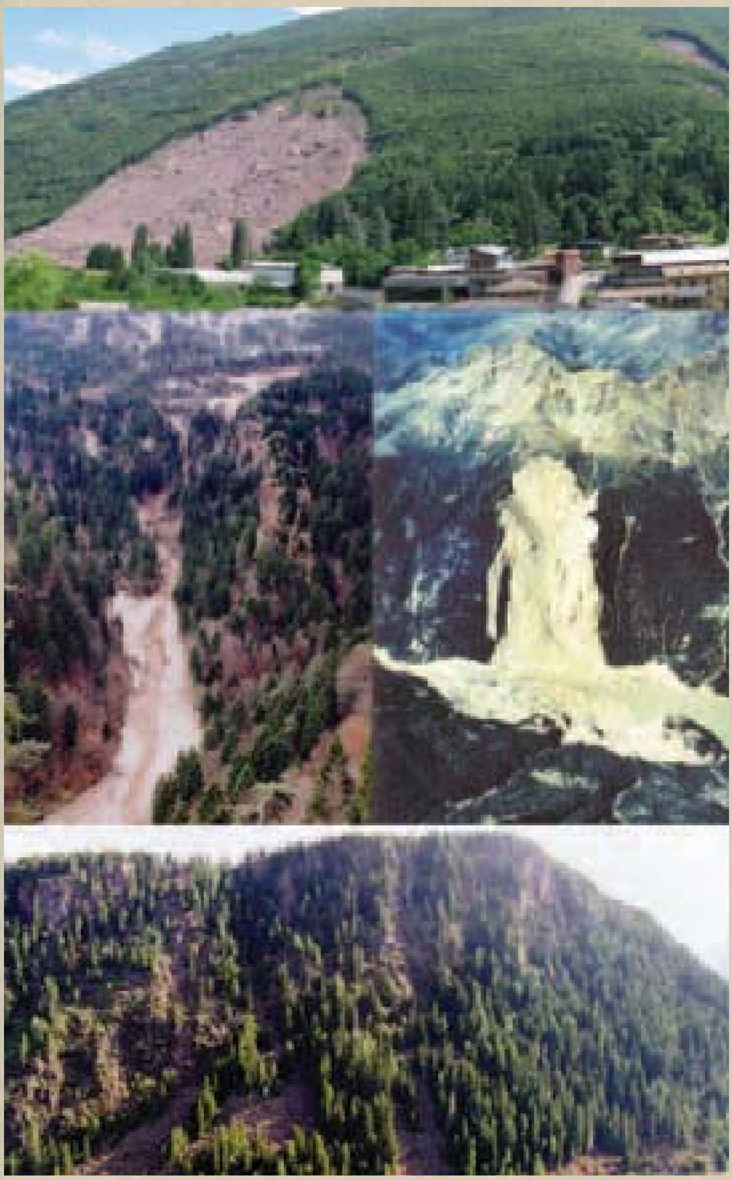
Field Trip Guide Book - P05

Florence - Italy
August 20-28, 2004

Volume n° 3 - from D01 to P13

32nd INTERNATIONAL GEOLOGICAL CONGRESS

ITALIAN ALPINE LANDSLIDES



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Post-Congress **P05**

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Front Cover:
"Panoramic views of four landslides visited during the field trip: Cortenova (SO), Nalles (BZ), Valpola (SO) and Forte Buso (TN)"

Leader: M. Amanti
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Introduction

The field trip described in this Guide is coordinated by the Italian Geological Survey (now part of APAT, Agency for Environment Protection and Technical Services) in collaboration with the Geological Surveys of the Regione Lombardia and Province Autonome of Trento and Bolzano. At most stops scientists from local Geological Surveys and/or Universities will act as expert guides.

Italy is a country where a large number of geological disasters often occur; landslides and slope movements in the years 1945-1990 resulted in more then 3500 victims and caused a large amount of damage. The Italian Geological Survey, together with the Regional Geological Surveys, has started a Project to realize an inventory of the landslides of the Italian territory (IFFI Project - Inventario Fenomeni Franosi in Italia), linked to a comprehensive database, to be used as a support for Decision Makers in natural hazard reduction (Amanti *et al.*, 2001).

The main purpose of the Project is to map all the landslide-related data already existing in Italy, in particular the ones collected by the Regional Administrations. To reach this objective it is necessary to validate, homogenize and integrate the data that will be stored in a database related to a GIS. The database will be realized according to the guidelines produced by a working group whose members belong to all the involved structures (National and Regional Geological surveys, Civil Protection Department, Environment Ministry, Agricultural Policy Ministry, National Council of Research).

Data related to landslides will be differently detailed, according to existing knowledge about the phenomena, their extension, the survey scale and interaction with the human environment.

There will be three detail levels; the first one will be compulsory and common to all the entries; it will contain the minimum required information about the phenomena (location, type of movement, source). The other two levels will show increasing knowledge coming from direct survey in the field (second level)

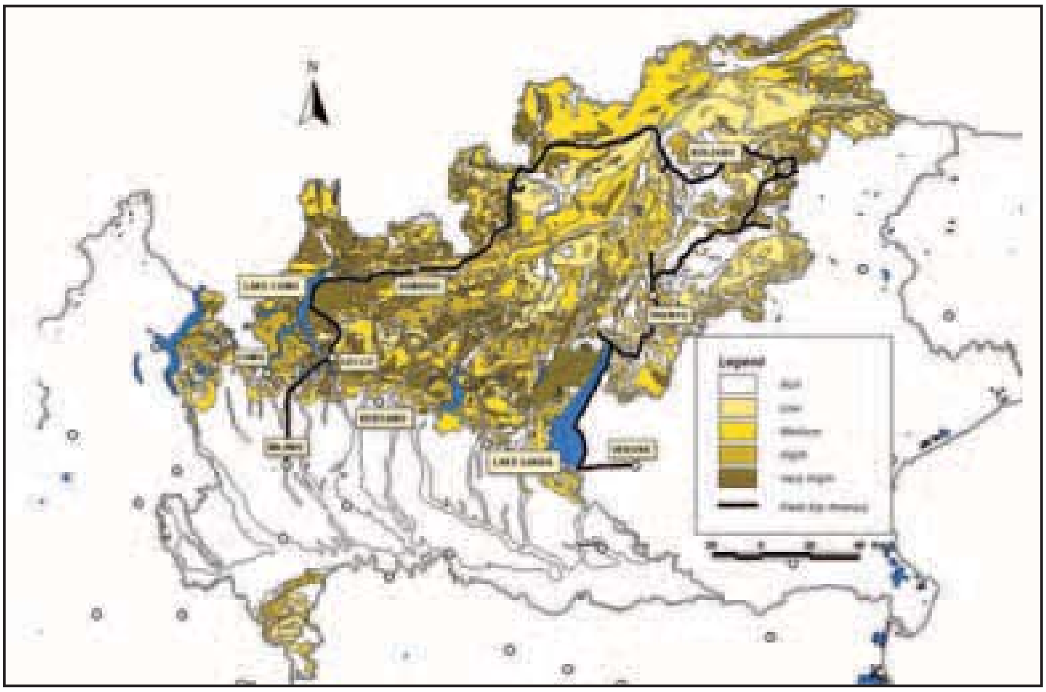


***Figure 1** - Map of the field trip area showing the landsliding index (n. of events per km², per each geological unit), calculated for a total of about 136.000 events existing in the IFFI database. No distinction among the different landslide types has been done. The total area is about 37.464 km². The average index for the total area is 3.6, while the index of the different units ranges from 0 to 20.*

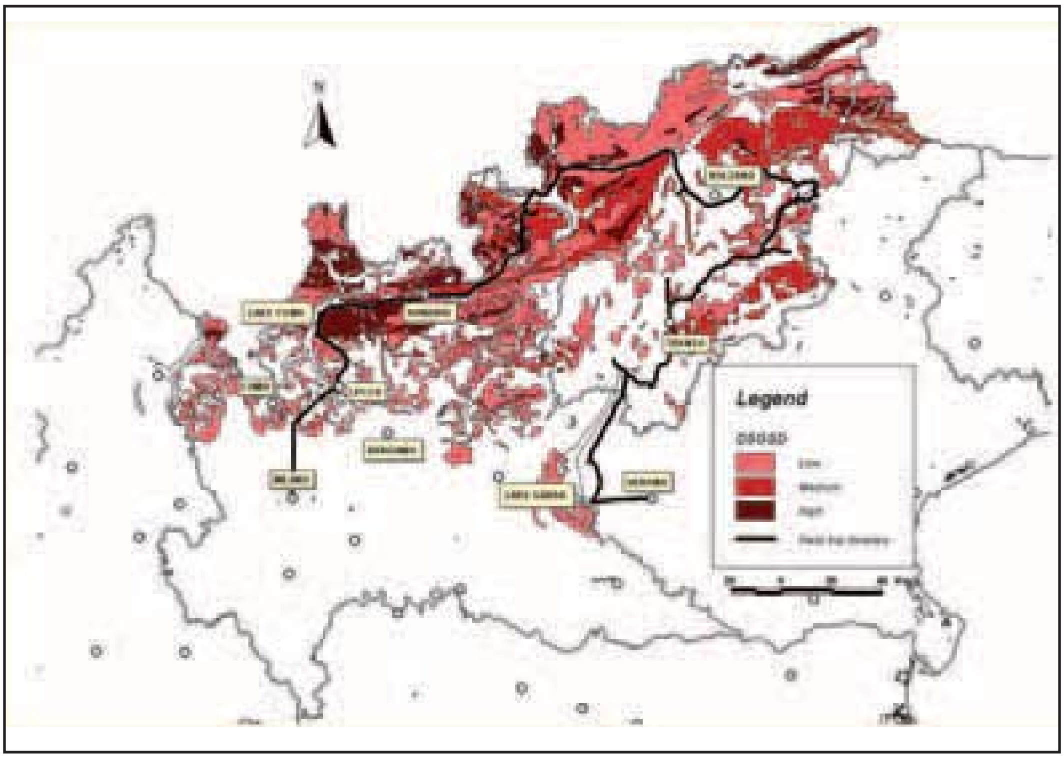


Figure 2 - Map of the field trip area showing the DSGSD index (n. of DSGSD per km2, per each geological unit), calculated for a total of 129 events existing in the IFFI database. The index of the different units ranges from 0.000 to 0.046

and more detailed studies and tests on the landslide (third level).
The reference point of each landslide (identified with geographic coordinates) will be the higher (above sea level) point of its crown; nevertheless all the landslides will be represented (if possible on a 1: 25.000 scale map), as a polygon.
All the data will be part of a Geographic Information System related to a database and will be visible on Internet. Periodical revisions of the data are scheduled to have an always up-to-date database. The inventory will be one of the instruments that the Geological Survey will use to better know the national territory and to evaluate, together with other geological and social-economical data, the hazard and risk areas on a regional scale.
At the moment we write this Guide, about one third of the project is finished, and the first sets of data are being validated.
In figures 1 to 4 it is possible to see how different types of landslides are distributed in the geological units outcropping in the Regions that we will cross during the field trip. To obtain the maps, the distribution of the PIFF (Identification point of the landslide, corresponding to the higher point of the crown) has been used, as well as the Italian Geological map at 1: 500.000 scale.
In figure 5 the number and types of landslides present in the area are shown.
While IFFI Project results can be very useful on a regional and national scale, they can also be the basis of a more detailed system for Regional Administration to use in the management of landslide hazard and risk at local level.
Many resources have been used in Italy in the last years to develop monitoring programs and detailed studies to evaluate hazard and risk; some of them have turned out to be very useful for risk reduction at site level and could be used as examples for similar areas in other locations.
The common use of real time data collecting systems and the availability of innovative technologies such as Differential SAR Interferometry, as well as the integration of ground and satellite based sensors,

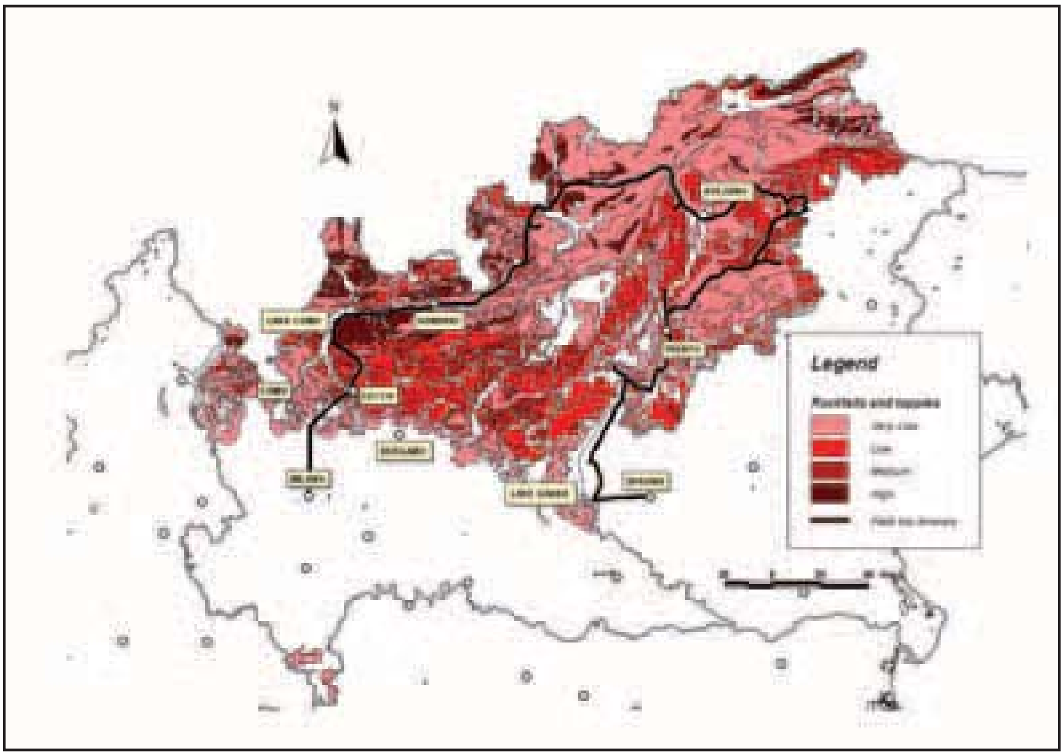


Figure 3 - Map of the field trip area showing the Rockfall/topples index (n. of Rockfall/topples per km2, per each geological unit), calculated for a total of 13365 events existing in the IFFI database. The Rockfall/topples index of the different units ranges from 0 to about 3.

proved to be a great step forward towards the correct landslide hazard management in Italy.

The aim of this field trip is to show some examples of peculiar landslides that occurred in Northern Italy in recent years, with a particular attention to the geological and morphological conditions leading to instability. The efforts that are being done to reduce landslides hazard on a regional/national scale (IFFI Project - Italian Landslides Inventory) as well as on a local scale (slope movements monitoring and warning systems) will be described too. Discussion will be encouraged, especially regarding the data survey criteria and standard definition, as well as the use of GIS in landslide hazard management.

Two northern Regions (Lombardy and Trentino Alto Adige) will be traversed, and some interesting sites will be shown. During the trip it will be possible to enjoy amazing alpine landscapes, to taste and buy local delicious food (Pizzoccheri, speck, ..), to drink wonderful wines and spirits (Pinot, Teroldego Rotaliano, Inferno and “grappa”, of course..) and to take a relaxing hot thermal bath in the Bormio Ancient Roman Thermal Baths.

Regional Geological setting

The Alps are a collisional belt that formed since the Early Cretaceous as a response to the diachronous closure of oceanic troughs (Liguride-Piedmont Ocean or Alpine Tethys; Valais Trough). These oceans started to open between southern Europe and the north-western margin of Gondwana (Adria/Apulia: Stampfli & Mosar, 1999) since the Early Jurassic as a side-effect of incipient sea-floor spreading in the Central Atlantic. The Alpine collision resulted in the juxtaposition of distinct tectonic domains, each of them belonging to a distinct part of the pre-collisional palaeogeographic scenario (Figure 6).

The Penninic Units consist of metamorphosed ophiolitic sequences, representing the ocean floor of the Alpine Tethys and Valais Trough, as well as of metamorphosed continental lithosphere of the interposed Briançonnais Terrane. The crustal elements from the southern passive continental margin of Europe are conventionally termed Helvetic

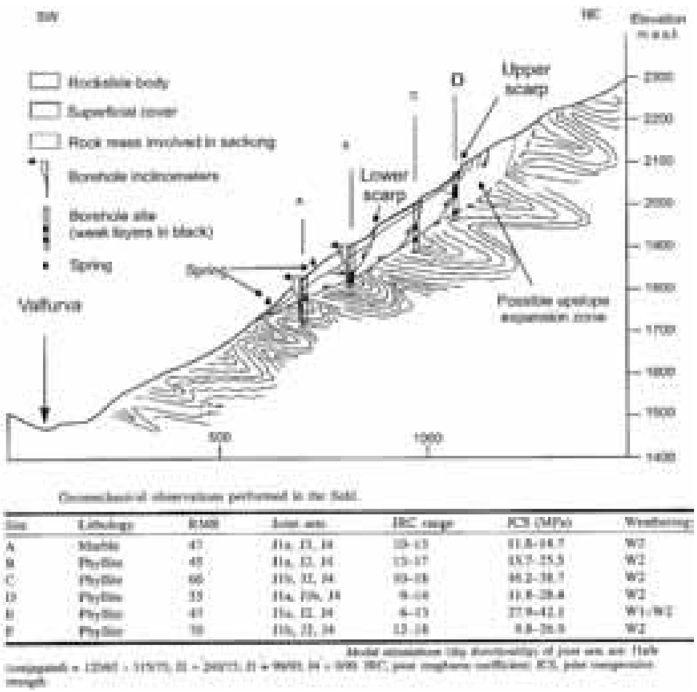


Figura 34 - Cross section of the Ruinon rock slide, showing morphological features and main surfaces in the rockslide. Information on the borehole drilled in the rockslide body is also shown (from: Crosta & Agliardi, 2003).

