Volume n° 3 - from D01 to P13

32nd INTERNATIONAL GEOLOGICAL CONGRESS

APENNINE TUNNELING WORKS: IMPACTS ON THE SURFACE AND UNDERGROUND WATER RESOURCES

Leader: S. Rossi

Associate Leaders: A. Doni, L. Ranfagni

During-Congress **D08**

Field Trip Guide Book - D08

Florence - Italy
August 20-28, 2004

The scientific content of this guide is under the total responsibility of the Authors

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Front Cover:
Apennine tunneling works-water inflow

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Introduction

The field trip deals with the significant changes in the hydrogeological and hydrological features of a sector of the Northern Apennine range, caused by one of the most important tunnelling works actually in progress in Italy: the Bologna-Florence new High Speed Railway.

The Tuscan stretch of the new railway will include 6 mainline tunnels (three of which exceeding 15 kms in length) and 14 kms of servicing tunnels, the so-called access “windows”.

Just to have an idea about the magnitude of the influence of tunnelling works on the general water resources of the area crossed, about 50 millions m^3 of water have been drained since the beginning of the underground work up to now.

These tunnels were planned to cross the Apennine range, characterised by fairly steep slopes, the maximum elevation of which being around 1000/ 1100 m a.s.l. Here the land shows both a complex geological setting and a high sensitivity from an environmental point of view. The field trip will proceed along the most important geological and hydrogeological features, following the progress of the tunnelling works and the consequent impacts on both superficial (streams and torrents) and ground waters (springs and wells). During the trip some information about the stratigraphic sequences and the tectonic setting along a regional geological section will be provided.

The trip will run through the wonderful landscapes of the “Tosco-Romagnolo” Apennine and Mugello valley, two sites classified as SIC (Sites of Communitary Interest), without leaving out the local historical monuments as well as the gastronomic delicacies.

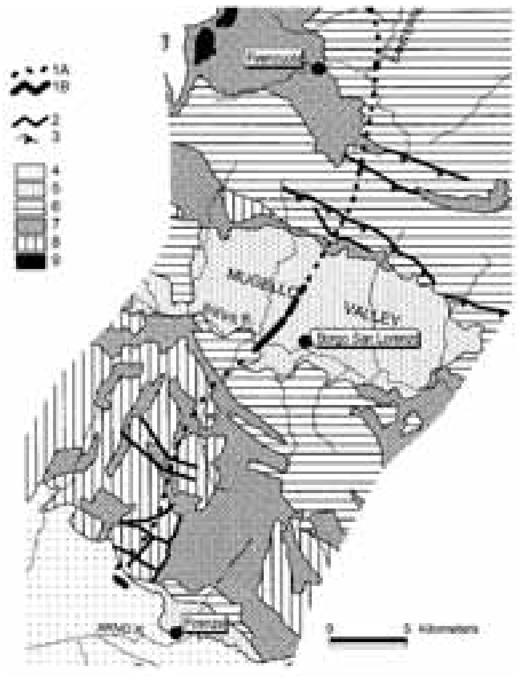

Figure 1 - litotechnical sketch along the Tuscan stretch of the new railway line 1A=tunnels; 1B=open air stretches; 2=faults or master joints; 3=thrusts; 4=alluvial deposits; 5=fluvio-lacustrine deposits; 6=Flysch-facies formations (alternating sandstones and marls); 7=mainly clayey formations; 8=marly limestones; 9=ophiolites.

Field References:

Topographical maps 1:25,000:
- Dintorni di Firenze e Mugello. Sheet 26/27 Multigraphic Editions - Firenze
- Appennino Toscoromagnolo Ravennate e Mugello Sheet 25/28 - Multigraphic Editions - Firenze

Geological maps:
- Carta Geologica d’Italia 1:100,000- sheet 106 Firenze
- Carta Geologica d’Italia 1:100,000- sheet 98 Vergato

Geological Guidebooks:
- Guide Geologiche Regionali / 4 / Appennino Tosco-Emiliano - BE.MA. Ed.

Web resources:
- www.cm-mugello.fi.it (Mugello Mountain Community - in italian
- www.firenzeturismo.it (tourist information - in italian and english)
- www.geo.unifi.it (University of Florence - Earth Science Dept.)

Regional geologic setting

The Northern Apennine constitutes the exposed portion of a large orogenic wedge as a consequence of the shortening and crustal thickening associated with the subduction of the Adriatic plate under the Iberian one (Treves, 1992).

The emergence of the thickened crust to form this northern sector of the Apennine range was accompanied by tectonic deformations, namely folding and faulting.

Oligocene-Miocene turbidite complexes, mainly fed by the rising Western-Central Alps, now forming

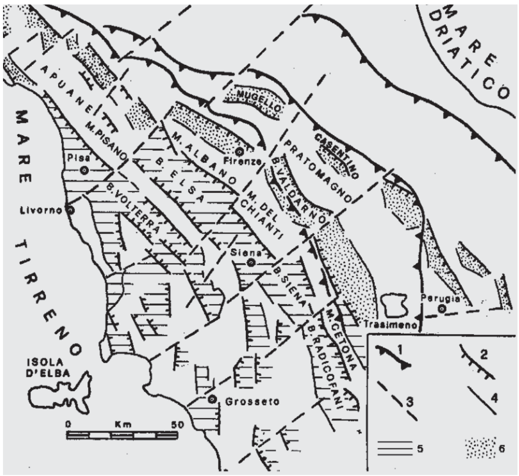

Figure 2 - Main Neogenic and Quaternary basins in the Northern Apennines. 1=thrusts; 2=master faults on basin borders; 3=transversal tectonic lines; 4=minor faults; 5=Mio-pliocene basins filled by continental and marine deposits; 6=Plio-Pleistocene basins filled by fluvio-lacustrine deposits (after Bossio et alii, 1992, in Bortolotti V., 1992, modified)

most of the range, were deposited in the migrating Northern Apennine foreland basins.

Different lithological types are present: alternating marls and sandstones in facies of flysch, marly limestones, clayey chaotic complexes with inclusions of marly limestones and ophyolites.

Roughly, the beginning of the rise can be dated back to the late Cretaceous, starting with a compressive tectonic. This phase caused the overthrusting of the different stratigraphic sequences, leading to the emersion of the chain in the Middle Miocene and continued until the Late Miocene.

