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HYDROGEOLOGICAL STUDY OF CORNIOLO LANDSLIDE (HIGH BIDENTE VALLEY, ITALY)

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INTRODUCTION AND STUDY SITE

Corniolo town (Santa Sofia, Forlì-Cesena, Italy, **Fig. 1**) lies on an isocline slope, on the marls and sandstones of a flysch formation, precisely a sandstone lens (original survey data) in the Corniolo Member of Marnoso Arenacea Formation (Langhian).

In the past, the slope was interested by large landslides, testified by extensive debris deposits (colluvium) above and among the town, while the village lies mostly on a sandstone layer that forms a wise structural surface. These gravity movements can be classified as translational rock slides (on structural surface) with local small rock falls that evolve in translational debris slide (Varnes 1978); they let recognize the whole displacement as a complex and combined slide. Thanks to borehole logs, the stratigraphy of the body has been precisely identified: an upper thick colluvium (maximum thickness of about 21 m) overlays a highly fractured bedrock 5-10 m thick stratum and this last one lays on the normally fractured bedrock.

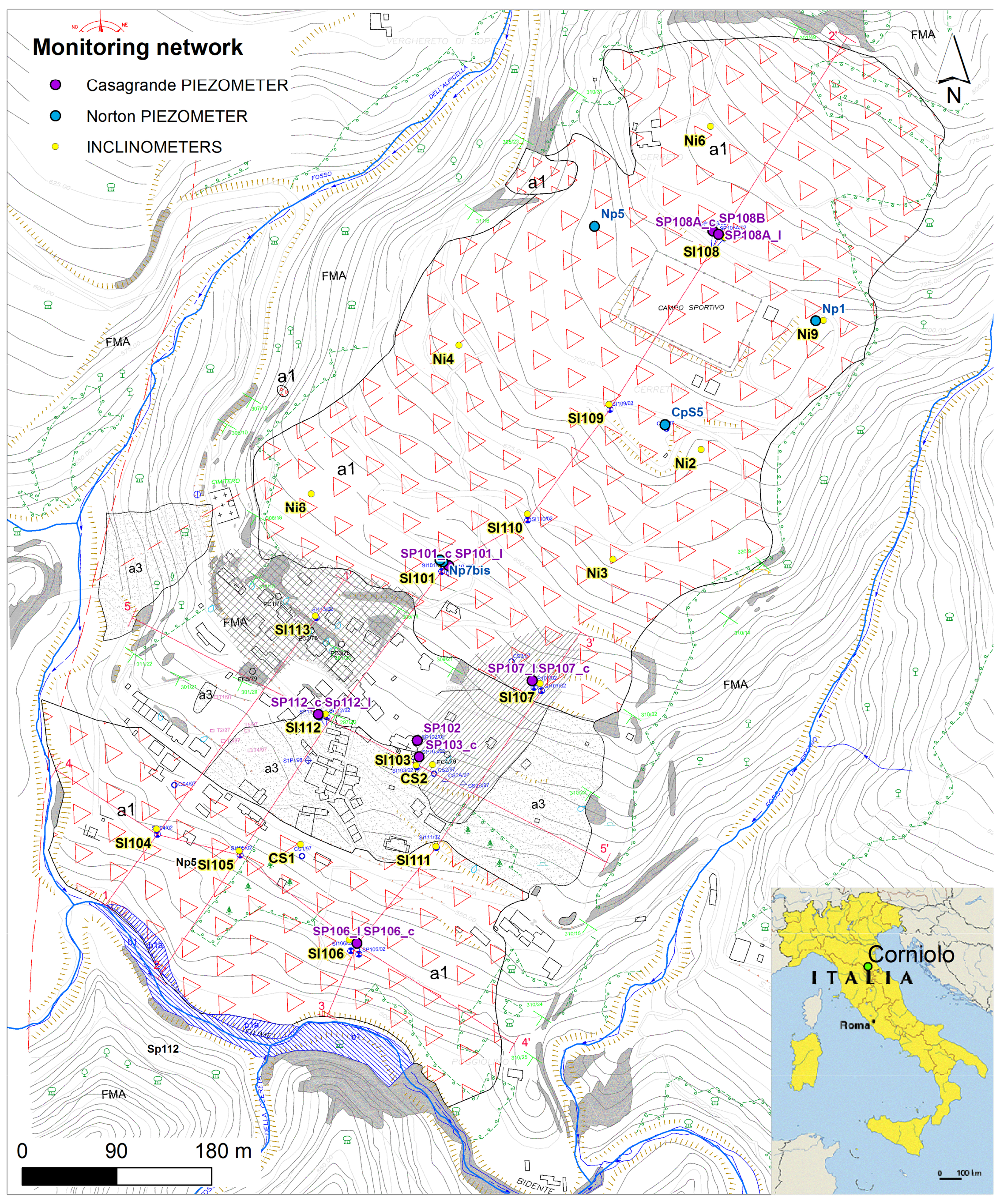

Fig. 1. Geographical location of the study site, geological map and monitoring network (modified from STB, 2008); a1 = active landslide; a3 = debris deposits; FMA = Marnoso-Arenacea Formation (in gray color outcropping rock); b1=gravel alluvial deposit).

At the beginning of the last century, the slope was interested by a large gravity movement, in its lower part, from the town to Bidente River, immediately below the main road. In the '20s the Civil Engineering Office of Florence made the first slope settlement works, mainly represented by river arrangements to protect the lower part of the slope by fluvial erosion. In the '60s, in order to prepare building squares, the thick sandstone layer below the village was cutted leaving footwall without a sustain ridgeward. After the cuts, the rock slope showed instability indications, mostly represented by fractures on civil buildings. Since it, the Technical Basin Service