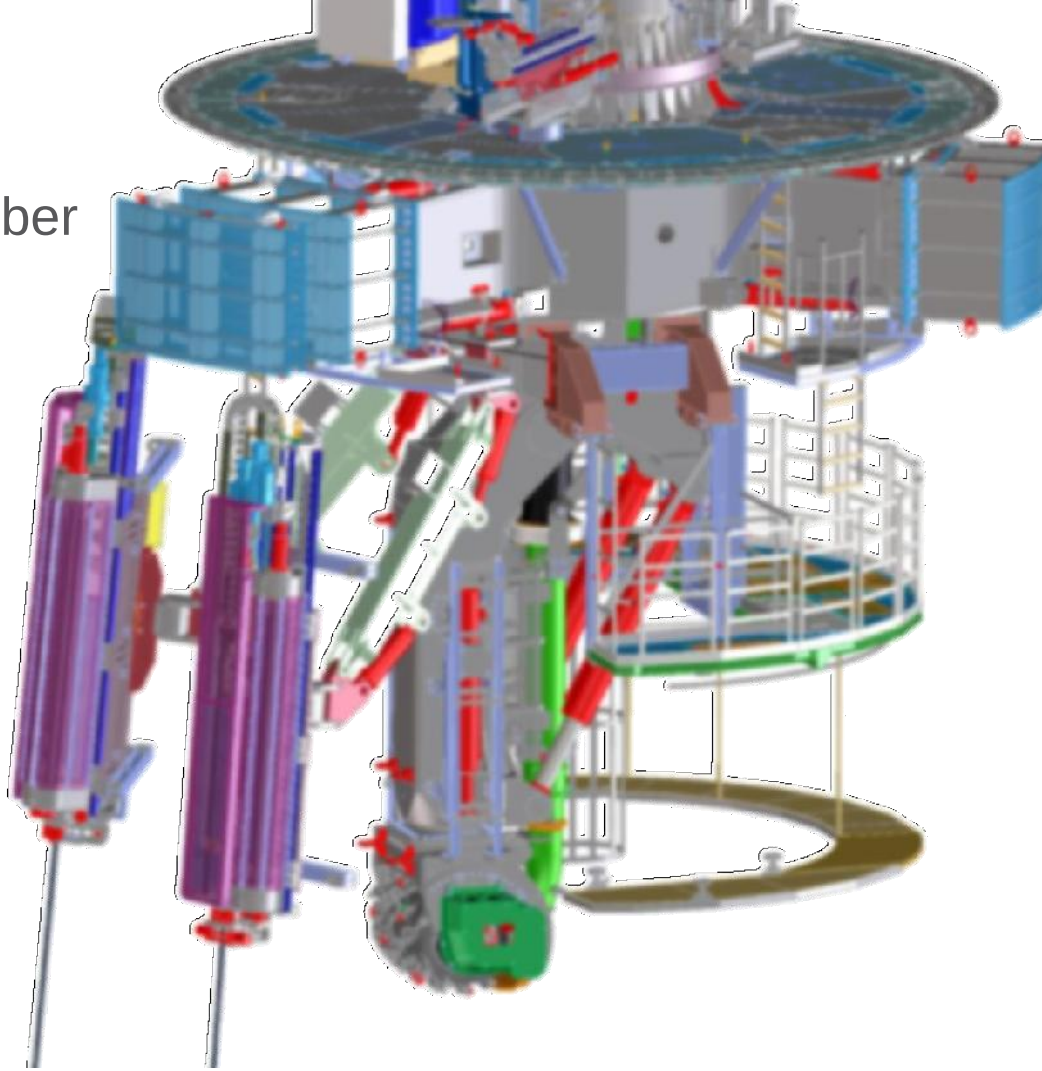
SBR | Sirius | Jobsite overview

SBR | Sirius | Grounting

Jumbos in the Excavation Chamber

The main functions are:

- Initial grouting program
- Potential probe drilling
- Ground support installation
- The 2 jumbos can be dismantled and operated independently
- WASSARA hammer drills



SBR | Sirius | Workshop Assembly in Schwanau

HERRENKNECHT MINING

SBR | Sirius | Site Assembly

Shaft Boring Roadheader | Comparison

	MI-003/04	MI-029/30	MI-035/36
Project Name	Jansen	Slavkaliy Nezhinsky	North Yorkshire Polyhalite
Project Owner	BHP	Slavkaliy	Sirius Minerals PLC
Country	Canada	Belarus	United Kingdom
Client	DMC mining services	Deilmann-Haniel GmbH	DMC UK
Shaft depth "Service Shaft"	1000,0 m	698,0 m	1562,0 m
Shaft depth "Production Shaft"	1000,0 m	726,0 m	1600,0 m
Finished Inner diameter	8,0 m		6,8 m
maximumcutting diameter	12,3 m	10,1 m	10,5 m
Total height SBR	45,0 m	45,0 m	50,0 m
Total weight SBR	380 to	400 to	350 to
Type of mucking method	Pneumatic Mucking System		
Filter system	Dry filter system		
Forzen shaft	yes	yes	no
Tubbing Installation	yes	yes	yes
Ring Erector in excavation chamber	yes	no	yes
Ring Erector on rock support deck	optional	manual	yes
Bolt and Mesh	yes	no	yes
Concrete Liner System	yes	yes	yes

SBR | The Path Forward for Herrenknecht SBR's

The future of shaft sinking is moving toward automation while ensuring the highest levels of safety possible. As Herrenknecht we want to ensure the SBR will meet if not exceed our client´s expectation and to achieve this:

1. Increase simultaneous working processes

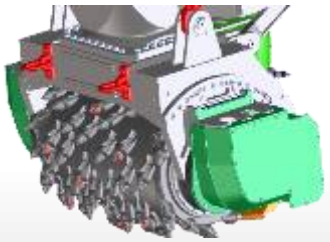
2. Modular format for individual client customization & quicker delivery times

3. Increase machine torque / advance rates

4. Capability to mine in harder geologies

Herrenknecht developed the 2nd generation of SBR based on lessons-learned from Jansen:

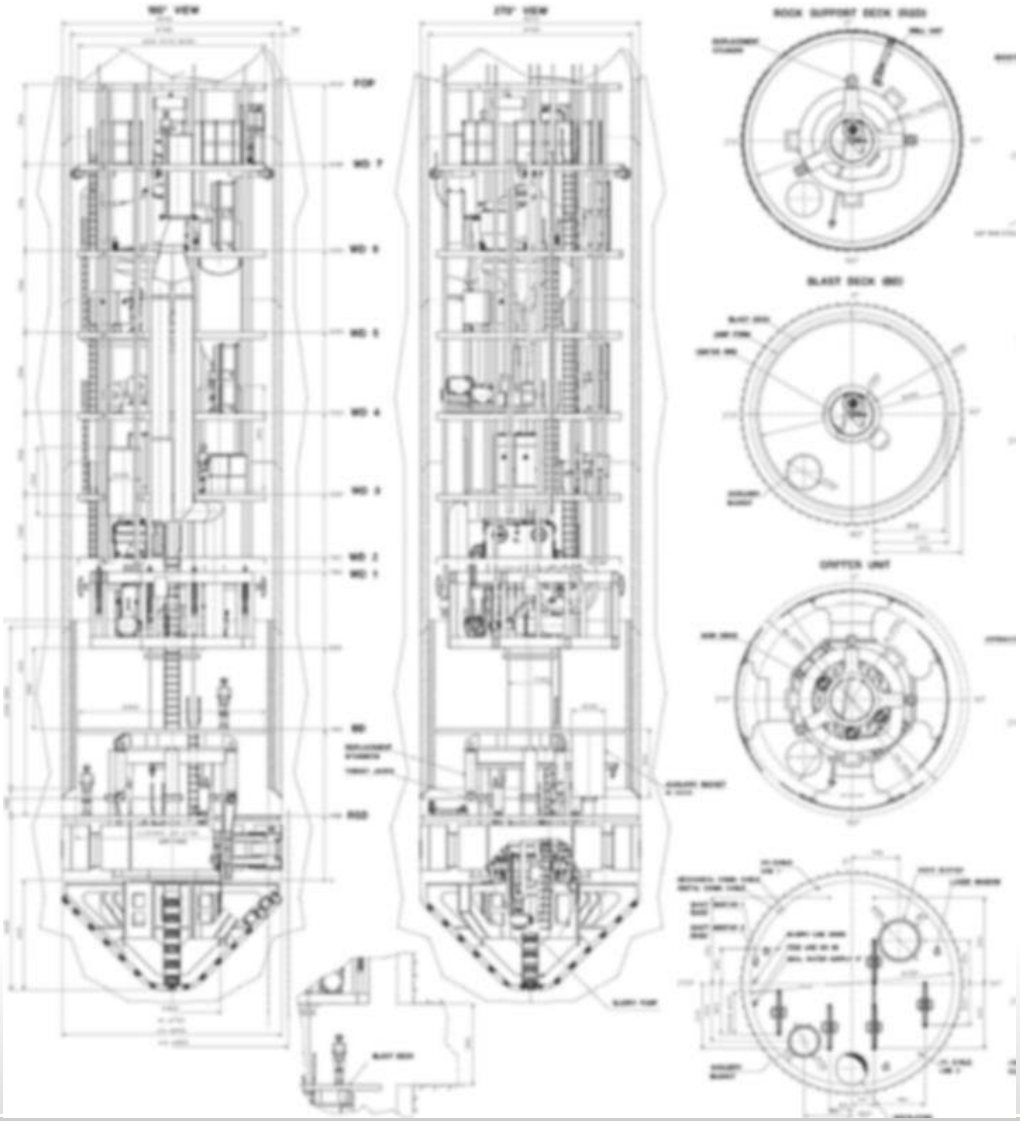
- More power at the cutting drum
- Better stabilization
- Improved PNM system
- Sheave deck on top

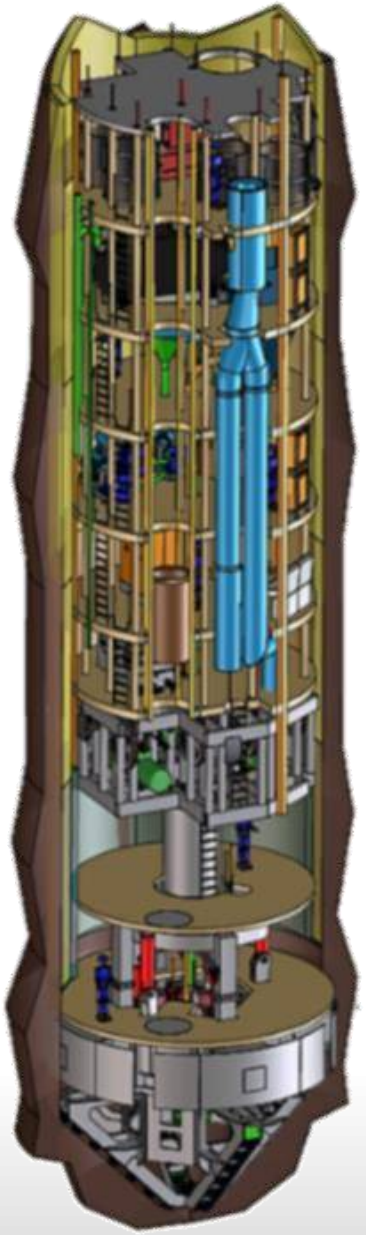


SBC - Shaft Boring Cutterhead

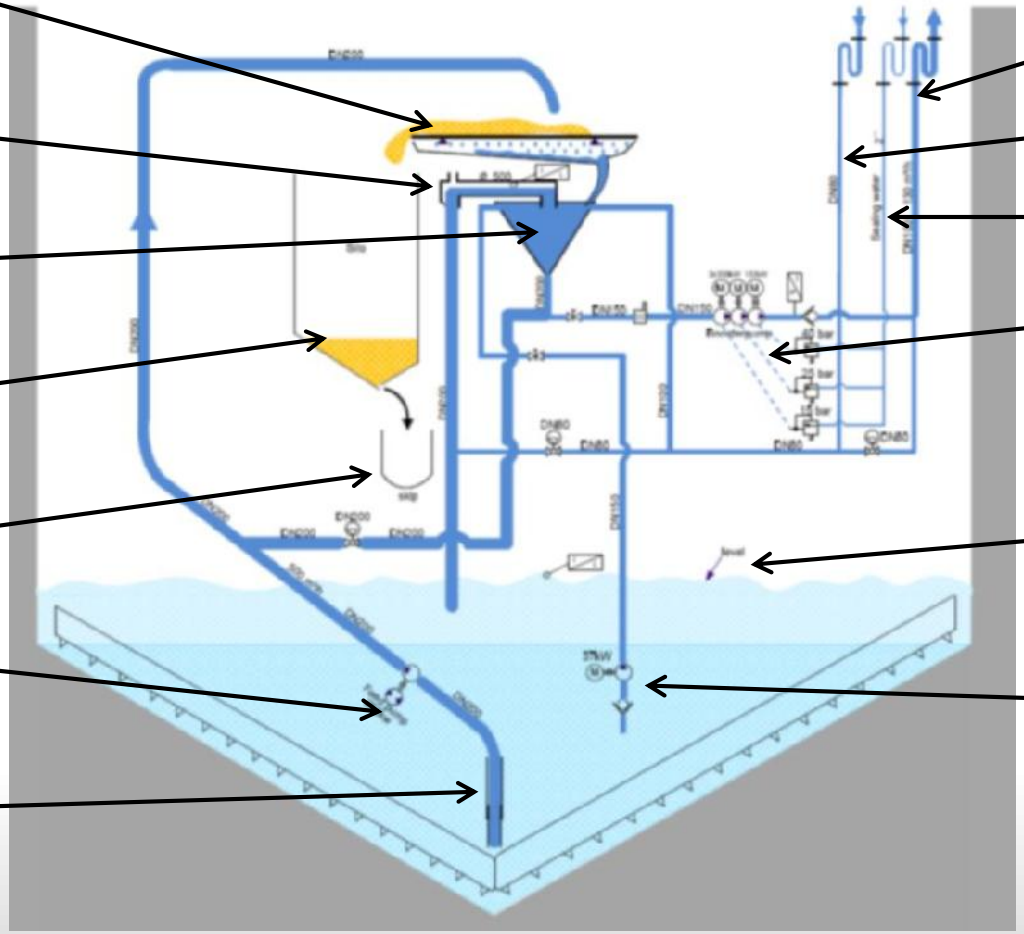
Geology	Hard Rock (~200MPa)
Shaft diameters / depth	8.1 – 8.6m / ~1000 m
Machine height / weight	35m / 350t
Suspension	Headframe / Ropes
Mucking method	Slurry
Rock Support/Lining	Per. Requirement
Net excavation	~3 - 6m/d

