Webinar
Túneles con TBM
Experiencias en proyectos extranjeros

CTES COMITÉ DE TÚNELES Y ESPACIOS SUBTERRÁNEOS DE CHILE

29 de Septiembre

“Long Infrastructure Tunnels in Great Depth - Benefits of a 3rd Tunnel Tube”

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“Long Infrastructure Tunnels in Great Depth - Benefits of a 3rd Tunnel Tube”

Experiences gained from the 64km long Brenner Base Tunnel Project between Austria and Italy using both TBM and Drill and Blast Excavation Methods

Thomas Marcher

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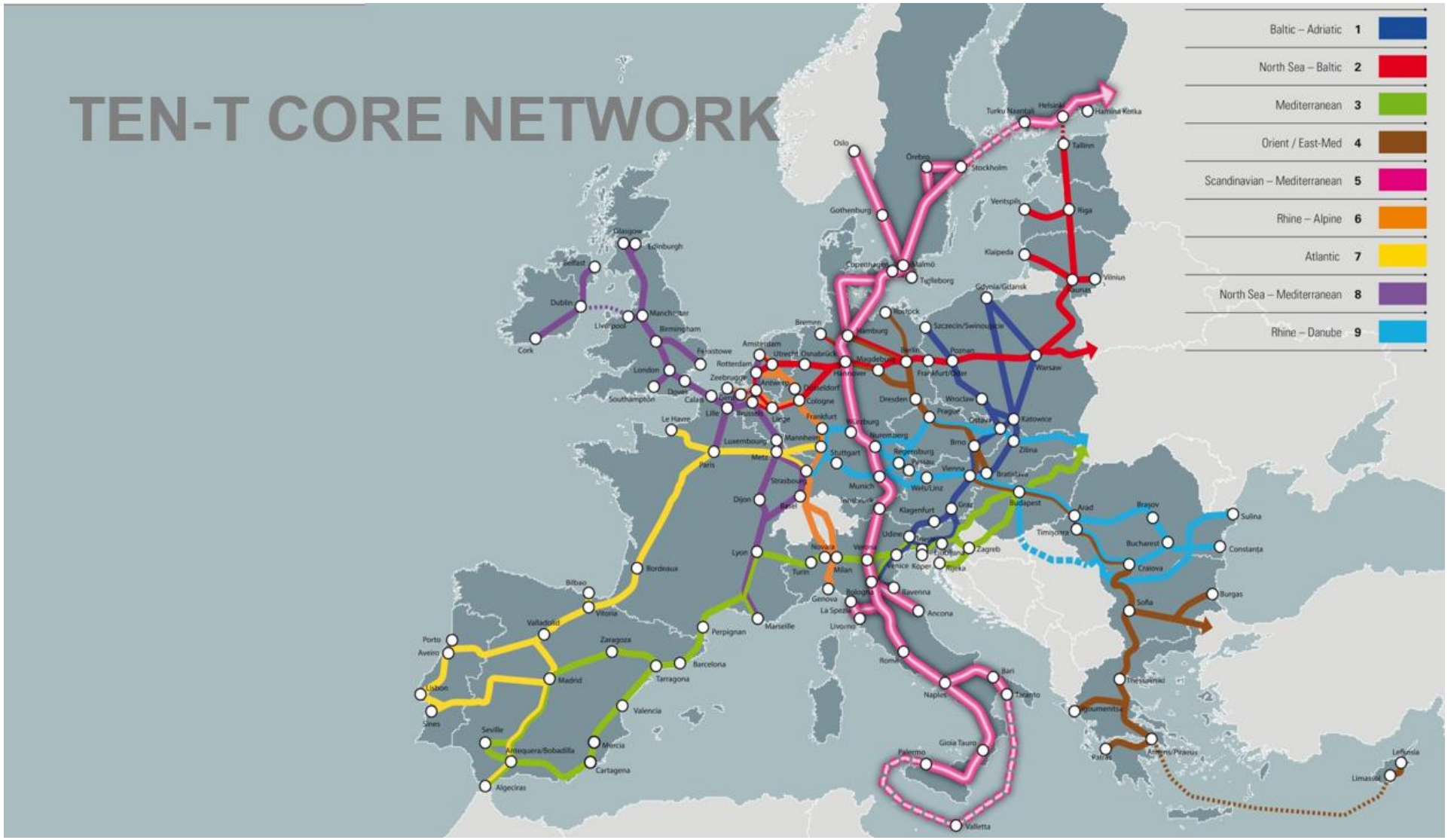
Head of the Institute for Rock Mechanics and Tunnelling, Graz University of technology, Austria

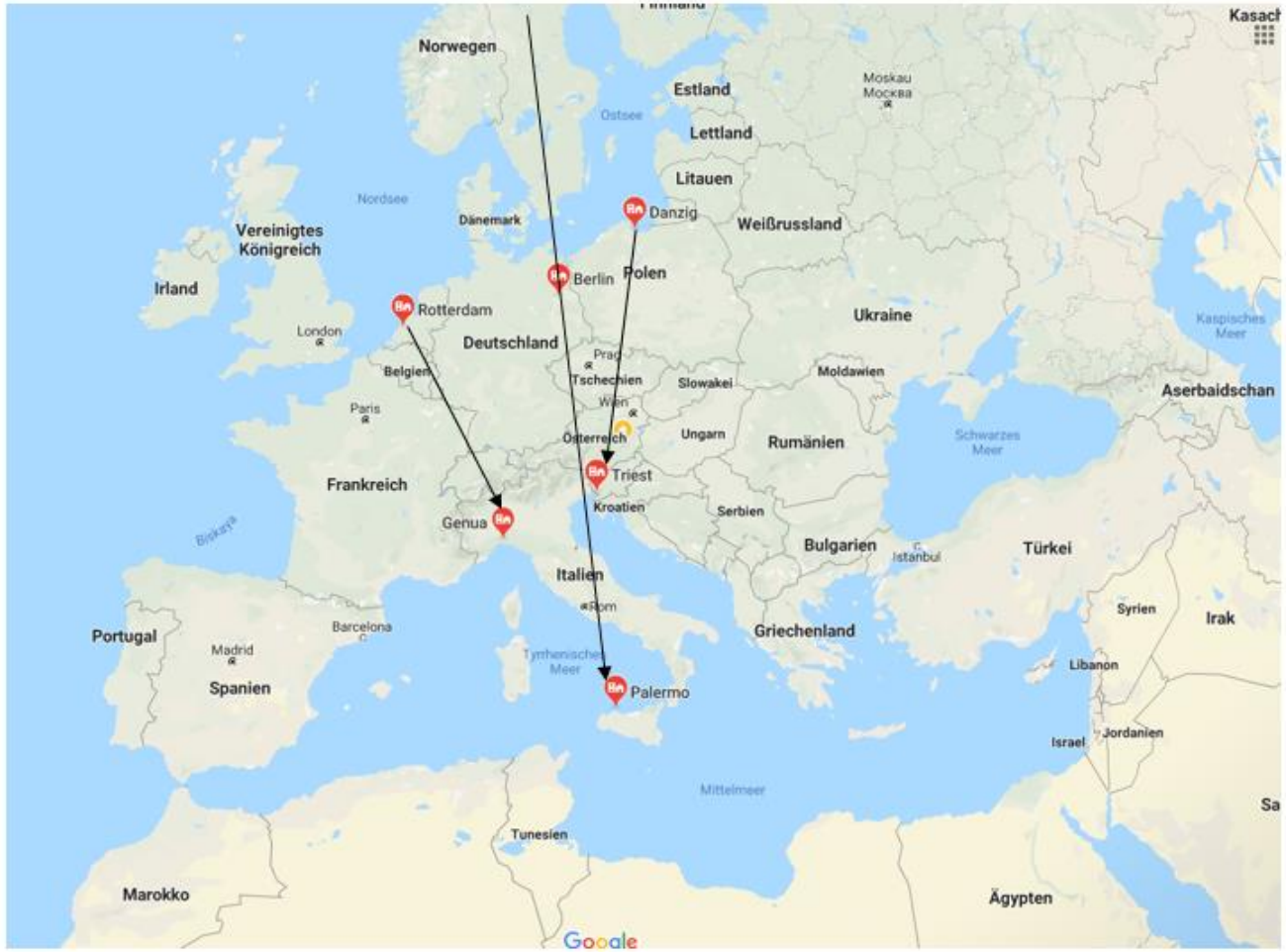
CONTENT

- Long Infrastructure Tunnels in Central Europe
- BBT – Brenner Base Tunnel Project
- Benefits of an Exploratory Tunnel
- Summary

Long Infrastructure Tunnels in CE



Long Infrastructure Tunnels in CE



- European North-South Railway Links
  - Rotterdam to Genoa (Western Corridor)
  - Berlin to Palermo (Central Corridor)
  - Gdansk to Trieste (Baltic – Adriatic Corridor)

Long Infrastructure Tunnels in CE

Western Corridor tunnels (situated in Switzerland):

- Lötschberg Base Tunnel opened in 2007 (length 35 km, max 830 m overburden, 90 km running tunnels)
- Gotthard Base Tunnel opened in 2016 (length 57 km, max 2450 m overburden, 152 km running tunnels)
- Ceneri Base Tunnel will open in 2020 (length 15 km, max 800 m overburden, 40 km running tunnels)

Long Infrastructure Tunnels in CE

Central Corridor tunnels (situated in Austria / Italy / France):

- Brenner Base Tunnel
  started construction in 2006
  (length 64 km, max 1800 m overburden,
  250 km running tunnels)
- Mont Cenis Base Tunnel
  started construction in 2006
  (length 58 km, max 1650 m overburden)

Long Infrastructure Tunnels in CE

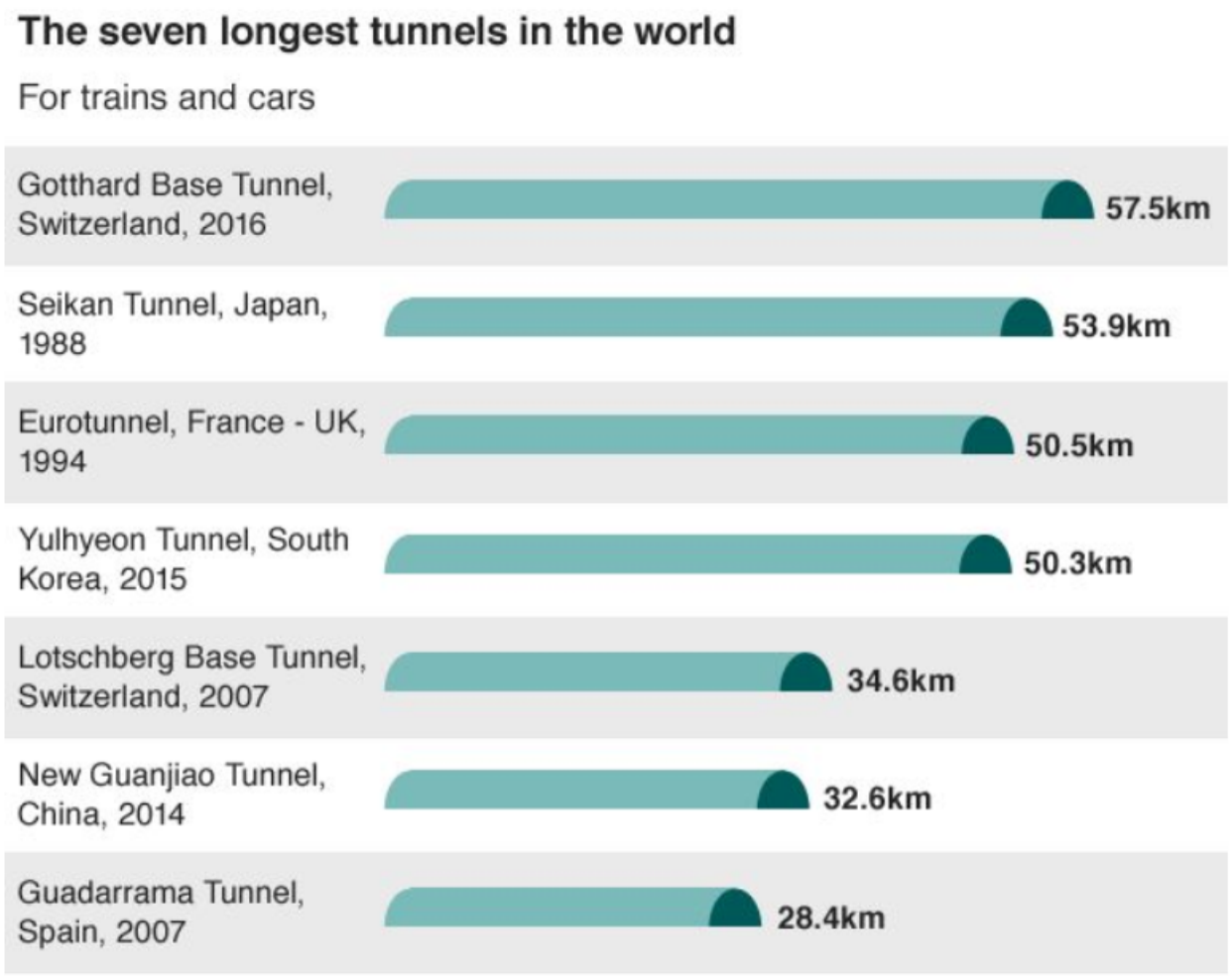
Baltic Adriatic Corridor tunnels (situated in Austria):

- Semmering Base Tunnel connecting Vienna with Graz (started construction in 2012, length 28 km, max 875 m overburden)

- Koralm Base Tunnel connecting Graz with Klagenfurt (started construction in 2009, length 33 km, max 1200 m overburden)

both intended to finish construction within the next 7 years.

