HALLANDSÅS TUNNELS

TBM erection chamber

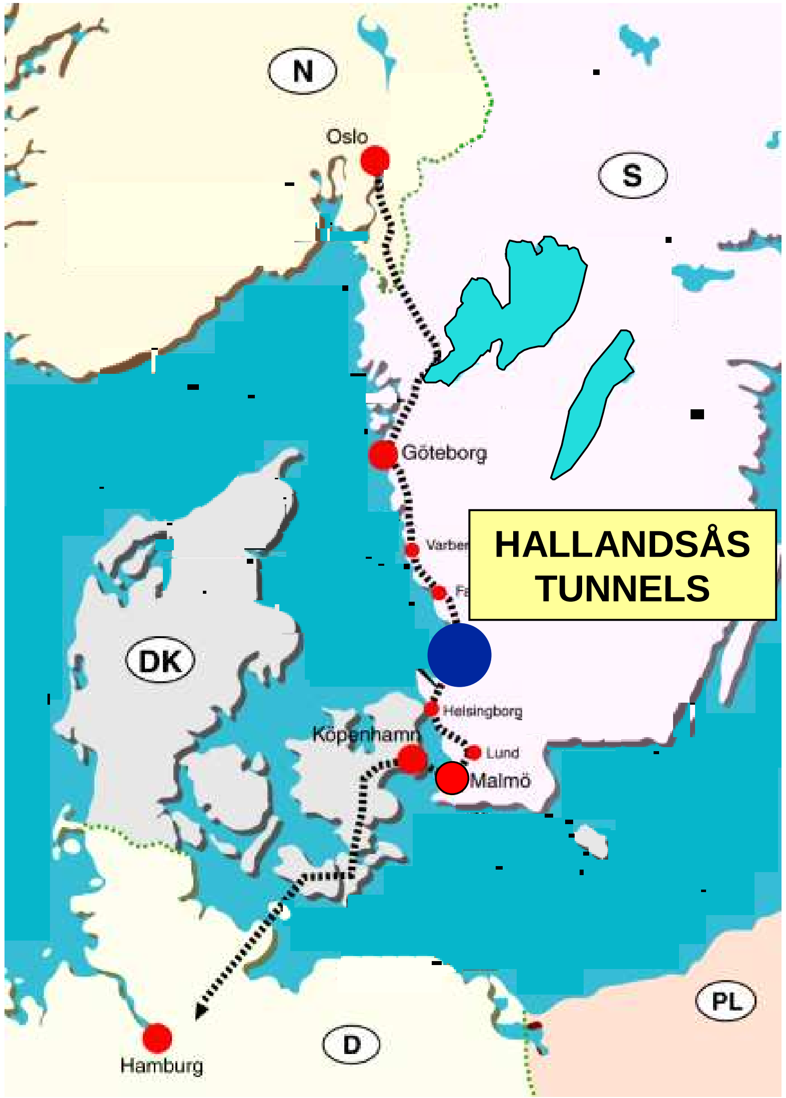
Hallandsås ridge

Mid-adit

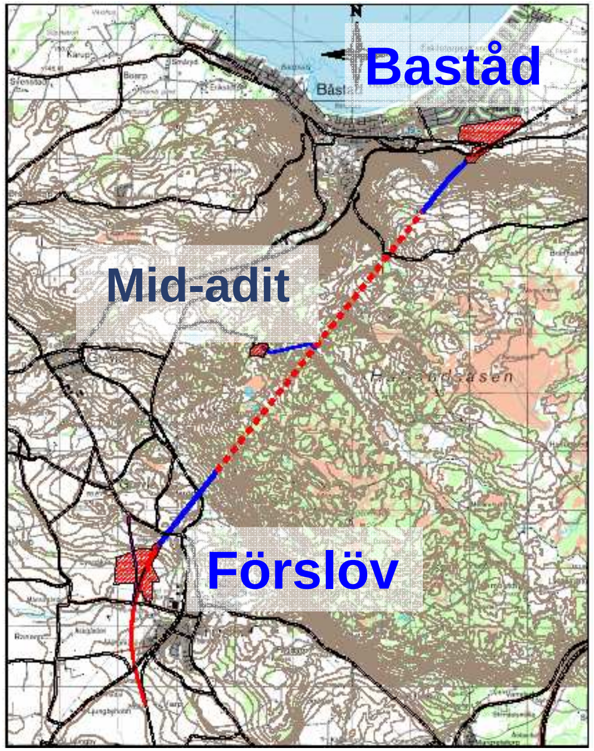
Probe hole

06 June 2009

General project information

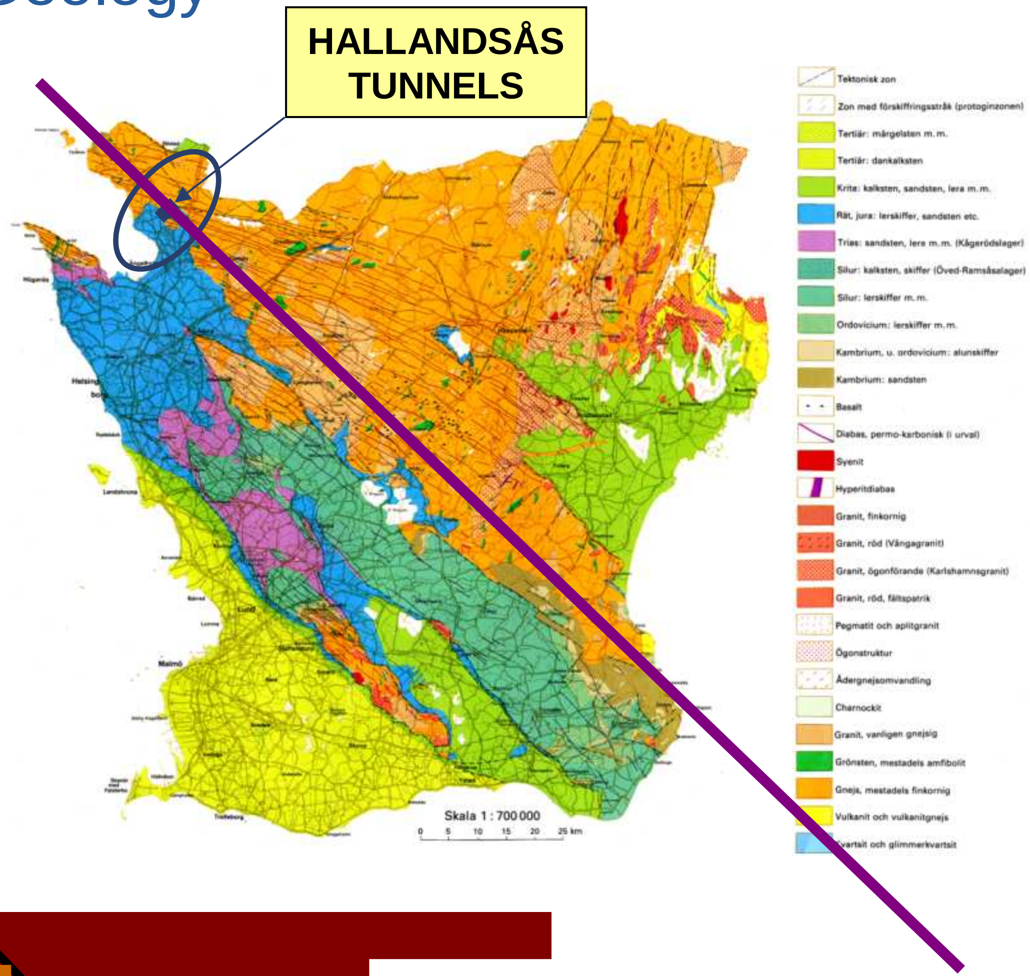


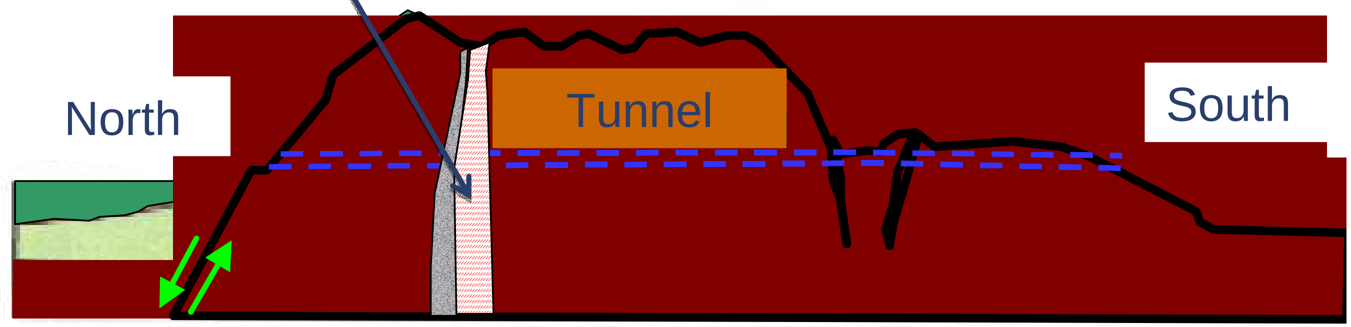
- Part of the West coast line railway project in South Sweden
- 2 tunnels 8.5 km long with 2 x 5.5 km to be excavated with a TBM (diam. 10.6m) and lined with segmental lining.



General project information - Geology

- Hallandsås ridge is an horst with a long history of tectonic movements. It is quite heterogeneous in terms of fracturation and weathering
- Rock: gneiss, amphibolite (either massive or dyke) and dolerite.
- Hydrology: presence of long zones with very high permeability. Hydrostatic pressure up to 15 bars.
- Presence of a major difficulty: Mölleback zone.



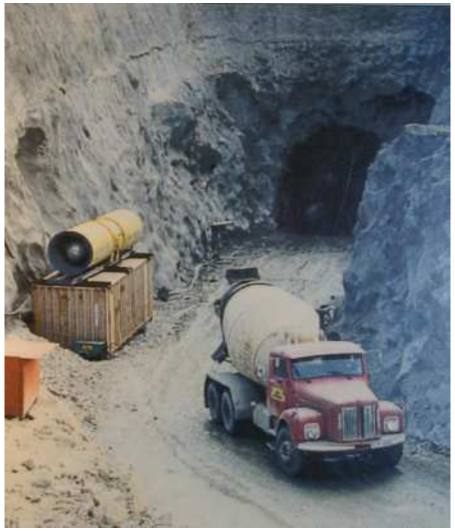


First attempt: open type TBM (1993-1995)

- May 93 - KRAFTBYGGARNA started tunnel excavation with the hard rock TBM named HALLBOR (type JARVA MK27).
- July 93 - The TBM is blocked after 16m being excavated. Tunnel excavation resumed with drill and blast technique.
- Dec. 95 - KRAFTBYGGARNA left the project, 3 000 m being excavated.

Second attempt: drill and blast technique (1996-1997)

• Jan. 96 - The project restarted using the drill and blast technique. 4 additional faces were opened (mid-adit).



• June 96/Feb 97 – Excavation was continuing with significant water inflows despite systematic grouting (60 l/s for a contractual flow set at 33 l/s). Ground water lowering was experienced and several wells were dry.

• Sep 97 - The grout material RHOCA-GIL, used to seal rock fissures and containing acrylamides is discharged outside, where some animals were poisoned. Some workers were as well intoxicated.

• Oct 97 - The works were stopped. National scandal.

• April 99 - Decontamination works were completed as an in-situ lining in the areas associated with significant water inflows

Third attempt: Project restart

- 8 Nov. 2002 - Contract between BANVERKET and SKANSKA-VINCI signed.
- 15 Mars 2004 - Order to start the works.

Basic principles of the new contract

- Contract : Design and build
- Value : 430 M Euros (Base 2001)
- TBM: Mixshield, specially developped for HALLANDSÅS with HERRENKNECHT.
- Environment - Very strict conditions
  - Control of water inflows: maximum 100 l/s average over 30 days; 400 l/s instantaneously
  - . - Control of the discharged water
  - All chemical products on site must be approved
- MBZ fault: Treatment of this fault prior TBM excavation by freezing and grouting.

Original TBM excavation principles

• Three probe holes drilled ahead of the shield in order to get information pertaining to ground water inflows and to rock conditions (fracturation, weathering…

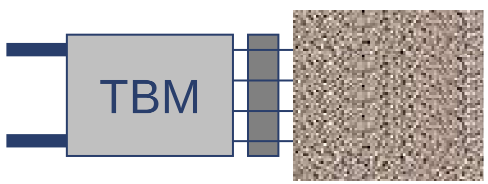
• In the event ground water inflows are low:

>> Excavation in open without pre-grouting

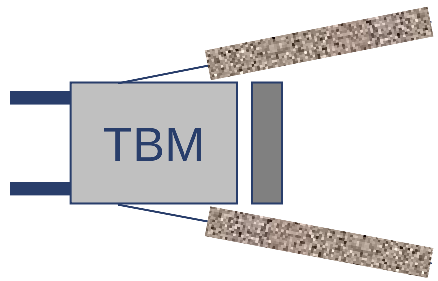
• In the event ground water inflows are high:

>> Pre-grouting and excavation in open mode
>> Excavation in closed mode.
>> Pre-grouting and excavation in closed mode.

