Chemical and isotope composition of waters from Firenzuola railway tunnel, Italy

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** CNR – IGG (National Research Council)

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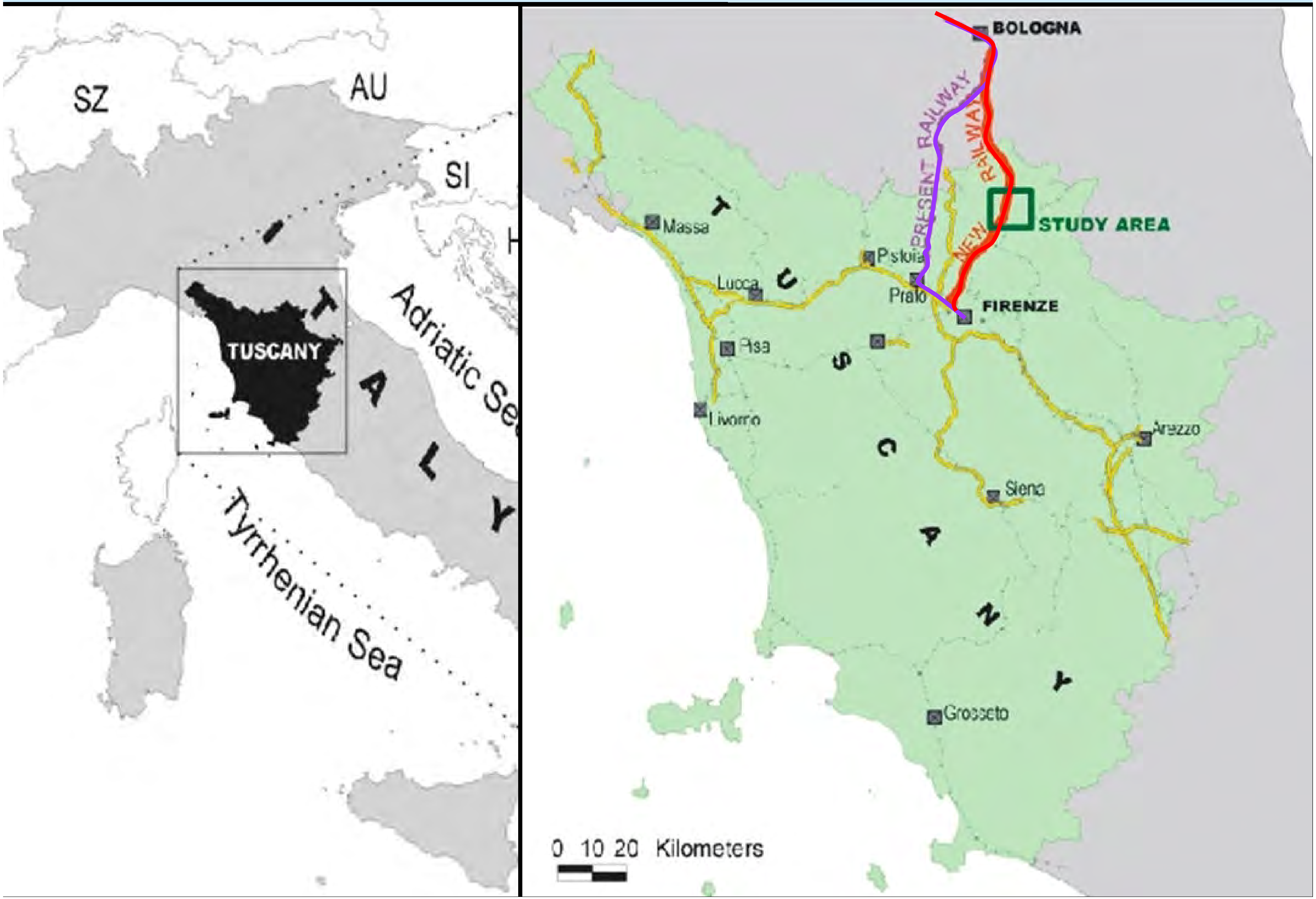
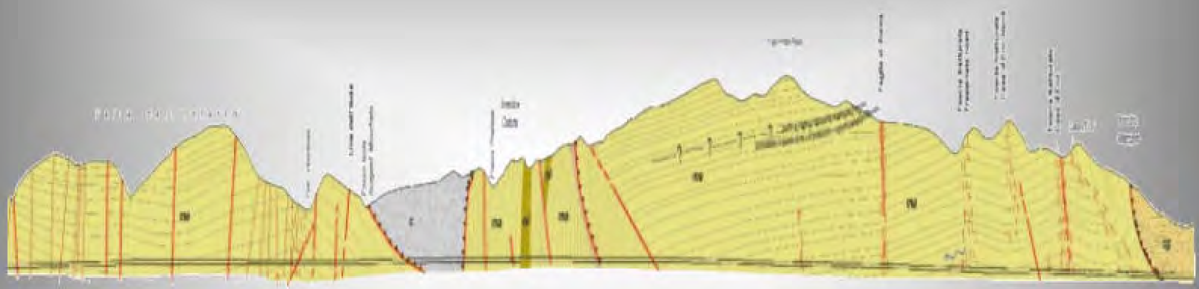
IAEG XII CONGRESS

Opened in 2009, the new Bologna-Firenze high-speed railway has a length of 78.5 km, and includes 73.3 km of tunnels. The Tuscan stretch of the new railway includes 6 mainline tunnels (three of which more than 15 km in length).



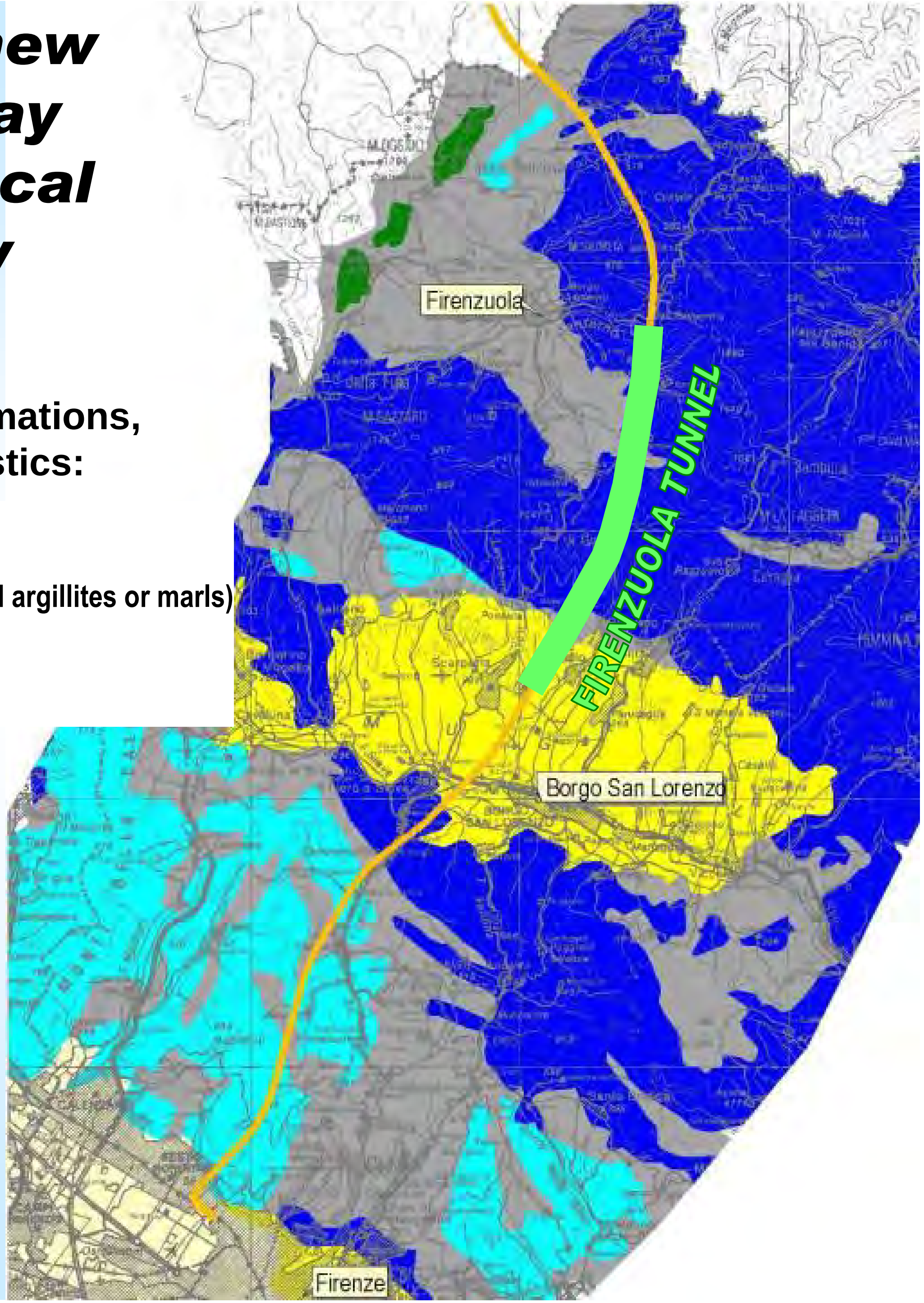
FIRENZUOLA TUNNEL
GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS



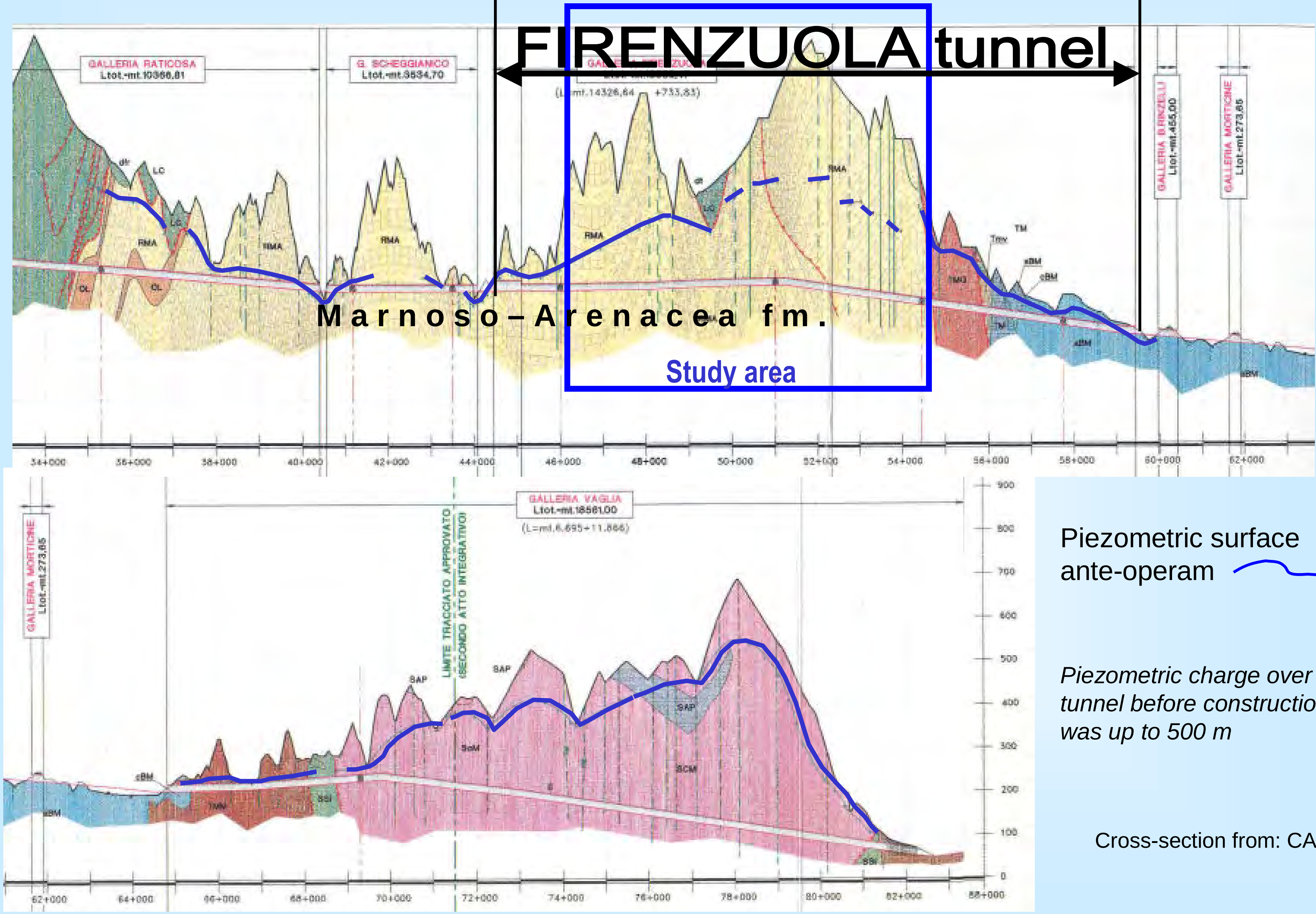
Tuscan stretch of the new Firenze-Bologna railway crossed mainly geological units with secondary permeability

Synthetic partition of the crossed formations, sorted by hydrogeological characteristics:

- **Alluvial deposits**
- **Lacustrine deposits**
- **Siliciclastic turbidites formations (alternating sandstone and argillites or marls)**
- **Mainly argillitic formations**
- **Mainly marly-limestone formations**
- **Ophiolites**



Geological cross-section of the tuscan stretch



Piezometric surface ante-operam

Piezometric charge over the tunnel before construction was up to 500 m

Cross-section from: CAVET

The Firenzuola tunnel was dug mainly in the Marnoso Arenacea formation

Marnoso Arenacea Formation is a Siliciclastic turbidite , that can be sketched as an alternating of sandstone and marls layers

In some areas layer thickness is up to some decimeters.

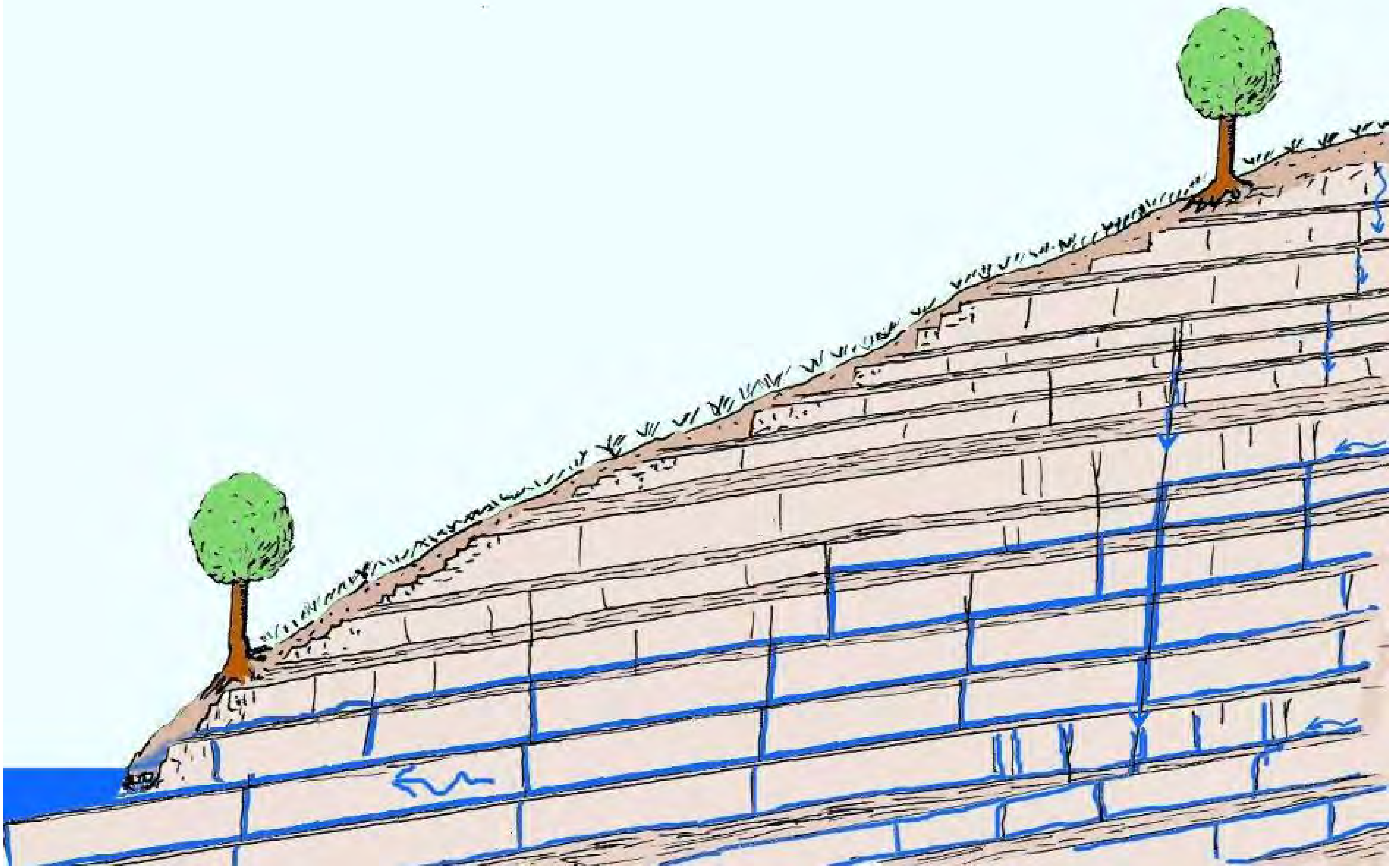
In other cases, layer thickness is up to a few meters, and there is an high sandstones / marl ratio

Marly layers are substantially impermeable. Instead, Sandstone layers are characterized by orthogonal fractures, usually limited to the single layer.

But there are faults or more persistent fractures that cross a number of layer, also forming fractured belts.

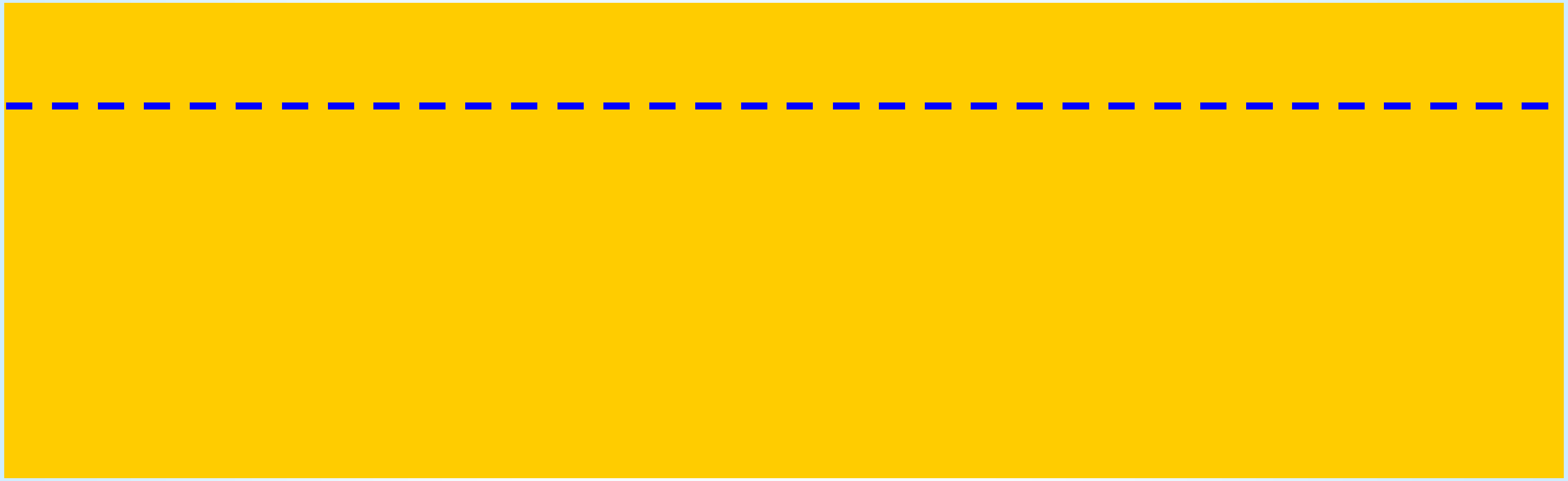
These patterns allow ground water circulation on a wider scale.