The compressive phase was followed by the extensional Plio-Pleistocene phase, which allowed the formation of some horst-graben structures, as the ones of Florence and Mugello. A second hypothesis suggests that the basins were developed under an overall compressional regime and they would have been formed as surficial byproducts of deep-seated thrusts (Martini I.P. & alii, 2001).

Closely tied to these orogenetic episodes, some discontinuities (faults and fractures) of various persistency (from a few metres to several kilometres) and oriented in two main directions, WNW-ESE and NNE-SSW, took place .

The railway also crosses the Mugello valley-bottom, where Villafranchian lacustrine formations (mainly silty-clayey) and Pleistocene-Holocene alluvial deposits are present (Fig.3).

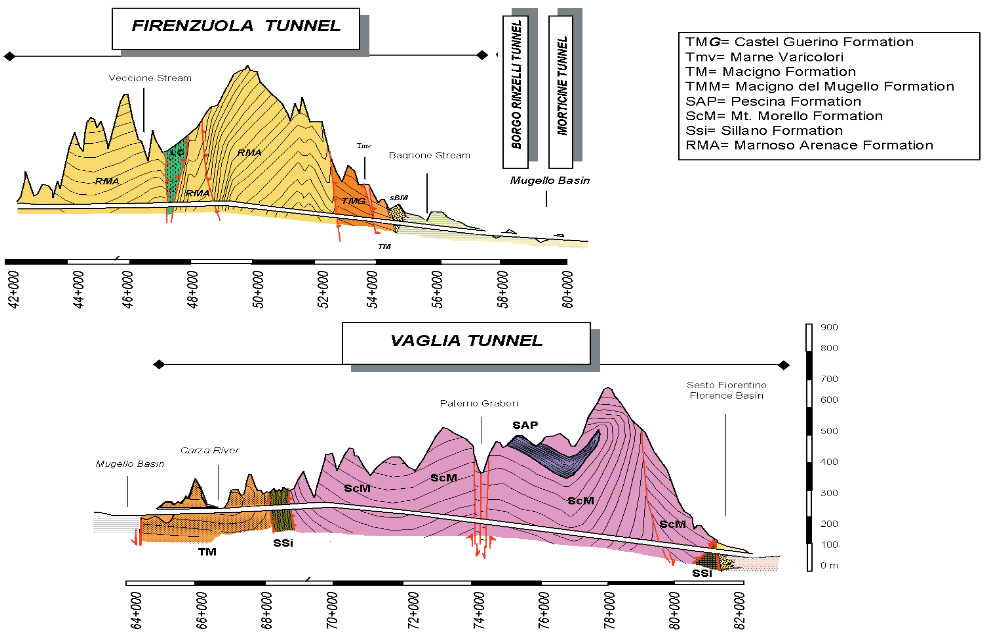

Figure 3 - Cross section along a part of the Tuscan stretch of the new railway (after Gambelli 2002, modified)

Field itinerary

The field trip starts from Florence (Piazza Adua, near the Central Railway Station). Driving along the "via Bolognese" we will climb the slopes of Mt. Morello. The name of this relief, dominating the Arno River floodplain, is due to the colour ("morello" = dark) of the vegetation cover, as it appears from Florence.

Stop 1:

Mt. Morello (Piazzale Leonardo da Vinci): general geologic setting.

This is a very good panoramic point from which to look at the town of Florence and its hinterland, built at the eastern margin of the large floodplain of the Arno River, which extends westwards to Pistoia.

Piazzale Leonardo Da Vinci is situated on the slopes of Mt. Morello, that gives the name to the geological formation outcropping here.

The Florence Basin and the Arno River floodplain

The Florence Basin was formed during the Apennine extensional phase, aged Villafranchian. The master fault runs along the N-NE side, dipping SW, accompanied by some synthetic faults. On the South side antithetic faults dipping NE occur. The genesis of these structures is linked with the last tectonic events of the Apennine's geological history. The predominance of extensional movements led to the formation of the some tectonic depressions, like the Florence and Mugello ones.

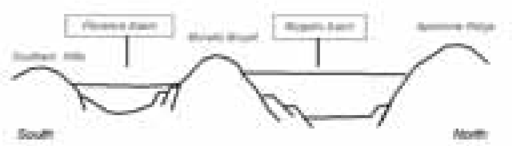

Figure 4 - Schematic cross-section SSW-NNE showing the Florence and Mugello basins

The field trip itinerary runs closely parallel to the axis of the High Speed Railway. It crosses first the Florence Basin, and then the M. Morello massif, the Mugello Basin and the main Apennine ridge.

During the Villafranchian, both the Florence and Mugello basins hosted two lakes, in which the tributary rivers deposited a big amount of gravel, sand and clay. The thickness of the sediments in the Florence basin is of about 400 meters, reaching its maximum near the master fault margin (NE side).

Just after the Villafranchian lake filled up, the valley-bottom was drained by the Arno River and its tributaries (Mugnone, Terzolle, Zambra and other streams on the right side), forming a wide floodplain with some remnants of the original swamps. The whole area (at the eastern side of which the town of Florence was built since Roman times) was periodically affected by catastrophic floods, like the last one of November 4th, 1966. In correspondence to the lowest elevations (S. Croce quarter) the town was inundated by 6 m of water. Since this event, several flood control measures have been taken into consideration, but the flood risk in the inner town remains very high.

Mt. Morello's formation and its geological setting

According to the general plan of the High Speed Railway, the first of the main tunnels which one meets starting from Florence (Vaglia tunnel, 16 kms in length) is being bored through the Mt. Morello formation. A pilot tunnel, parallel to this one, for operating and safety purposes, was also bored using a Tunnel Boring Machine (TBM).

The Mt. Morello formation outcrops in flysch facies, constituted by alternating limestones, marly limestones ("alberese") marls, claystones and, subordinately, sandstones. Marly limestones and marls constitute 80 % of the whole sequence, the thickness of which being about 700-800 m (Bortolotti, 1962). Two pelitic units outcrop at its top (Pescina formation) and at its bottom (Sillano formation).

The Mt. Morello massif is the result of a typical multiphase tectonic: firstly (Miocene) a translation which produced an isoclinal recumbent folding, with N-S trending axes, then a secondary folding originating anticline structures with NW-SE trending axes. During Plio-Pleistocene a prevalently extensional faulting caused the subsidence of the Florence and Mugello depressions, while the interbasin areas, like the Mt. Morello – Mt. Senario one, were uplifted.

Hydrogeological features and tunnel impacts.