of Romagna (ex Civil Engineering Office) made a lot of set ups and consolidation works in order to make the village free from hydrogeological risk and avoid the replay of the phenomenon; it also installed a first monitoring net on the landslide (piezometers, inclinometers and extensometers). The triggenning causes (the most are foot erosion and subdigging by Bidente River) were solved by the works on the river bed, while in the area upgradient to Corniolo town, uncontrolled and widespread infiltrations and groundwater occurrences, triggened slow land movements identified by the inclinometer monitoring net.

In 2009 intense and long duration rain events caused the rising up of groundwater levels inside piezometers and an abrupt movement along the landslide moving surface, measured by the inclinometers located up-gradient of Corniolo village. The displacement at the boundary between bedrock and debris, always detectable only by monitoring instruments, registered a movement velocity increase from some mm/year to some cm/year. In particular, these displacements have been registered by inclinometers nn. SI101, SI109 e SI110, located along the central axis of the landslide body up-gradient to Corniolo town. In **Fig. 2** the inclinometers data are presented as integral differential displacements: the maximum displacement took place at SI110 inclinometer, and was about 15 mm in 1,5 years.

This movement re-activation induced Regione Emilia Romagna with S. Sofia Municipality to plan new monitoring and restoration activities on the landslide, between them: implementation of the monitoring net and investigations surveys, drainage works and arrangement of subsurface and/or ground hydric regulation systems. In this context, the hydrogeological study here presented was propaedeutic to future restoration works on the landslide body. The main goals were: the definition of the hydrogeological conceptual model of the landslide, the identification and localization of groundwater flows and the planning of a slope tracer test with fluorescent tracer, aimed to definitely prove groundwater velocities inside the debris and the highly fractured bedrock.