Illustrative sketch of ground water circulation in Siliciclastic turbidites



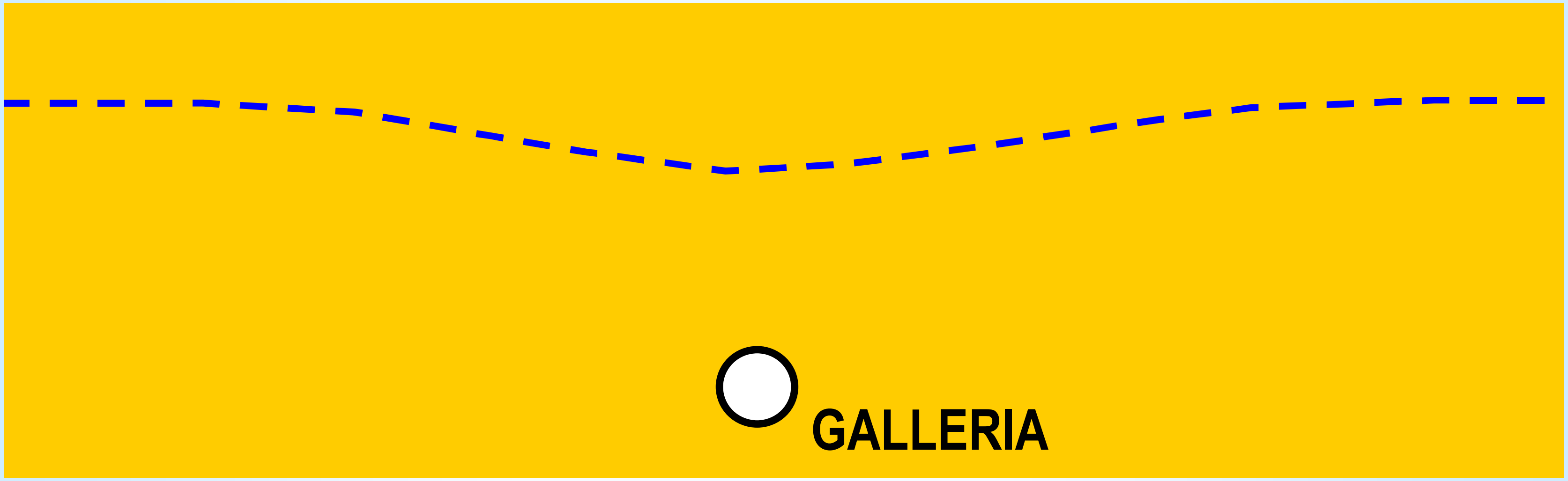
FIRENZUOLA TUNNEL
hydrogeological impacts

Sketch of the effects induced by tunnel drainage



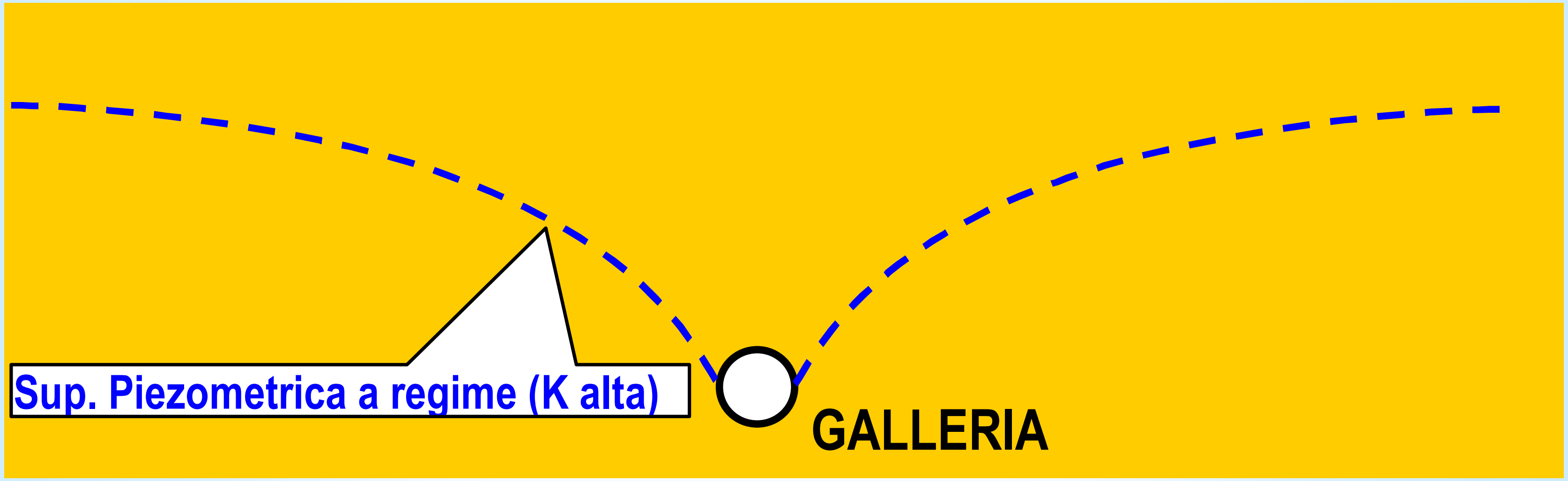
Hypothetic piezometric surface before tunnel construction

Sketch of the effects induced by tunnel drainage



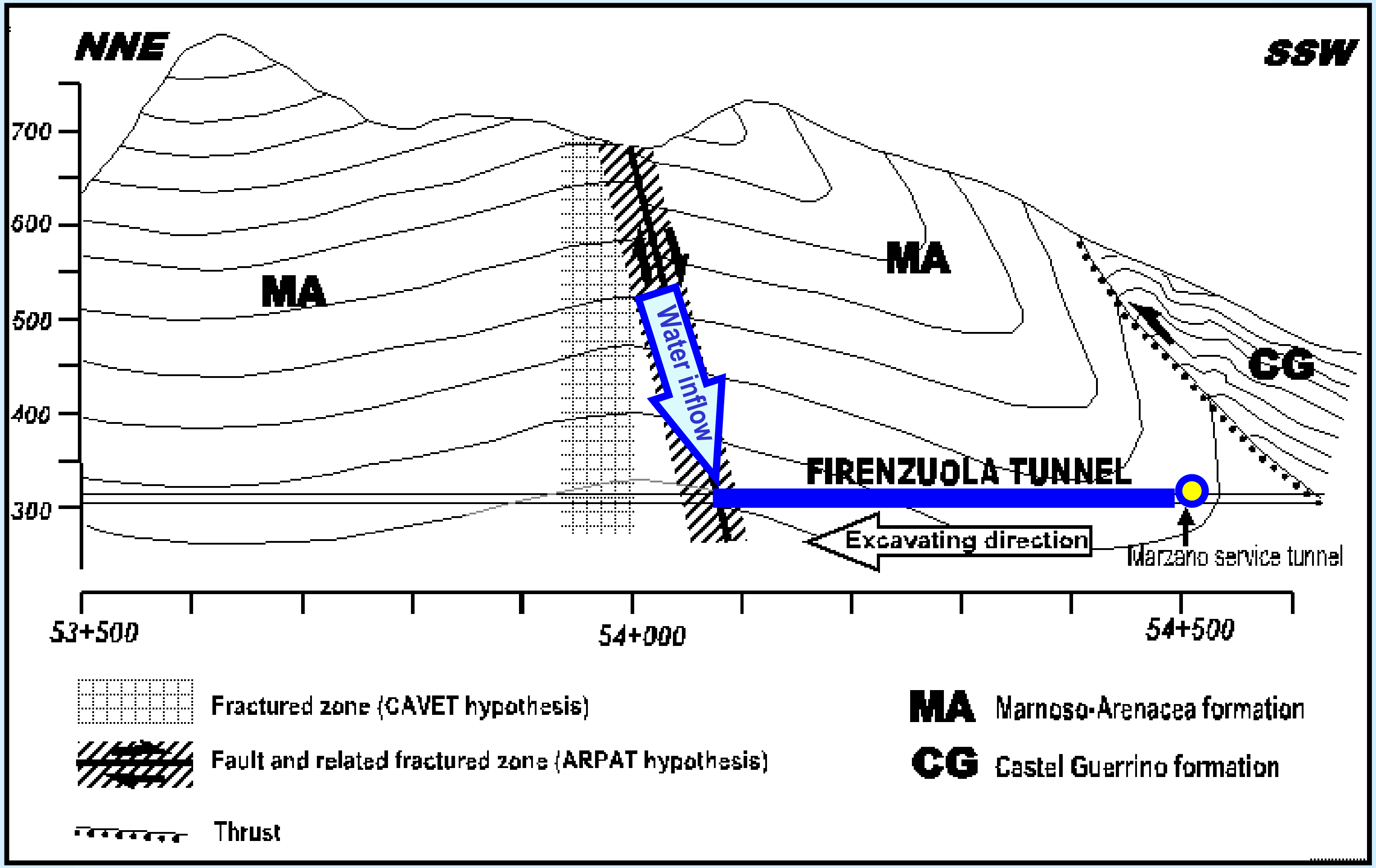
Tunnel digging - start of drainage and drawdown

Sketch of the effects induced by tunnel drainage



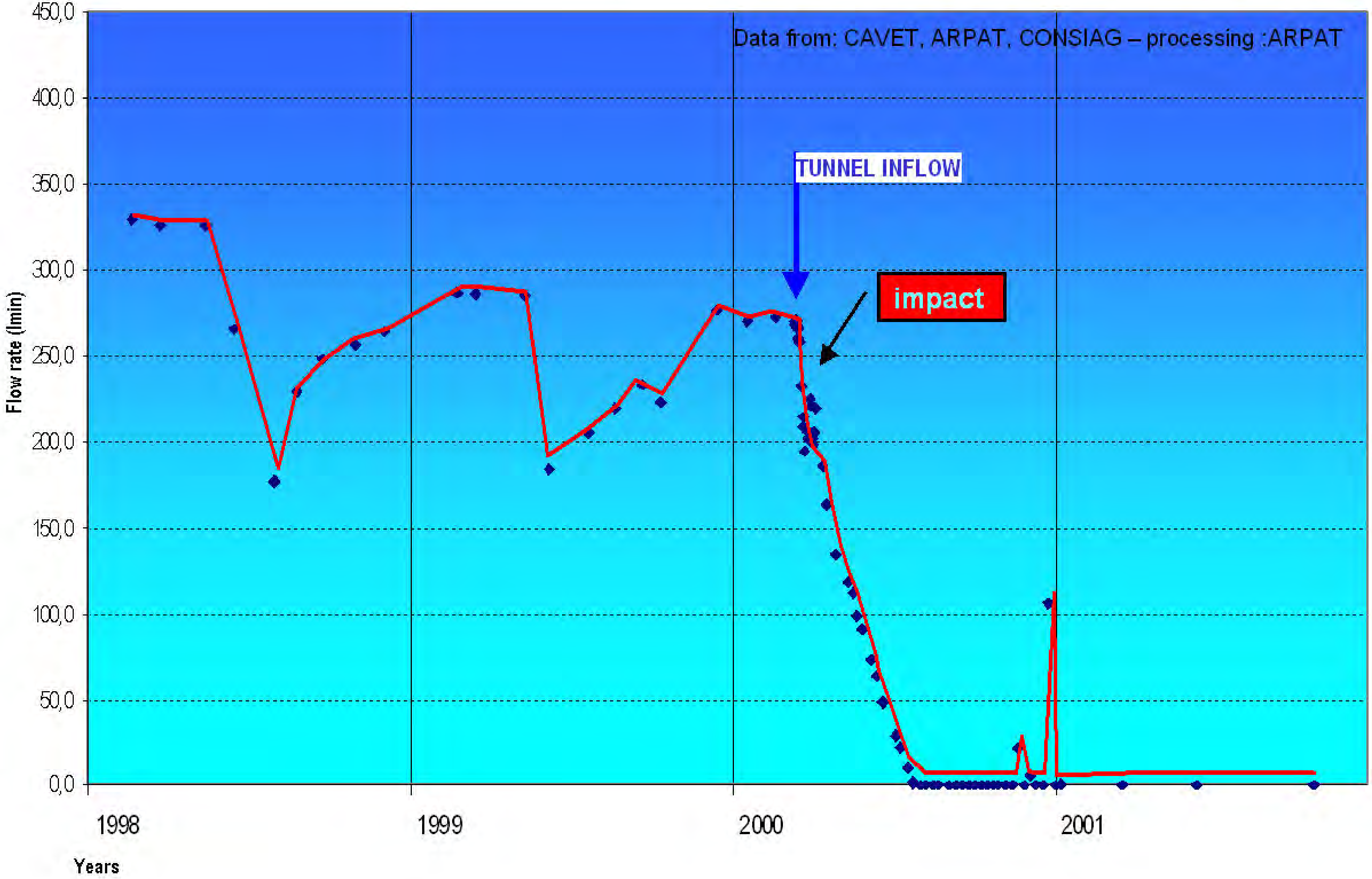
In case of high transmissivity, piezometric surface is connected to tunnel

A typical example of impact due to the tunnel drainage: Casa D'Erci springs

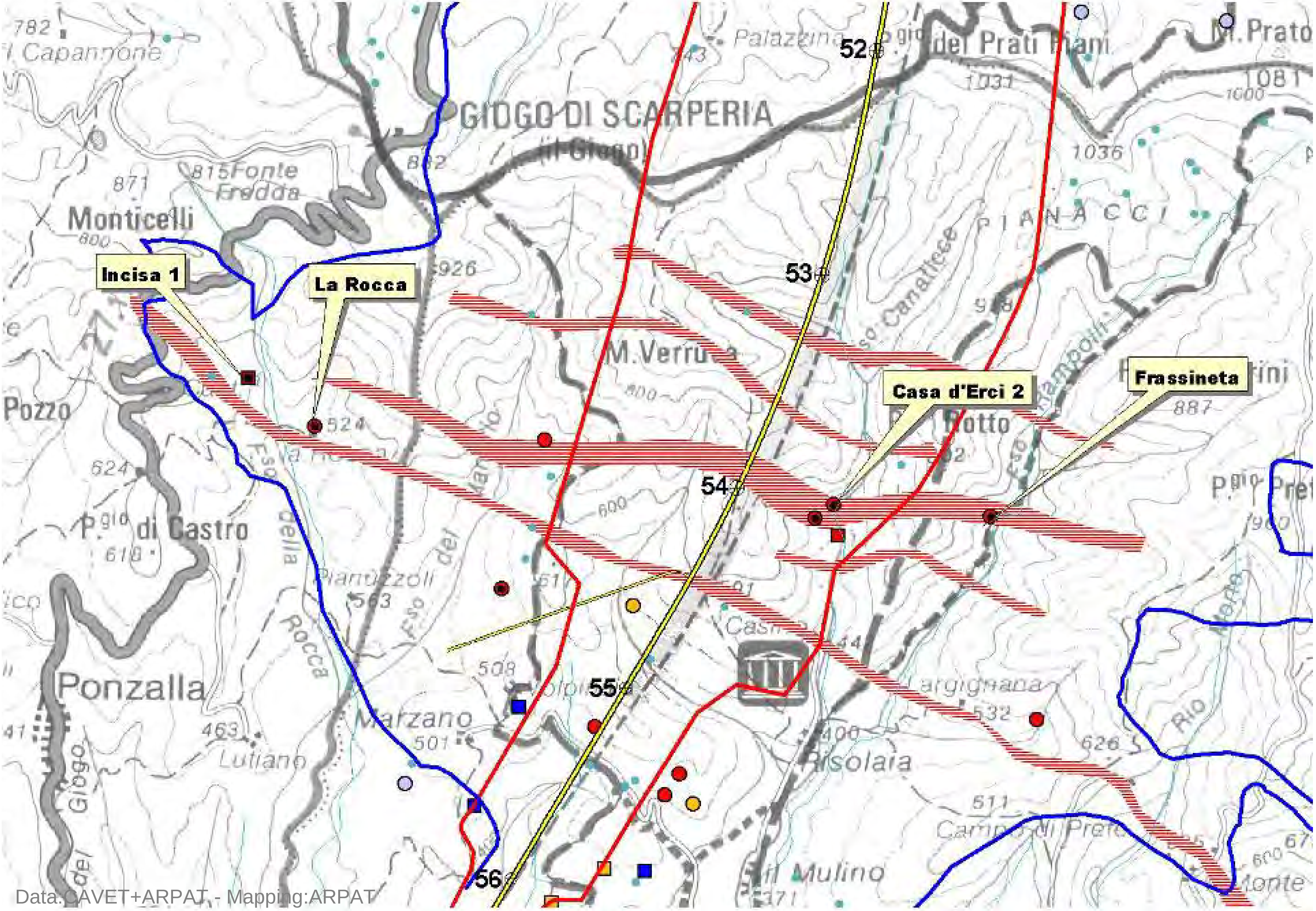


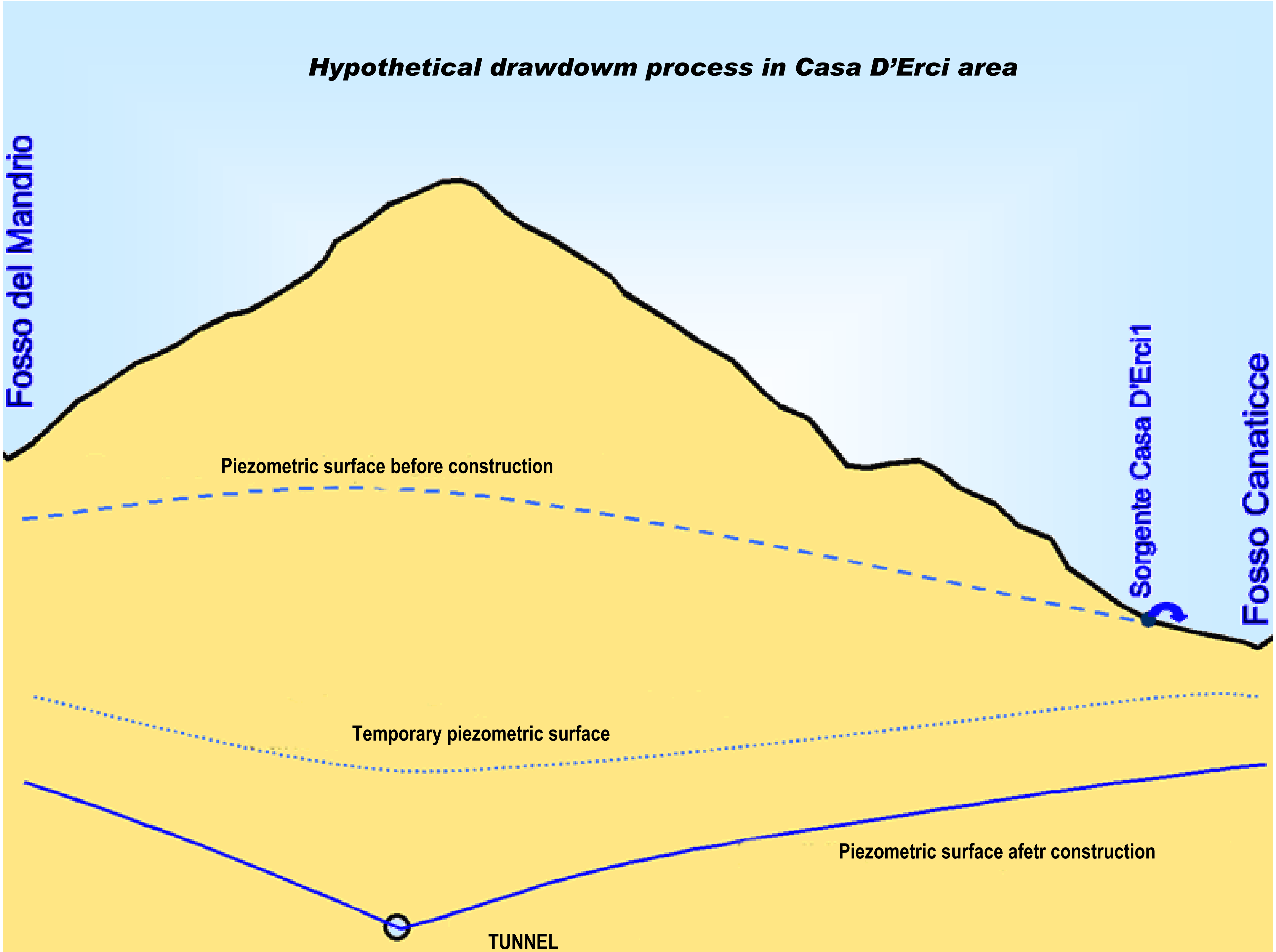
Elaborazione sezione:ARPAT con contributo di dati CAVET