SBC | Concept Finished up to Detailed Design





SBC | Slurry Mucking System



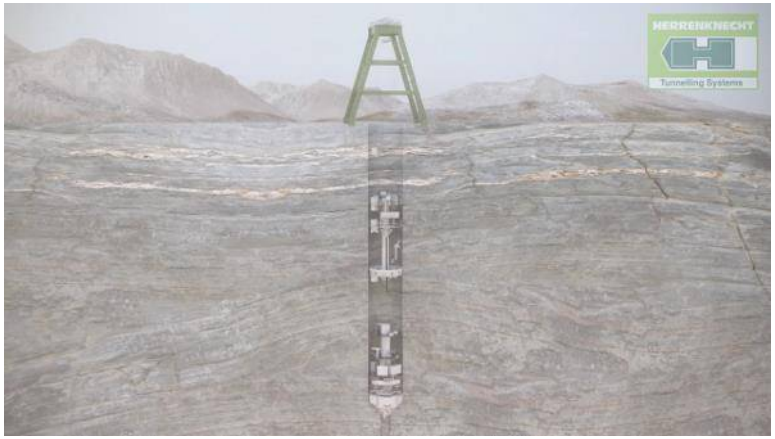
SBE - Shaft Boring ExtensionMachine

Geology	Hard Rock (~200MPa)
Shaft diameters / depth	7.5 – 9.5m / ~3000 m
Machine height / weight	18m / 350t
Suspension	Gripping System
Mucking method	Pilot Hole
Rock Support/Lining	Rock Bolts, Shotcrete
Net excavation	~6-10 m/d

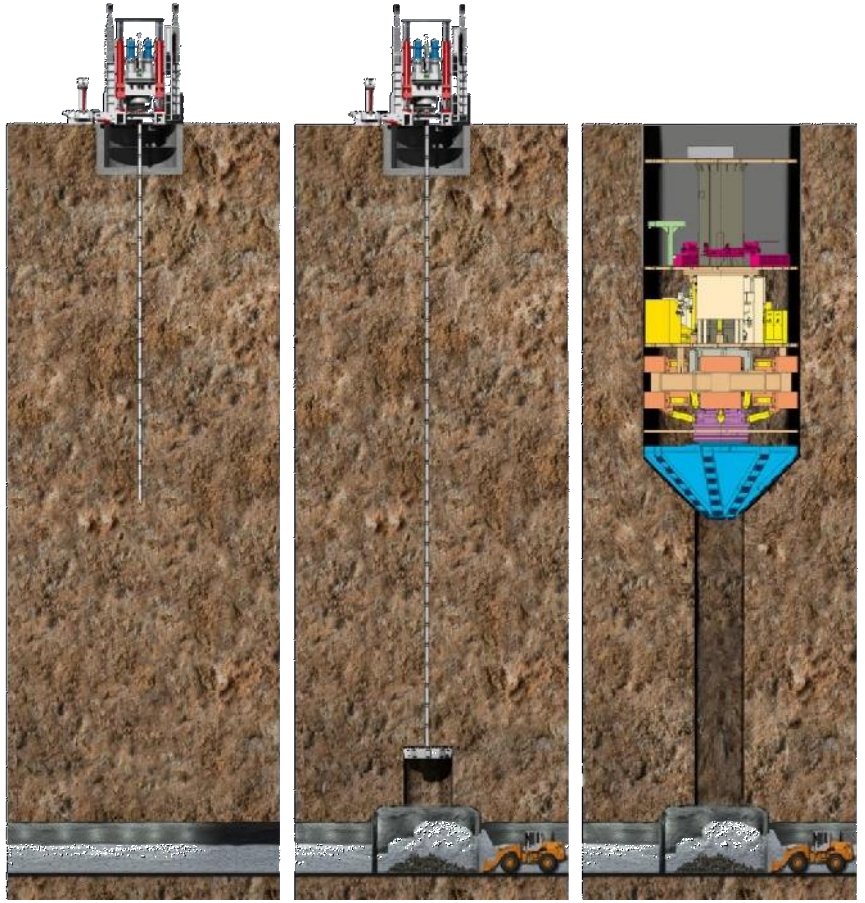
SBE | Construction Procedure

Technology consists of 3 steps:

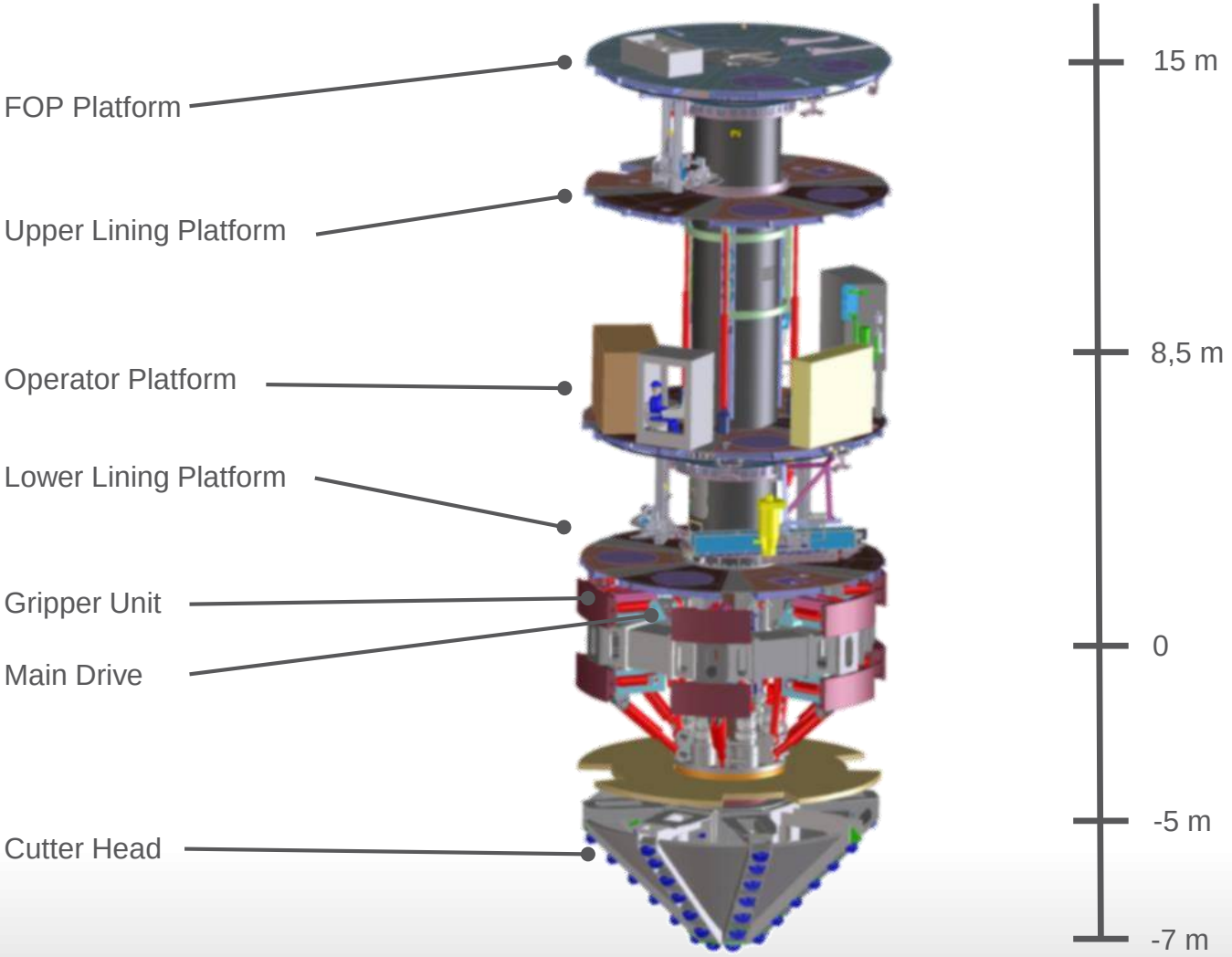
1. Directional drilling of pilot hole
2. Back reaming the pilot hole by Raiseboring
3. Extension of the raisebored hole to the final diameter by means of the shaftboring machine



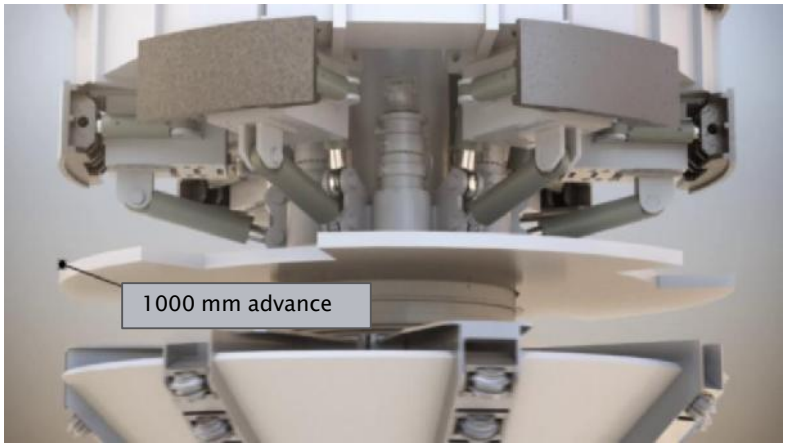
https://www.herrenknecht.com/en/products/productdetail/shaft-boring-extension-machine-sbe/