Long Infrastructure Tunnels in CE



Long Infrastructure Tunnels in CE

Long tunnels at great depth (ITA 2010):

“the deeper the tunnel, the larger the uncertainties; the higher the probability of encountering adverse or unforeseen conditions for tunneling, the greater the effort and the cost for site investigations to reduce the uncertainties".

Long Infrastructure Tunnels in CE

- Long Infrastructure Tunnels in Central Europe
- BBT – Brenner Base Tunnel Project
- Benefits of an Exploratory Tunnel
- Summary

Central Corridor (SCAN MED corridor)

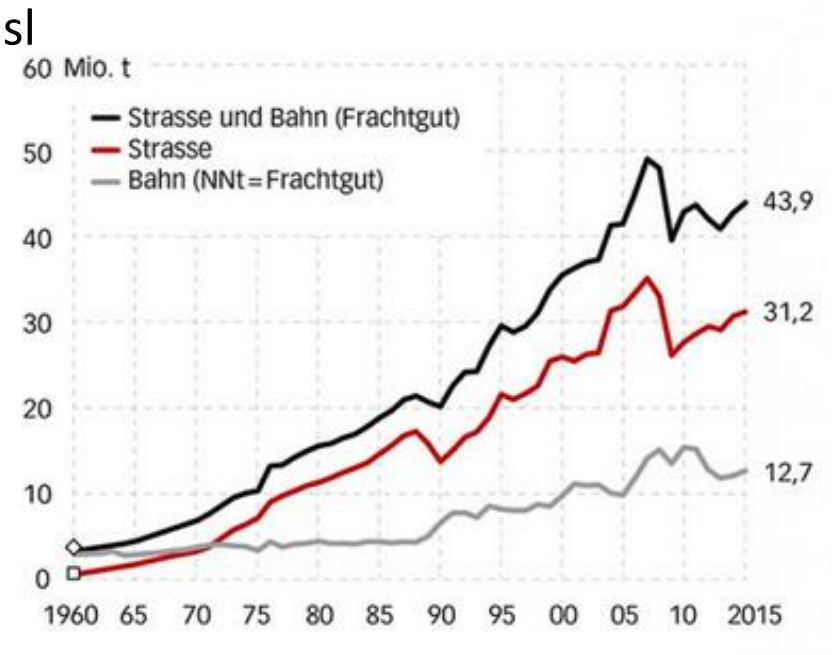
- length 9.300 km
- 7 states, 19 airports, 25 harbors

Central Corridor (SCAN MED corridor)

BBT - Brenner Base Tunnel Project

Existing ROADWAY connection:

>2,3 mio. trucks a year
pass altitude 1.370 m asl



Magazine, Bauwerk Europas: der Brenner-Basistunnel 20, 2016

High Noon on the Brenner Pass over traffic volumes

Germany calls crisis summit as Austria threatens further action against motorists

Tue, Jul 23, 2019, 17:40

Derek Scally in Berlin

The motorway and street following the valley near Sankt Nikolai in the Brenner Pass.

The Brenner is a miracle of post-war engineering and one of Europe's great drives: an Alpine autobahn on concrete stilts up to 140m high that connects Bavaria and Austria with Italy.

BBT - Brenner Base Tunnel Project

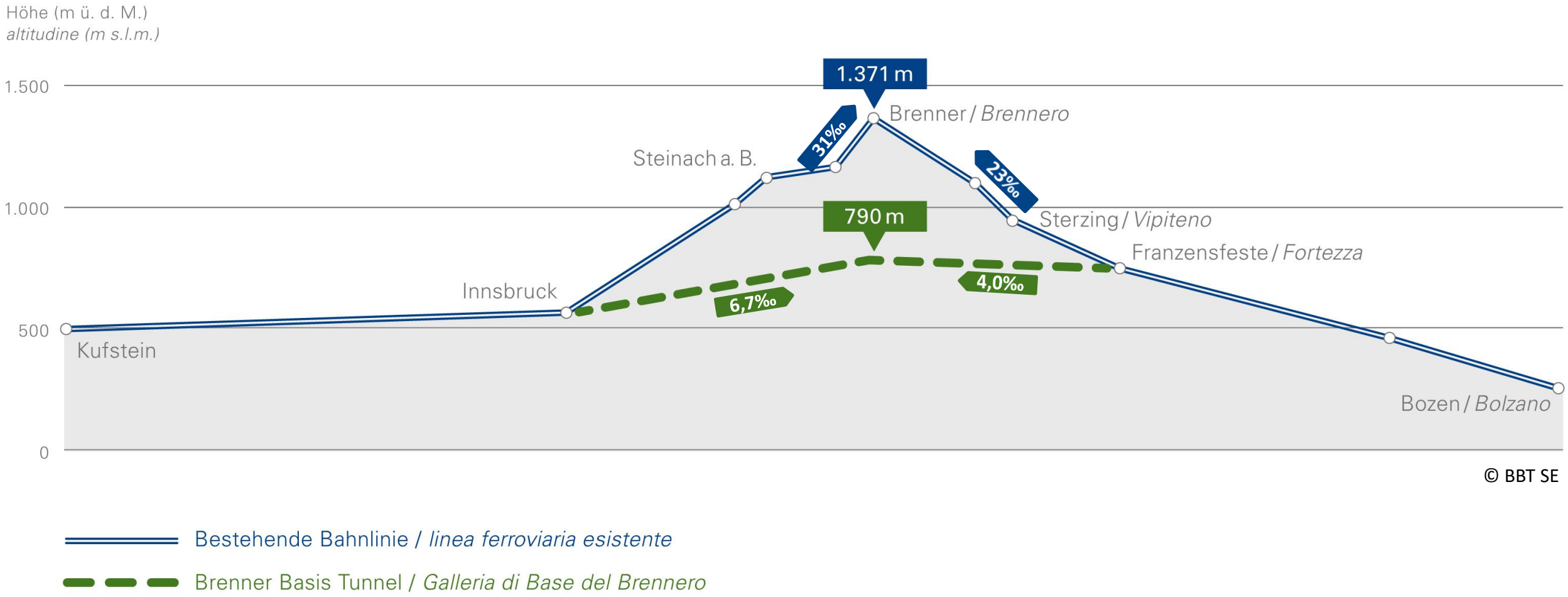
Existing RAILWAY connection

Max. grade on the track is 31 per thousand.

The minimum curve radius is 264 meters. The highest point of the track is Brenner station at 1,371 m

