Field Trip Guide Book - P13

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32nd INTERNATIONAL GEOLOGICAL CONGRESS

# LANDSLIDES OF THE EMILIA APENNINES

*Leader: G. Bertolini*

*Associate Leaders: M.T. De Nardo, G. Larini, M. Pizziolo*

Post-Congress

P13

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

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# LANDSLIDES OF THE EMILIA APENNINES (NORTHERN ITALY)

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*"DIREZIONE GENERALE AMBIENTE, DIFESA DEL SUOLO, DELLA COSTA E PROTEZIONE CIVILE.*
*Servizio Geologico, Sismico e dei Suoli.*
*Servizio Tecnico bacini Enza e sinistra Secchia"*

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Front Cover:
*The Morsiano landslide is the oldest among those dated in the Reggio Emilia Province. It formed from the Late-glacial to the Subboreal period, but several parts of it are still active today.*

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## Introduction

**The Emilia-Romagna Region is one of the most landslide-prone territories in the world. Approximately 20% of the mountainous terrain is subject to the risk of landslides.**

Almost 99% of present-day landslide activity is due to the *reactivation* of pre-existing landslide bodies.

*Reactivation* is a key-concept which must be addressed.

Since medieval times, 2000 villages in Emilia-Romagna have been built upon or very close to dormant landslides, despite the recurrent damage which was inflicted upon some of them.

After WW II, these villages expanded during the ensuing economic boom, without regard for such “minor” problems as landslides. This urban expansion continued into the 1970s and 1980s, when the climate was generally milder and landslide reactivation events infrequent.

People, swept up by their new-found wealth, lost some of their historical memory. Houses and factories were built upon the flatter, wider and apparently stable portion of slopes …. which instead often turned out to be the feet of dormant landslides!

An awareness of landslides on the part of the regional administration, the media and the public, was finally heightened in 1994 with the Corniglio landslide. This landslide was reactivated after one century of dormancy as it completely destroyed the hamlet of Linari (70 houses and industrial buildings).

Since then, this region’s territory has been affected several times (in 1996, 2000 and 2001) and some other hamlets have been either destroyed, severely damaged or threatened.

In Emilia-Romagna there have been no casualties, but the economic costs and the repercussions upon industrial development have been heavy. The costs of reconstruction and consolidation works have amounted to several hundreds of millions of Euros. These costs have been entirely covered by the national and regional governments.

In order to confront this problem, the Emilia-Romagna Geological Survey developed a new and detailed “Landslide Inventory Map” starting in the mid-1990s. This map is a powerful tool: it was immediately put to use in new territorial and urban planning. On the basis of the new cartography, Emilia-Romagna became the first Italian region to enforce rules and obligations addressing landslide hazard reduction**.**

Even before the Landslide Inventory Map, the Regional Geological Survey was a national leader in the study of landslides and their distribution. In the 1980s a survey was performed for the 1:10.000-scale regional geological cartography project. The detailed scale of this map allowed data from about 32.000 landslides to be collected. Under pressure from renewed public awareness, much work has been accomplished during the last decade. In addition, events occurring in this time period have been studied (a synthesis is found in Bertolini *et al*., 2001). A historical database of landslide events has been set up and some thousand records have already been collected for the National Inventory of Landslides (IFFI) project.

The aim of the fieldtrip is to show and explain experiences with landslides occurring within the region. Geological and environmental conditions leading to instability will be described. Discussion will be encouraged especially regarding the role of mathematical modelling, cartography, historical research, monitoring and remote-sensing, as applied to landslide hazard evaluation.

References

This guide contains both original unpublished data and references to recent publications. The main sources are:

- Bettelli and de Nardo (2001) for the geological setting of marine units;
- Bertolini G. and Pellegrini M. (2001) for historical data, radiocarbon dating and statistics about landslides;
- Bertolini G., Canuti P., Casagli N., De Nardo M.T., Egidi D., Mainetti M., Pignone R. and Pizziolo M. (2002) for cartography.

## A simple Glossary of Italian terms

Frana: how is it defined? *Frana* in Italian is a comprehensive term for any mass of rock, debris or soil moving under the force of gravity, independent of the mechanism or the volume involved (sinkholes are included). *Frana* is derived from the Latin noun “*frangina*, ” which in turn is derived from the verb “*frangere*,” which means “to break.”

The use of this term is widespread in all Italian regions, although several local dialect terms exist: “*lama,” “lezza,” “lavina”, “rovina*,” and “*ruina*.” In

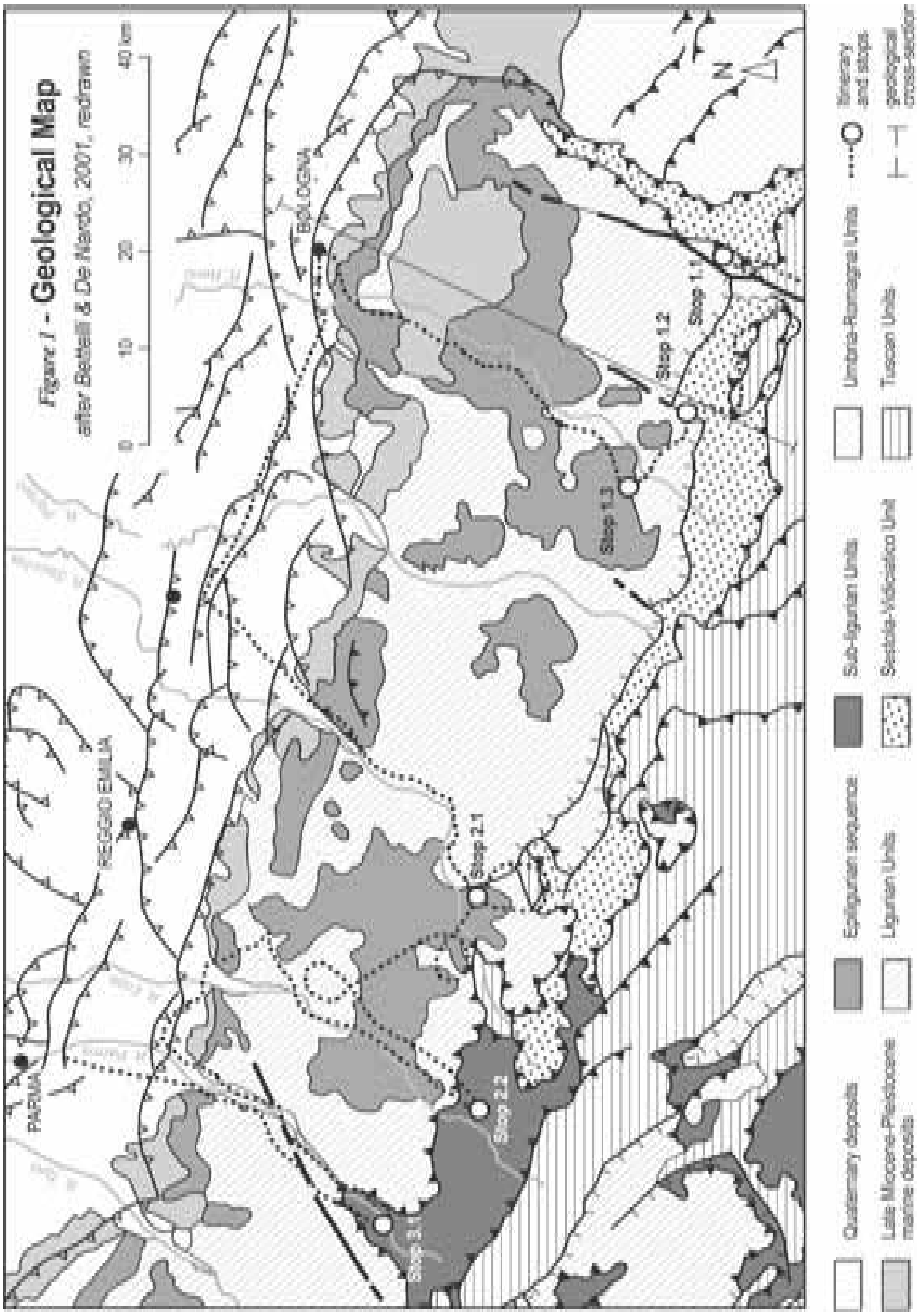



*Figure 1 - Geological Map*

particular, this last term is quite old: it was used in the written form in Dante's "Divina Commedia" (Inferno, XII, 4-9, 28-30) in reference to a large rockslide near Rovereto in the Adige Valley ("*la grande ruina*").
A list follows of the most commonly used specific landslide classifications. But remember! Rarely is there a perfect correspondence between the Italian and English terms. The translations of Cruden & Varnes' definitions are not definitive and often are a cause of endless debate! You can find a more detailed discussion in Canuti & Esu, 1995.

The more specific terms about landslide classification are:

- referring to the landslide mechanism: *Colata di terra* (Mudslide, Mudflow), *Colata rapida di detrito* (Debris flow), *Scivolamento* (Sliding), *Scivolamento traslativo* (Translational slide), *Scivolamento rotazionale* (Rotational slide), *Crollo* (Fall), *Ribaltamento* (Toppling), *Smottamento* (Land, Soil slip), *Espansione* (Spread), *Sprofondamento* (Sinking);
- referring to the material involved: *Suolo* (Soil), *Terra* (Earth), *Detrito* (Debris), *Roccia* (Rock), *Substrato* (Bedrock);
- referring to the state-of-activity: *Attiva* (Active), *Quiescente* (Dormant), *Inattiva* (Inactive), *Sospesa* (Suspended), *Relitta* (Relict).

## Regional geological setting

A little over half of the land surface in the Emilia-Romagna region is covered by the Apennine mountain chain. This mountainous region extends from the Apennine ridge (in the SW part of the region), reaching elevations of 2165 m a.s.l. (Mt. Cimone in the province of Modena), to the pede-Apennine margin (in the NE) which ranges from 100 to 200 m a.s.l. The "Emilian Apennines," where the fieldtrip takes place, are the main subject of this paper. They are located in the southern part of the Bologna, Modena, Reggio Emilia and Parma provinces.
The main reference for the description of the geological setting is the 1:10,000-scale Geological Map that was produced by the Regional Geological Survey, and the map synthesis at a scale of 1:50,000, commissioned by the National Geological Survey to the Regional Administration and now in press. Both projects were conducted in collaboration with university departments and research institutions.
The Northern Apennines are a fold-and-thrust post-collisional belt, built-up during the Tertiary as the Thetian basin closed due to continuous convergence between the European and the Adriatic plates. First, in the Early-Middle Eocene, the subduction of oceanic crust produced an accretionary prism of sediments. After the oceanic crust was completely consumed, the ongoing collision between the two continents produced three broad allochthonous assemblages which correspond to three distinct paleogeographic domains (from internal to external): Ligurian, Sub-Ligurian and Tuscan-Umbria-Romagna (Figure 1 and 2).
The Tuscan Units formed a fold-and-thrust belt which was then buried by the Ligurian and Sub-Ligurian Nappes, both moving toward the NE. The Tuscan Units are now partially exposed in a few tectonic windows (Mt. Zuccone, Gova, etc.) and on the ridge of the Apennine chain.
The relatively more allochthonous Ligurian Nappe consists of the uppermost structural units and is well-exposed in the Emilian Apennines, from Pavia to the Bologna Apennines. Its basal contact upon the Umbria-Romagna units is evident in outcrops along the transverse "Sillaro Line". As a consequence of the Early-Middle Eocene closure of the Ligurian oceanic basin, sediments which compose the semi-allochthonous "Epi-Ligurian sequence" were deposited in "satellite" basins, just above the Ligurian Nappe. The deposition of terrigenous sediments in the Po Plain foredeep from the Late Miocene-Pliocene to the Quaternary ended the period of marine sedimentation in the Apennines.

**Tuscan-Umbria-Romagna Units**

These are the deepest occurring sedimentary rocks in the Northern Apennine mountain chain and may be subdivided into three sequences: the Metamorphic Tuscan Sequence, the Umbria-Romagna Sequence and the Tuscan Nappe Sequence. The first stage of sedimentation is common to all these sequences. The deposition upon the crystalline Palaeozoic basement began in the Middle-Late Triassic with the "Verrucano" unit (alluvial, lagoonal, shallow marine coarse sediments), followed by the Late Triassic "Gessi Triassici" unit (evaporites), then by Late Liassic carbonate shelf deposits and, in turn, by various pelagic units from the Late Liassic to Early Oligocene in age. The foredeep clastic turbidites of the Macigno-Falterona-Trasimeno sequence (Late Oligocene to Aquitanian in age) finish off the Tuscan Nappe Sequence. Outside the study area, in the Umbria-Romagna sector, sedimentation continued until the Late Miocene with slope mudstones and a foredeep turbidite sequence assigned to the "Marnoso Arenacea Formation." Deposition of the Metamorphic Tuscan Sequence probably finished in the Late Oligocene with the "Pseudomacigno," since this is buried beneath the Tuscan Nappe.

In the study area, only a few units belong to the Tuscan Nappe outcrop. These outcrops are evident in the upper part of the mountain chain: they are the Macigno and Gessi Triassici Formations.

**Sestola-Vidiciatico tectonic Units**

In the field-trip area other Miocene clastic turbidites (the Mt. Cervarola, Mt. Modino-Mt. Ventasso Units) are present. They filled the foredeep basins situated at the front of the Ligurian and Sub-Ligurian Nappes and are frequently associated with chaotic melanges composed of materials derived from the Sub-Ligurian, Ligurian and Tuscan Sequences. These chaotic assemblages are considered to be one distinct tectonic unit that overthrust also the foredeep sediments (i.e. Cervarola Formation) during its deposition.

**Sub-Ligurian Units**

This sequence mainly constists of Paleocene-Middle Eocene shaly-calcareous turbidites (the Canetolo Complex). The upper part of the sequence, Late Eocene-Early Miocene, is also made up of interbedded turbiditic sandstones (the Petrignacola and Ponte Bratica Formations).

The Sub-Ligurian sequence also crops out in tectonic windows beneath the overlying Ligurian Nappe (at Mt. Zuccone, Bobbio).

**Ligurian Units**

These are deep-sea sediment sequences which are Late Jurassic to Early Eocene in age. They are subdivided into many different local sequences that share major features: in the lowest part of the sequences, Early and Late Cretaceous clayey complexes ("Complessi basali") are composed of calcareous or arenaceous turbidites ("Argille a Palombini", "Arenarie di Ostia") and multicoloured shales ("Argille Varicolori").

All these formations exhibit a block-in-matrix texture due to the effects of continuous and intense tectonic stresses which almost destroyed the original well-layered lithology. Because of this textural feature, these units were grouped together under the comprehensive term "Argille Scagliose" ("scaly clays"), and then the term "Complesso Caotico" ("Chaotic Complex") until the late 1970s.