(Valdisotto) the Levissima mineral water bottling plant can be seen; the spring is right on the edge of the Stelvio National Park. **Table 3** shows the principal physical and chemical properties of the water.

On the approach to Bormio, the Valfurva opens up on the right; at its mouth is the alluvial fan formed by the Frodolfo Torrent, a tributary of the Adda from the left.

To the north, above the roofs of Bormio can be seen traces of several debris flows which struck the slope on 21 July 1992, cutting the main road to the Stelvio and also damaging the buildings in Bagni Vecchi.

At Bormio we turn right into Valfurva, on the left bank of the Adda, passing close to the old mediaeval bridge across the Frodolfo Torrent. The road along the valley floor skirts the Frodolfo towards Santa Caterina Valfurva.

Passing through the village of Uzza we cross the alluvial fan formed by the Frodolfo; this stream gives its name to the valley and washes down large quantities of detritus. In the past, the alluvial fan shifted the course of the stream from one side of the valley to the other, and the arrival of new large masses of detritus could cause the blockage of the valley.

A similar situation is to be found shortly afterwards, at the confluence of the Valfurva and the Val Zebr. This too is a zone critically prone to flooding.

Driving on, we find numerous support and restraining works on the left of the road, until we come upon a great reinforced earth wall (Figure 32), which partially protects the road from the rocks falling from the lower parts of the Ruinon slope, between the Fosso (creek) Cavallaro in the north-west and the Fosso (creek) Confinale in the southeast.

Stop 2.3:

The Great Ruinon Landslide

The next area of interest is that part of the right bank of the Frodolfo known as "il Ruinon". The name itself, which means "great ruin", is indicative of the state of the slope and the intensity of its past activity.

The landslide is considered active and the overall volume of rock involved in the displacement is in excess of 30 million m^3 (Figure 33).

A partial or total collapse of a mass of that magnitude would block the floor of the Frodolfo valley, cutting off the road to the important tourist centres in the Valfurva, such as Santa Caterina, and would probably create a lake upstream, with all the attendant dangers for the valley downstream, should the temporary dam collapse.

The slope is composed of formations belonging to the Upper Austroalpine basement, represented by Pre-Permian metapelites; locally, the basement is covered by earth of glacial origin and by fault detritus.

The landslide zone extends over a front of about 1 km, and presents two main nearly parallel escarpments, having a northwest-southwest orientation, lying respectively at altitudes of approx. 2,100 m and 1,900 m (Figure 34).

The still controversial interpretation of the phenomenon seems to suggest the presence of weak cataclastic zones, found in surveys at a depth of over 90 m from the level of the countryside.

One recent interpretation puts the great landslide in

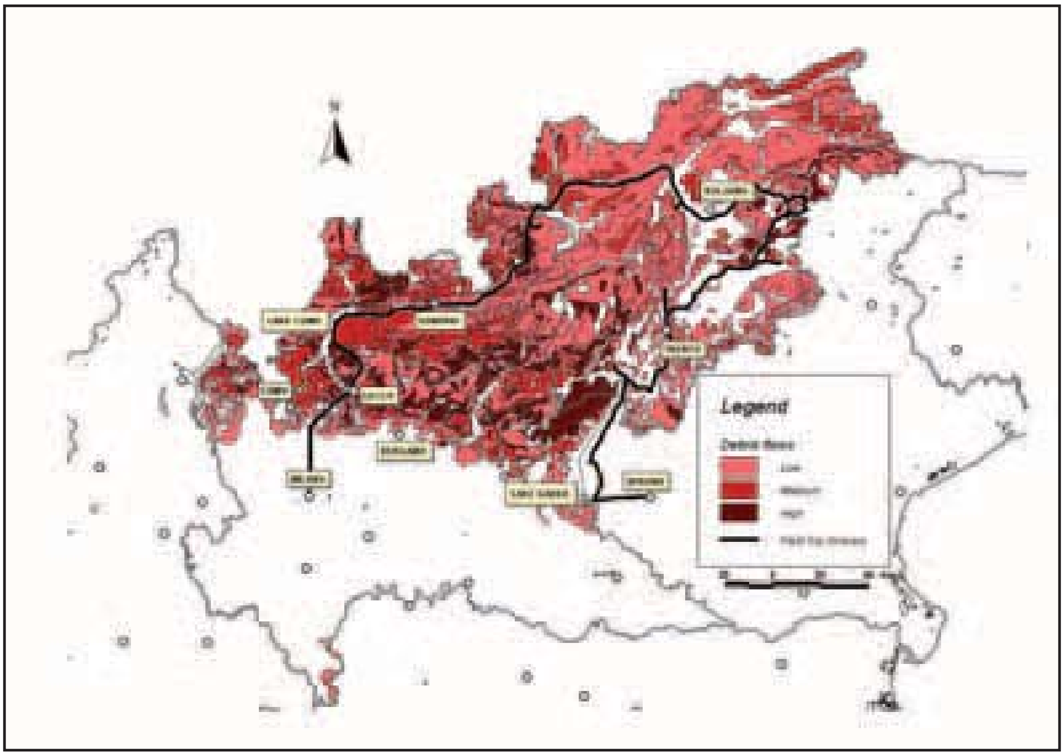


Figure 4 - Map of the field trip area showing Debris Flow index (n. of Debris Flows per km2, per each geological unit), calculated for a total of 73122 events existing in the IFFI database. The Debris Flows index of the different units ranges from 0 to about 12.5.

Units, whereas the Austroalpine Units are crustal elements from the northern passive continental margin of Adria. All these units underwent Alpine metamorphism up to eclogite facies.

The Southern Alps represent a more internal part of the northern margin of Adria, that during the Alpine Orogeny experienced only deep diagenesis to anchimetamorphism (up to the stilpnomelane facies) and extensive south-verging, thin-skinned backthrusting. The Southern Alps are bounded to the north by a prominent tectonic line, the Periadriatic Fault, commonly known in Lombardy also as Insubric Line or Tonale Fault. Mostly E-W trending in Lombardy and running on the northern slopes of Valtellina, some 500 m above the Adda River floodplain. The tectonic line goes on towards NE, from Tonale paass to Merano and Mules, near Vipiteno, where it shows again an E-W trend running along Val Pusteria up to Klaghenfurt and beyond.

It sharply separates the properly-called Alps (Austroalpine, Penninic and Helvetic nappes) to the north from the Variscan basement of the Southern Alps to the south.

Unmetamorphosed slivers of sedimentary and volcanic rocks from the Southalpine cover crop out discontinuously along the fault. A dextral strike-slip displacement of several tens to hundreds of kilometres is suggested by the westward drag of the southern fringe of the Masino-Bregaglia Pluton, whereas an upthrow of some kilometres for the northern hanging-wall is indicated by the sharply contrasting grade of Alpine metamorphism between the opposite blocks.

Nearly all of the transcurrent movements should have occurred before the Miocene, when the Periadriatic Fault was in turn sinistrally-dowthrown by the NNE/SSW-trending Giudicarie Fault System (GFS), creating a restraining bend that practically hampered any further transcurrency. According to Laubscher (1990), the southern end of the GFS bends westwards underneath the Messinian to Quaternary basin fill of the Po Plain to join the buried – and still active – thrust front of the Southern Alps (“Milano belt”). This would also account for the recent, moderate seismic activity recorded in the area.

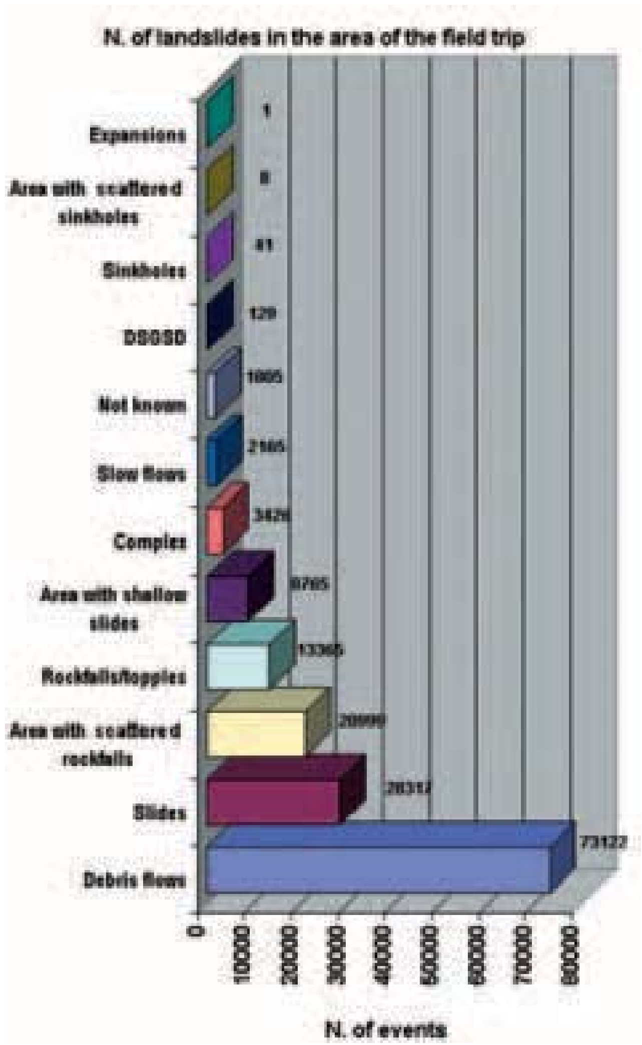


Figure 5 - Types and number of landslides in the field trip area

The proposed field-trip crosses the Southalpine and Austroalpine tectonic domains. They represent the result of tectonic deformation and metamorphism, under strongly contrasting conditions, of a correlatable sedimentary and – subordinately – volcanic succession of Late Carboniferous to Tertiary age, that unconformably overlies a Variscan crystalline basement. Basement rocks consist of prevailing metasediments (Bormio and Ambria Phyllites, Edolo Schists, Bressanone Phyllites, etc.) and subordinate metavolcanic and metaplutonic rocks: the age of the protoliths largely spans the Early to Middle Paleozoic, while the metamorphic peak is commonly constrained as Early to Mid-Carboniferous.

The metamorphic host rocks were intruded by Upper Variscan plutons during the Late Carboniferous to Early Permian (Sondalo Gabbro, Val Biandino Granodiorite, Cima d'Asta and Dos del Sabion Plutons; Bressanone, Ivigna, Monte Croce plutons).

The stratigraphic succession includes prevailing clastics and volcanics in its Upper Paleozoic part, whereas the Triassic succession is dominated by shallow-water carbonates; poorly-deformed carbonate platforms are magnificently exposed in the Dolomites, one of Europe's most beautiful natural monuments. In the central-eastern Southern Alps the Atesina Volcanic District (AVD) represents a volcanic sector, Permian in age, consisting of dominant ignimbrites with subordinate lava flows and domes. The thickness of the volcanic rocks is estimated up to 2000 m.

Generalized drowning of the continental margin since the Early Jurassic (Bertotti et al., 1993) resulted in the deposition of pelagic and siliceous limestones, as well as of nodular limestones in "Rosso Ammonitico" facies (Winterer & Bosellini, 1981), while the early stages of tectonic convergence and subduction are documented by the Cretaceous Flysch of Lombardy (Doglioni & Bosellini, 1987; Bersezio et al., 1993). In the Southern Alps these 250 Ma of geological history are recorded continuously enough to identify possible Global Stratotype Sections and Points, like Tesero for the Permian/Triassic boundary and Prati di Stuores for the base of the Carnian stage (Broglio Loriga et al., 1999); on the contrary, in the Austroalpine and Penninic Units the Alpine metamorphism strongly overprinted the stratigraphic succession, commonly reducing it to a poorly-discernable "cover" attached to strongly deformed Variscan crystalline nuclei.

Subduction-related HP, LT metamorphism is documented in the Alps by eclogitic blueschists dated to 130-90 Ma, as well as by detrital blue amphiboles in the Cretaceous Flysch of Austria and Sardinia (Polino

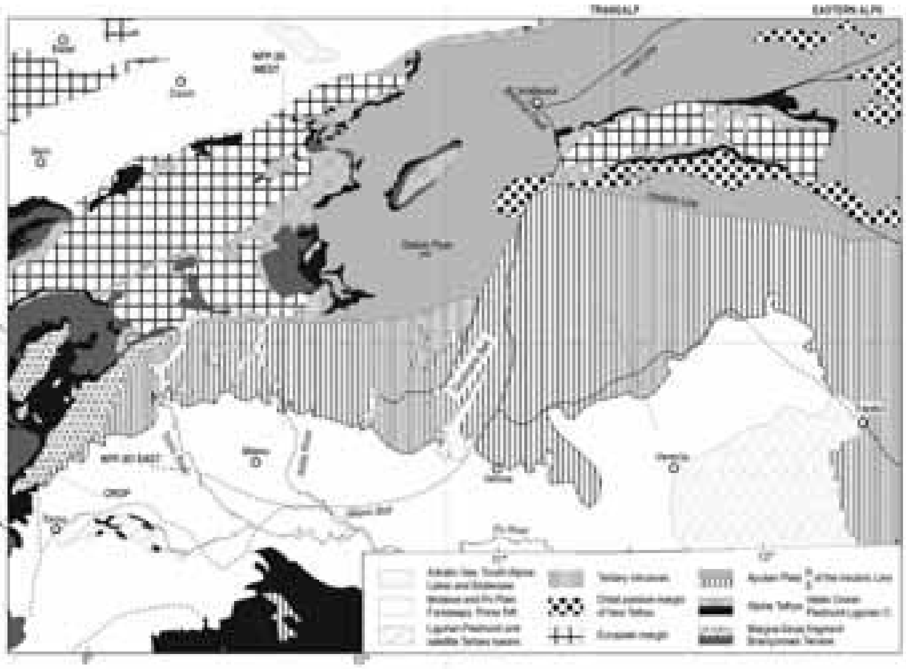


Figure 6 - Palaeogeographic framework for the Central Alps (modified after Schmid et al., 2003). Northern latitude and western longitude figures are reported. The names in bold refer to published deep seismic transects.

et al., 1990). Since the Middle Eocene (Lutetian), basalts to andesites have erupted from the western Po Plain subsurface (ENI/Agip Mortara-1 well) to the Veneto Magmatic Province. During the Oligocene, a widespread extensional tectonic regime, that favoured the intrusion of large calc-alkaline plutons (Adamello, Masino-Bregaglia; Vedrette de Ries, Rensen, Lago verde and Gran Zebrù), is best explained by slab detachment in the subduction trench (Stampfli & Marchant, 1995).

A stage of continental collision has been documented since the Late Oligocene by the deposition of fluviatile clastics (Swiss Molasse) and of foredeep turbidites (Lombardian Gonfolite Group) on – respectively – the northern and southern sides of the uplifting mountain range.

Desiccation of the Mediterranean Sea at the end of the Miocene resulted in a stage of enhanced erosion, causing the incision of deep canyons that were to host the main Southalpine lakes (Bini et al., 1978). After a new flooding stage in the Pliocene, onset of the major Quaternary glaciations since the late Early Peistocene (0.87 Ma: Muttoni et al., 2003) caused increasing sediment supply to the Po Plain foredeep. Sharp progradation of alluvial facies eventually caused the delta of the palaeo-Po to reach as far south-eastwards as Vasto (Abruzzo) during the Last Glacial Maximum. Holocene deglaciation also had prominent effects on the Alpine environment: glaciers had been a powerful sedimentary agent in terms of erosion and transport.

Therefore glacial and fluvio-glacial deposits crop out extensively; only in few great valleys, as Val Venosta, Val Pusteria, etc, it is possible to find very thick alluvial sediments up to 670 m (for example close to Merano).

Furthermore, glaciers also exerted an effective lateral confinement on rock slopes. The waning of ice caps resulted in a generalised release of this confining pressure, triggering large-scale, deep-seated gravitational slope deformation (Agostoni et al., 1993; Bistacchi & Massironi, 2001). In general, the location of major landslides shows however to have been controlled primarily by the distribution of Alpine tectonic structures (especially fault and thrust planes).

Field Itinerary

DAY 1

Milano - Lecco - Valsassina, Cortenova (Stop 1.1) - Bellano - Colico - Morbegno - Sondrio (Stop 1.2).