Pre-grouting from TBM



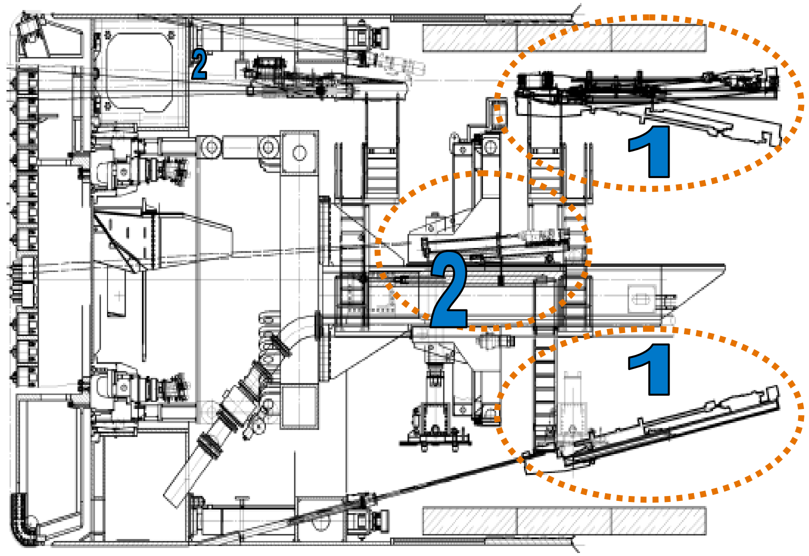
Face pre-grouting



Peripheral pre-grouting

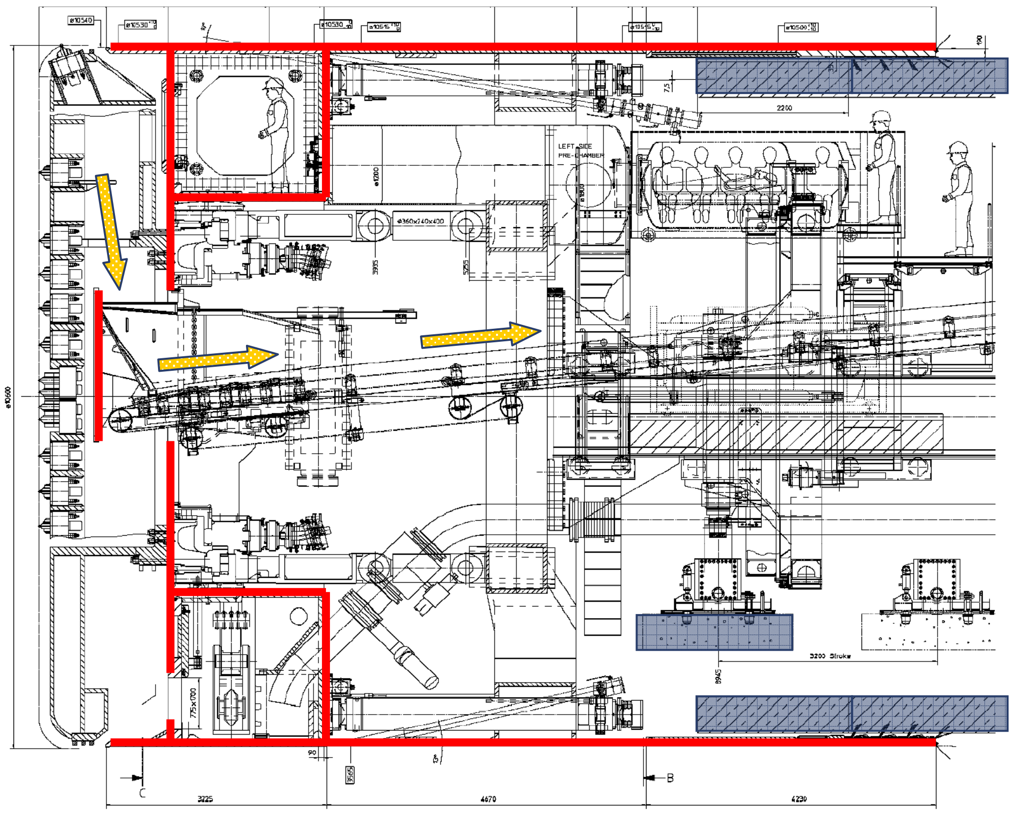
TBM main technical features

- Hard rock mixshield: Open mode + Closed mode (Cutterhead: power 4 000 kW and torque 2 600 T.m – Thrust:18 000 T).
- Possibility to work in closed mode up to 8 bars (Slurry circuit).
- Possibility to work exceptionaly in closed mode between 8 and 13 bars over short stretches (faults).
- Segmental lining erected in the tail skin.
- Designed for 15 bars (static)
- Equipped with drilling and grouting facilities :
  - 1 • 3 boomers for drilling through shield/cutterhead
  - 2 • 1 boomer for drilling through cutterhead center



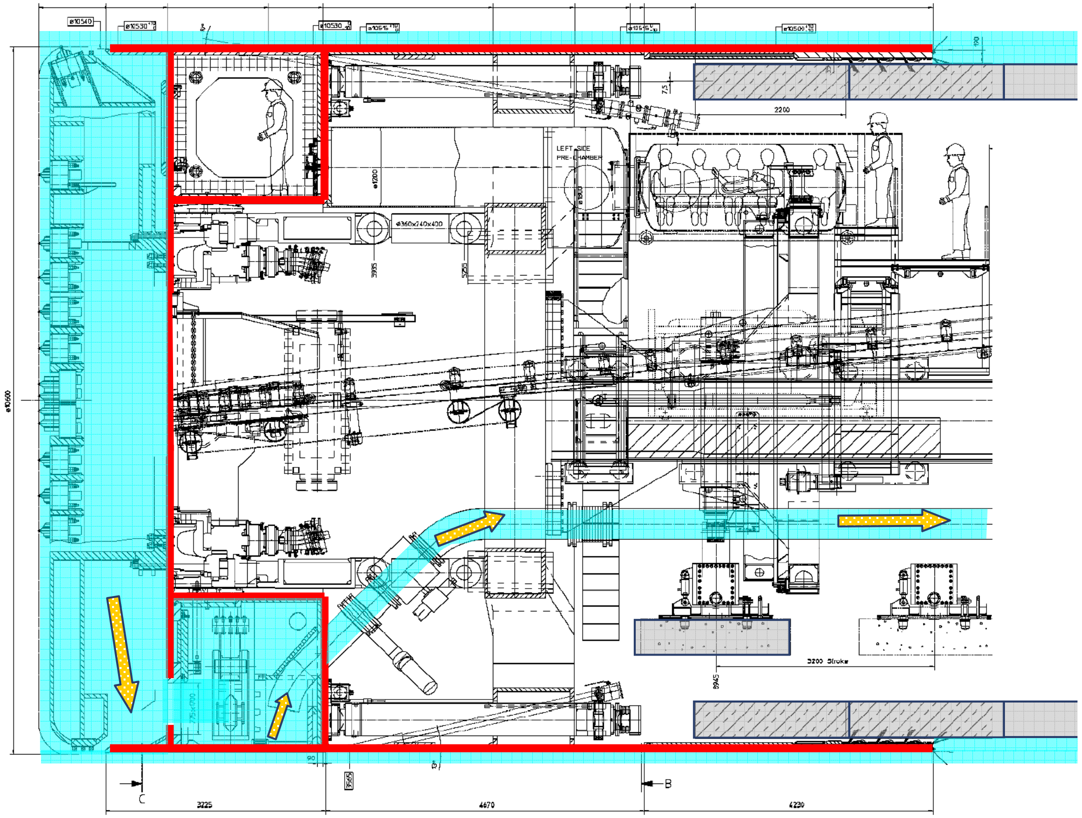
Boomer

TBM operation in Open mode



- Originally estimated over 80% of tunnel alignment
- Transport of excavated rock by belt conveyor (1000 T/hr)
- Maximum TBM advance speed 8cm/min

TBM operation in Closed mode

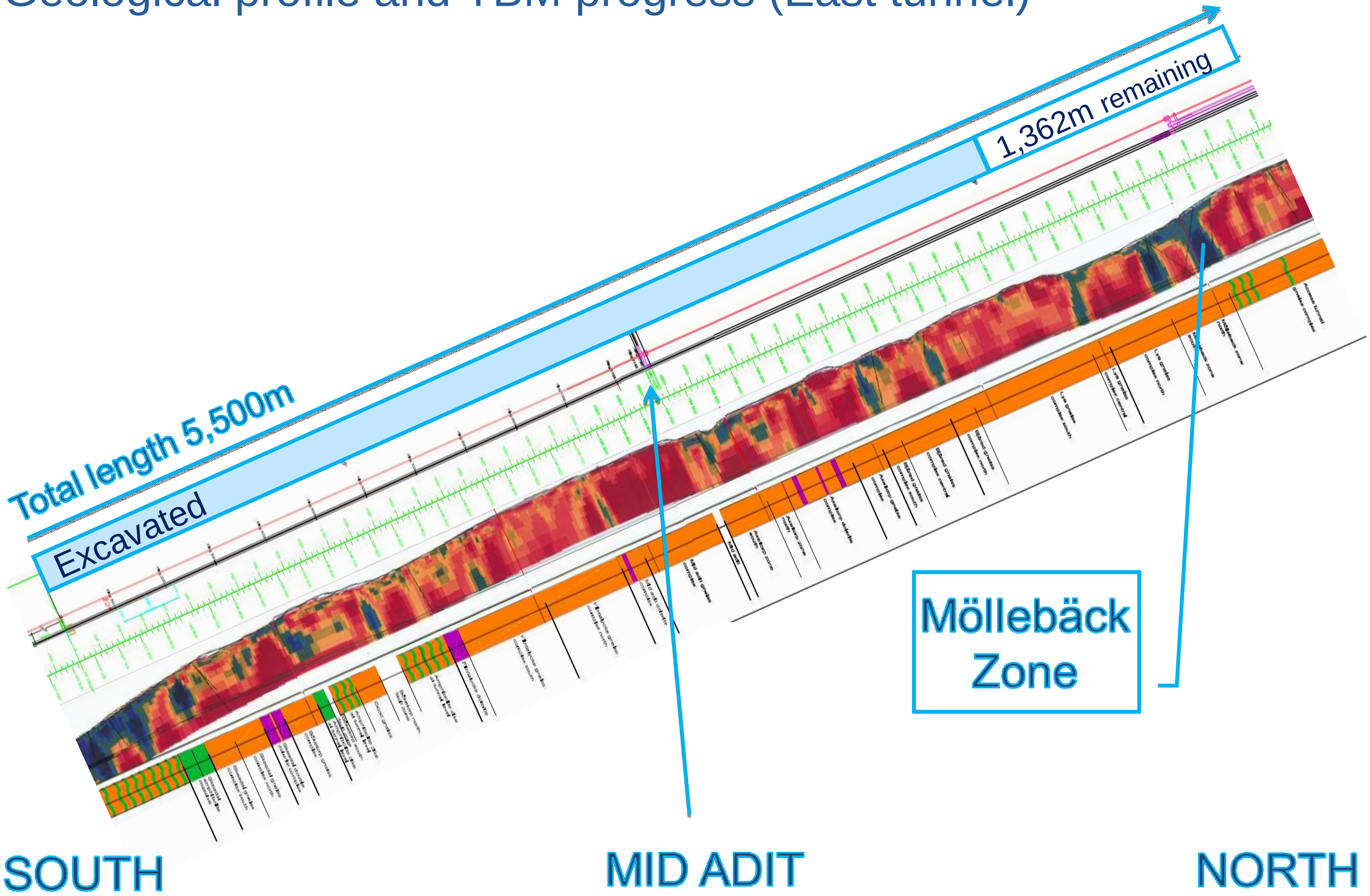


- Originally estimated over 20% of tunnel alignment
- Transport of excavated rock by slurry circuit (1800 m3/hr, increased later to 2000 m3/hr)
- Maximum TBM advance speed 4cm/min
- Maximum working pressure 8 bars
- Exceptional working pressure 8 to 13 bars

Technical particularities:

- Main bearing sealing arrangement designed and tested in factory for 13 bars
- Compensated cutters to permit operation up to 13 bars
- Tail skin sealing arrangement designed and tested for 13 bars

Geological profile and TBM progress (East tunnel)



Main technical problems encountered

Due to very difficult geological conditions:

- Highly heterogeneous rock mass requiring continuous changes in operation parameters

- Bocks instability at the face with the following consequences:

  - damages on the cutterhead

  - damages on the belt conveyors

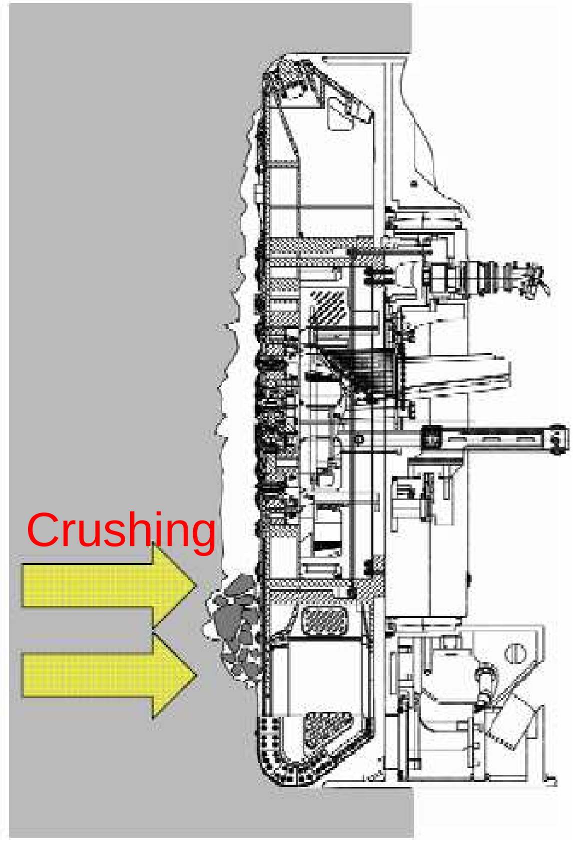
  - damages on the slurry circuit

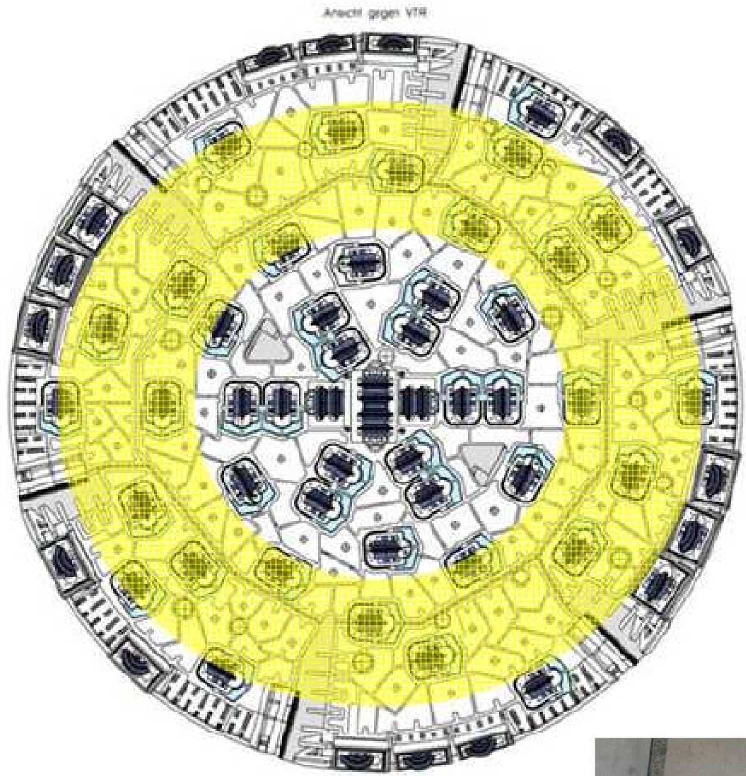
- Significant water inflows with the following consequences:

  - extensive pre-grouting
  - construction of barrier to stop water flows along the lining
  - difficulties for backfilling

TBM excavation through blocky ground conditions

Cutterhead action on the blocks: crushing





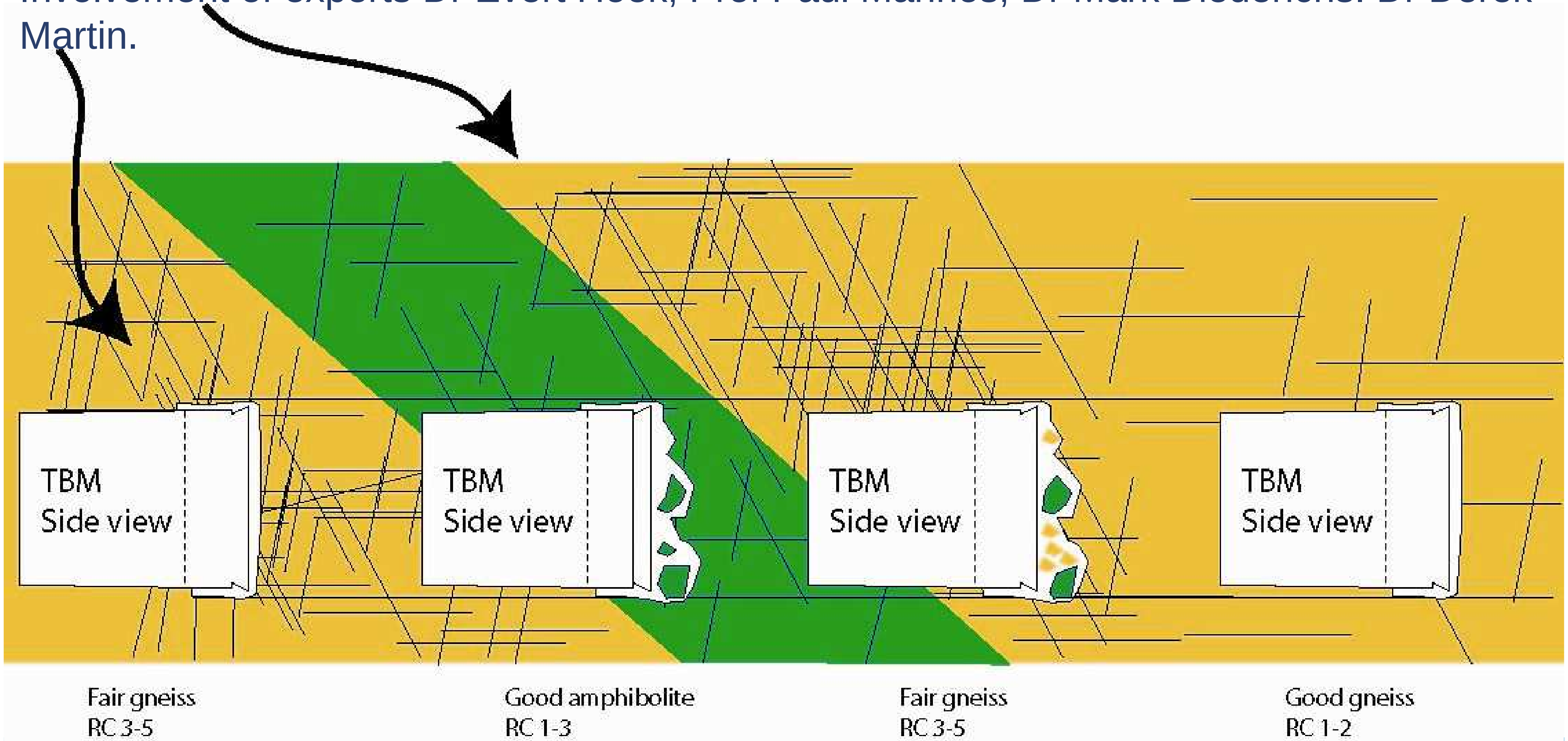
Large blocks at the outside separation unit after actions of the cutterhead

TBM excavation through blocky ground conditions

Investigation regarding the possible causes of blocks instability focussed on two routes:

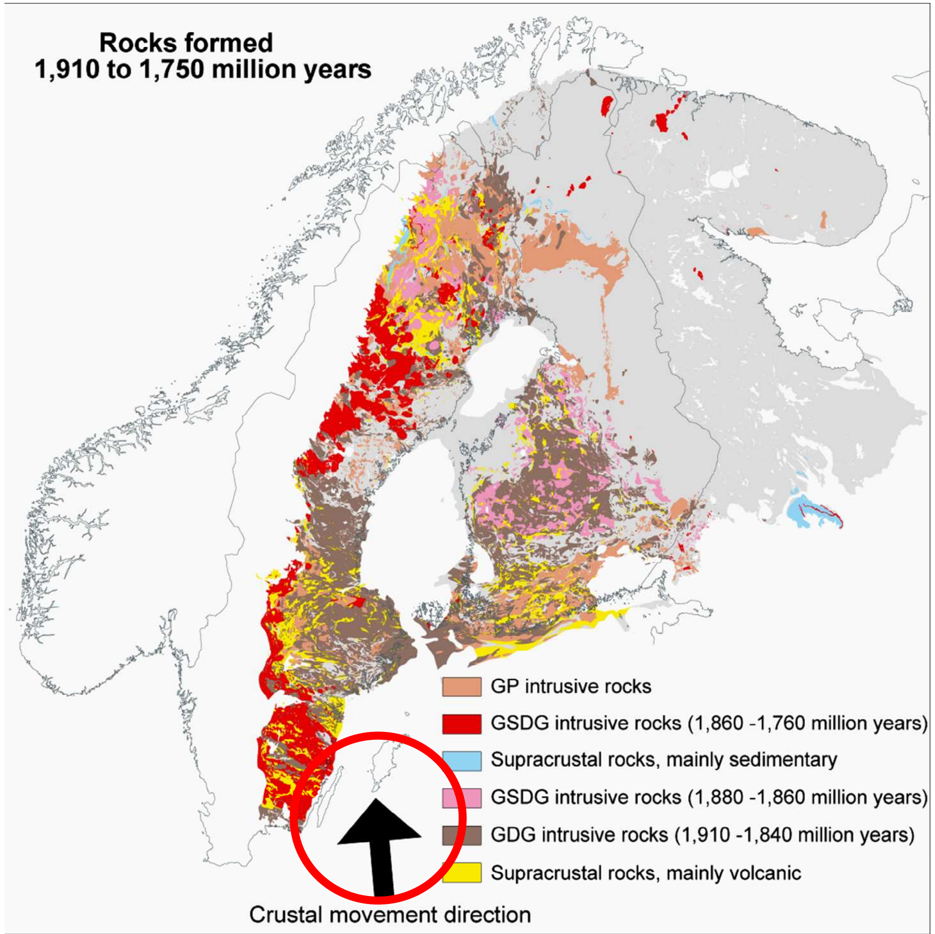
- In situ stresses
- Mechanical characteristics of the joints

Involvement of experts Dr Evert Hoek, Prof Paul Marinos, Dr Mark Diederichs. Dr Derek Martin.