The units are now considered to be tectonic melanges (fragments of formations and olistostromes), in which the common block-in-matrix feature was acquired during formation of the accretionary prism during

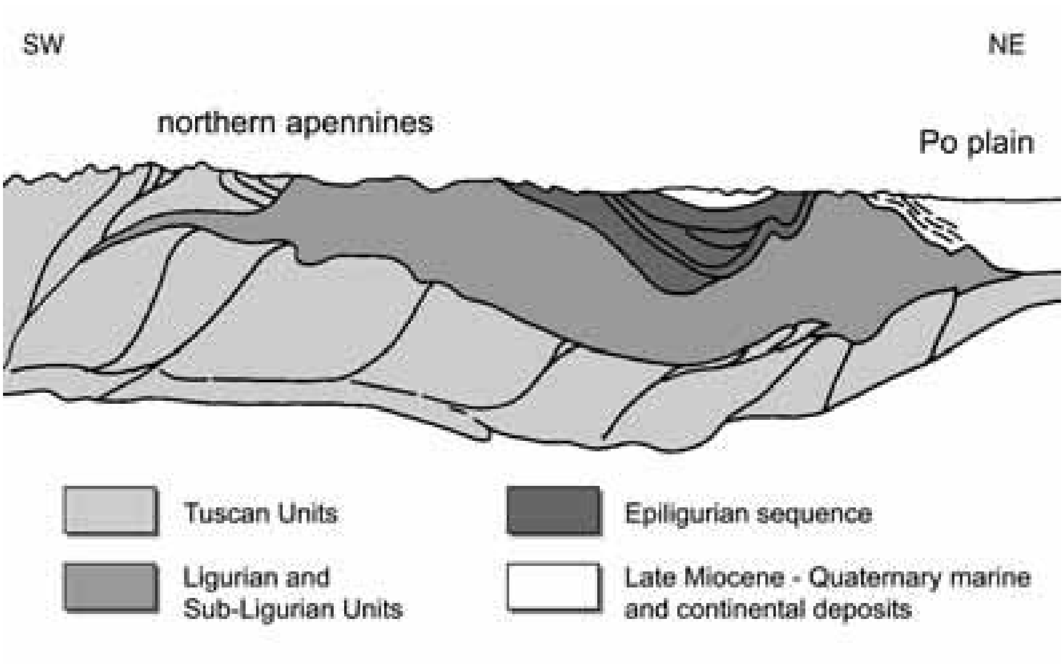



*Figure 2 - Geological cross-section of the Emilia Apennines*

the Late Cretaceous to Early Eocene. The degree of tectonisation is very intense, with shear surfaces observable at all scales.

All these chaotic units are usually referred to as “Basal Complexes.” They are overlain by a thick series of more coherent Late Cretaceous to Early Tertiary calcareous or arenaceous turbidites known as “Helmintoid Flysches.” These form wide, thick and less-deformed slabs, lying on top of the basal complexes. This layered structure is usually well-preserved. Physical weathering processes make these formations susceptible to erosion and landslide processes.

We estimate that almost two-thirds of all the landslides occurring in Emilia-Romagna originate within Ligurian units.

**Epi-Ligurian Sequence**

After the closure of the Ligurian oceanic basin, a thick sequence of sediments was deposited in marine basins (“satellite basins”) lying at first upon the already deformed accretionary prism, and then upon the translating Ligurian Nappe.

These sedimentary sequences were deposited from the Middle Eocene to the Early Messinian. In the lower part of the sequence argillaceous breccias and olistostromes were deposited as a result of mud flows and debris flows (Bettelli & De Nardo, 2001). They were formed by reworked materials coming from the front of the Ligurian Nappe.

The “normal” sedimentation commences with deep-water shale and turbidites (the Monte Piano and Loiano Formations, Middle to Late Eocene) followed by muddy and sandstone turbidites (the Ranzano Formation, Early Oligocene), by hemipelagic slope deposits (the Upper Oligocene-Burdigalian Antognola Formation) and, in turn, by Miocene shallow-water (sandstone) and slope (marls) sediments (the Bismantova Group). The clay of the Termina Formation (Late Serravallian to Early Messinian) tops the Epi-Ligurian Sequence. Huge lenticular units consisting of clay-supported breccias (i.e. Canossa Olistostrome) are interbedded in the Antognola Formation. These are made up of reworked Ligurian materials.

As a consequence of their different depositional history, the Epi-Ligurian Sequence and the Ligurian Units show remarkably different degrees of deformation. The Epi-Ligurian Sequence forms thick, flat, horizontally-bedded, gently-folded slabs; it lies on top of the more deformed Ligurian complexes. These rocks are very resistant to weathering processes, with the exception of the already mentioned clayey breccias and olistostromes which are present at two levels of the sequence (in the Middle Eocene and the Late Oligocene-Burdigalian). These chaotic Epi-Ligurian Units are quite similar to the Ligurian Units, also from lithological and geotechnical points of view.

**Marine units of the Apennine margin**

A sequence of marine terrigenous sediments filled the youngest foredeep, during the Late Miocene to Pleistocene. The sequence commences with Messinian evaporites (“Gessoso Solfifera”), related to the Mediterranean desiccation event, overlain by continental, brackish water clastic deposits (the “Colombacci” Formation). These deposits are in turn overlain by deep-water Early Pliocene to Early Pleistocene blue clays (“Argille azzurre”).

The blue clays outcrop along the Apennine margin and plunge gently northward underneath the regressive sands and the Po Plain continental infill. The so-called “Intra-Apennine Pliocene” is an exception: it is a large slab of Pliocene blue clays and sands, gently synclinal in shape, located in the Bologna Apennines and physically separated from the corresponding “blue clays” of the margin.

**Quaternary continental deposits**

*Alluvial deposits*: gravel deposits are in the valley bottoms, independent of bedrock type and basin hierarchy. The deposits are a results of the worst historical and pre-historical climatic periods as, for example, the recent Little Ice Age from 1500 to 1850 B.P. and the Last Glacial Age from 75,000 to 11,500 yr. B.P. The lithosomes that fed these deposits were mostly the bases of numerous landslides which were eroded by the hydrographic network. Peat and lacustrine clay lenses are often found interbedded with coarser fluvial sediments, attesting to ancient landslide dams. A clear, modern example of this phenomenon is found on the Secchia River: a landslide dam occurred in 1960 A.D. and formed a lake about 26 $km^2$ wide. Within a three-month interval, more than 5 metres of clay was deposited on the valley floor.

After the end of the Last Glacial Age, moraines became important sources of gravel that fed the alluvial deposits on the valley floors. Gravel alluvial terraces of five to six different orders are found on the present-day hillsides, at elevations of tens of metres above the existing riverbeds. They are relics of previous valley floors and attest to the recent, actual uplift of the mountain chain.

*Moraines*: Glacial cirques and moraines are found on the highest parts of the ridge and particularly in the upper Parma, Enza, Secchia and Panaro Rivers catchment basins. The Glacial deposits are usually ascribed to the Last Glacial Age that lasted form 75,000 to 11,500 yrs. B.P. It corresponds to the Würm phase of the Alps and Wisconsinian in North America. The Last Glacial Maximum ("Val Parma Phase" in the Apennines, after Larini et al., 2001) was reached 18,000 to 20,000 years ago, when the snowline ranged from 1300 to 1200 m a.s.l. On the basis of a geomorphologic reconstruction, we know that only a few, small glacial tongues were present, and that they rarely extended below 900 m. a.s.l., as attested to by the Cedra and Parma Valley glaciers (Larini et al., 2001).

*Slope-deposits*: Quaternary continental cover, consisting of coarse debris and eluvio-colluvial deposits, is present. The former is frequent in the upper chain where Tertiary sandstone outcrops (i.e. the Macigno, Cervarola, or Modino flysches), and is directly exposed to physical weathering processes including freeze-thaw cycles. The eluvio-colluvial deposits are almost always present on the slabs, which are often mesa-shaped, composed of Ligurian Cretaceous Helmintoid Flysches, and they are very susceptible to physical weathering processes. The eluvio-colluvial deposits may reach thickness of several metres and are frequently affected by creep and landslide activity.

Epi-Ligurian Units such as the Bismantova Group are prone to chemical weathering processes because of their high carbonaceous content and consequently the eluvial cover is often thicker than 1 meter.

Usually, the Ligurian Basal Complexes and Sub-Ligurian Units do not have considerable cover and are often visible in outcrop or buried under only a few decimetres of soil. Weak permeability, and consequently the narrowness of the stratum of rock exposed to weathering processes, causes this.

**The Apennine landscape**

The Emilian Apennines can be divided into two different landscape types. Above 1000 m in elevation, along the mountain chain's crest, the mountain chain prevails. Tertiary sandstones outcrop (i.e. the Macigno Formation) along the steep and rocky slopes. Below 1000 m, a more gentle, hilly aspect prevails: Ligurian Basal Complexes (i.e. "Argille a Palombini," "Argille Varicolori") or Sub-Ligurian units (i.e. "Arenarie di Ponte Bratica," "Argille" and "Calcari") are overlain by more resistant slabs of Helmintoid Flysches or Epi-Ligurian Sandstones (i.e. Bismantova Group). The slopes composed of clay and chaotic units have a gentle gradient (usually 10-20°) and are often affected by badlands and landslides, whereas the superimposed flysches or sandstones can even present sub-vertical slopes and mesa-like features (i.e. "Pietra di Bismantova" near Castelnuovo Monti).

## Landslide distribution, features and causes

The variability of landslide distribution within Emilia-Romagna is assigned by the *Landslide Density Index (LDI),* which has been determined based on two different parameters (Bertolini *et Al.* 2002):

•*FLDI (Formational LDI) = s/S* * 100, where *s* is the sum of all landslide areas occurring within each geological formation and *S* is the mapped surface (over the Emilia-Romagna regional territory) of the entire formation taken into consideration.

•*TLDI (Territorial LDI) = s/St* * 100: where *s* is the sum of the landslide area occurring within a given territorial surface-type classification (e.g. Municipality, Province, drainage basin, etc.) and *St* is the area of the territorial surface considered.

For the entire Emilia-Romagna Region, the average *TLDI* value is 17.1%. The rock units affected by the largest number of landslides are those assigned to the Ligurian and Sub-Ligurian Domains (e.g.: "Argille a Palombini," "Argille Varicolori," "Arenarie di Scabiazza," "Argille Scagliose" Auctt.), as well as the sedimentary breccias (Eocene and Oligocene) belonging to the Epi-Ligurian Sequence (e.g. "Melange di Baiso," "Melange di Costa dei Buoi," and "Olistostroma di Canossa"). All these units have a Formational Landslide Density Index which ranges from 20% to 40%.

Lithologic and geotechnical features of the most landslide-prone rock units

The clearest feature of the most landslide-prone rock units is a complex and disarranged or even chaotic structure, sometimes even at a microscopic scale (occurring in tectonic or sedimentary mélanges). The size of the clastic fragment aggregates and of the sheared lenses of clay, clay shales, marly clay or marl, is on the order of one millimetre (or less) up to one centimetre. The lenses or scales are bounded by evident slickensides. Indeed, the term "scaly clays" is also used for these materials. In the geological literature these have often been called *Argille*

*Figure 3 - The flatter, wider and apparently stable parts of the Apennine slopes where many villages grew up over the last few centuries often are the exposed feet of very large, dormant landslides. Photo by Giovanni Bertolini, September 2002.*

*scagliose* ("scaly clay") and *Complesso caotico* ("chaotic complex").

In terms of their shear strength properties, these materials show a high degree of variability, which is difficult to quantify. This is particularly true because progressive water absorption in these prevalently argillaceous materials is accompanied by physical weathering processes that often lead to a consistency lower than the solid state; in this way their initial condition of "weak rock" is lost and they assume the characteristics of a clayey soil aggregate. The minimum shear strength values are found in

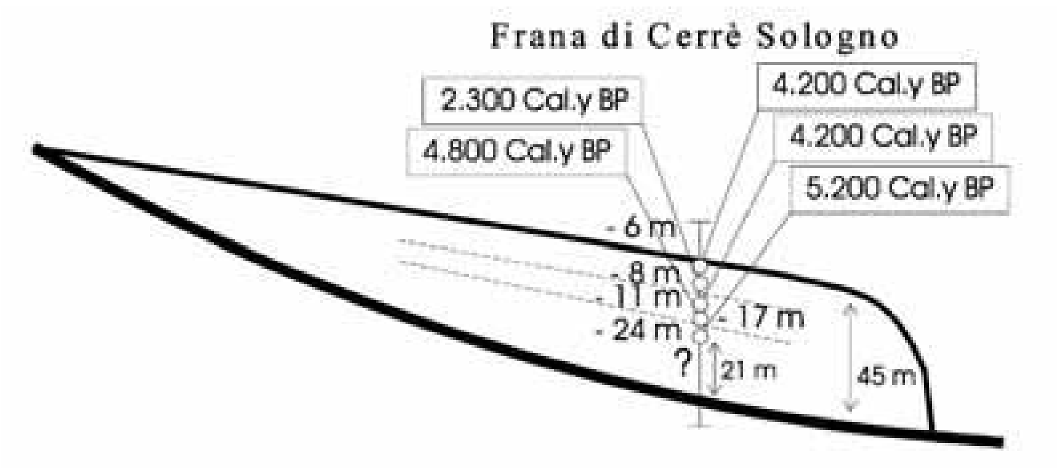



*Figure 4 - The layered structure of a typical landslide investigated by means of continuous-core borings. Sample age increases as depth increases. A well-preserved 2400-year old tree trunk was found inside the landslide. (original data by Giovanni Bertolini).*

*Figure 5 - The Rossena Castle, once the property of Countess Matilde di Canossa, is located upon a cliff composed of red ophiolite lying within the Chaotic Complexes of the Ligurian Domain. It is a mass of pillow lavas which was sheared off from the "Ligurian" ocean floor by the Ligurian nappe during its translational movement. Here we'll have dinner and lodge the second night of the fieldtrip. Photo by Giovanni Bertolini, September 2003.*

argillaceous materials with montmorillonite minerals (for example, *Argille di Viano*).

Some tests and direct field observations made on the breaking point surface during movement revealed a higher natural moisture content (at least 20 to 30% more) compared to the bedrock and the landslide body itself. Moreover, grain-size selection was clearly shifted toward the finer fraction: this is obviously due to the mechanical action (a grinding of the coarser fragments and a squeezing of the clay fraction) affecting the material when the movement takes place in fully confined conditions.

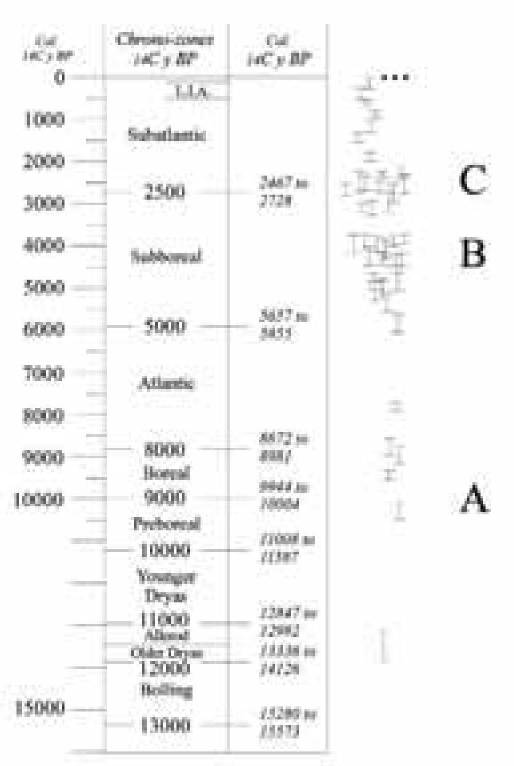
**Features of landslides**

Approximately 32,300 landslide bodies have been identified during surveys carried out for the production of the Regional Geological Map, 1:10.000 scale, in the Emilia-Romagna Apennines. Twenty-six percent of landslides were classified as "active" at the time of the survey, the remaining ones were classified as "dormant." Obviously, some of these classifications—established by the surveyors over a period of time ranging from 1982 to 1995—may now be outdated, owing to subsequent evolution of the landslide. The actual and typical velocities vary from slow to rapid, according to Cruden & Varnes's classification.