From Milan's central station, we pass through the city streets and take National Road 36 (SS 36) in a north-north-easterly direction, towards Lecco.
At km 36, and for the next 2 or 3 km, to the North the limestone quarry used by the Merone cement factory may be seen. The quarry has unearthed siliceous limestone and radiolarites of the Jurassic (Lombard Rosso Ammonitico/Sogno Formation, Selcifero Group and Maiolica: Cecca & Landra, 1994). This area suffered a landslide in 1997, which started in a clayey stratum inside the carbonate sequence. The side of the quarry has now been reterraced.
On the right, at around km 42, we can see the intra-morainal Lake Annone (224 m. above sea-level, perimeter 14 km., surface approx. 5 km², depth 11 m). At this point, the road runs over 100 m-thick peat soil, then through a series of tunnels, the longest of which (about 3 km) bypasses the built-up area of Lecco, where the traffic has made it very difficult to pass. This bypass took almost 20 years to construct, at an overall cost of more than 400 million euros.
The origin of Lake Como, like that of many sub-Alpine Italian lakes, can be traced to the glacial remodeling of ancient Messinian canyons (Bini et al., 1978; Finckh, 1978). In the Pleistocene, the whole basin was covered by a large glacier which, beyond the southern branches of the lake (Lecco and Como), reached as far south as the Brianza area, where it created the present-day morainal hills. The lake formed in the trough occupied by the glacier, whose slow passage is testified to by the rounded rocks which still bear the signs of erosion and by numerous erratic blocks, especially on the high ground of the Larian Triangle.
Inhabited since prehistoric times, the Lake Como area has always been a very important crossroads between the regions of the North and the Po Plain. For centuries, the region suffered invasions and dominations, because of its strategic position which gave easy access to the Maloja and Spluga passes.
In the nineteenth century, Lake Como was made famous by the novel "The Betrothed" by the Milanese author Alessandro Manzoni (1785-1873), which was set in the area around the Lecco branch of the lake.
Lake Como, also called Lario, covers 146 km^2 and is the third-largest lake in Italy after Garda and Maggiore. Its characteristic inverted-Y shape is formed by the three branches of: Colico to the north, Lecco to the south-east and Como to the south-west. It has a total perimeter of 170 km and a maximum depth of 410 m (the deepest lake in Europe). The lake is entirely surrounded by mountains, the highest of which is Mount Legnone (2609 m), above Colico. The only island in the lake is Isola Comacina, in the Como branch, in front of the town of Sala Comacina. **Figure 7** compares schematic sections of the main Alpine lakes.

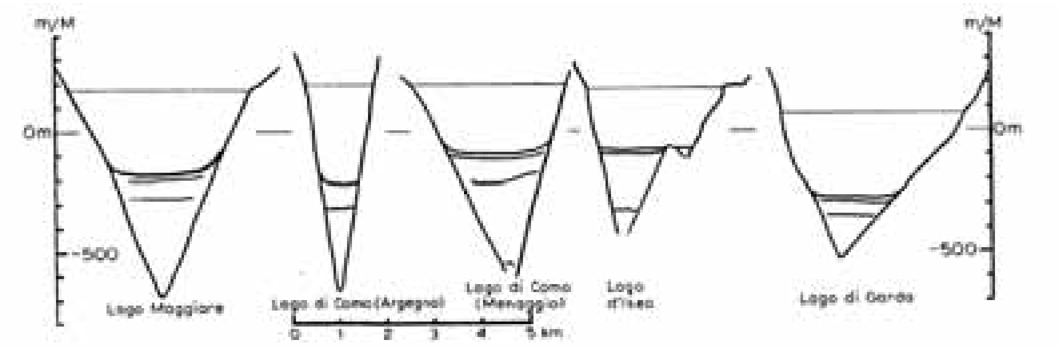


Figure 7 - Schematic sections of the main Alpine lakes (Finchk, 1978)

From the National Road, we turn into the Valsassina Provincial Road 62 (SP 62), which runs through part of the built-up area around Lecco. In particular, we pass the foot of Mount San Martino, which can be seen on the left, an area subject to rockfalls (in February 1969, the collapse of 10-15,000 m^3 killed 7 people) which threaten the dwellings below. The Corno di Medale, a little farther on, is one of the highest peaks

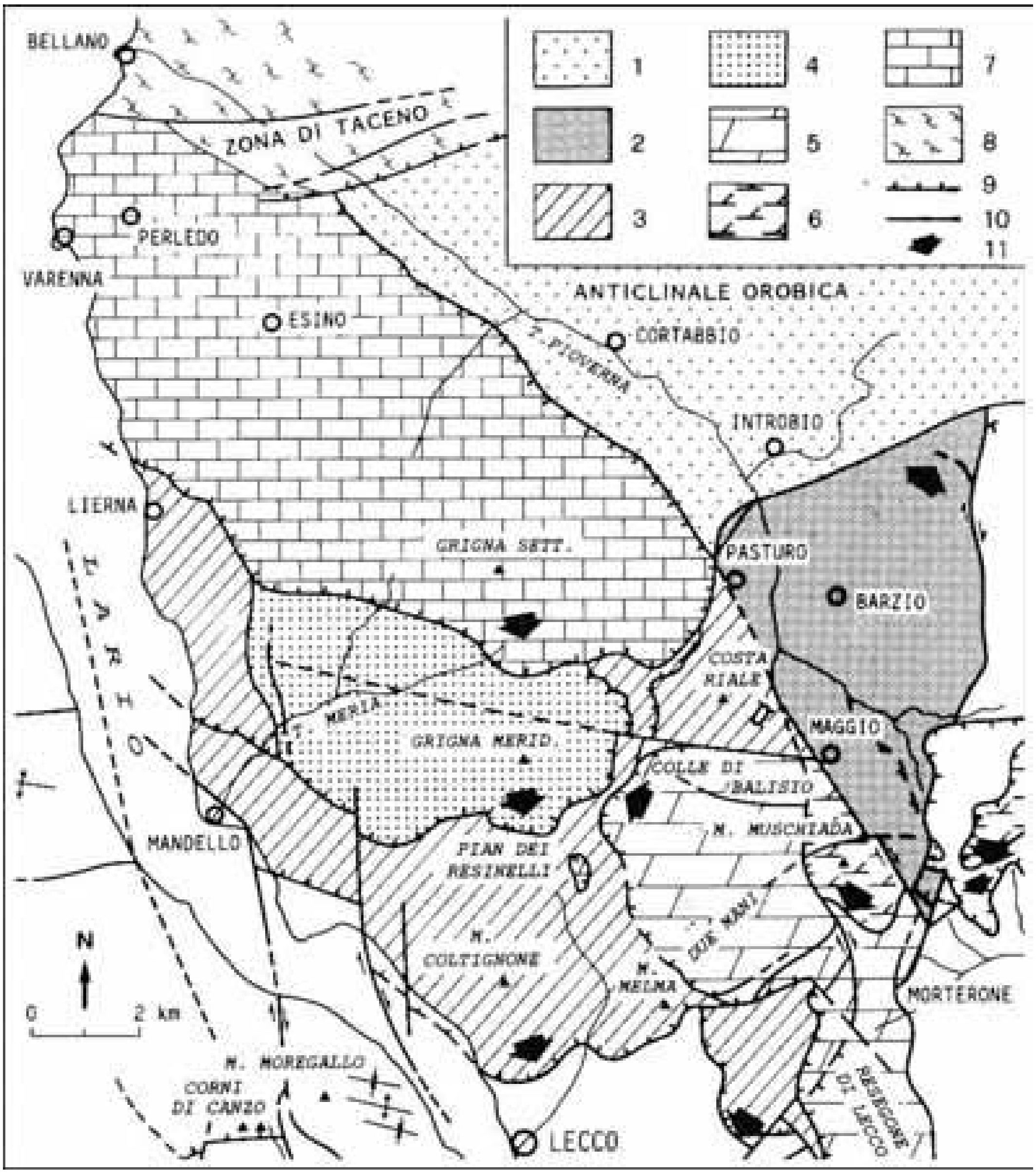


Figure 8 - Structural map of the Grigne group and the Valsassina 1) Orobic anticline Paleozoic. 2)Barzio zone medium and upper Trias. 3) Coltiglione Slab. 4) Southern Grigna slab. 5) Resegone-Muschiada Slab. 6) Due Mani slab. 7) Northern Grigna Slab. 8) Orobic basement. 9) Thrusts. 10) Faults. 11) Direction of the overlapped slabs.

in the massif, which is composed mainly of dolomitic limestone from the Middle Triassic, with indistinct stratification, belonging to the Esino Formation. In this huge mass, many fracture systems encourage the detachment of material which collapses onto the layer of detritus below. The almost vertical rock walls reach a height of 330 metres in places.

This area was studied in detail by the Regione Lombardia, at the time of the European Interregional IIc project called "Falaises" ["Cliffs"] (AA.VV., 2001).

The road is very narrow and passes between close rows of houses. A bypass tunnel to avoid the town altogether is expected to be completed in a few years.

At the end of the rise, a plateau known as Pian Balisio is reached; this stretches out longitudinally, into the Valsassina. The nearly vertical walls bordering the eastern side of the level ground are made of ruiniform Dolomia Principale.

Noteworthy in the more recent geological history of the Valsassina is an important evolution in the flow of the Pioverna Torrent. Before the middle Pleistocene, this stream flowed north-south, in the direction of Lecco through the Balisio canyon and the fossil valley between Ballabio and Laorca. Sedimentary analysis (clastic sediments from the Valsassina imbricated in one direction by the N-S current) of the Ponte della Folla Conglomerates (Bini, 1990) demonstrates this inversion. In the middle Pleistocene, tectonic movement led to a change in the valley's structure, so that the course of the Pioverna was deviated toward the north.

Beyond the Balisio pass (723 m.), at the northern end of the level stretch, one enters the Valsassina, the largest of the eastern valleys of the Lario. It is bounded by the Grigne group to the west, and the Tre Signori peak to the east; the Pioverna runs through it, joining the Lario at Bellano. Once famous for its steel industry, the Valsassina nowadays is notable for the production of cheeses, which are matured naturally in the local caves (called "casere" or "crotti"), and for tourism, both in summer and winter. The little village of Morterone, at the foot of Mount Resegone, with its 27 inhabitants, is the smallest municipality in Europe.

Near Introbio are the noteworthy Troggia Falls, first described by Leonardo Da Vinci and celebrated by the Abbot Antonio Stoppani in his famous work "Il Bel Paese" ["The Beautiful Country"].

Classification	Nat. mineral water
Spring height	1935 m a.s.l.
Total Dissolved Solids mg/l	50,5
Acidity (pH)	7,4
Hardness F°	3.3
Silica (SiO2) mg/L	7,2
Sodium (Na+) mg/L	1,6
Potassium (K+) mg/L	0,7
Calcium (Ca++) mg/L	10,5
Magnesium (Mg++) mg/L	2,2
Chloride (Cl-) mg/L	0,4
Sulphates (SO4--) mg/L	4,8
Bicarbonates (HCO3-) mg/L	39,5
Nitrates (NO3-) mg/L	3,2

Table 1 - Principal properties of the Daggio springwater. Data provided on the label.

The road runs beside the Pioverna and crosses it several times until it comes, after a broad level stretch of ground, to the Chiusa di Baiedo, a narrow in the valley which would have been ideal for the construction of a dam if Pasturo at the bottom of the valley had not grown to such an extent and if the basin upstream had been broad enough to justify the expense.

Figure 9 - Memorial stone for the victims of the 1762 landslide in Gero e Barcone

At Chiusa di Baiedo there is a change from harder rock types to less substantial ones, as is demonstrated by the different morphology of the landscape: this becomes softer, without the sheer walls typical of the upper valley. The changed landscape coincides with the Valtorta Fault, an important tectonic line which separates two quite distinct structural domains: to the north the Orobic Anticline, to the south the "Parautochthonous" of the Alpine foothills of Lombardy and the associated system of *horsts* crossed by a fragile thin-skinned tectonic

Figure 10 - Reconstruction of the areas hit by the 1762 landslide in hamlets of Gero and Barcone

plate. The Orobic Anticline is a fold running basically east-west, which extends longitudinally for almost 25 km along the fault-line: at its centre, the Variscan basement is much in evidence, while along the edges, the volcanic-sedimentary succession extends from the Lower Permian to the Lower Anisian. The "Parautochthonous" and the associated system of channels, instead, display mainly carbonate successions of the Triassic, deformed in a mostly brittle way. The type of stone appearing after the narrow is the Verrucano Lombardo: this is a characteristic succession of conglomerate and sandstone *redbeds*, wine-red in colour, in rows which sink away to the SSW. Extending over the whole of the Alpine foothills of Lombardy east of Lake Como, this facies demonstrates the presence of a great alluvial plain at the foot of the Hercynian Orogen at the end of the Permian (Tatarian). At Introbio, the Verrucano Lombardo rests on a condensed succession of the Lower Permian (Ponteranica Conglomerate and volcanic rocks of the Collio Formation: Sciunnach, 2001) and, just away to the NW, directly on the metamorphic Variscan basement with its intrusive late-Variscan magmatic bodies (Val Biandino Granodiorite, Valle San Biagio Granite). Figure 8 shows a structural diagram of the region.
Following the road running along by the Pioverna on the left we find the towns of Pasturo e Baiedo. In the first, which breeds cattle and produces cheese, we can see, amongst the stone houses with carved wooden balconies, the house supposedly belonging to Agnese from Manzoni's celebrated novel "The Betrothed", which is set in this region. At Baiedo there are the ruins of a mediaeval fortress built entirely of Esino Limestone, which is very common in the area.
Esino Limestone is a Middle-Triassic carbonate buildup cropping out in the Grigna Mountains (Lake Como, Lombardy). Carbonate lagoonal layered facies contain peritidal m-thick cyclothems with stromatolithic bindstones and intrabioclastic packstones. In the same lithofacies, small patch reefs are also present; they developed from the binding action of blue-green algae (Porostromata and Spongiostromata) and *Tubiphytes*. (Pagni Frette, 1993).
Shortly thereafter, at Introbio, the Norda mineral water bottling plant can be seen on the left-hand side of the road. The waters of the Daggio spring, the highest in Europe, gush out in abundant quantity at 1,935 meters above sea-level. **Table 1** summarizes the water's principal properties.
Continuing through the valley, to the right of the road near the township of Primaluna, there is evidence of the rock avalanche of gigantic proportions which, on 15 November 1762, struck the hamlets of Gero and Barcone, killing 115 people (Figures 9 and 10).

Stop 1.1:
The Landslides of Cortenova.
A couple of kilometres farther along the SP36, we come to Cortenova, where we'll make three stops to examine the slides which have afflicted this area (Figure 11).
From the left bank of the stream, we can view on the other side a large widely-spread landslide phenomenon, already active in the post-glacial era (Figure 12). The base of the slope has suffered the effects of a massive collapse which struck the hamlet of Bindo, causing damage to houses and infrastructures.
Higher up, in the middle part of the slope, there has been a series of debris flows which were channelled into the little side-valley of the Rossiga Torrent, a right-hand tributary of the Pioverna, thereby threate-

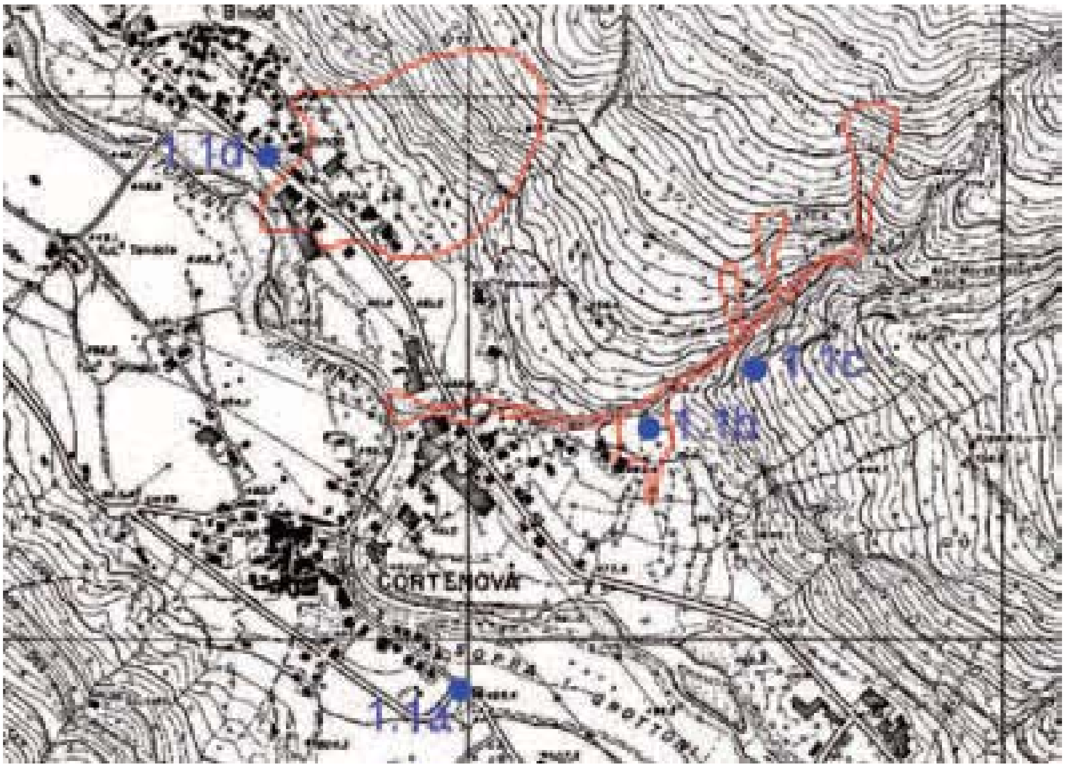


Figure 11 - Cortenova area map showing the landslides localization and the stop spots

ning a few isolated dwellings.
The story of these events began on the evening of Friday 29 November 2002 when, between the hamlets of Galera and Bindo, on the right of the Rossiga valley, three debris flows started up, dumping 40-50,000 m3 of material into the river-bed. The detritus built up the alluvial fan of the stream with the creation of new deposits at the outlet of the channel, almost reaching several houses in Galera.
The following day, Saturday 30 November, geologists from the Regione Lombardia judged the base of the slope to be in critical condition, based on certain evidence, such as the reactivation of several quiescent slips, some becoming active flows, and the fact that the water arriving at the bottom of the slope was becoming more and more turbid (Figure 13), presaging an imminent landslide. So the emergency plan was put into effect and the inhabitants of Cortenova and Bindo (about 500 people) were evacuated.
During the night of Sunday 1 December 2002, between 3.00 and 5.00 a.m., a huge rockfall of about one million m3 came down on Bindo, wiping out 15 houses and the buildings of three farms, and causing enormous damage to infrastructures and services, in particular the electrical network. Evacuation measures already taken meant there were no deaths or injuries amongst the population (Figure 14).
Given the continuing high level of risk, including the possibility that the crown of the slide might propagate uphill, as was indicated by the presence higher up of a series of fractures, the Regione Lombardia proceeded to set up monitoring systems.
The first monitoring effort was directed toward keeping an eye on the main phenomenon, which risked further damaging Bindo, and to this end a ground-based SAR interferometer technique was applied.
This method is based on the principle of cross-correlation of two SAR images of the same scene, taken at different moments but from exactly the same position. The device moves along a rail, whose length is a function of the required spatial resolution. Displacements of the terrain can be detected with an accuracy of less than one millimeter.
Data gathered immediately after the event and during the subsequent period, between December 2002 and March 2003, demonstrated a progressive stabilization of the landslide front.
Since spring 2003 a monitoring system has been