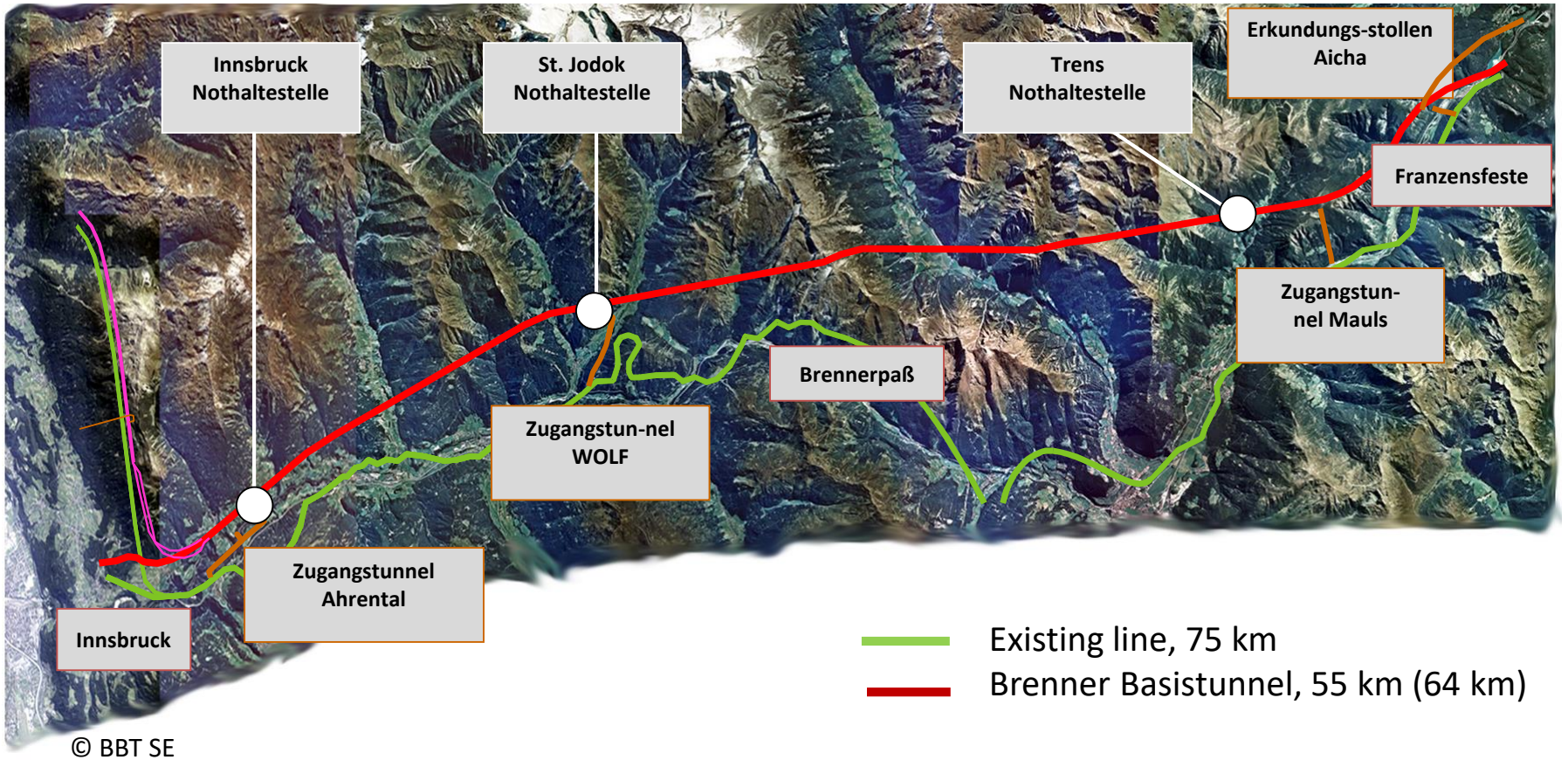
BBT - Brenner Base Tunnel Project

Longitudinal section

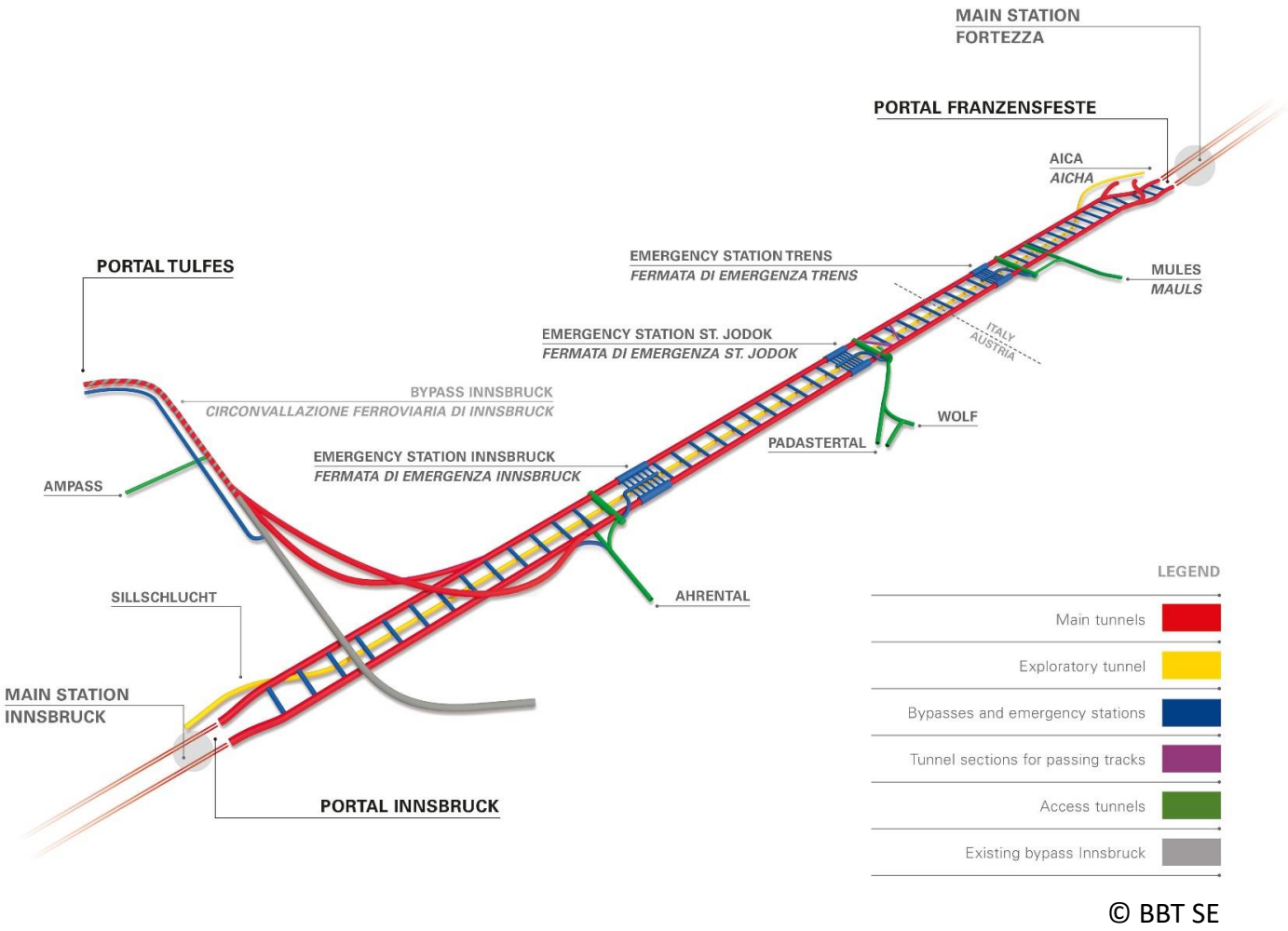


BBT - Brenner Base Tunnel Project

Site map



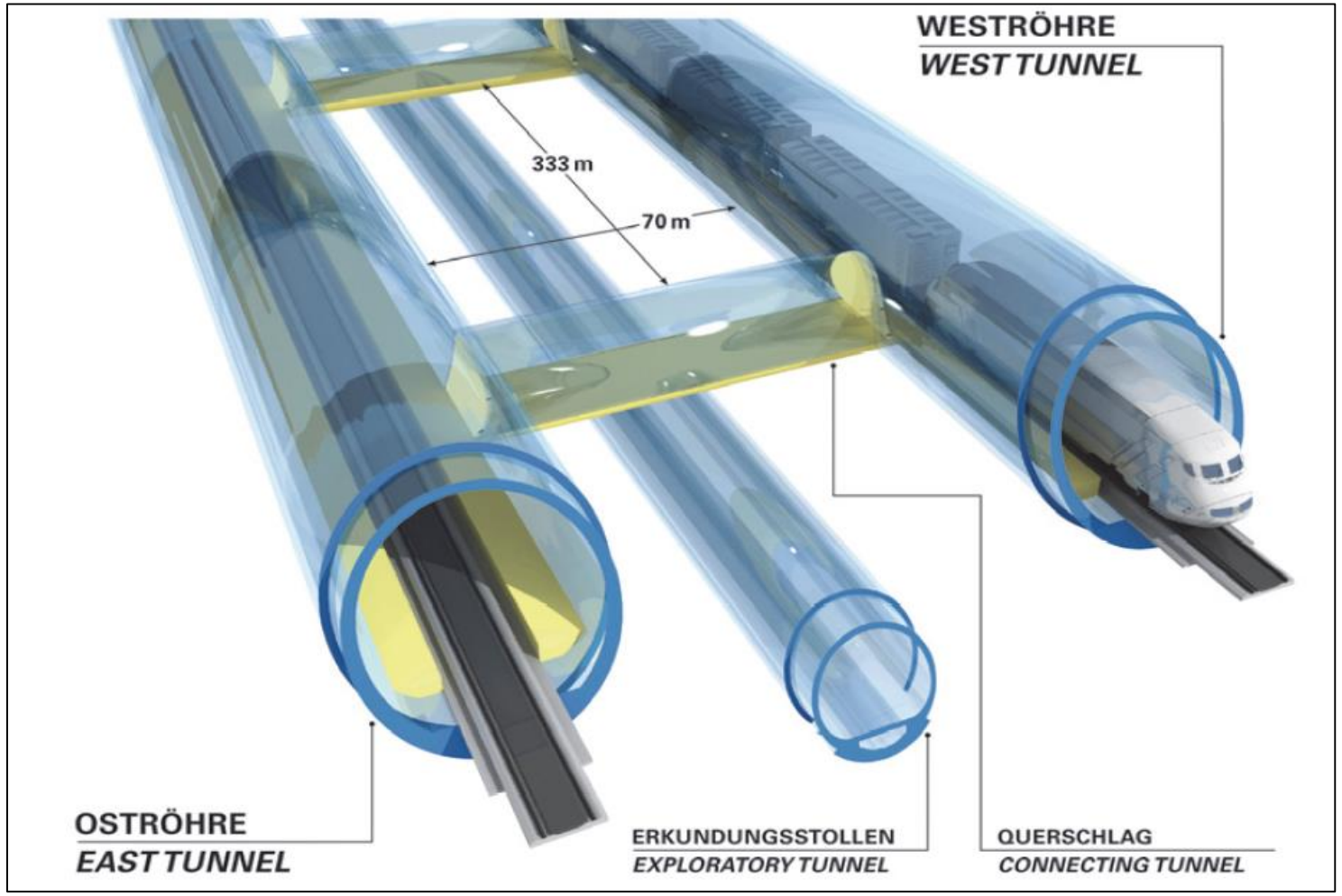
BBT - Brenner Base Tunnel Project



© BBT SE

- 64 km long tunnel system
- connecting Innsbruck (Austria) – Fortezza (Italy)
- design speed 250km/h
- tunnel system with 3 underground stations (for logistics and for emergency stops)
- tunnel system with 3 tunnel tubes

BBT - Brenner Base Tunnel Project

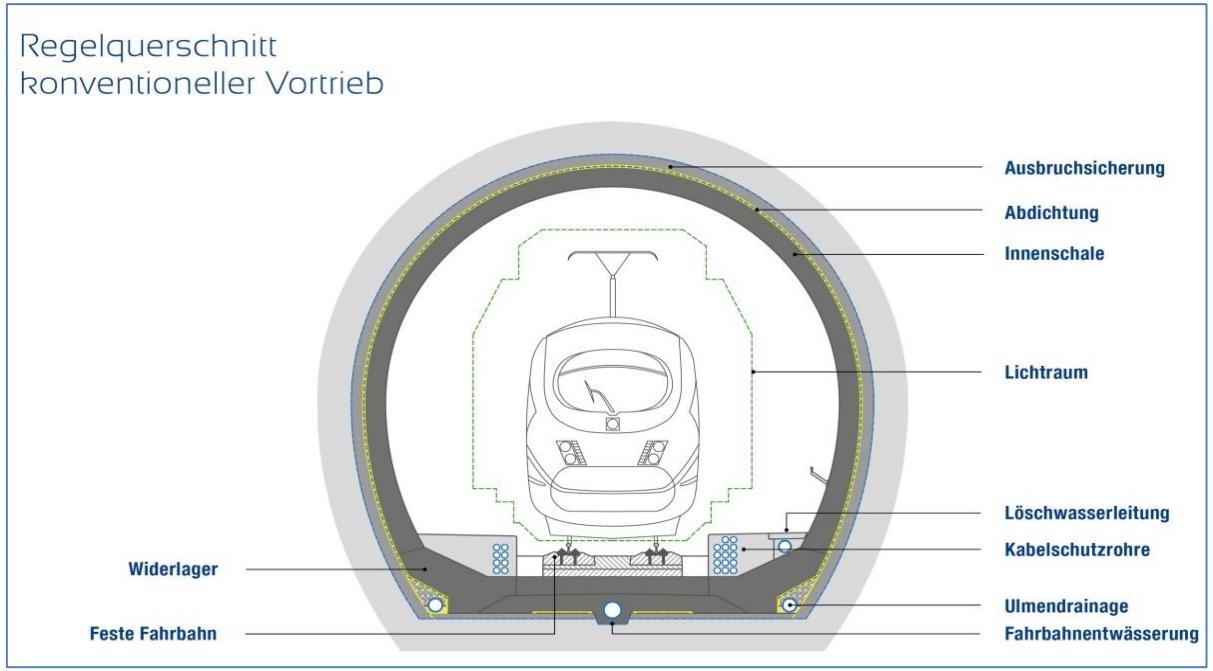


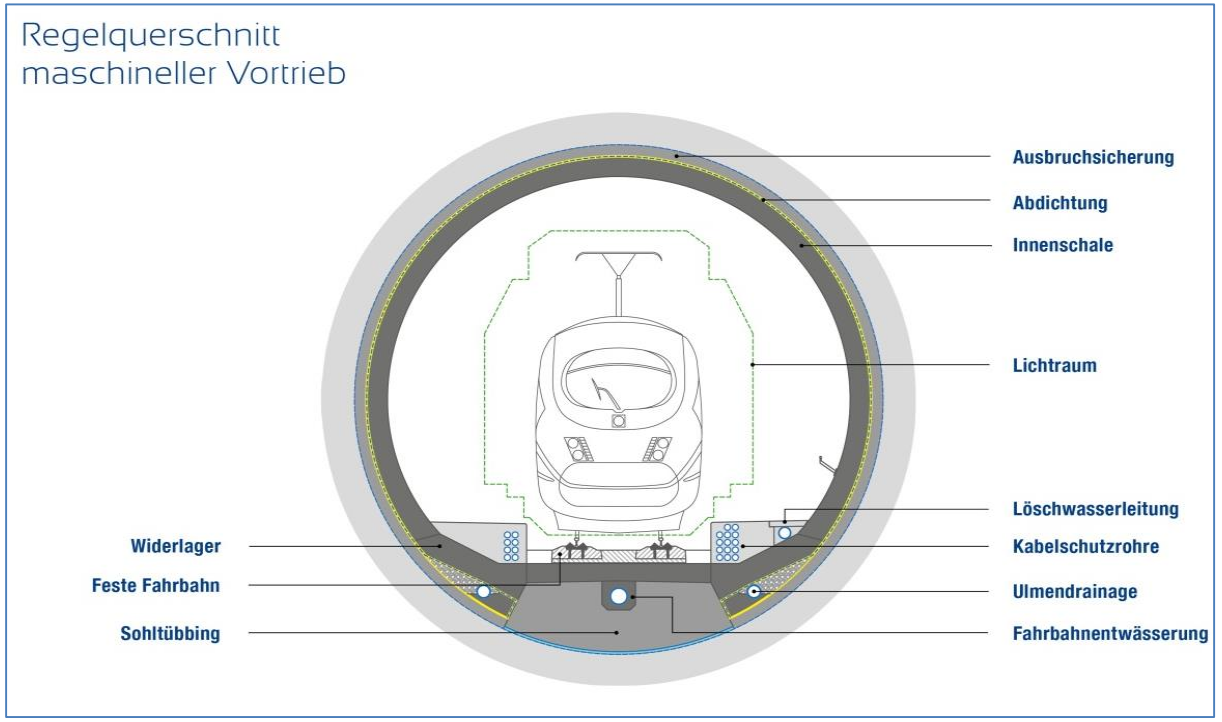
© BBT SE

- **2 single track tubes**
  (inner diameter: 8,1 m)
- Cross passages every 330 m
- **exploratory tunnel**:
  (inner diameter: 6,0 m)
- **Purpose of exploratory tunnel:**
  - exploration
  - logistics (during construction)
  - dewatering adit
  - emergency adit
  - space for pipes, lines, E&M equip.
  - maintanance during operation
  - reduce interruption of operation

BBT - Brenner Base Tunnel Project

Typical (regular) tunnel sections





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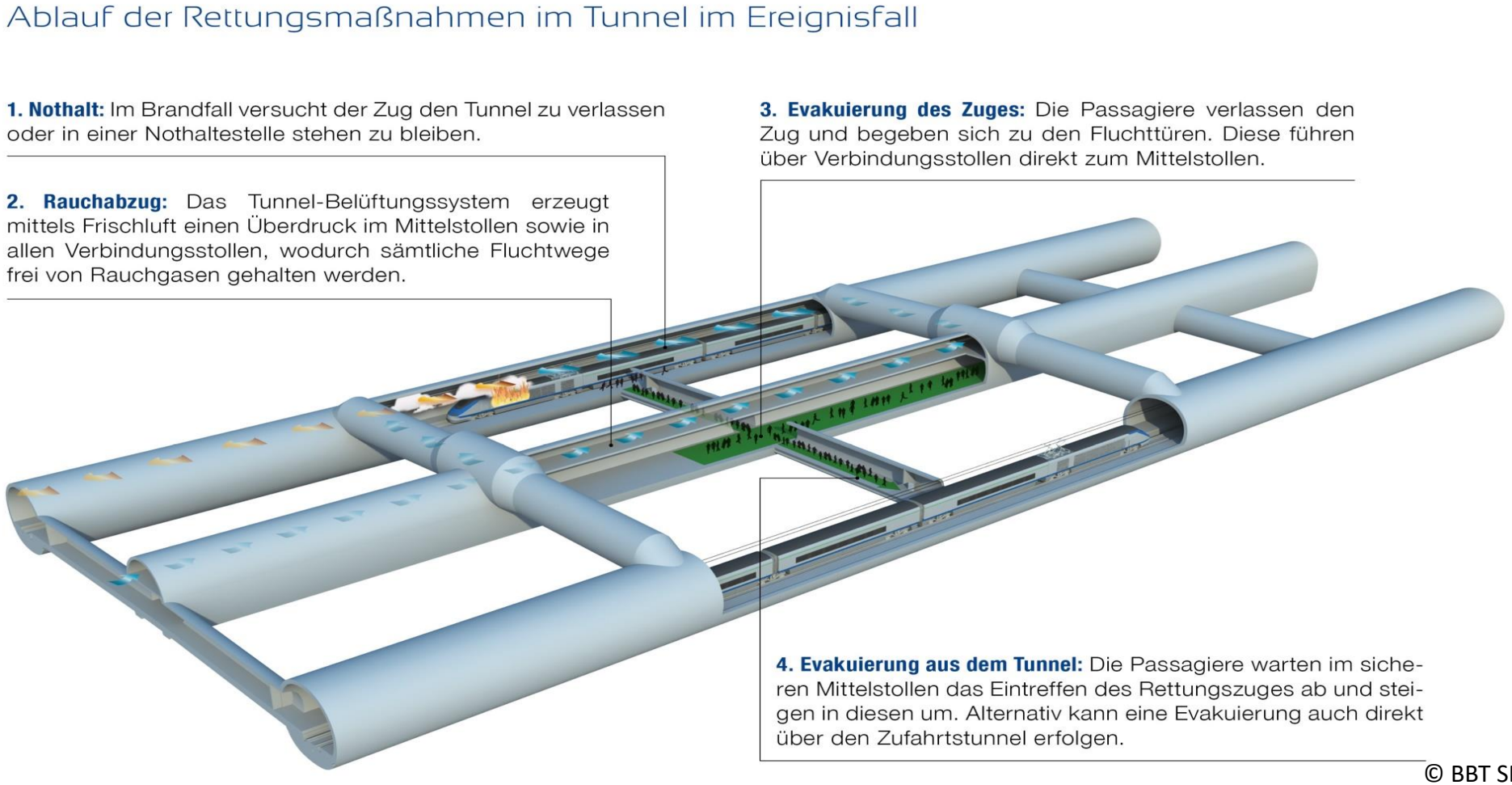
Emergency stops (stations)