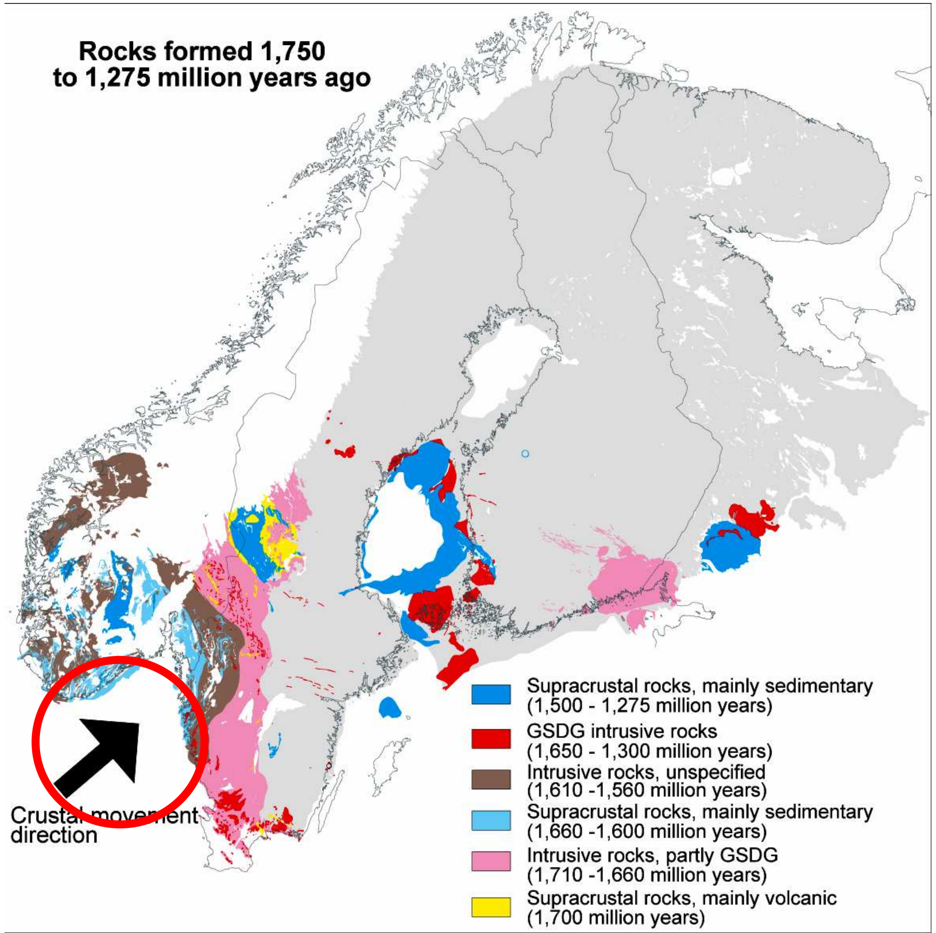


Scandinavian rocks formation

1,970 to 1,750 million years



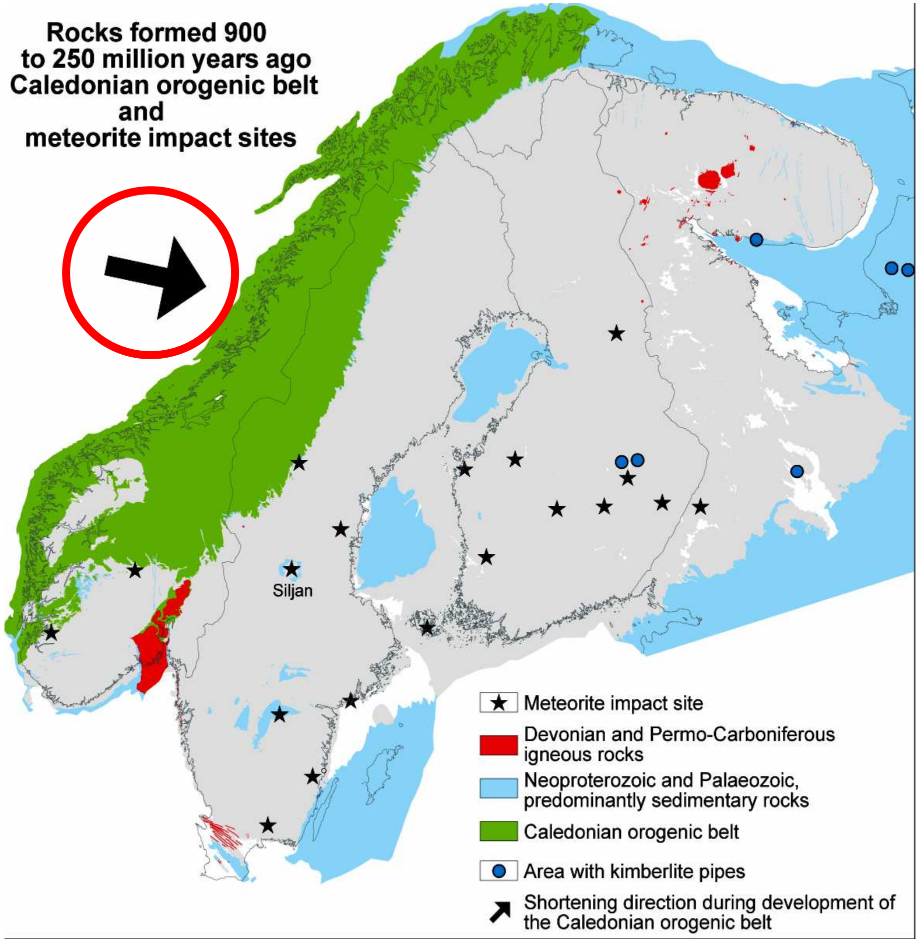
1,750 to 1,275 million years



Scandinavian rocks formation

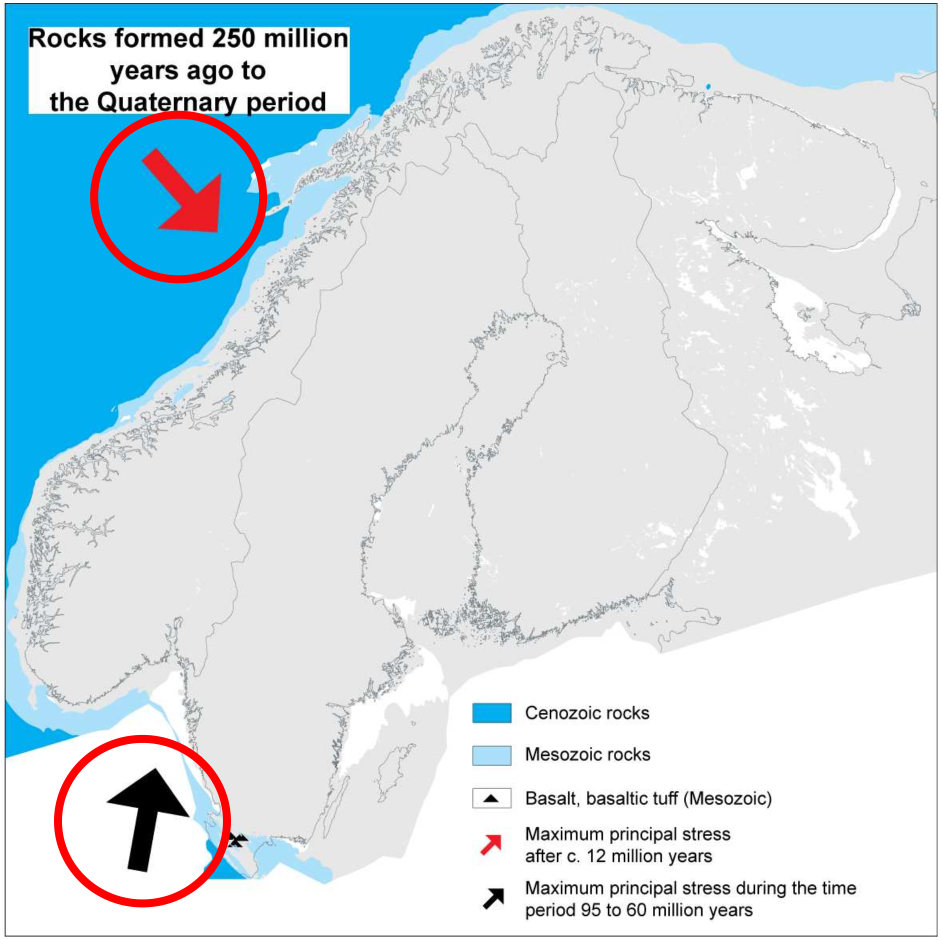
Horst and dykes conditions in Hallandsås are unique in Sweden

900 to 250 million years



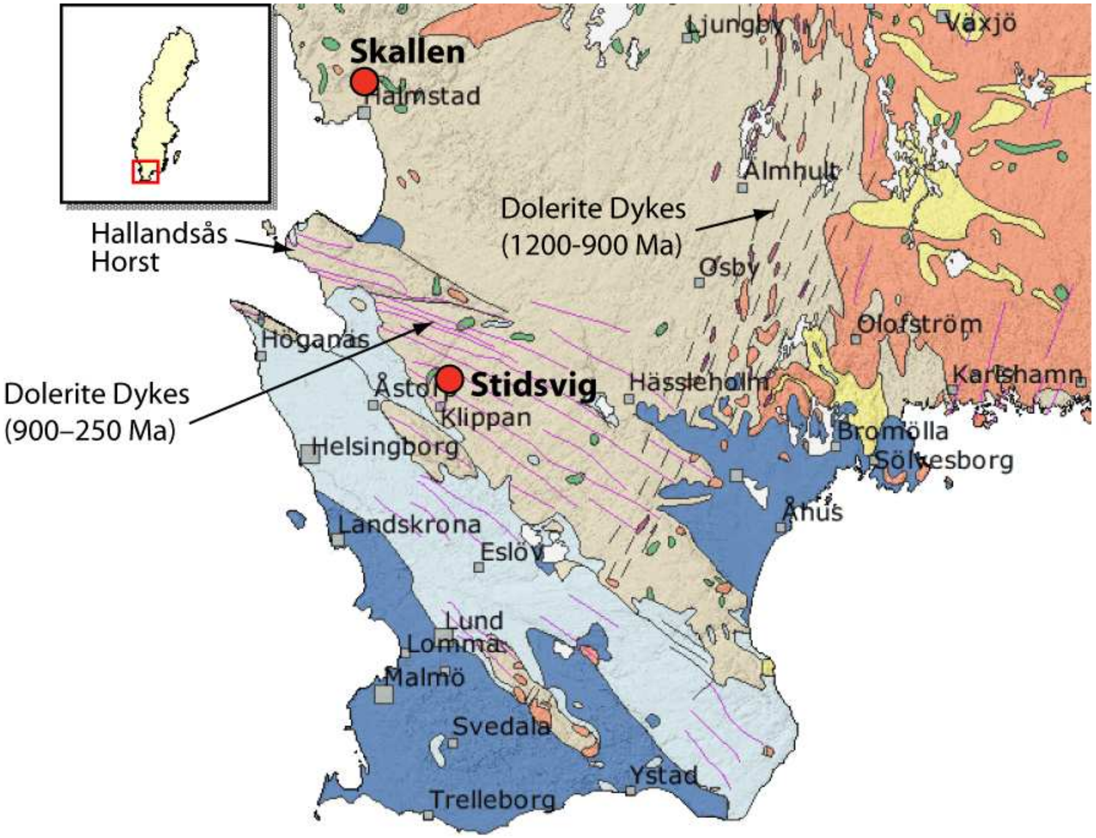
Dykes formation in Hallansås horst

250 million years to Quaternary period



Rotation of stress 12 million years ago

In Situ Stresses



<u>Typical known stresses conditions:</u>

The vertical stress σ v is equal to the pressure from the overlying soil and rock.

$\sigma h = 1 \cdot \sigma v$

(perpendicular to the tunnels)

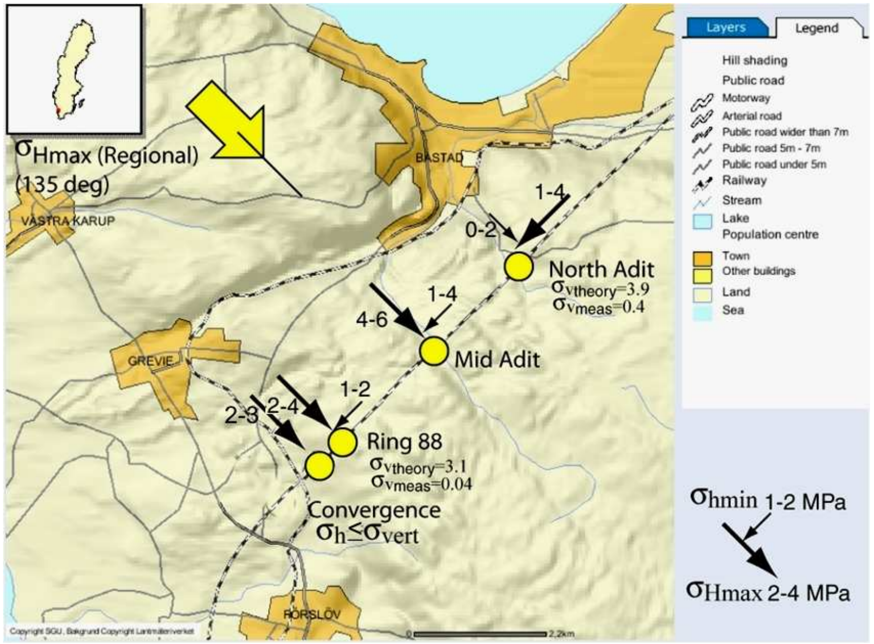
$\sigma H = 2 \cdot \sigma v$

(parallel to the tunnels)

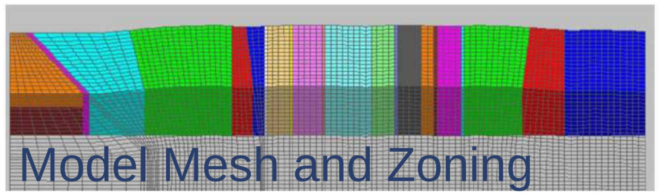
In Situ Stresses

In order to establish the actual regime of in situ stresses:

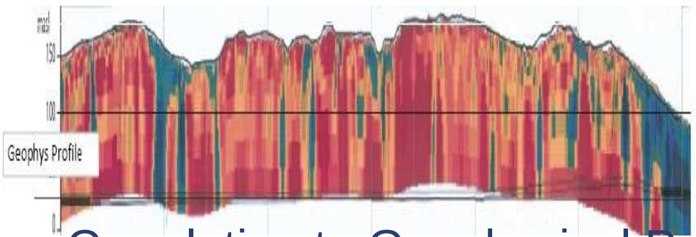
- Measurement of in situ stresses at various locations in the tunnel



- Modelisation of the Hallandsås ridge and of its formation

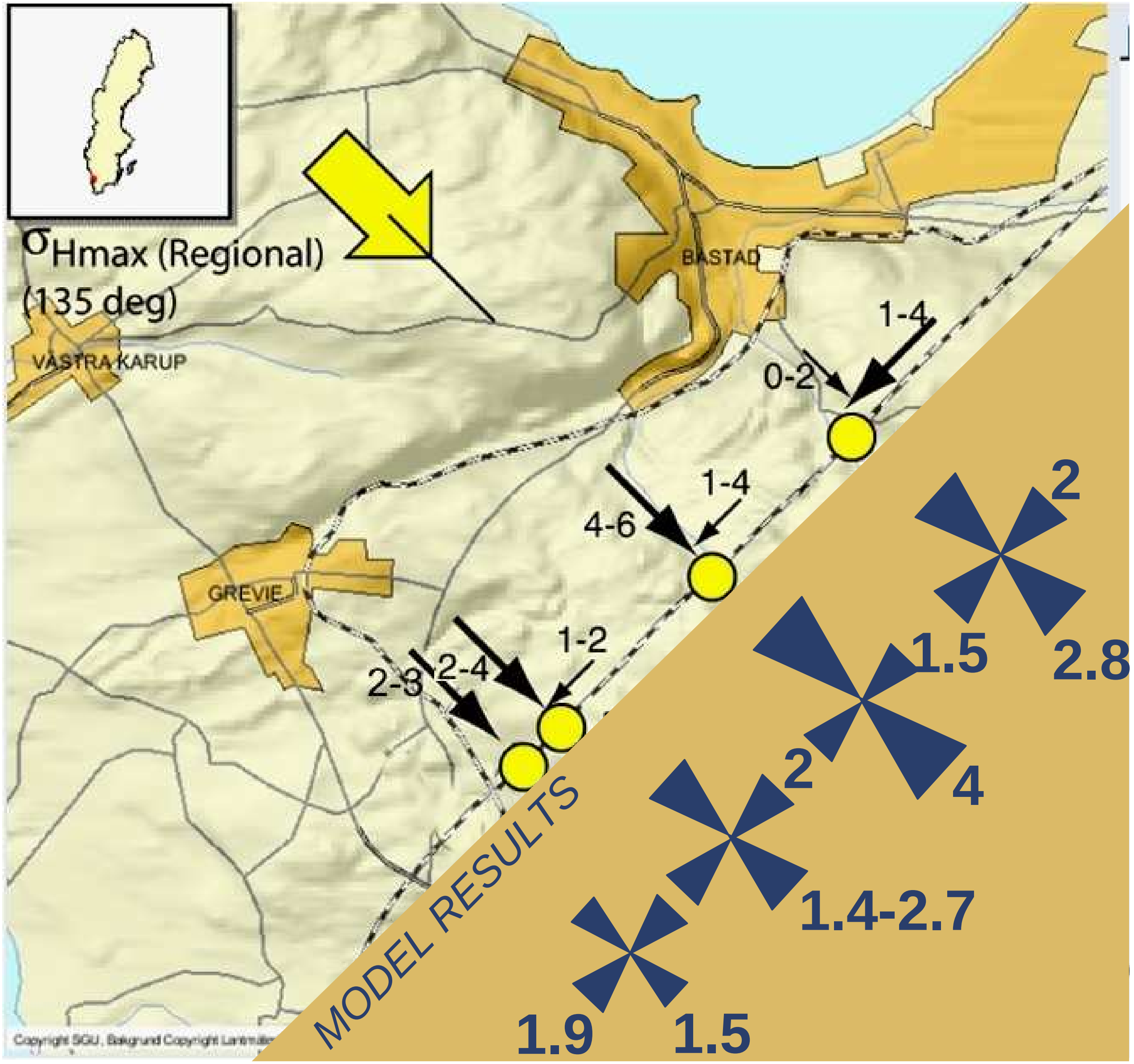


Model Mesh and Zoning



Correlation to Geophysical Profile

In Situ Stresses: comparison model with measurements



Actual stresses conditions in Hallandsås horst:

$\sigma h = (0.7 - 1) \cdot \sigma v$

(perpendicular to the tunnels)

$\sigma H = (0.5 – 0.7) \cdot \sigma v$

(parallel to the tunnels)

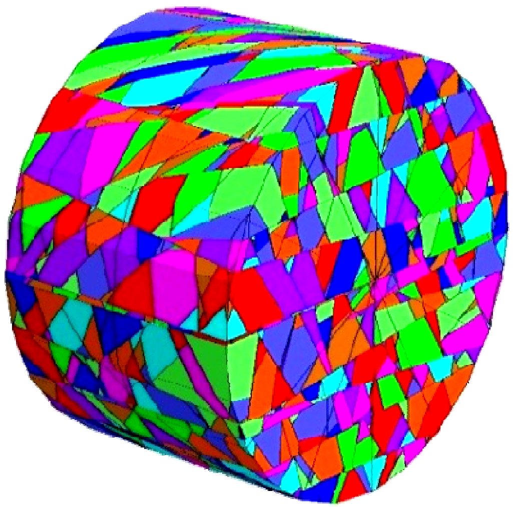
Low stresses conditions

Joint frictional strength

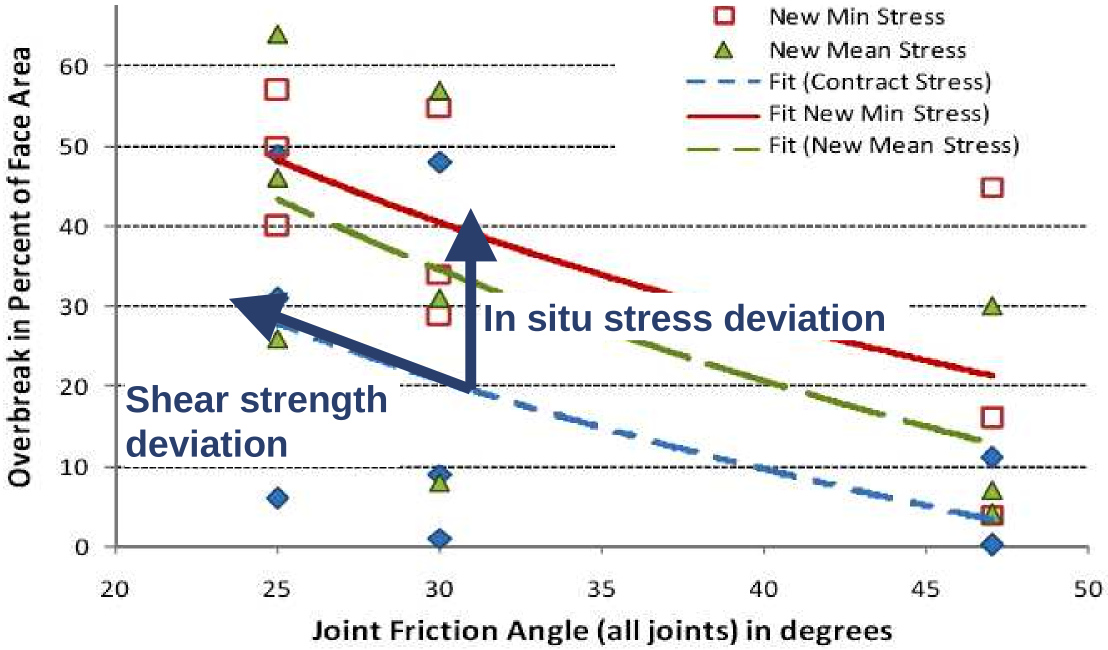
Measurements of joint frictional strength gave significantly lower values with Amphibolite:

- Gneiss: 49 degrees
- Amphibolite: 30 degrees

Blocks stability – Overbreak at face



Modelisation of blocks structure at the tunnel face



Calculation of % of overbreak at face in function of:
- in situ stresses
- Joint frictional strength

Conclusion:
Increase of overbreak with decreasing in situ stresses and decreasing joint frictional strength

Other consequences of low in situ stresses

1. an open jointed rock mass, highly permeable
2. large water inflow

TBM excavation through blocky ground conditions

Measure 1:

Definition of boring classes with specific boring parameters (penetration, cutterhead rotation speed, cutter load…) in relation to the degree of blockiness in order to limit wear and damages on the cutterhead.

Cutter load can vary quicky from being almost null to exceeding 20 tons within few metters of tunnel.

Ga Unblocky

Slightly blocky Gb

Highly blocky Gc

TBM excavation through blocky ground conditions

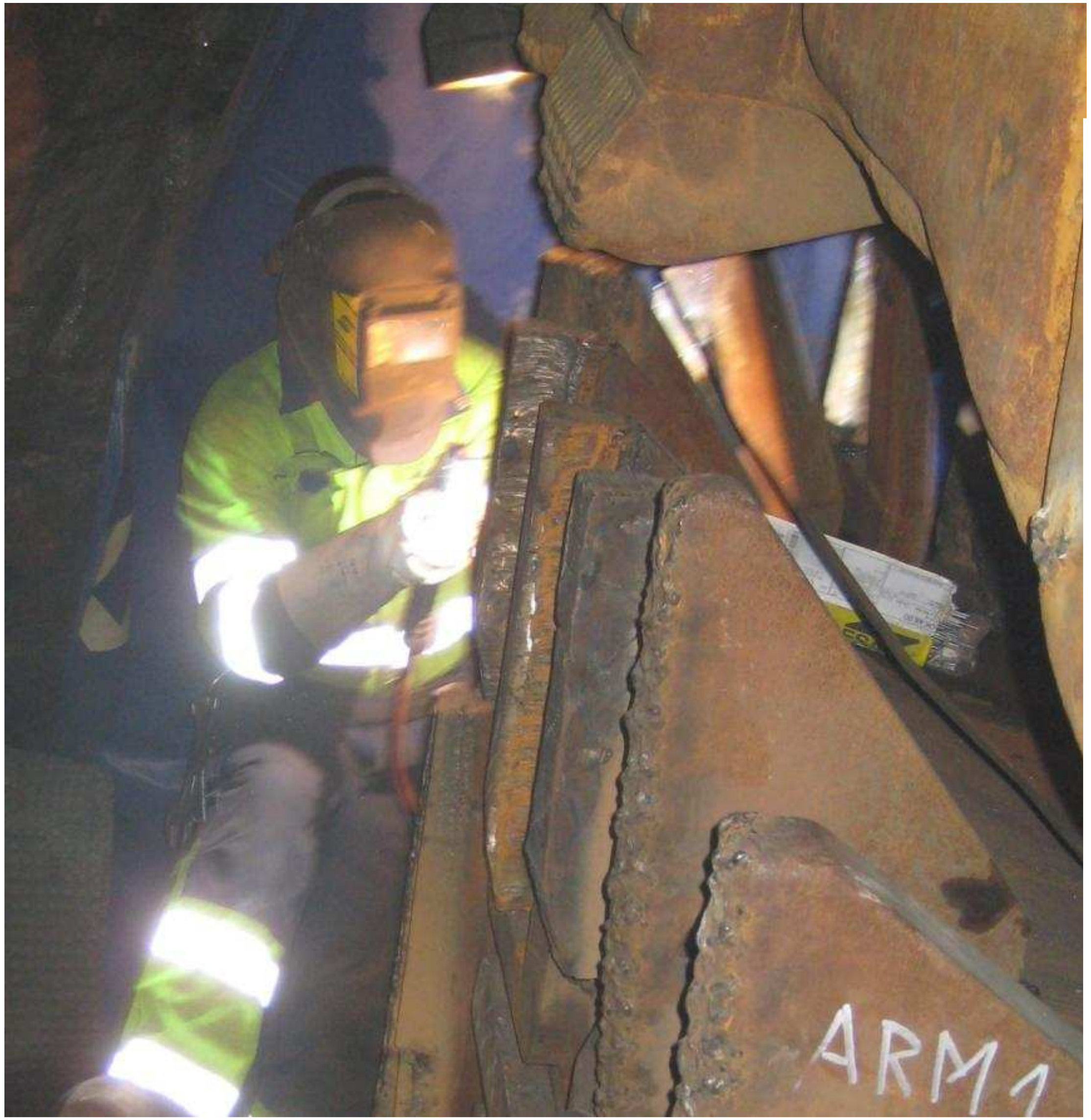
Measure 2:

Frequent inspections of the cutters and scrappers (about every 5m of tunnel)

TBM excavation through blocky ground conditions

Measure 3:

Large cutterhead maintenance every 500 to 1000m for a period of one month. 4 to 5 t of hardox plates and 1000 to 1500 kg of electrodes per large maintenance.

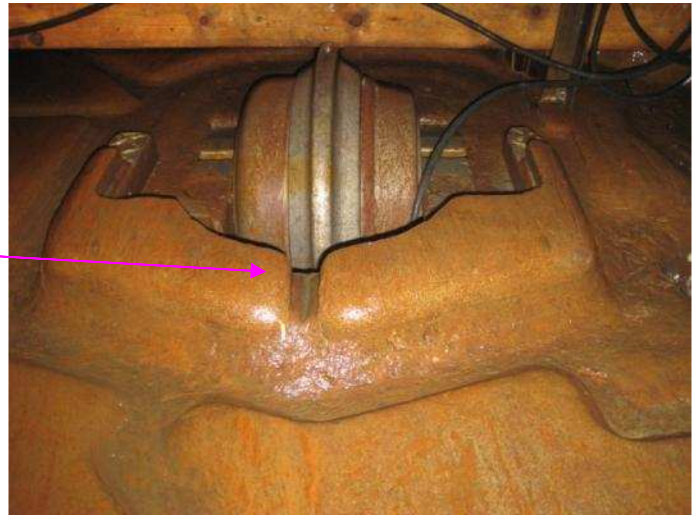


TBM excavation through blocky ground conditions

Measure 3:

Large cutterhead maintenance – Cutters protections refurbishment

Before



Cutter protections
worn out

Welding of Hardox
plates + carbide
plates and hard
facing to refurbish
the cutter
protections

After

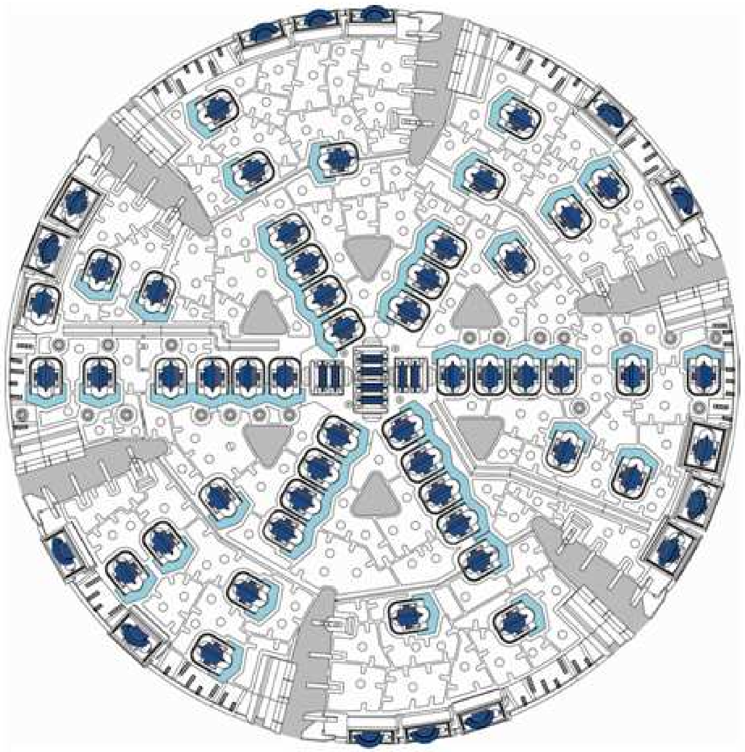
TBM excavation through blocky ground conditions

Measure 4:

Installation of a new cutterhead at the mid-adit (after 2500m of tunnel excavation)