From an hydrogeological point of view, this rock mass shows a secondary permeability linked to fragile structures, like extensional faults and joints. Important karstic features developed in the inner rock mass were not found (Cicali e Pranzini, 1984). The storage of water occurs into the conductive joint net of the limestone beds. The main underground flow develops into tensional discontinuity (open joint sets, associated to transtensive and dip-slip faults) .

The biggest open discontinuities develop mainly at a low depth and feed the springs with a high flow rate in winter, which becomes very low in late summer.

It has to be noted that the climate of this sector of the Northern Apennine is to be included in the Köppen *csa* type, that is "temperate with an arid season". The

Table 1

Tunnel	Tunnel progressive mark *(kms)*	Rock mass thickness along the tunnel (kms)	Geological formation	Litology
Vaglia Tunnel (18,561 kms)	68+150-68+800	0,650	Sillano Formation	Mainly pelitic
	68+800-81+100	12,300	Monte Morello Formation	Limestones, marlstones and siltstones
	81+100-82+500	1,400	Sillano Formation	Mainly pelitic
	68+150-65+300	2,850	Macigno formation	Sandstone with pelitic beds
Firenzuola Tunnel (15.060 Kms)	59+670-56+600	2930	Fluvial-lacustrine deposits	Gravels, sands and clays
	56+600-56.000	600	Macigno formation	Alternating sandstones and siltstones
	56+000-55+700	300	Marne varicolori	Variegated marls
	55+700-54+800	900	Castelguerrino formation	Alternating silty marls and sandstones
	54+800-49+870	4950	Marnoso arenacea	Alternating sandstones and marls
	49+870-49+500	370	Chaothic complex	Claystones with included polygenic fragments
	49+500-44+250	5250	Marnoso arenacea	Alternating sandstones and marls

Figure 5 - stratigraphic setting of the formations in the Morrello Mt. Area (after Coli and Fazzuoli, 1983).

Table 2

Mt. Morello area stratigraphic sequence		
	Geological Formation	lithology
Top		
	Pescina Formation (SaP) (Eocene)	Mainly claystones and siltstones with thin limestone or sandstone beds
	M. Morello Formation (ScM) (Paleocene-middle Eocene)	Alternating limestones, marly-limestones with metrical beds; subordinately fine sandstones and marly-siltstones-claystones
	Sillano Formation (Ssi) (Cretaceo sup.)	Siltstones and claystones with chaotic structure and alternating sandstones, marls and marly-limestones
Bottom		

mean annual rainfall is about 900-1000 mm in the valley bottoms, but it can reach 1300-1400 at the top of the mountains. Precipitations reach their maximum during fall (November) or spring (April), while the minimum is in July-August.
The major problems encountered during the tunnel boring were caused by water inflows, making working conditions difficult. The drainage of waters into the Vaglia Tunnel was shown as water seepages on the tunnel crown. The strongest event occurred in correspondence to the progressive marks Km 74+010¸74+290, due to the interception of a fractured zone (Paterno graben structure) at a depth of 200-250 m (fig.6).
The underground drainage caused the lowering of the water level in some piezometers and the lack of water in some private wells at a distance of 200 meters from

the tunnel axis. The underground drainage also had a surface impact on the discharge of some streams, which underwent a decrease up to about 45 l/s as in the case of the Carzola Stream (Paterno area). Twenty main leakage points were surveyed, with a total inflow of about 30 l/s. The mean hydraulic conductivity of the rock mass is estimated to be $k=1,5x10^{-5}$ m/s. The constructor's society engineers (CAVET) had designed some grouting to make the rock mass impermeable. Boreholes were made for sealing water leakage in the crown and in the side walls of the tunnel with concrete and chemical grouting.

Other problems on the Sesto Fiorentino hills were caused by the boring of the servicing tunnel from Isola towards north. Here a lack of water in some springs occurred (fig.7).