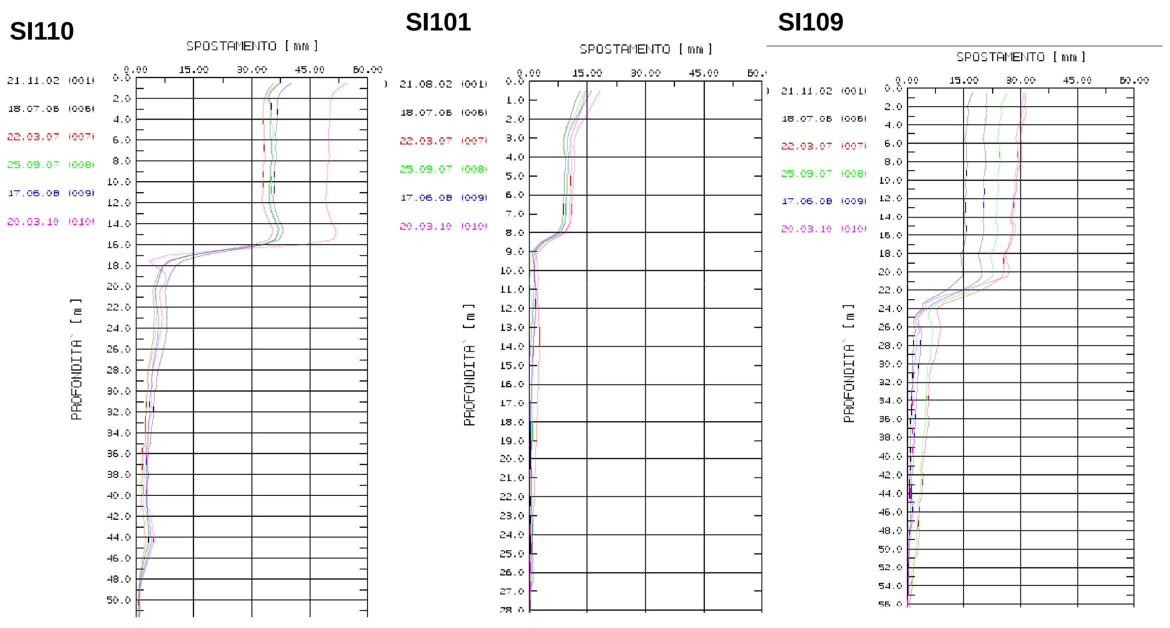

Fig. 2. Displacement graphs at inclinometers SI110, SI101 and SI109 (location on the map of Fig. 1).

MATERIALS AND METHODS

The first phase of the study is already finished and included different field activities, aimed to define the hydrogeological conceptual model of the Corniolo slope and aimed to plan the consequent phase of the study.

The second phase, now in progress, aims to verify the conceptual model and the groundwater flow lines by means of a tracer test.

The existent monitoring network on Corniolo landslide is made of extensometers (in the '80s), inclinometers and piezometers, made during years 1997 (Comune di Santa Sofia) and 2002 (STB); then it has been implemented by Servizio Tecnico Bacino Romagna in 2010 with the perforation of 4 Norton piezometers and 6 inclinometers. All the piezometers and inclinometers are located on the map in **Fig.1**.

For the present study a continuous monitoring network of hydraulic heads has been set up by installing pressure transducers inside 7 piezometers (4 Norton type, 3 Casagrande type). The monitoring activities started in November 2010 and are still going on: the instruments measure the groundwater level every hour. Manual piezometric surveys are regularly performed in order to check the status of the instruments and the reliability of recorded data.

Then, a census of spilling water points has been performed with the help of local people indications: the surveys allowed to identify natural water spilling points, springs and fountains (active or abandoned) and existent drainage works. This activity was also very important for the tracer test now in progress.

Hydraulic conductivity tests have been made inside the Norton piezometers, testing two different methods:

1) bail tests with water injections and measurement of the dynamic level until its stabilization to static level (data interpretation by means of Bouwer & Rice method);
2) single borehole dilution tests made by injecting a sodium chloride solution and monitoring the electrical conductivities in order to assess the groundwater flow velocity (Käss, 1998).

Both the methods have been applied to the 4 Norton piezometers available on the study area.

In order to get a 3D visualization of the subsurface structure, a detailed geological map of Corniolo landslide and several geological sections have been made, starting from the stratigraphic data collected at a large number of boreholes and all the data available from geological surveys; minimum and maximum groundwater levels have been plotted on the geological sections, in order to understand which parts of the landslide body are saturated during different conditions (high flow and low flow).

The tracer test interests the landslide body located upgradient to Corniolo town and it consists of injections of tracers into groundwater inside the rock mass at piezometers Np1 and Np5 and inside the shallow debris inside the spring catchment (point n.29). Point locations are showed in **Fig. 3**, where some picture of the injections are also showed.

Three different fluorescent dyes were selected as tracers because of their favorable properties and proven safety (Behrens et al. 2001). Uranine, Eosine and Amino-G-Acid. The injection masses of the dyes have been estimated starting from an empirical formula, available in Käss (1998).

After a first background sampling before injections, performed on 2012/06/05, an intense sampling programme started two days after injections and is in progress, now with a sampling frequency of 2 times per week.

Monitoring interests all the accessible points located downstream to the injection points: Norton piezometers, shallow and deep drain pipes, natural water outflows from the rock mass distributed in Corniolo village (where the rock outcrops), etc.. Monitoring activity consists of both discrete water sampling (manually and automatically with a field fluorometer inside Np7tris and with an auto-samplers) and accumulative sampling by means of activated charcoal bags.

