Hydrogeochemistry of warm inflows in tunneling – technical risks and geothermal use

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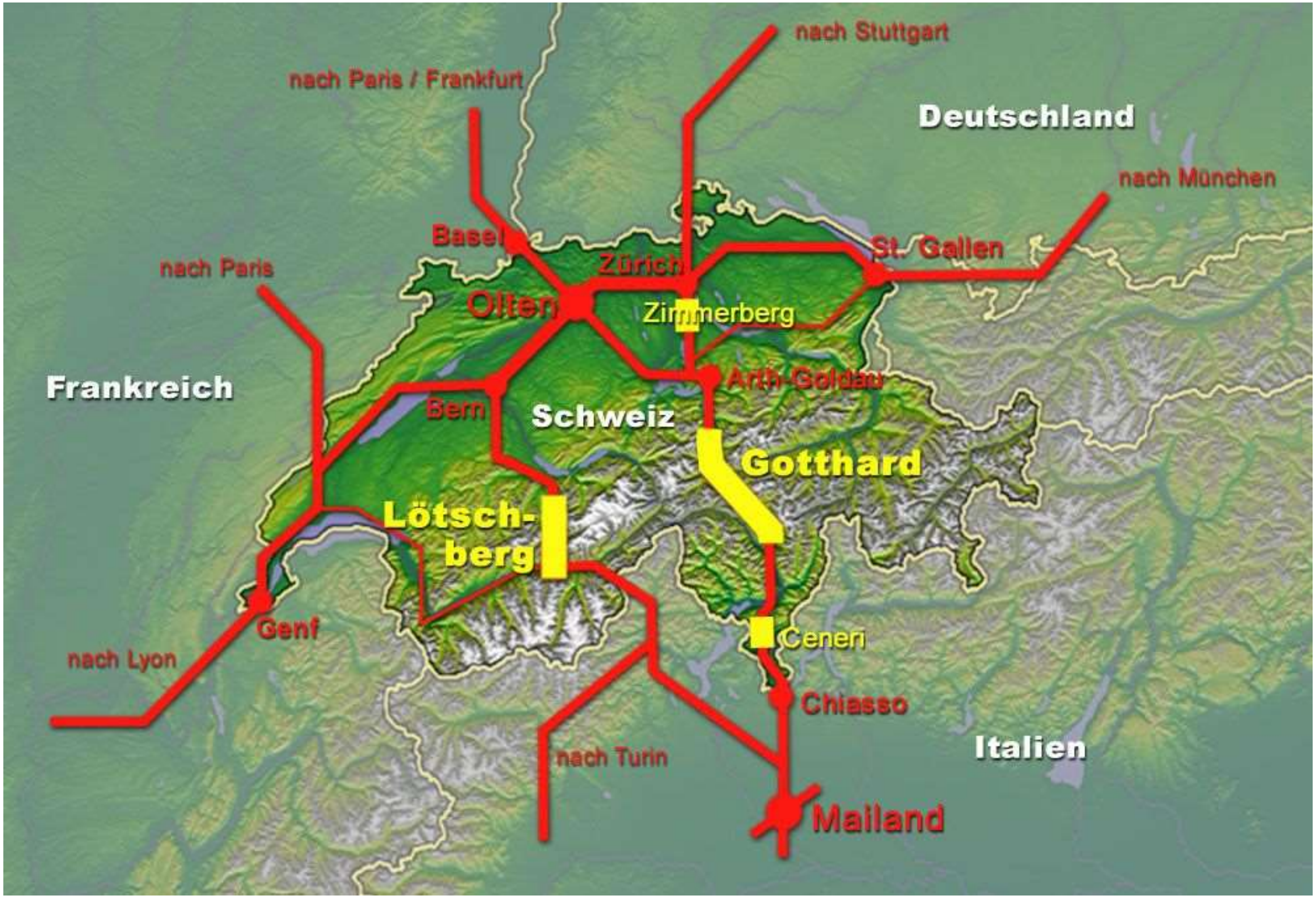