As for the *state*, *distribution* and *style of activity* of landslides, they should be considered as "reactivated landslides" (WP/WLI, 1993): "retrogressive" in the upper part; "advancing" in the mid-lower part; and "widening" on both flanks. From a time-sequence viewpoint, these landslides are generally characterised by multiple and retrogressive rotational-translational slides in the upper part, and multiple and advancing translational slides in the lower and frontal parts.

When reactivation occurs, the first movements are large rotational slides in the source area. Each reactivation causes a regression of the main scarp, accompanied by slides of rock masses of various sizes. The displaced material undergoes a rapid decline of its mechanical properties and, following break-up of the mass, becomes saturated with water. A liquid consistency is reached, thus producing earth flows. These earth flows move downward with displacement velocities which in some cases may be classified as "rapid," according to WP/WLI (1993). These earth flows soon widen as far out as

*Figure 6 - Landslide distribution within the Emilian Apennines during the last 15,000 years. Legend: A - probable origin of landslides; B and C - reactivations. (original data by Giovanni Bertolini).*




the landslide body's mid-section, and may partially overlap the accumulation zone, thus forming wide, flat fans with average slope inclinations of less than 10°. The accumulation of earth flows over the basal accumulation material may induce an undrained overload and, consequently, a sudden increase in porewater pressure, thus reactivating the whole landslide body, from head to toe.

At least 1300 of the landslide bodies in Emilia-Romagna have an estimated volume exceeding one million cubic metres. Some landslide bodies have a total length exceeding 5 km: the largest ones are classified within the most frequent complex type, that is, the slide-flow. From plan view, these landslides show a large crown (with slope inclinations >20°), a relatively narrower middle "channel" corresponding to the area of flow, and a wide basal fan with a modest slope inclination which is often <10° (example: the Morsiano Landslide represented on the cover of this booklet).

The depth of the rupture surface is most frequently from 10 to 15 m; about 20% of landslides have a

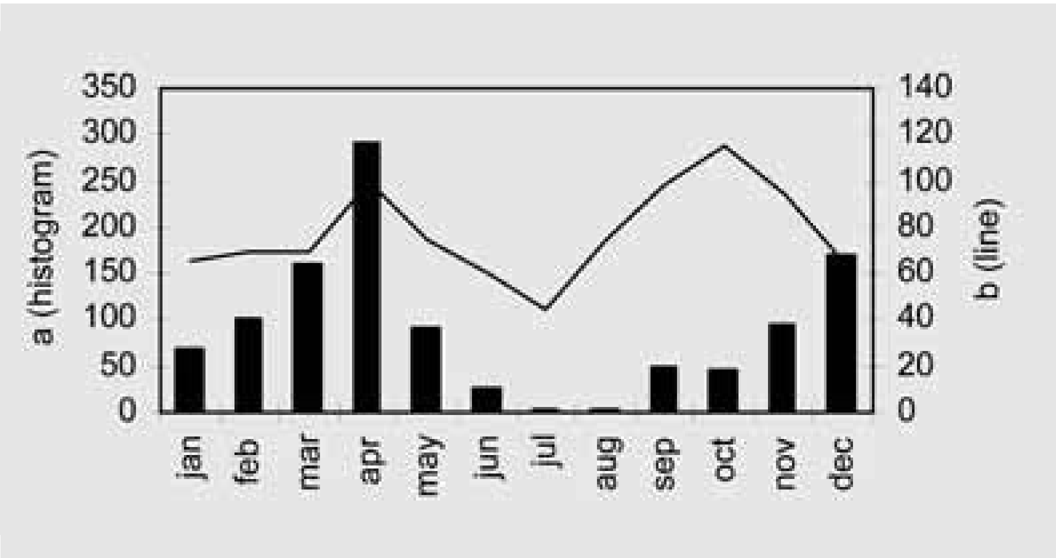



*Figure 7 - Reggio-Emilia Apennine: monthly distribution of landslide-triggering events in the 20th century (histogram "a") vs a typical curve of rainfall (line "b"). This graph was drawn on the basis of the triggering dates (mostly reactivations) available for about 1000 landslides. Despite the time distribution of precipitation, landslides occurring in the spring are much more frequent than autumn ones. That demonstrates the importance of spring snowmelt as a triggering factor. (from Bertolini & Pellegrini, 2001).*

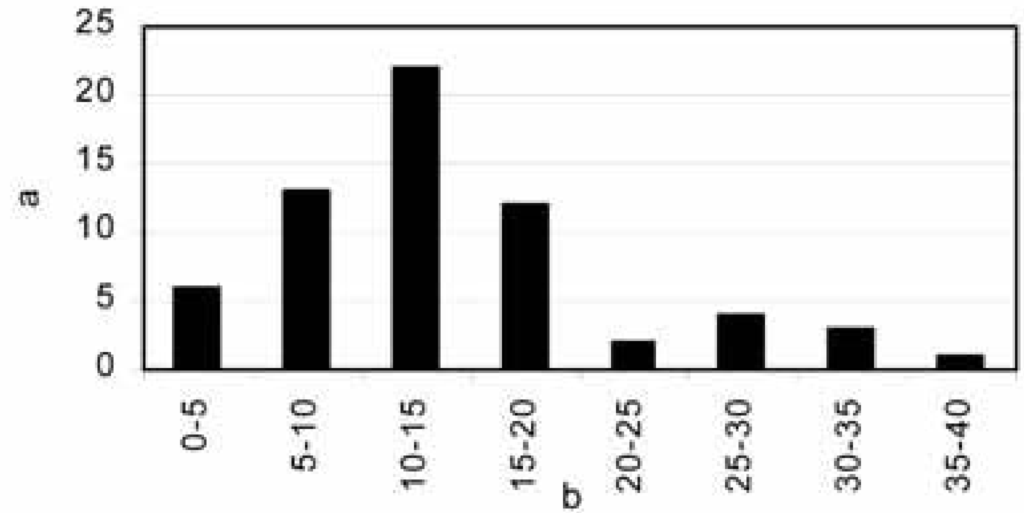



***Figure 8 - Depth (in m) of the rupture surfaces of the landslides in Reggio Emilia Province. This calculation was carried out on about 70 inclinometer curves. As one can see, the highest frequency is found for depths ranging from 10 to 15 m, whereas about 20% of landslides show a depth exceeding 20 m. Legend: a) number of landslides; b) classes of depth (from Bertolini & Pellegrini, 2001).***

depth exceeding 20 m (Figure 8).
The majority of landslides are considered to be a complete or partial reactivation of pre-existing landslide bodies, many of which were originally earth flows from several thousands of years ago; this is demonstrated by about 50 radiocarbon datings carried out in recent years. The increasing usage of continuous core borings allows for the collection of wood remnants (buried by the landslides) useful for radiometric dating. Samples of different (and progressive) age are found at different (and progressive) depths, thus demonstrating that each large landslide body is comprised of several superimposed, relatively minor, earth flows (Figure 4). These landslide bodies are the product of the Late-glacial and Holocenic climate.
In fact, the last glaciation eroded almost all the previous landslides. As shown in Figure 6, the present litosomes originated during the Late-glacial or the beginning of the Holocene (A in Figure 6). Their subsequent growth occurred in the following period, mainly during periods B and C.

**The Risk**

The new Inventory Map of Landslide Distribution (Pizziolo, 1996), and the Landslide Susceptivity Map (Bertolini *et al*. 2002) produced by the Emilia-Romagna Region (both the maps were surveyed at a scale of 1:10,000 and published at the scale of 1: 25,000), are the most useful documents for examining the statistical occurrence of landslides. These maps show that 281 inhabited places (defined as four or more buildings, excluding "scattered houses") lie upon, or are directly affected by, active landslides, with 1608 more by dormant landslides. This large number is a direct result of the Apennine environment, which is subject to many weathering processes (badland development, rill erosion, creep, etc.). Large dormant landslides have been areas deemed suitable for human settlement since ancient times, thanks to the low slope of their frontal and mid-accumulation zones (often <10°). The low reactivation frequency (for large landslides, reactivation time may be on the order of several centuries) and the well-known shortness of human "memory," especially for local historical events, have always favoured this choice, thus creating risky situations for so many settlements.
The risk of human casualties is relatively low, yet not negligible. Catenacci (1990) states that from 1945 to 1990 in Emilia-Romagna "just" 47 lives were lost because of landslides. According to this author, Emilia-Romagna is in 10th place amongst the Italian regions, in the sad classification of casualties caused byslope instability in that same period. The relatively

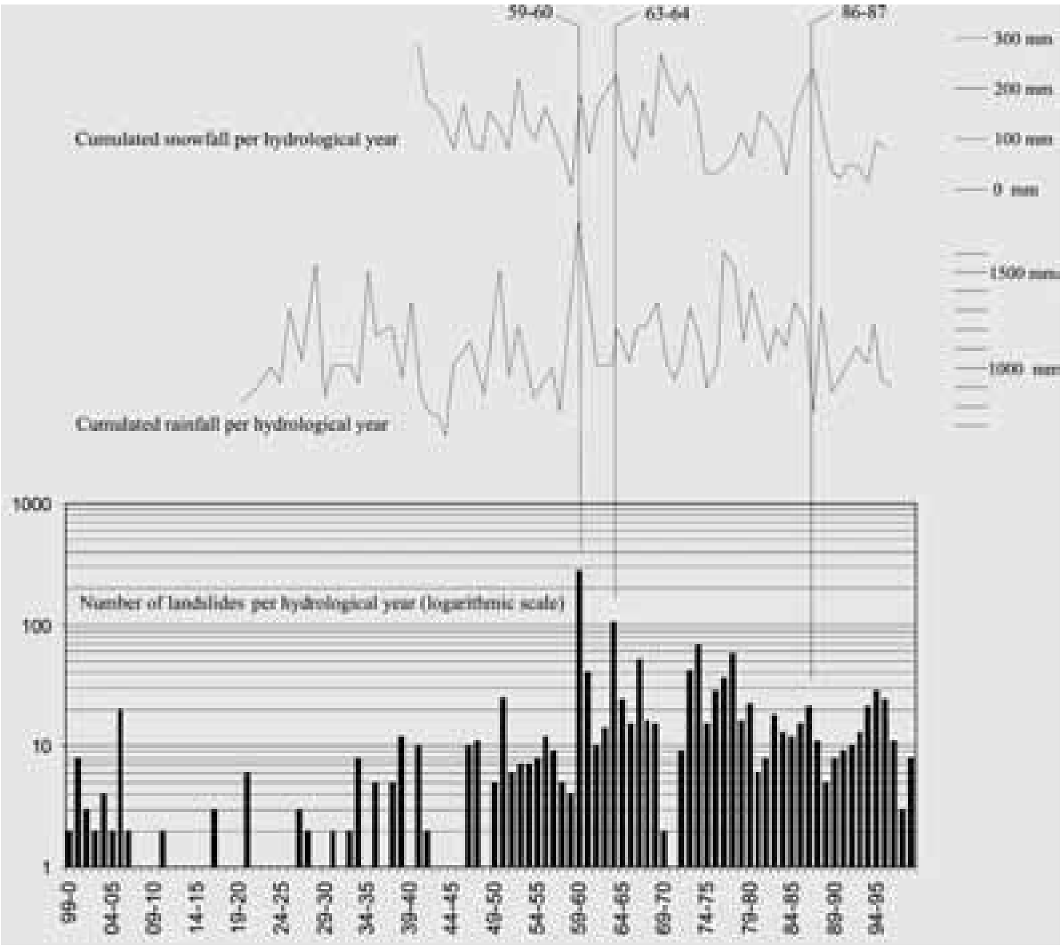



***Figure 9 - The number of landslide reactivations per hydrological year is here compared to the cumulative rainfalls and snowfalls. The dates of events are from Brunamonte (1999), who recorded over 1000 pieces of data, taken from historical documents in the archives of the province of Reggio Emilia. Since the pluviometric regime shows here two main peaks (October and November) and a minimum in July, all data are grouped per hydrological year (from August to August). The number of landslides occurring during the first half of the century is slightly underestimated, because of different laws and loss of data. The hydrological year 1959-60 was the most rainy and with the greatest number of landslides in the century. This graph is useful for establishing the triggering causes as well. In fact, one can see that normally there is a good correlation between events and rainfalls. Instead, when the landslide maximums do not agree with rainfall peaks (e.g. 1963-64 and 1986-87), they correspond to the snowfall peaks. 1963-64 was the second landslide apex of the century, but was caused mainly by snowmelt waters (from Bertolini & Pellegrini, 2001).***

low number of lives lost in this region is due to the generally slow displacement velocity of landslides.

Unlike bodily harm, social and economic damage is extremely difficult to quantify, however the amount is noteworthy. All the mountainous areas of Emilia-Romagna are, in fact, affected by the presence of landslides, causing a consequent progressive human migration out of the rural areas. A good 16% of the total road network is on top of existing landslide bodies, and so is threatened, as well as periodically affected, by slope movements.

Sometimes, owing to the uplift of the landslide foot (in the case of landslides with a rotational-translational rupture surface) and/or complete obstruction of the valley floor (simple earth flow), a dammed impoundment is formed. In this case, hydrodynamic risk related to the possible collapse of the damming materials is very high. In recent times, these impoundments — sometimes of considerable size — are artificially drained in order to avoid a sudden, uncontrolled collapse of the impoundment. In about half of the known cases, the size of the impoundments exceeded one million cubic metres.

**Causes**

The extremely high number of landslides occurring in the mountains of Emilia-Romagna is primarily related to *geological causes*. Nearly all the geological formations outcropping are, in fact, composed of weak sedimentary, sensitive and intensely tectonised rocks, which are classified as *lithologically and/or structurally complex materials*. Also *physical causes* such as *intense and/or prolonged precipitation* play a major role in triggering mass wasting. It is usually possible to correlate long-lasting precipitation with the reactivation of large landslides.

On the other hand, the importance of snowmelt in causing landslides is demonstrated by the monthly distribution of mass wasting events. From investigations of the more than 1000 landslides occurring over the past several centuries in the Reggio Emilia Province we find that 48% of the mass wasting events occurred between March and May, whereas only 29% between October and December. Figure 7 shows that the maximum of autumn-winter landslide events (December) occurs one or two months after peak rainfall (October), whereas the maximum in spring landslide events (April, which is higher in absolute value) actually accompanies the second rainfall peak (on average slightly lower than the autumn one).