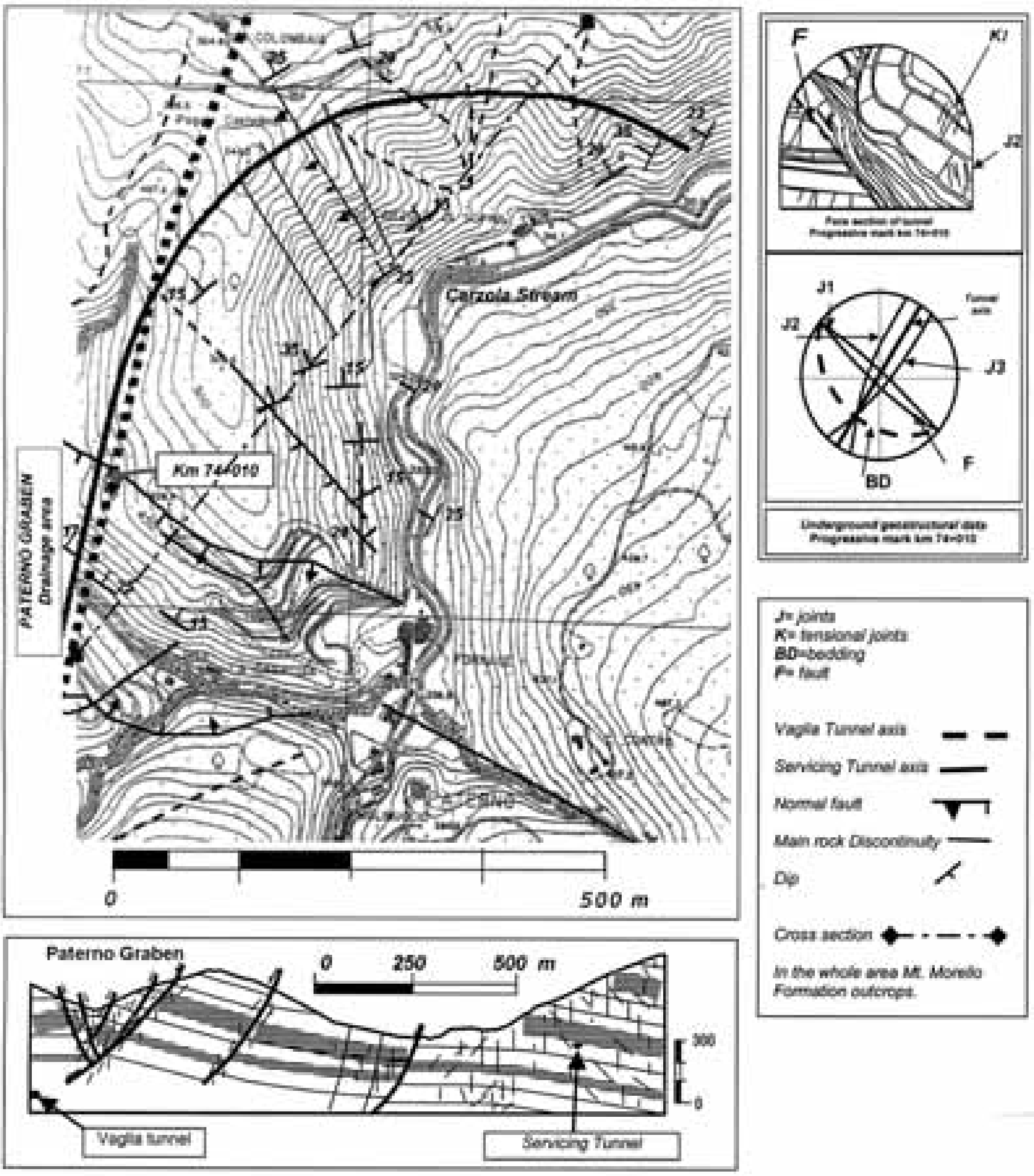

Figure 6 - geological sketch of the Paterno area, crossed by the Vaglia tunnel

Road Log 1

During the transfer to Borgo San Lorenzo, one can observe the entrance of the Carlone window, one of the secondary tunnels reaching the main one, built both for safety and management purposes.
Along the way it is possible to see the North building site CAR 1 of the Vaglia tunnel and the "cut/fill" quarry of Cardetole. This site, located on the Holocene floodplain of the Sieve River, the major tributary of the Arno, provides most of the material used to make the concrete for the tunnel lining and other buildings, like the bridge on the Sieve R. and the viaduct crossing its alluvial plain. The volume of the material extracted is counterbalanced by the volume of material coming from tunnel boring ("marino"). The management of this quarry, very close to the Sieve R. banks, is a bit difficult, due to the presence of a water table a few metres below the alluvial surface, which risks to be polluted by contaminated material.

The Sieve River is the main stream of the Mugello valley. It has an important role in the rise formation of the Arno R. floods. For this reason, some kms uphill at the Bilancino gap, a reservoir was built in order to regulate floods and provide the town of Florence with drinking water during dry summers.
The maximum capacity of Bilancino reservoir reaches 84.000.000 m^3.

Stop 2:

Borgo San Lorenzo (Villa Pecori Giraldi): engineering information about the new railway (by the Constructor's Consortium)

A brief illustration of the General Railway Plan will be given by the Constructor Consortium (CAVET).

Road Log 2

On the road between Borgo San Lorenzo and the southern entrance of the Firenzuola tunnel, which will be run by bus up to the Marzano access window, one travels along a particular landscape unit of the Mugello valley, the Crocioni area. Here, in the year 710 AD, the Romans fought against the Goths of Totila and won.

The Railway also crosses this area, by means of alternating short tunnels, cuttings and levees, due to a hilly morphology modelled in Villafranchian

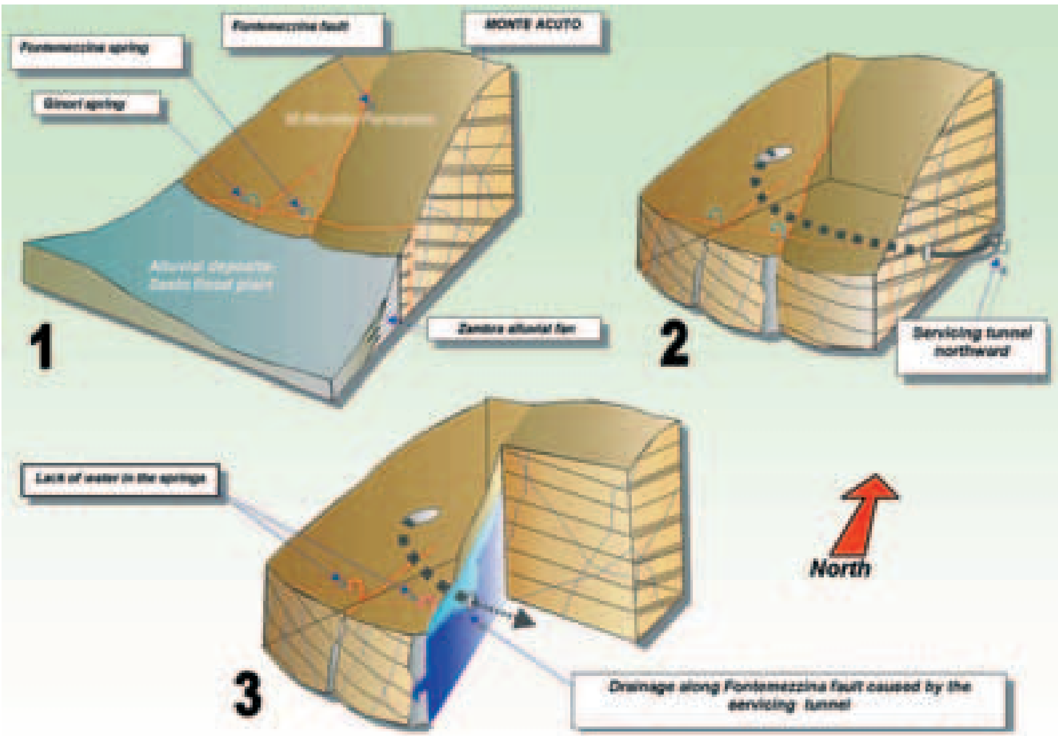

Figure 7 - Block-diagram showing the drainage caused by the boring of the servicing tunnel.

lacustrine silty-clayey sediments. Here the slopes are gentle, due to the poor geotechnical properties of the outcropping sediments; tracks of actual and recent mass movement (mainly creeping) can be observed here and there. Particular care should be taken during and after the work, in order to avoid any collapsing, even though minimum.

Stop 3:

Firenzuola Tunnel – southern stretch.

The next step is devoted to the direct observation of tunnelling works, running by bus through the Firenzuola Tunnel, crossing the main divide of the Apennine range. During a short underground stop, the main hydrogeological impacts caused by this tunnel and a technique for controlling the drainage, planned by the constructor and aimed to limit the hydrogeological impacts will be explained.