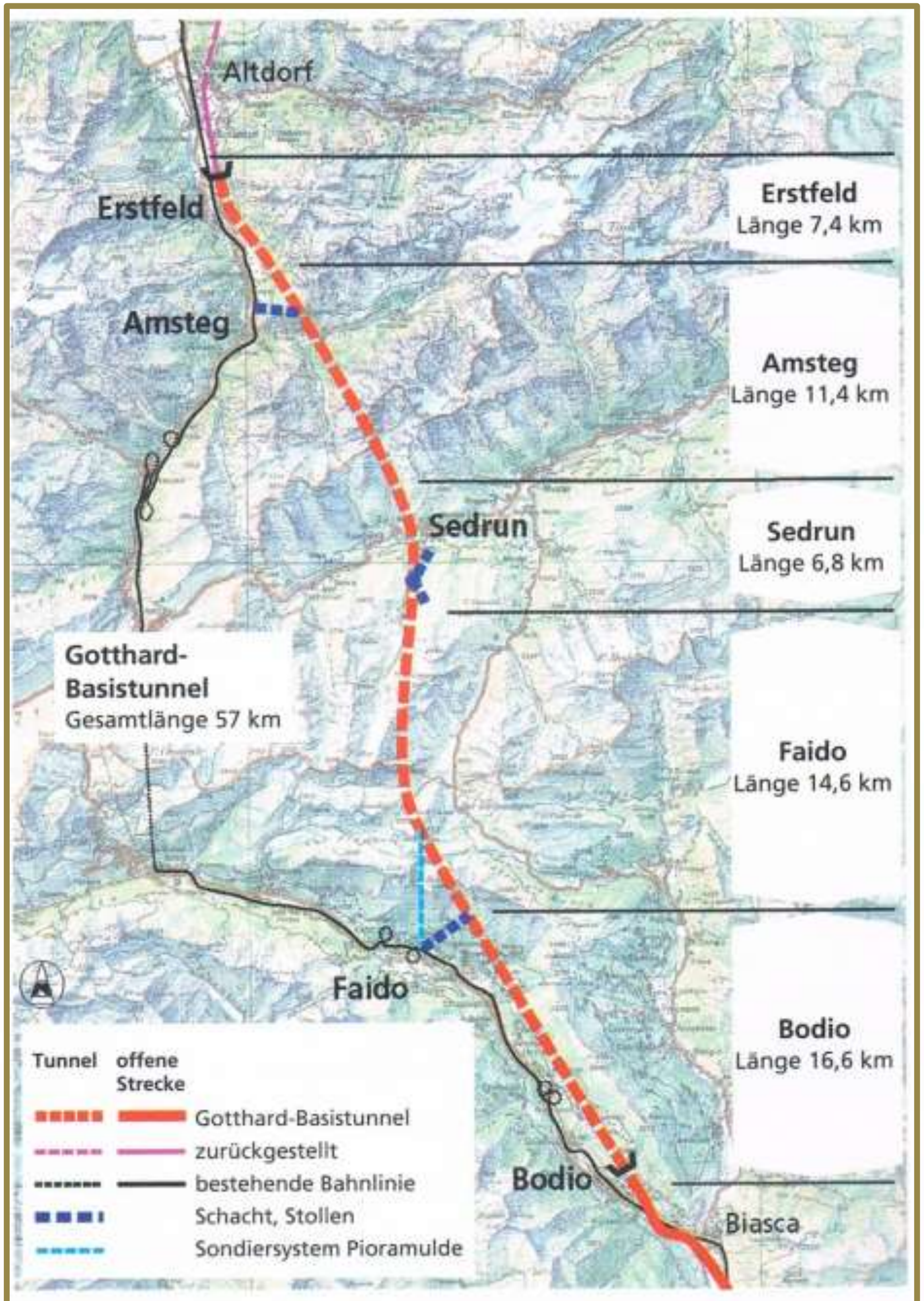
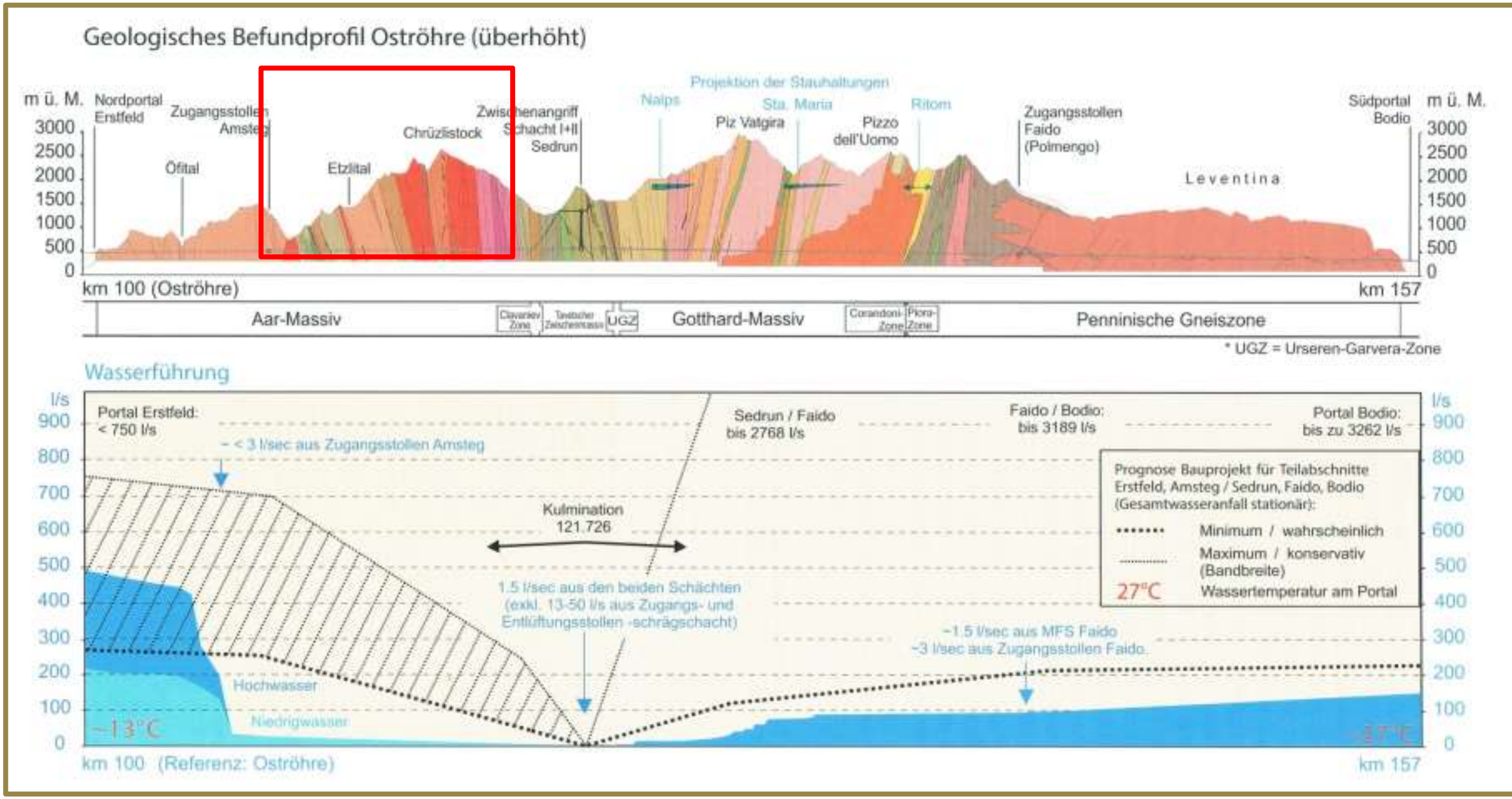
Tunnelwater inflow
from boreholes drilled
for explosives