The samples will be analyzed with a GUNN fluorometer for surface water, suitable for laboratory analyses.

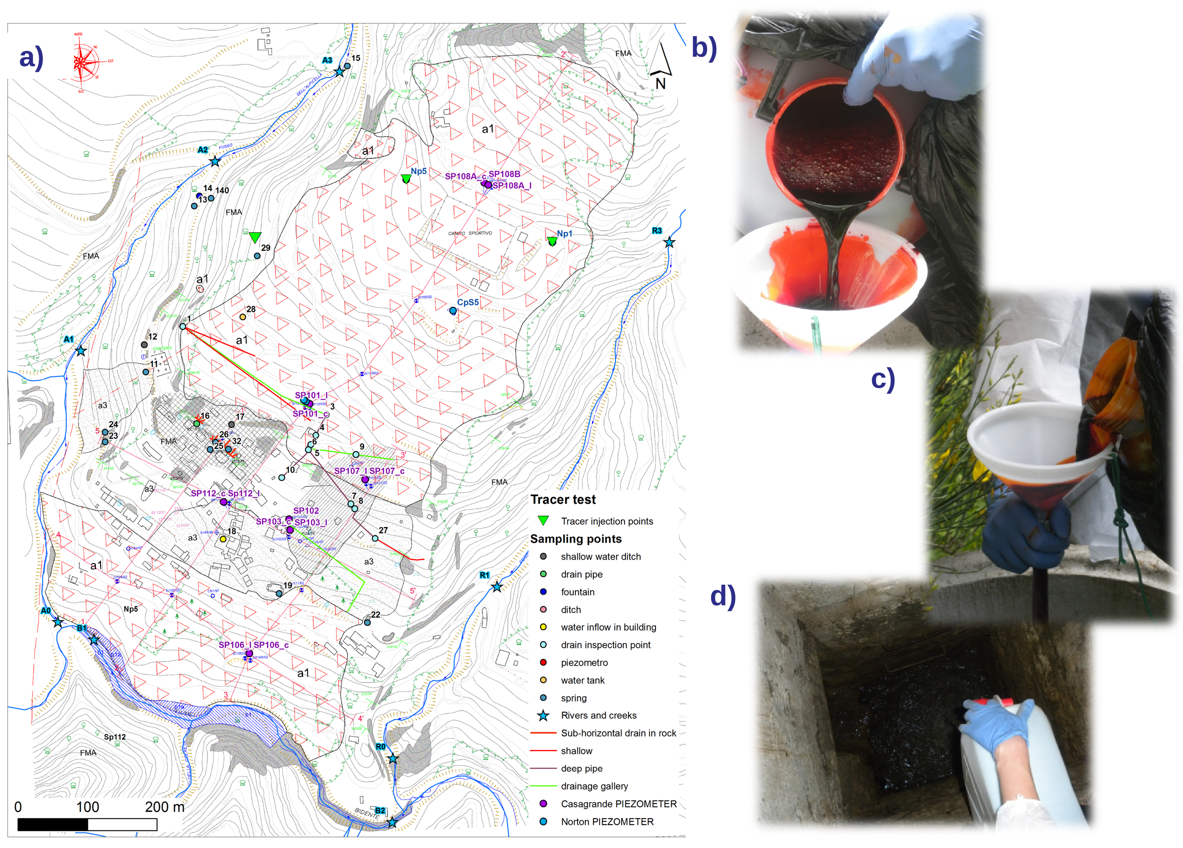

Fig. 3. a) Schematic map of tracer test: injection and monitoring points; on the right: b) Eosine injection in Np1; c) Uranine injection in Np5; d) Amino-G-Acid injection at point 29.