Firenzuola tunnel: geological setting

The Firenzuola Tunnel has been bored mainly inside the Marnoso-Arenacea formation which dates back to Langhian-Tortonian (Lower-Middle Miocene) (Capozzi et alii, 1992). It is a formation in flysch-facies, composed by alternating layers of sandstones (greywackes), marls and, subordinately, siltstones and claystones. The thickness of the layers ranges from decimetres to metres, with a variable sandstone/marl ratio. The permeability in these rock masses is mainly due to fractures and joints.

In general, these fractures are limited to the arenaceous banks; less frequently, fractures with a persistence exceeding that of the individual layers may be present; in this case the permeability of the formation is increased, generating a water circulation on a wide scale. This circulation is strictly linked to the joint trending, which is mostly WNW-ESE, subordinately SSW-NNE. Fractures are more frequent near tectonic structures such as anticline/syncline axes or faults, mostly oriented in the Apennine direction (WNW-ESE). This occurrence produces fractured belts, often 50÷200 m in width and up to some kilometres in length, that constitute aquifers of table-like shapes.

The outcrops of this formation is characterised by areas with a wealth of perennial springs and streams.

In a smaller area the Castel Guerrino formation outcrops. This formation is similar to Marnoso-Arenacea one, but has thinner layers and a larger marl content, which means it is characterised by a lower permeability.

The "Casa D'Erci" case history

The Casa D'Erci group of springs was the main source of water supply for the villages of Luco and Grezzano (approximately 1200 inhabitants near the south entrance of the tunnel). Tunnel burdens in the springs area are about 400 m, and pre-works hydraulic head was about 250 m.

The hydrogeological preliminary studies and the forecast models set up by the Executive Plan, as well as a report by the Constructors Consortium (CAVET) in June '99, identified Casa D'Erci as being at risk of drying, without, however, having clearly stated neither the forecast entity nor the time span involved. This information is essential, if one is planning and carrying out work to substitute the affected resource.

In October '99 CAVET presented another report in which the presence of a fractured zone was identified. This was around the progressive mark Km 54+000, and was indicated as the point of a possible beginning of drainage of the aquifer feeding the springs. The time span of the impact on the springs was calculated using a mathematical model (Federico, 1984). This time span resulted to be over fourteen months after reaching the km 54+000 (the distances along the tunnel are marked decreasingly from North to South).

ARPAT had already claimed in the past that the forecast model used was based on assumptions which were fundamentally different from the real situation. So, at the beginning of 2000 ARPAT carried out field surveys, so that it was able to define with a fairly good approximation that the fractured area was characterised by a relatively high permeability, probably connected with a fault plane having a slope angle of about 75°, dipping approximately southwards (fig.8). The probable point of the beginning of drainage was placed at 54+100 km (fig.9), about 100 metres before the point forecasted by CAVET, and within a lapse of time estimated as "imminent", which means within weeks.

The Environmental Authority Committee (Osservatorio Ambientale) was rapidly informed, and it ordered a stop to the work at the point 54+100 (14/03/2000) while alternative water supplies were set up. Boring work was stopped at the point km 54+102 when a water inflow of about 10 l/sec was registered. On March 18th, 2000, four days after the stop, the Casa D'Erci 1 spring (situated in correspondence exactly of the fractured belt), began to show a fall in its discharge, which completely dried up around March 10th.

The Casa D'Erci 2 spring, situated slightly further

Table 3

Mt. Morello Formation Hydrogeological and geomechanical data
<u>Hydraulic load</u> - *H=110÷160 m* (between the km 70+300÷71+853 progressive marks) *R.Ribacchi (2002)* <u>Hydraulic conductivity</u> - Lugeon tests: $K=1\div3x10^{-7}$ m/s(<100 m deep); $k=1\div3x10^{-8}$m/s (>100 m deep). *R.Ribacchi (2002)* - Geostructural survey: $K=1,1x10^{-5}$ m/s (surface value from geostructural data) <u>Rock Mass Rating</u> RMR=40÷60 (III Fair- Bieniawsky rock quality class) <u>Ratio A/P</u> high strength litology (limestone, marly-limestone)/low strength litology (pelitic litology) - Mainly limestone, marly-limestone: A/P≥1 max thickness= 8 m % $CaCO_3$=80-94% - Mainly marly- pelitic: A/P≤1 max thickness=12 m % $CaCO_3$=70-80 %

Table 4

Vaglia Tunnel Hydrogeological Impacts		
	Impacted	*Probably impacted*
Springs	*8*	*7*
Wells	*6*	*7*
Streams	*3*	*2*
total maximum drainage rate of the whole Vaglia tunnel	*about 140 l/s*	

away from the fractured belt, showed a slower decrease and dried up only during the summer 2000. At the same time, a limited decrease in discharge was observed in the Frassineta spring; in September the La Rocca spring, which provided some other small villages with drinking water, also dried up.
This situation led to serious problems for the population, that was supplied temporarily by means of mobile tanks, until a new municipal water system was set up. It was also the cause of an escalating conflict between the Local Administration and CAVET, the direct consequences bringing to a stand still the boring work for more than six months.
From this situation, as well as from other similar, CAVET realised that it was impossible to face environmental complexity of the area using a single reference model. From then on, they changed their approach. In the successive reports the investigation methodology was based on a more detailed analysis of the data coming from field surveys and monitoring activity. The use of geostatistical tools allowed the identification and delimitation of the most probable areas through which water may enter the tunnel.

Table 5

Bilancino dam data	
Max capacity	84.000.000 mc
Surface	488 ha
Earth dam's elevation	42 m
depth of the basin	10-32 m
Sieve River Maximum flow at Bilancino section	546 m^3/sec

The successive inflows

After the impacts of spring and summer 2000, boring work restarted in December 2000. After the 54+120 progressive mark the technique of "controlled drainage" was adopted (see below).
Other water inflows were recorded.
In June 2001 an unexpected 200 l/s inflow was recorded at 53+826, due to a fault not visible on the surface. The discharge decreased quickly, but the whole tunnel discharge was then increased up to 100 l/s. As a consequence of this impact the Frassineta spring dried.
Afterwards, other important inflows were recorded. In particular, in the period between March and August 2002 (mostly after June) the total discharge of the tunnel increased from 100 l/s to 400 l/s. This event was followed by some decreasing of discharge and new water inflows, but the whole flow rate fluctuated always around 350 l/s. All these important inflows do not seem to cause an evident impact on the remaining springs, at this moment in time.