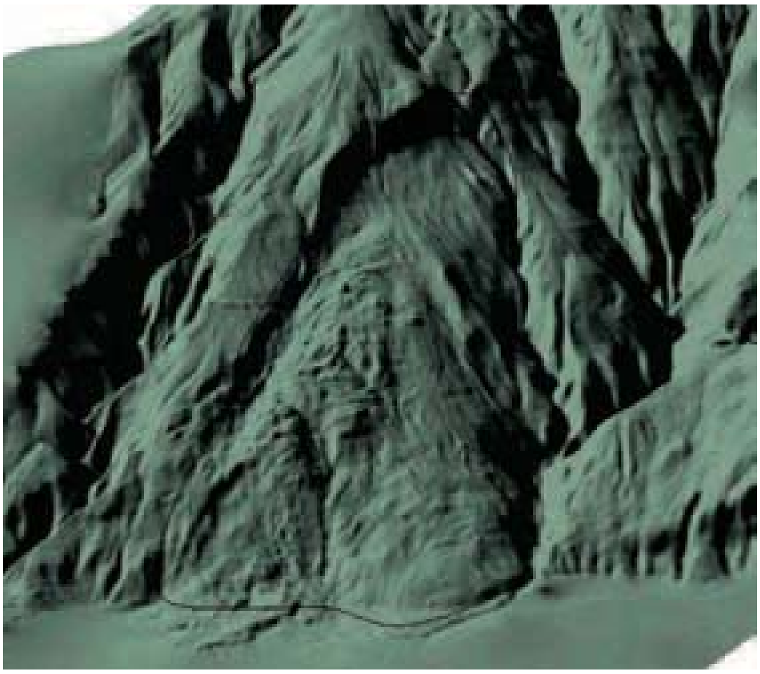


Figure 12 - DTM of the slope behind Cortenova (the black line shows the old landslide perimeter).

operating which is made up of a high-precision network of topographic sensors, with numerous optical sights along the landslide crowns. Measurements are made by two robotic theodolites and remotely transmitted to the geological office set up at the Comunità Montana (Figure 15). In the emergency plan of the Civil Protection department of Cortenova municipality, risk thresholds have been defined based on the correlation of precipitation and earth movement. The monitoring network will be completed with the installation of a number of GPS reference points, wire extensimeters and distometric bases. Three geognostic surveys will also be carried out which will allow us to learn more about the geometric and geotechnical characteristics of the movements taking place.

In the long period of drought up to October 2003 we witnessed a substantial stabilizing of the displacements. Nevertheless, an acceleration was recorded in the movement of the lateral portions of the main scarp of the Bindo slide after heavy rain (150mm in 24 hours) on 31 October-1 November 2003.

Figure 13 - The water arriving at the bottom of the slope was becoming more and more turbid presaging an imminent landslide

As for the Val Rossiga debris flows, the following steps were taken to mitigate the risk to the alluvial fan on which the hamlet of Galera is built: emptying and reshaping of the bed of the Rossiga Torrent from an altitude of about 500 m down to where it flows into the Pioverna; demolition of the old bridge; reshaping and widening of the bed near the right bank of the Rossiga Torrent, just above the old bridge; construction of a diversion cone near the top of the alluvial fan (Figure 16); raising and

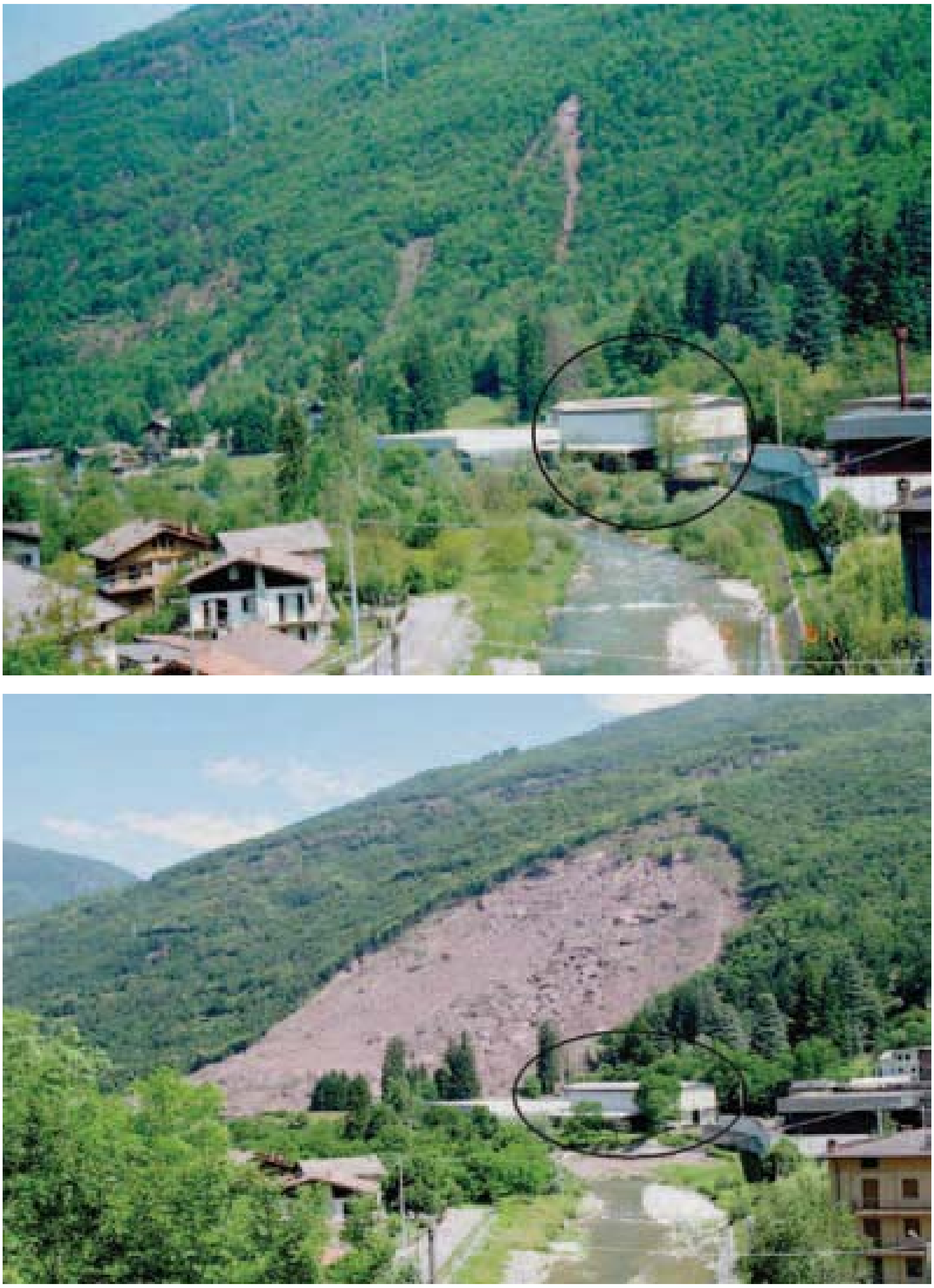


Figure 14 - Panoramic view of the slope behind Bindo in June 2001 and June 2003.

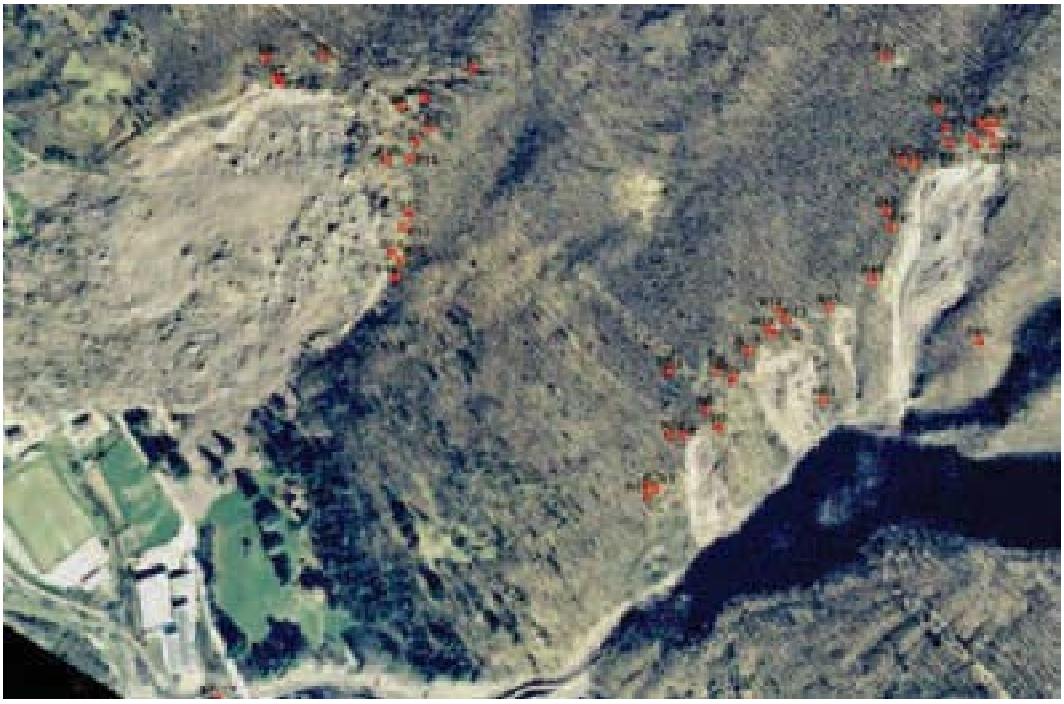


Figure 15 - Digital ortophotograph of the slope, showing the position of the optical benchmarks used to monitor movements.

Figure 16 - Diversion cone placed near the top of the alluvial fan in the Rossiga Torrent, built to protect the hamlet of Galera.

reinforcement of the banks on the left of the stream. The collapsed materials belong to a single lithotype, the Verrucano Lombardo formation of which there are outcrops all along the hillside in question, showing other evidence of active deformation.

The first observation point (stop 1.1a) will be in Prato S. Pietro, near the town cemetery, at an altitude of 495m, on the left side of the Pioverna valley.

From this point, and from a number of others along the road leading to the turnoff to Cortenova, there is a

Figure 17 - Panoramic view of the landslide area above Cortenova village: on the left, the collapse which struck the hamlet of Bindo, and on the right, a glimpse of the area where the debris flows originated

full view, in a north-easterly direction, of the opposite bank, where the slides took place (Figure 17).
Stop 1.1b will be at the little alluvial fan in the Rossiga Torrent, which flows into the Pioverna from the right. The protective works constructed here after the 2002 event consist of a diversionary cone made of huge boulders, rather like an avalanche protection; the main function of this is to protect the houses in the hamlet of Galera, which is built at the mouth of the little valley, from occurrences of floods and debris flows. From here a short uphill walk on a steep track which skirts the Rossiga, leads to a good point (stop 1.1c) for observing three debris flow phenomena involving the same lithotypes as the main occurrence; two of these took place at higher altitude. The debris flows visible on the opposite side of the narrow valley began on a slip plane representing the surface of contact between the conglomerate cover and the basement which can be seen at the level of the lowest of the three phenomena.
During the climb along the path, it will be possible to observe at close quarters this contact between the cry-

Figure 18 - The accumulation area of the Bindo landslide, interrupting the provincial road

Figure 19 - Damages to buildings and factories in Bindo area

stalline basement, which here is made up of granitic rocks of the Upper Palaeozoic (Upper Carboniferous-Lower Permian), and the conglomerate cover of the Verrucano Lombardo.
Afterwards, we can approach the foot of the main landslide (stop 1.1d) in the hamlet of Bindo to assess the consequences of the event on the homes and infrastructure (figure 19).

We get back on the SP 62 road in the direction of Bellano, on Lake Como. During the descent, tortuous in parts, with hairpin bends, one can observe the deep gorge cut by the waters of the Pioverna, which the Provincial road skirts on the left.
The SP 62, at Bellano, joins the Valtellina SS 36 road, which we take in a northerly direction, towards

Floods of November 2002

During the period 12-28 November 2002, Lombardy's pre-Alpine belt suffered heavy and prolonged downpours, unlikely to be repeated in over 100 years. This precipitation was accompanied by temperatures well above the average for the season, the freezing point being reached only above 2000m. The weather station at Introbio (at 580m above sea-level), was typical of the area, and measured around 800mm of rain spread over 18 consecutive days, with an early spike of 263.6mm on the 3 days between 14 and 16 November, and another between 22 and 27 November, of 349.2mm. The daily maximum recorded at the station was 128.4mm on 26 November (**Table 2**).

DATE	Brivio	Colle B.	Esino L.	Galbiate	Introbio
22.11.02	43.9	45.9	41.9	60.4	47.2
23.11.02	4.4	3.5	3.4	2.4	3.6
24.11.02	63.5	56.7	67.6	54.8	49.4
25.11.02	57.6	54.5	114	67	91
26.11.02	119.1	115.1	145.4	128.4	128.4
27.11.02	18.2	16.4	17	1.4	29.6
Total (5 days)	306.7	292.1	389.3	314.4	349.2
Nov. 2002	516.3	519.3		583.6	770.0
Year average	1400.0		1645.0	1450.0	1592.0

Table 2 - Rainfall data (mm) between 22nd and 27th November in Lecco area

Figure 20 - High-water mark recorded on an inside wall of the "La Brace" bar-and-restaurant at km. 24 of SS 38, left on the buildings by the floodwaters of 17-19 July 1987.

Sondrio.
The name of the Valtellina (Tellina vallis) is first found in a text of Ennodius, Bishop of Pavia, early in the sixth century. The most convincing explanation so far offered by historians is that it derives from Teglio. It is true that the name *Telium* (or *Tellium* or *Tilium*) only shows up much later in relatively recent mediaeval documents, but the position of the village, overlooking the middle reaches of the Adda Valley, and archaeological finds pointing to important human settlements from prehistoric times, make it highly likely that Teglio was also one of the principal centres of the Valtellina in Roman times. As to the mythical Volturena, the supposed twin city of the Etruscans' Volterra which was supposed to have existed on the plain of Pian di Spagna near where the Adda flows into the Lario and to have given its name to the Valley, it is a fantasy born of a misreading or misinterpretation of a passage from the Longobard historian Paolo Diacono. Others maintain that the name Valtellina derives from Vallis Turrena or Valley of the Tyrrhenians (ancient Etruscans who had taken refuge here), or else is an allusion to the great number of towers which once adorned the valley.

The SS 38, on this stretch, runs through many tunnels as it skirts Lake Como, which can be glimpsed from time to time on the left. The tunnels were necessary to replace the old road which ran along the east edge of the lake and was continually subjected to landslides and floods.

The tunnels cut through the metamorphic micaschist formations ("Scisti dei Laghi" *Auct.*) and near the Monte Piazzo structure, suffer from Deep-Seated Gravitational Slope Deformation (M. Legnoncino DSGSD) which causes deformations on the order of several millimeters in the cladding; this requires constant maintenance, so that hundreds of steel reinforcements and upturned arches have been installed to consolidate the cavity.

Recent data, obtained by analysing radar images from the period 1992-2002, using the permanent scatterers technique, show evidence of subsidence of between 4 and 11mm per annum along the whole shore.

At Colico, shortly before turning off onto the Stelvio SS 38 road, there is a splendid view to the north of the entrance to the Val Chiavenna, which lies along a NNW-SSE axis.

In this side-valley, which enters the Valtellina from the right, there are outcrops typical of the Alpine orogenic belt, such as the deformations linked to the "Insubric Line" and the "Root Zone" (almost vertical), as well as lithologies of the deepest units of the Alpine chain.