Die Neue Eisenbahn- Alpentransversale (NEAT), mit den Kernstücken Gotthard –Basistunnel (GBT, 57 km) und Lötschberg-Basistunnel (LBT, 36 km)



Tunnel trace (57 km) of Gotthard Base Tunnel (GBT)



Gotthatd Base Tunnel: Geologic profile; cumulative water inflows

From «Tunneling the Gotthard»

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Water deep inside the mountains: Unique water samples from the Gotthard rail base tunnel, Switzerland

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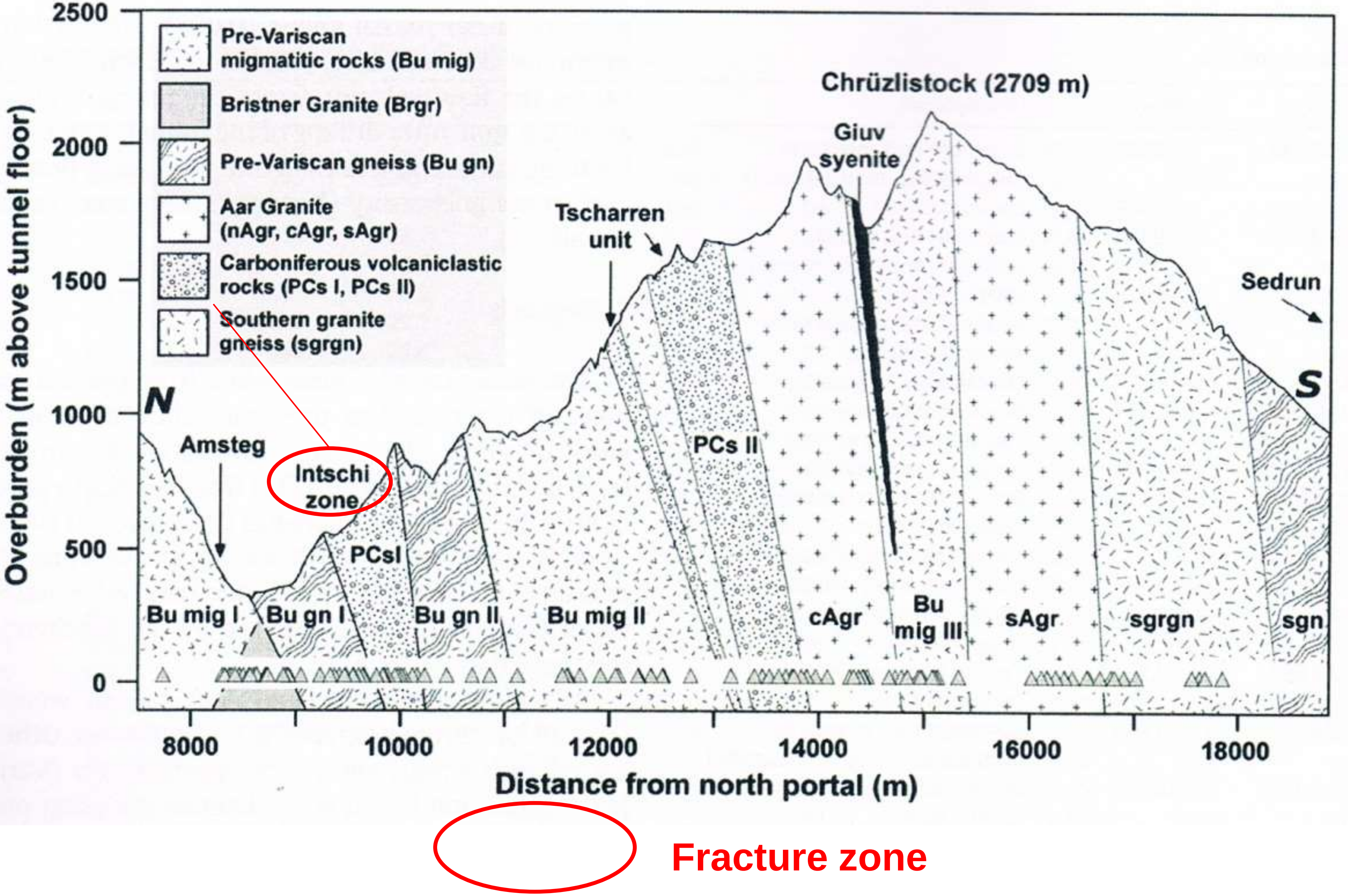
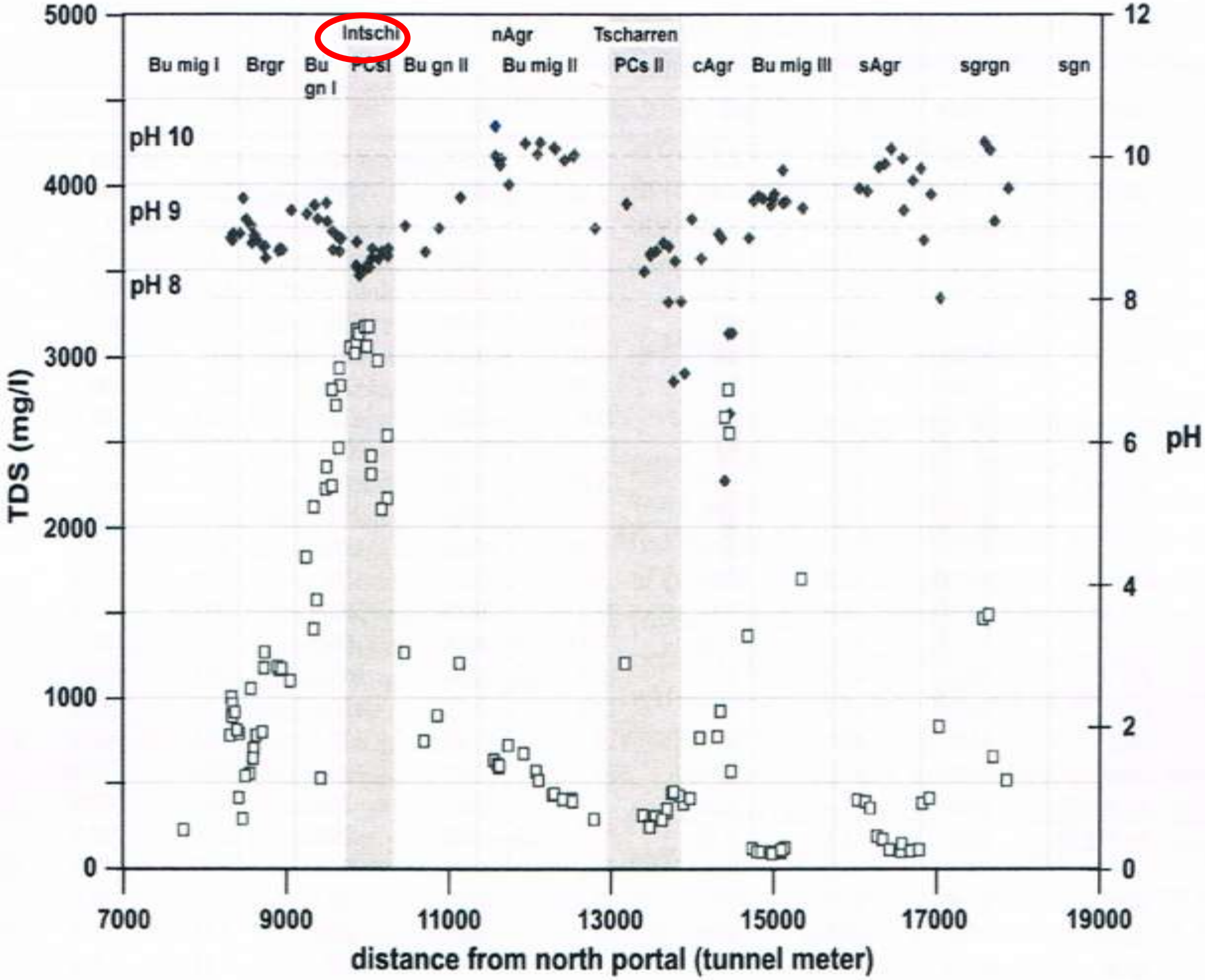
ABSTRACT

The construction of the new 56 km long Gotthard railway base tunnel in Switzerland opened a large number water conducting fractures and 122 water samples were collected along the Amsteg section of the tunnel and then chemically analyzed. The Amsteg section of the tunnel cuts across granites, gneisses and metarhyolites of the Alpine basement. The overburden of basement rocks above the tunnel axis is up to 2200 m thick with rock temperature reaching 45 °C. Sodium is the prime cation of most waters; calcium, potassium and magnesium are low to very low in concentration. The associated anions are carbonate/bicarbonate, sulfate and chloride in widely varying concentrations. High to ultra-high fluoride concentrations of up to 29 mg/L F and high pH values of up to 10.4 are significant properties of the waters. Six chemical types of water can be distinguished reflecting the different types of fractured rock present in the section. Most of the waters can be viewed as ternary mixtures of dissolved natrite (Na_2CO_3), thenardite (Na_2SO_4) and halite (NaCl).

The geological and hydrogeological context suggests a meteoric origin of the waters. The unique water compositions and characteristics result from interaction with continental basement rocks along the flow path. The assemblage of major minerals of the different rocks is generally very similar, but the rocks differ with respect to minor minerals and accessories. Derived rock data suggest that dissolution and precipitation of calcite and fluorite, albite dissolution, leaching of salty inclusions, sulfide oxidation by CO_2, alteration of biotite to chlorite, precipitation of stilbite and hematite are the important processes that create the observed water compositions. Although fracture water acquires its composition exclusively by chemical interaction with crystalline basement rocks with very similar mineral assemblages, the resulting waters are of great chemical variability.