The graph highlights the greater number of landslides occurring in spring (disproportionate to rainfall); this must be related to snowmelt, since extensive snow cover may last at the highest elevations in the Apennines until late spring. Thus the action of snowmelt water is combined with the spring rainfall. The same graph in Figure 7 also clearly pinpoints the delay of one or two months between the autumn precipitation peak and the correlative landslide peak. Obviously, this phase shift corresponds to the time necessary for most landslide bodies to reach a state of water saturation sufficient to initiate resumption of movement. The slow recharge of groundwater is certainly caused by very slow percolation due, in turn, to the extremely low hydraulic conductivity of the clay materials that make up most of the slopes and landslide bodies.

Among the *triggering causes* of the Emilian Apennine landslides, *earthquakes* should not be forgotten, even though seismic triggers have seldom been identified with certainty. In this region those few, definitely seismic cases were caused by particularly strong earthquakes, like the seismic shock (6.5 magnitude) in September 1920, which struck the upper Apennines (Reggio Emilia and Modena Provinces) with an 8 degree MCS intensity.

**Occurrence and recurrence of landslides.**

The repetitiveness of reactivations, and their return time, represent quantitatively the "hazard" of each landslide body. The probability of occurrence may be quantitatively described by the event's "return time" which can be established looking at the past history (*"historic failure rate"* in Wu *et Alii*, 1996). Landslide hazard may be garnered from a historical analysis of archival documents, as shown by research of the Apennines of the Reggio Emilia Province (records of over 1000 landslides occurring over the 20th century have been collected). This research also enabled us to compare the landslide history, grouped by hydrological years, with the rainfall and snowfall trend (Figure 9). The number of landslides per year shows that the maximun of activity was reached in the 1960-1961 hydrological year. Afterwards, the data show a decreasing trend down til the present time, although some ten-year fluctuations are evident throughout the overall trend. According to Figure 7, the snow graph in Figure 9 shows that in some years (e.g. hydrological years 1963-64 and 1986-87) the landslide triggering cause is clearly the melting of the snow pack in early springtime.

## Field trip itinerary

### DAY 1

**Florence - Bologna itinerary**

Via the A1 highway to Pian del Voglio and then local roads to Montovolo (Stop 1.1), Rocca Pitigliana (Stop 1.2), and state road (S.S. 64) on to Bologna.

**Topics of the day:** Apennine geology, landslide cartography, GPS, ground- and satellite-based Synthetic Aperture Radar monitoring

**Itinerary A description** – from Firenze to Monte Beni (Stop 1.1).

We leave the highway at Roncobilaccio and go along local roads to Monte Beni.

Coming from Florence, the highway crosses the Apennine mountain ridge near Passo della Futa at about 900 m a.s.l.. Here we are close to the "Sillaro line" that runs straight towards the NE and divides the "Ligurid" nappe of the Emilian Apennines from the harder sandstones of the Marnoso-Arenacea flysch, Miocene in age, which outcrop extensively in the Romagna Apennines. Once on the Emilian side of the Sillaro line, following along our journey, the Marnoso-Arenacea forms the deep substratum of the Ligurian Nappe and does not outcrop, except forthe tectonic window of Salsomaggiore near the Parma Apennine border.

The highway tunnels take us through a ridge composed of foredeep clastic turbidites of the Macigno Formation (Late Oligocene to Aquitanian in age) that conclude the Tuscan Nappe Sequence. In this area the Macigno is composed of alternating well-cemented sandstones and pelites, and shows its large-scale NE verging fold-and-thrust structure. We are now entering into the Po Plain side of Apennines where, during the journey, we can see several splendid views. They all present ideal opportunities to describe the geological structure of the Apennines and visualise the complicated relationships amongst the different domains and units.

## Stop 1.1:

**Monte Beni**

***by Nicola Casagli, University of Florence***

Monte Beni (elevation 1260.5 m a.s.l.) is located in Northern Tuscany (Italy), about 8 km NW of Firenzuola, a town well-known for the industrial production of quarried stones.

The eastern slope of Monte Beni was worked over by quarrying activity, to produce construction material, from an ophilolitic sequence, which lies reversed over Cretaceous clay-shales pertaining to the Ligurian nappe. The sequence is composed, from the top to the bottom, of the following units:

a) massive jointed basalts;
b) basalts with a pillow-lava structure;
c) basalt breccias;
d) a thin layer of laminated cherts (Diaspri Formation);
e) limestones with marl inter-beds (*Calcari a Calpionelle* Formation) with a regular bedding dipping into the slope.

The lower part of the mountain chain is covered by slope-waste deposits with visible remains of ancient rockslides.

A geological study, commissioned by the Firenzuola Municipality for the recovery of the quarry area, finished in July 2000, confirmed the well-known instability problems associated with the fall of blocks of several cubic metres in size. However, for the first time, it also recognised the presence of a mass of heavily jointed rock in precarious stability conditions, located at the upper part of the mountain.

In April 2002 after a moderate rainstorm (66.4 mm of rain between the 12th and the 13th of April), new dramatic evidence of instability appeared on the slope.

After a field survey it was possible to assess the actual size of the problem: the upper boundary and the right flank of the rockslide were clearly defined by an opened perimetral crack, 320 m long.

In a case like this it is very important to assess the volume of the incipient rockslide rapidly and precisely, because volume is one of the main factors controlling the runout in the case of a catastrophic failure and, therefore, the consequences in terms of expected loss. In particular the value of 1 million $m^3$ seems to be the limit between low mobility and high mobility rock avalanches.

For this reason it was decided to employ LISA, a new remote sensing technique based on SAR (Synthetic Aperture Radar) interferometry, developed at the Joint Research Centre (JRC) of the European Commission, specifically for the field assessment of ground surface displacements (Figure 10). This novel system was used at Monte Beni in a monitoring campaign lasting 2 weeks, from the 5th to the 19th of May 2002.

The basic principles behind the system involve the SAR interferometric technique developed over the last decades in the realm of satellite imaging.

This system must be installed in a stable position in front of the area to be monitored, which must be completely visible from this position.

The entire operational chain of data processing can be done directly in the field using portable instrumentation and a laptop PC, thus providing real-time information.

The final product is a sequence of interferograms showing, pixel by pixel, the phase differences between successive images.

Interferograms, after the transformation of phase values into displacement, come up with direct, multitemporal deformation maps showing the field of displacements along the sight-line of the system over all the area where the radar backscattering is coherent enough (corresponding to the less vegetated sectors of the slope).

The atmospheric conditions during the monitoring of Monte Beni were quite troublesome since for most of the time the slope was covered by dense fog. In

these conditions it was not possible to use any optical topographic systems, whereas the radar observations were fully carried out.
The data provided by the LISA clearly defined the rockslide mechanism and has allowed us to delimit, with high precision, the boundaries of the moving mass and the evolution of the movement over space and time.
After the LISA project it was possible to assess the effective magnitude of the rockslide, confirming the initial estimate of $1 \times 10^6$ $m^3$ of material involved. The maximum depth of the sliding surface is about 30 m.
Monte Beni represents the first case in which the new SAR technology of LISA was applied in real operational conditions, on the basis of a decision supported by Civil Protection authorities.
From this first operational test the following positive points arose:

a) LISA can be used for monitoring movements during an emergency since its installation requires only a few hours and it is able to provide real-time data;
b) LISA is capable of assessing the entire deformation field of a mass movement, at least in zones with scarce or moderate vegetation;
c) LISA delivers multitemporal information at short time intervals (10 minutes);
d) LISA remotely assesses displacements, without needing to access the unstable area.

**Itinerary B description** – from Monte Beni (Stop 1.1) to Montovolo (Stop 1.2).
We take the highway northward and exit at Pian del Voglio, then go along local roads to Camugnano and Montovolo.
Once we leave the Macigno Formation of the Castiglion dei Pepoli anticline, the highway proceeds through the Sub-Ligurian Sestola-Vidiciatico Unit, consisting of Paleocene-Middle Eocene shaly-calcareous turbidites (Canetolo Complex), with a chaotic structure. Further on, after the Pian del Voglio exit, we'll take municipal and provincial roads

*Figure 10 - LISA is a ground-based portable apparatus consisting of a motorised sled, carrying a transmitting and a receiving antenna, which slides along a straight rail, about 3 m long . The synthetic aperture is realised by acquiring raw data at selected positions along the rail.. Photo by Nicola Casagli, 2003.*

that will head NW across the Sub-Ligurian Units to Castiglion dei Pepoli, and farther on, across the Ligurian nappe, to Montovolo where the first stop is planned.

## Stop 1.2:

**Montovolo.**

The Montovolo and Monte Vigese cliffs (approximately 1000 m a.s.l.) are composed of Miocene sandstones belonging to the Epi-Ligurian Bismantova Group. They are calcarenites and calcirudites deposited in a shallow marine environment (continental platform), highly fractured by systematic joints and mesoscopic faults. The two cliffs stand on the clayey units of the Ligurian Nappe and provide one of the best views of the Bologna Apennines. On one cliff stands a small one-thousand-year-old monastery. The large Lissano landslide lies at the foot of the slope and is almost completely visible. This is a very ancient earthflow showing all the typical features of a landslide: it is a few kilometres long, several hundreds of meters wide and it has the typical hourglass shape with the large and flat toe lapped by the watercourse. After each reactivation, its lateral convexity effectively channels rillwash towards the landslide's flanks, forming two streams that erode these flanks, thus creating the characteristic shape. The toe extends onto the main valley floor, creating somewhat of a meander in the river, often damming the valley and causing the temporary formation of a lake. The existence of a third stream that cuts the landslide body, running parallel to the flanks, suggests possibly two different yet now coalesced landslide bodies.
At this moment this landslide is considered dormant. Several hamlets and scattered houses have been built upon it during the last century; for this reason it represents an example of a local population unknowingly accepting a hazardous condition.

A brief presentation about landslide cartography and the use of satellite-based earth observation techniques (InSAR) will be held by the geologists of the Regional Geological Survey, utilizing computer projections.

Lunch is planned in the field in Montovolo. We will have grilled meat and typical dishes catered by a local restaurant.

**Itinerary C description** – From Montovolo (Stop 1.2) to Rocca Pitigliana (Stop 1.3):
This short excursion runs across the Ligurian Nappe and Epi-Ligurian Units: we will cross through the Cretaceous Argille a Palombini and then through the Miocene sandstone of the Bismantova Group. Stop 1.2 is located close to the sedimentary border between these units. The church of Rocca Pitigliana stands upon a small cliff composed of well-exposed Miocene sandstones.

## Stop 1.3:

**The Rocca Pitigliana monitoring system.**
***By: Matteo Berti, Monica Ghirotti, Alessandro Simoni, and Paolo Baldi (University of Bologna).***

This recurrent landslide represents a small but fruitful field test of several ground-based monitoring techniques: GPS, pore pressures, and inSAR.
This mudflow, rapid to moderate in speed, originates on a slope made up of the Cretaceous "Argille a Palombini" Formation. It is a unit pertaining to the Ligurian Domain, with block-in-matrix structure, made up of a grey clay-shale matrix, including blocks of limestone and sandstone. The features of the unit is clearly shown in the crown of this little landslide.
Long-term automatic monitoring has proved to be effective in answering some of the most compelling questions:

- what is the relationship between rainfall and landslide movement?
- how do groundwater pressures respond to transient rainfall?
- does rainfall influence groundwater only by modulating a steady or quasi-steady water table (slope-parallel flow) or by transient infiltration of water (vertical flow)?
- which is the most effective drainage system?
- were the preventive works successful?

A good understanding of the subsurface flow field would reveal rainfall effects on the timing and style of landslides, and it would hone model forecasting and countermeasure design.
The aim of the monitoring system is to detect the subsurface flow field in the headscarp area and to correlate landslide movements to rainfall events. The system consists of:

- 16 pore pressure sensors
- 3 soil moisture sensors (electrical capacitance)
- 3 tensiometers
- 1 rain gauge
- 1 surface wire extensometer

Data is recorded every 15 minutes and downloaded via GSM every 15 days.

Sensor recordings

The general picture that has emerged from the first month of data may be summarised as follows:

- Saturation extends very close to the ground surface in the wet season, when responses to single rainfalls at shallow depths are synchronous and relatively quick. During summer months, shallow sensors are dry and single rainfall episodes do not generate pressure pulses at any depth.
- Hydraulic heads tend to be higher in shallow sensors than in deep sensors, indicating that deeper portions are recharged by percolation from above rather than by slope-parallel flow.

Following each individual storm, sensors recorded sizeable pressure increases followed by a drop to a value generally greater than that before the storm. Shallow sensors tended to respond quickly (an approximately 10-hour-delay from the onset of rainfall), with a sharp rise and then a smoother decrease; deeper sensor responses tended to be delayed and less sharp.

**Movement detection and topographic surveys**

Beside wire extensometers, a combination of digital photogrammetry and different GPS techniques (static, fast-static and kinematic) were applied to the Rocca Pitigliana landslide. The accuracy achieved with these GPS measurements ranges from several millimetres to a few centimetres for static and kinematic observations respectively.

1- The initial “zero” situation of the landslide area is provided by the digital photogrammetric survey: it gives a high resolution DTM to which the subsequent DTMs obtained from GPS will be compared.

For the Rocca Pitigliana site two aereo-photogrammetric surveys were performed (the 1976 and 1993 images) and two 1x1m regular- spaced grid DEMs of the area were obtained. this configuration enabled us to obtain internal DEM accuracy ranging from 0.5 to 1m. The use of 22 ground control points measured with GPS in the same reference frame permits direct comparisons of the successively generated DEMs.

Moreover, in the headscarp area, a survey was performed by Laser Scanning. Measurement resolution was up to 5mm: processing resulted in high density DEMs accurate down to a few centimers. Subsequently, it was reduced to a 1x1m grid in order to perform a direct comparison with the landslide’s shape obtained from others surveys, and to check the accuracy of the other methodologies adopted.

2- GPS surveys are efficient and a precise means to determine the location of a point, as well as its movement through time. Static surveying methods require GPS receivers to be stationary throughout the measurement session and produce the highest possible precision. Static occupation times depend on network characteristics and may be reduced to about 10 minutes for baselines shorter than a few kilometres (rapid static method), as long as at least five GPS satellites per period are visible and a sophisticated post-processing method using all the observable GPSs is applied. The achievable accuracy is sub-centimetre for the planimetric coordinates, while the altimetric components may be strongly influenced by tropospheric conditions, giving lower precision, of the order of a few centimeters. In rapid static surveying, observations are made for a period of minutes on several marked points distributed along the longitudinal axes of the landslide: these provide both accurate time-series coordinates for kinematic techniques and, if periodically repeated, topographical variations along selected profiles.