Casa d'Erci 2 Spring

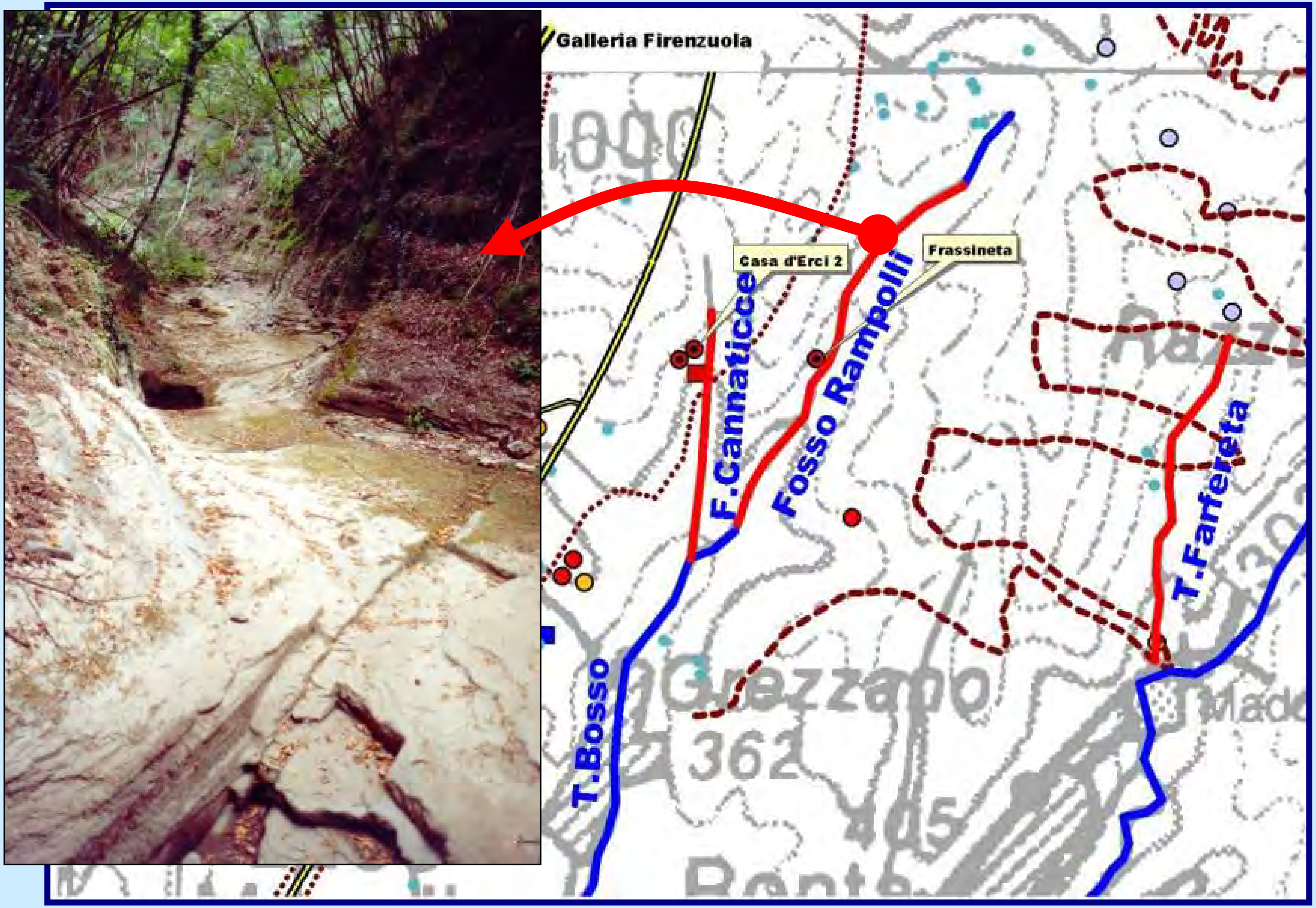


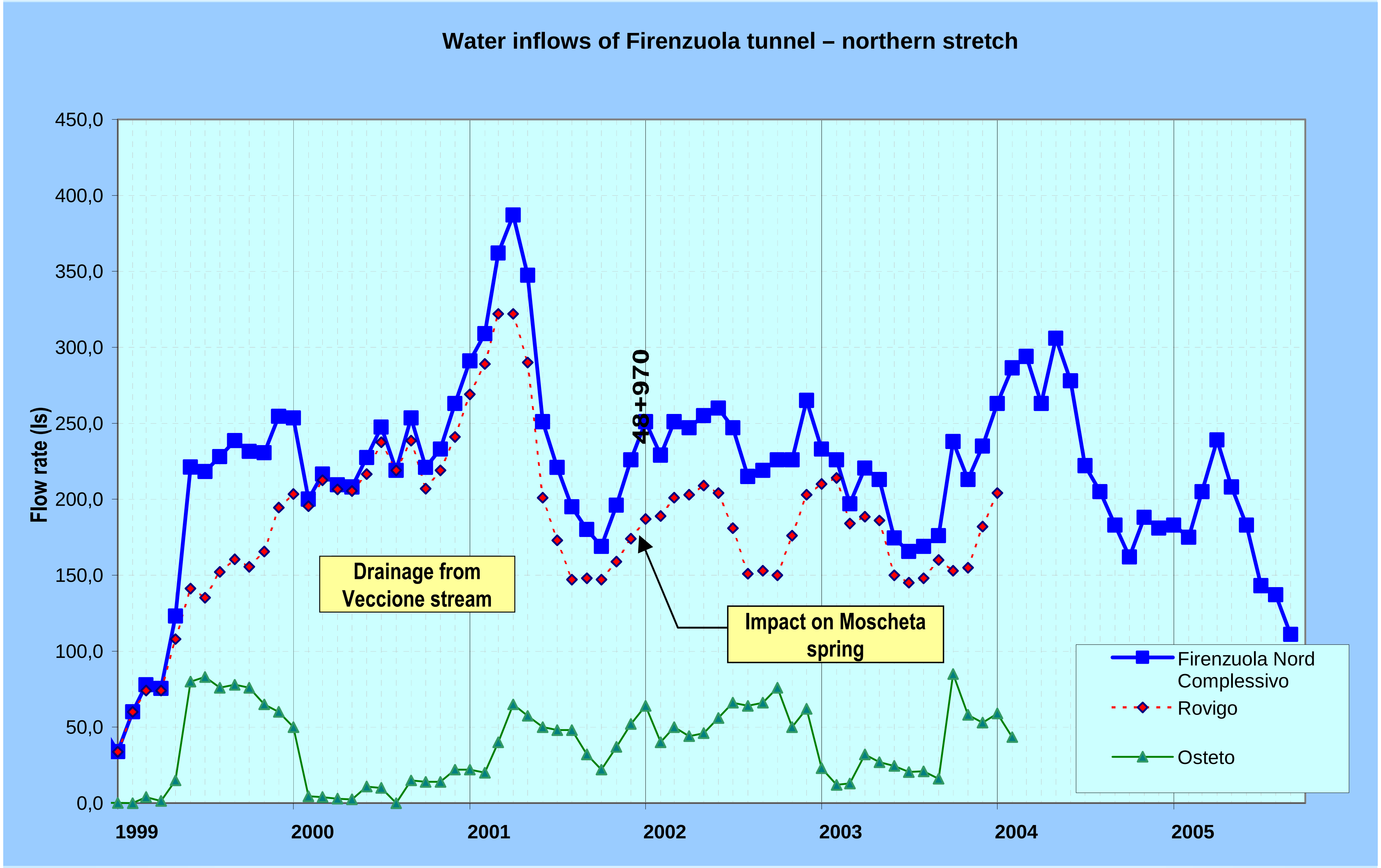
Fractured belts in the southern sector of Firenzuola tunnel




Hypothetical drawdowm process in Casa D'Erci area
Fosso del Mandrio
Sorgente Casa D'Erci1
Fosso Canaticce
Piezometric surface before construction
Temporary piezometric surface
Piezometric surface afetr construction
TUNNEL

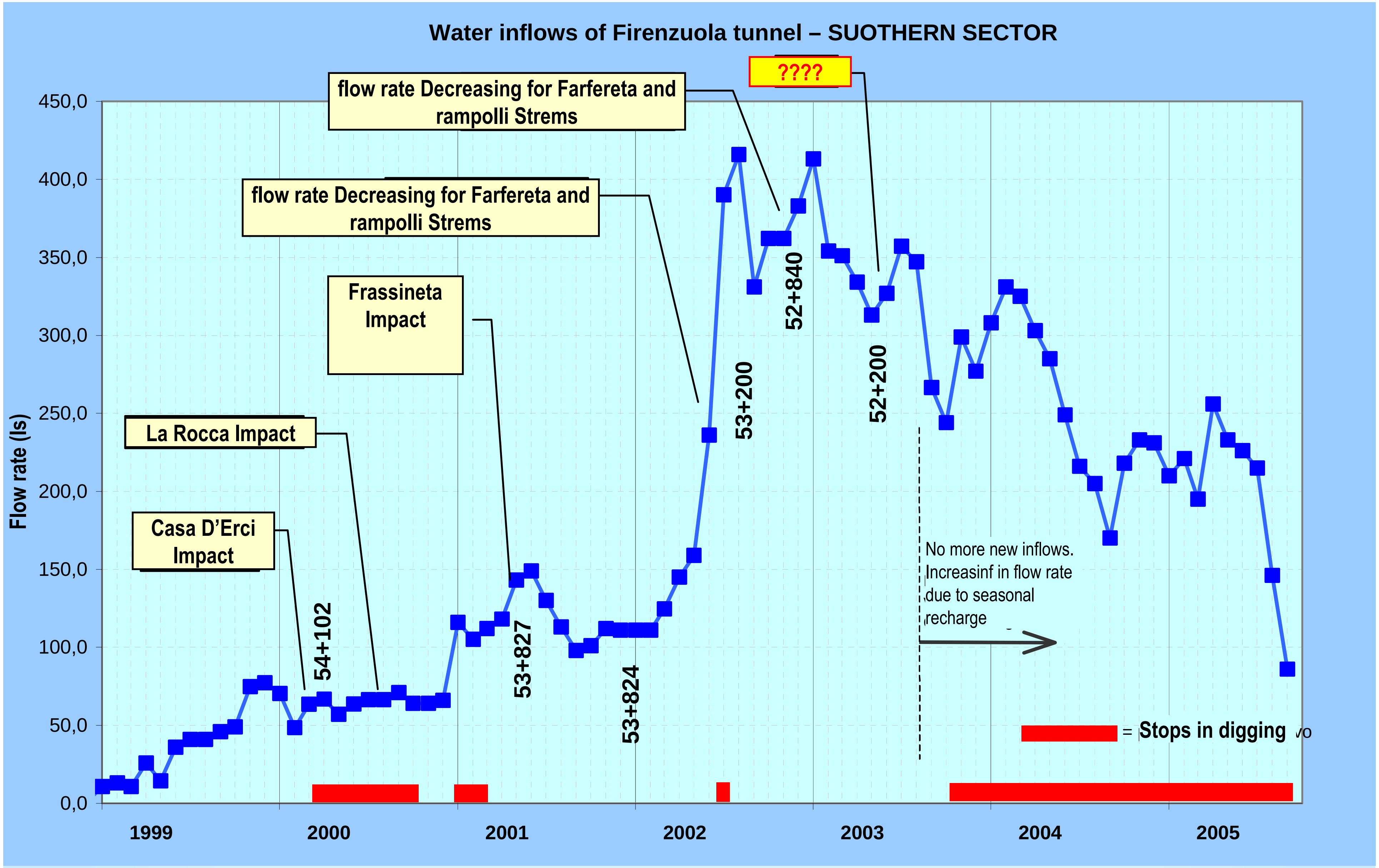
Tunnel drainage results not only in impacts on springs, but also in drying some stretch of streams during summer.





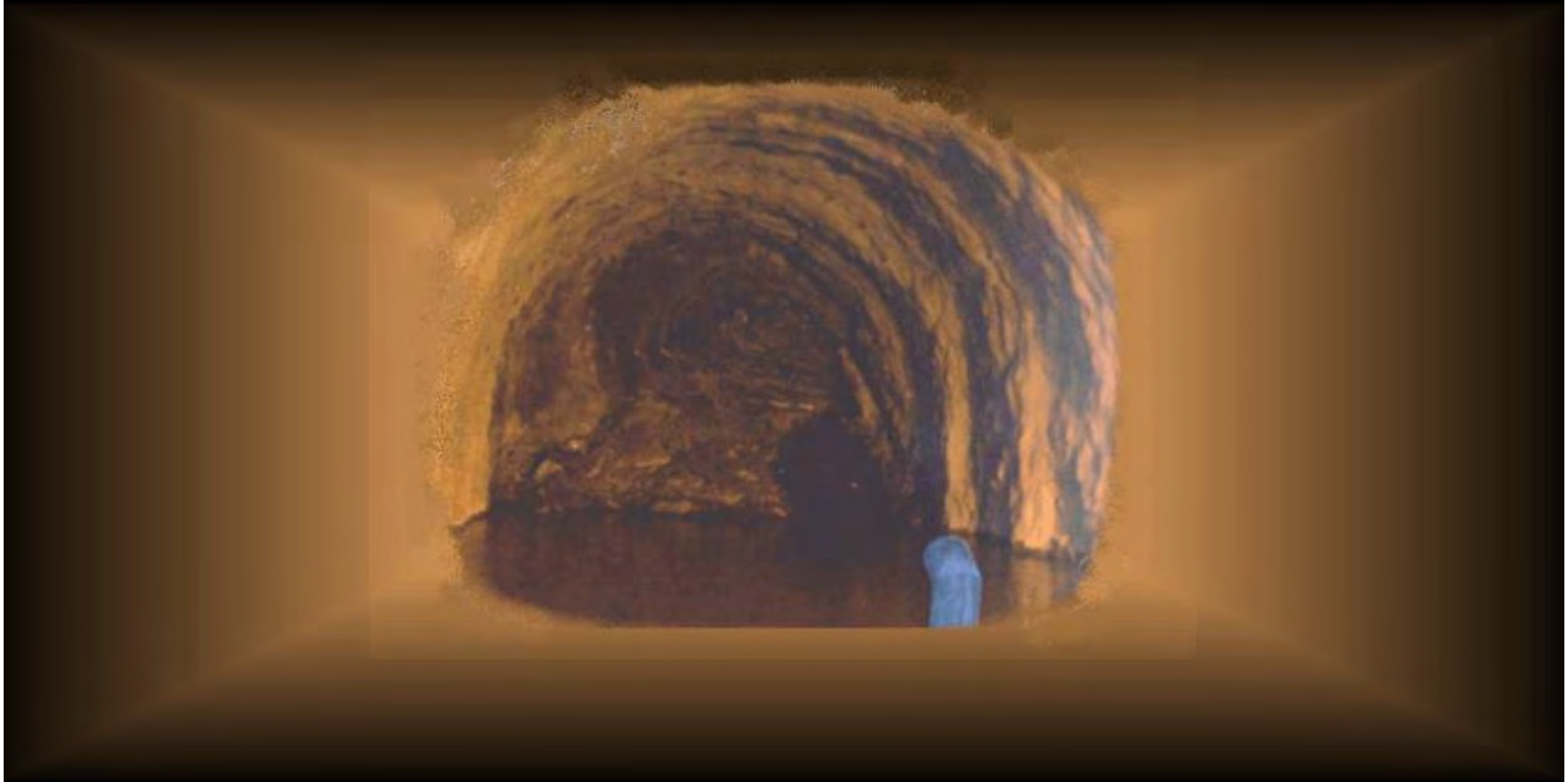
Data:CAVET+ARPAT - Processing:ARPAT

Alcune immagini da Galleria Firenzuola da Marzano verso nord - venute intorno alla progressiva 53+215 (11/7/02)



Data:CAVET+ARPAT - Processing:ARPAT

Geochemical and isotopic characterisasion



Progetto di caratterizzazione geochimico-isotopica

Realized by ***ARPAT*** (Environmental Protection Agency of Tuscany), and ***CNR*** (National Research Council, IGG, Pisa)

Financing: within the so-called "Addendum" (2002) (a plan including a number of actions aimed to mitigate hydrogeological impacts after construction) .