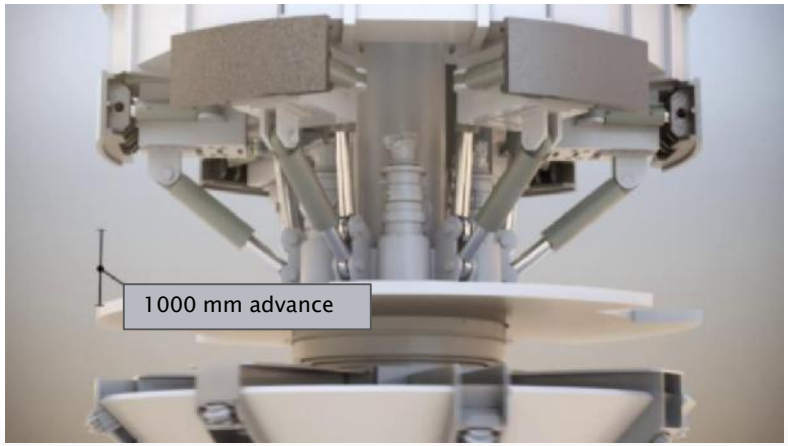


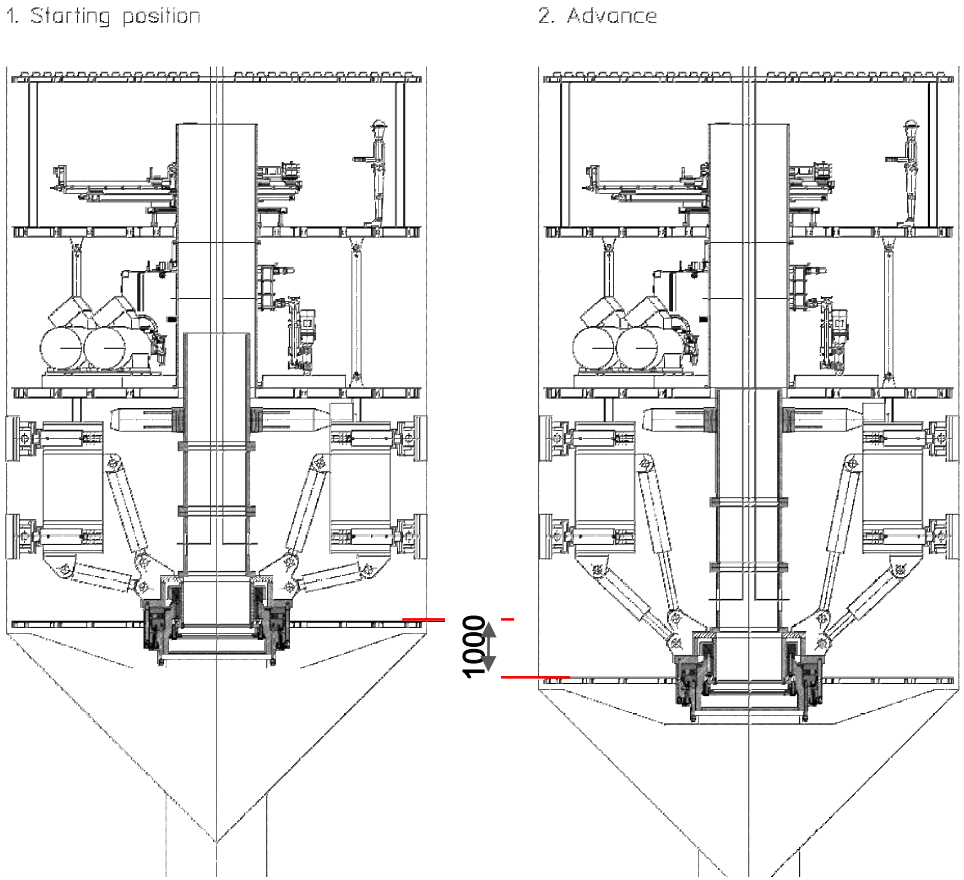
SBE | Overview



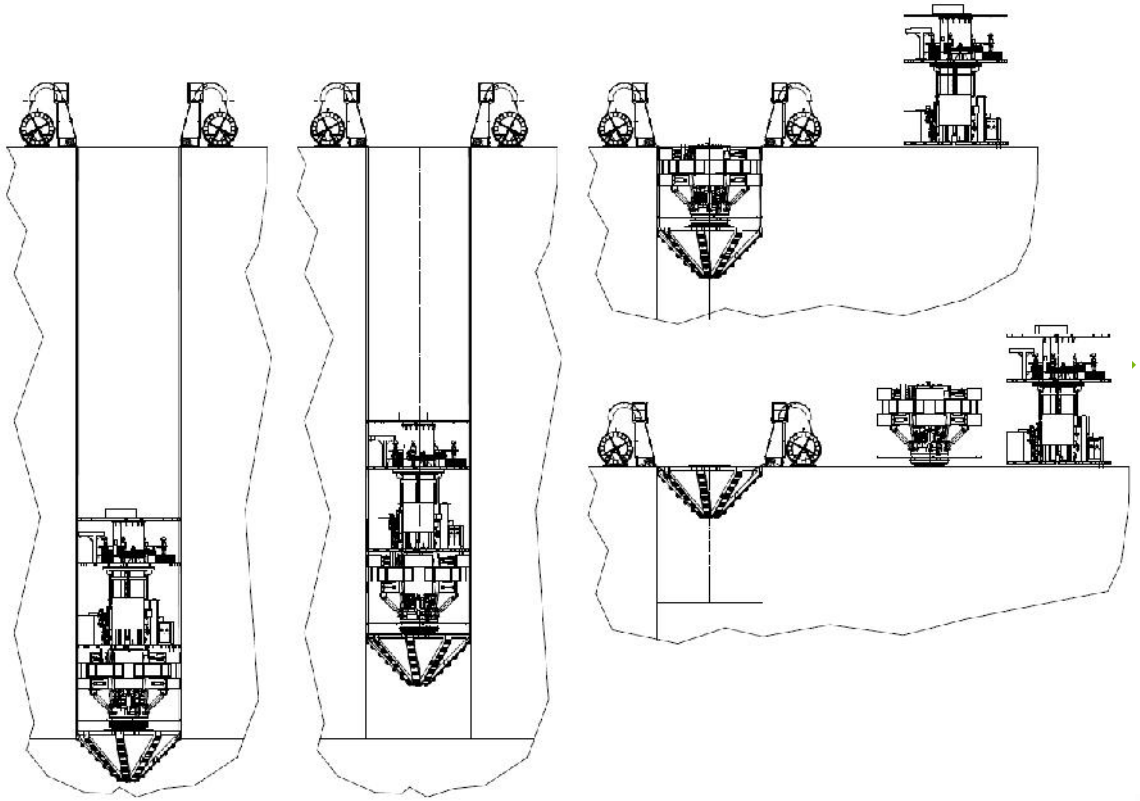
SBE | Advance


1000 mm advance


1000 mm advance


1. Starting position
2. Advance
1000

SBE | Assembly and Disassembly



Pre-Sink requirements:

- Required pre-sink depth: 8 – 10 m
- Pre-sink diameter to match max. gripper stroke
- Cutterhead can be equipped with support structure for assembly

Picture left an example for breakthrough and lifting:

- Before breakthrough the SBE will be attached to the strand jack system.
- Lifting the SBE to surface by use of heavy duty lifting equipment like strand jack cylinders & long steel cables

Conclusion | Shaft Sinking Machines

Modular Concepts are Proven and Available!

Mucking Method:

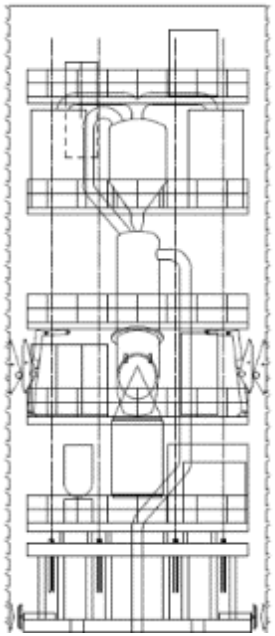
- Pneumatic, Slurry, Conveyor Belt or via Pre-hole

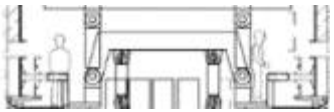
Shaft Wall Support:

- Bolt and mesh, shotcrete, segmental liner
- Either on the bench or above stabilizer

Excavation Unit:

- SBR for medium soft rock
- SBC for hard rock





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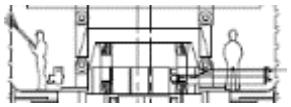