Driving along SS 38, from the town of Delebio, near km 3.1, it is possible to see the town of Dubino on the left, on the distant southern slope of the valley. In November 2000 a debris flow which started above the town caused damage to the houses and one death.

Another few km along SS 38 and we come to Morbegno, built on the alluvial fan of Bitto Torrent, which flows into the Adda from the left.

In the basin of that stream, near Pizzo Tronella, a huge movement of the slope, with very slow deformations, has been observed since at least 1965; a penstock belonging to the electricity company Enel has been affected. A manual monitoring system installed in the tunnel has measured displacements, fairly continuous and constant over time, on the order of 4mm/year over 15 years of measurements from 1984 to 1996. The morphological conditions of the slope in which the penstock is embedded are notable for the presence of trenches and fractures parallel to the slope and the presence of highly fractured and deformed areas. The lithotypes appearing in the area, which is not far from

Figure 21 - Map showing the distribution of monitoring networks controlled by the Valtellina Landslide Monitoring Centre (Sondrio).

the Orobic Line, here running in an E-W direction and sinking away towards N by about 50°-60° (Foglio Sondrio, geological map of Italy 1:100.000), are the slates of the Collio Formation which are in contact with the Morbegno Gneiss (Conte G., internal report SGN - Min. LL PP, 1998).

The part of the valley immediately to the east of Morbegno is in critical geomorphological condition, due to a combination of various factors such as: the development of alluvial fans of the Bitto and the Tartano streams, which divert the course of the river Adda toward the north; the large contributions of these same streams in terms of both water and debris, especially the Tartano, in whose valley an enormous landslide is active (approx. 80 Mm^3), contributing very greatly to the movement of debris towards the Adda; the bed of the Adda itself, which along this stretch tends to form a hanging valley.

The sum of these factors was largely responsible for the flooding of the Morbegno area at the time of the 1987 flood, the head of water on Pian della Selvetta reaching 4 meters above the level of the fields.

At km 24 of SS 38, as we stop at the "La Brace" bar-and-restaurant on the left-hand side of the road, we can observe the signs left on the buildings by the floodwaters of 17-19 July 1987; indeed, the owners have kept the high-water mark on an inside wall (Figure 20).

From this point on, for about 3 km along SS 38, we can see numerous debris flows along the slopes; in particular, at km 24.0 behind the "La Brace" restaurant, two phenomena, which began in November 2000 and were again in movement in November 2002, caused damage to some houses. At about km 25.2 on the right-hand side of the road, a noteworthy surface phenomenon can be seen (slip-debris flow evolving into a debris avalanche) which in November 2002 swirled into a high-voltage tower, destroyed two houses and cut off the Provincial road; at about km 26.4, again on the left, there is a debris flow which began in November 2000, upon which work has been done to control water flow and repair the damage.

Thus we arrive in Sondrio (310m above sea-level),

Figure 22 - Topographical and GPS monitoring sites controlled by the Valtellina Landslide Monitoring Centre (Sondrio).

Provincial capital with 22,000 inhabitants, situated where the Valtellina and the Valmalenco meet; the zone is crossed by the Mallero Torrent (*Malus rivus*) which in the course of the centuries has several times caused serious damage to the city.

Stop 1.2:

Geological Monitoring Center

The Geological Monitoring Centre of the Valtellina (now belonging to the ARPA Lombardia, Regional Environmental Agency) was set up in 1987 to meet the requirement, by now pressing, to check on the development of landslides, so as to ensure as far as possible the safety of people, property and infrastructures.

The start-up of the Centre coincided with the monitoring experience begun after the floods which, in the summer of 1987, caused the great landslide in Val Pola (which we'll visit later in the excursion). From that moment, the centre's functions have been to acquire and process data recorded by the existing control networks (Figure 21), plan any necessary measurement activities and maintain the instrumentation installed, design monitoring networks for new unstable areas and furnish specialist consulting to local entities (Regione Lombardia, 2000).

At this Centre, we will make our second stop of the day and will be able to observe first-hand the incoming flow of data from the monitoring networks in Valtellina. This is also the place where data arrive at predetermined intervals from special monitoring teams equipped for high-altitude work.

The types of data recorded range from geotechnical data, to topographical and hydro-meteorological data.

In particular, the geotechnical monitoring aims to observe the progress of fractures, identify slip

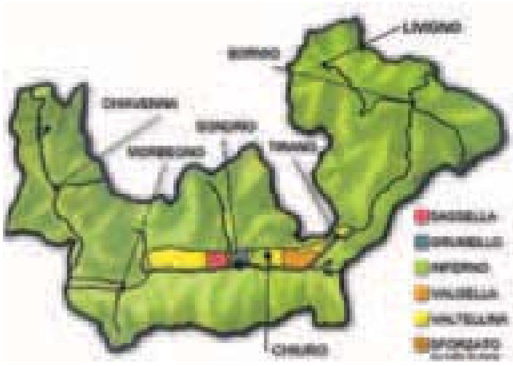


Figure 23 - Valtellina's wines are D.O.C, 'Denominazione di Origine Controllata', which guarantees their origin from the Valtellina region. On the map above, it is possible to see the geographical domains of the Valtellina Superiore D.O.C..
After four years of storage, the wine can be called "Riserva". There is also a Young Valtellina wine, which is an easy to drink wine and which is suitable for any occasion. The geographical position of Valtellina creates a particular microclimate, typical of the valley, which is unique in the Alps and particularly suitable for vine-growing, thanks to its general climatic conditions and the sunny exposure from morning to evening of its right slope, which favor temperatures that are normally found at a more southern latitude.

surfaces, measure the dimensions of the fault and, more generally, identify any movement deep underground; the instruments used are extensimeters of various types, fixed and mobile inclinometric probes, piezometers and surface inclinometers for checking vertical walls of buildings.
For topographical monitoring, where the objective is to evaluate surface deformations, in addition to the classic topographical instrumentation, both automatic and manual, GPS satellite techniques are used (Figure 22). In recent times, in monitoring large rock slides, use has been made of both radar Interferometry with land-based sensors (the Synthetic Aperture Radar, or SAR, technique) and satellite-based radar Interferometry (Permanent scatterers technique).

Figure 24 - the old bridge known as "punt de sass", or "stone bridge". In the flood of 1817, the Adda river changed its course and left it "high and dry", sitting in its own very original place in the middle of the fields!

To complete the picture provided by the above data, hydro-meteorological monitoring is also carried out, which involves recording precipitation (rain and snow), air temperature, water-flow in the rivers and streams, direction and velocity of the wind, humidity, direct and reflected solar radiation. The analysis of these data allows probabilistic models to be built for forecasting flood-waters.
The data acquired by the monitoring networks are processed by a decision-support system to evaluate any alert, pre-alarm or alarm status, and to notify the relevant authorities in case of need.

DAY 2

Sondrio - Tirano (stop 2.1) - Grosio - Valpola (Stop 2.2) - Bormio - Valfurva, Ruinon (Stop 2.3) - Bormio.

Departure from Sondrio in the direction of Tirano and Bormio, still on SS 38 for Stelvio. The valley stretches out in an E-W orientation as far as Teglio (Insubric Line or Tonale Line; cfr. Regional map), where it takes a north-easterly turn for a few kilometres, then turns almost due north around Sondalo.
The northerly slope of the valley, as for many kilometres before, is filled with terraces used mostly for vineyards. Lithologically, the land is made up of mylonitized materials having their origin in the activity of the conjugate faults of the Insubric Line which runs immediately to the north of this valley. This is the area which produces the famous Valtellina wines: Valgella, Grumello, Inferno, Sfursat and Valtellina (Figure 23).
For a long stretch (approx. between km 43 and 47) SS 38 crosses the alluvial fan of the Rhon Torrent; this is the largest fan in Lombardy with a surface area of about 4 km^2 (compared with the basin below of only 10 km^2), and is completely covered by apple trees. This fan is made up of the accumulation of huge debris flows of post-glacial origin, mixed with accumulations from landslides from a broad slope which has undergone regressive erosion (Monte Croce della Fine), composed mainly of metamorphic lithotypes where gneiss and micaschists are

Figure 25 - The Madonna of Tirano sanctuary

prevalent.
To the right of the road at Chiuro, which is built on the Rhon alluvial fan, it is possible to see the path of a debris flow which on 16 November 2002 swept away a car, dragging it into the Adda and killing the two occupants.
We drive on towards Tresenda where on 22 and 23 May 1983, at approx. km 55, a series of flows reached the National Road, cutting it in several places, and killing more than 10 people. Similar phenomena took

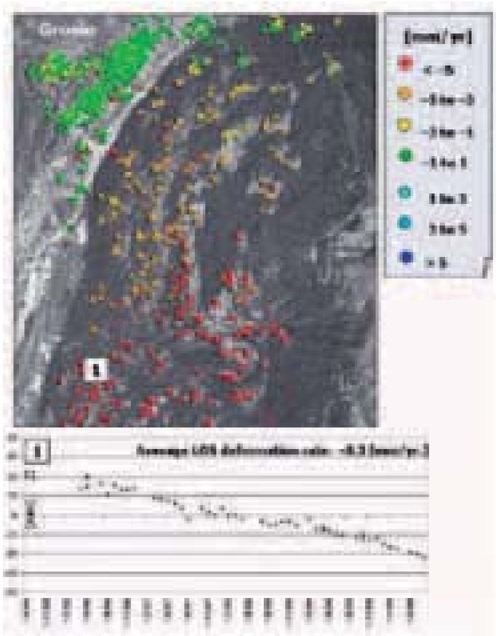


Figure 26 - Padrio-Varadega DSGSD. PS average deformation rates depicted on orthorectified photography. Displacement time series of an individual PS.

place in November 2002, fortunately without causing fatalities.
At Villa di Tirano, around km 59, on the left of the road a debris flow from November 2000 can be seen which, beginning on farmed land which had been formed into terraces with low dry-stone retaining walls, overran these and developed into a debris avalanche.
At km 60.2, near a dry branch of the Adda River the old bridge known as “punt de sass”, or “stone bridge” can be seen, sitting in its own very original way in the middle of the fields! Local legend has it that it is of Roman construction, but though very old, it is probably from a later date. In the flood of 1817, the Adda changed its course and left it “high and dry” (Figure 24).
Before entering the built-up area of Tirano on the left we can admire the old hydroelectric power station from the early twentieth century and its penstock coming down the slope with water drawn from the Poschiavino Torrent, a right-hand tributary of the Adda.

Stop 2.1:
The Madonna of Tirano
The first stop of the day is intended as a kind of historical-cultural break, at the Sanctuary of the Madonna of Tirano (Figure 25).
The story goes that at dawn on 29 September 1504, on the bridge over the Poschiavino Torrent, the Madonna appeared to a resident of the town, requesting that a temple should be built to her and promising to put a halt to the scourge of the plague which was afflicting the Valtellina at that time. Thus a small chapel arose which was later replaced by the present Sanctuary, whose construction began on 25 March 1505; it presents all the characteristics of Renaissance architecture, with a floor plan in the shape of a Latin cross, and three naves.
Numerous works are conserved here: a carved wooden group of the Virgin; the high altar by G. B. Galli, made entirely of black marble inlaid with other multicolored marbles, behind which the spot where the Madonna appeared is marked; and the organ, made up of 2,200 tin pipes, which still works thanks to the many restorations done over the years. The sacristy houses the “book of miracles” in which the miracles taking place between 1504 and 1519 are described.
During year 2004 many celebrations will be held to remember the 500th anniversary of the miracle.

We set off again in the direction of Bormio and after coming in sight of the township of Tirano, we can see, on the left of the road (at about km 66), the ridge of Monte Masuccio, which is part of the Bernina Fault (Austro-Alpine Units). This is subject to a very slow-moving Deep-Seated Slope Deformation (DSGSD). The deformation extends from the peak of Monte Masuccio at 2,820 m down to the bottom of the Adda valley at 360 m.

Traces can be seen of the activity of the DSGSD in historical times, especially the Sernio landslide of 8 December 1807 which dammed up the Adda River at km 68 of the present-day National Road, causing the formation of a temporary lake. The bursting of the obstructing wall on 16 May of the following year was more or less expected and did not injure anybody.

At about km 73.5 of SS 38, on the right-hand side, we come across the great DSGSD which concerns the structure of Monte Padrio - Varadega; the presence and activity of the deformation are confirmed by analysis of the data from the satellite-based radar interferometry which indicate displacements on the order of 4-16 mm per year in the period 1992-2002. The area being deformed, the largest in the whole of the Lombardy Region, occupies overall almost 30 km² with an estimated volume of over 4 billion m^3 (**Figure 26**). Further confirmation of the displacement comes from the topographic monitoring of the penstock located at approx. km 76, on the same slope, which also shows displacement of the same magnitude.

The new road uses a tunnel to avoid the town of Sondalo; this road constantly passes from one side of the valley to the other, crossing the Adda at a number of points. All the work along the road as far as Bormio (tunnels, bridges, rock-barriers etc.) has been built since the flood of July 1987. We leave the new road and turn onto the old route, from which it is easier to make the subsequent observations.

Not far along, in the town of Le Prese, t we can see to the right of the road the end of the bypass channel (see later description of the flood), placed immediately above the Fine Valley, which is rich in river bed material and site of continual debris flows.

Stop 2.2:

The Monte Zandila or Val Pola Landslide.

We are about to arrive at the landslide known as the Monte Zandila (or Pizzo Coppetto or Val Pola) landslide, which took place during the flood that struck the whole of the Valtellina in July 1987. The following description of the landslide and associated

Figure 27 - The Valpola Landslide, some days after the main event. Adda river flows from right to left. On the right it is possible to see the Valpola lake, created by the damming of the valley.

events have been summarized in various publications (in particular: Catenacci, 1992; Fossati & Mannucci, 1996; Govi & Turitto, 1992; Govi & Gull, 2002), which may be consulted for a more complete treatment of the subject.

From a geological-structural point of view, the area belongs to the Upper Austroalpine domain and in particular to the Scarl-Umbrail structural nappe bounded by the Tonale Line and the Engadine Line, with the intrusion of the Sondalo Gabbro.

The lithotypes outcropping in the zone are gneiss and micaschists of the “Cristallino del Tonale” *Auct.*; micaschists, phyllites and paragneiss of the “Cristallino di Grosina” *Auct.*; norites, amphibole gabbros and diorites of the Sondalo Gabbro.

All the rocks described are involved in fracture systems associated with mylonites and cataclasites, and so are often disaggregated even at depth.

Measurements made in the area after the 1987 event have shown not only the action of the Quaternary glacial moulding, but above all neotectonic activity,

Figure 28 - The exit of the bypass tunnels, situated downstream the Valpola landslide, near locality "Le Prese".

represented by dislocations of morainal cover, microseismic activity, recent river captures and morphologically active alignments (*sackungen*) which find their expression in terracing, counterslopes and subsidence over accumulations of older landslides (Fossati & Mannucci, 1996).

The main event hitting the area in July 1987 was preceded and followed by other phenomena, so for a correct understanding, there follows a brief description of events beginning some days before the main one.

On the evening of 25 July 1987 a fracture opened on the eastern slope of Mount Zandila, on the right bank of the Adda; this was accompanied by falling rocks. This was the reactivation of a landslide from post-glacial times, covering an area of about 120-130 ha. At the base of the main pre-existing slide escarpment, the new perimeter fracture extended for about 800 m,

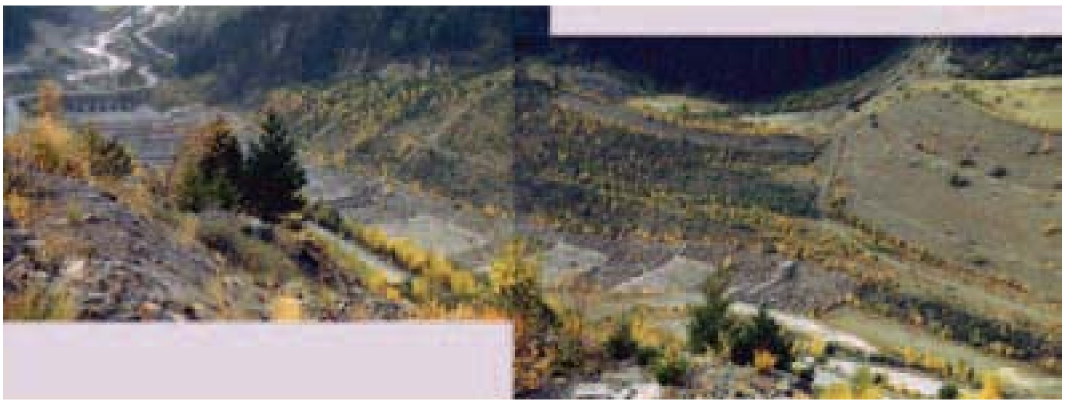


Figure 29 - The repairing works at the foot of the Valpola landslide. On the right it is possible to see the huge earth wall built to protect the new Adda river bed, completely running into concrete walls.

below, causing a reservoir to form upstream. So the villages of Morignone, Poz, Tirindr and S. Antonio Morignone were evacuated.

On 28 July, in the early morning, 32-33 million cubic metres of rocky material broke off and fell from 2,250 m down into the valley floor, bouncing up the opposite slope for several hundred metres (Figure 27).