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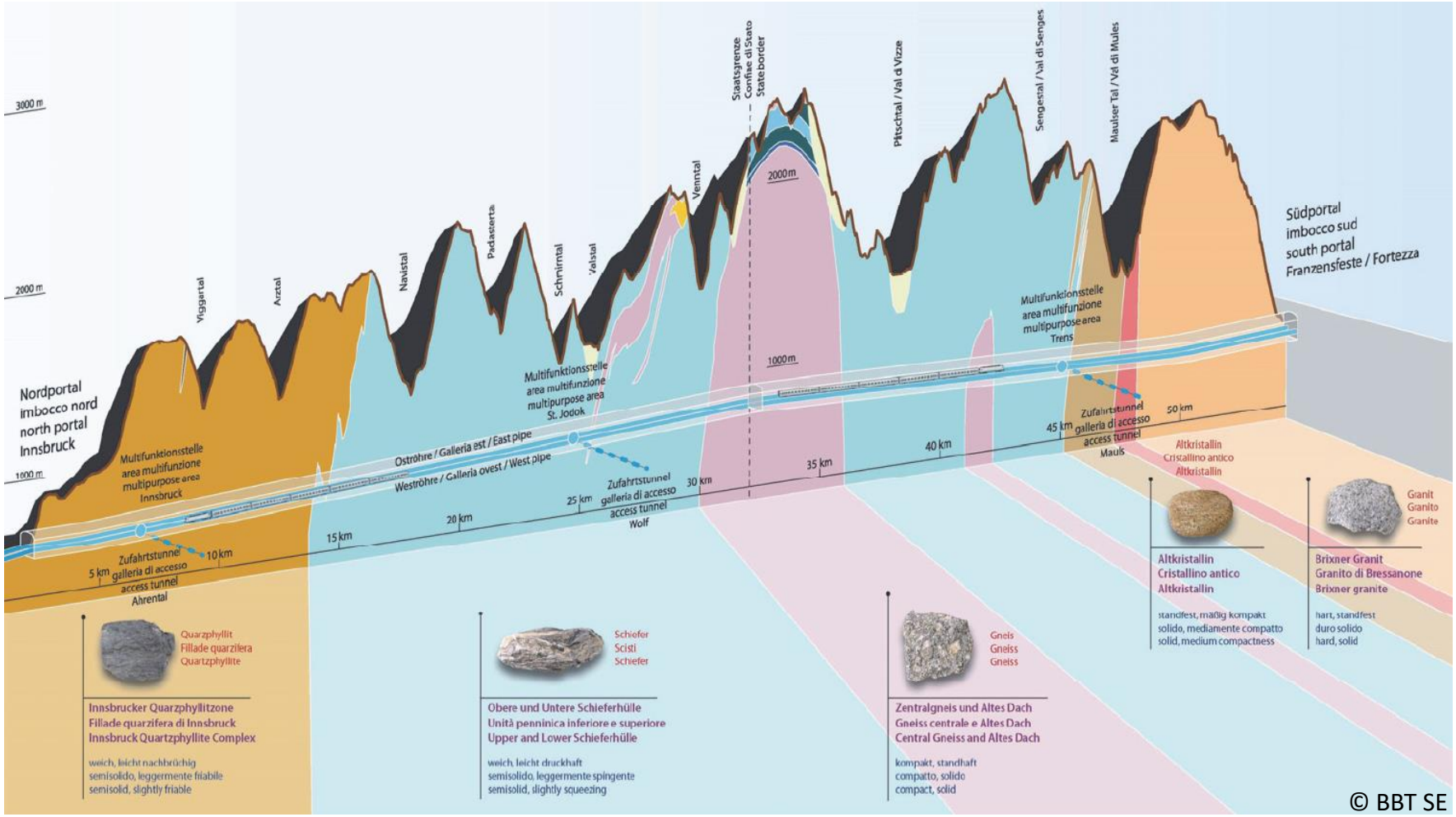
BBT - Brenner Base Tunnel Project

Project geology



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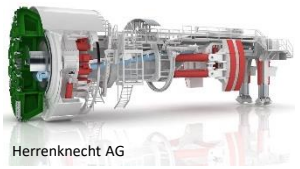
BBT - Brenner Base Tunnel Project

Excavation type

- Conventional tunnelling
  - By blasting

  - By roadheader

- Continuous tunnelling
  - Open TBM

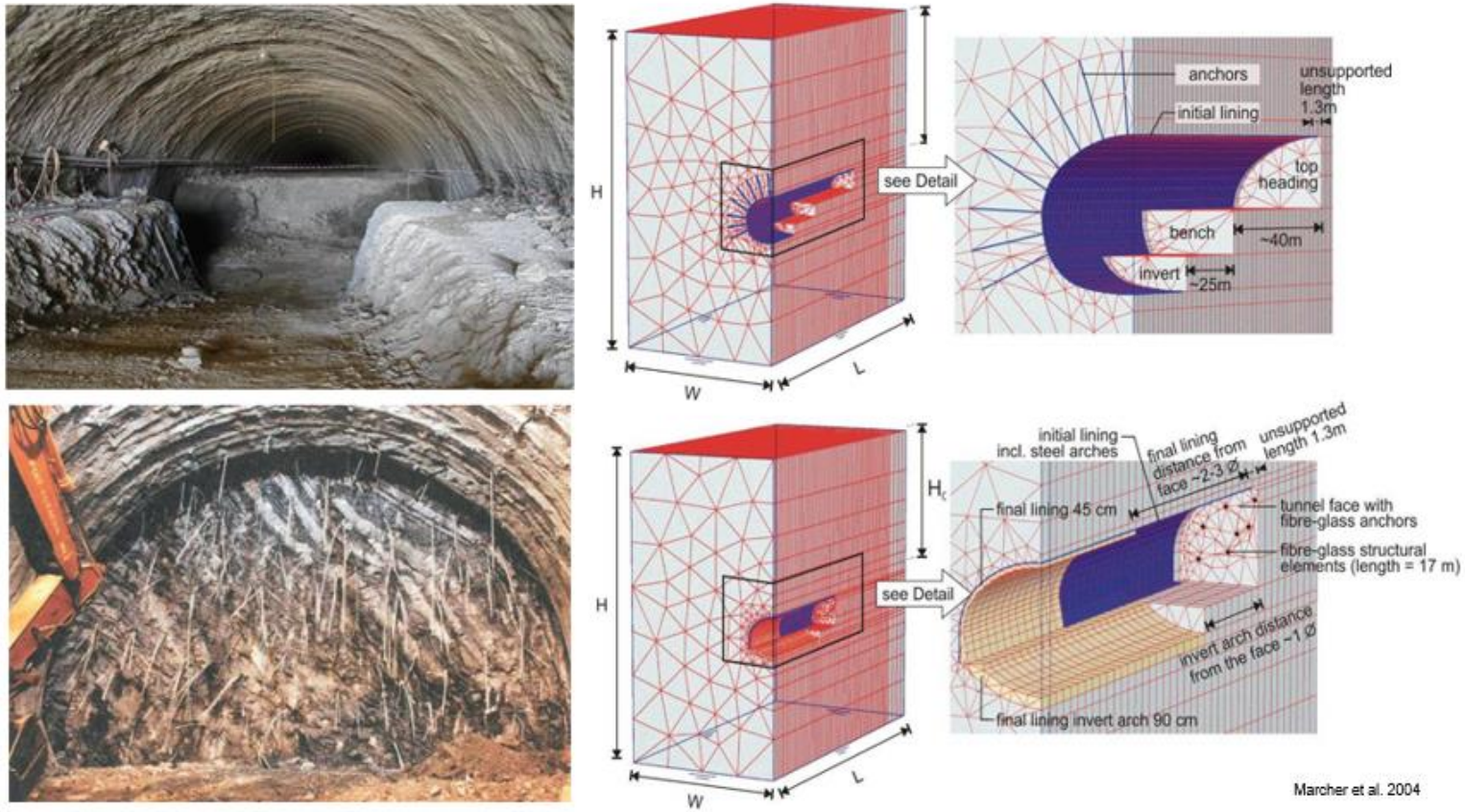


  - Shield TBM

- „Pipe Jacking“

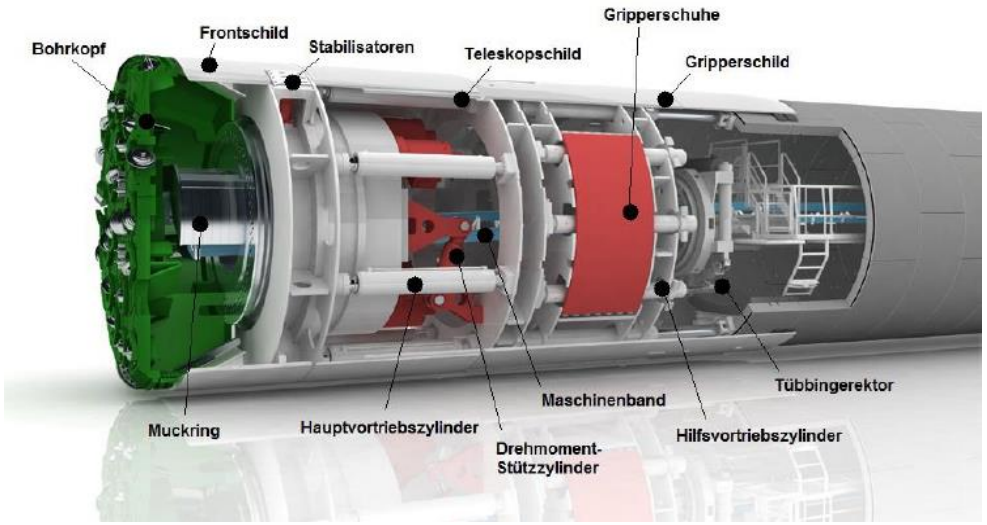
BBT - Brenner Base Tunnel Project

Conventional tunneling (drill & blast)
full face vercus sequential excavation method (NATM / ADECO)