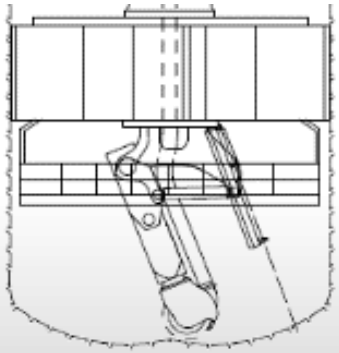

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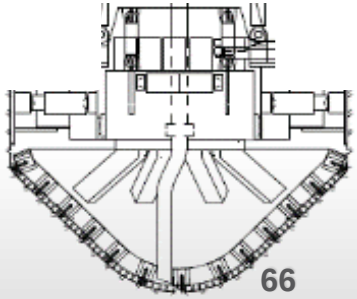
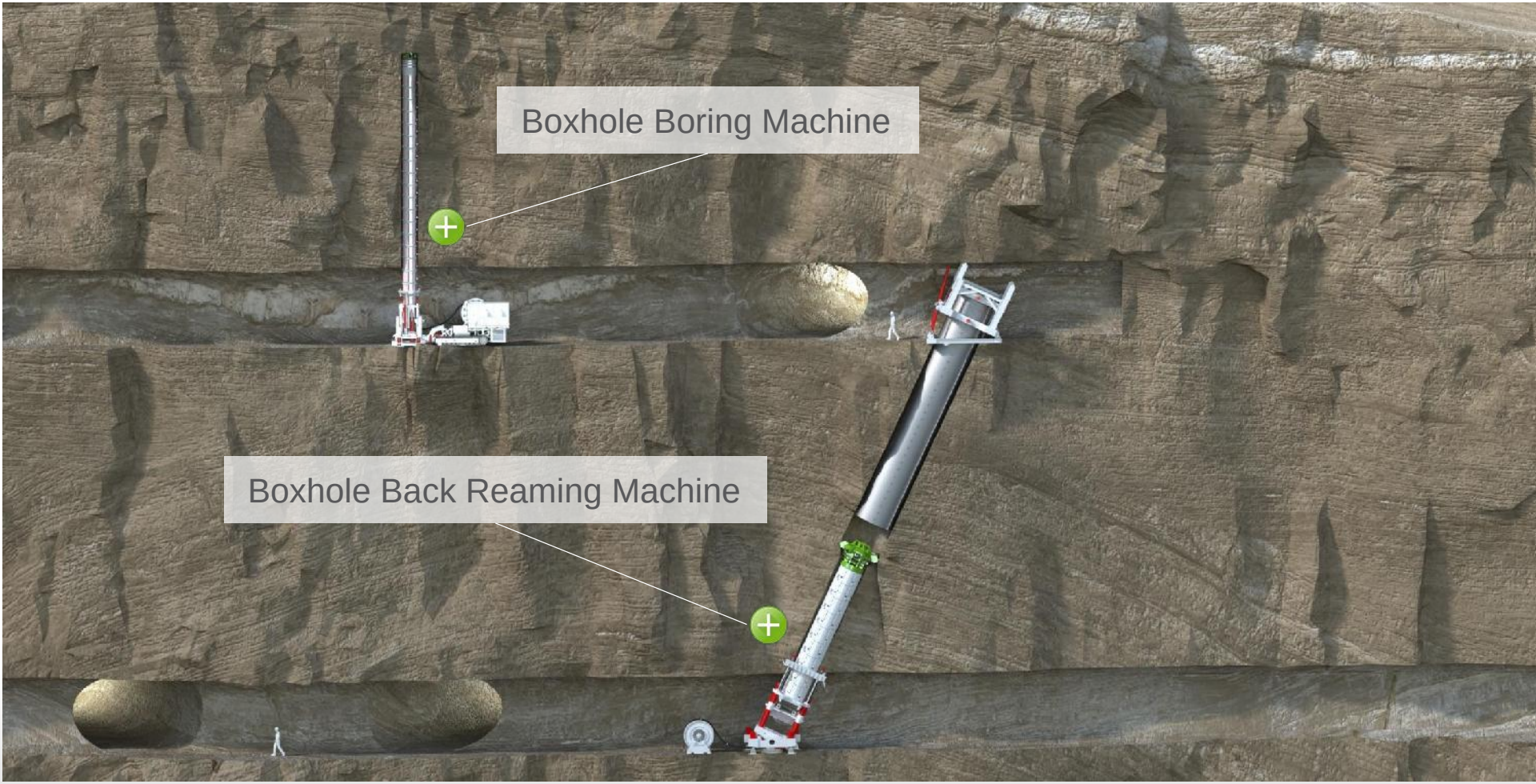


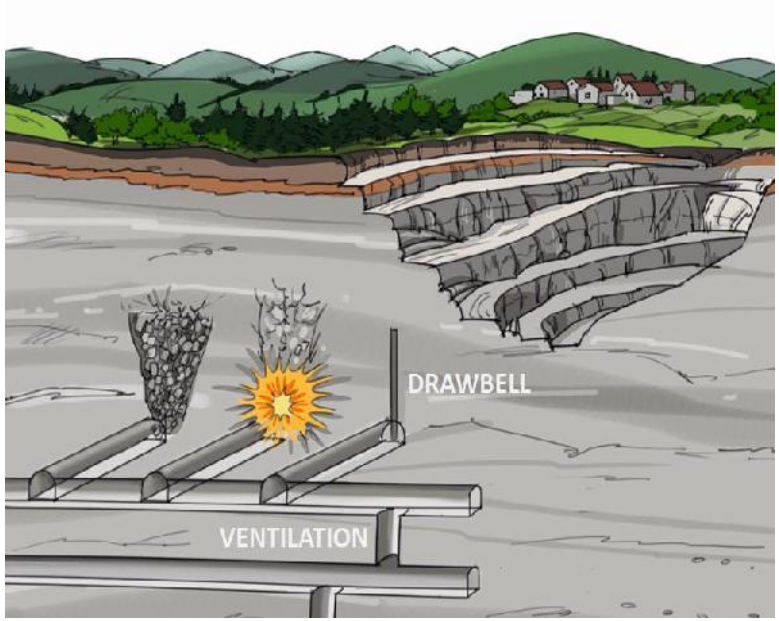
- Introduction Herrenknecht and Mining
- Overview of Shaft Boring Machines and references
- Boxhole Back Reaming Developments
- Questions?