“The landslide mass smashed into the Adda Valley below, breaking up completely and bouncing 300 m up the opposite slope; the town of Morignone was totally buried. The material from the landslide, thrown up the opposite bank, in part fell back into pre-existing floodwaters, provoking a tidal wave of mud which hit and destroyed Poz, S.Antonio Morignone and Tirindre. Eyewitnesses felt a violent shockwave and saw the bell-tower of S.Antonio and trees fly through the air a few seconds before the landslide material hit.” (Catenacci, 1992).

The landslide material blocked the valley for about 4 km, from the hamlet of Tola to the Ponte del Diavolo (“Devil’s Bridge”). The maximum depth of the cover was 90 m while the volume of the debris was 45 million cubic metres.

27 people died in the tragedy.

The event was recorded by the national seismic network (Istituto Nazionale di Geofisica); the parameters equate to the impact of an earthquake of Richter magnitude 3.9; the slide movement took place at 07:24 a.m., the detachment of the material took 8 seconds and the fall lasted 23 seconds.

The detached mass interrupted the course of the Adda and blocked the valley, creating a lake which grew in volume over the days following the event, since the

Figure 30 - Orthorectified photography (1999) of the Valpola landslide area, showing the stops. In the lower part the whole rock avalanche area is visible, as well as the repairing works. The upper part of the picture shows the area that was flooded by the ValPola lake, after the main event.

gaping wide in places, with evidence of slippage from 50 cm to several meters.

The first evaluations on the following day, 26 July, suggested the existence of a slide surface at a depth of about 50 m, and the danger of a slide of such proportions as to block the floor of the Adda valley

Figure 31 - The Valpola landslide. October 2003.

water could not find a way through the detritus. Fed, too, by the heavy rains of the second half of August, the lake finally reached a volume of over 18 million m³.

The valley below the barrier, in the meantime, was evacuated and more than 30,000 people took refuge upstream, lest the dam should burst and collapse.

Figure 32 - The great reinforced earth wall which partially protects the road from the rocks falling from the lower parts of the Ruinon slope.

The controlled overflowing which was tried in an attempt to erode the blockage gradually did not have the desired effect and it was finally decided to empty the lake with pumps.

Later, two bypass tunnels were also constructed (diameters of 6,00 and 4,20 m with a capacity of about 300 and 150 m³/sec respectively) to impede any rise in the level of the lake and to make it easier to empty it definitively. (Figure 28). Huge consolidation works were also carried out on the detritus, with reshaping and terracing, a drainage

Figure 33 - The Ruinon rock slide. Both the upper and the lower scarps are visible.

canal was dug at the base of the accumulated rocks, restraints were constructed and gigantic earthworks were built to protect the site (Figure 29).

The first stop having to do with the Monte Zandila landslide (stop 2.2a) will be on the slope opposite the slide, on the left bank of the Adda, in the parking area in front of the so-called "high-road" tunnel, a detour from the National Road built immediately after the event (Figure 30).

From this lookout point, it is possible to take in the crown, the slope on which the material slid and the valley floor, filled with the debris on whose stabilization so much effort has been expended (Figure 31).

Stop 2.2b will be made a little farther north, after following the old road as far as the Romanesque church (twelfth-fourteenth century) of S. Bartolomeo de Castelaz (at an altitude of 1214 m). From the lookout point below the church, toward the south the accumulated landslide material can be seen and the work which has been carried out so far, until the definitive solution is reached. Near the ancient ossuary beside the church, there is a plaque recalling the victims of the tragedy.

Walking 50 m down the road one finds another lookout, north-facing, from which it is possible to overlook the part of the valley which was covered by the waters of Lake Val Pola. High on the opposite slope the ridge of the Dosso il Filetto can be seen, with its very evident double crest due to the DSGSD present over the entire slope, with formation of trenches and counterslopes.

In 1987, when Lake Val Pola was at a higher level, the town of Presure, which can be seen halfway up the opposite slope, suffered cracks in the walls of the houses. The valley of the Massaniga Torrent, with its large alluvial fan and basin strewn with active landslides, is a continual source of debris flows.

Stop 2.2c will be right at the foot of the landslide, on the large bank constructed to protect the above-ground drainage canal and the work sites (see again Figure 29). The view from below of the landslide slope, with its still-active collapse and detritus flow, is very impressive.

We continue along the National Road in the direction of Bormio. On the right an avalanche protection cone at Cepina Piazzistolo can be clearly seen, to protect a village which in May 1985 was struck by an avalanche, causing two victims.

On the left, a short distance farther on, at Piazza

Figure 35 - Orthorectified photography (1999) of the Ruinon landslide area, showing the stops.

the context of a deep gravitative deformation of the slope beginning from the ridge (Monte Confinale) and reaching down to the floor of the valley, a difference of over 1,500 m, over an area of about 6 km² (Crosta & Agliardi, 2003).

For some time, the area has been subject to a complex monitoring system conducted by the Regione Lombardia (see Stop 1.2 on Day 1, the Valtellina Monitoring Centre) which, by way of a complex network of sensors (extensimeters, distometers, topographical and GPS measurements, some of which with real-time data acquisition and transmission), demonstrates a general picture of activity which is typical of a *rock slide* having a deep slip surface. The main displacements measured at the upper escarpment are on the order of 6 mm/day, accelerating at times of heavy downpours.

The lack of good instrumentation presently installed at the lower escarpment makes it difficult to quantify movement in this area; it is nevertheless significant.

An experimental monitoring campaign has been carried out on this landslide using land-based

Figure 36 - Felice Gimondi alone on the top of Stelvio pass.

SAR; the results, when compared with the data produced by some of the above-mentioned ground sensors, confirm the state of activity of the slope and the movement taking place (Tarchi et al., 2003).

The stop 2.3a (Figure 35) will be at the turning area in front of the stone protection wall beneath the landslide area, to the right of the road; from here, we can see only part of the lower escarpment and signs of rocks having fallen right onto the road.

To reach the second stop (2.3b), we must cross the Frodolfo (the bridge is narrow and the gravel road fairly steep) and climb the left-bank slope, by way of a couple of hairpin bends, up to a mountain hut. This high lookout point offers an excellent view of the two crumbling escarpments and the whole slope up to the crest. With binoculars it is possible to see the monitoring instruments installed near the escarpments.

DAY 3

Bormio - Stelvio Pass - Trafoi - Prato - Val Venosta, Lasa (Stop 3.1) - Merano - Val d'Adige, Nalles (Stop 3.2) - Bolzano - Valle Isarco - Chiusa - Val Gardena, Selva - Gardena Pass - Corvara in Badia.

The Bormio-Passo dello Stelvio transect offers an excellent geological and panoramic view across the Central Alps, and in particular across the central part of the Austroalpine nappe stack. Here (structural bottom to top) the Campo, Ortles, and Umbrail-Chavalatsch nappes are exposed:

- the Campo Nappe consists of schistose crystalline basement rocks;
- the Ortles Nappe comprises sedimentary rocks of Early Permian to Early Jurassic age, but in the considered area only Triassic rocks occur. Once considered the normal sedimentary cover of the Campo Nappe, it is actually separated from the latter by a major thrust, the Zebr Line;
- the Umbrail-Chavalatsch Nappe can be subdivided into two distinct parts. The structurally lower part ("Quattervals Nappe" *Auct.*) consists of strongly-deformed and deeply-diagenised Triassic carbonate rocks, thrusted over the Ortles Nappe along the Alpisella Line; the structurally upper part consists instead of crystalline basement schists and orthogneisses, as a whole thrusted over the lower part along the Gallo Line.

The town of Bormio rests partly over a blanket of slope, alluvial fan and floodplain deposits, and partly over metamorphic rocks: the Bormio Phyllites, belonging to the Campo Nappe and largely covered by fir woods. Outcrops of the phyllites are best exposed along the road cut of the SS 38 up to km 105, consisting of sericite-chlorite quartz-phyllites with prasinite lenses. The tectonic contact between these metamorphic rocks and the carbonate succession of the Ortles Nappe (Zebr Line) is hidden by an extensive slope scree cover up to the Bagni Vecchi road tunnel. The fault controls the mineral springs of the Bagni di Bormio, where the abundant sulphate content in water (733 mg/l) is due to the occurrence of thin gypsum slivers at the base of the carbonate nappe.

At the Bagni Vecchi road tunnel, the lower part of the carbonate succession of the Ortles Nappe is exposed. It consists of strongly brecciated, dark grey massive dolostones ("Valle Lunga Dolostones" *Auct.*) held as Carnian in age. Uphill from km 108, the Dolomia Principale = Hauptdolomit ("Cristallo Dolostone" *Auct.*) starts to crop out, consisting of thick beds of dolomitic limestone, light grey in colour at the surface and displaying thin stromatolitic layers, alternating with up to decametric intervals of blackish marly limestones in thin, plane-parallel beds. The latter yielded the bivalves *Isognomon exilis*, *Mytilus eduliformis* and *Myoconcha* sp. indicating a Norian age (Pozzi, 1965). The bedding dips downslope at angles mostly ranging between 20° and 45°, thus favouring the release of rock blocks that accumulate as large scree slopes, and often invade the road.

Between Ponte dei Vitelli and the II Cantoniera, a series of hairpin curves borders a spectacular falls of the Braulio Stream, still carved into the Dolomia Principale. At the small iron bridge on the Braulio stream, 100 m downhill from the II Cantoniera, it is possible to pinpoint the stratigraphic boundary with the overlying Fraele Formation (Rhaetian), that here displays its most distinctive characteristics. It

Figure 37 - The Ortles Massif (3905m)

consists of dark marly limestone with thin, parallel lamination, evenly-bedded and crossed by a net of calcite veins, alternating with fetid and splintery black mudstone. Looking towards the Corne di Pedenolo, it is possible to appreciate in a panoramic view the structural relationship between the Ortles and the lower Umbrail-Chavalatsch ("Quattervals") nappes: the Fraele Formation on top of the Ortles Nappe is overthrusted by a recumbent fold, cored by Dolomia Principale and displaying mylonitic Fraele limestone on the limbs, in turn overthrusted by a ridge-forming slab of Dolomia Principale. The upper two thrust sheets, both belonging to the lower Umbrail-Chavalatsch ("Quattervals") Nappe, can be observed in their mutual relationships on both sides of Bocca del Braulio, where a deeply recrystallised, grey-greenish Dolomia Principale, tectonically overlies the Fraele Formation.

From this point on, the morphology of the valley abruptly changes as an effect of glacial moulding. Deeply incised by stream erosion up to Bocca del Braulio, the valley widens considerably and starts to display glacial deposits that tend to host large meadows, and reveal their peculiar diamicton facies only where cut by small erosion scarps. The underlying rocks, that start to crop out along the road cut above 2500 m asl, belong to the upper Umbrail-Chavalatsch Nappe and consist of interfingering orthogneiss (commonly with augen gneiss structures) and phillitic paragneiss, with biotite ± muscovite and local mylonitic levels. The change in morphology is thus largely controlled by the Gallo Line, nicely exposed on the crests of M. Radisca and Filone dei Mot. To have a closer look at this important thrust plane it is sufficient to look just East of the Stelvio Pass (2757 m asl), where the Dolomia Principale crops out a few metres away from the metamorphic basement rocks and the Gallo Line is hidden by a thin belt of glacial and slope deposits.

After a short stop at the Stelvio Pass we will leave toward NE and enter the Alto Adige, going downhill along the 48 hairpin bends of the SS 38 - Stelvio road. This road constitutes a pioneer work in the construction of mountain roads. In only five years of work, from 1820 to 1825, the project of engineer Carlo Donegani connected Spondigna (BZ) to Bormio (SO) with postal carriages. The road, which is 49.24 km long, connects three neighbouring valleys of the Central Alps: the Val Venosta, the Val Monastero and the Valtellina i.e. the geographic regions of the Alto Adige, of the Grigioni and the Lombardia.

The Road of the Stelvio has always represented an aspired destination of bicyclists. Cycling fans from all over the world know the SS 38 to be the Queen lap of the Giro d'Italia, where the Stelvio Pass has many times represented the so-called "Cima Coppi", the highest point of the Giro. Cycling champions like Coppi, Bartali, Gimondi, Merckx and so many others have passed alone on this pass (figure 36).

Along the path to Val Venosta, the Ortles Massif is visible on the right (figure 37). At its top the front line between Italy and Austria passed during the 1st World War.

Along the road it is possible to see evidence of many landslides that in the past have interrupted it in different places; anyway, the main problem for the safety of the road is represented by snow avalanches. In many places avalanche protection is present.

About half–way down the descent, near the Rocca Bianca hotel (about at km 134, 1875 m asl) a cataclastic zone can be seen on the left of the road; it is evidence of the Trupchun-Braulio tectonic line that juxtaposes the dolomitic formations of the Ortles Nappe (the top nappe of the Dolomites of the Engadina) with the basement of the Schuppenzone

Figure 38 - The Lasa marble factory viewed from the upper station of the funicular that carries marble blocks from the mine to the working place.

of Umbrail-Chavallatsch. In this place the road is frequently interrupted by rock falls.

Immediately after the Rocca Bianca hotel, it is possible to see, on the left of the road, one of the antennas used to transmit the data related to the monitoring system working in the area. In particular, some inclinometers, piezometers and thermometers, which transmit the values measured to the Geological Survey of the Provincia Autonoma di Bolzano through GSM, are connected to this monitoring station.

Looking north, along the road in front of the hotel, it is possible to see in the distance, across Val Venosta, the peak of the Palla Bianca (3739 m asl), where at present the border between Italy and Austria passes.

The SS 38 road, which runs on the left slope of the narrow valley of Rio Trafoi, takes us to Trafoi, the small town home of Gustavo Thoeni, alpine ski champion, who won 4 World Cups during his career.

His family manages a hotel-restaurant, situated around km 138.5 of SS 38 road, on the open space that dominates the attractive small church of the town.

The town of Trafoi (1530 m asl) has for some years been interested by a Deep Seated Slope Deformation that has origin at about 3000 m asl and produces visible cracks on some houses, mainly built outside the original historical centre area which, on the contrary, stands on a tectonically stable alluvial fan. In this sector quaternary sediments are thicker then 50 m.

Those cracks enlarged after the heavy rains occurred in autumn 2000 and in correspondence to an earthquake (epicentre NW of Merano, hypocenter about 19 km, magnitude 4.8) that struck Alto Adige in 2001. While the extension of the area subject to deep seated movement was already known (Corbi, et al., 1995) only the detailed investigation and monitoring program started in 2003 has checked the position of a few deep sliding plans (deeper then 100 m) with different rates of movement. Measured movements range from some mm to some cm per year. They are tied to the presence of extremely cataclased micaschists and ortogneiss close to the already described tectonic line Trupchun-Braulio.

After Trafoi evidence of slope movement, active in historical age in the whole valley, can be seen along the road; the road itself moves from time to time on the opposite slope to avoid landslides.

The frequency of such phenomena and the geologic-

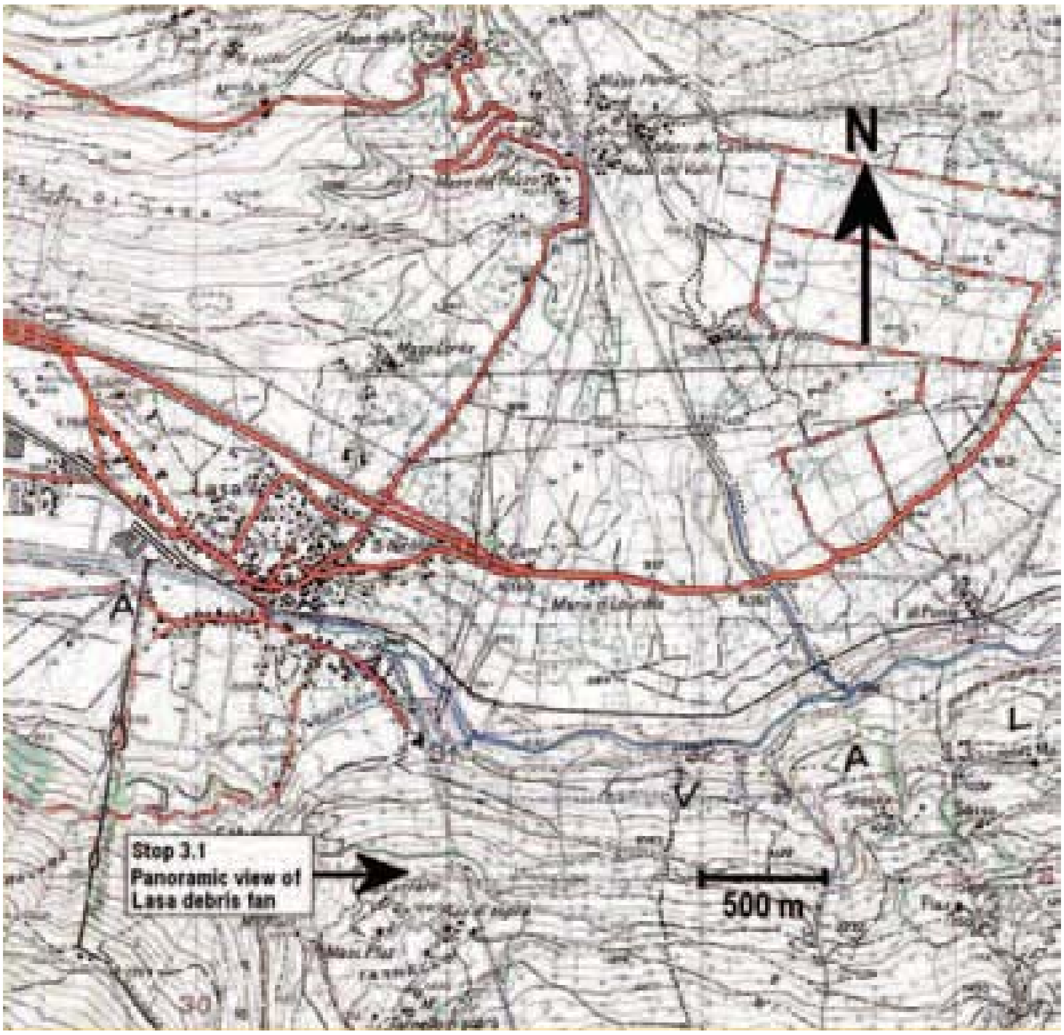


Figure 39 - Lasa area map showing the location of the stop.

structural complexity of the area even make just the project of a diversion passing through a gallery very difficult. Trafoi valley flows into Val Venosta, close to the small town of Prato allo Stelvio; we drive east along the SS 38 Stelvio road, up to reach the town of Lasa where the first stop of the day is scheduled.