Pre-Variscan migmatitic rocks (Bu mig)
Bristner Granite (Brgr)
Pre-Variscan gneiss (Bu gn)
Aar Granite (nAgr, cAgr, sAgr)
Carboniferous volcaniclastic rocks (PCs I, PCs II)
Southern granite gneiss (sgrgn)
Chrüzlistock (2709 m)
Giuv syenite
Tscharren unit
Sedrun
N
S
Amsteg
Intschi zone
PCsI
PCs II
Bu mig I
Bu gn I
Bu gn II
Bu mig II
cAgr
Bu mig III
sAgr
sgrgn
sgn
Overburden (m above tunnel floor)
2500
2000
1500
1000
500
0
8000
10000
12000
14000
16000
18000
Distance from north portal (m)
Fracture zone



TDS and pH of water inflow, investigated section of GBT

Bucher et al. (2012)

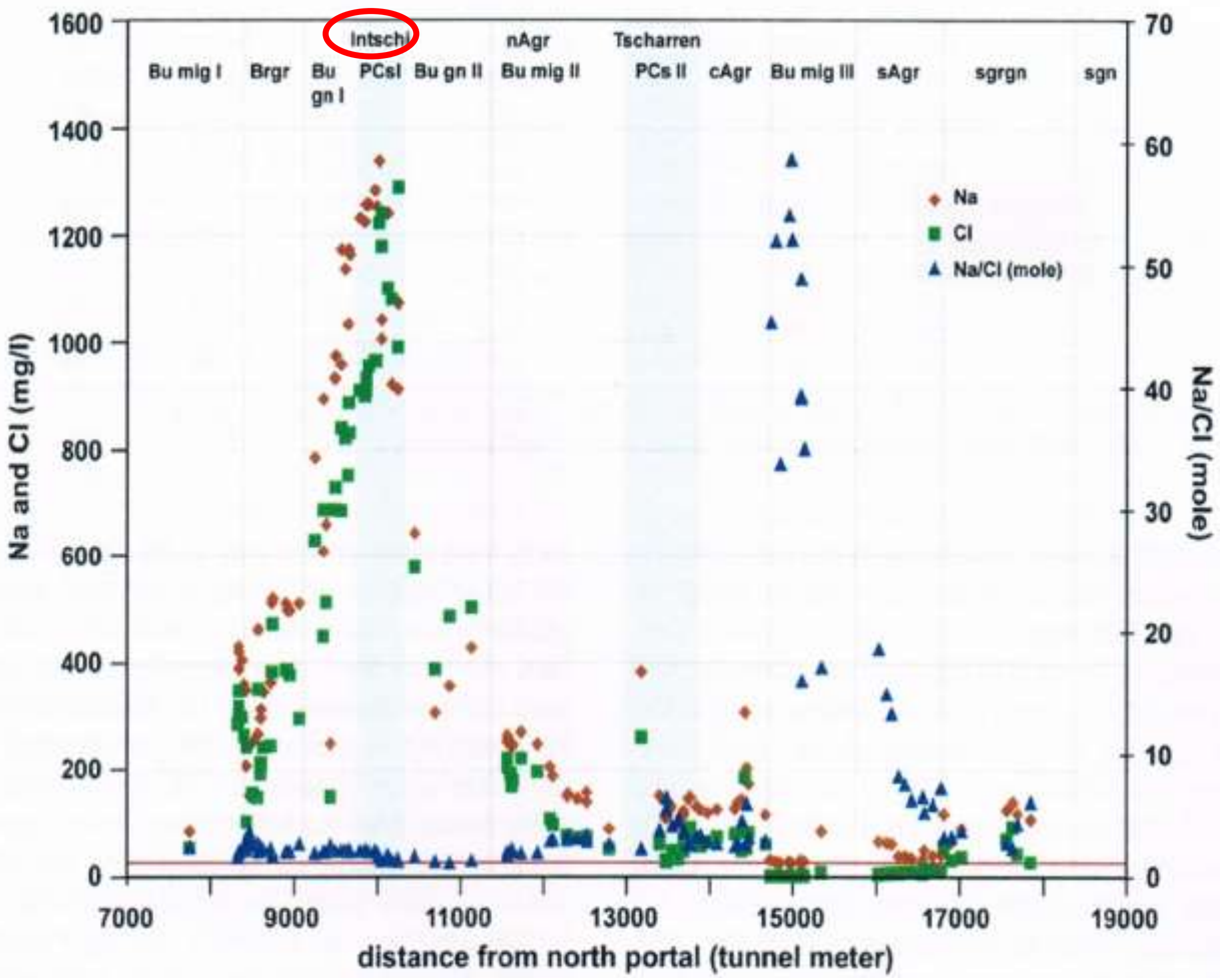
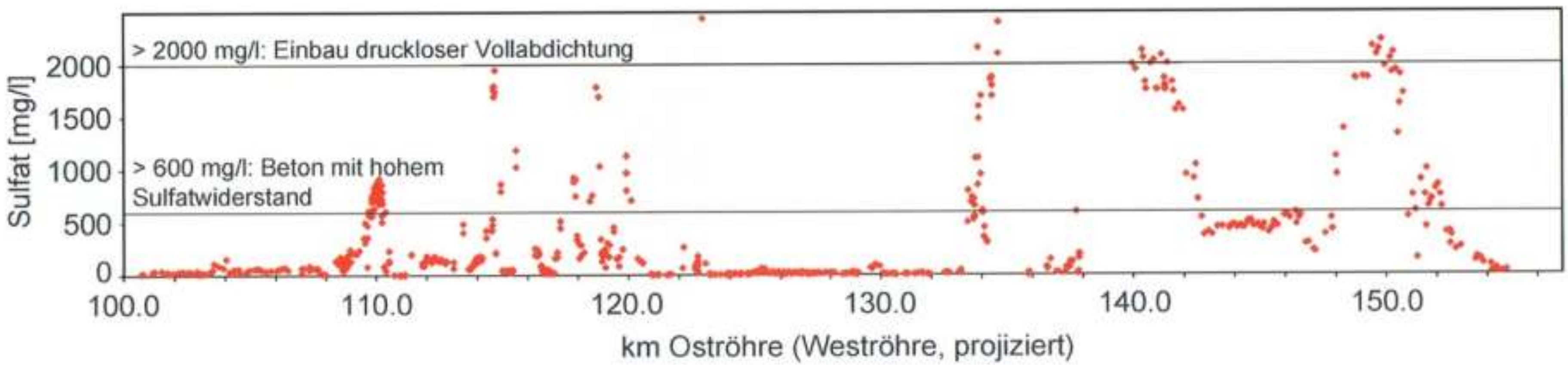


Fig. 5. Sodium (red diamonds) and chloride (green squares) concentrations of water along the tunnel section. Molar Na/Cl (blue triangles) is typically low but increases with decreasing Cl.