Boxhole Back Reaming Machine | Combining Technologies for New Applications



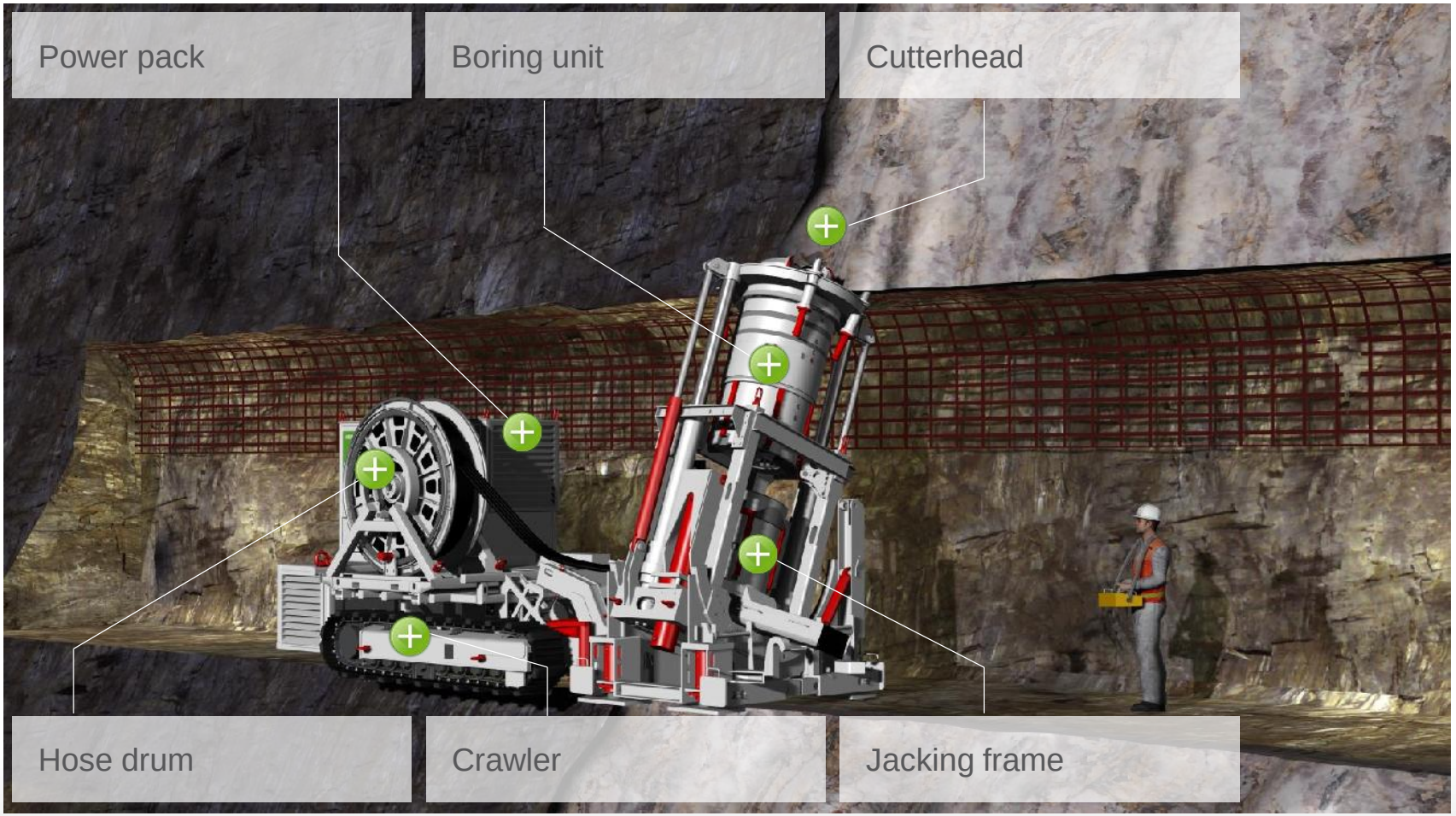
BBR – Boxhole Backreaming Machine

BBM | Rapid Production of Shafts and Slot Holes With Small Diameters



- Boring of vertical and inclined shafts in hard rock conditions
- Shaft diameter up to 1.5 m
- Shaft depth up to 70 m