This stop doesn't properly belong to the main thematic of large alpine landslides, but nevertheless it will be worthwhile to stop near Lasa to discuss the geological-structural asset of the Val Venosta and the set-up of large alpine debris fans such as the Lasa one.

This area is also famous for the extraction of the "Lasa Marble". With this name we designate the metamorphic rocks extracted from the quarries situated close to the entrance of the Lasa valley and more precisely from the one called "White Water" (for the presence of a falls of whitish water in that zone).

Physical-chemical characteristics of Lasa Marble are:

- Calcium Carbonate ($CaCO_3$) up to 96-98% (according to the types)
- Crushing strength 1160 kg/cm^2
- Flexural strength 185 kg/cm^2
- Water absorption coefficient 0.0015
- Specific weight 2.7 g/cm^3

This marble was already certainly known to the Romans; its employment for construction is however

Figure 40 - Lasa debris fan seen from Maso Tarnello

documented only starting from the XV century, to carve portals, columns and different ornamental sculptures, especially within religious buildings.

Until around 1850 it is not possible to speak of mining activity in Val Venosta; in fact, it was easier to recover marble blocks of glacial residual origin, also of notable dimensions (locally called "trovanti"), lying above the surface, in the upper part of the Lasa valley, along the north slope of Croda of Jenn" (Jennwand) massif. Such blocks could therefore be easily transported downhill, to be worked or sold.

Real excavation activity began only after 1850, first as an open pit, then in galleries.

Contrarily to what happens and has always happened for the more famous Carrara marble, the Lasa marble is now completely extracted from galleries. Owing to the rigid climate and the snow of the 1600/2300 m asl of the "white water" and "Malga of Covelano" mines, stripping activities would have been suspended in winter time, if the extraction of the marble had occurred in open pit mines.

The drawback of this mining technique is that many meters of very good marble layers cannot be extracted, because they support the more superficial schists layers. Fortunately in this way the landscape is not definitely defaced as has happened for the Carrara marble.

The main difference between the Lasa and Carrara marbles consists in a different strength (around 20% more in comparison to Carrara). Moreover, the Lasa marble is brighter, more lucent, more "alive". Thanks to the really low absorption coefficient (0.0015), it better withstands bad weather and its "white" lasts longer, allowing sculptures to stay almost unchanged for a long time. Probably for these reasons at the beginnings of the '50s, the U.S.A. Government chose Lasa marble to realize the 86,000 crosses and stars of David set in the war cemeteries displaced in the most distant parts of the world (Tuscany, Lazio, Sicily, Normandy, Philippines), in memory of the Americans fallen in World War II.

Lasa marble has a lot of varieties: from the statuary one (absolutely white), to the *arabescato* (with fantastic undulated coloured veins ranging from blue to grey) and various other intermediate varieties with veins of different colours, from brown to reddish, from greenish to reddish-yellow.

In the last 20 years marble processing has been notably modernized through the use of new machinery, in order to face the orders coming from every part of the

Figure 41 - Juval Castle

world (Figure 38).
In this context, since the years 1982/83, the "School of art for the workmanship of marble" has been opened, to renew the tradition of the school already active in the period 1879/1911. It is a full-time school with triennial courses for young people of both sexes, Italians and foreigners, that starts students off in handicraft activity or even in a career in sculpture.

Stop 3.1:
The Lasa debris fan

The stop in the Lasa area will mainly concern the great debris fan that expands in Val Venosta from the valley of the Rio Gadria, left tributary of Adige river. From the overview point near Maso Tarnello (Stop 3.1), about 1240 m asl, it is possible to enjoy a complete view of the debris fan, that extends for more than 5 km^2 (Figure 39).
The Adige river bed has been moved southward, toward our observation point, by the growth of the debris fan. The small town of Lasa stands on the south-western part of the fan and a wide alluvial plain is visible upstream. The origin of this plain is to be attributed to a lake, generated in the past by the damming of the Adige course caused by the debris fan (Figure 40).
The Val Venosta, along which we will later drive eastward, shows a sort of "steps" morphology, because of the frequent obstructions of the Adige river course generated by the debris fans. Every obstruction produced therefore a lake, generating a fluvial lacustrine plain.
A morphological-sedimentologic analysis of the valley brings to some particular consideration about the origin of the materials transported by the streams. The geological structures laying south of the Adige valley (where Maso Tarnello stands) are characterised by a scarce presence of glacial deposits, while they

Figure 42 - Main crowns of the Nalles debris flow on October 2003, viewed from St. Jakob

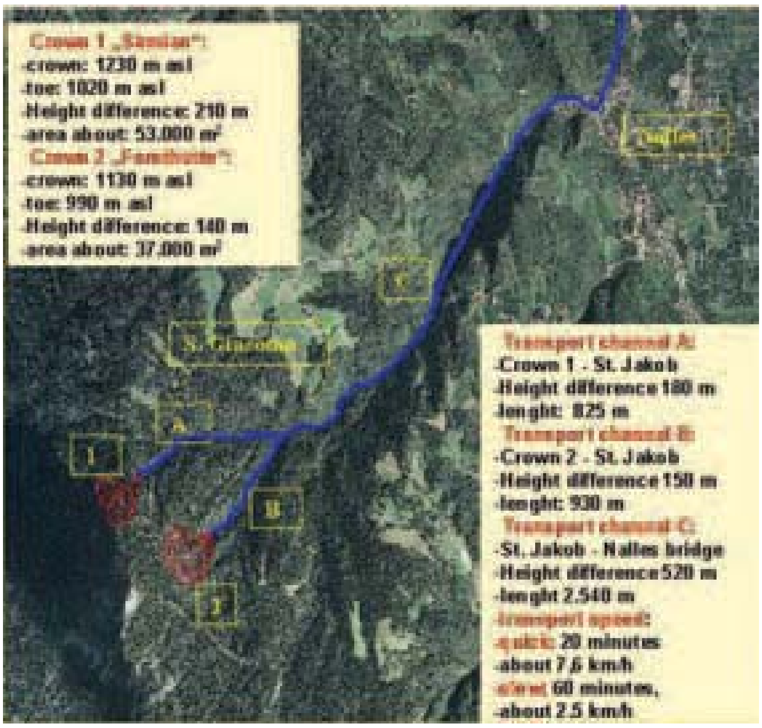


Figure 43 - Ortophotograph of the Nalles area, with the main morphologic data.

are abundant in the northern area. As a consequence of such material distribution, the greater part of the streams that flow into Val Venosta from the left, and therefore with general direction from N toward S, have produced debris fans of notable dimension, while on the right side of the valley debris fans are nearly non-existent. Therefore the valleys on the right show a very low debris coverage and rocks crop out widely.

The origin of this asymmetrical disposition of the materials on the left and right sides of the valley is probably due to the action of the Ortles glaciers that, moving in a prevailing northward direction, have transported and deposed the materials in such direction; during their withdrawal they have mainly left debris on the left side of the Adige valley that has a prevailing east-west course. The only exception to this situation is the Laces debris fan, located downstream from the Lasa fan, generated from a valley in hydrographical right, which shows a notable extension.

According to K. Fischer (1965), who has estimated the volume of the various debris fans, the Malles - S. Valentine one, the largest in Val Venosta, has 1550 million m^3; the Lasa debris fan has about 1350 million m^3, while Laces has only 630 million m^3.

Vegetable material recovered from a drilling, inside the Lasa Debris fan, was dated to about 7200 years B.P. (pers. comm. Prof. Gernot Patzelt, Institute of Geography, University of Innsbruck).

In the middle of the debris fan, close to the apex, the accumulation zone of a debris flow, colonised by trees, is visible. The remaining part of the fan was largely modelled in the ’50s to develop an extensive apple cultivation.

The last known debris flow event on this fan dates back to about 20 years ago.

The excursion goes on along the SS - 38 road of the Stelvio toward east. On the left, it is possible to see the historical Castel Juval (Figure 41), situated in a beautiful position at the beginning of Val Senales. It is more then 700 years old and is now owned by Reinhold Messner, the famous climber, who has restored the castle and enriched it with his collections (Tibetan objects, masks from five continents, pictures of mountains), imbuing it with his personal style. Nowadays the Renaissance castle has assumed the appearance of a Tibetan monastery.

Some km ahead we will exit the Val Venosta near Merano, where the river Passirio, coming southward from the Passiria valley, flows into the Adige river. From here onwards the course of the Adige river turns decidedly toward south while the valley widens and is filled with recent alluvial deposits.

Stop 3.2:

Nalles landslide

The second stop of the day will be in Nalles. which we reach driving along the Merano-Bolzano (MEBO) speedway.

The Nalles slope movement is a quick debris flow, that has repeatedly struck the inhabited area of Nalles in the last few years and is currently monitored by the Geological Survey of the Autonomous Province

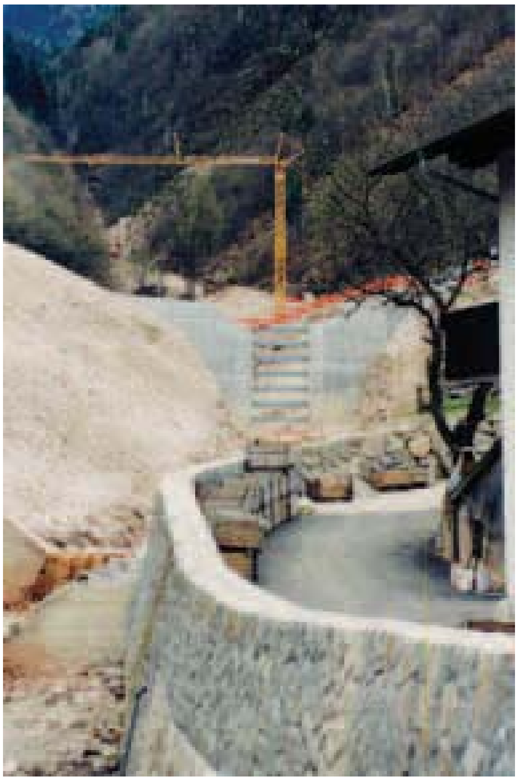


Figure 44 - Building works for one of the the containment basins

of Bolzano. The flow starts on the higher part of the slope, on a morphology that shows evidence of an ancient huge rockfall.

Two different scarps (Figure 42 - 43), set at 1230 and 1130 m asl, with an area of 50,000 and 37,000 m^2, respectively, set at the top of two different gullies (about 800 m of length each), furnish the material coming from the ancient rockfall. The two channels flow into each other to create a single transport channel, (the Rio Grissiano) more than 2.5 km long; it finally flows up to the small town of Nalles, standing on a small mixed (debris flow and alluvial) fan.

From the morphological point of view the bed of the Rio Grissiano, before the apex of the fan, is carved in outcropping rocks and, owing also to old repair work, forms an angle of about 90 degrees, immediately downstream from a narrow gorge. The contemporary presence of the confluence with another stream and of a bridge that joins two districts of the town makes the terminal part of the valley very dangerous from a geological hazard point of view.

The first events known as "Nalles landslide" refer to the 17^{th}, 18^{th} and 26^{th} of November 2000, when two separate debris flows, originating in two adjacent but confluent gullies, struck the town of Nalles, causing notable damage to the residences and to the infrastructures. SP-10 road was interrupted, many houses and about 300 inhabitants were evacuated.

Further minor activations followed, causing no damage, between the end of 2000 and April of 2001 when two new events, on April 16th and 18th, again struck the inhabited area. More then 300 thousand m^3 of debris were involved in the two events while more then 1 million m^3 still lie on the upper part of the slope.

From spring 2001 to the beginning of 2004 more then 30 new flows occurred. Many of them had low intensity, only signalled by the monitoring system. Others, such as the events of November 2002 and 2003, mobilised more than 20000 m^3 of material each, and completely filled the containment basins built to protect the town (figure 44).

An analysis of the slipped material, also compared with the geological asset of the crown area, has recognised in the accumulation zone: slope debris, material from an ancient rockfall, till, shales and siltstone with chalks belonging to the top of the Werfen Formation, Dolomia del Serla inferiore, rich in chalks and referred to the Member of Lusnizza.

The main cause triggering the debris flow, or better, the debris flows, can be found in the extremely heavy rains (more than 730 mm in two months, corresponding to the annual average) that hit the zone between October and November 2000 (figure 45). After the first two events, also lower rainfall could mobilise small portions of debris, dangerous for the safety of the inhabitants of the zone.

To reduce the hazard in the town area, two containing basins have been built for a total of about 40,000 m^3.

The Geological Survey of the Provincia Autonoma di Bolzano immediately started a monitoring program of the landslide area to warn geologists and technicians from the Geological Survey and the local Civil Protection department.

As a first step some benchmarks for manual observation of the terrain movements in the crown area, through a theodolite, were used. The recorded displacements in the period from December 2000 to July 2002 are sometimes very high, up to 11.7 m, with an average movement of 3.1 cm a day.

Owing to the fact that many events occurred in the monitored period and also to the presence of a huge quantity of material on the slope (more then 1

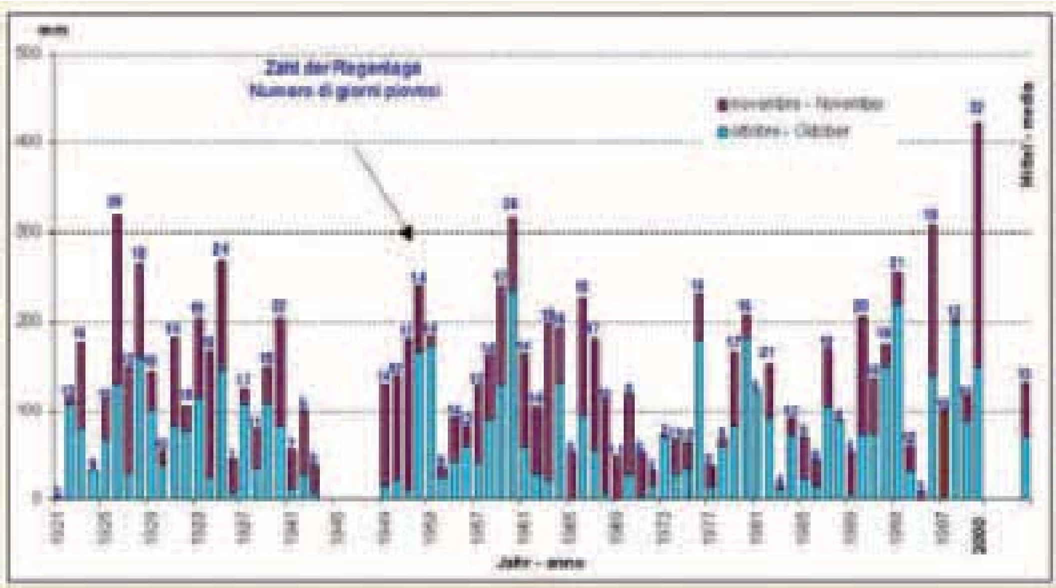


Figure 45 - Rainfall data in Nalles area

million m^3 as already mentioned), on July 1st 2002 a more complete system was installed with continuous measurements of movements and real time data transmission. The monitoring system is constituted by pluviometers, geophones, an ultrasound sensor, a video camera and topographical controls of fixed points on the landslide crown; the sensors send the recorded data to the master station for data collection close to St. Giacomo, from where they are transmitted to the competent authorities through an ISDN line.
Owing to the well known morphology of the crown area, with a well defined feeding zone and a transport

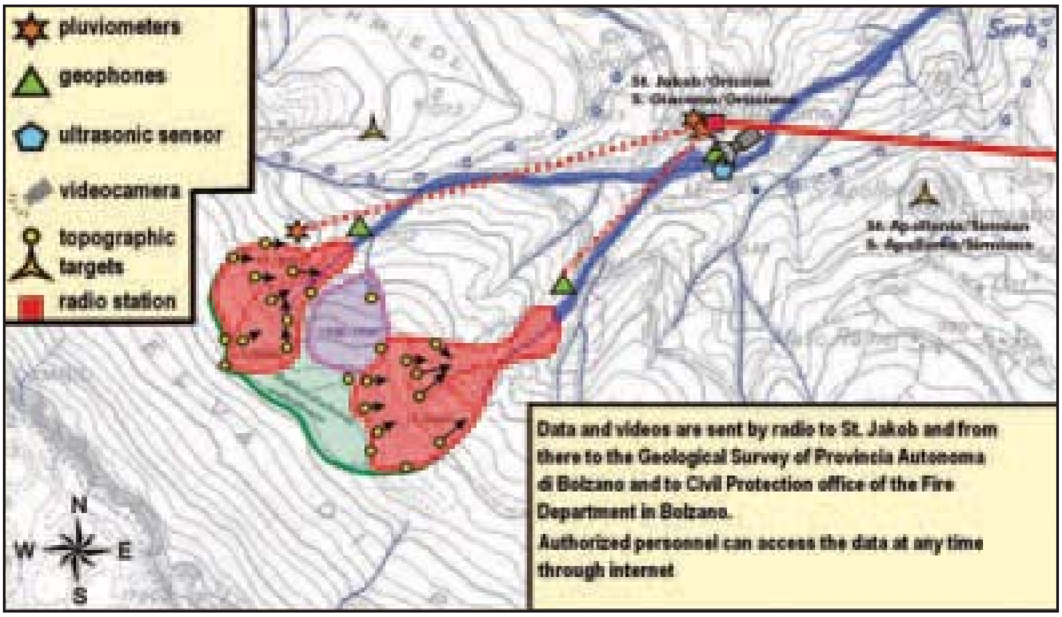


Figure 46 - Nalles debris flow monitoring system.