3- Kinematic methods allow for data acquisition with a moving receiver; it is possible to determine the position of many points in a shorter time period, although with reduced precision (some centimeters). the kinematic technique provides models of the surface (a 1x1 metre grid) by measuring the positions of irregularly distributed points. Then, by comparing the elevation values of successive DEMs, the volume of material involved in landslide movement can be obtained. In March 2003 a kinematic survey was performed to obtain a DEM of the landslide surface. The moving GPS receiver was carried by an operator walking along the landslide recording the GPS signal at a sampling rate of 1 per second. The paths were planned so as to cover the whole active area, with a density of about 1 point per square metre, and to define the landslide perimeter. More than 40,000 coordinate positions were collected on the whole landslide area (about 160000 m2) in 12 hours operating time.

3- Finally, continuous observation of landslide movement is provided by two permanent GPS stations: the reference station is set up on a rock outcrop outside the landslide, and the other one on a pillar built at the head of the landslide area. Continuous data observations from the two stations, sampled at 10 second intervals, are automatically downloaded from the remote receivers via GSM to a server in our Local Area Network. Three-hour sessions are automatically run through once a day. The increase in the baseline length between the two permanent GPS stations gives information about the velocity of the monitored point. The achievable precision is the same as automated geodetic stations, but with a lower temporal resolution.

**Itinerary D description** – From Rocca Pitigliana (Stop 1.3) to Bologna.
The journey follows the national "Porrettana" road (S.S. 64) that runs along the Reno valley. At first we will encounter Chaotic Complexes of the Ligurian Nappe. Beyond the village of Vergato, the steep and overhanging cliff of Calvenzano marks the southern limit of the superimposed slabs composed of Epi-Ligurian Miocene sandstones of the Bismantova Group. Thick layers of calcirudites are evident, as well as their sub-parallel and horizontal attitude.
The high cliffs (Monte Sole, on the right), consisting of the Epi-Ligurian Sequence, are evident on both sides of the valley from Calvenzano to Marzabotto, and as far as the merging of the Reno and Setta Rivers. Some outcrops of clayey marls belonging to the Antognola Formation (Upper Oligocene-Lower Miocene) are evident near "Pian di Venola" (on the left), whereas the Reno River flows directly over Bismantova sandstone outcrops (on the right).

*Figure 11 - The ruins of Matilde di Canossa's castle, rising on a thick stratum of miocenic arenites pertaining to the Bismantova Group. The castle was one of the main centres of power in the Middle Ages, during the War of Investitures. Here, in 1077, the German Emperor Henry IV, barefoot, kneeled before and begged Pope Gregory VII to repeal his excommunication. Aerial photo by Giovanni Bertolini, September 2003.*

From Sasso Marconi (birthplace of Guglielmo Marconi, the famous scientist and inventor of the telegraph), the highway will bring us to the city of Bologna, passing through the intra-Apennine Pliocene clays and sandstones (observe the high cliff on the left, just in front of the highway entrance) and then through Ligurian and Epi-Ligurian Units. Bologna is situated upon the Po Plain, yet very close to the Apennine's margin. The city's southern edge and the St. Luca Abbey (which rises on the last hill, and can be seen to the right of the highway as we approach the town) lie upon the Epi-Ligurian sandstones of the Bismantova Group. The southern part of the city lies upon Calabrian sandstones, the western part upon coarse-grained Holocene deposits of the Reno River fan. The remainder is set on the clayey and sandy overbank deposits of the Reno and Savena rivers. In the city we will have a few hours to rest, and an optional tour, followed by dinner.

## DAY 2

**Bologna-Canossa itinerary**

Along the A1 motorway to Modena and then on local roads to Sassuolo, Cerredolo and Cavola (Stop 2.1). From there we'll continue the trip to Poviglio (Stop 2.2) by helicopter. We'll fly over the impressive landslides of Morsiano, Valoria, Roncovetro and others. From there we'll go by bus to the well-preserved medieval Rossena Castle, historically the property of Matilde, Countess of Canossa. In the castle, built on rough and steep ophiolites, we will have dinner and also lodge

**Topics of the day:** the risk-management of villages founded on large landslides, monitoring methods, and relocation of villages.

**Itinerary E description** – From Bologna to Cavola (Stop 2.1):
From Bologna to highway A1 ("Autostrada del Sole"), we will come to Modena, and then take regional and provincial roads to Sassuolo and Morsiano.
The first part of the journey will be quick as we cross the Po Plain. Past Sassuolo, we will follow the Secchia River Valley and enter into the Apennine hills,

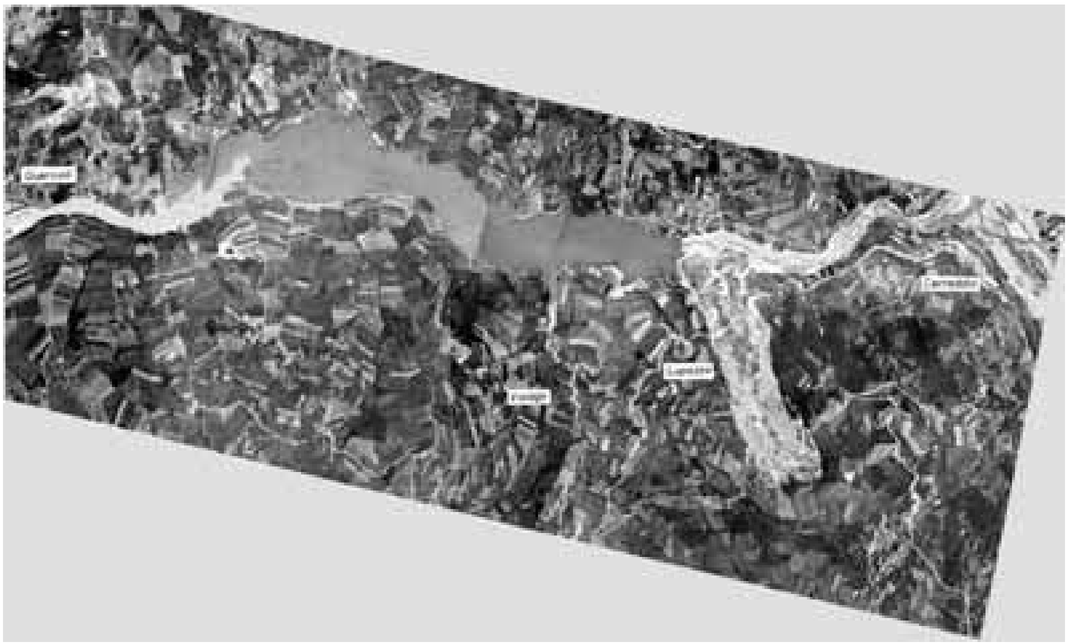


***Figure 12 - This photo was taken immediately after the detachment of the large rock block of calcareous flysch which dammed the valley floor and formed Lake Cerredolo. This lake lasted 8 months before it was drained. Photo by E.Carra, Parma, 1960.***

crossing through marine Pliocene sediments (“Blue Clays” and sands), and then Ligurian units (Argille a Palombini, Argille Varicolori, Arenarie di Scabiazza, Flysch ad Elminntoidi, etc.).

*Panoramic view I*: The Lupazzo landslide
Past Cerredolo and visible on the left, is the large body of the Lupazzo landslide, now inactive, which moved rapidly on April 23, 1960 (Figure 12). While we do not plan a stop at the Lupazzo landslide, it still merits description.
A large block of Helmintoid flysch and debris detached and slid along a downstream dipping layer. 13,000,000 $m^3$ of material accumulated and dammed the valley floor, forming the temporary Cerredolo lake (maximum impoundment 26,000,000 $m^3$ over a surface of about 2,000,000 $m^2$). At that time, there was discussion about reinforcing the blockage in order to make a natural dam. However, stabilisation measures adopted soon after the event by the *Genio Civile* led to the regulated drainage of the impoundment over six months. Since then, the watercourse’s profile and hydraulic regime have been considerably disrupted: a 15 m high step was left over, which afterwards was artificially stabilised by means of three successive dams. During its lifespan, Cerredolo Lake deposited some 1 million $m^3$ of clay and silt, only partially eroded by the river. The present wide valley floor sill hinders almost completely the passage of the coarser materials. It is still possible to find old postcards representing smiling people rowing on Cerredolo Lake.
We pass the Lupazzo landslide on a provincial road which follows along the valley floor. The valley slopes on both sides are composed of Ligurian complexes, while the valley floor is consists of fluvial gravel buried by clay and silt rapidly deposited in 1960 by Cerredolo Lake. If possible, a brief stop will be made to see these lacustrine deposits.

## Stop 2.1:
**Cavola, a Sub-Boreal landslide.**
Beyond Colombaia, the right bank of the Secchia River abuts the toes of three large landslides (Figure 13). The large Cavola landslide is one of the most impressive examples of how people can implicitly tolerate the risk associated with landslides. The large village of Cavola lies directly upon the landslide body’s ridge, which is 4 km long. The territory of the village has increased threefold in recent decades,

in spite of several local reactivation events which occurred before 1960, as well as several recent local reactivation events occurring near the landslide's perimeter. The apparently inactive main body of the landslide is moving slowly (a few mm/year) at a depth of 45 m., as demonstrated by inclinometer monitoring.

| *Depth (m)* | *Lab.code* | *yr.BP* | *Cal.yr BP(2⇧)* |
|---|---|---|---|
| -9 | Beta 135395 | 2970±40 | 3255-2990 |
| -24 | Beta 135394 | 3250±40 | 3895-3690 |
| -32 | Beta 137039 | 3720±40 | 4160-3690 |
| -37 | Beta 137040 | 3660±40 | 4070-4035 4000-3700 |
| -45 | Beta 135396 | 3600±70 | 4090-3700 |

***Table 1 - Radiocarbon dates on wood fragments found within the Cavola landslide.***

The 60-m-long continuous core, bored through the landslide body in 1997, is available and has been described. The landslide is mainly nourished by Ranzano Sandstones (Oligocene) that form the left side of the valley in which the landslide is lying. The right side is formed by Helmintoid Flysch. The vertical fault between them is directed N-S and buried by the landslide. The high clay content determines the mechanical behaviour of the descending mass. This landslide is one of the most investigated in terms of its evolution through time. Several wood samples were collected at different depths and allow the reconstruction of the landslide's evolution, starting from the lowest sample (45 m, near the base of the landslide) that dates back to 4090-3700 years before present (95% probability, calibrated according to Stuiver's curve). Younger remnants were found at lesser depths, as shown in Table 1.

The ages are chronologically in order from the youngest (on the surface) to the oldest (at the landslide's base) and testify to the layered internal structure of the litosome. The landslide is actually formed by the superimposition of several minor mudslides over a time span of approximately 1000 years during the Sub-Boreal period. More precisely, the landslide's growth corresponds to the so-called "Lobben oscillation" (Veggiani, 1986) or "notable cold episode" described by Rothlisberger (1986), when the climate was cold and wet, as demonstrated by the advances of the Fernau and Forni Glaciers in the Alps.

In historical times, the oldest record dates to 1100-1600 A.D., when the "old" church was "destroyed by a landslide" and a "new one", which still exists today, was built. The most recent failure of a large portion of the landslide body was in 1960, when a mudslide-mudflow descended from the crown to the present position of the village of Cavola,, destroying the hamlet of Morra and several scattered houses. Total displacements of several hundreds of metres were observed. The landslide body of the 1960 event is presently covered by vegetation and agricultural fields. People, completely unaware of the landslide's recent past, again want to build upon the landslide.

We are going to Cavola's football ground where we'll have our lunch. From there we'll take off by helicopter for a panoramic flight through the Secchia and Enza Valleys. The next destination: the Poviglio landslide. During the flight we will see several landslides. The most interesting ones are the Morsiano and the "Lavina di Roncovetro" landslides. Obviously, there will be no time for in-flight conferences, so the case-histories will be discussed on the ground before the flight.

*Panoramic view II:* The late-glacial Morsiano landslide.

The oldest landslide dated in the Reggio Emilia-Province is the Morsiano. It is also the most well-defined with a clear hourglass shape (photo on the cover). Total length is 4 km. The estimated volume is more than $100*10^6$ $m^3$. The Dolo river abuts and erodes the landslide's toe, thus revealing several well-preserved tree trunks (Figure 14) which were once buried by the mudslides and mudflows descending from the cliff of Mt. Penna. The slope's bedrock is composed of Hepiligurian flysch, Cretaceous in age.

The oldest trunk dates to before the Holocene (Table 2).

| *Depth (m)* | *Lab.code* | *yr.BP* | *Cal.yr BP(2⇧)* |
|---|---|---|---|
| -10 | Beta 125333 | 11390±70 | 13790-13670 13500-13145 |
| 0 | Beta 166926 | 3720±60 | 4240-3900 |

***Table 2 - Radiocarbon dates on wood fragments found within the Morsiano landslide.***

The landslide originated during the so-called Late-Glacial period, between the Last Glacial Maximum (18,000-20,000 yr. B.P.) and the beginning of the warmer and wetter Holocene period (11,800 cal. yr. B.P.). After the Last Glacial Maximum, a rapid increase of 7-8°C occurred at 14,700 cal. yr. ago and the temperature became quite similar to the present. A sudden increase of methane (40%) in the atmosphere testifies to the development of large wet areas, with an increase of 100% in rainfall. The Sapropel layer on the Mediterranean seafloor, dated between circa 12,000 and 6,000 cal. yr. B.P. by Geraga *et al*. (2000), is another clue that large amounts of freshwater were released by melting glaciers.
More precisely, this landslide originated during the Allerød cold fluctuation that lasted from 14,000 to 13,000 cal. yr B.P., occurring shortly before the Younger Dryas which brought about glacial period-like conditions until the beginning of the Holocene. Tree trunks outcrop on both banks of the watercourse. Some have a diameter of over one-half meter. Younger trunks were also dated.
As with the Cavola landslide, the Morsiano landslide cannot be considered as "relict" (Cruden and Varnes's sensu) despite its old age. Several sections of it have been repeatedly reactivated even in the last few centuries and decades. The oldest records for Morsiano, existing in the regional data-base of landslide events, dates back to 1631 and 1651. Between 1700 and 1725, the old church ,which dated to before 1300, was destroyed by "the landslide." The new church built shortly before 1725 still exists. Other partial reactivations date to 1880, 1959 and even today. An inclinometric tube, excavated from where the landslide is seemingly inactive, indicates slow, small movements which are directed down slope and are occurring now in the main body of the landslide at a depth of 25 meters.

These small displacements (2 cm in 4 years) are not evident on the surface, but are sufficient to maintain the shear strength at residual values along the sliding surface. The entire landslide is classified as "dormant" since only small portions have shown recent movement.

*Panoramic view III:* the Valoria landslide.
The active Valoria landslide lies below the summit of Mt. Modino and extends down to the valley bottom on the opposite side of the Dolo River. The most recent reactivation occurred in autumn 2000, and was an earth flow. The landslide's length is almost 4 km, and its volume is $8\text{-}10 \times 10^6$ m$^3$. The slope's bedrock is composed of helmintoid flysch (the upper part) and clayey Ligurian chaotic complexes. The 2000 event originated within a larger landslide body, clearly evident from the morphology. The major resultant risk was the threat of a large rock mass damming the river at the foot of the slope. In order to avoid the risk of downstream flooding due to a possible break in the dam, a monitoring system was immediately set-up. It is composed of four water-level gauges set within the watercourse and a web-cam focussed on the landslide's foot. All the data are transmitted daily via GSM.
To date, the threat of river damming has not become reality.