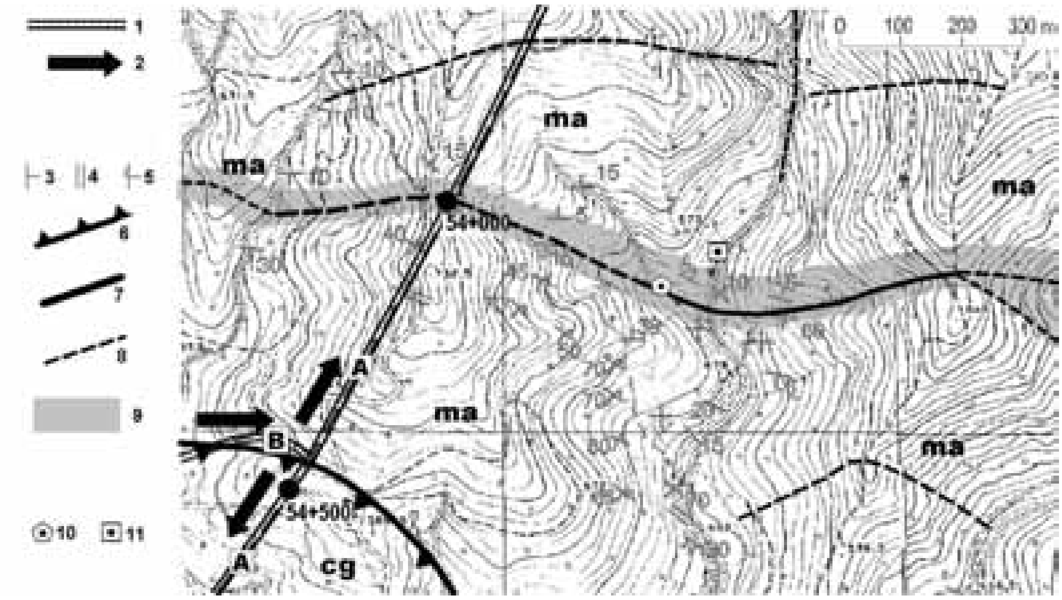

Figure 8 - Fig.1. Geological sketch of Casa D'Erci area. 1.Tunnels (A-Firenzuola tunnel; B-Marzano access window); 2= boring direction; 3,4,5= strike and dip of bedding (3 normal, 4 sub-vertical; 5 overturned); 6= thrust; 7= fault; 8= main lineations; 9=fractured belt; 10= "Casa D'Erci 1" spring; 11= "Casa D'Erci 2" Spring (after Rossi et alii, 2001, modified)

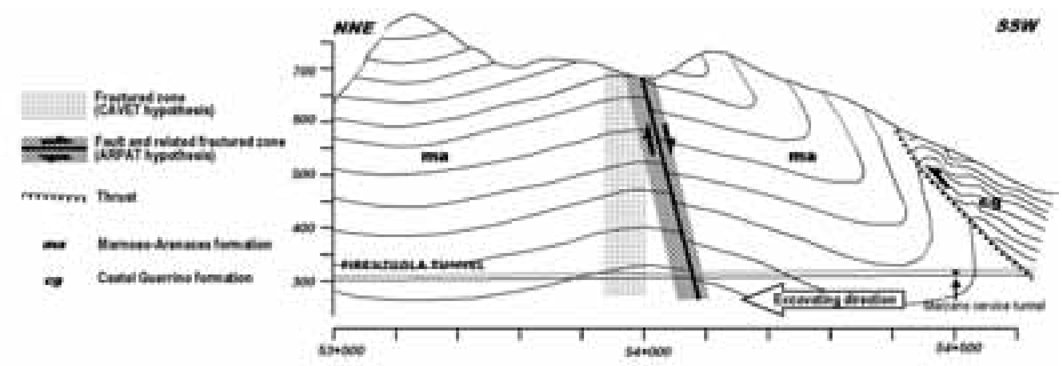

Figure 9 - Geological cross-section along Firenzuola tunnel axis in the Casa D'erci springs area (after Rossi et alii, 2001, modified).

The environmental situation around Firenzuola tunnel – southern side

The environmental situation at the date of the delivery of this guidebook (sept.2003) is illustrated below. This information will be updated during the field trip. In the table and map below the impacts on ground waters are summarized, as they result from the monitoring activity around this stretch of the tunnel.

As far as the superficial stream waters are concerned, evidence of impact are shown in particular by the Rampolli stream, which was a perennial stream before boring.

After 2001 inflows, in the upper basin it maintains a minimum discharge of about 2 l/s until 750 m. a.s.l. Below this elevation the discharge decreased to 0 l/s in correspondence of two main fractured belts. Only when the upper basin flow rate results over about 20 l/s, a water flow can reach the lower part of the stream. This impact can be explained with the mechanism illustrated further on (stop 5 - "Valle dell'Inferno" paragraph). Other minor streams on these slopes were

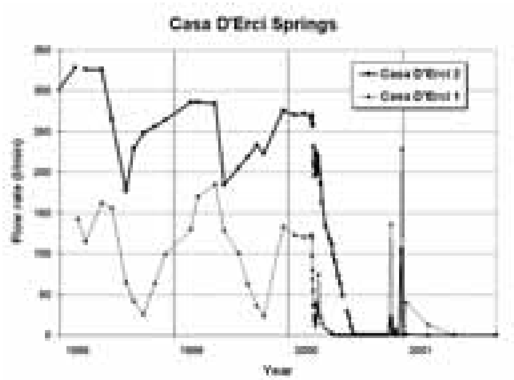

Figure 10 - Flow of Casa D'Erci Springs from 1996 to the impact

affected, too. (Fig 12)

The "controlled drainage" lining

In order to limit the tunnel drainage, after the events of the year 2000 the Environmental Authority Committee (Osservatorio Ambientale) agreed on the Constructors' Consortium's proposal of building a "controlled drainage" section.

On this stretch, the executive design foresaw a final lining of non-reinforced concrete of a 90 cm thickness. Between the rock and final lining, the executive design foresaw an impermeable layer of PVC with draining elements like a layer unwoven fabric, PVC panels and / or rock drainage holes, linked to a longitudinal collector pipe (Gambelli, 2002).

In the proposal of the "controlled drainage" section, impermeabilization water stops and a PVC layer under the inverted arch were added, and a system to regulate the water outflow by the draining fabric was employed. In Sept.2003, some stretches of this section were built, and are under experimentation, monitoring its effects. During the field trip the results of this experimentation will be explained.