Hallandsas

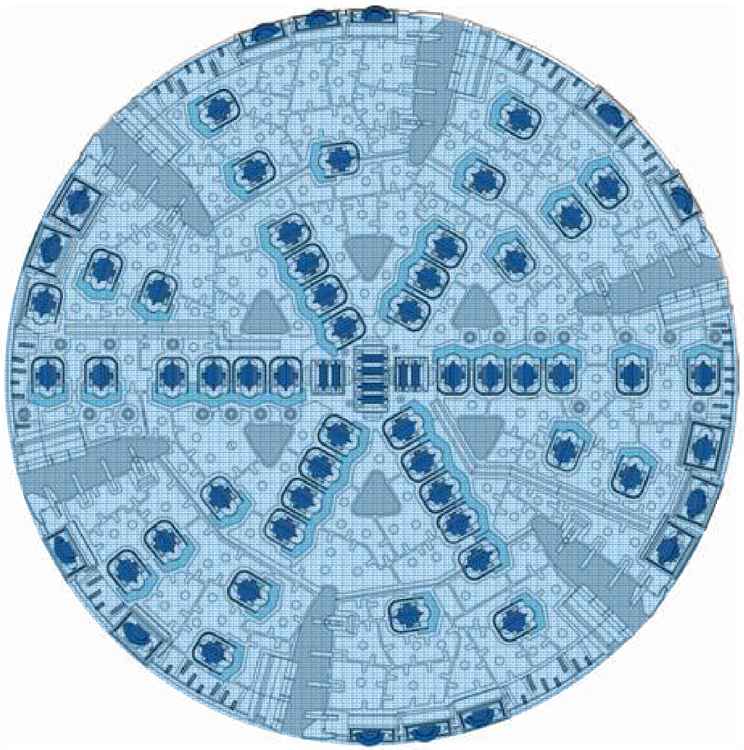
S-246 Cutterhead Layout



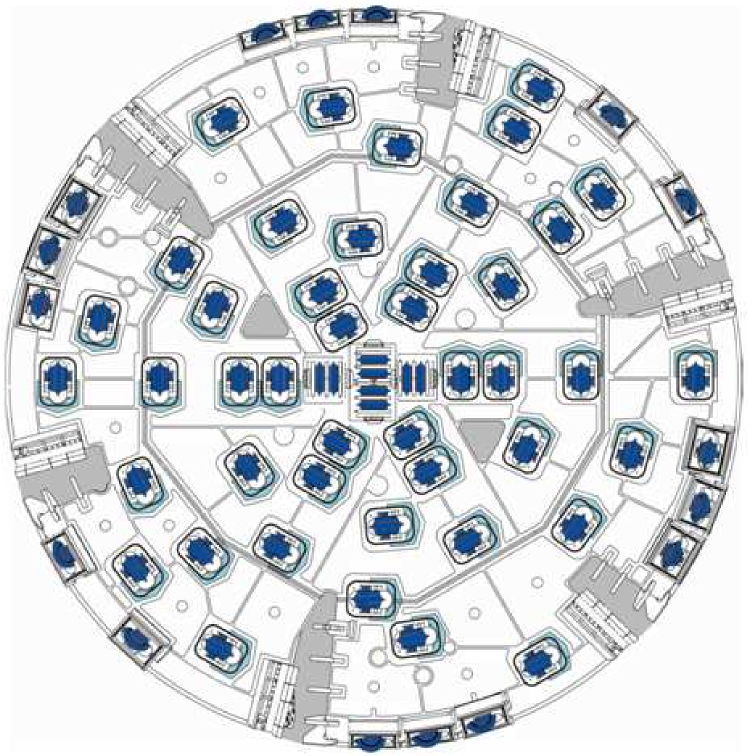
Requirements:

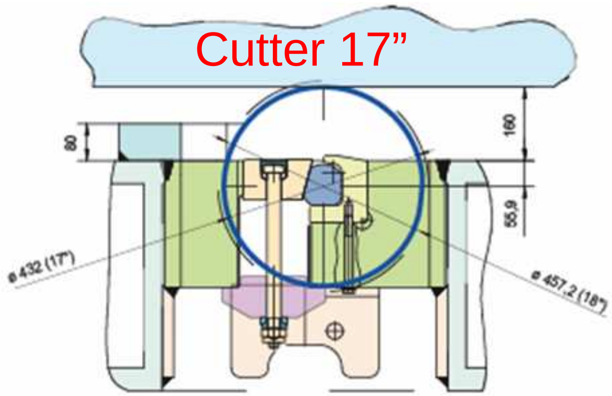
- conventional hard rock with closed mode possibility
- hard and abrassive rock conditions
- occasional blocky rock
- high water inflows
- dual mode operation (center belt - slurry)
- potential soil like ground behaviour in closed mode BC 2D (clogging)

First

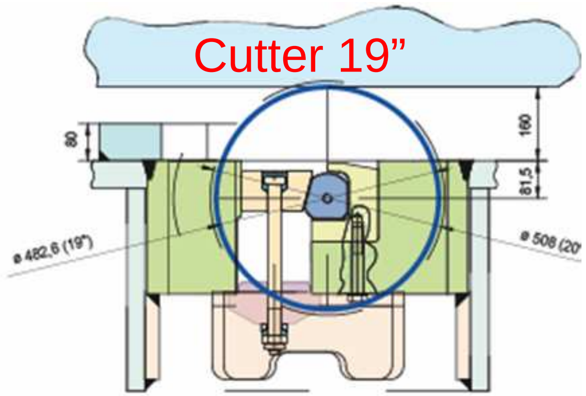


Second





nominal load: 250kN



nominal load: 320kN

New cutterhead:

- 19” cutters instead of 17” cutters
- Redistribution of cutters
- Additional protection

TBM excavation through blocky ground conditions

Measure 4:

Installation of the new cutterhead at the mid-adit in april/may 2008

Preliminary conclusions relative to the new cutterhead:

- Significant decrease of the amount of cutters damaged by blocks, 19” cutters withstand better impacts associated to blocks.
- Cutters consumption reduced by 50%
- Daily cutterhead maintenance reduced by 50%

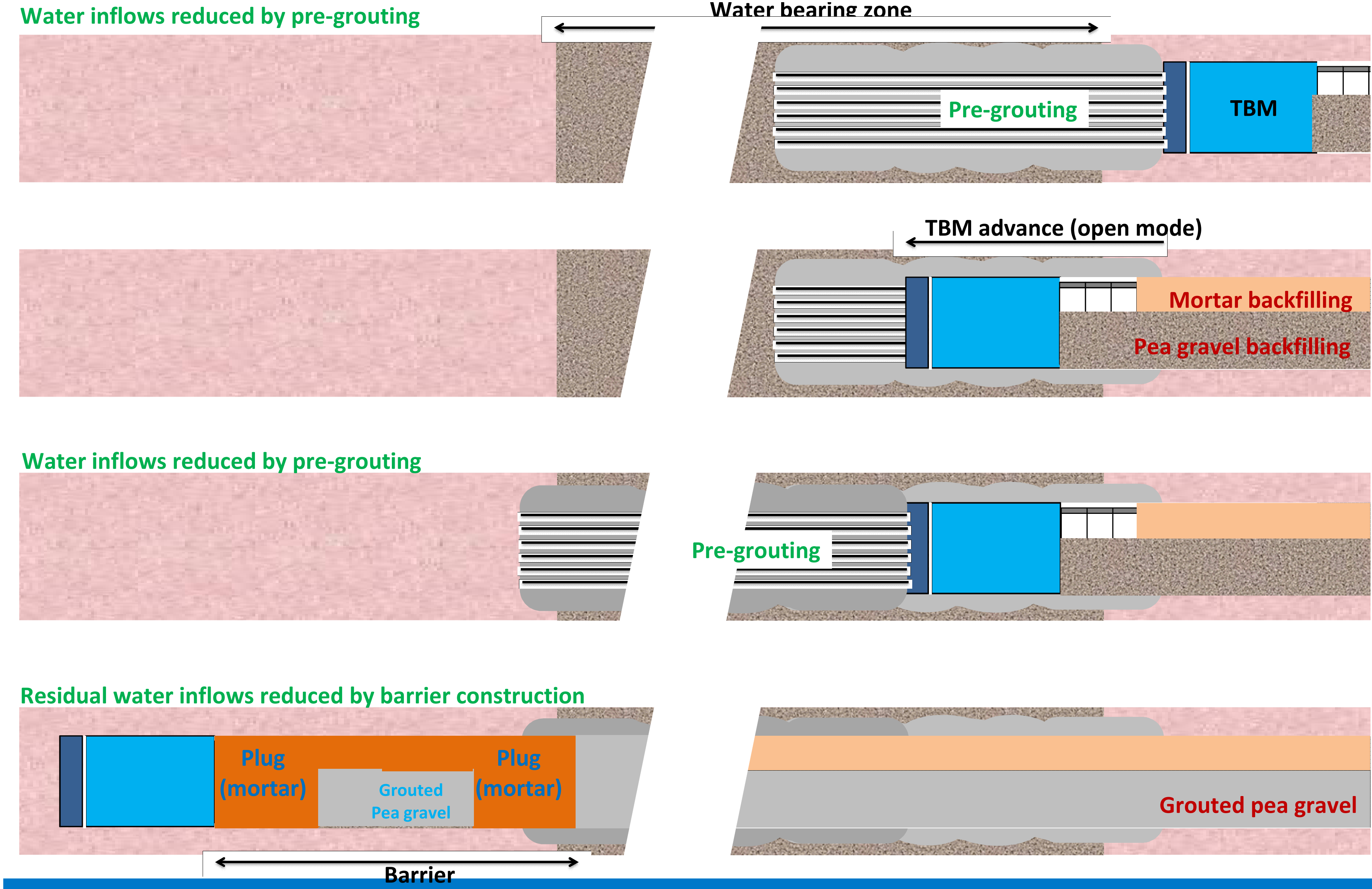
Water management: a major constraint

In order to control the ground water inflows within the demands of the Swedish Environmental Court, the following means are used:

- **Pre-grouting** with SH or microfine cement (generaly 6 to 14 holes at the face). Drilling in open mode and generally grouting in pressurized condition (to save water and to avoid grout circulation towards the face). Effect of pre-grouting on the water inflows extremely variable (scale 1 to 10) and difficult to be predicted (complexity of the rock mass).

- **Barrier construction** in order reduce the water inflows along the segmental lining. The following technique is used:
  - Excavation of 6 rings backfilled with pea-gravel
  - Excavation of 4 rings without backfilling
  - Pressurization of the shield to stop the ground water circulations
  - Backfilling of the empty rings with mortar
  - Cementituous grouting of the pea-gravel matrix
  - De-pressurization of the shield

Water management: TBM advance through water bearing zones



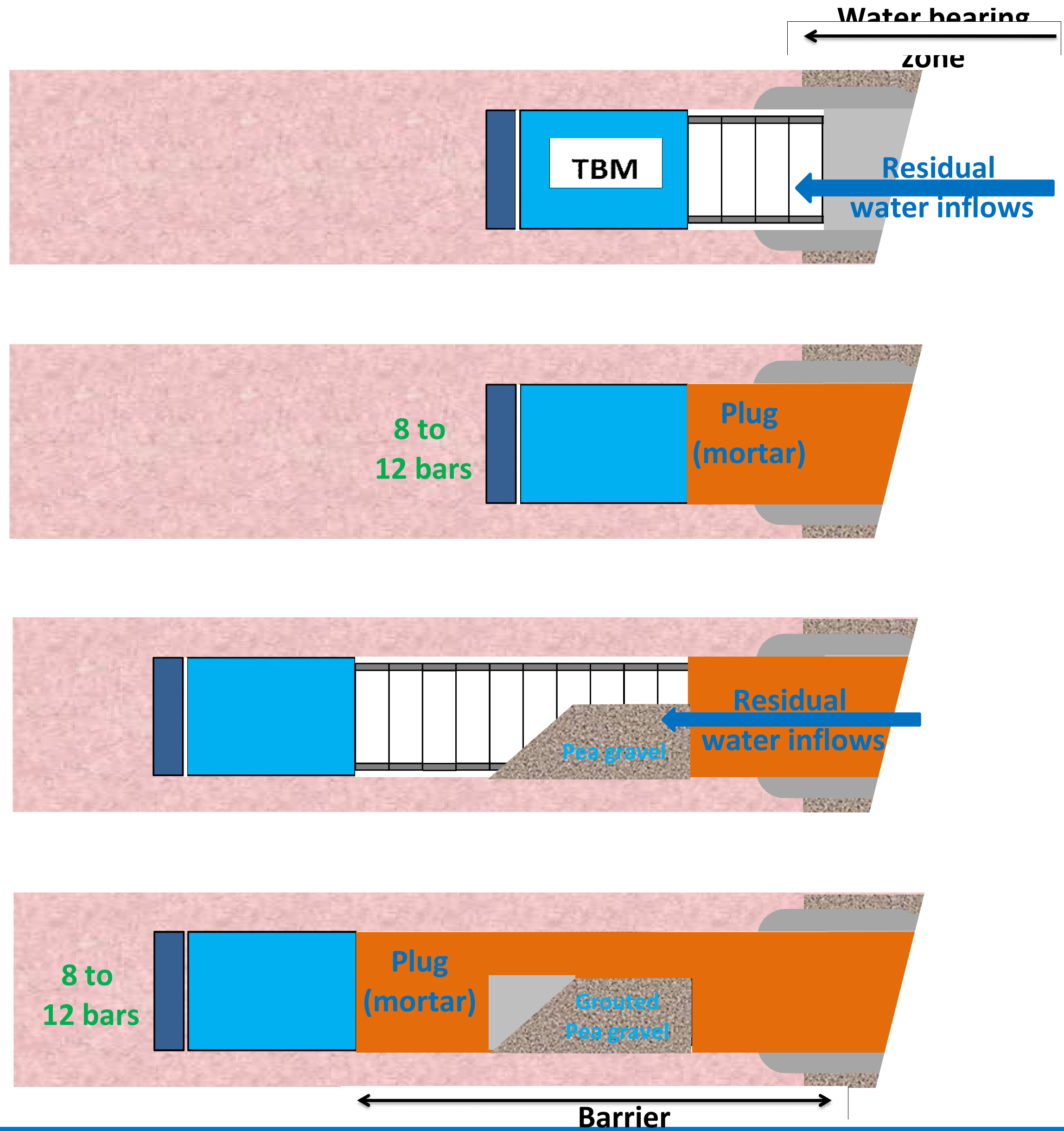
Water management: sequence for barrier construction