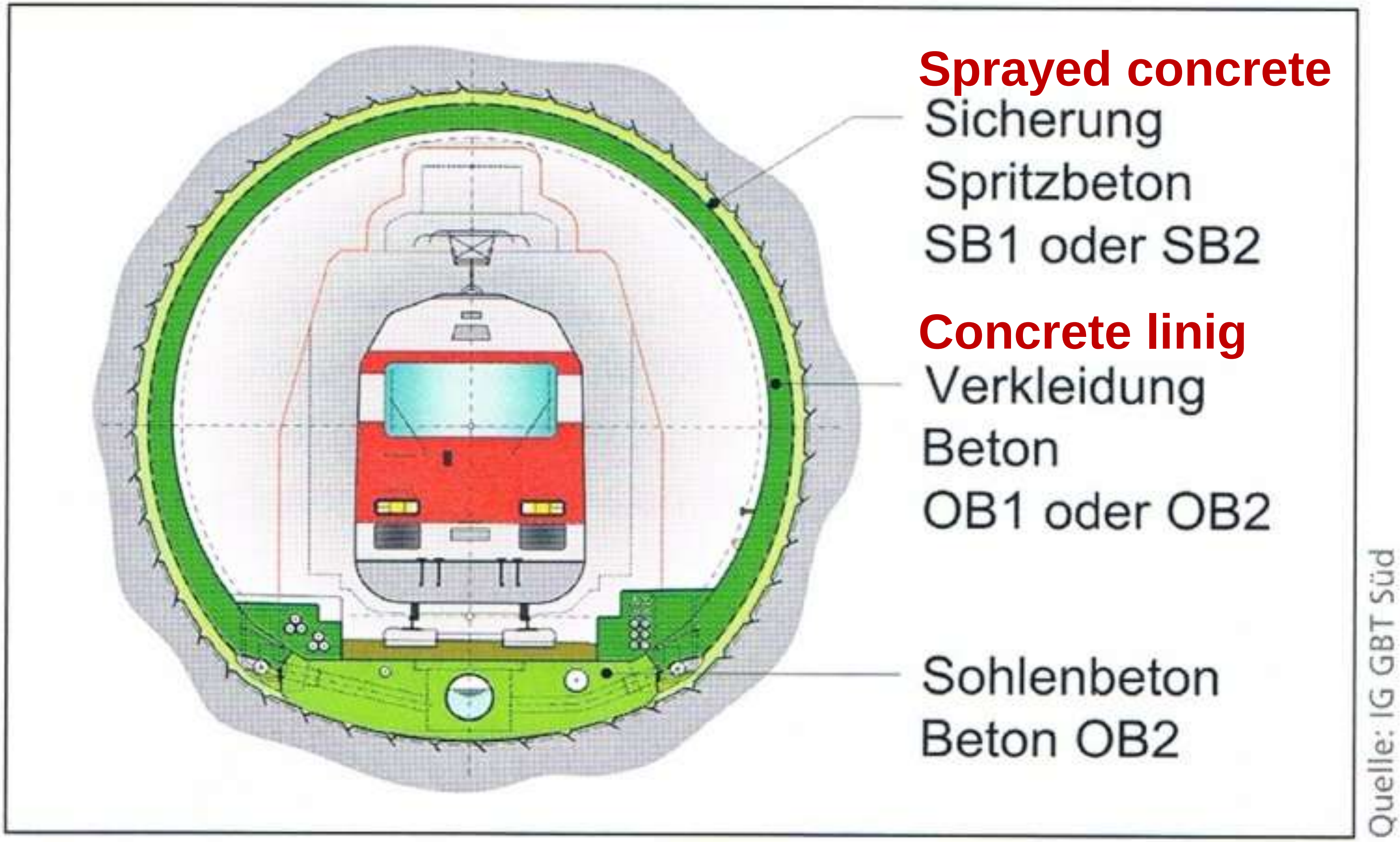
Sulfate content of inflowing waters to GBT

Defined aggressivity limits of sulfate-containig waters and prescribed protective measures *Aggressivity limits: > 600 mg/l (Norm SN EN 206-1, 2000); > 2000 mg/l (GBT project requirement)*		
Aggressivity	**Sulfate content (mg/l)**	**Measure**
Light	200 – 600	none
Medium	600 - 3000	> 600 mg/l: use of concrete with higher sulfate resistance
High	3000 – 6000	> 2000 mg/l: zero pressure full lineing

From TG 2016

Concrete varieties: ER: early resistance; WT: water-tight; CR: chemical resistance			
Variety	**Marking**	**Class**	**Properties**
Lining concrete 1	LC 1	B40/30	ER, WT
Lining concrete 2	LC2	B40/30	ER, WT, CR
Sprayed concrete	SC1	B35/25	ER, WT
Sprayed concrete	SC2	B35/25	ER, WT, CR

Aus TG 2016

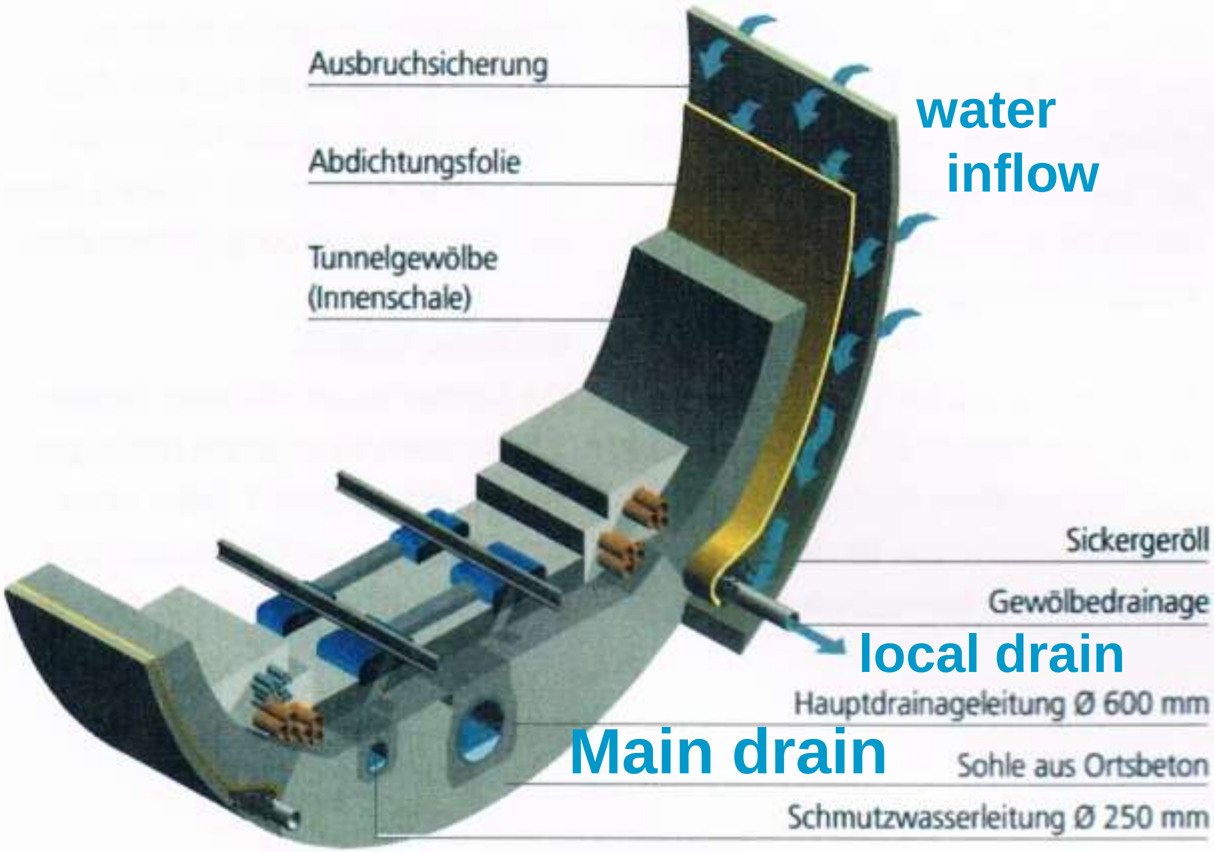


Concrete types/functions, Gotthard Base Tunnel

From TG 2016

Abdichtung gegen Bergwasser
Die Tunnelgewölbe sind ständig anfallendem Bergwasser ausgesetzt. Entlang einer speziellen Abdichtungsfolie läuft es zum Gewölbefuss in die Gewölbedrainageleitung. Diese führt alle 100 m über einen Kontrollschacht in die Hauptdrainageleitung, die sich unter der Fahrbahn befindet.