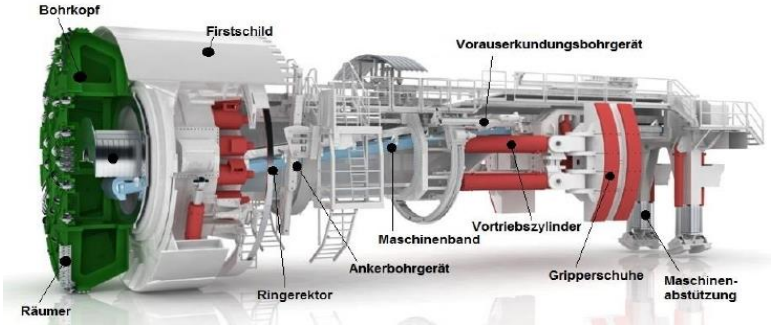


BBT - Brenner Base Tunnel Project

Hard rock TBM tunnelling



Herrenknecht AG



Herrenknecht AG

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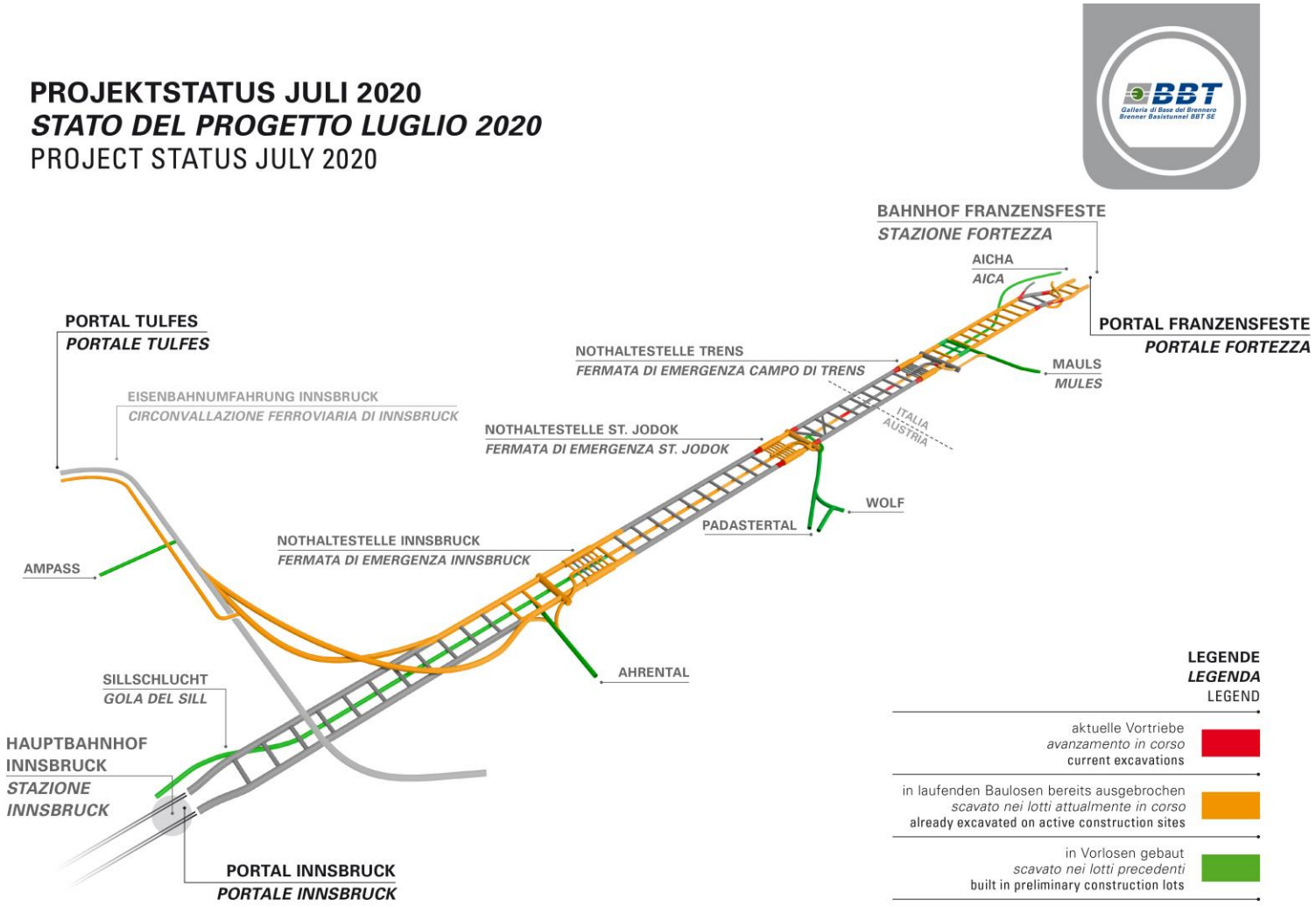


BBT - Brenner Base Tunnel Project

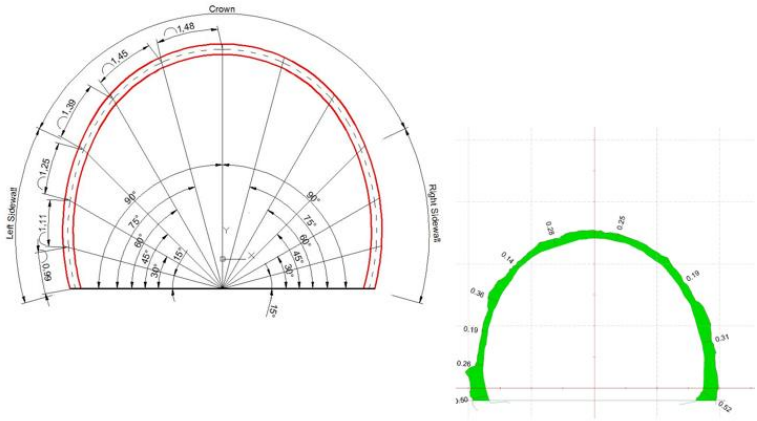
Exploration (geological investigations)

- Surface mapping
- outcrops
- Deep drill exploration

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel

- gather as much information about encountered geology and rockmass behavior as possible
- Transfer knowledge to main tunnel tubes
- Utilize TBM operational data for rockmass classification



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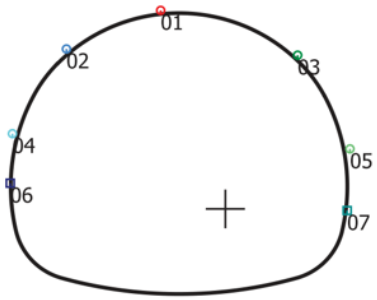

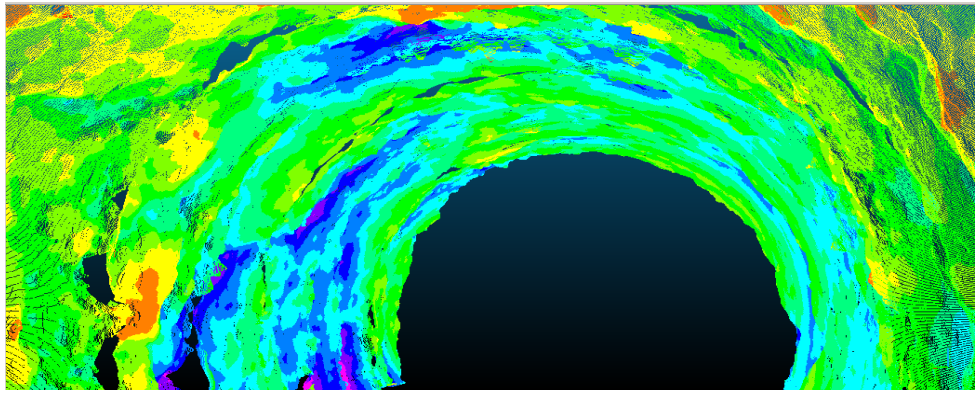

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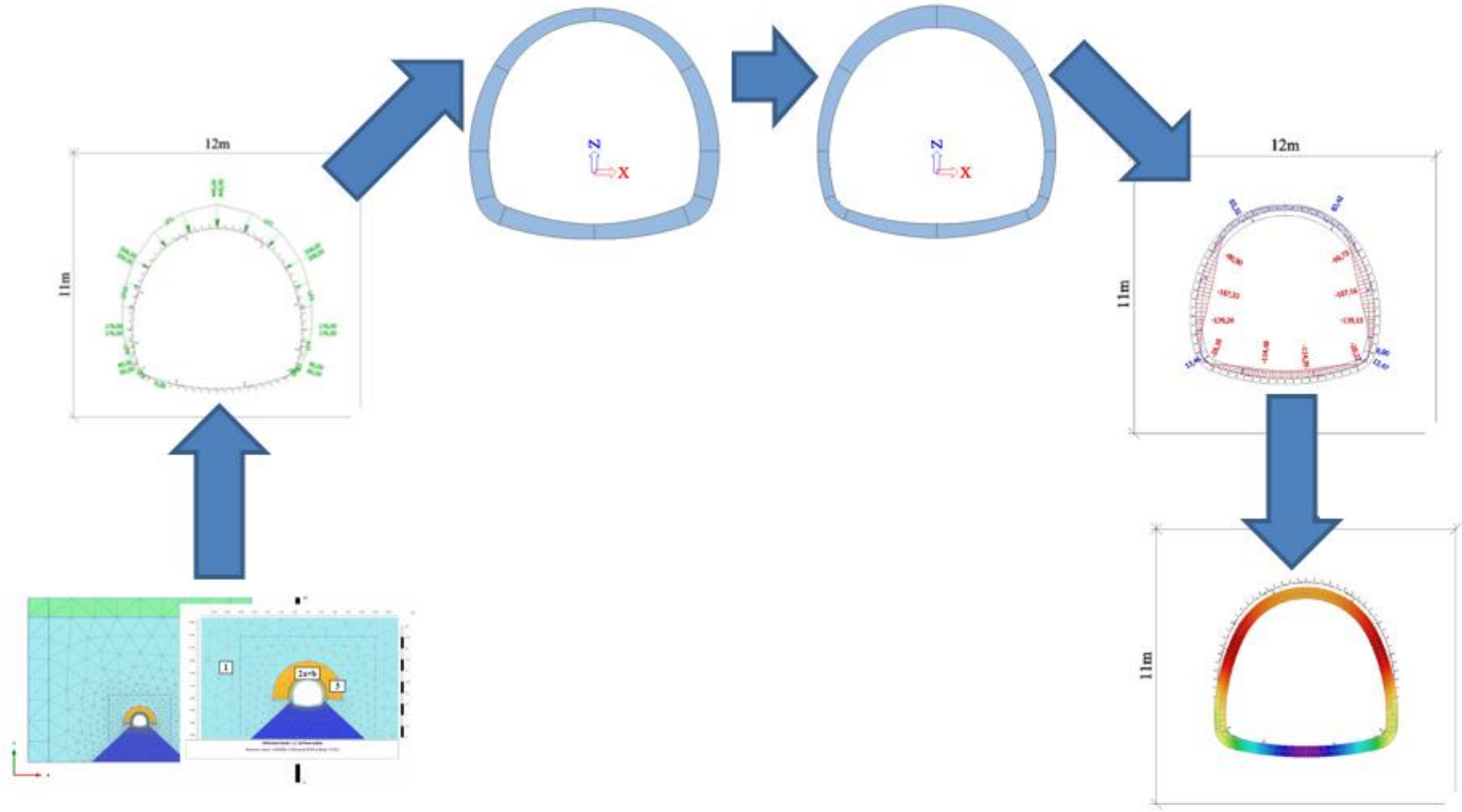
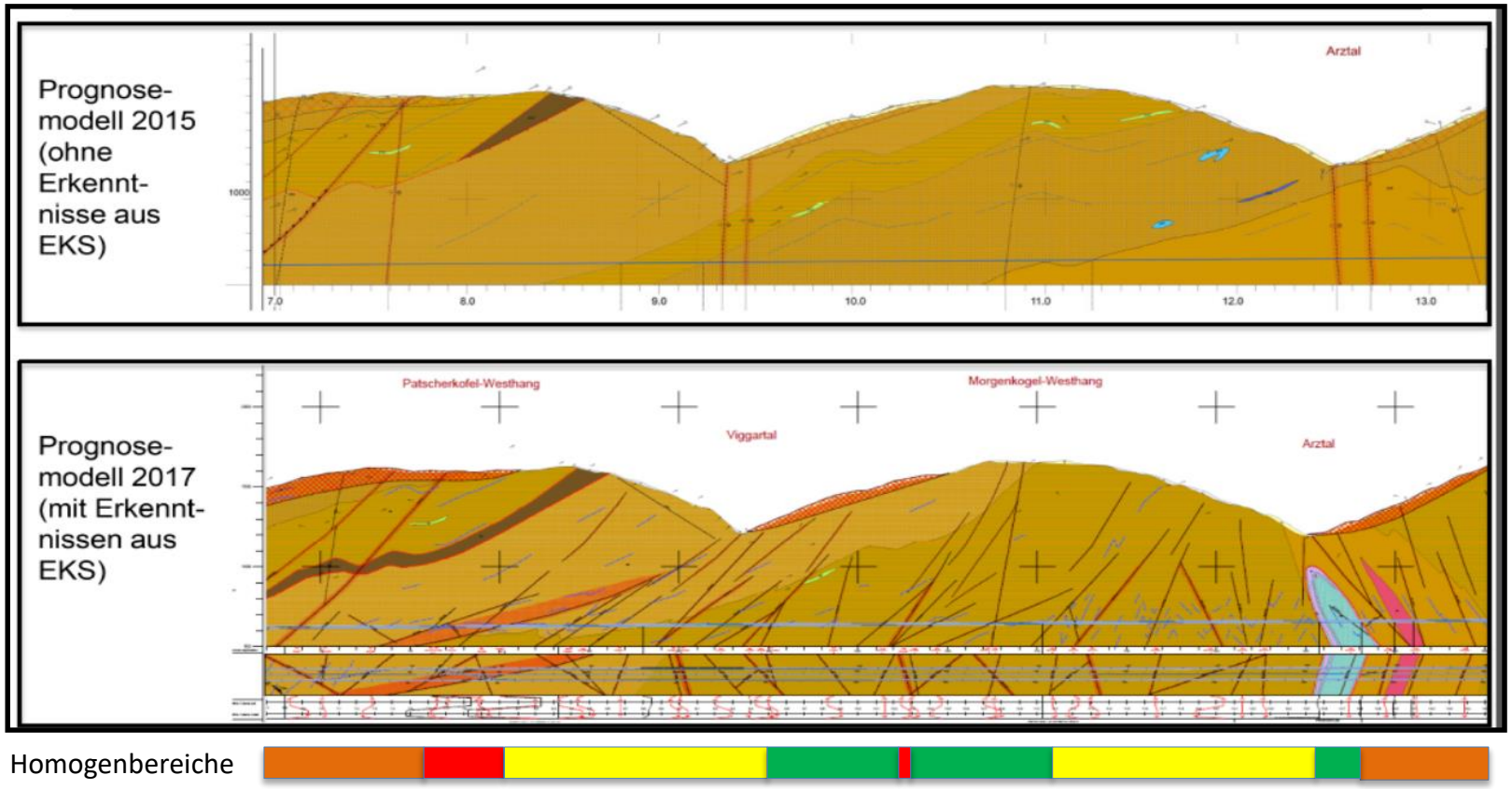


BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel

By interpreting the knowledge gained from the exporatory tunnel, it was possible to:

1. refine the geotechnical longitudinal section
2. the deformation behaviour is documented in detail
3. the rock mass behavior and the tunnelling process is
4. Critical fault (disturbance) zones are addressed
   (and can be preconditioned or excavated in advance
   / prior to TBM drive)



BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

- **TBM standstill (non-advance):**
  - Face documentation

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Learn from Exploratory Tunnel (15 km of open gripper TBM)

- **TBM standstill (non-advance):**
  - Face documentation
  - Digital face mapping

BBT - Brenner Base Tunnel Project

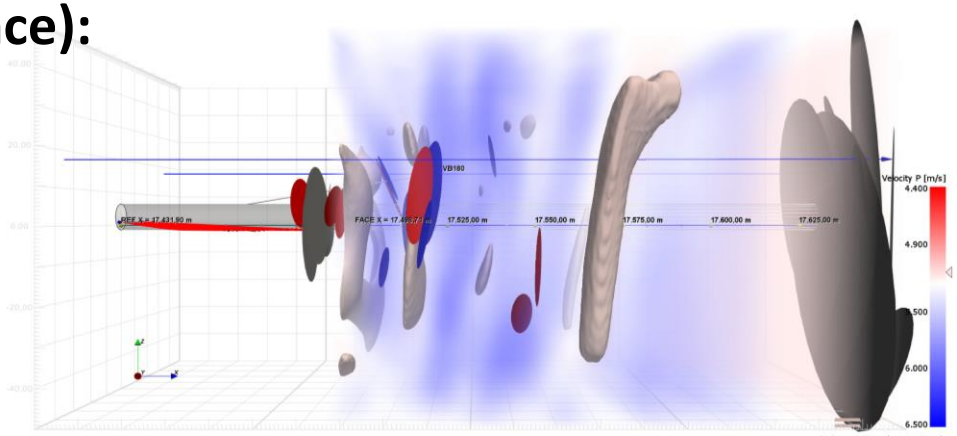
Learn from Exploratory Tunnel (15 km of open gripper TBM)

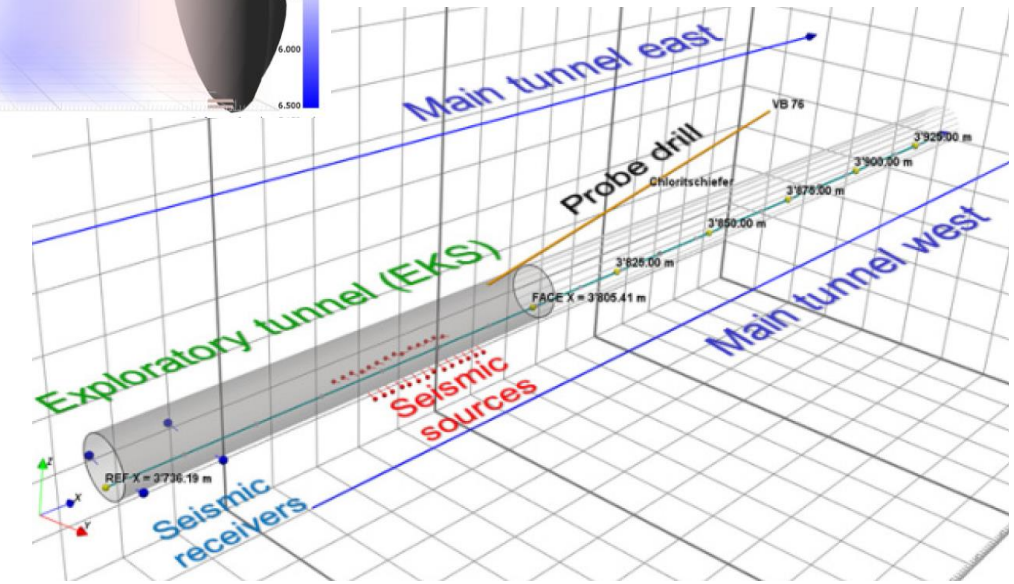
- **TBM standstill (non-advance):**
  - Face documentation
  - Digital face mapping
  - Drilling ahead of face

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

- **TBM standstill (non-advance):**
  - Face documentation
  - Digital face mapping
  - Drilling ahead of face
  - Seismic investigations





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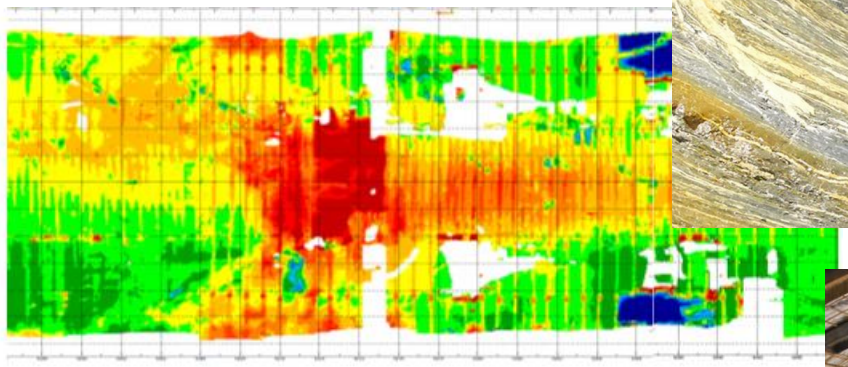
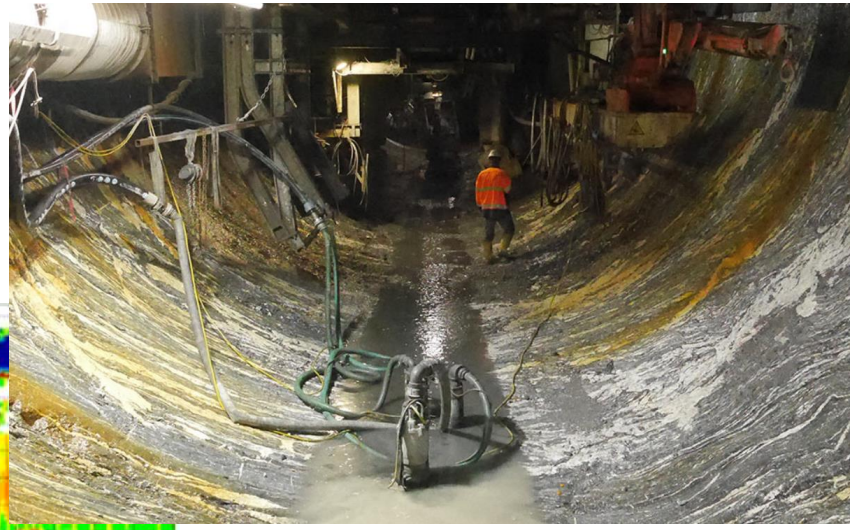
Learn from Exploratory Tunnel (15 km of open gripper TBM)

- **TBM standstill (non-advance):**
  - Face documentation
  - Digital face mapping
  - Drilling ahead of face
  - Seismic investigations
  - Geological documentation of surrounding rock surface





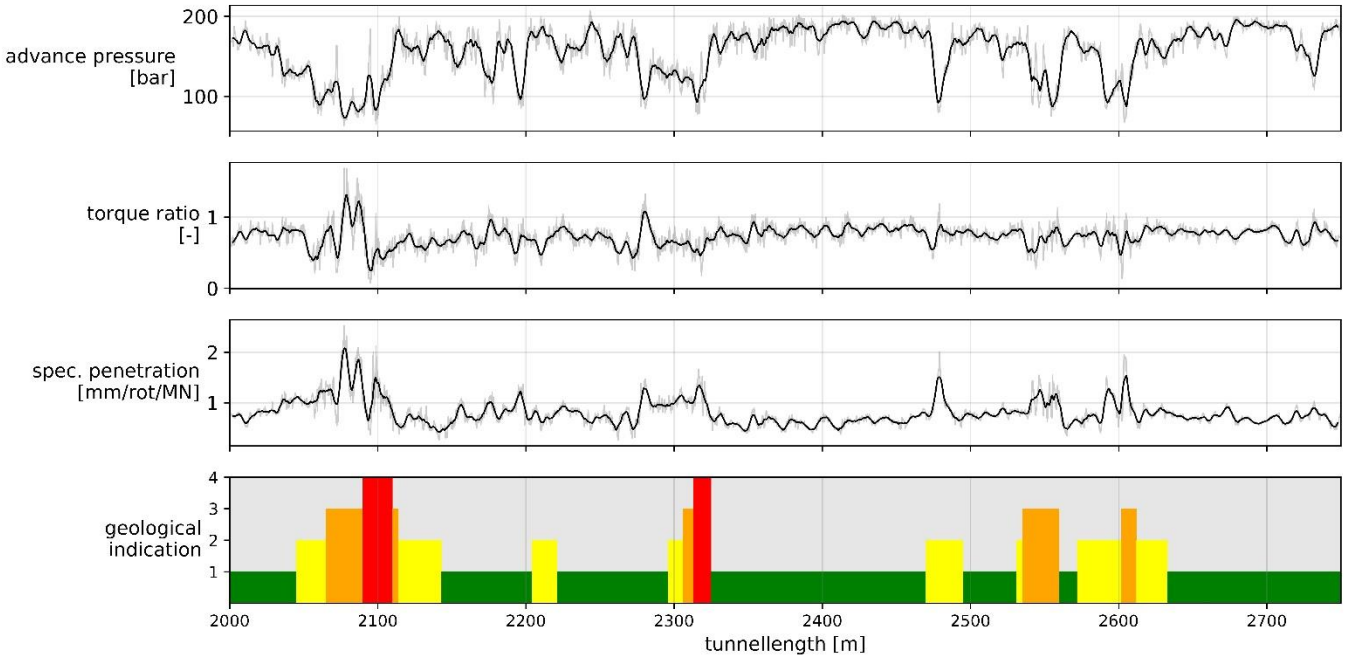
BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

- **TBM standstill (non-advance):**
  - Face documentation
  - Digital face mapping
  - Drilling ahead of face
  - Seismic investigations
  - Geological documentation of surrounding rock surface
- **During TBM advance:** Use TBM sensor data
  - TBM Data
    - 15 km of TBM operational data
      - advance-speed [mm/min]
      - rotational speed [rpm]
      - advance pressure [bar]
      - **cutterhead torque [MNm]**
      - total advance force [kN]
      - penetration [mm/rot]
      - pressure of crown-support-cylinder left & - right [bar]
      - path of crown-roof-support-cylinder [mm]
      - rotatory share of the specific energy (spezE [MJ/m]) (Teale, 1965)
      - specific penetration
      - **torque ratio** (Radoncic et al., 2014)
    - Geological Indication (Reinhold et al., 2017)

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)



(Marcher, et al., 2020)

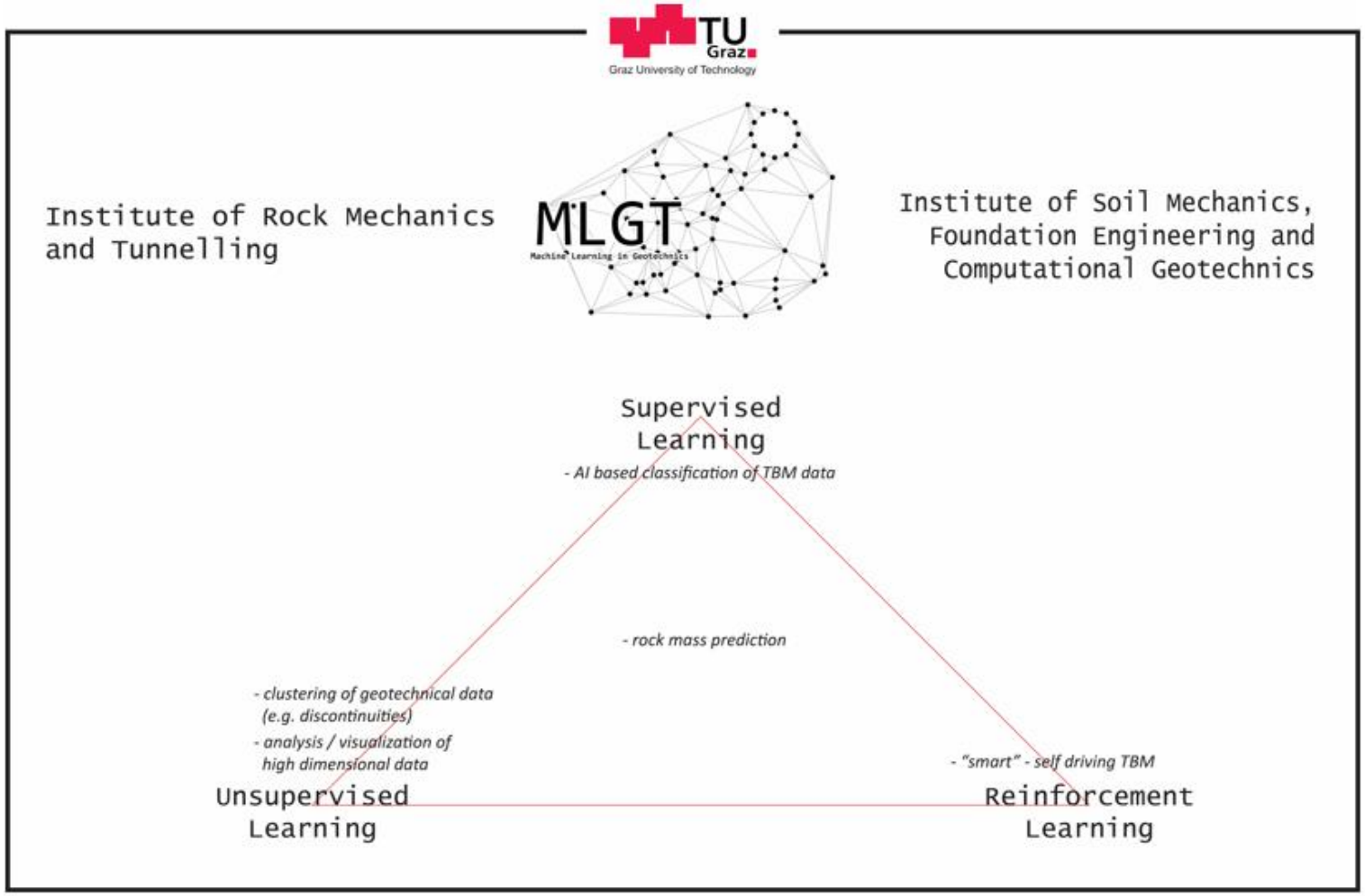
- Geological Indication

(Reinhold et al., 2017)