Problems:

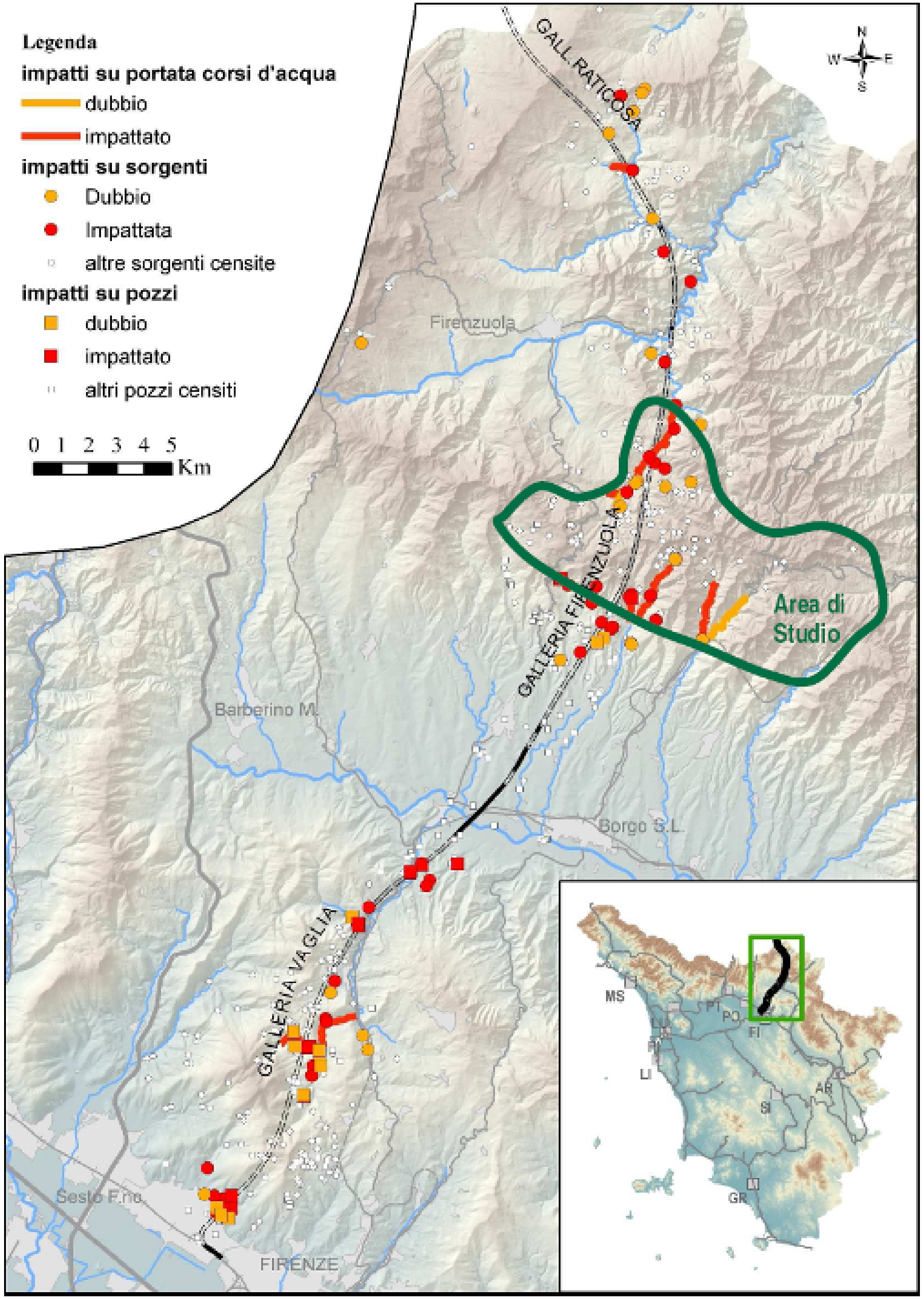
•occurrence of considerable inflows in the tunnel, some of which didn't apparent cause impacts

•Difference between amount of tunnel inflows and total of water resources resulting impacted.

Tool: sampling, analyses and surveys aimed to geochemical and isotopical characterization of water from tunnel, springs and streams.

Purpose: acquire data useful to:
- better define hydrogeological paths
- better defining and comprehension of impacts and possible trend
- have more data for the planning of mitigation works.

Timetable:
- 1st phase 2004
- 2nd phase 2007
- Additional samples have been collected in 2008, 2009 and 2012



Legenda
impatti su portata corsi d'acqua
dubbio
impattato
impatti su sorgenti
Dubbio
Impattata
altre sorgenti censite
impatti su pozzi
dubbio
impattato
altri pozzi censiti
0 1 2 3 4 5
Km
N
W
E
S
GALL.RATICOSA
Firenzuola
GALLERIA FIRENZUOLA
Area di Studio
Barberino M.
Borgo S.L.
GALLERIA VAGLIA
Sesto F.no
FIRENZE
MS
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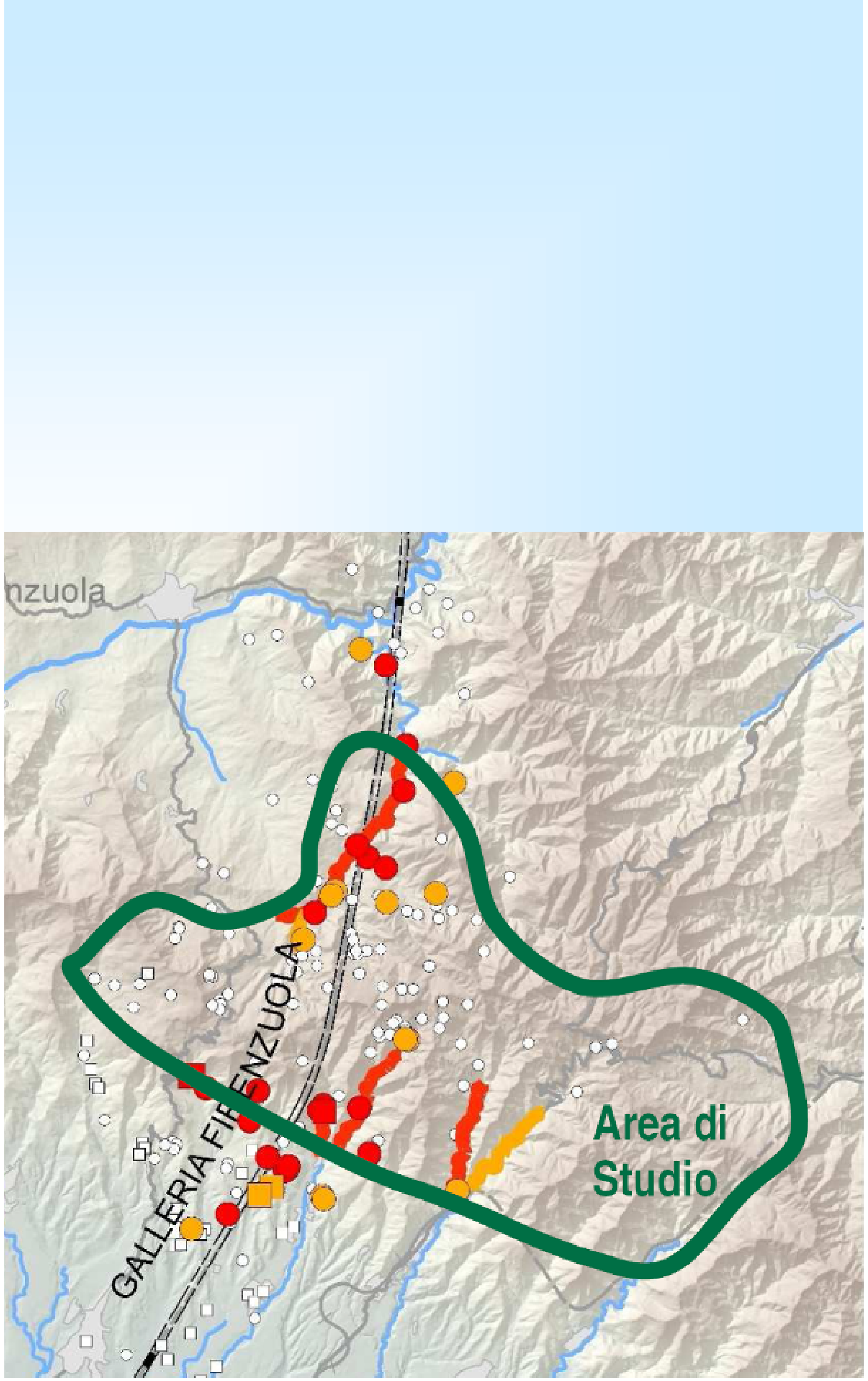


nzuola
GALLERIA FIRENZUOLA
Area di Studio

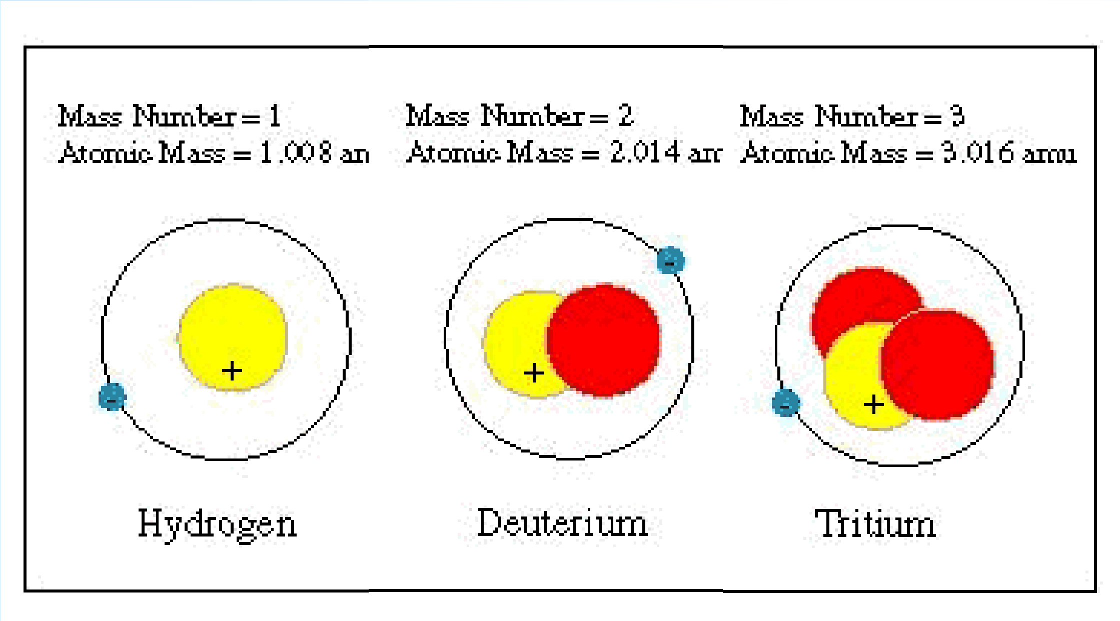
Chemical analyses: HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+

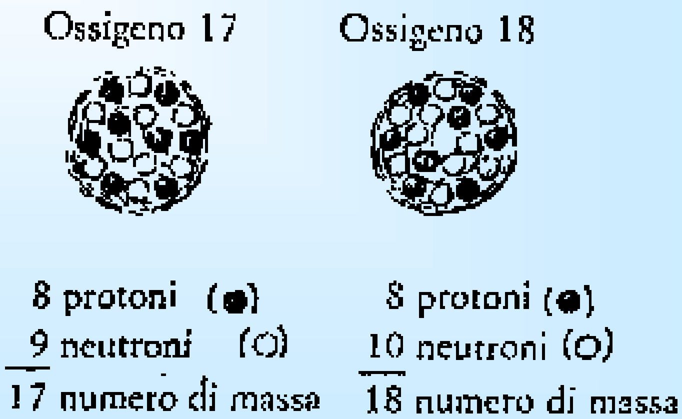
(some analyses have been carried out also on SiO_2 e di NO_3^-).

Isotopic analyses: $^{16}O/^{18}O$, $^{1}H/^{2}H$, ^{3}H

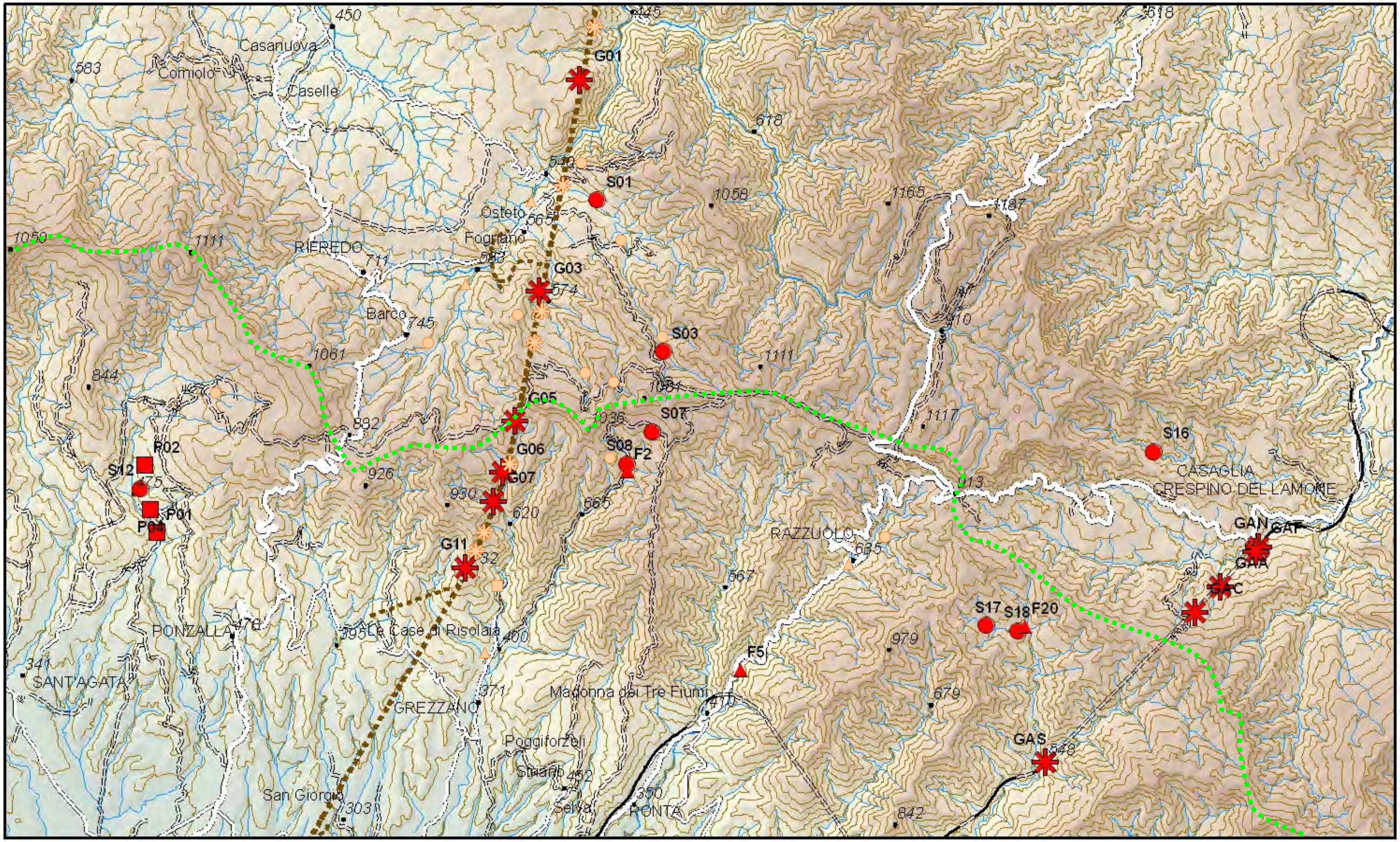
$^{16}O/^{18}O$ and $^{1}H/^{2}H$ are significant naturale water tracers: can give some information on recharge altitude.

^{3}H is an unstable isotope and therefore can give information on the length of groundwater paths.





Progetto di caratterizzazione geochimico-isotopica del sistema idrogeologico Marzano-Osteto



Map of sampling points

1:70.000

0 1 2 3 Km

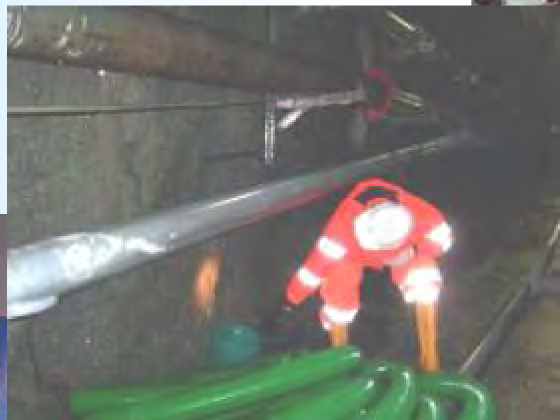
Sampling point type

- tunnel
- well
- spring
- stream

Activities 2004 ÷ 2008

46 sampling points, of which:

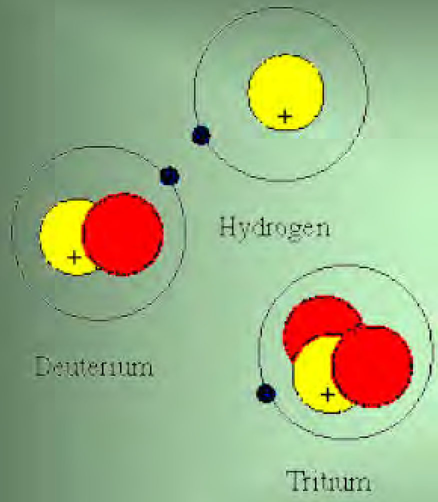
37 were reapetedly collected.

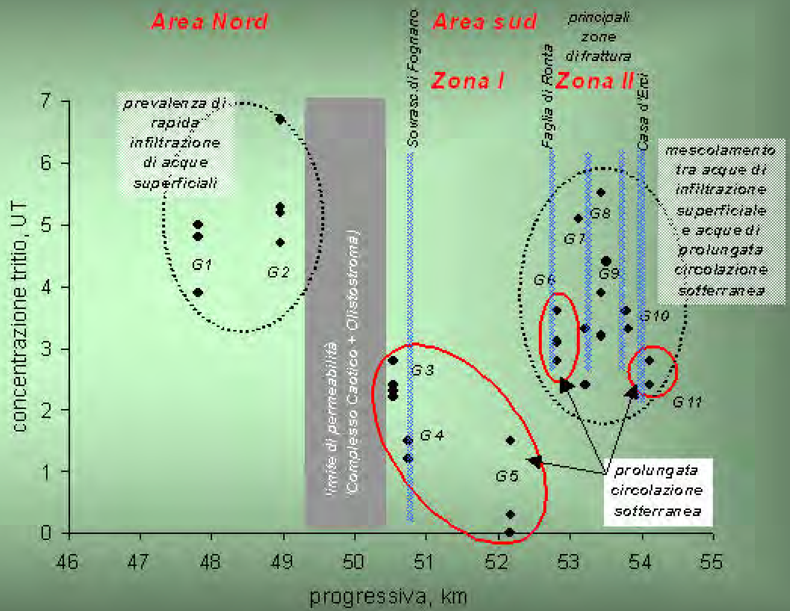


On the whole:

- **732** samples
- **861** in-situ measures (flow rate, pH, EC)
- **2260** chemical parameters analysed
- **559** isotopic analises