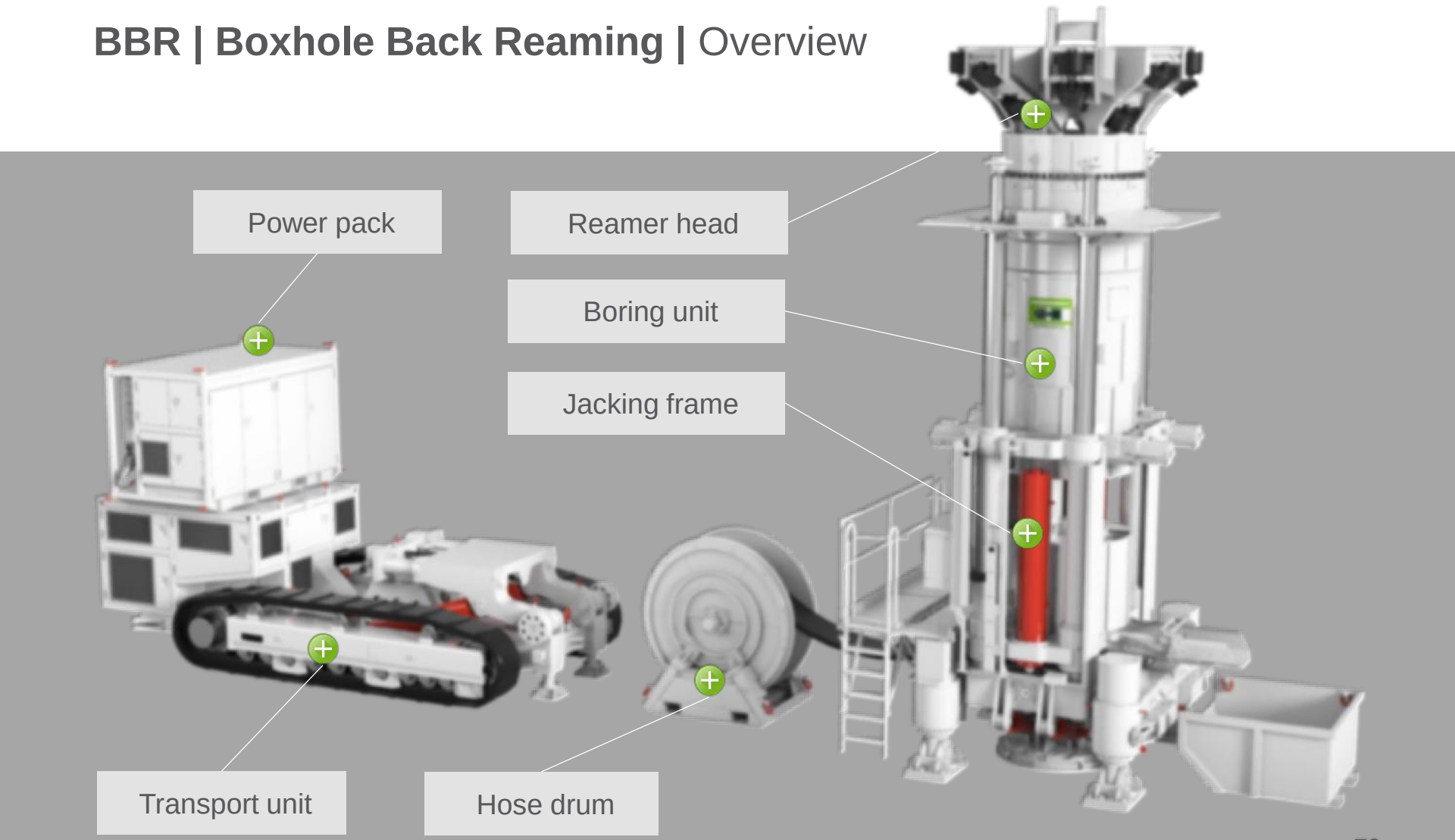
BBM | Setup in Open Drift



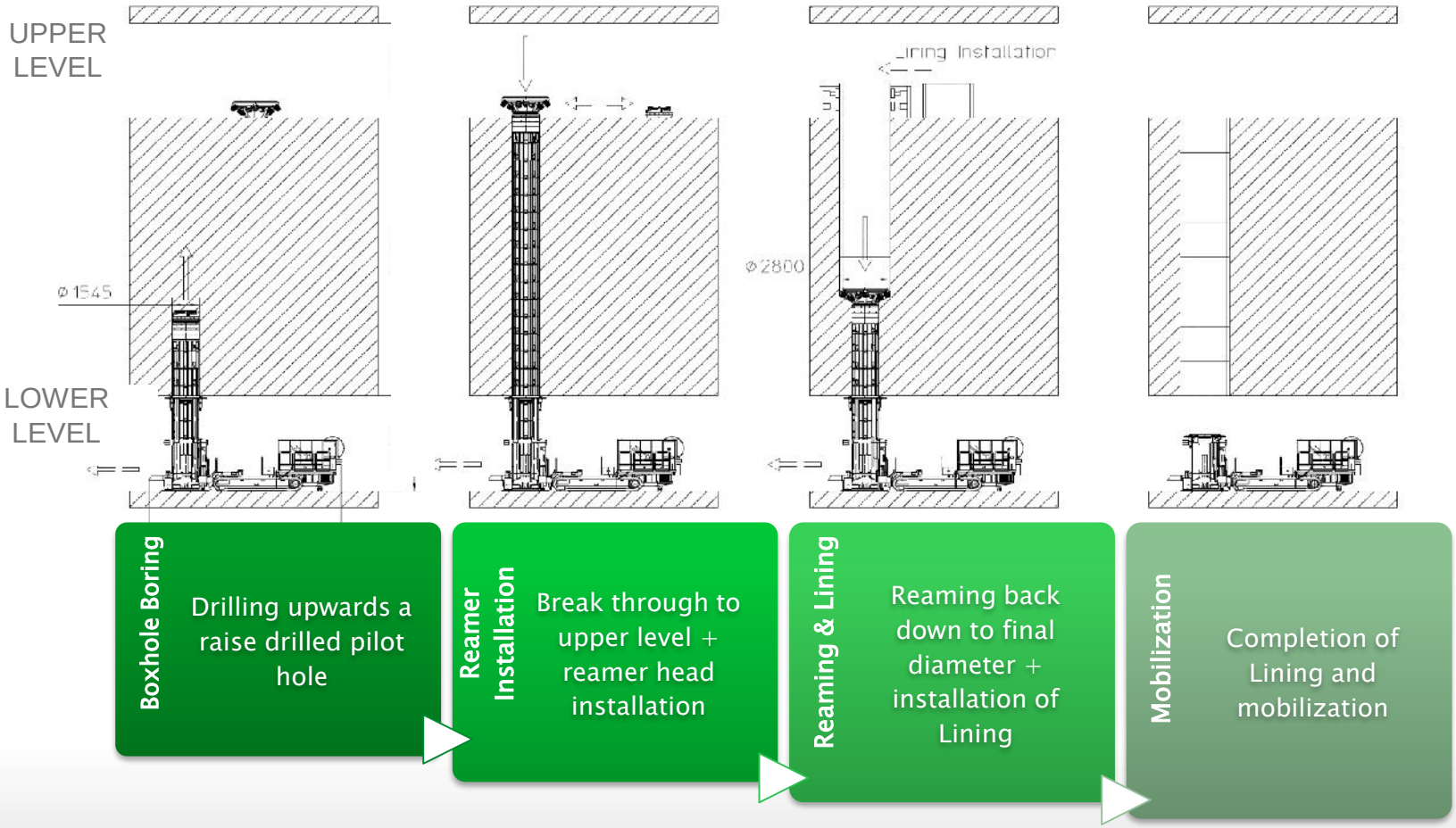
BBM | Advantages

- **System with the highest safety level**
  - Good control of falling material and small annular space
  - No exposure to falling rocks
  - Reduction of dust and noise
  - Highly mechanized operation. i.e. pipe installation, muck-removal, machine setup
  - PLC system: high level of control and safety interlocks
- Accident-free excavation of more than 5.500m

BBR | Boxhole Back Reaming | Overview



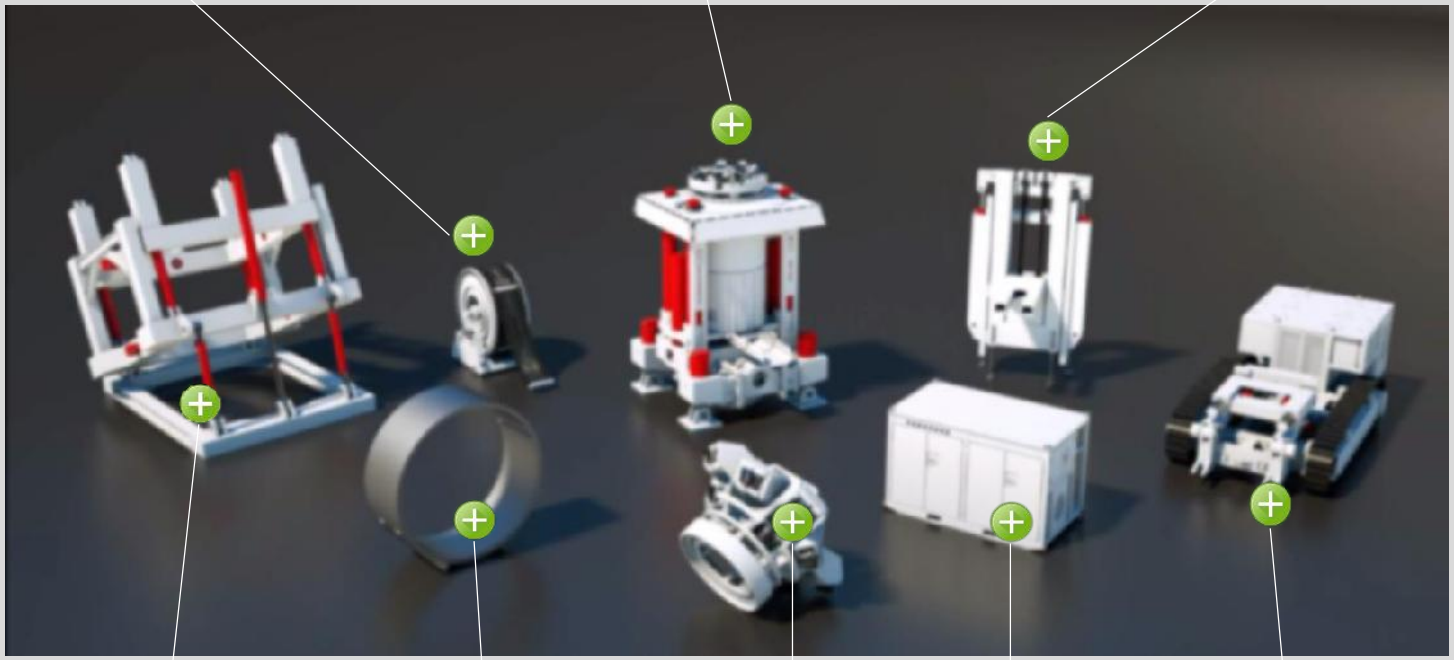
BBR | New concept for creating ore passes and ventilation raises



BBR | Customer value

- Allows simultaneous drilling and lining
- Stabilizing shaft with thrust pipes and by steel liner, avoiding collaps of shaft and rework
- Reducing amount of activities in upper level during mine development
- Diameter up to 3.5m, drilling length up to 60m

BBR | Equipment Overview



BBR | Field Trial

Development of one ore pass in German mine

- Pass specifications (Ø 2.8m)
  - Length and angle (to vertical): 22m, 19°
  - Reaming rates up to 1.3m/h (Ø 2.8m)
  - Rock: Gneiss

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Thank you very much for your attention.

Please feel free to ask questions or give comments.

PIONEERING
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