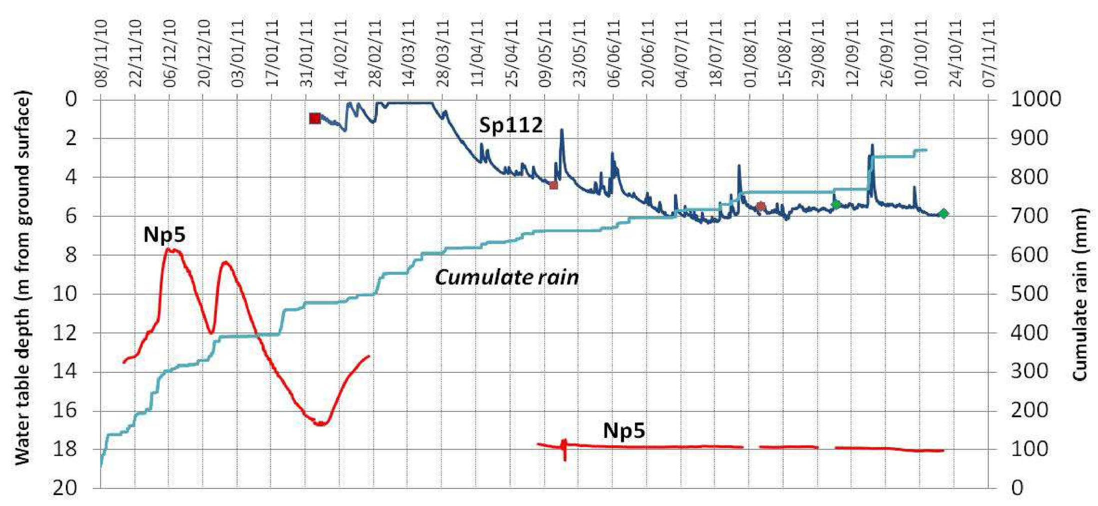

Fig. 4. An example of piezometricmonitoring data: Np5 is a Norton piezometer at the head of the landslide body and Sp112 a Casagrande piezometer in Corniolo town; locations in Fig.1.

ID	Screen position (m b.g.l.)	Filtered lithology	Zone	Maximum groundwater head (m a.s.l.)	Minimum groundwater head (m a.s.l.)	Piezometric range (m)	Time lags from rain events: high flow conditions	Time lags from rain events: low flow conditions	K values from in situ tests (m/s)
Np1	12-20	fractured rock mass	landslide up-gradient	688.5	690.8	2.3	6 hours	40 hours	4E-07
Np5	0-12	fractured rock mass	landslide up-gradient	693.9	704.2	10.22	36 hours	n.a.	5E-07
CpS5	0-23	mass (only rock mass saturated)	landslide up-gradient	665.2	*666.3*	*1.1*	8-9 hours	n.a.	8E-08
Np7bis	0-24	mass (only rock mass saturated)	landslide up-gradient	622.8	*623.8*	*0.98*	n.a.	4 days	5E-07
Sp103_	6.1	siltitic strata of rock mass	Corniolo town	580.8	585.5	4.72	3 hours	38 hours	n.a.
Sp112_	6.9	arenitic strata of rock mass	Corniolo town	573.2	579.6	6.36	1-2 hours	1 hour	n.a.
SP106_	26.4	fractured rock mass	down-gradient	508.0	*513.5*	*5.5*	n.a.	48 hours	n.a.
n.a.	**not assessed**								
16.2	**mazimum of the available data series (not maximum of the hydrological year)**								

Tab. 1. Summary table of piezometric monitoring results: for each piezometer maximum and minimum groundwater head, piezometric range and time lags at high and low flow conditions are presented, together with the K values obtained from in situ permeability tests.

MAIN RESULTS

The main result obtained from the here presented study is the hydrogeological conceptual model of the landslide body upgradient to Corniolo town.

More in detail, the most important results are:

- the groundwater distribution (in space) and regime (during time, as a function of rainfall events): the piezometers monitoring data put in evidence that the lithological unit always saturated by groundwater is the fractured rock, while the debris deposits above it are in saturated conditions only occasionally (some weeks/years, after exceptional rainfall events). Particularly, the piezometric monitoring (**Fig. 4**) allowed to define the water table position during the high flow (maximum in winter-spring season) and low flow conditions (minimum at the end of the summer) for the different part of the bedrock (**Fig. 5**). The comparison of piezometric heads with rainfall data allowed to define the time-lag (from rain event to piezometric peak) and to compare this information with piezometer depth and position, filtered lithology and with K values derived from field experimental tests;
- the hydrogeological parameterization of the translated bedrock stratum: it presents K values ranging from 10^{-6} to 10^{-7} m/s (**Tab. 1**) and of the debris unit (around 10^{-5} m/s);
- the hydrogeological behavior of the different portion of the landslide and of the bedrock; the comparison between the time lags measured at the piezometers in response to rainfall events and the K values assessed with the in situ permeability tests resulted particularly interesting (**Tab. 1**);
- a census of spilling water points (**Fig. 3**), that allowed to derive the potential main groundwater flow lines: for example the area western area of Corniolo town represents an important drainage axis of groundwater flow; the informations obtained from the census and the comparison with the other data were essential for the planning of the tracer test.