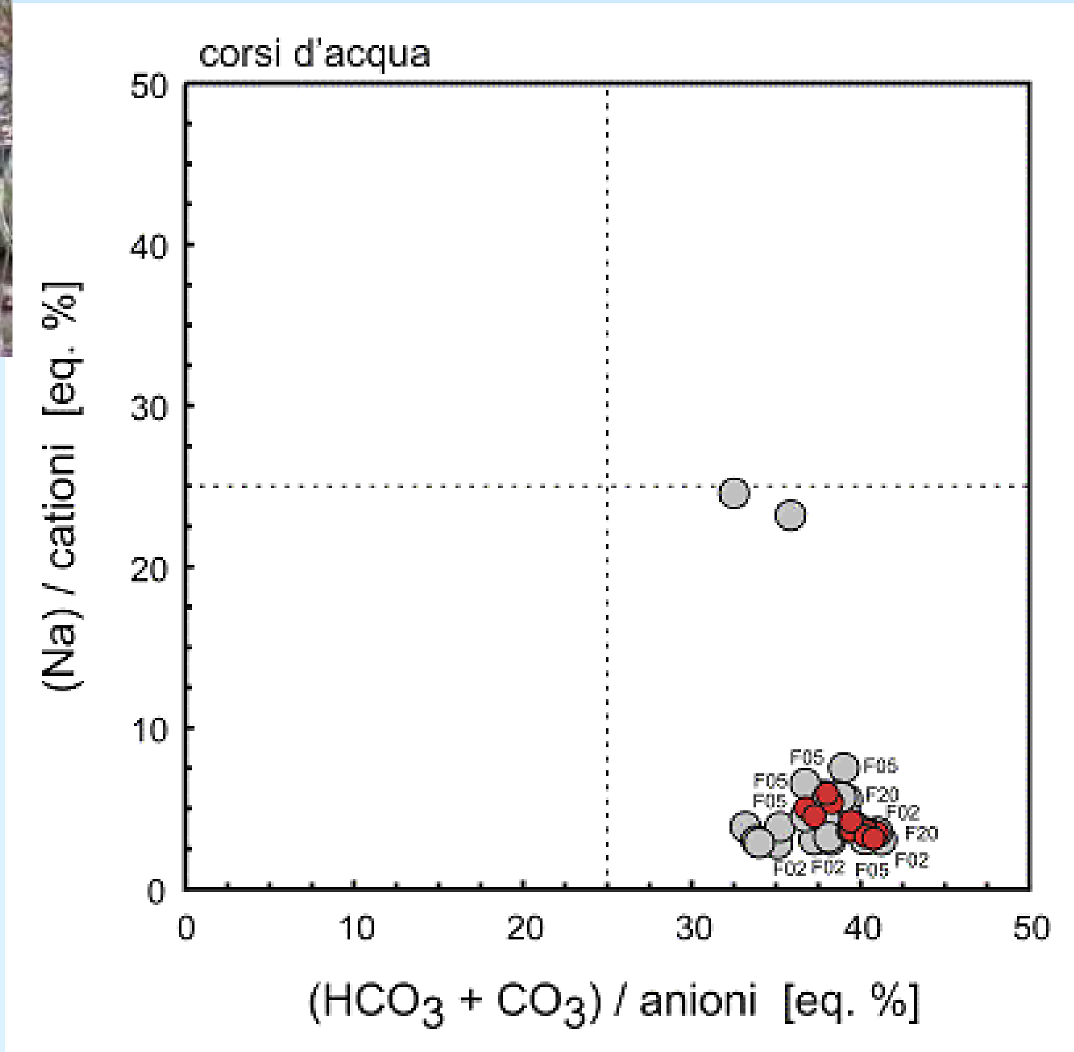
Data processing and discussion





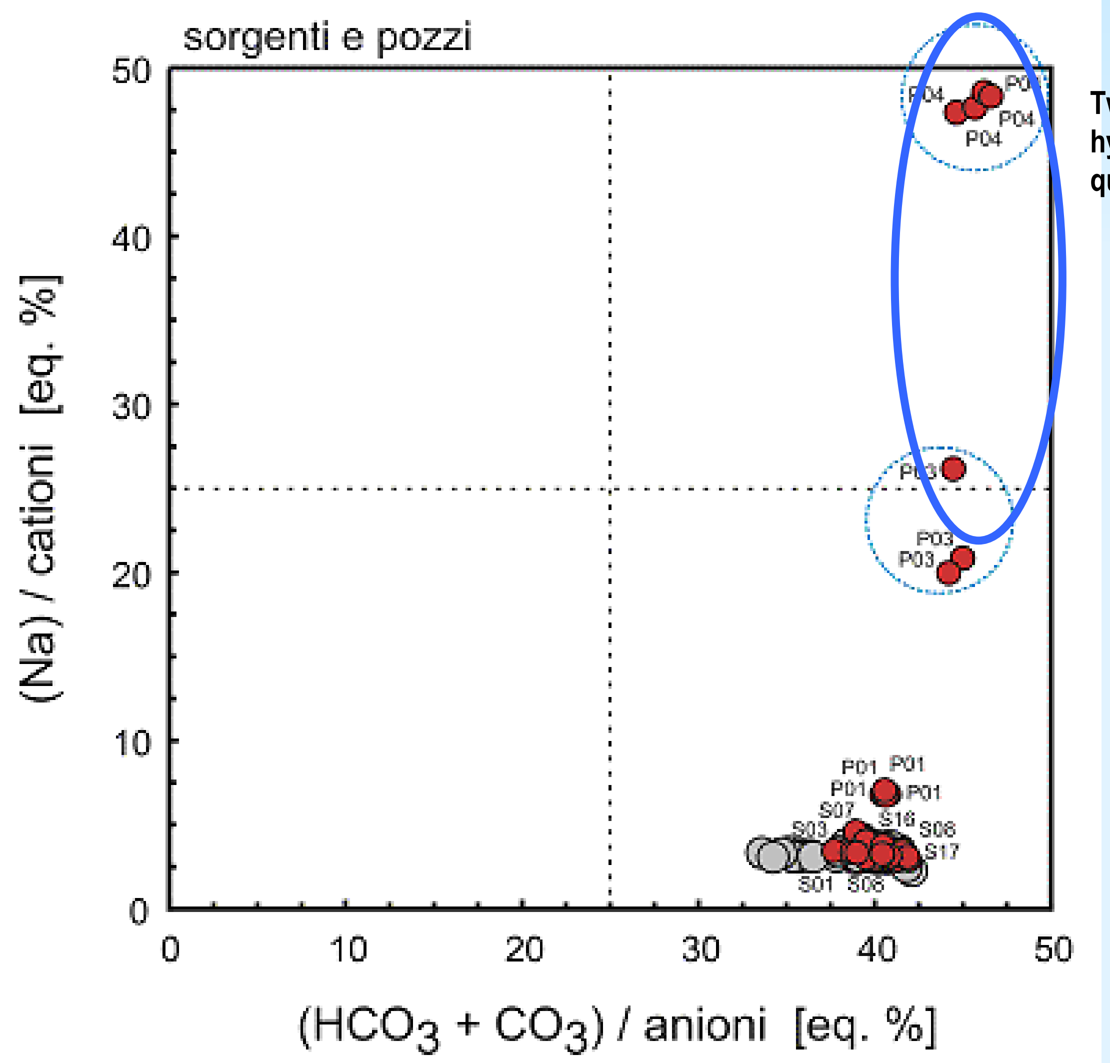
geochemical classification

Na >> K



Langelier-Ludwig diagram for streams shows bicarbonate-calcium facies.

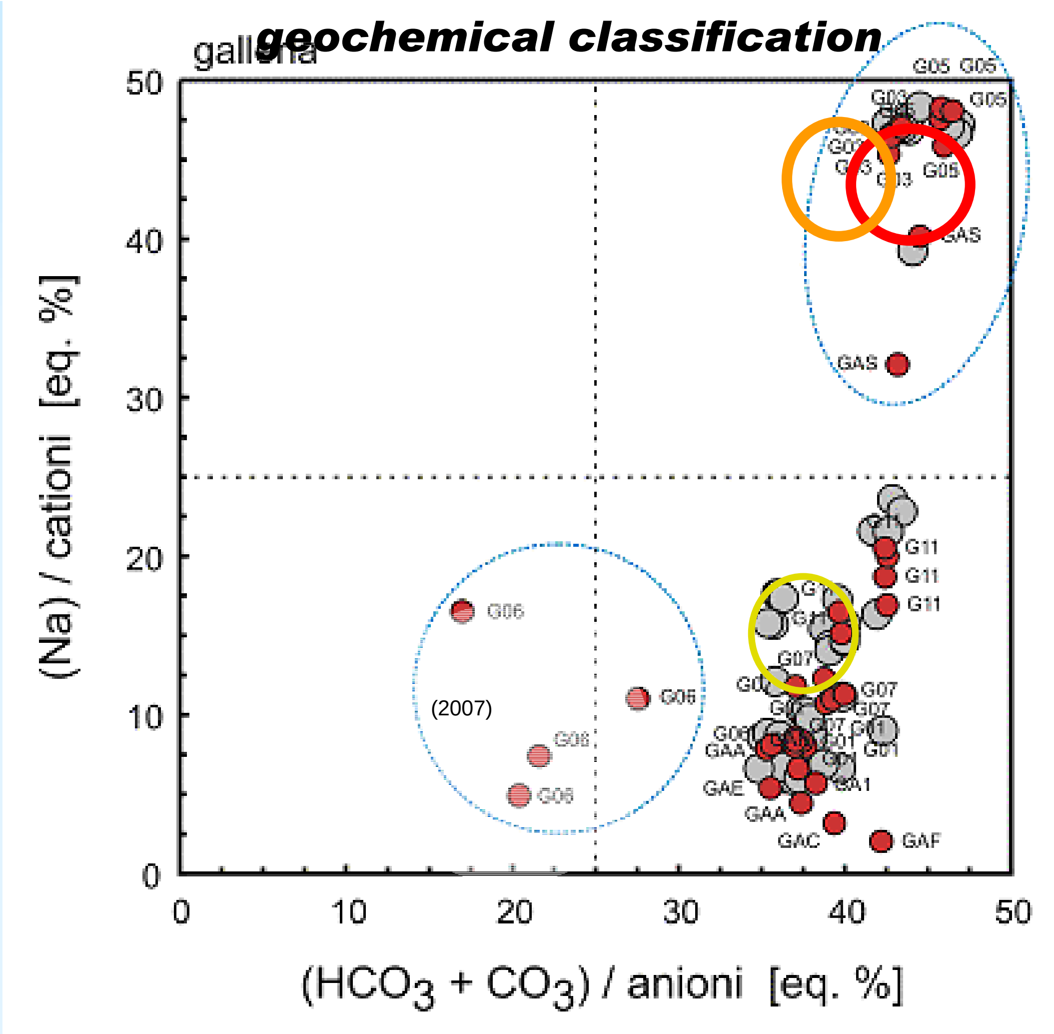
geochemical classification



Two wells in a different hydrogeological basin, quite far from tunnel

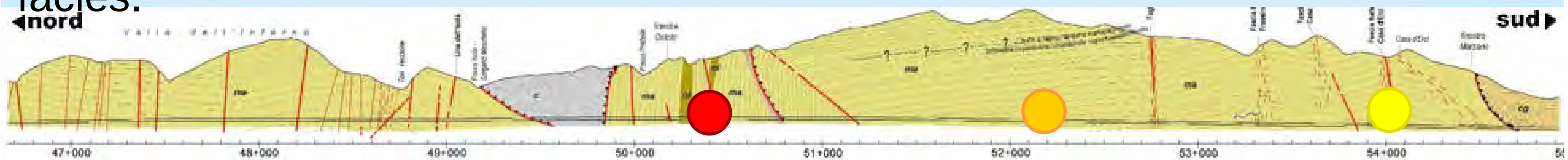
Na >> K

Diagram for springs and wells shows the same bicarbonate-calcium facies.

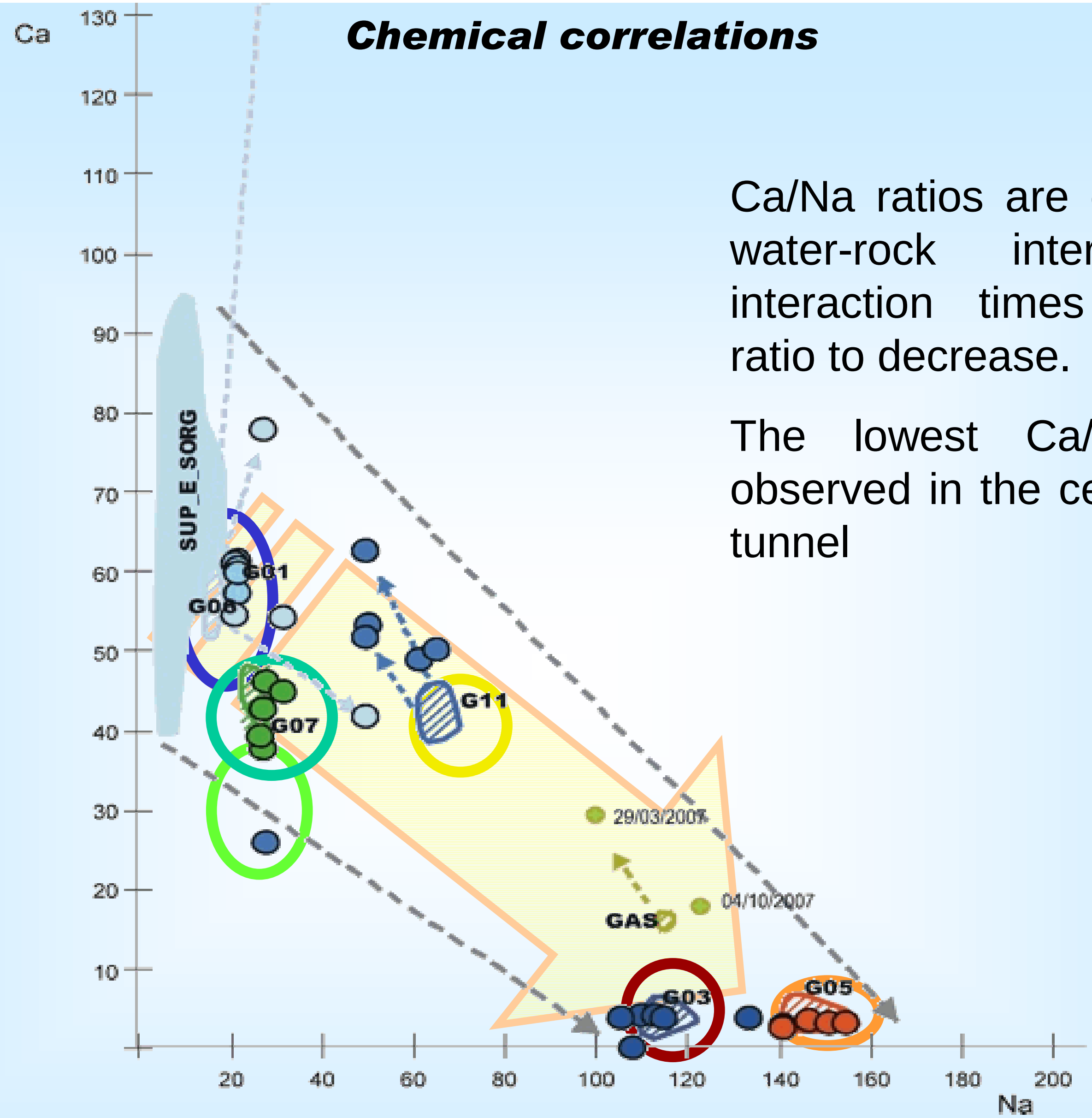


Na >> K

Tunnel drainage waters have a predominant bicarbonate-calcium facies, except samples from the central part of the tunnel, which have a bicarbonate-sodium facies.

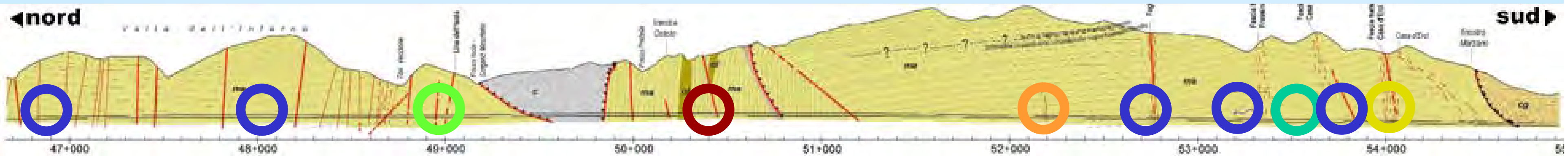


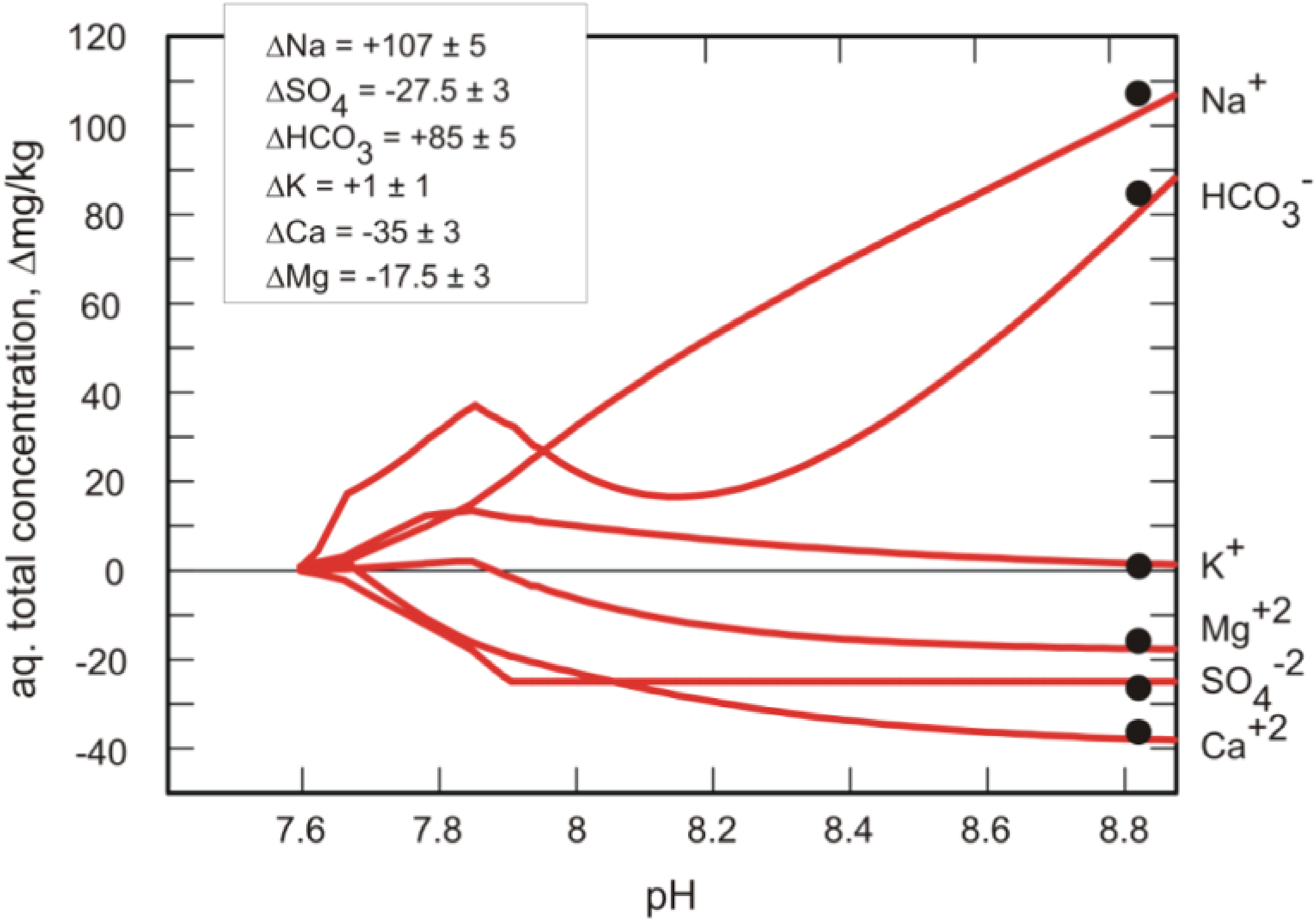
Chemical correlations



Ca/Na ratios are good tracers for water-rock interaction: larger interaction times cause Ca/Na ratio to decrease.