Separate Ableitung für Tunnelwasser
Sollte im Havariefall im Gotthard-Basistunnel Schmutzwasser im Bereich der Fahrbahn anfallen, wird es alle 100 m über einen Schacht gesammelt und in eine separate Ableitung geführt; deshalb spricht man von einem «Trennsystem». Das Schmutzwasser gelangt zur Analyse in ein Auffangbecken ausserhalb des Tunnels. Je nach Zusammensetzung wird es aufbereitet und dann in natürliche Gewässer abgeleitet.



Inflow water drainage system Gotthard Base Tunnel

Inflowing waters are captured and piped (under gravity) to the portals

Disposal options for outflowing warm tunnel waters at the portals (into nearby rivers) is limited.

Without energetic use (at least during contruction), cooling ponds (or even towers!) would be needed due to environmental regulation in Switzerland.

The tunnel operators are therefore generally interested in use of the warm tunnel waters.

The prerequisite is that possible users of the heat exist in the neighborhood of the portals.

ENVIRONMENTAL PROTECTION ISSUES

In case of no use of outflowing tunnel waters, they need to be disposed to nearby rivers. Swiss environmental regulation does now allow to warm a river –at its lowest flow-rate– , by more than 1.5 °C (=ΔT_{reg}).

The maximum permissible disposal flow-rate Q_{max} of the tunnel water can be calculated by:

$$Q_{max} = \Delta T_{reg} * Q_{rmin} / (T_p - T_{rmin} - \Delta T_{reg})$$

Q_{rmin} is the minimal river flow-rate and T_{rmin} the lowest river temperature (usually both in winter), T_p the temperature of the outflowing tunnel water at the portal.

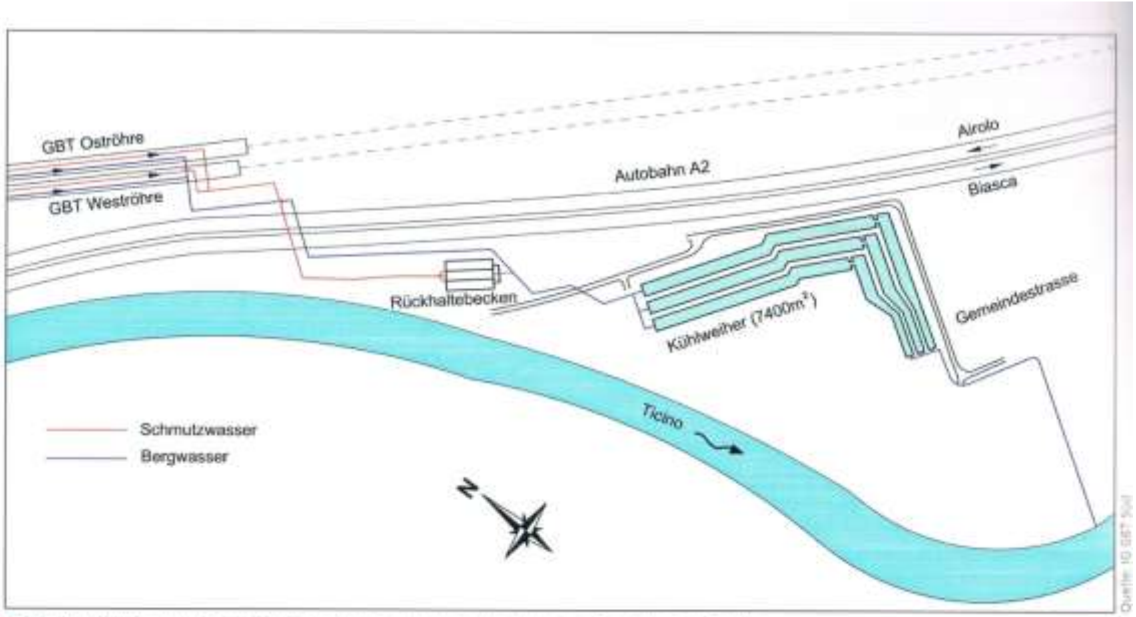
Maximum disposable tunnel water–flows Q_{max}, Gotthard Base Tunnel, to nearest river, calucalted with DT_{reg} = + 1.5 °C.

Portal	Nearest river	Q_{rmin} (l/s)	T_{rmin} (°C)	T_p (°C)	Predicted outflow (l/s)	Q_{max} (l/s)
Erstfeld (N)	Schattdorf	3000	3.5	31.5	60 - 555	170
Bodio (S)	Pollegio	610	3.9	29.0	80 - 460	39

It turns out that the disposable tunnel water outflow at the portal Bodio of GBT is too high, see below:

Data from the Report *Wärmenutzung Tunnelwasser BFE (2002)*

Cooling ponds at portal Bodio, GBT



▸ **Bild 1** *Vereinfachte Übersicht über das Entwässerungskonzept im Portalbereich Bodio*

Tunnel warter outflow at Portal Bodio:

85 l/s, 27 – 30 °C

▸ **Bild 2** *Kühlweiher Portal Bodio (Wasserkühlung)*

Solution:
Cooling ponds !
7400 m^2

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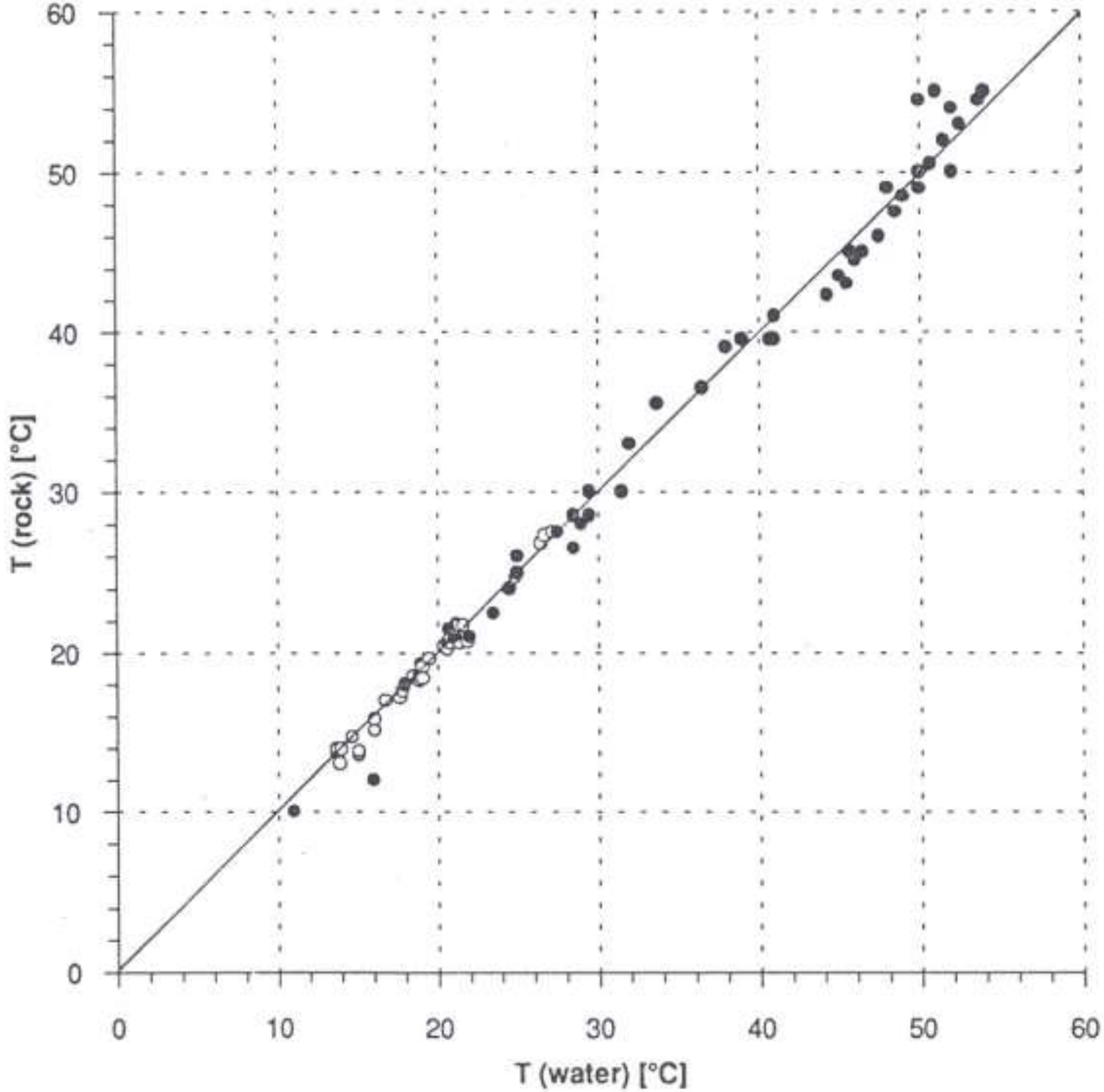
ENERGETIC USE OF TUNNEL WATERS

The simplest (and cheapest) tunnel water use is based on the heat content of the waters – outflowing free of charge.

Some Hydrogeology:

Inflow water temperature ≈ local rock temperature

Initial inflow >> stabilized inflow.



$T_{water} \approx T_{rock}$

Rock temperature vs. Temperature of inflowing tunnel waters. Data from the Simplon railway tunnel (dots) und the Gotthard highway tunnel (open circles). $R^2 = 0.996$

Rybach I(1995)

MANY TUNNELS IN SWITZERLAND !

Their heat potential is estimated to be greater than 30 MWth. The flow rates range from 360 liters/minute (Ascona) to 24’000 l/min (Grenchenberg), the outflow temperatures from 11.9 °C (Ricken) to 24.3 (Rawyl). Six heating systems are already in operation near the portals of the St. Gotthard, Furka, Mappo-Morettina, Hauenstein, Ricken, Grand St. Bernard, and Lötschberg Base tunnels.

Fig. 1-1: Vortriebsschema des Lötschberg-Basistunnels mit Ausbruch-methoden.

Lötschberg Base Tunnel (LBT), 36 km

Geologic profile, Lötschberg Base Tunnel

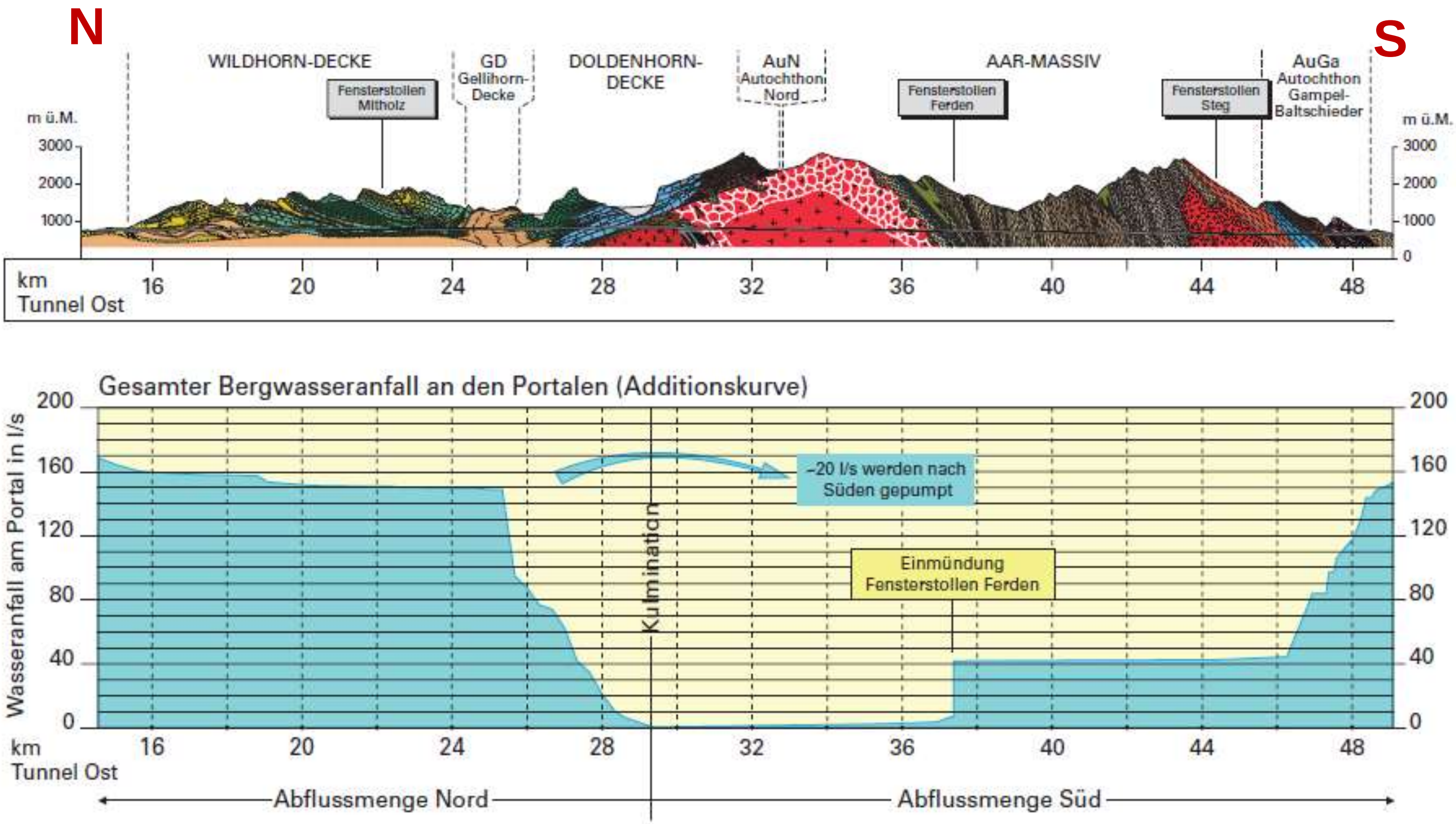


Fig. 4-1: Gesamter Bergwasseranfall an den Portalen (Additionskurve).