WORK IN PROGRESS

The monitoring activity connected to the tracer test (started on the 6th of June 2012) is going on, but unfortunately no results are available to date because the work is in progress.

The authors wish to verify the hydrogeological conceptual model and the main groundwater flow directions, with the final goal of a good planning of future works on the landslide for the protection of Corniolo town.

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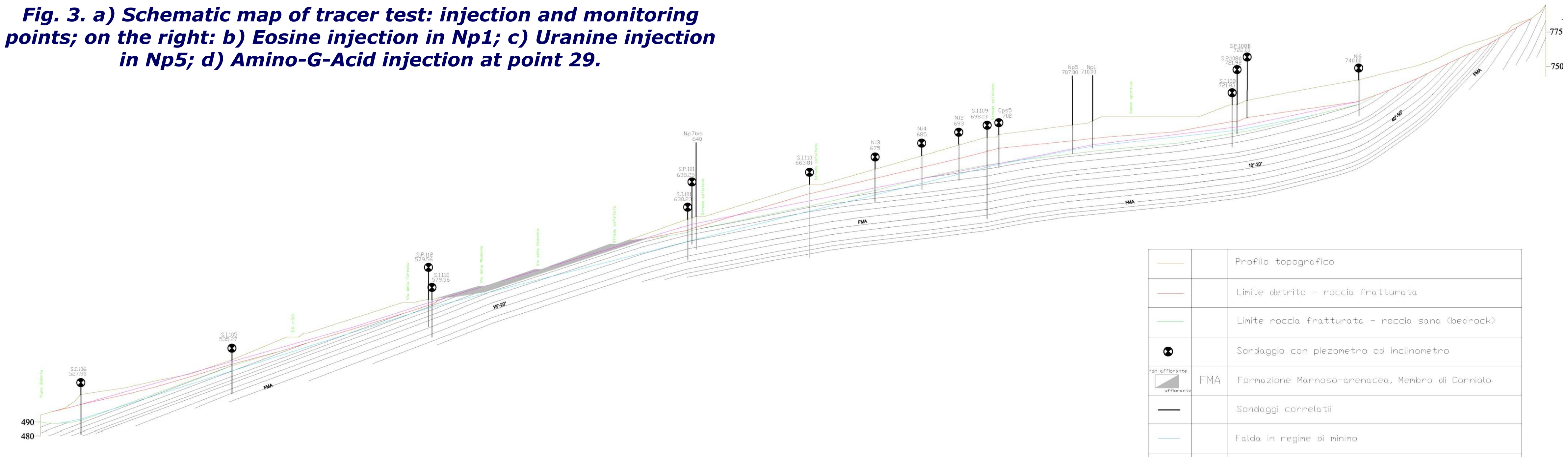

Fig. 5. Geological map along the longitudinal axis of Corniolo landslide (modified from STB, 2008).

REFERENCES

Behrens, H., Beims, U., Dieter, H., Dietze, G., Eikmann, T., Grummt, T., Hanisch, H., Henseling, H., Käss, W., Kerndorff, H., Leibundgut, C., Müller-Wegener, U., Ronnefahrt, I., Scharenberg, B., Schleyer, R., Schloz, W. & F. Tilkes (2001) Toxicological and ecotoxicological assessment of water tracers.- Hydrogeology Journal, 9, 3, 321-325.

Bouwer, H. and R.C. Rice (1976) A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Käss W. (1998) Tracing techniques in geohydrology. Balkema, Rotterdam, 581 pp.

Servizio Tecnico di Bacino Romagna (2008) per Comune di Santa Sofia "Relazione Geologica" allegata al Progetto di Riconsolidamento dell'abitato di Corniolo.

Varnes D.J. (1978) Slope movement and types and processes in landslide. In: Special Report 176:Landslides: Analysis and Control (Eds: Schuster, R. L. & Krizek, R. J.). Transportation and Road Research Board, National Academy of Science, Washington D. C., 11-33.