*Panoramic view IV*: the "Lavina di Roncovetro".
We are in the Enza Valley. The landslide extends from the top of Mt. Staffola down to the Tassobbio River, where it causes the formation of a small lake (Figure 15). Mt. Staffola is composed of Sub-Ligurian clayey calcareous-arenaceous flysch. The clay fraction is dominant from the mechanical point-of-view, causing the landslide to behave in its upper portion as a very-active fluid-viscous mudflow, with maximum velocities of up to 10 m/day. The upper portion (L1) is superimposed upon a thicker lithosome (L2), formed by several ancient mudflows. The upper lithosome is 1.5 km long and 10 m thick, while the lower part is 1 km long and almost 20 m thick. The upper part is continually replenished by clay and water entering from the crown, this may essentially be considered as a new formation (regressive), since soils which had been stable are now entering the slide zone. The lower lithosome is older and more compact, currently showing an "*en masse*" sliding movement: it had been dormant since at least 1936, while the upper lithosome has had frequent reactivations. Total collapse of both lithosomes together occurred after 1993 and is occurring even today.
The total volume of the landslide is about $3 \times 10^6$ m$^3$. The landslide reactivated completely in autumn 1993. It has since slowed, during the summer months, but has never completely stopped. The average speed of the upper lithosome is on the order of hectometres per year, while the lower one moves a few decametres per year. A unique feature is the long and narrow channel, 30 to 40 m wide and deeply carved into the bedrock, that links the depletion zone and the accumulation zone. The evident fluidity that characterises the upper lithosome is remarkable: the permanent fluid state is caused by high porewater pressures maintained by

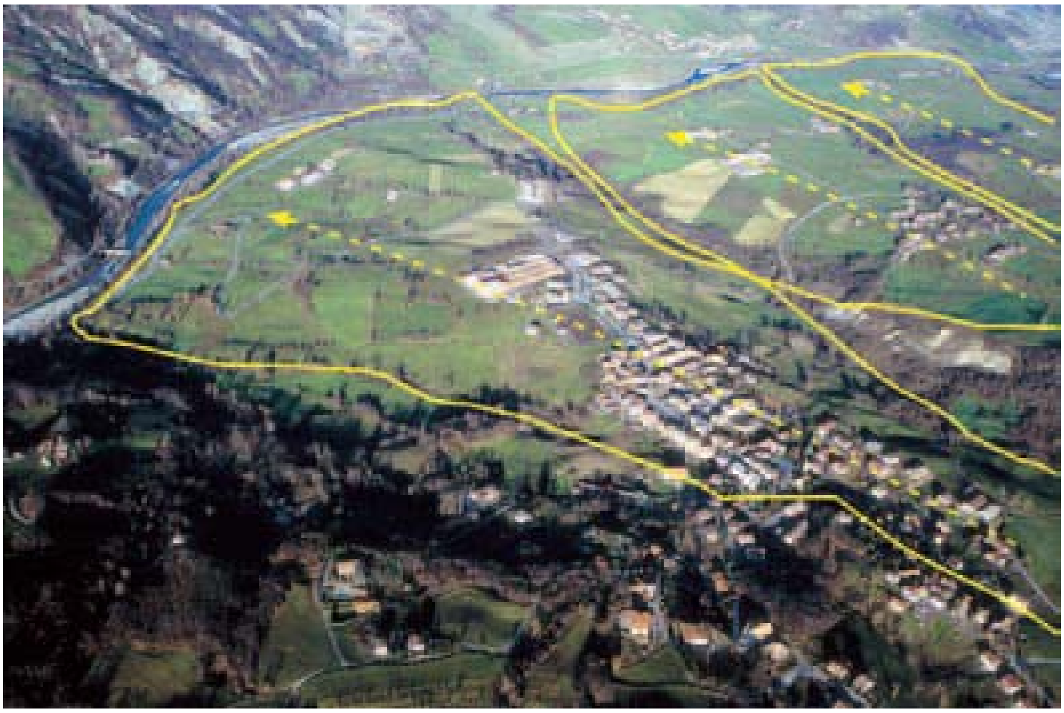


*Figure 13 - The Cavola (foreground) and other dormant landslides lying on the right side of the Secchia valley. Photo by Giovanni Bertolini, September 2002.*

*Figure 14 - These tree trunks outcrop at the tip of the Morsiano Landslide. They date to the Late Glacial period (circa 13.500 cal.yr BP). The landslide's clay matrix allows optimum preservation of the wood that appears fresh despite its age. Photo by Giovanni Bertolini, August 2003.*

highly-mineralised groundwater, mixed with methane, rising from the deep subsoil. This phenomenon is evident in the graph in Figure 16, which presents a daily record of water table depth (with respect to ground level). The open pipe piezometer is situated on the slope crest and the water table is found at the unusually shallow depth of only 1.0-4.5m. The graph shows sudden water-level rises of several metres, which cannot be directly related to the amount of precipitation (Bertolini & Gorgoni, 2001). Methane lowers the groundwater's density and facilitates its upward percolation. The state of fluidity varies over time and space, causing varying flow velocities inside the moving mass. Because of this, the narrow median channel is often completely empty and the two lithosomes appear clearly separated.

*Discussion:* Are we sure that an active landslide is more "dangerous" than a dormant one?
Cavola and Morsiano, as well as many others, demonstrate that landslides lying upon the region's slopes are products of previous periods when the climate deteriorated. In the present climate, landslide activity is mostly due to recurrent "pulses" of existing landslide bodies, alternating with relatively longer dormant periods. From this perspective, the upper part of the Roncovetro landslide is an exception, as it is related to a peculiar pattern of groundwater replenishment. More commonly reactivation occurs with a slow earth slide which is caused by the intrinsic instability of a more ancient landslide body.
The comparison amongst these landslides points out the main problems: anthropic factors and urban management. The longer the dormancy period (as with Cavola and Morsiano), the more people will build edifices and structures upon the landslide body. If landslide reactivation occurs more frequently (the Roncovetro example), the more people will be aware of the danger and therefore avoid building.
In conclusion, from the point-of-view of territorial management, our main problem lies in those landslides which show lower failure rates. The large Corniglio landslide (which we will see tomorrow) is the most obvious example: it was deceptively safe until complete reactivation in 1994, after nearly a century of dormancy.

## Stop 2.2:

**The extreme Poviglio solution: relocating the village.**

This small landslide reactivated in autumn 2000 after heavy rainfalls. The triggering factor was a total of 500 mm of precipitation, which is 25% of the annual

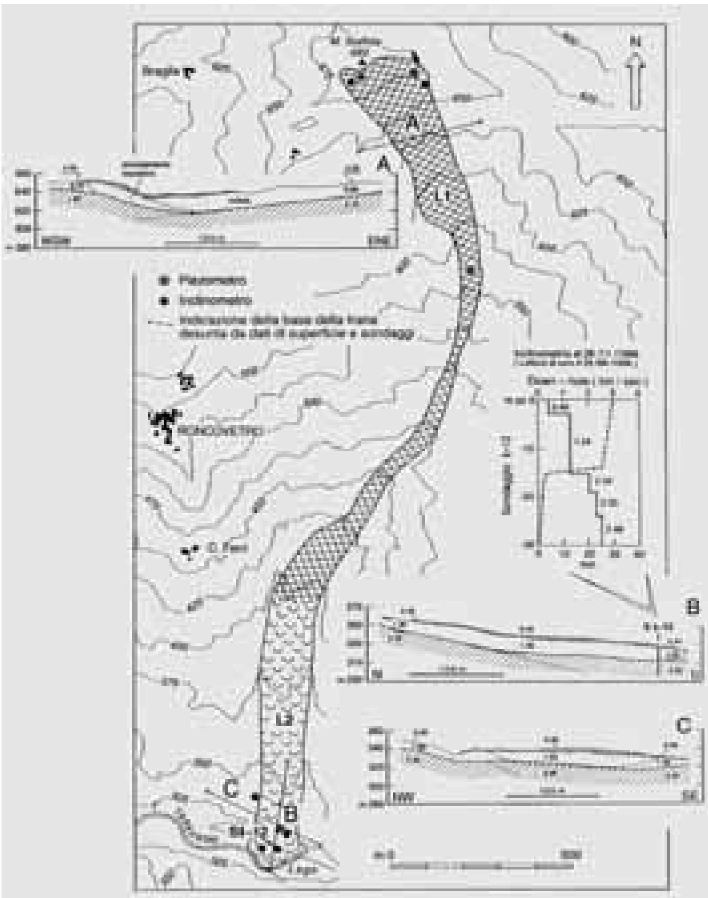



***Figure 15 - Plan view of the "Lavina di Roncovetro" landslide, showing the location of the two lithosomes (L1 is the higher and more active block, L2 is the lower and less active block). The measured seismic velocity (P waves) is approximately 0.80 km/s in L1 and 1.2 km/s in L2, while in the bedrock it is greater than 2.00 km/s. (from Bertolini & Gorgoni, 2001).***

average, that accumulated in only 10 days. The volume of the slope involved in the year 2000 event was about $2.5*10^6$ $m^3$. The average thickness of the block, as demonstrated by inclinometric gauges, is 35 m. The measured displacement during this event was approximately 60-80 m in the lowest part of the slope, and a few decimetres inside the village, which is located on the crown of the actual slide.
The crown has moved uphill approximately 50 m in the last 50 years. The region's historical records show that the same slope was affected four times in the last century. An older village had been completely destroyed in an event in 1947, and then was relocated to its present-day position, where it was damaged again in 1972.
In 2001, the regional government allocated funds for the construction of a new village, and a special technical committee found a safe site. The building of "New Poviglio" will take two to three years. In the meantime, 20 villagers will remain in the existing Poviglio thanks to a sophisticated monitoring system composed of automatically driven gauges (a motorised theodolite, a three-base extensimeter and one piezometer). All data are transmitted in real-time by GSM. In addition, satellite-based InSAR surveys were made by Telespazio s.p.a. Figures 17, 18, 19, 20 and 21 describe the one-year data output from the gauges.
The data shows that:

- the area affected by post-event movements is larger than the area affected by the 2000 event;
- a limited amount of rainfall may cause a noticeable rise in the water table;
- snowmelt causes a very large increase in the water table.

To conclude, it is important to stress the efficiency of the monitoring system and, in particular ,the value of the motorised theodolite; it has not failed during two years of monitoring.
The major problem related to the reconstruction of "new Poviglio" is that the new location must not be too far from the original site, because the inhabitants want to stay as close as possible to their farms. Another problem will be a new Regional law requiring the destruction of the old hamlet, even if the buildings are not damaged.

**Itinerary F description** - From Poviglio (Stop 2.2) to Canossa:
Large expanses of Epi-Ligurian clayey breccias (the "Canossa olistostrome," Late Oligocene-Burdigalian in age) are visible in outcrop within the large area of

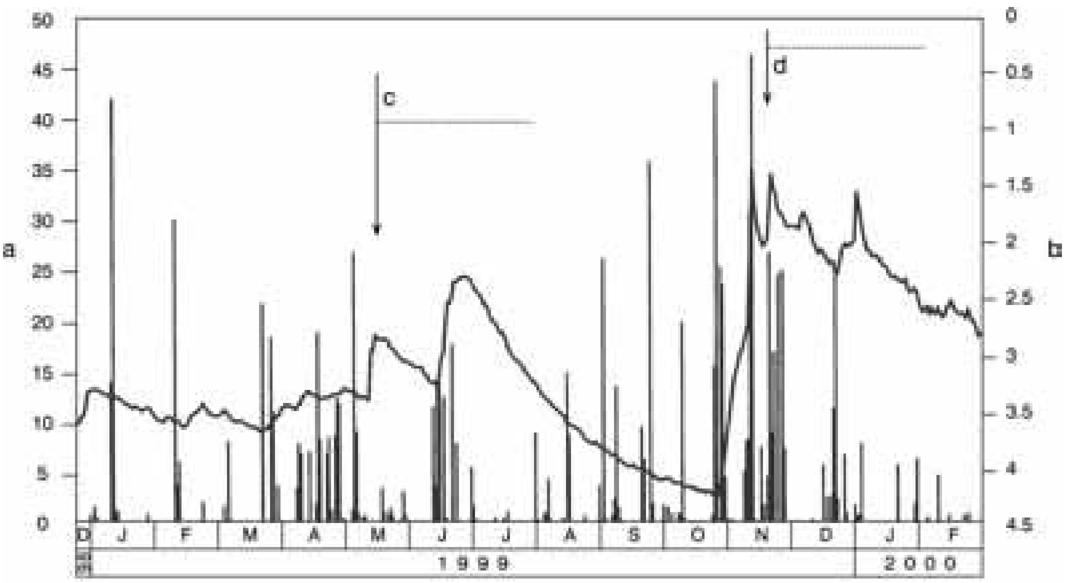



*Figure 16 - Lavina di Roncovetro: the graph shows the trend through time of groundwater level measured on L1 inside a 40-m-deep open-pipe piezometer with n automatic daily recording. It can be noticed that in concomitance with main reactivation (c and d), sudden uplifts of the water table occur (line-b), although they are disproportionate to the preceding rainfalls (histogram-a). This data, together with other factors discussed in the text, point to a groundwater feeding from deep subsoil sulphate waters (from Bertolini & Pellegrini, 2001).*

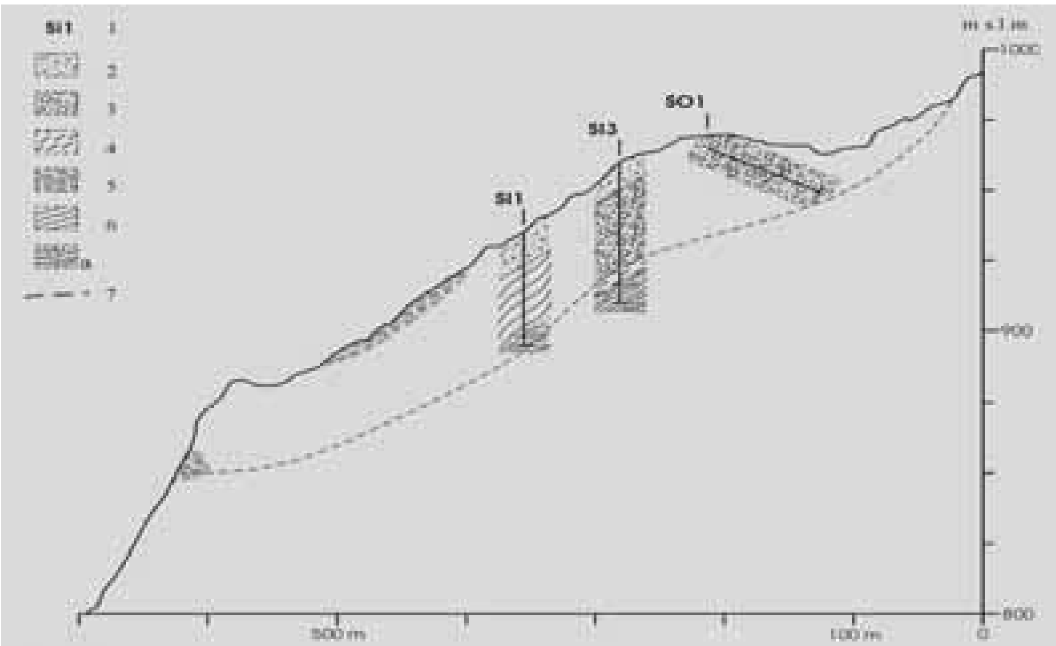



***Figure 17 - Schematic cross-section of the Poviglio landslide. Legend: 1. Continuous-core borings; 2. superficial] debris deposits; 3. poorly-consolidated clay breccia; 4. overconsolidated clay breccia; 5. Argille e Calcari di Canetolo (Eocene); 6. Arenarie di Ponte Bratica (Oligocene); a. fissured; 7. rupture surface (from Beretti, 2003).***

badlands, seen on the approach to Canossa Castle. The olistostrome is formed by submarine mudflows and debris flows, resulting from the reworking of the underlying Ligurian nappe and deposited in the satellite Miocene basin. The olistostrome is about 150 m thick and shows a block-in-matrix structure. Above it are sandstones of the Bismantova Group.