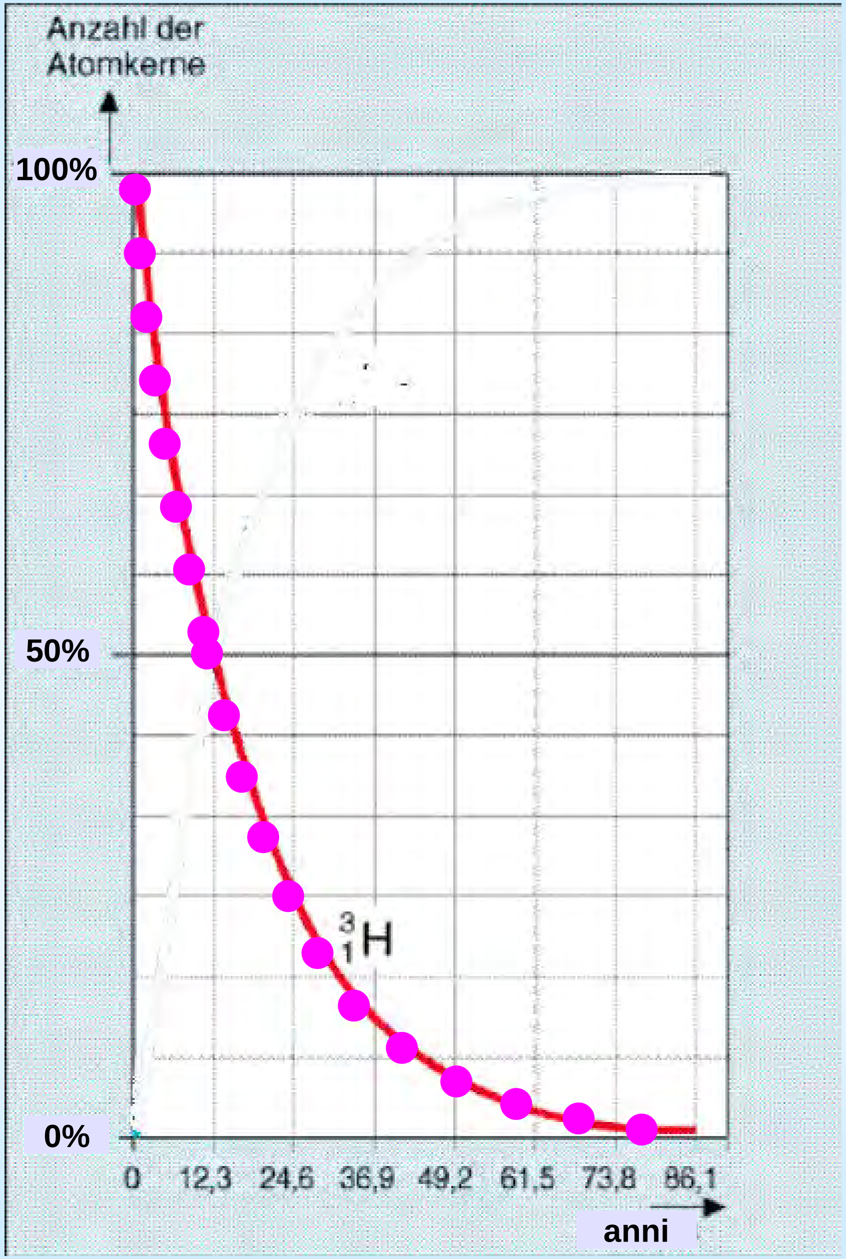
The lowest Ca/Na ratios are observed in the central part of the tunnel



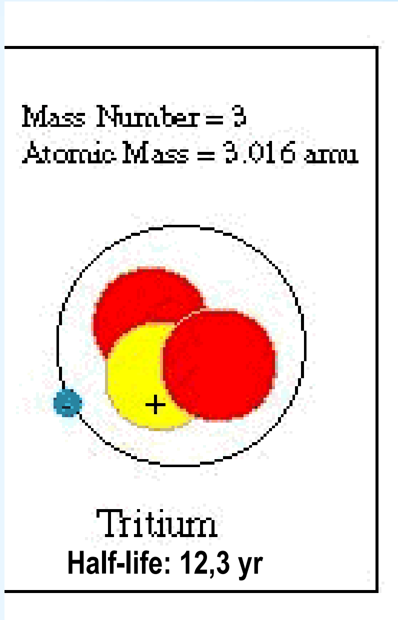


Reaction path modeling has been applied to investigate the processes governing the chemistry of the tunnel seeps. A flow-through configuration has been used to simulate the evolution of fluid traversing the Marnoso Arenacea aquifer, under the assumption that the interacting fluid has an initial chemical composition comparable to waters usually recognized in small, perched aquifers, and streams. This zero-dimensional, forward model considers that quartz, albite, K-feldspar, chlorite and carbonatic and/or dolomitic cements are the main reactive phases in the system, according to petrographic and mineralogical evidences. Numerical calculations (Fig. 4.2) indicate that the hydrolysis of the Marnoso Arenacea flysch is a possible way to generate the most saline, and alkaline waters sampled in the central part of the Firenzuola tunnel .

3H content

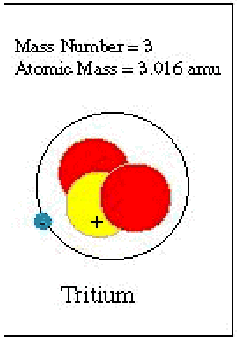


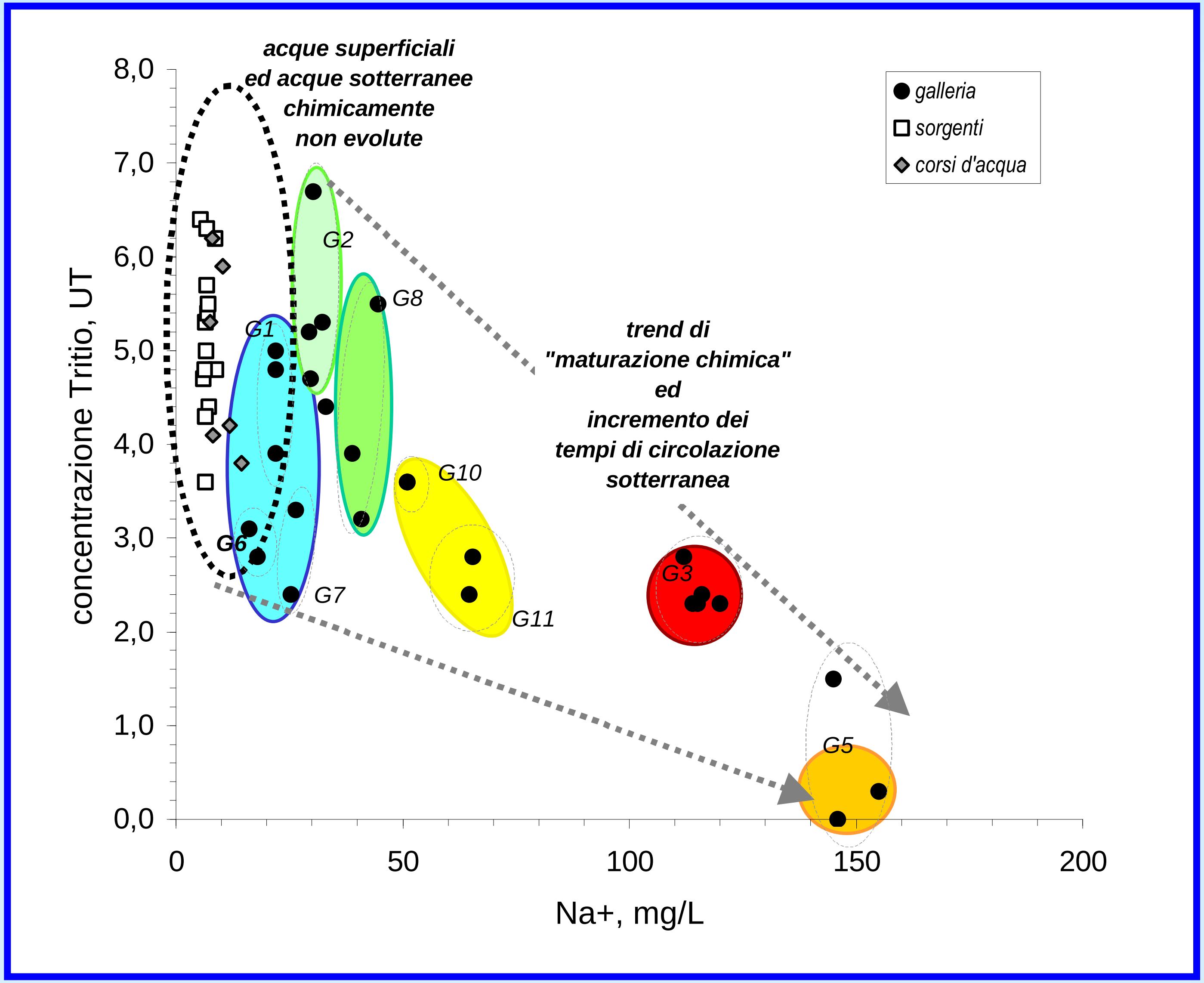
Anzahl der Atomkerne
100%
50%
0%
^3_1H
0
12,3
24,6
36,9
49,2
61,5
73,8
86,1
anni

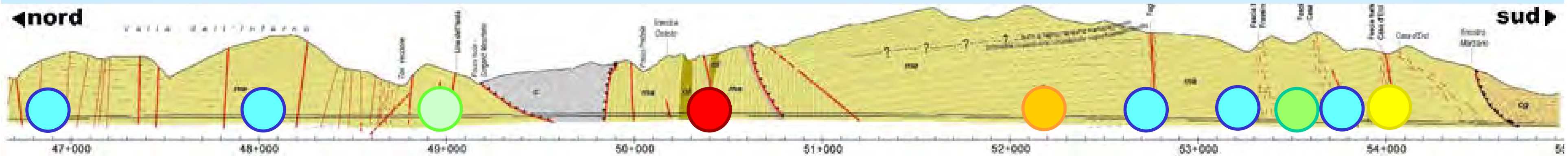


Mass Number = 3
Atomic Mass = 3.016 amu
Tritium
Half-life: 12,3 yr

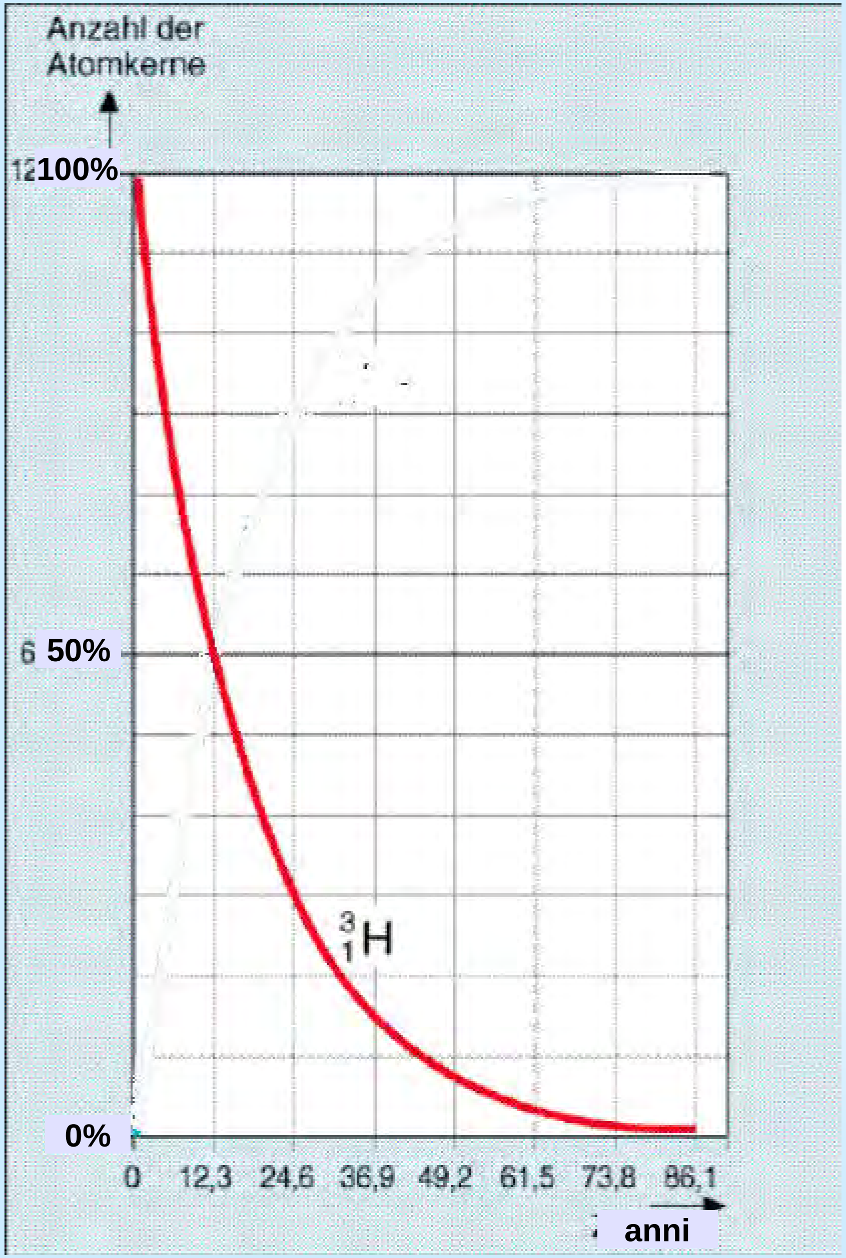
Tritium / sodium ratio





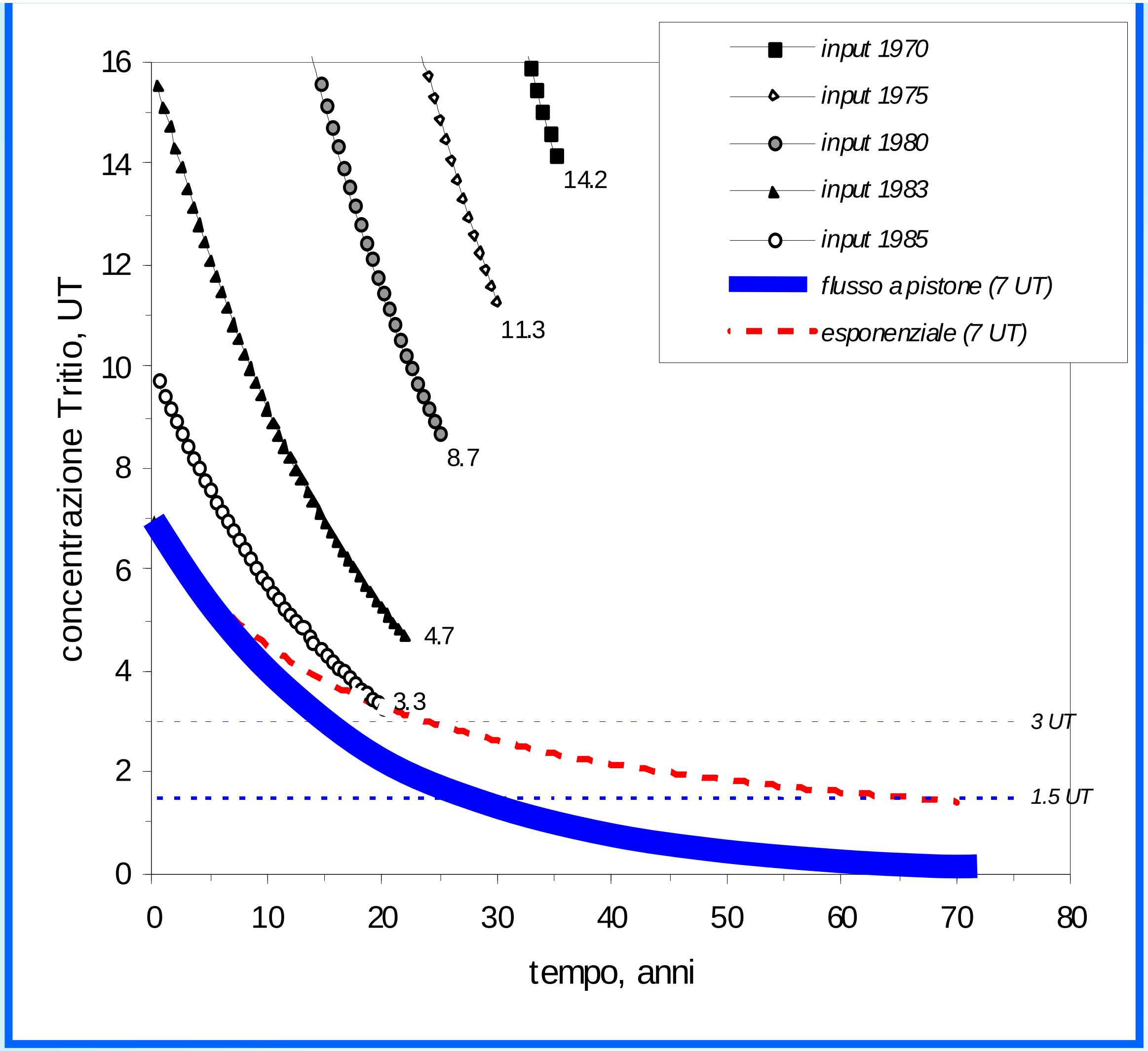


3H content – Evaluation of underground length of water paths



Use of tritium in evaluating residence times:

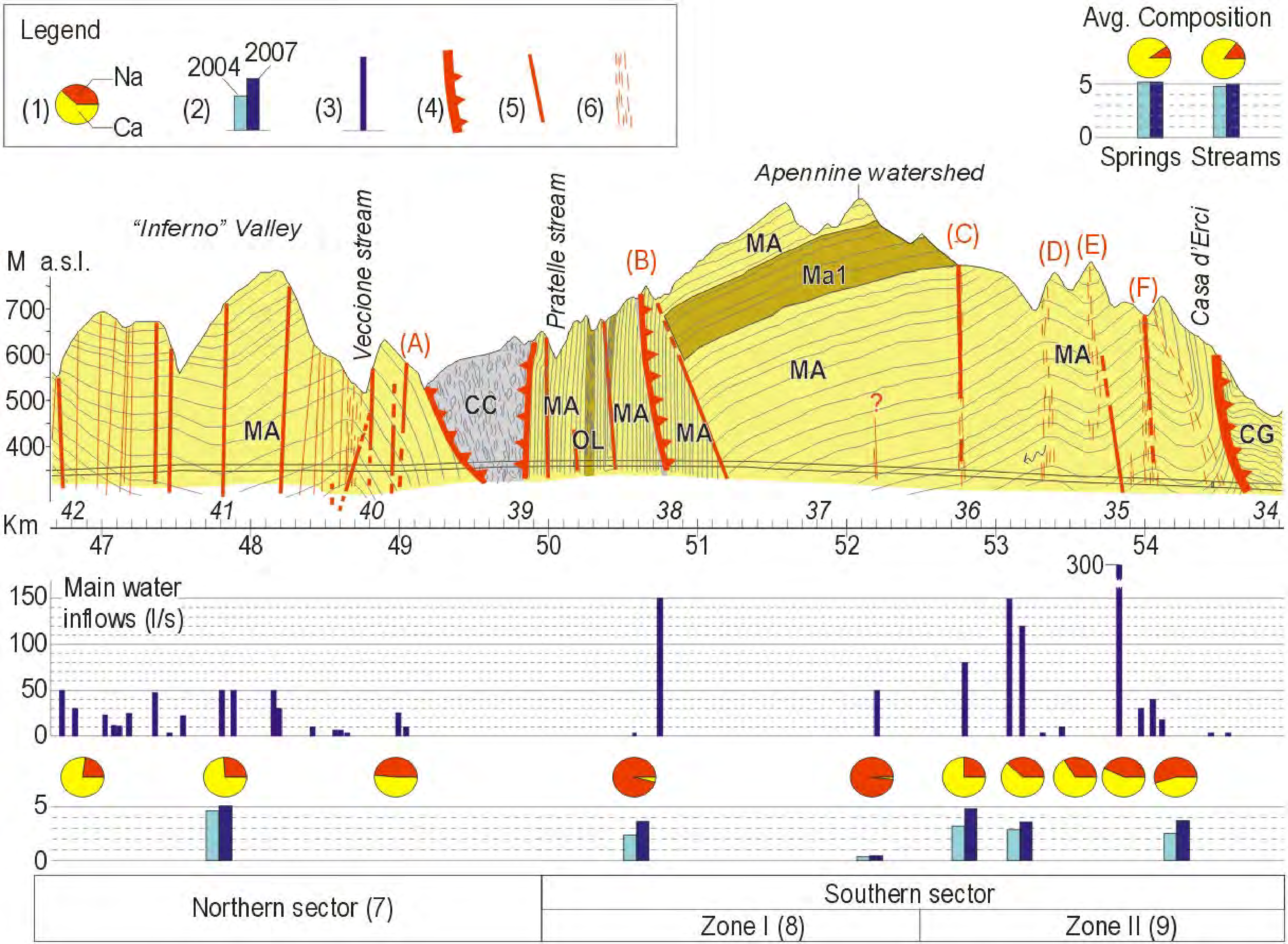
Intrinsic difficulties in obtaining unique calibration, relation of tracer ages to flow and rock parameters, etc.