GI	Description
1	favorable rockmass conditions
2	discontinuity driven deformations
3	fractured rockmass & minor faults
4	geotechnically relevant fault zones

BBT - Brenner Base Tunnel Project

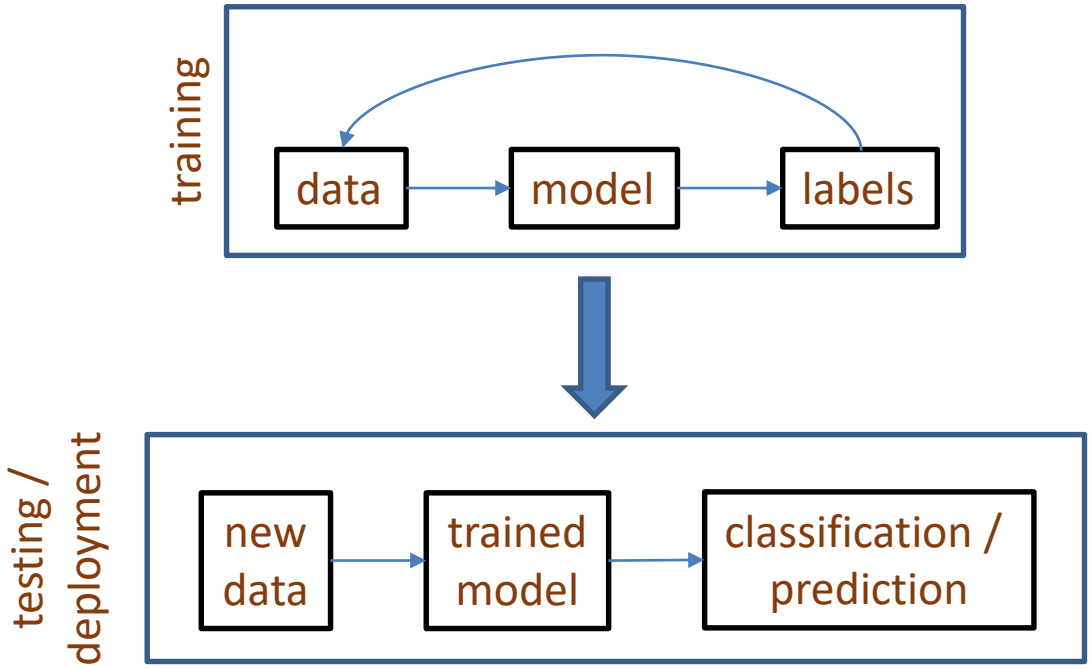
Learn from Exploratory Tunnel (15 km of open gripper TBM)



BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

“Automatic Rock Mass Classification by supervised learning”



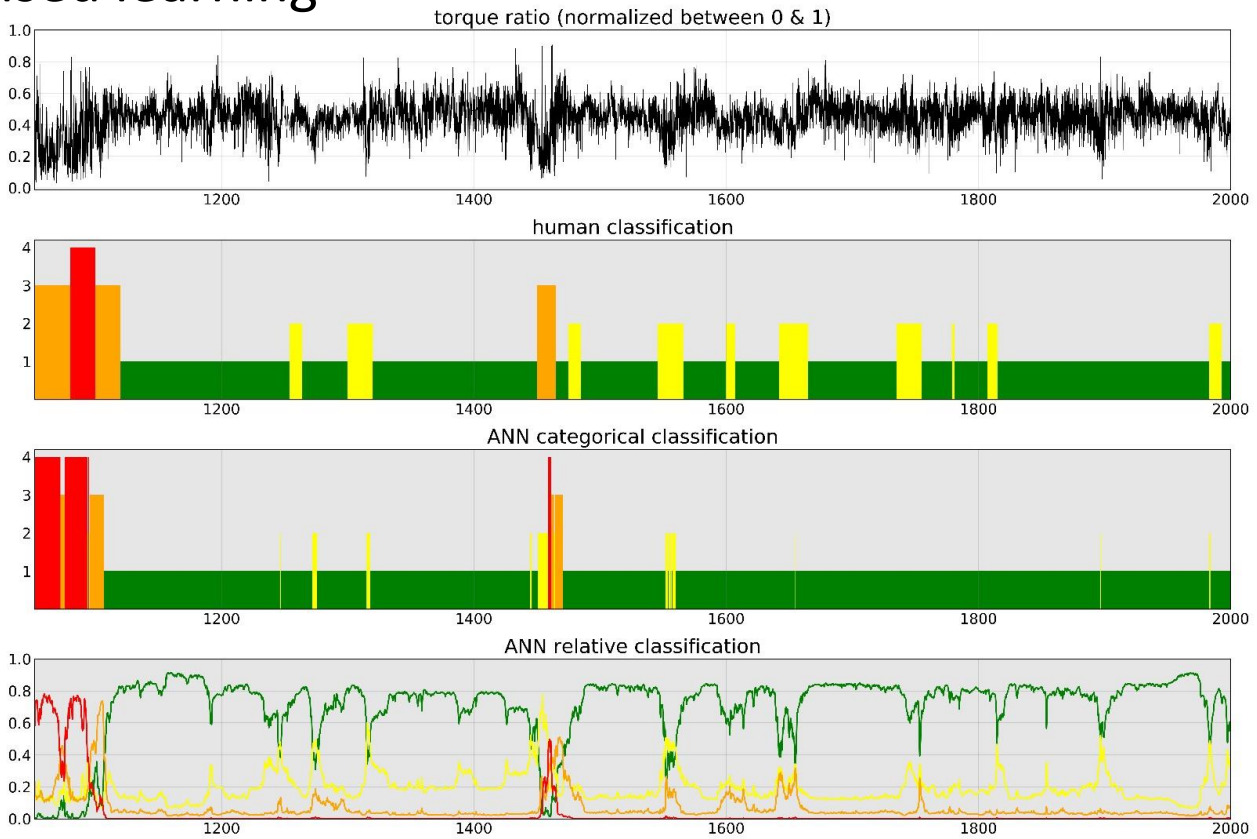
(Marcher et al., 2020)

- Machine Learning
  - „application and science of algorithms that make sense of data“
    (Raschka, 2017)
  - **Supervised Learning**, Unsupervised Learning, Reinforcement Learning
  - train Artificial Neural Network (ANN) to automatically classify TBM data according to rockmass behavior type classification

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

“Automatic Rock Mass Classification by supervised learning”



(Marcher et al., 2020)

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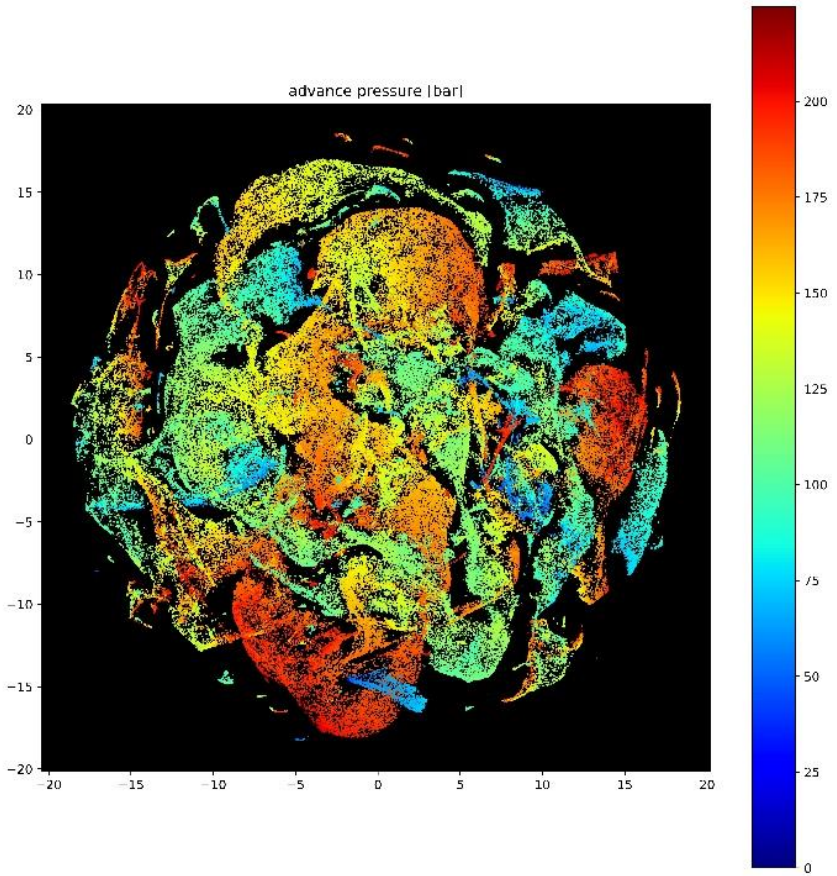


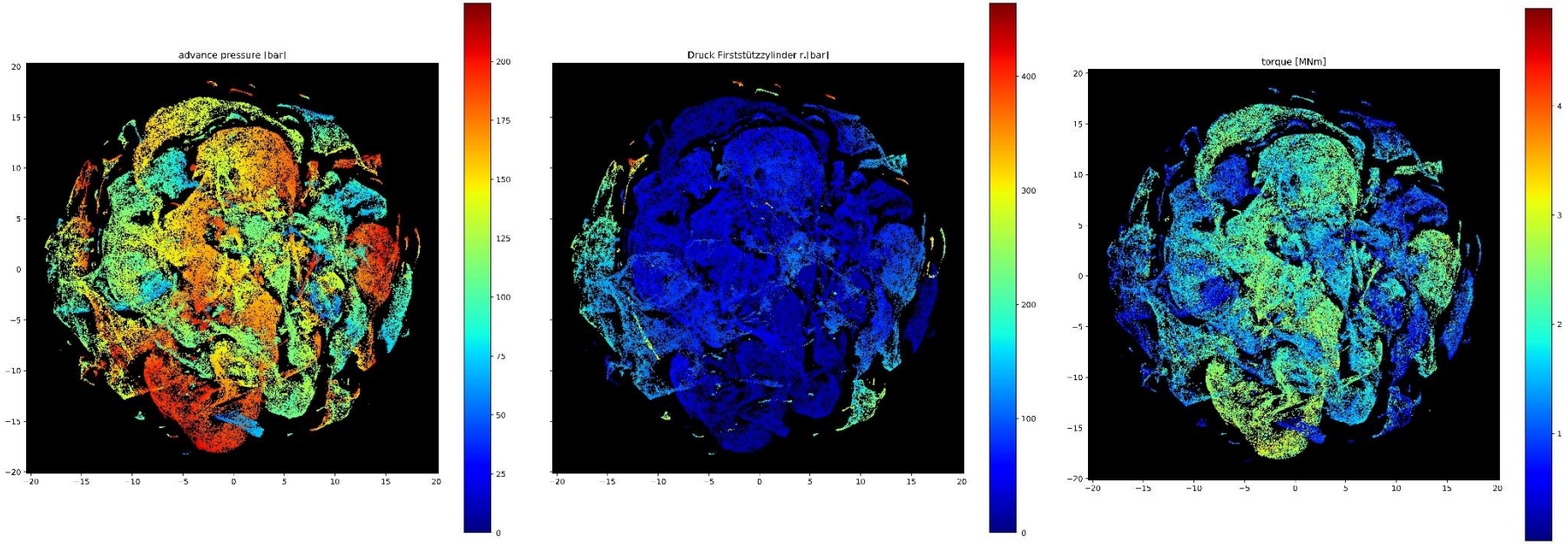
(Marcher et al., 2020)

- Unsupervised Learning
  - According to Ghahramani (2004) in unsupervised learning "…the machine's goal is to build representations of the input…" and "…can be thought of as finding patterns in the data above and beyond what would be considered pure unstructured noise."
  - Typical applications are clustering (i.e. partitioning a dataset into groups of similar datapoints (Rai and Singh, 2010)) or dimensionality reduction i.e. reducing the number of parameters of a high dimensional dataset without losing (too much) information.