TBM excavation in open mode with residual water inflows up to 300 l/s Four rings without backfilling

Backfilling with mortar, shield being pressurized

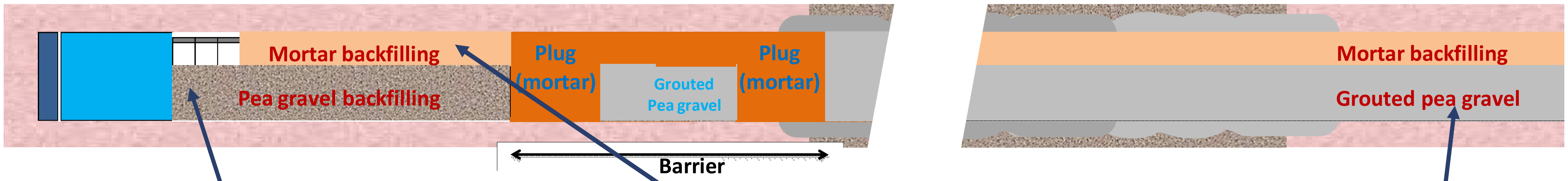
TBM excavation in open mode Six rings backfilled with pea gravel and four rings without backfilling

Backfilling with mortar and grouting of pea gravel matrix, shield being pressurized



Backfilling behind segmental lining

In open mode, use of pea-gravel and mortar injected through the segmental lining. The pea-gravel matrix is at a later stage injected with a cementituous grout (between barriers where the water circulation is reduced)



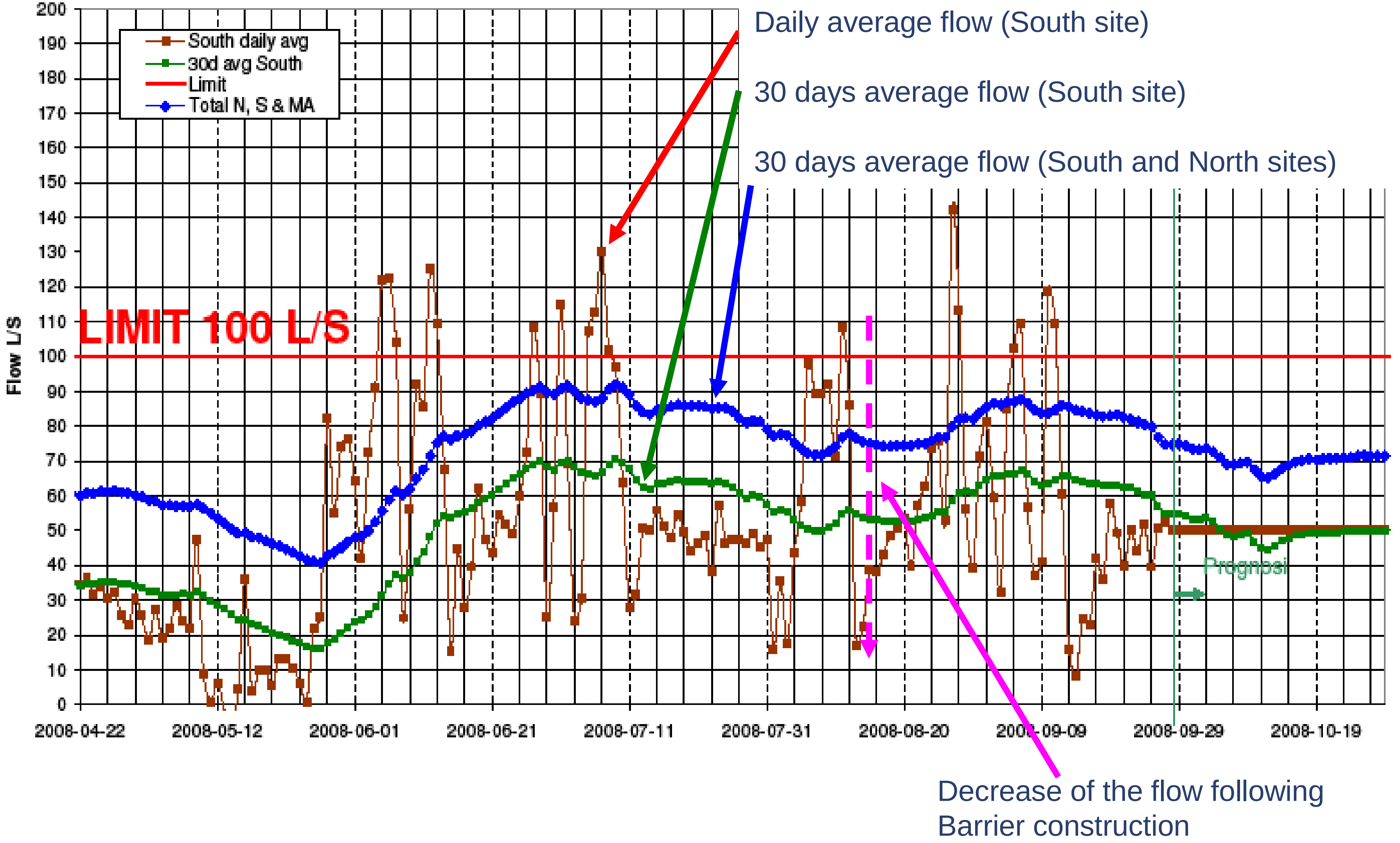
3 phases:

Backfilling with pea-gravel (2/3 inf.) behind the shield

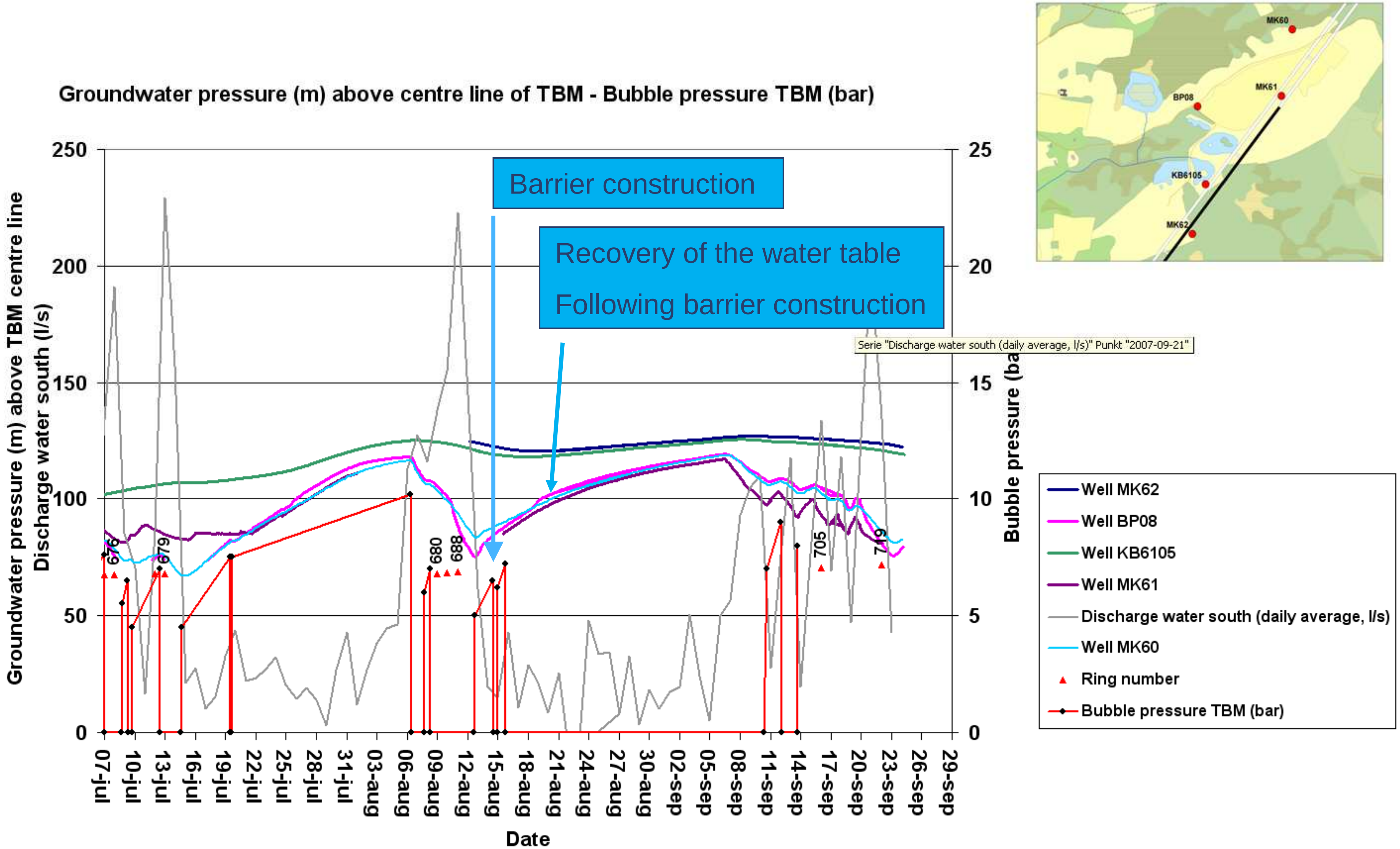
Backfilling with mortar (1/3 sup.) roughly 20m behind the shield

Injection of cementituous grout in the pea-gravel matrix

Water management



Water management: ground water table

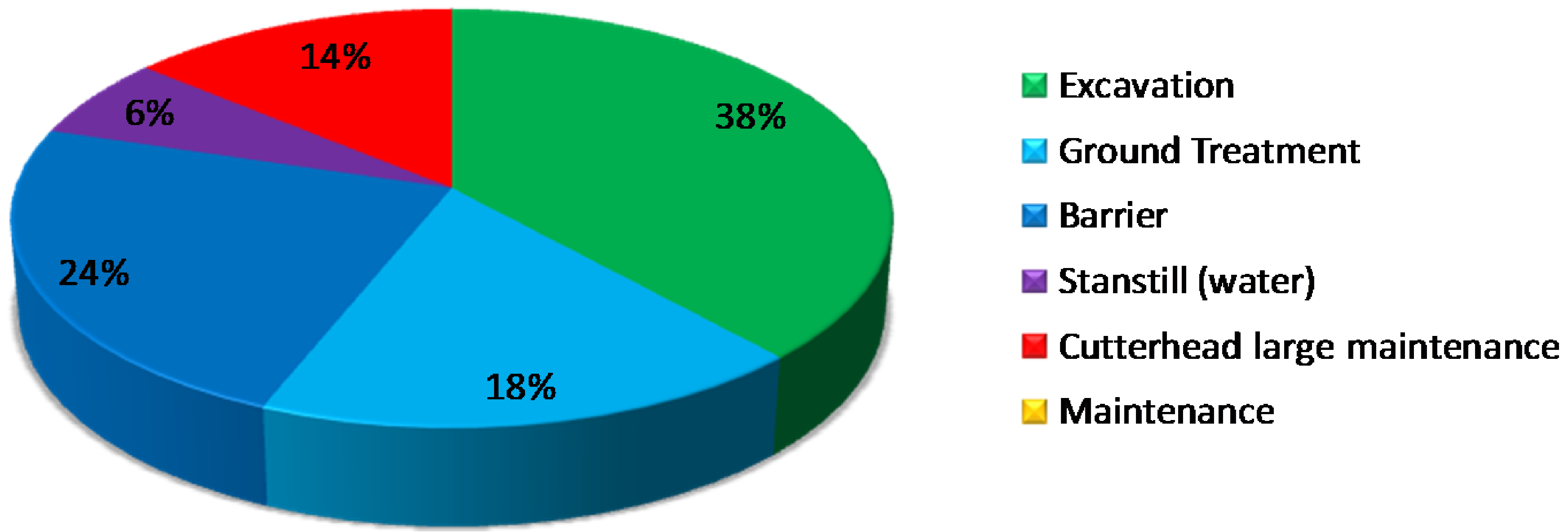


Water handling on TBM

• Use of a powerful pumping system (1400 m3/hr) for removing the water from the cutterhead chamber.
• Use of the slurry circuit for flushing continuously the cutterhead and bubble chambers and for maintaining the pumping systems operational.
• Removal of the water inflows transported on the TBM belt conveyor

The TBM can work in open mode with flow up to 300 l/s.