We apply a lumped-parameter approach (piston vs. exponential vs. dispersion flow models) to qualitatively constrain the residence time of the waters from the central part of the tunnel(1).

Main result: it is plausible that the relatively old waters captured in the central part of the tunnel have **residence times larger than 50 or 100 years**, depending on the assumed model.

(1) As input function we uswd thw weighted annual average tritium concentration of precipitaions collected in genova (IAEA), the longest available record in the marco-region



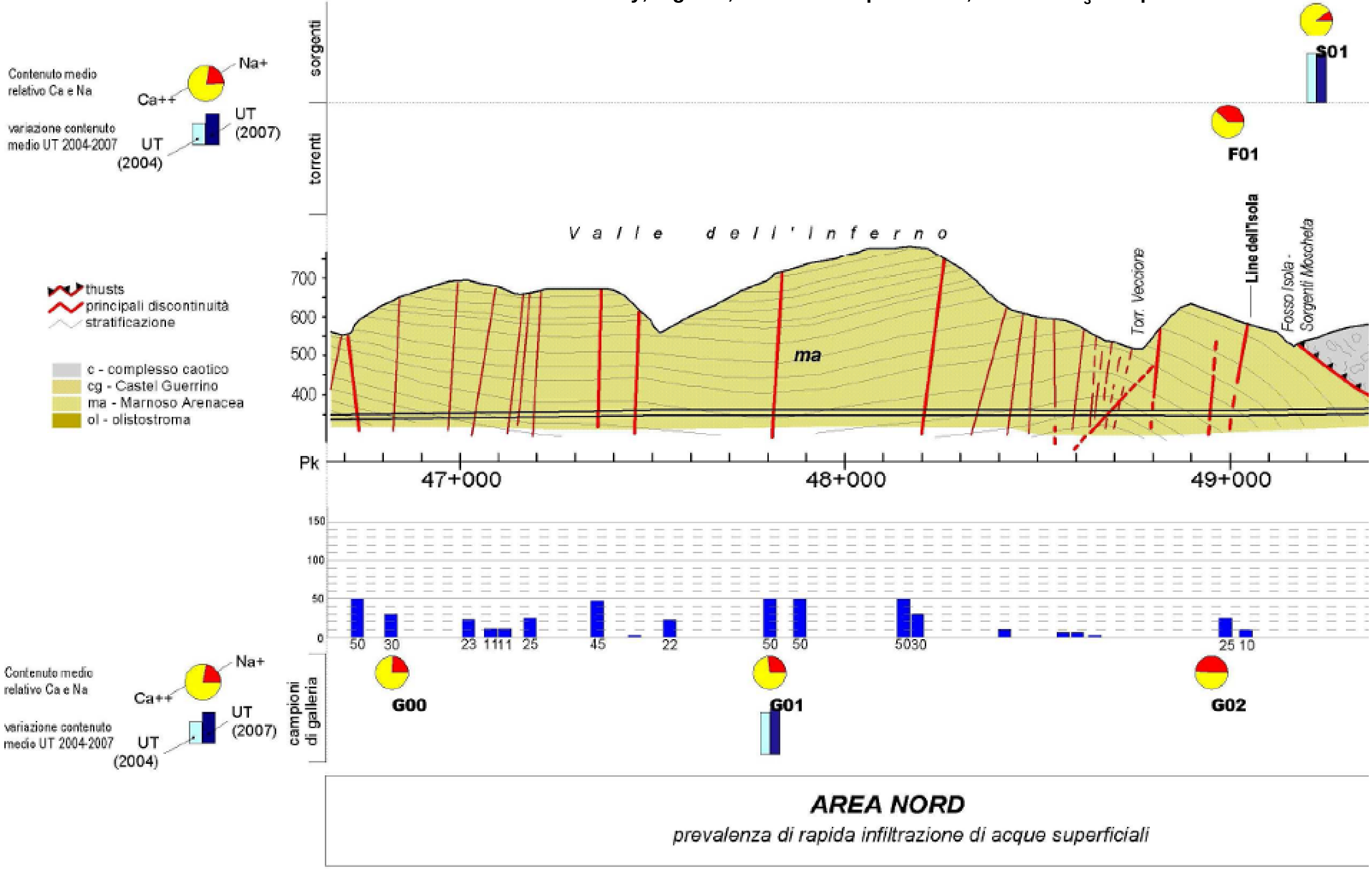
Legend
(1) Na Ca
(2) 2004 2007
(3)
(4)
(5)
(6)
Avg. Composition
Springs Streams
5
0
"Inferno" Valley
Veccione stream
Pratelle stream
Apennine watershed
Casa d'Erci
M a.s.l.
700
600
500
400
(A) (B) (C) (D) (E) (F)
MA
Ma1
CC
OL
CG
?
42 41 40 39 38 37 36 35 34
Km
47 48 49 50 51 52 53 54
Main water inflows (l/s)
300
150
100
50
0
5
0
Northern sector (7)
Southern sector
Zone I (8)
Zone II (9)

Sezione riepilogativa

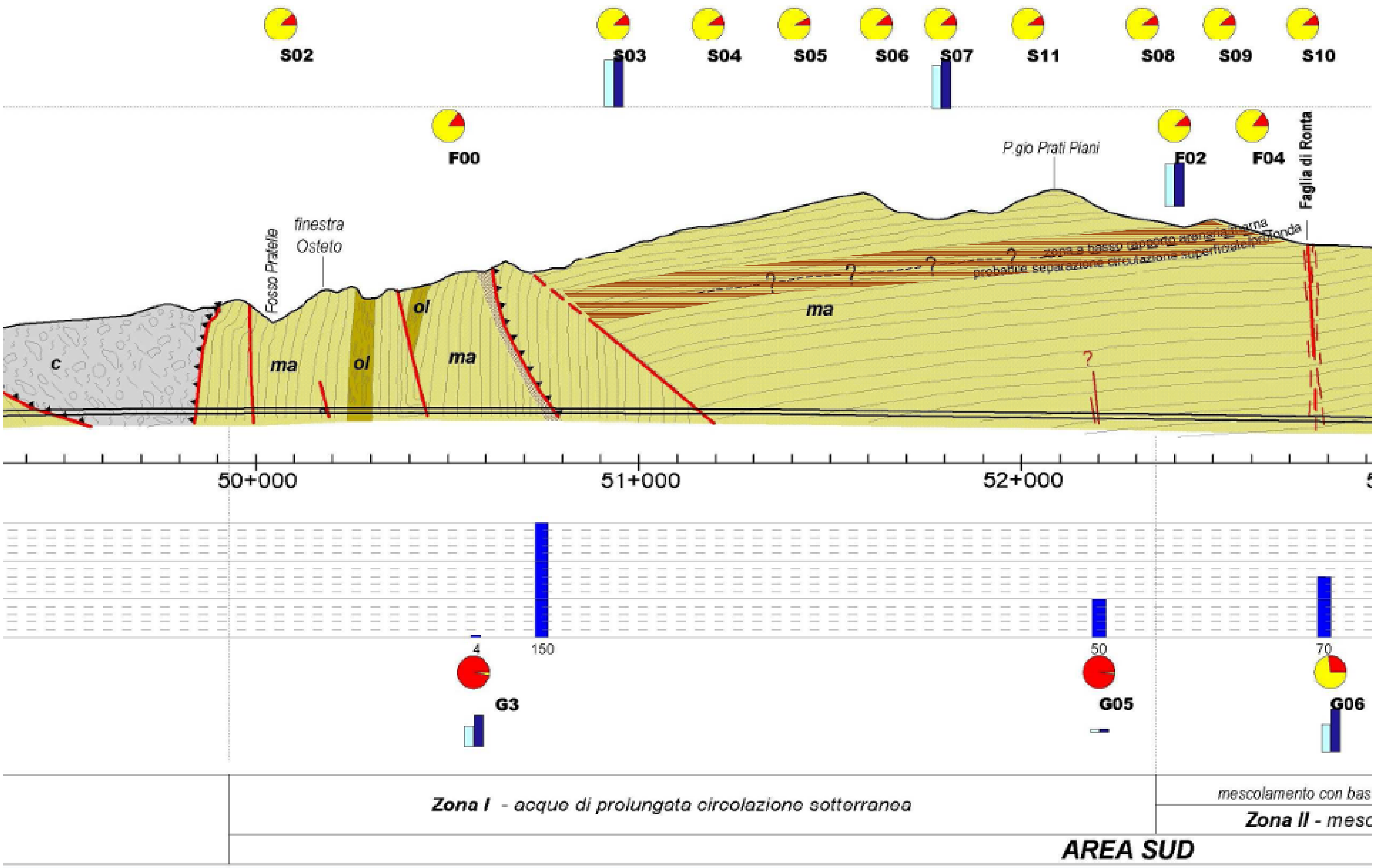
100 0 100 200 300 400 500 Meters

By combining hydrogeological and geological information with data on chemical and isotope composition of waters, we derived a model of underground water circulation which considers two main hydrogeological sectors in the tunnel. These sectors are separated by a chaotic assemblage of blocks of preexisting rocks (olistostrome), which acts as an impermeable barrier.

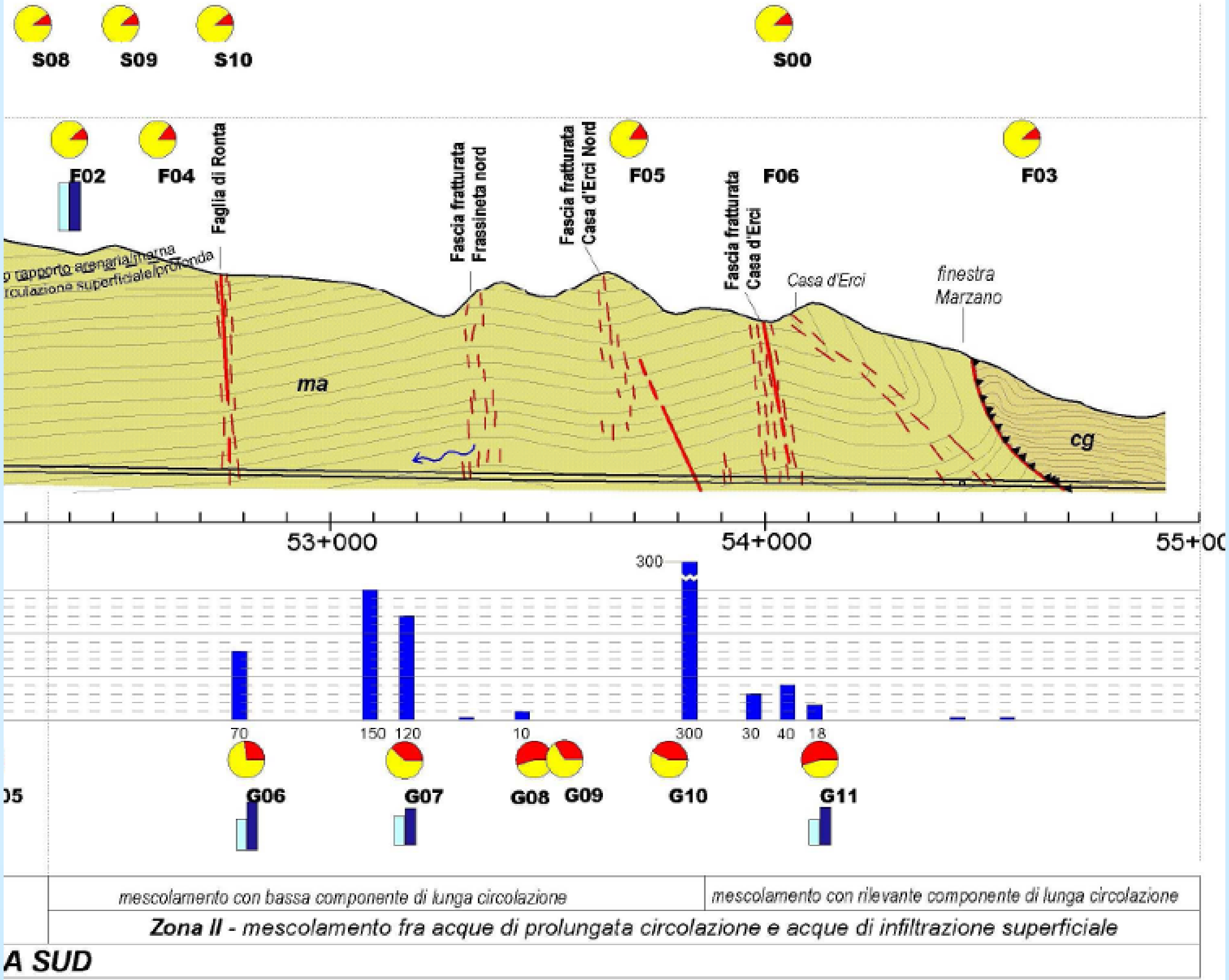
The northern sector is dominated by the rapid infiltration of meteoric waters, and then, by the occurrence of low-salinity, high-^{3}H, near-neutral pH waters, of Ca-HCO_3 composition.

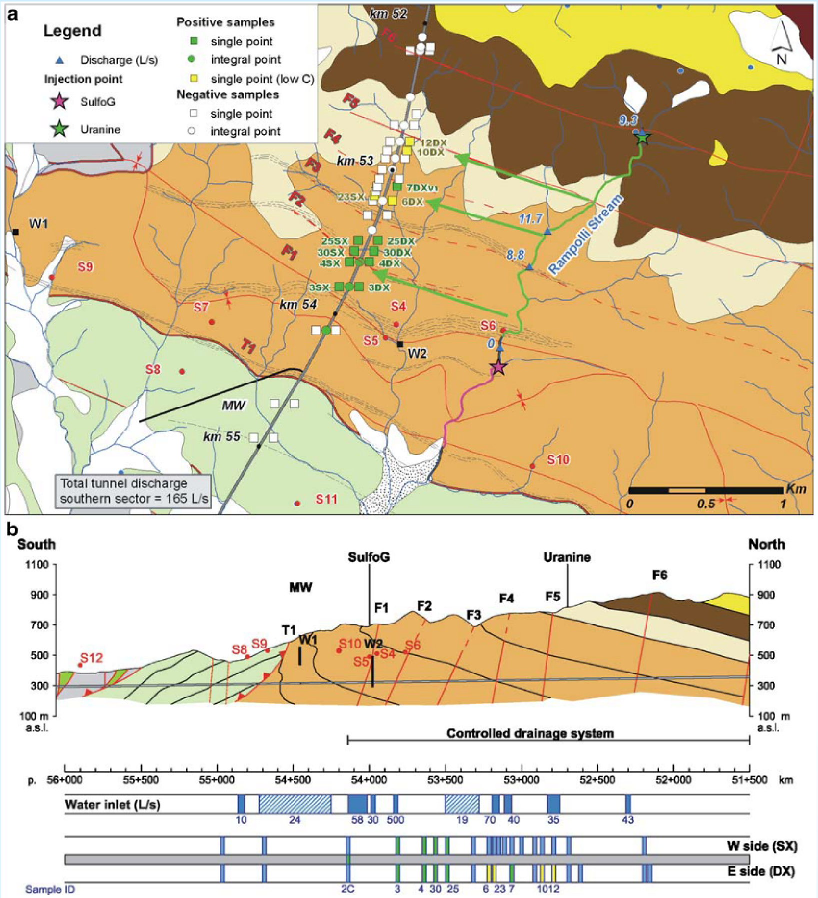


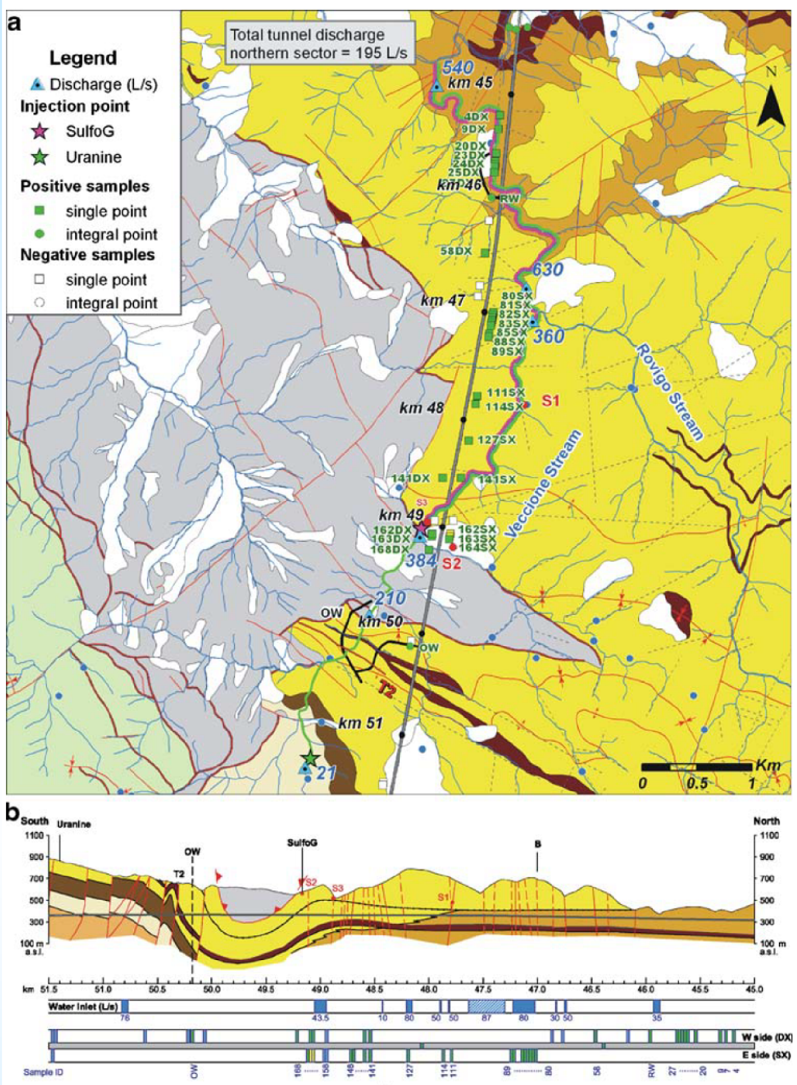
The central sector (Zone I), adjacent to the olistostrome, is dominated by relatively ancient waters (likely older than 100 years; 3H generally <2 UT), having high pH values, and Na-CO3-HCO3 composition. In this zone, the occurrence of marl-rich, relatively impermeable strata of the Marnoso-Arenacea fm. above the tunnel prevents meteoric pre-cipitation from infiltrating in the excavated area.