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

- t-SNE (T-distributed Stochastic Neighbor Embedding)
- example: 9 dimensions (torque, pressure of crown cylinder, advance pressure…) reduced to 2; 400 iterations; colored after individual features



BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

“Automatic Rock Mass Classification
by unsupervised learning”

MSAC: Towards data driven system behavior classification for TBM tunneling

- **M**ultivariate sequence **S**egmentation **A**bstraction and **C**lassification

- goal: unbiased classification system / indicator for hardrock TBM tunnelling
- utilizes statistics and techniques of **unsupervised machine learning**
- Tunnelling & Underground Space Technologies Sept. 2020 (*Open access*)
  https://www.sciencedirect.com/science/article/pii/S088677982030420X#f0005

Erharter, Marcher (2020)

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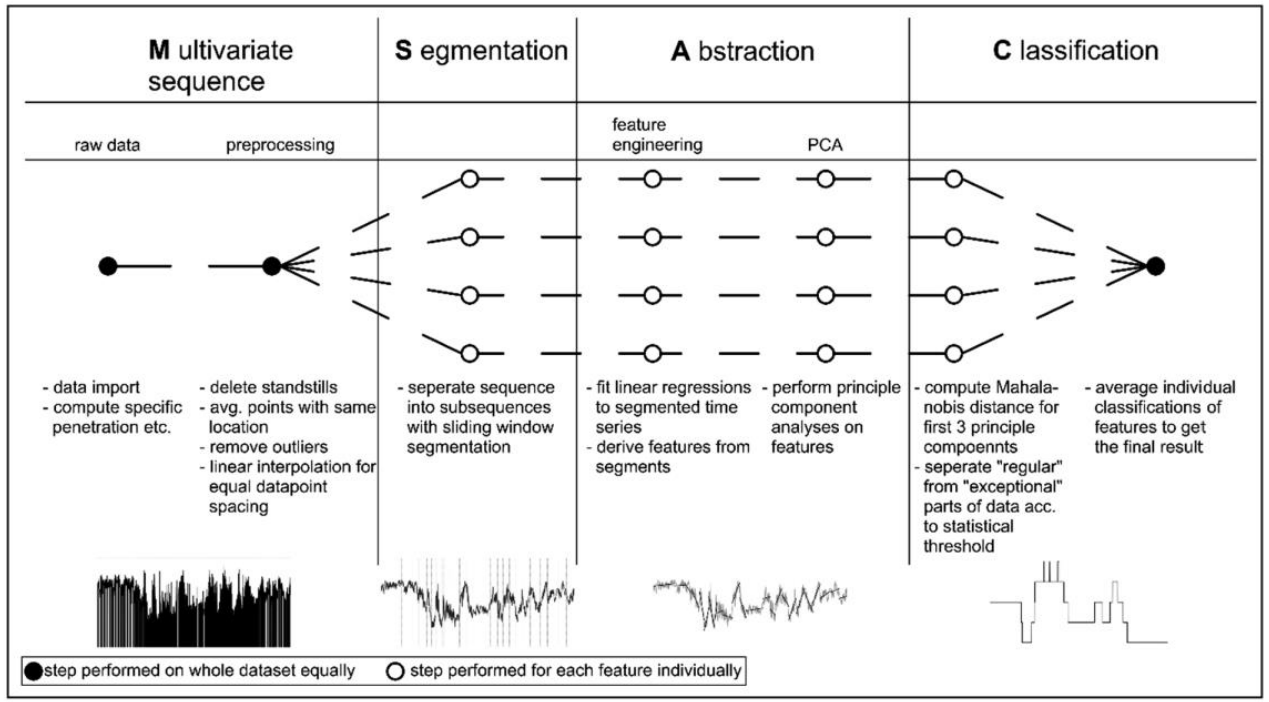


Erharter, Marcher (2020)

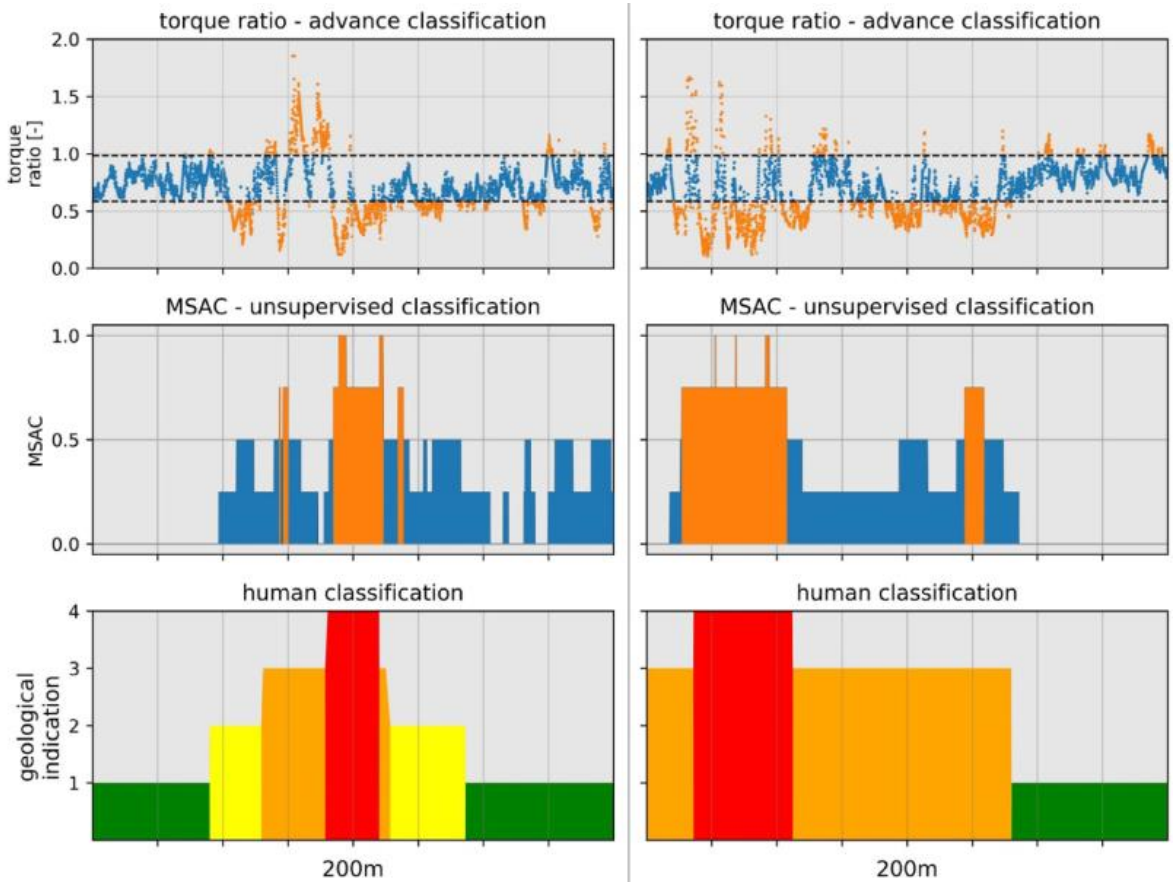
- MSAC (Multivariate sequence Segmentation, Abstraction and Classification) –
  a new approach for TBM data driven rockmass classification.

- The goal is to tell the user how "regular" the current TBM's data is and can therefore be used as an aid for interpretation to discriminate regular from exceptional advance.

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

“Automatic Rock Mass Classification by unsupervised learning method MSAC”



Erharter, Marcher (2020)

Results:

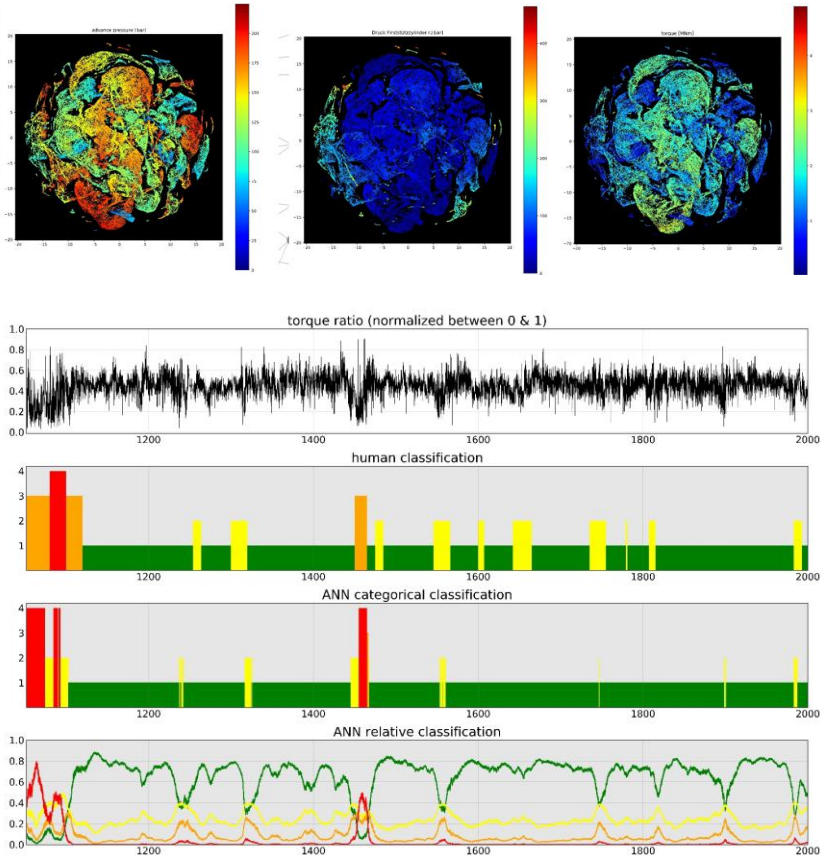
- 200 m long examples of the MSAC framework applied to TBM operational data.
- Upper row: torque ratio: regular advance is given in blue, hindered / exceptional advance in orange;
- middle row: unsupervised MSAC classification (same coloring);
- lower row: human classification – geological indication.

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

advantage of ML for TBM data interpretation:

- trained ML algorithmus can be used to classify main tunnels (shielded TBM tunnels)
- data from in advance of the TBM can be used to update geological / geotechnical model (drilling ahead / geoseismic data, etc.)
- contractually a so called regular advance can be distinguished automatically from exceptional TBM drive



Erharter, Marcher (2020)

BBT - Brenner Base Tunnel Project

Learn from Exploratory Tunnel (15 km of open gripper TBM)

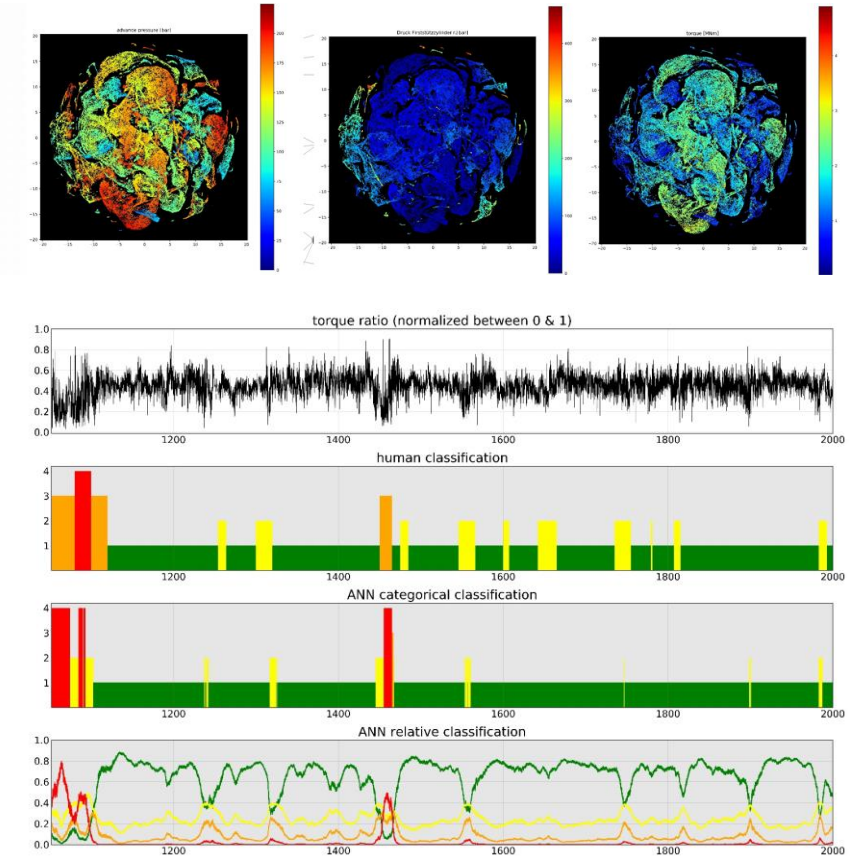
Application of ML for TBM data interpretation:

supervised learning should only be used as an aid and not as a replacement for onsite personnel.

This technology can be used to improve classification efficiency and self-consistency.

Ethical use from all involved parties is imperative to build the necessary confidence that is required to make the most out of this technology!

High potential is seen in **unsupervised machine learning** approaches where the final classification is not imposed upon the data, but learned from it.



Erharter, Marcher (2020)

Summary

Advantages of having the exploratory tunnel:

- the primary one being the geological, hydrological and geotechnical exploration of the rock mass encountered and the use of the data in a systematic way (including AI/ML)
- second advantage is the water drainage system. Completely independent water drainage system that will be used not only during the construction phase but also during the operational phase. Recently a research project is on he way regarding the thermal use of the water for the city of Innsbruck (Thermocluster BBT)
- Advantage #3: the exploratory tunnel allows the possibility to access geologically difficult zones of the main tunnels in advance of their regular TBM excavation.
- Advantage #4: an independent logistic system in a completely independent connection tube to the surface
- #5: equipment can be placed in the exploratory tunnel. Then operation in the main tunnels will be completely independent of maintenance issues

Thank you for attention!

21.07.2019: 15 km TBM excavation

10,85 m/day medium speed

61m / day world record

CTES
COMITÉ DE TÚNELES Y ESPACIOS SUBTERRÁNEOS DE CHILE

EXPOSITOR

Nombre

Cargo

Datos de contacto