Stop 4:

Badia di Moscheta - impacts due to the northern stretch of the Firenzuola tunnel

In this stop we will take a short walk in the Veccione valley, to have a look at the main features of the Marnoso-Arenacea formation, and to understand the context of the main hydrogeological impacts caused by the northern stretch of the Firenzuola tunnel.

See "stop 3" for the general geological setting of the Firenzuola tunnel.

Firenzuola tunnel – northern stretch.

The boring of the northern stretch of the Firenzuola tunnel affected the Veccione Basin influencing both some springs and superficial streams.

The formation crossed is mainly the Marnoso-Arenacea (see above), except for a stretch of 350 m where the Chaotic Complex comes to outcrop. This last formation is constituted by claystones including lythic fragments, mainly calcareous. It constitutes an impermeable septum in the northern stretch of the Firenzuola tunnel (see map), that we can divide in two parts: "Valle dell'Inferno" (north of chaotic complex outcrop) and Upper Veccione Valley (south).

"Valle dell'Inferno".

This stretch of Firenzuola tunnel was bored from the Rovigo access window since the end of 1998. Here the tunnel runs sub-parallel to the Veccione stream, entirely in the body of the Marnoso Areancea formation. The bedding gently dips northwards in the

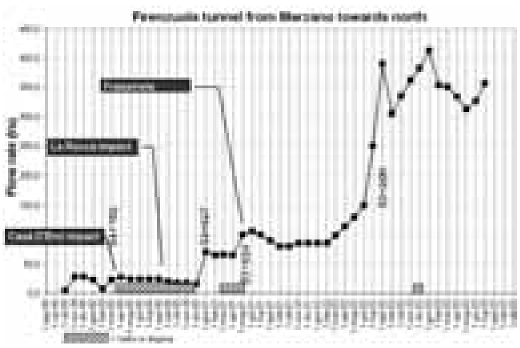

Figure 11 - seepage flow rate in southern h side of Firenzuola tunnel (based on CAVET data)

first stretch, and passes southwards to an anticline, its axis being oriented E-W, and bedding planes dipping about 20°30' on both sides. The Marnoso-Arenacea is also characterised by several master joints (see cross section), and is limited southwards by the tectonic contact (thrust) with the Chaotic Complex, that was encountered in the tunnel around the progressive mark km 49+500.

During the boring work, several points of water inflows were found until November 2001, but in this period no relevant spring seemed to be affected, notwithstanding the discharge reached up to about 300 l/s. Only some small springs, not used for civil water supplies, were affected. On the contrary, variations of the discharge of the Veccione stream were recorded. A definite assessment of the impacts is in progress at