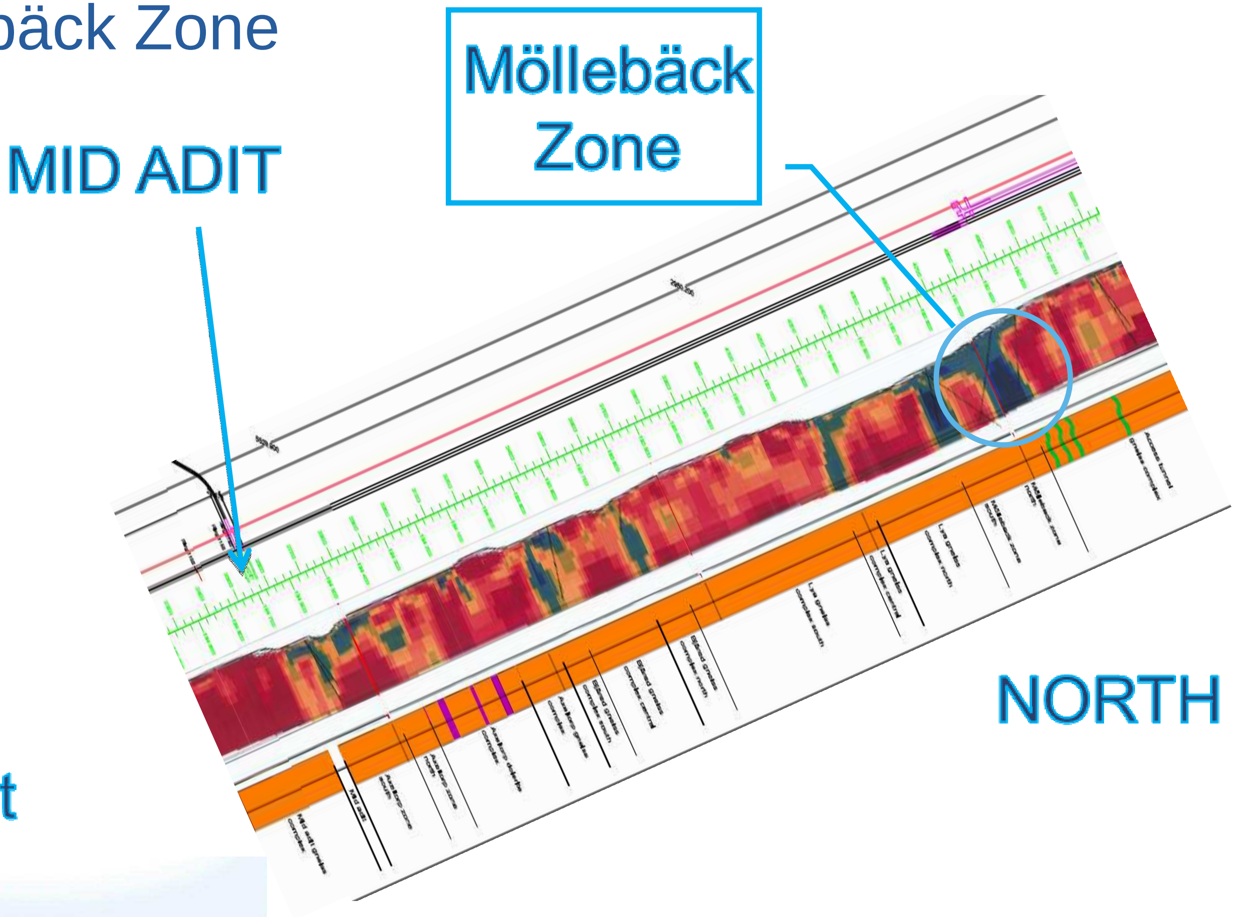
Progress rates (with new cutterhead)



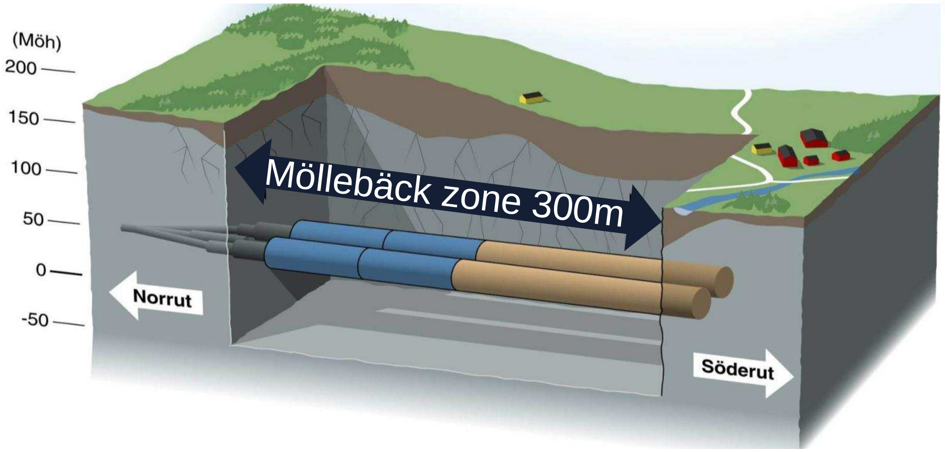
- About 50% of the time spent in dealing with water (ground treatment, barrier…).
- In ”dry” zones, average daily progress 11.5 m/day
- In ”wet” zones (meaning requiring ground treatment and barriers), 3.7m/day only1/3 of the time being spent in tunnel excavation.

In the geotechnical and hydrological conditions of the Hallandsås ridge and with the constraints associated to the Environmental Court rulling, the TBM permits progress 5 times faster than with drill and blast technique.

Pre-treatment of Möllebäck Zone



Details of pre-treatment

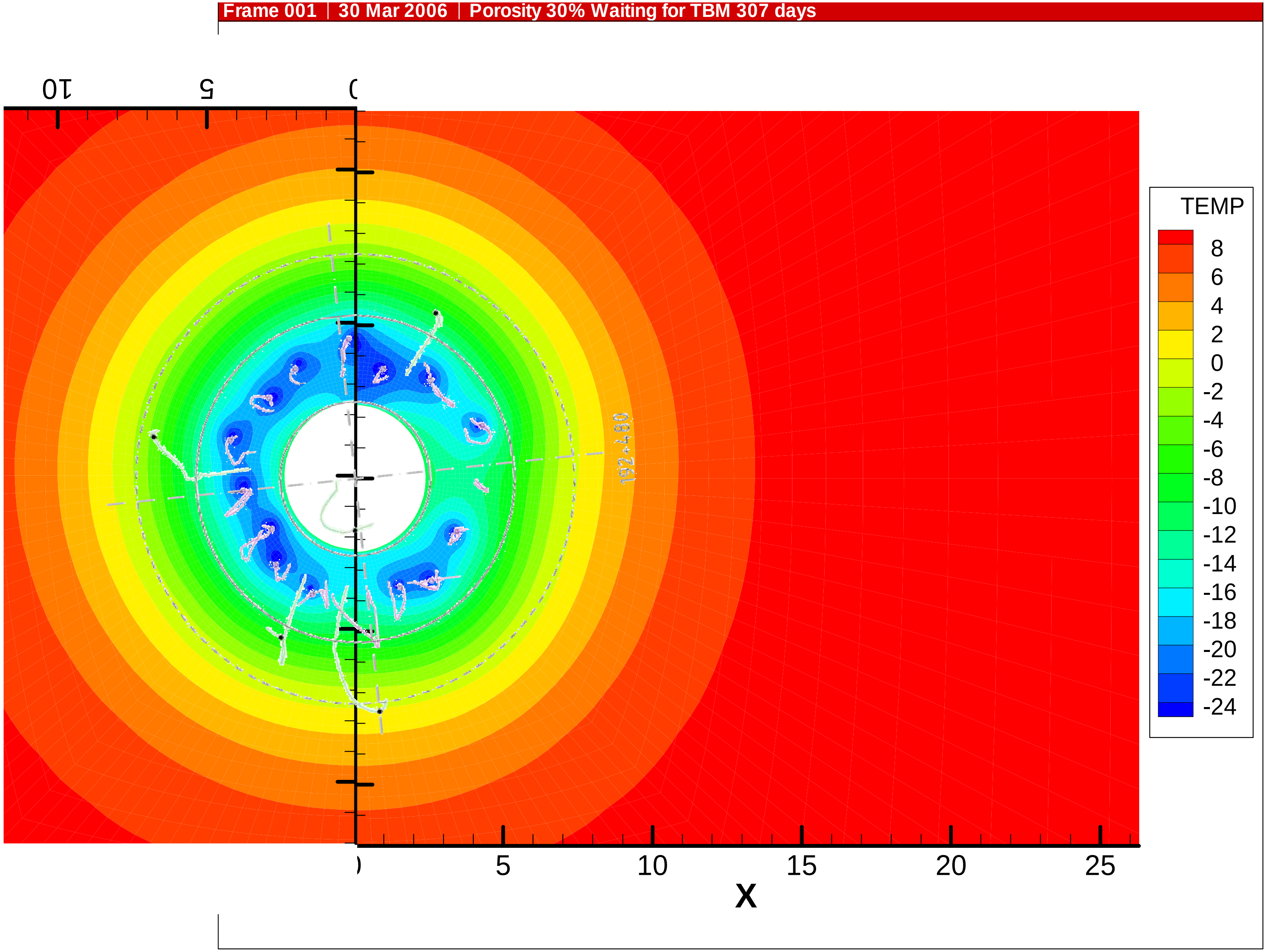


Freezing
Grouting

Pre-treatment of Möllebäck Zone: methods

- Construction of a 600m long access tunnel to work as close as possible to the Möllebäck zone.
- Additional exploratory investigations.
- Drilling of 100m long freeze holes (steered drilling).
- Freeze tubes installation (GRI)
- Freezing of the ground
- Excavation of a 5m diameter pilot tunnel, 100m long through the frozen ground.
- Drilling for freezing 30 additional meters of tunnel and for pre-grouting 200m.
- Pre-grouting with microfine cement
- Freezing of the additional 30m of tunnel
- Excavation with the TBM of the pre-grouted part and reaming of the frozen part.

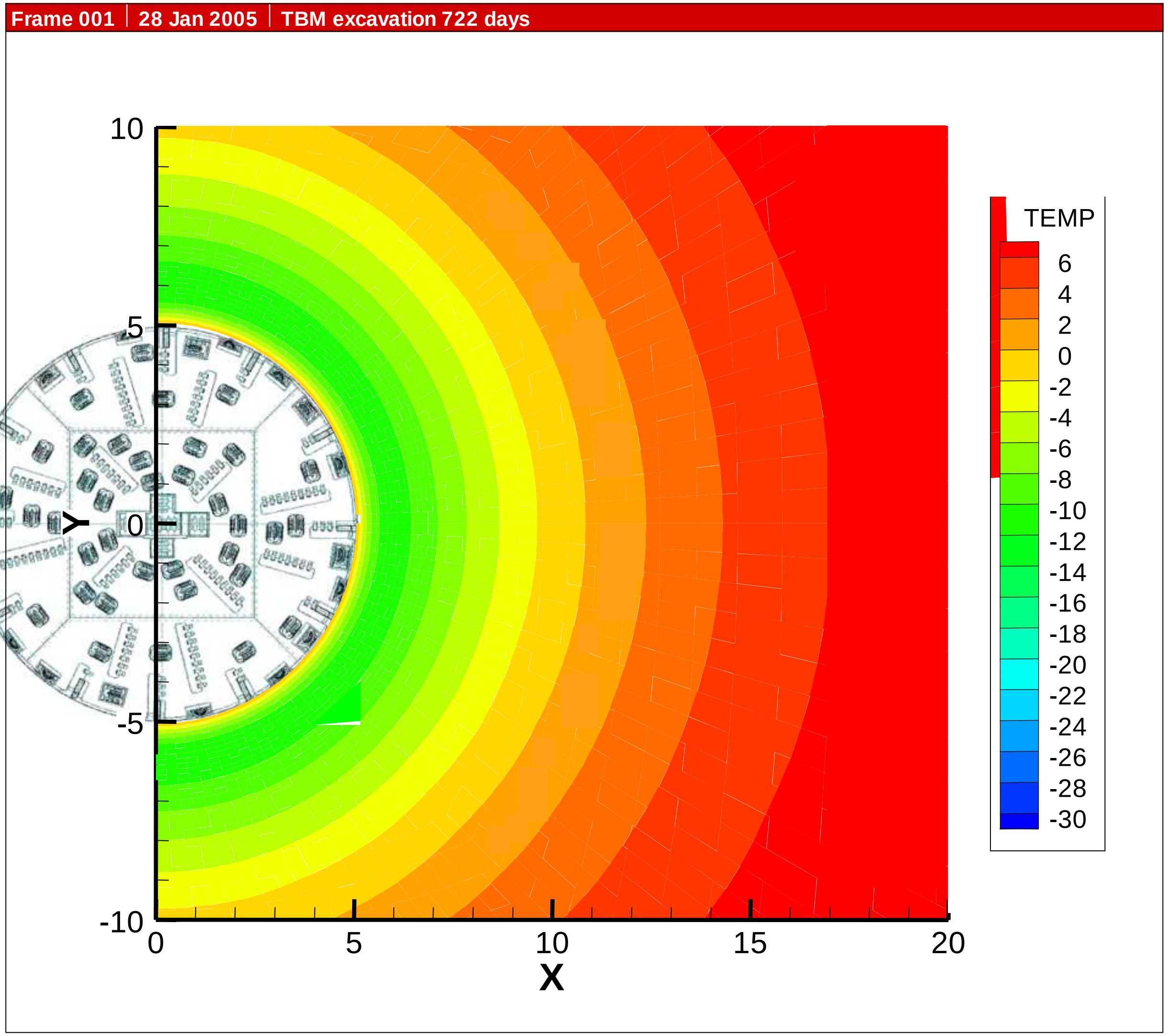
Pre-treatment of Mölleback Zone: freeze devolpment



Pre-treatment of Mölleback Zone: pilot tunnel through frozen ground

Skanska - Vinci HB

Pre-treatment of Möllebäck Zone: reaming of the frozen pilot tunnel by the TBM



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