Canossa castle (Figure 11) sits upon a steep cliff formed by Miocene sandstones. It was the property of Countess Matilde di Canossa (1046-1115) and one of the most important centres of power in medieval Europe during the War of Investitures: here, in 1077, the German Emperor Henry IV, barefoot, kneeled before and begged Pope Gregory VII to repeal his excommunication. Matilde always was a valiant defender of the Vatican's power and that's why she is the sole woman to have the privilege of being buried in St. Peter's cathedral in Rome. She was glorified by Dante as an extraordinary example of an active life. In memory of those events, even today the saying "to go to Canossa" means to "humble himself" both in Italian and German ("nach Kanossa gehen"). The Canossa castle was almost completely destroyed several times during the last centuries. The history of the castle attracts many German tourists, although the view of the few remaining ruins is quite disappointing. Unlike Canossa, Rossena castle and the nearby "rossanella" tower are well preserved. They also were the property of Matilde. They are located upon a cliff composed of red ophiolite lying within the Chaotic Complexes of the Ligurian Domain. The name "Rossena" derives from the colour of the rock, *rosso* meaning red. Ophiolite is a mass of pillow lavas which was sheared off from the "Ligurian" ocean floor by the Ligurian nappe during its translational movement. Here we'll have dinner and lodge.

## DAY 3

**Canossa-Corniglio-Florence Itinerary**

From the Castle of Rossena, we cross the Po plain to Pannocchia, and then head upstream along the Parma River, passing through Torrechiara (notice the marvellous castle on the right), Langhirano (a region in which the characteristic "*Prosciutto di Parma*" is produced), and finally Corniglio.

**Topic of the day:** the large Corniglio Landslide.

**Itinerary G description** – from Canossa to Corniglio (Stop 3.1).

We will pass through Ligurian flysches (the Monte

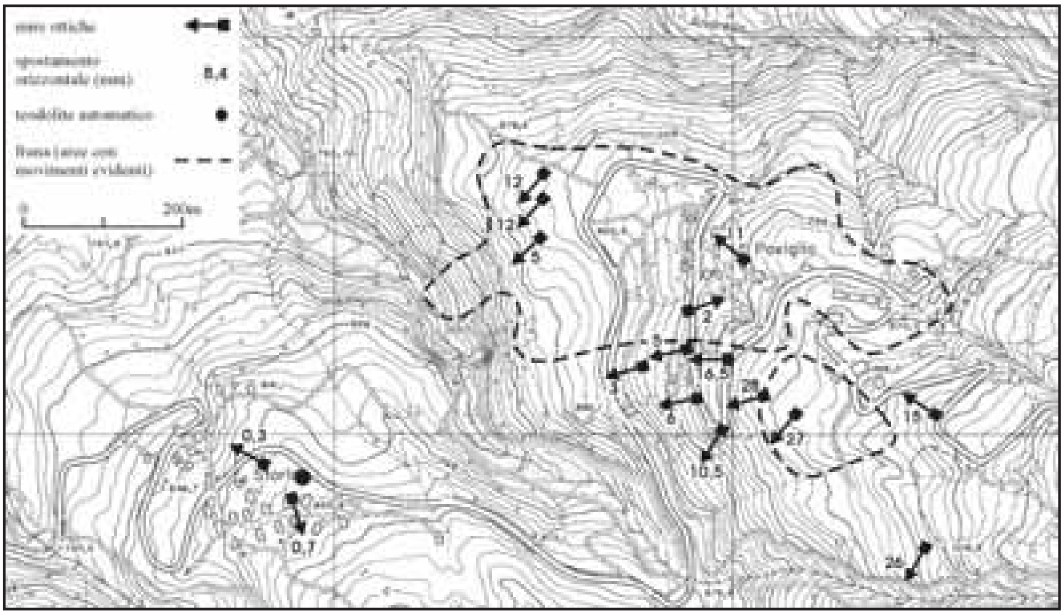



*Figure 18 - Poviglio landslide: the dashed line delineates the year 2000 landslide event. The vectors indicate the direction and total displacement (in mm) measured over one year by the motorised theodolite. The area involved by these post-event displacements is greater than the actual area affected by the year 2000 event (from Beretti, 2003).*

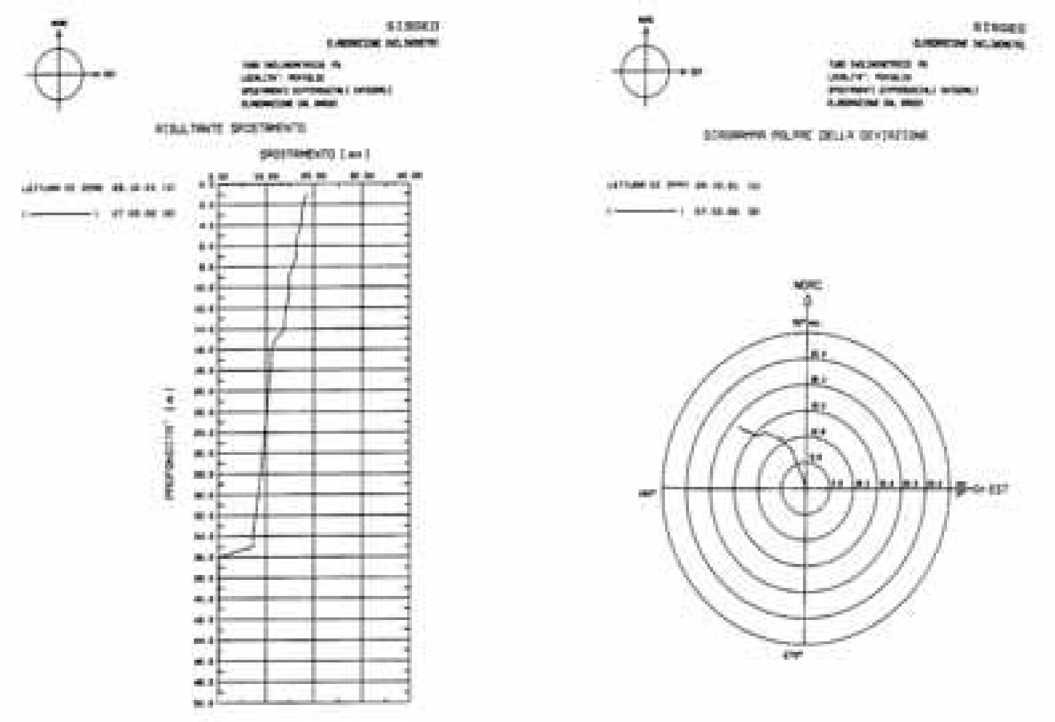


*Figure 19 - Poviglio landslide: Inclinometric curve showing a double rupture surface at depths of 36 and 15 m (from Beretti, 2003).*

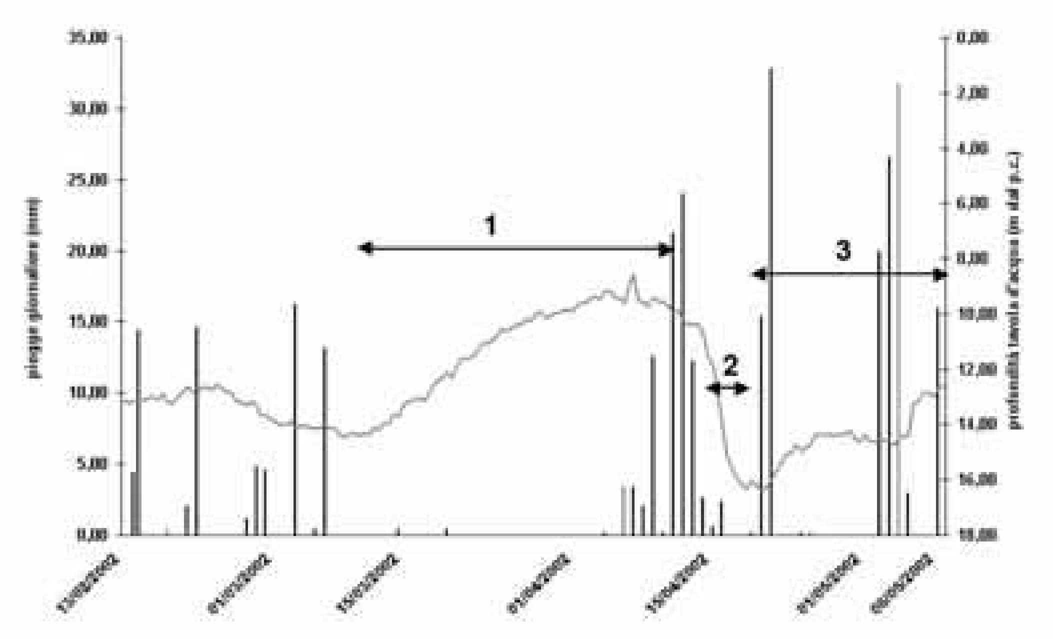



*Figure 20 - Poviglio landslide: comparison between daily rainfall (histogram) and water table depth (line). It is notable that 45-90 mm rainfalls over two-three days raised the water table by 2-3 meters (n. 3). The 6-metre long-lasting rise (n.1) is caused by the infiltration of snowmelt waters, followed by a sudden decrease (n.2) (from Beretti, 2003).*

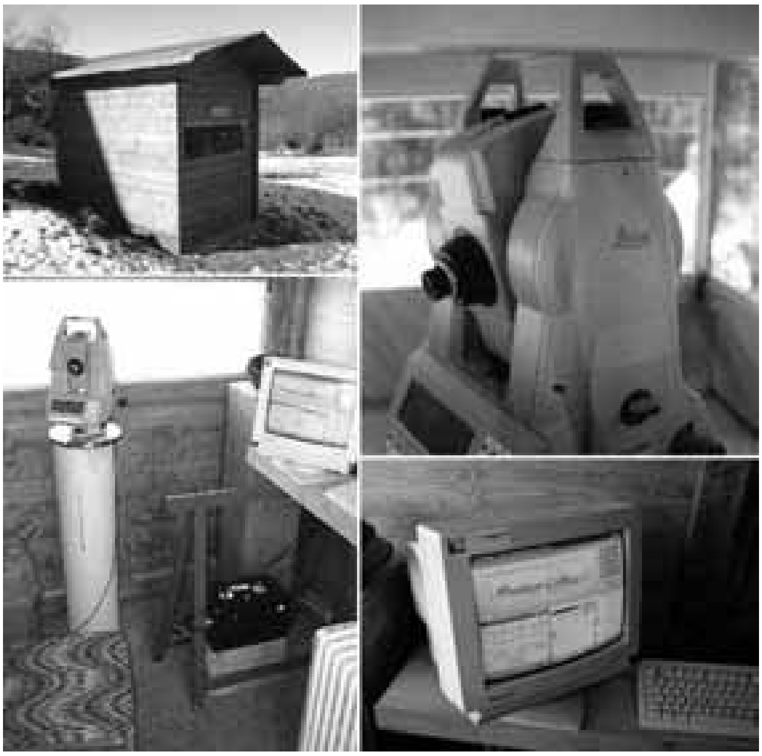


*Figure 21 - Poviglio landslide: the automatic motorised theodolite surveys the landslide's movements, enabling villagers to remain in their houses during the construction of the new village in a safer area. Photos by Giovanni Bertolini, September 2003.*

Sporno and Monte Caio Formations) until Ghiare. We then pass through the Sub-Ligurian Units (Canetolo Unit Auctt) of “Argille e calcari” (a clayey and block-in-matrix structured unit, alias the “Mèlange di Lago”), the Arenarie di Ponte Bratica Formation (thinly-bedded, arenitic Eocene turbidites), until we reach Corniglio.

## Stop 3.1:

**The large Corniglio Landslide**

***by Gianfranco Larini and Claudio Malaguti***

The Corniglio landslide is a large mass movement (Figures 22 and 23) which has affected the old village of Corniglio (700 m a.s.l.), a medieval hamlet, on several occasion during the past 400 years. Total reactivations of the landslide were recorded in the years 1612, 1740 and 1902, but the evidence collected shows that other movements had occurred in previous times, as documented also in the land registry of 1559, in which the term “Lama” is reported. Its present dimensions are considerable: over 3000 m long, 1000 m wide and up to 120 m deep, stretching from an altitude of 1150 m to 550 m a.s.l., in correspondence with the torrent Parma riverbed, in an area characterised by an annual mean rainfall of 1500 mm. After a long period of dormancy lasting nearly a century, in mid-November 1994 this vast landslide, classified as a slow, intermittent complex and composite landslide, resumed its activity striking once more the village of Corniglio. The landslide, which has developed within arenaceous and calcareous flysches overlying chaotically arranged clay shales and limestones, consists of multiple rotational-translational slides in the upper part, associated with earth flows (up to 20 m in depth). The total volume is about 0,2 $km^2$. A new phase of urban development started in the early 1970s and continued until 1994, with the construction of some 70 new houses and 5 industrial buildings, mostly built on the old landslide accumulation zone. The displacement measured during two recent reactivations, occurring in the 1994-1996, period showed that the landslide’s frontal part has undergone a displacement of about 50 m, with consequent partial damming of the Parma riverbed. Moreover, displacement of some centimetres has been recorded along the whole ridge made up of an arenaceous flysch (the Sub-ligurian Ponte Bratica Formation) delimiting the landslide’s eastern flank, where the rest of the village lies, with displacement vectors aiming both at the Torrente Bratica (eastward) and at the landslide’s body. Indeed, on this highly fractured arenaceous formation the main landslide movement has also caused dragging effects, with deep-seated rotational failure surfaces and displacements of up to some decimetres recorded simultaneously with each reactivation. Displacement vectors, variable both in space and in time, and sometimes even of opposite directions, have been recorded within the same inclinometer, according to the different tension states determined by the main landslide body.