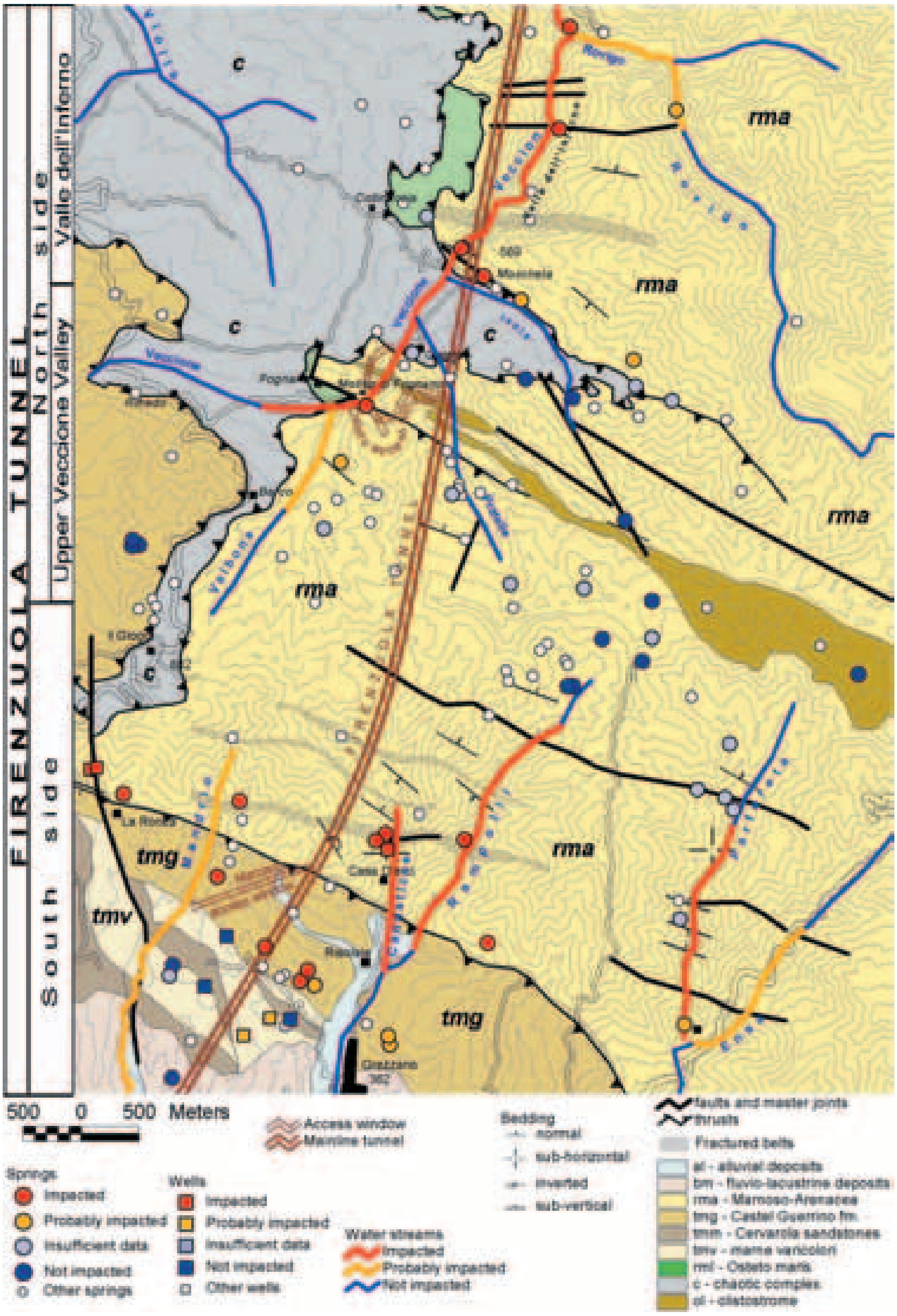

Figure 12 - map of the Firenzuola tunnel

the moment (Sept. 2003). We can only indicate that about 10 l/s, at least, are being drained from Veccione stream in the "Valle dell'Inferno" stretch (between Moscheta bridge and the confluence in Rovigo stream - about 2 kms downvalley).
This fact can be interpreted as below.
Inside the Veccione valley, acquifers inside the fractured belts (see above - stop 3 - Firenzuola tunnel geological setting) supplied a discharge (probably limited) to the stream until the beginning of the works. Once one of these acquifers was crossed by the boring work, the water level was lowered, below the stream level. Then, the stream was deprived of a part of its water flow and, furthermore, the fractured zones became an hydraulic link between the stream and tunnel, capturing part of the water flowing from the upper part of Veccione basin (fig. 12 and fig. 13).

Boring work also had an impact on a spring for water supply in december 2001. In this period pk 48+970 was reached and some inflows were registered (about 12 l/s). A few days after this occurrence, the historic spring of Badia di Moscheta dried. This impact can be explained by the interception, by the tunnel, of the "Isola line" (Morandi, unpublished), that is a persistent lineation, with Apennine direction, that links the tunnel itself with the Badia di Moscheta spring.

Upper Veccione Valley

This stretch is limited northwards by the progressive point km 49+870, where the thrust line between Marnoso-Arenacea and the Chaotic Complex was encountered. Between 49+870 and 50+800 the Castellaccio unit of Marnoso-Arenacea is present. This unit is characterised by a lower sandstone/marl ratio and is strongly tectonized. Southward, the Castellaccio unit passes to the Mt.Nero unit by a thrust. The Mt. Nero unit is characterised by a higher sandstone/marl ratio, and is set in a NNE verging overturned syncline, ramping on the thrust. Southward, the bedding planes become a constant dipping about 10° NNE.
This stretch was mostly bored from Osteto access window. Works started in June 1998, without relevant water inflows until June 1999, when about 100 l/s water inflow occurred. Works were stopped, in order to find a way to manage this unexpected arrival.
This inflow was due to the fractured area present in correspondence of the thrust between the two Marnoso-Arenacea units. This inflow caused the drying of a small spring (Molino di Fognano), and probably a decreasing in Felciaione spring. In 2003, other impacts became evident on the upper basin of the Veccione stream. In fact, in summer 2003 at Fognano Bridge, it showed a 0.5 l/s discharge, that decreased 0 l/s at Molino di Fognano, a few tenths of metres downvalley.
In November 2001 work restarted, but using a new design, to bypass the critical zone. At the moment of the delivery of this paper, the access window will be completed, such as the mainline tunnel northward, while in the southward one works are in progress, and have still not encountered the forecasted relevant water inflows. This situation will be updated during the field trip.

Stop 5:

Firenzuola - The "Pietra Serena" Museum

The Pietra Serena was the most important rock type used especially in the times in Florence and its area. With this material several architectural elements were built, such as columns, capitals, cornices, etc. and was, together with the "Pietra Forte", the main

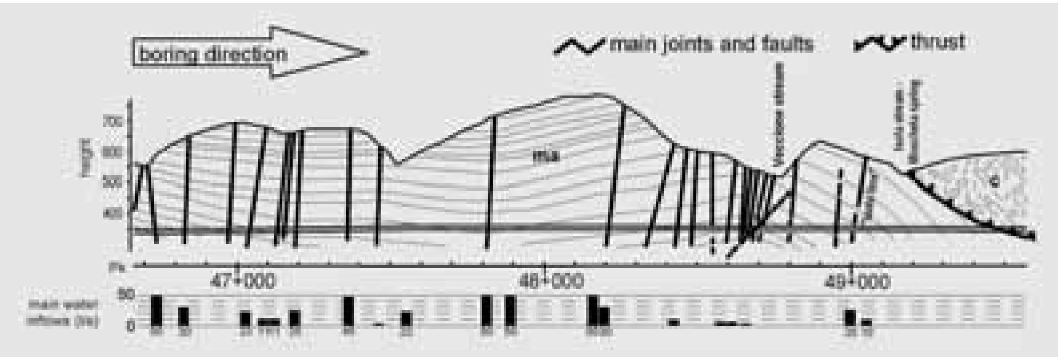

Figure 13 - Geological cross-section along the Firenzuola tunnel axis in the "Valle dell'Inferno" area

material in building the most important palaces in Florence (Cantisani et alii., 2002).

These rocks came from a different place and a different formation compared to the rocks actually extracted with the same name.

The “Pietra Serena” used in the past times in Florence was extracted from quarries near Florence and Fiesole, and came from the “Macigno” and “M.Modino” formations. Tha Macigno is a quartz-feldspar turbiditic sandstone dated back to Middle/ Late Oligocene - Early Miocene (Bruni P. and Pandeli E., 1992). On the upper side, Macigno passed to the M.Modino fm. Dated back to the Early Miocene. Both these formations belong to the Tuscan sequence.

As almost all the quarries in the Florence area have been closed, great importance was given to the “pietra serena” extracted in the Firenzuola area (named also “Pietra di Firenzuola”). This type of Pietra serena derived from the Marnoso-arenacea formation, that is part of the umbro-marchigiana sequence, and can be dated back to the period between Langhian and Tortonian. The quarrying techniques are exposed in the museum, some examples of the use of this material, from common use tools to the artistic works and the architectural-structural uses.

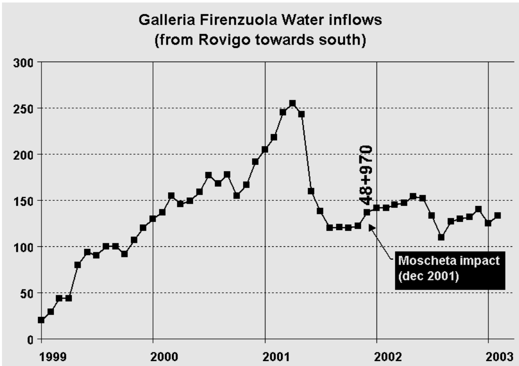

Figure 14 - seepage flow rate in northern side of Firenzuola tunnel (based on CAVET data)

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Back Cover:
Map of Florence and Mugello area
with field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP

Edited by APAT