The remaining zone (Zone II), is characterized by the occurrence of the same "old" waters of Zone I, locally mixed with surficial (3H generally >5 UT) or meteoric (3H up to 10 UT) waters rapidly percolated in the aquifer. Low-salinity, high-3H waters are expected to percolate through well-defined fractures zones, such as the Fognano overthrusting, and the Ronta and Casa d'Erci faults.

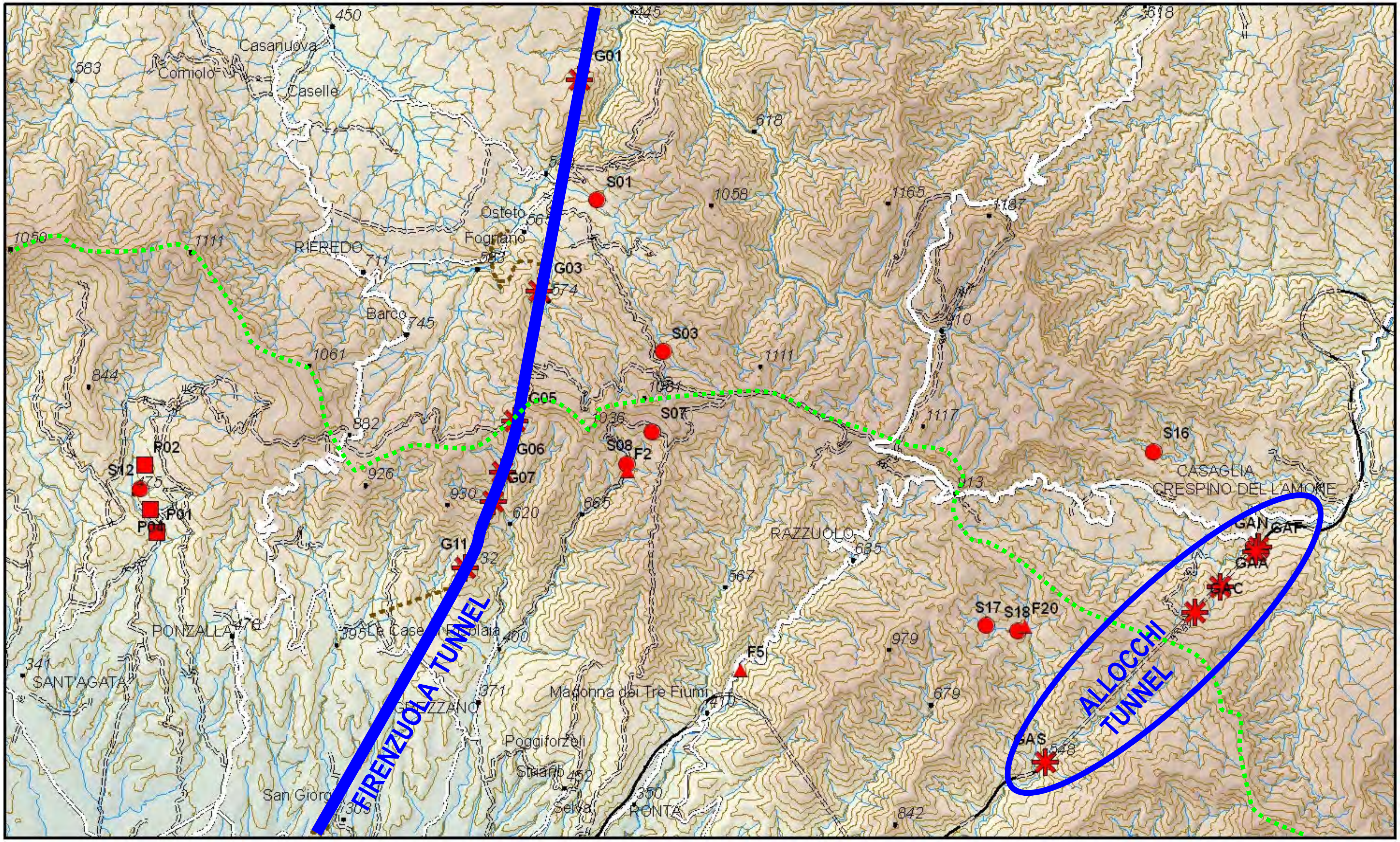






This hydrological subdivision is confirmed also by Tracer Tests carried out by, Vincenzi, Gargini and Goldscheider (2009). These tracer tests didn't find any direct connection between tunnel and surficial waters in the central section of the tunnel

Progetto di caratterizzazione geochimico-isotopica del sistema idrogeologico Marzano-Osteto



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Map of sampling points

1:70.000

0 1 2 3 Km

Sampling point type

- tunnel
- well
- spring
- stream

gico Marzano-Osteto

Allocchi tunnel ("Faentina" railway), a railway tunnel excavated in 1890 at about 550 m a.s.l. in the same flysch formation of the Firenzuola tunnel, not far (6 km) from the area of study

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Map of sampling points

1:70.000

0 1 2 3 Km

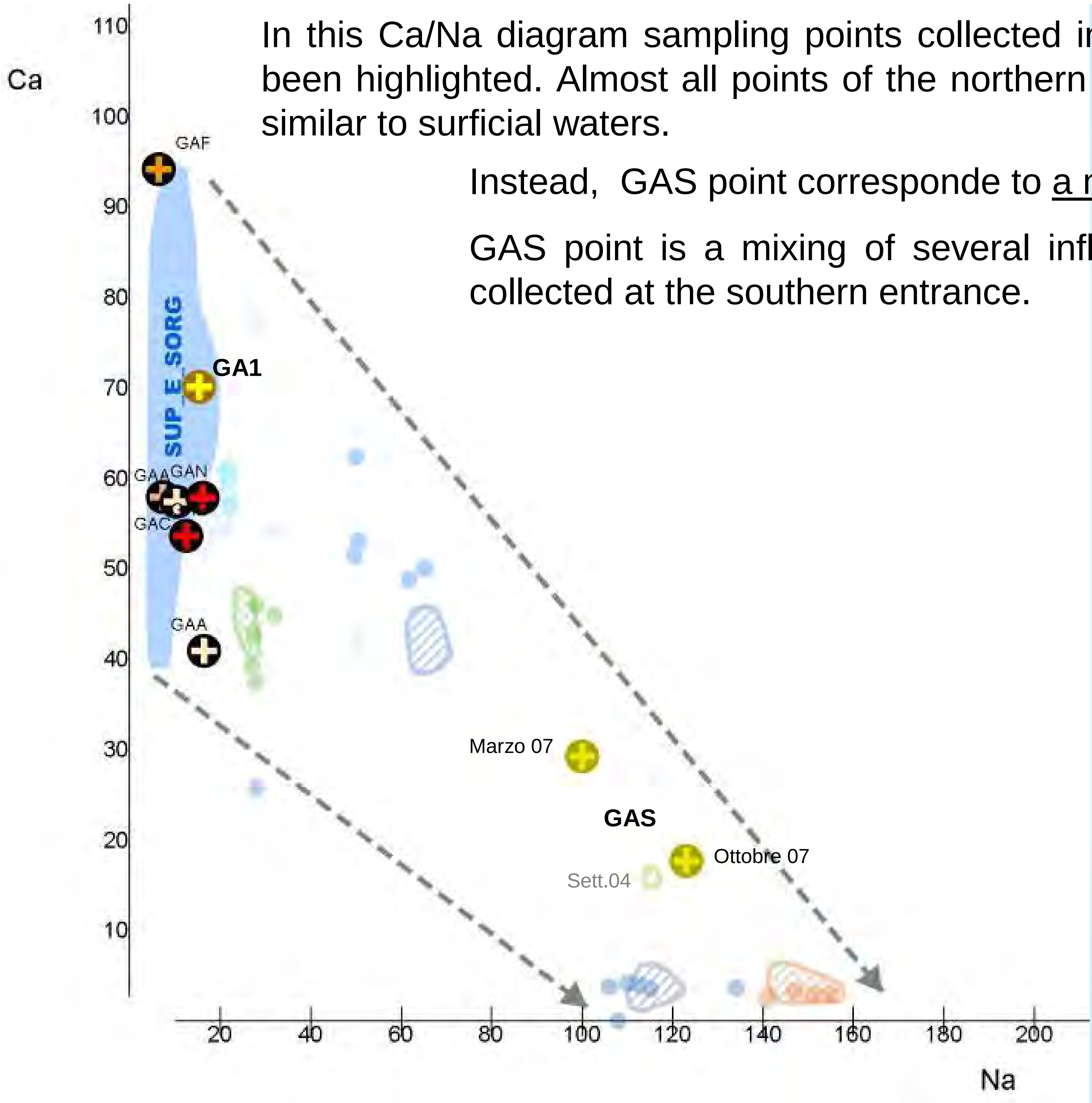
Sampling point type

- tunnel
- well
- spring
- stream

In this Ca/Na diagram sampling points collected in Allocchi tunnel have been highlighted. Almost all points of the northern side of the tunnel are similar to surficial waters.

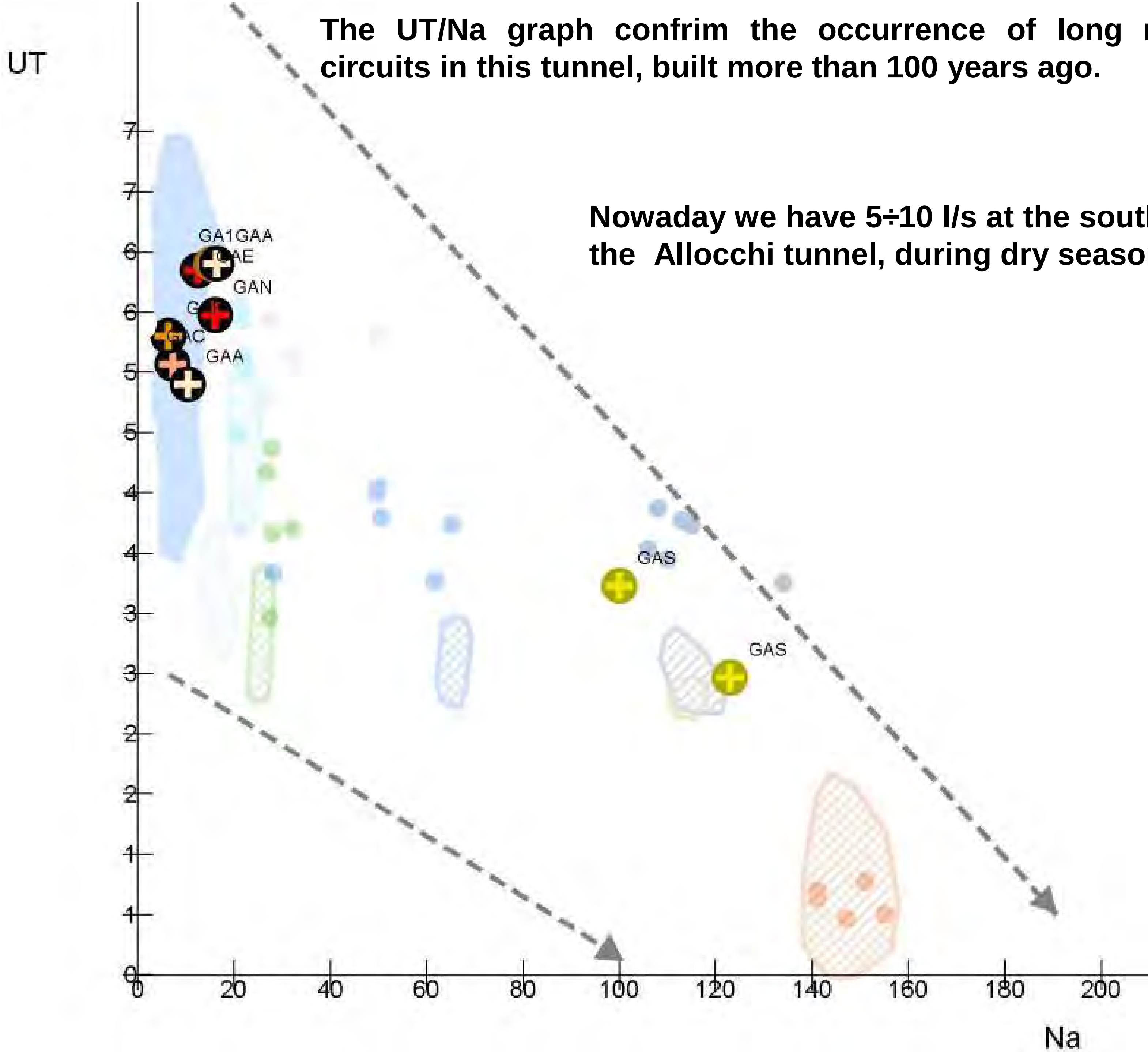
Instead, GAS point corresponde to <u>a mature water</u>.

GAS point is a mixing of several inflows along the tunne, collected at the southern entrance.



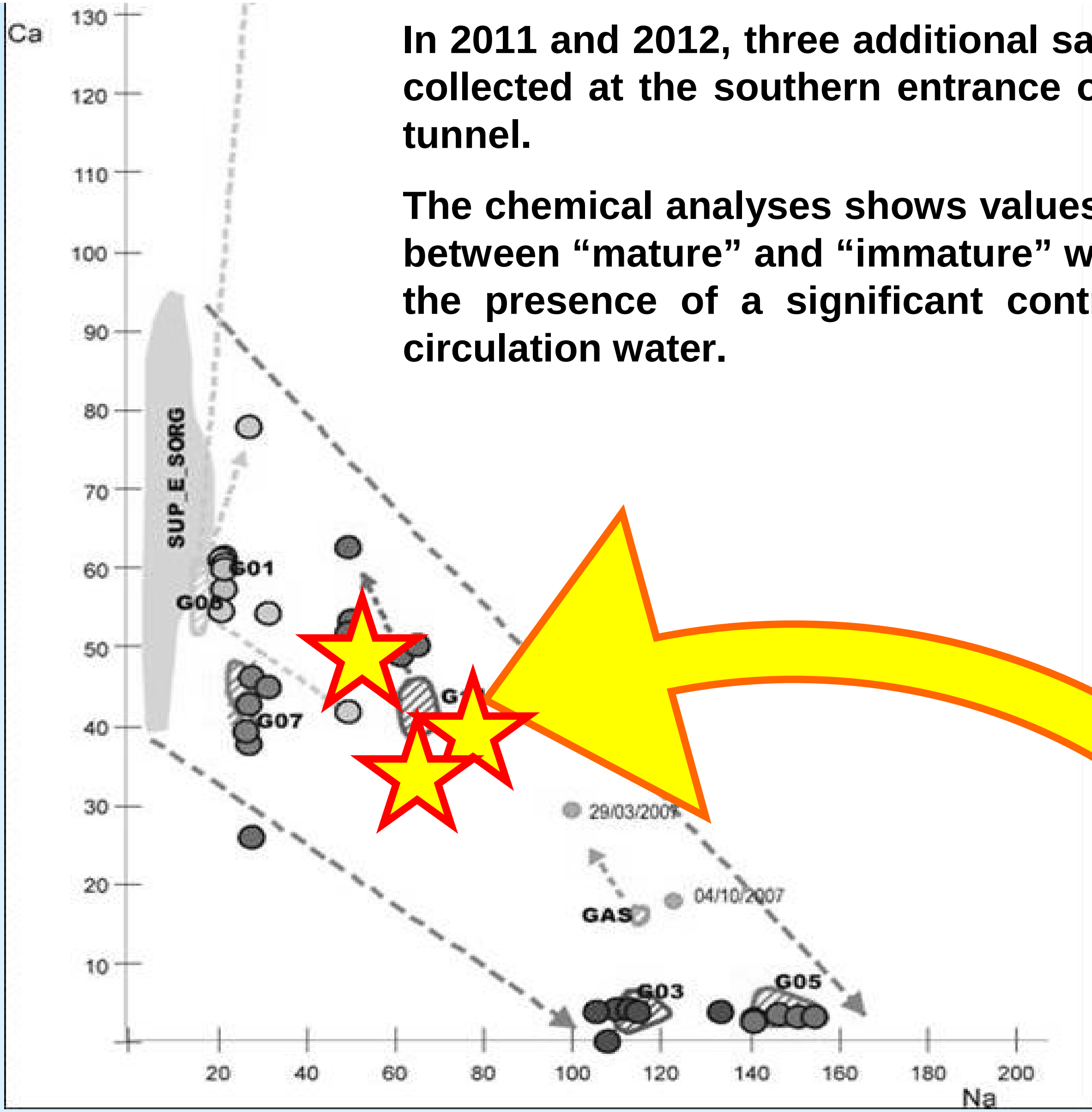
The UT/Na graph confrim the occurrence of long residence water circuits in this tunnel, built more than 100 years ago.

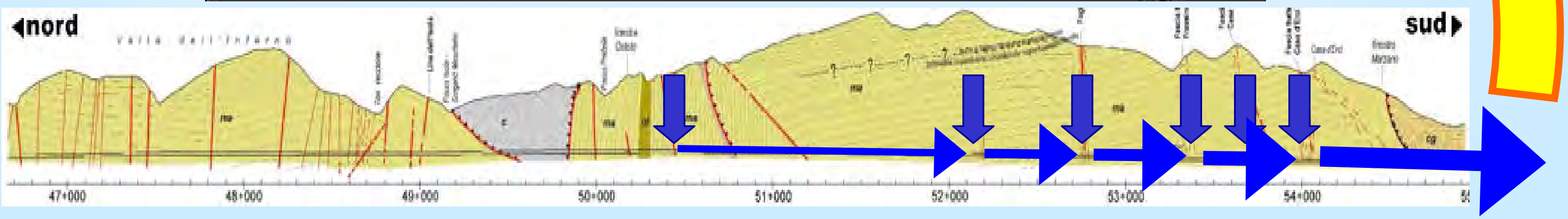
Nowaday we have 5÷10 l/s at the southern entrance of the Allocchi tunnel, during dry season.



In 2011 and 2012, three additional samples have been collected at the southern entrance of the Firenzuola tunnel.

The chemical analyses shows values that are halfway between “mature” and “immature” waters, confirming the presence of a significant contribution of long-circulation water.





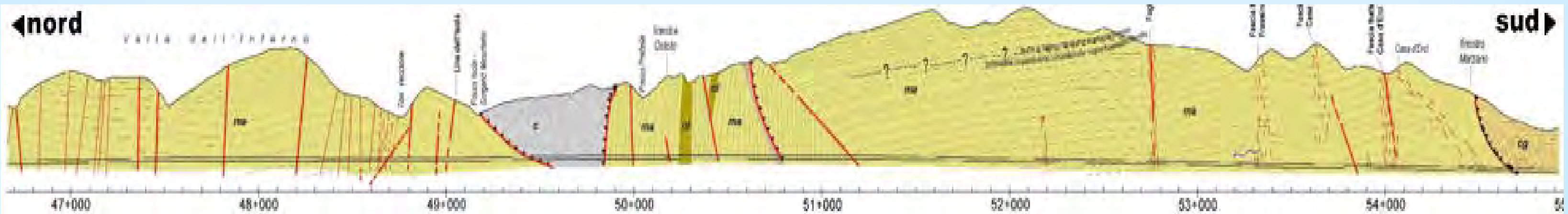
Conclusions

Isotopic and geochemical methods allowed a good identifying of the ground water circulations

IN the central part of the tunnel waters with low tritium content are part of long-path circulations.

This is confirmed also by the presence of the same characteristics also in an older tunnel.

The results suggest that nowaday the framework of impacts and water flowrate of the tunnel can be considered as stable.



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THANK YOU