Water inflows (cumulative)

From Geologic Final Report LBT (2013) swisstopo

GEOTHERMAL USE OF TUNNEL WATERS

Relevant factors are: the available thermal power and the outflow temperature at the portals.

The thermal power P (e.g. in MW_{th}) is given by

$$P = c\,Q\,\Delta T$$

where c ist the heat capacity of water ($4.2 \cdot 10^3$ J/l,°K), Q the flowrate (l/s) and ΔT the useful temperature difference ($T - T_o$). T is the fluid temperature, T_o the reference temperature (usually 10 °C).

Thermal power of outflowing tunnel waters the northern portal Frutigen, Lötschberg Base Tunnel / TROPENHAUS

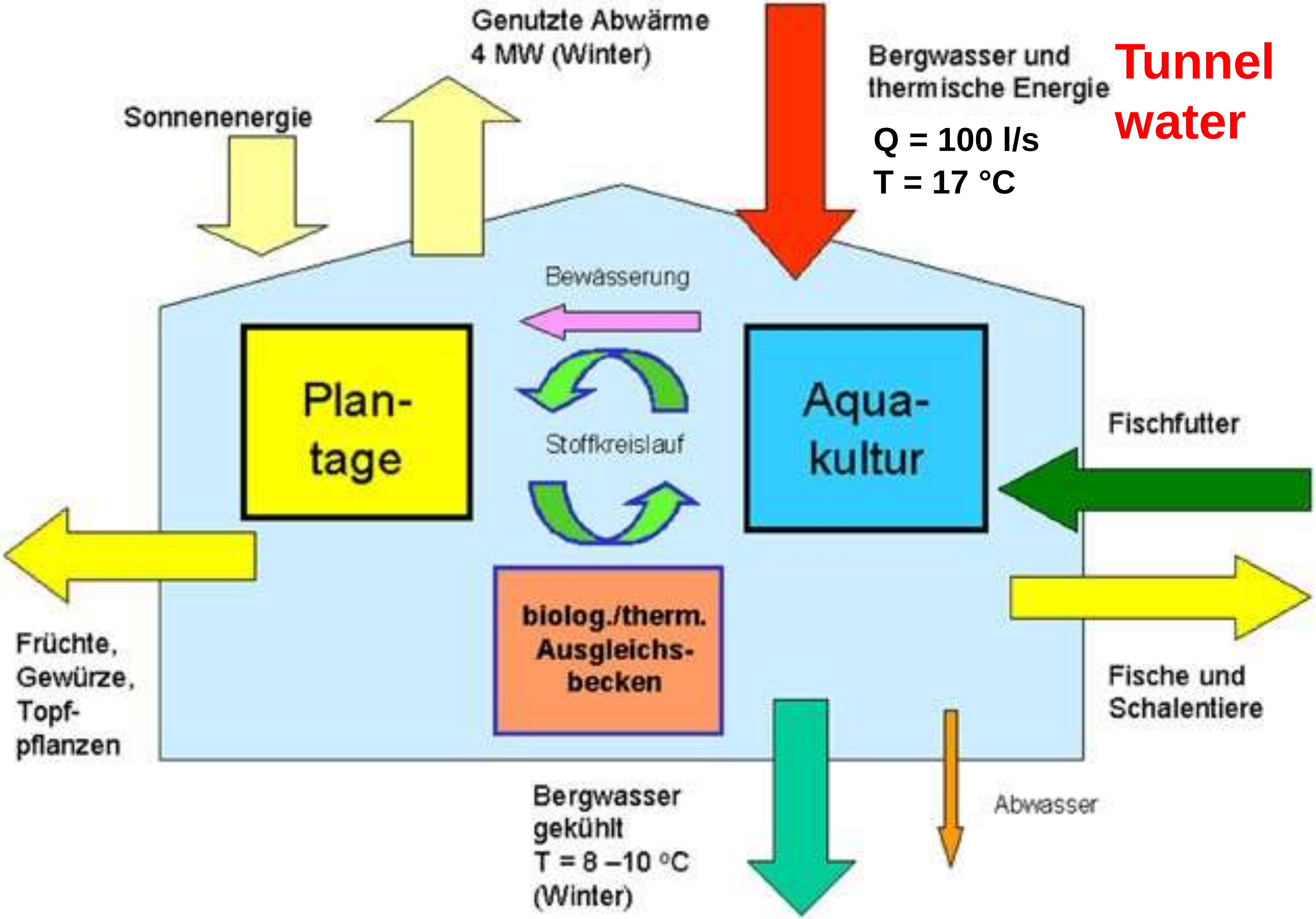
$Q = 100$ l/s

$T_w = 17$ °C

$T_o = 10$ °C

$$P = 4.2 \cdot 10^{-3} \cdot 100 \cdot (17 - 10) = 4.2\ MW_{th}$$

Energy supply to Tropenhaus Frutigen



GEOTHERMAL BRINGS TROPICS TO THE ALPS !

Greenhouses of *Tropenhaus Frutigen/BE*.

Tropcal fruits and flowers grow in the middle of the Alps!

Tropenhaus Frutigen / BE

Warm waters outflowing from the Lötschberg Base Tunnel (100 l/s, 17 ° C) is the energetic base. Warmwater fish Sturgeon is raised in special ponds, tropical fruits like banana, pineapple, mango and exotic flowers grow in greenhouses.
The sturgeons provide caviar…...

(Source: www.tropenhaus-frutigen.ch)

Caviar production im *Tropenhaus Frutigen*

KAVIAR

Neben dem ausgezeichnet mundenden Störfleisch, für das zahlreiche Zubereitungsarten bekannt sind, gehört der Störkaviar zu den berühmtesten Delikatessen auf unserer Erde. Durch mildes Salzen und eine gute Verpackung wird der Kaviar haltbar gemacht. Unser Ziel ist, den Kaviar aus Frutigen zu einem Markenbegriff für eine nach den Grundsätzen der Bioproduktion hergestellte Schweizer Delikatesse von höchster Qualität werden zu lassen.

quite a business….

CONCLUSIONS, OUTLOOK

Deep tunneling usually experiences some (sometimes ample) inflowing water. The waters are collected and channeled to the portals.

The chemical composition of the waters on one hand and their temperature on the other can lead to technical problems as well as economic benefits.

As demonstrated by Swiss examples, especially effects of high Cl or SO_4 contents of the inflowing waters (Gotthard Base tunnel) can be coped by special composition of sprayed and lined concrete.

Inflowing waters with elevated temperature can be used for geothermal heating, greenhouses, fish farming (even for caviar production), as demonstrated by *Tropenhaus Frutigen*, Lötschberg Base Tunnel.

For future deep tunnel projects, the planning should already include the search for portal-near potential customers of geothermal heat.


Many thanks for your attention!
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