The formations bounding the landslide body belong to the Ligurian and Sub-Ligurian sequences, and are made up of calcareous (Mt. Caio Formation) and arenaceous (Arenarie di Ponte Bratica Formation) flysches, chaotically arranged clay shales (Argille e Calcari, Melange di Lago) and Quaternary slope deposits of various origins. All the rock types cropping out in the area are highly tectonised, lithologically- and structurally-complex formations (“weak rocks”). They are therefore subject to intense and rapid weathering, eventually turning into clay matrix debris covers. According to water content, their consistency can reach the plastic or even liquid state, thus causing large earth flows. The landslide causes are ascribable to a decrease of geomechanical parameters, owing to weathering processes.

In the short term, the causes of instability result instead from an increase of porewater pressures, after periods of intense rainfall. The whole upper Parma River valley is affected by several landslides which are also connected to the Late-Pleistocene morpho-climatic processes, when two glaciations (Riss and Wurm) deeply altered the outcropping rock types by forming thick slope deposits. According to the evidence collected during the investigations carried out in the five past years, the landslide body does not seem to have ever reached truly stable conditions. In 1995, during a dormant phase, consolidation efforts were made: thousands of trees displaced by the landslide were cut down, new topographic mapping of the landslide was performed, the runoff network was re-established, draining trenches were dug to a depth of 12 m, and seismic investigations (refraction prospecting, down-hole and cross-hole tomography) were carried out.

Early in 1996, a large new detachment occurred along rotational slip surfaces. In February 1996 the formation of tension cracks in the ground and fissures in several buildings and streets of the village followed mass re-mobilisation of the ancient landslide body. One inclinometer showed moderate deformations along the whole tube, up to its lowest extremity (80 m in depth). Monitoring equipment has been further

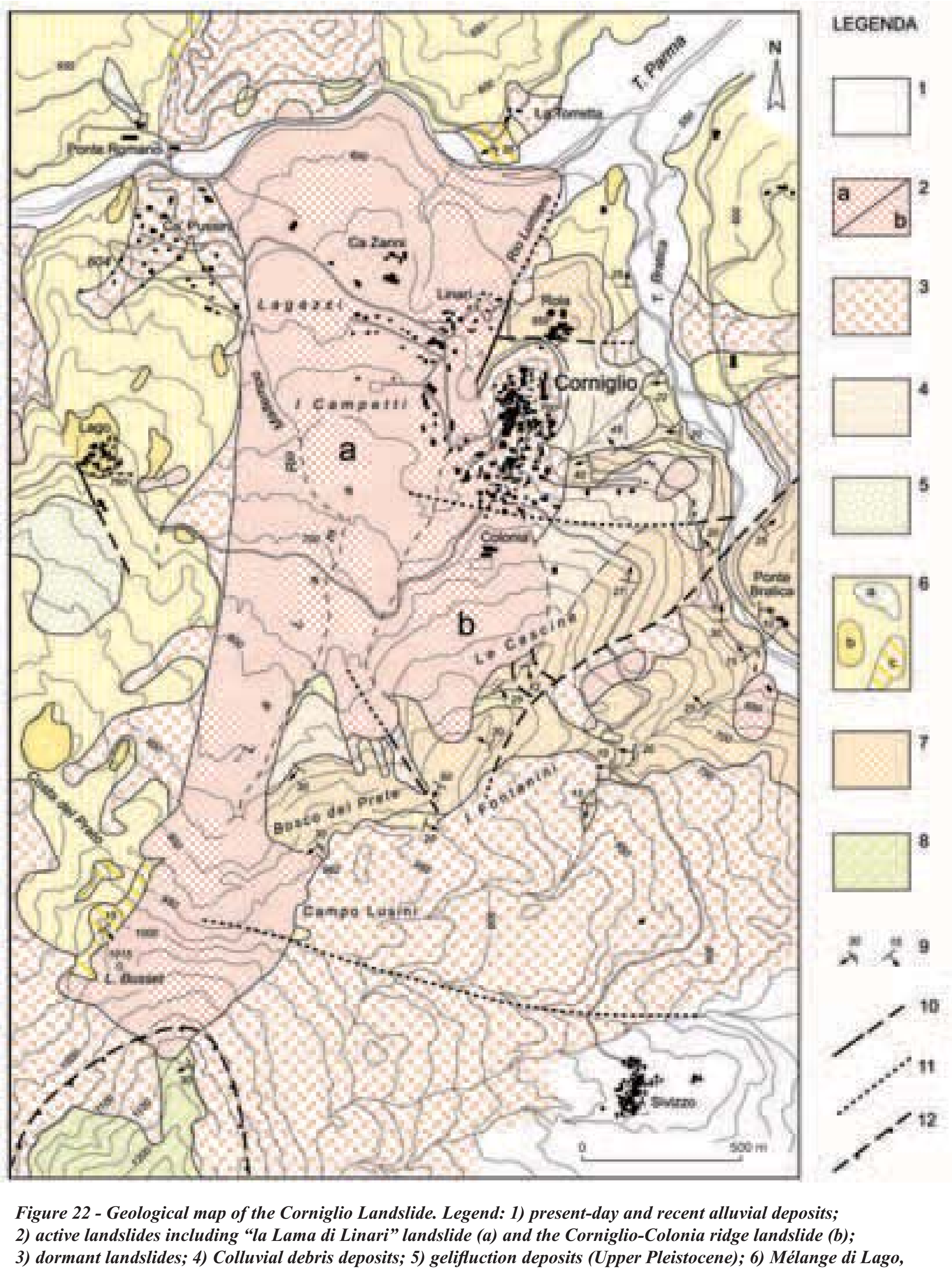



*Figure 22 - Geological map of the Corniglio Landslide. Legend: 1) present-day and recent alluvial deposits; 2) active landslides including "la Lama di Linari" landslide (a) and the Corniglio-Colonia ridge landslide (b); 3) dormant landslides; 4) Colluvial debris deposits; 5) gelifluction deposits (Upper Pleistocene); 6) Mélange di Lago, with calcareous fragments (a), with arenaceous fragments of the Arenarie di Petrignacola type (b) and Arenarie di Ponte Bratica type (c); 7) Arenarie di Ponte Bratica; 8) Mt. Caio Flysch; 9) layer attitude; 10) the fault and its possible continuation; 11) fault buried by slope deposits; 12) overthrust (from Larini et al., 2001).*

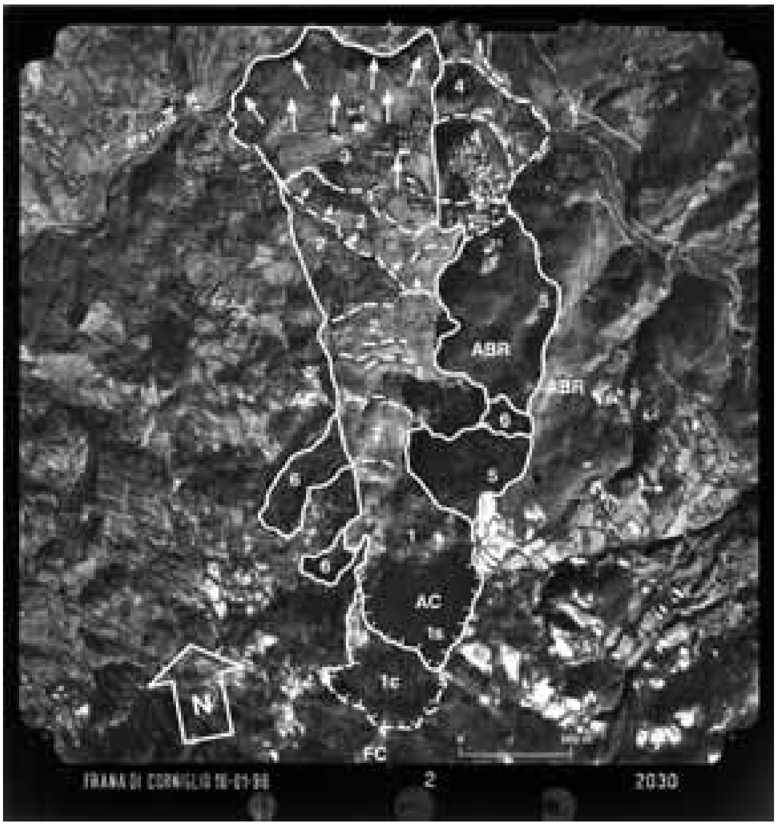



*Figure 23 - Aerial view of the Corniglio Landslide (16 January 1996, courtesy of Compagnia Generale Riprese Aeree). Italian Air Force authorization #.I-46 of 30/01/96. Legend: FC = Mt. Caio Flysch; AC= Mèlange di Lago; ABR= Arenarie di Ponte Bratica; 1c= crown zone; 1s= main scarp; 1= rotational slide (February-April 1996) along a failure surface deeper than 100 m; 4= portion of landslide not reactivated; 22= Lumiera area, where NNW displacements occurred in February-April 1996, afterwards partially annulled by displacement in opposite direction; 5= rotational slides within ABR, with formation of trenches and para-karst depressions; 21= Colonia area, showing displacements exceeding 80 m in depth; landslide sectors reactivated in 1902 (from Larini et al. 2001).*

improved with the setting up of an Automatic Inclinometric System and electric piezometers with automatic data acquisition to safeguard the most important built-up area. All the interventions carried out so far have been aimed at risk mitigation, including the Parma stream hydraulic risk resulting from the partial damming of its riverbeds. Consolidation measures, consisting of drainage systems, were carried out near Corniglio, where slower and low-intensity displacement occurred. Most of the costs for these restorative measures (which roughly amount to 20.000.000 Euros) have gone for interventions on the houses, storehouses and structures built on the landslide body during the past 30 years.

## Conclusions

During recent years the Italian territory has been hit by destructive landslides several times. Events including the Sarno, Valtellina, Soverato, Val di Stava and Corniglio landslides have caused the public to demand increased protection. People are now ready to accept new regulations and restrictions, but they want clarity from the geological community. This community has a responsibility: excessively prudent management could inhibit human activity in terms of growth, even when local conditions might permit such activity. On the other hand, the previous situation of deregulation led to extremely dangerous conditions.

***Recent progress***

During the last decade great progress has been made:

- today we have clearly identified the positions, shapes and dimensions of the region's landslides bodies;
- the large landslides represent the superimposition of several relatively more minor mudslides, which occurred during previous periods of worsened climate. They are a result of multi-phase events occurring over a period of several thousands of years;
- we know that the present-day landslide activity is directly related to the intrinsic instability of those ancient landslide bodies, and that their dormancy period may last months, years, or decades;
- above all, we have learned that the geological and recent history of the large landslides is important in order to understand their present-day behaviour.

***Problems***

Active mudflows and mudslides are not problematic in regards to their risk-management: the population understands the landslide-related hazard and avoid them. Instead, defining and explaining the hazard related to more inactive landslides, those not moving for years or decades, is more difficult. In most cases we can distinguish between "active," and "inactive" landslides, but we cannot yet distinguish "relict" (not dangerous) from "dormant" (still dangerous) landslides. A deterministic approach including stability analyses and numerical modelling is useful in order to assess the triggering mechanisms (causes), but it cannot forecast large-scale landslides.

***Future goals***

Historical research and real-time monitoring are very effective instruments in defining the rate of failure, or hazard, in probability. Other essential tasks include the continuous updating of the cartography , and measuring motion at an instrumental-scale by utilizing long-term monitoring and earth observation techniques.

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Back Cover:
*field trip itinerary*

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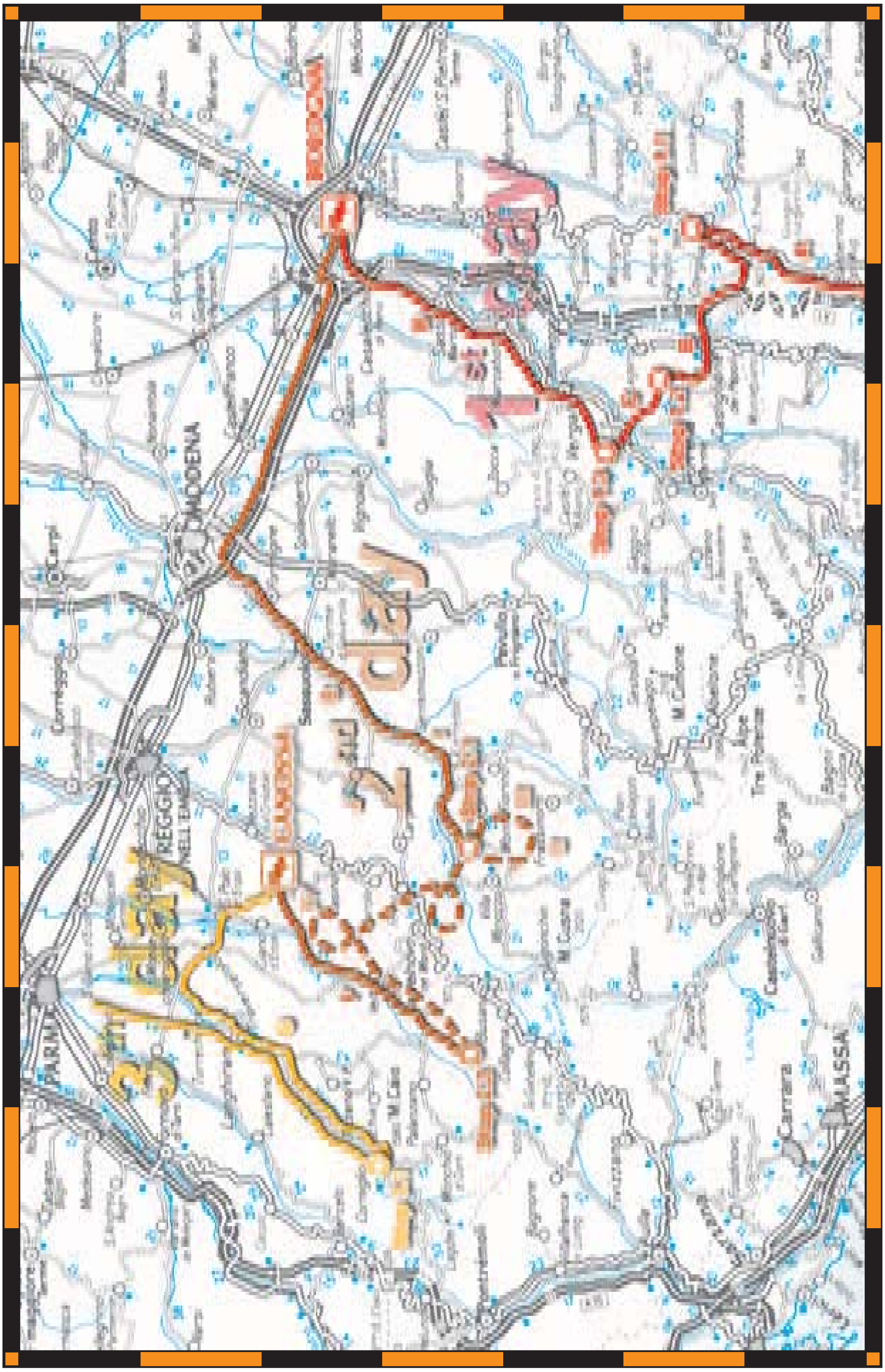
# FIELD TRIP MAP

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