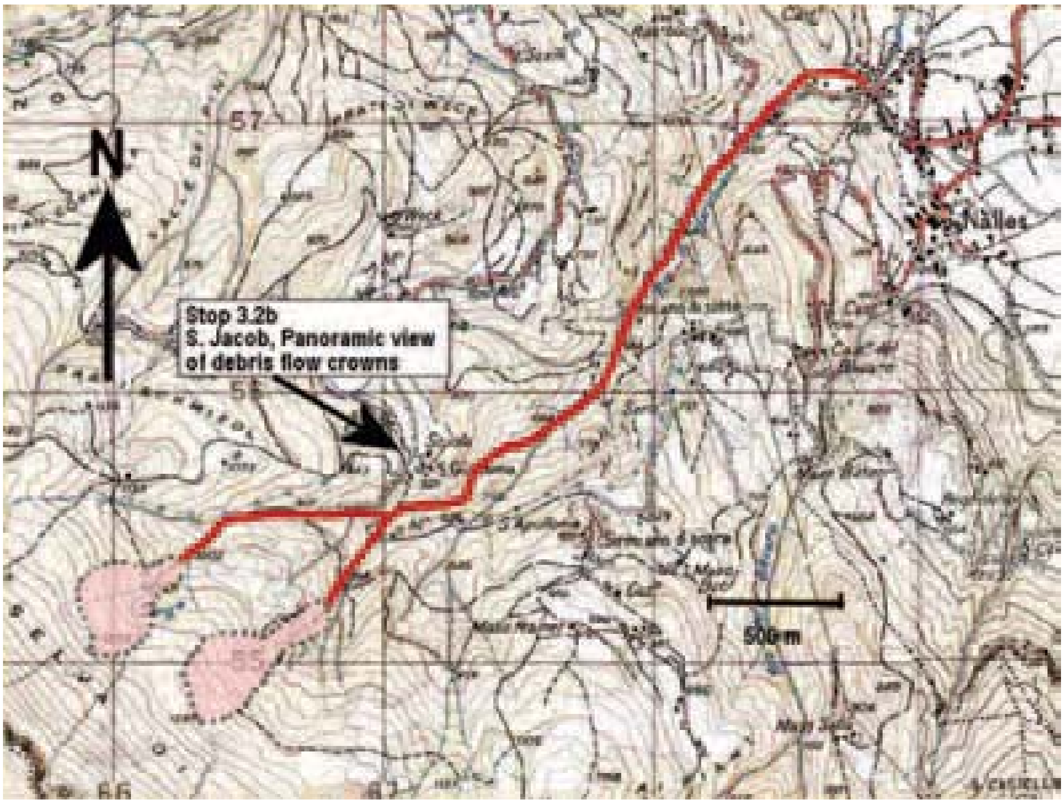


Figure 47 - Map showing the location of the second stop in Nalles area. Stop 3.2a is not visible in this map.

channel more than 2.5 km long and to the by now well-known triggering factors, the automatic alarm system allows Authorities, if needed, to evacuate the inhabitants of the town and to organise further possible safeguard measures. In figure 46 it is possible to see the location of the sensors and of the measure points.

The efficiency of the described automatic monitoring and alarm system and the effectiveness of the protection work, has enabled the local Civil Protection Department, supported by geologists and firemen, to keep the evolution of all the described events under control, without adopting useless and unpopular measures of evacuation of the population.

Owing to the large quantity of monitoring data available, this area, as well as that of Corvara in Badia, to be visited on the 4th day of the excursion, have been selected to test the efficiency of a monitoring system that uses radar satellite interpherometry. The project has been developed by the Provincia Autonoma di Bolzano in collaboration with the European Space Agency (ESA).

The first stop (stop 3.2a), for an overview of the landslide area, can be made in the square in front of the petrol station, just after leaving the highway by the Nalles Exit. From there it is possible to see the two major crowns of the debris flow, now almost joined in one large active area; the large alimentation area by now almost reaches the top of the slope that connects Mt. del Cambio (1772 m asl) to the ridge of Monti Alti di Prissano (1722 m asl).

Driving uphill toward the following stop, it is possible to see, from the bridge crossing the stream, the check dams connected to the debris basins built immediately outside of the town.

The second stop (Stop 3.2b) can be made at the panoramic square in front of S. Giacomo church (921 m asl), from where it is possible to have a complete view of the multiple crown and of the main flowing channel. To reach the church we drive along a narrow road that only allows the passage of automobiles or a small van; from Nalles the road goes uphill through the town, passes the bridge on the Rio Grissiano, passes below the Castle of S. Erasmo and reaches

Figure 48 - Passo Gardena landslide crown.

Prissiano where it turns to the left and comes up to the fraction of Grissiano. Finally here we turn left along a country road that reaches S. Giacomo (Figure 47).
In the square is visible the antenna of the monitoring station collecting data from the sensors situated on or near the landslide. On the opposite slope, it is possible to see the benchmarks used for topographical measurements. A great poster written in two languages (Italian and German) realised by the Geological Survey of the Provincia Autonoma di Bolzano illustrates the monitoring activities "in progress".
From Nalles we drive back to the MEBO speedway and then on the Brennero highway (A22) to Bolzano Sud. Then we continue along A22 that enters the valley of the Isarco, left tributary of the Adige.
The valley is narrow, the highway often runs between outcropping rocks and almost everywhere is protected by rockfall protection nets and walls. In particular around km 64, on the right side of the highway, it is possible to see the protection work built after the sudden rockfall that interrupted the road leading to the Alpe di Siusi in November 2000. A huge rock block fell from the slope and shattered, interrupting the connections between the valley and the Alpe di Siusi district. On the secondary road an artificial gallery was therefore built, while a strong rockfall protection wall now protects the highway.
At Chiusa we will exit the highway and drive along SP 242 road that initially climbs the slope and then enters the Val Gardena. The famous valley continues eastward and passing through the towns of Ortisei, S. Cristina and Selva, very well known as skiing resorts and for their splendid position in the dolomitic landscape.
While reaching Selva it is possible to see the Sella Massif on the right, which culminates with the 3152 ms of Piz Bo; it represents the pivot around which the Sellaronda, also known as 4 Passes Tour, develops. This very famous ski run, which crosses the Passo Sella (2,180 ms.) - Passo Gardena (2,137 ms.) - Passo Campolongo (1,875 ms.) - Passo Pordoi (2,242 ms.), is one of the most beautiful ski paths of the world. The itinerary has many possibilities and it can be adapted to anybody. For example you can choose, while doing the circuit, to ski on the Ski World Cup runs: Sasslong, Gran Risa or Ciampinoi.
Just after passing through Selva, we will drive to Passo Gardena, the first one of the three Passes we will see during this excursion, almost completing (by car of course) the Sellaronda.
The last two km of the road before the Pass are frequently interested by debris flows, coming from the glacial deposits located at the top of the steep slope on the right of the road.
Reaching the Pass the rocky crest of the Grande Cir that reaches Col Rotondo towards east is visible on the left. Just under the ridge it is possible to see some rock block topples that outline the crown of the Passo Gardena landslide (Figure 48).
This large landslide, which starts with a rockfall and topple in the upper part and evolves in the middle-low part into an earth flow, is fed by the upper portion of the crest, composed by the layers of the Dolomia dello Sciliar; the underlying layers, belonging to the formation of S. Cassiano, are constituted by tuffs and low strength sandstones that facilitate the collapses and topples of the overlying dolomitic layers.
Just downstream from the alimentation area, the upset dolomitic blocks are englobed into the terrain resulting from the undoing of the Formation of S. Cassiano; the resulting mass moves as an earth flow.
The road from Passo Gardena to Corvara shows

evidence of movement towards northeast of the earthflow. On the dolomitic walls on the left of the road it is also possible to see many cataclased areas. They are interested by a fault that reaches up to Corvara (see tectonic scheme of day 4) with a ESE-ONO direction.
Reaching Corvara we will enter Val Badia.

DAY4

Corvara in Badia (Stop 4.1) - Campolongo Pass - Arabba - Pordoi Pass - Canazei - Val di Fassa, Predazzo - Paneveggio, Forte Buso (Stop 4.2) - Predazzo - Cavalese - Val di Cembra, Lases (Stop 4.3) - Mezzocorona.

The fourth day of the excursion will take us from Corvara in Badia to Trento, crossing quite different geological landscapes. In fact we will first meet the carbonatic platform facies and the associated transitional and basinal areas, that constitute the typical geological asset of the Dolomites; then the volcanic formations, in the area where the industry for the extraction and workmanship of porphyry, one of the main economic activities of the Provincia di Trento, is very extensively developed.
Corvara in Badia is the most representative centre of Val Badia where, besides geology, it is possible to admire architectural testimonies of the Gothic period: Santa Barbara church in La Valle; the foundations of St. Nicol in Marebbe; remnants of the Rina's church. Also the first church of St. Vigilio di Marebbe, destroyed by a landslide, was in Gothic style. In Corvara, particularly, the ancient little church of Saint Caterina still largely preserves Gothic furnishings. Furthermore, tourism and infrastructures are growing due to skiing and hiking activities, so that the villages are expanding and an increasing number of ski-lifts is present on the slopes. Therefore the vulnerability of the area related to slope instability phenomena is significantly increased.
As regards geological and geomorphological features, the terrains present in the Corvara in Badia area

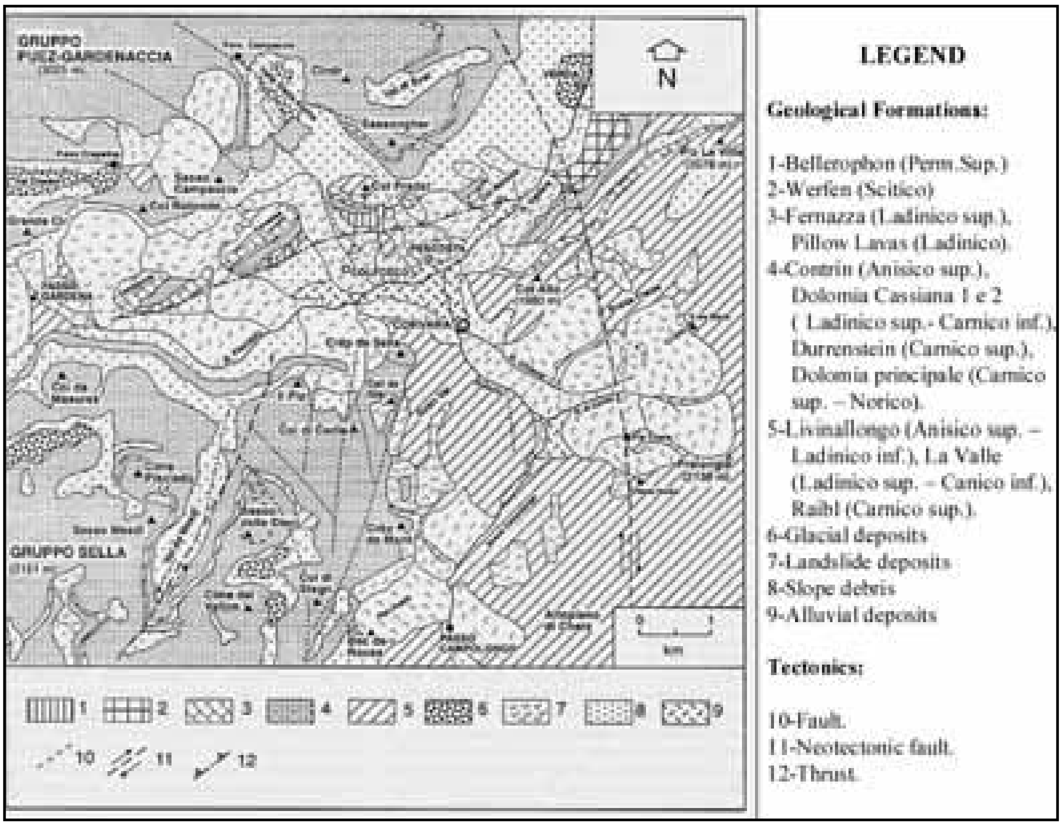


Figure 49 - Geological sketch-map of the Corvara in Badia area (from Corsini et al., 1998).

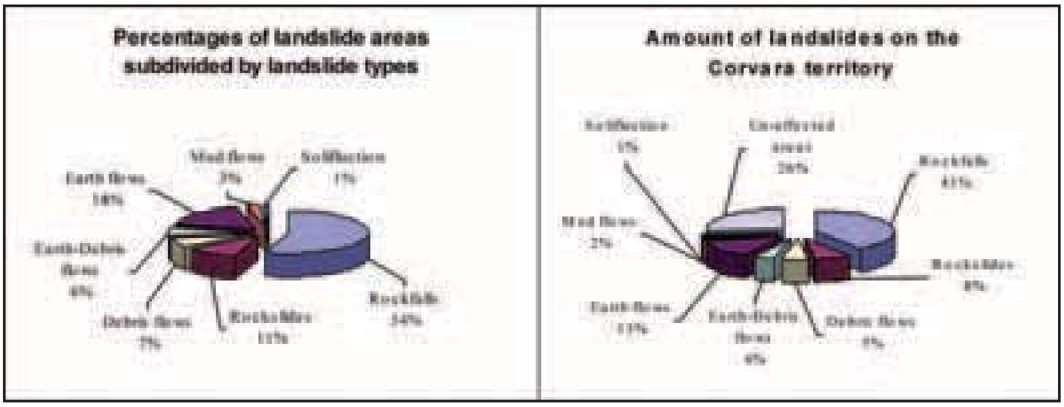


Figure 50 - Landslides distribution in the Corvara in Badia area.

belong to the typical stratigraphic succession of the Dolomites, whose age ranges from Upper Permian to Lower Cretaceous (Geological Survey of Italy 1970; 1977; Corsini *et al.*, 1998) (Figure 49).

Recently, in the proposed "Piano del rischio idrogeologico del Comune di Corvara" (Plan for hydro-geological risk mitigation in the Corvara territory) such formations have been grouped into five units, according to their geomechanical and hydrogeological properties: 1) Dolostones and Limestones; 2) Alternating sequences of *calcarenites*, *marls* and *pelites* (S. Cassiano Formation); 3) Alternating sequences of *pyroclastic arenites* and *siltites* (La Valle Formation); 4) Volcanoclastic Arenites, Volcanoclastic conglomerates and lavas; 5) Limestones, sandstones and marls; (Provincia Autonoma di Bolzano, 2001). In particular the geomechanical behaviour of units 2) and 3) depends on the geotechnical characteristics of the over consolidated silty-clayey levels (Ip ranging from 10% to 25%; ∀' about 18°-20°; c ' from 35 to 50 Kpa; K about 10^{-6} cm/sec).

The whole area shows morphological evidence of active slope movement affecting roads, houses and skiing infrastructures. The landslide typologies affecting the Corvara area are summarised in Figure 50 and Tab. 4.

LANDSLIDES TYPOLOGY		% on total landslide area	% on total municipality area
Rockfalls	15,67	54	41
Rockslides	3,07	11	8
Debris flows	2,04	7	5
Earth-Debris flows	1,74	6	4
Earth flows	5,09	18	13
Mud flows	0,86	3	2
Solifluction	0,21	1	1
Total landslide area	28,59	100	74
Un-affected area	10,25		26
Total municipality area	38,84		100

Table 4 - Landslides classification in the Corvara area (first column); areal extension of each landslide typology (column 2); Percentage distributions related to the total landslide area (column 3) and to the entire Corvara territory (column 4).

The morphology of the area, modelled by glacial and gravitational processes and by the rill wash erosion, is obviously strictly connected with the geological structure of the slopes. These appear sub-vertical in Permian and Triassic dolomitic rocks and strongly steep in limestones and in volcanoclastic sandstones. In the structures mainly constituted by the sedimentary formations of the Middle-Upper Trias (S. Cassiano and La Valle formations) the slopes appear weakly steep or undulated. The last two formations constitute the western slope of the Col Alto – Pralongi geological structure, where they give origin to a showy series of landslide phenomena that we will have the opportunity to observe during today's excursion.

Stop 4.1:

Corvara Landslide

In particular, the first stop of the day (Figure 51) will concern the "Corvara landslide", the most imposing slope movement in "Alta Val Badia". It is classified

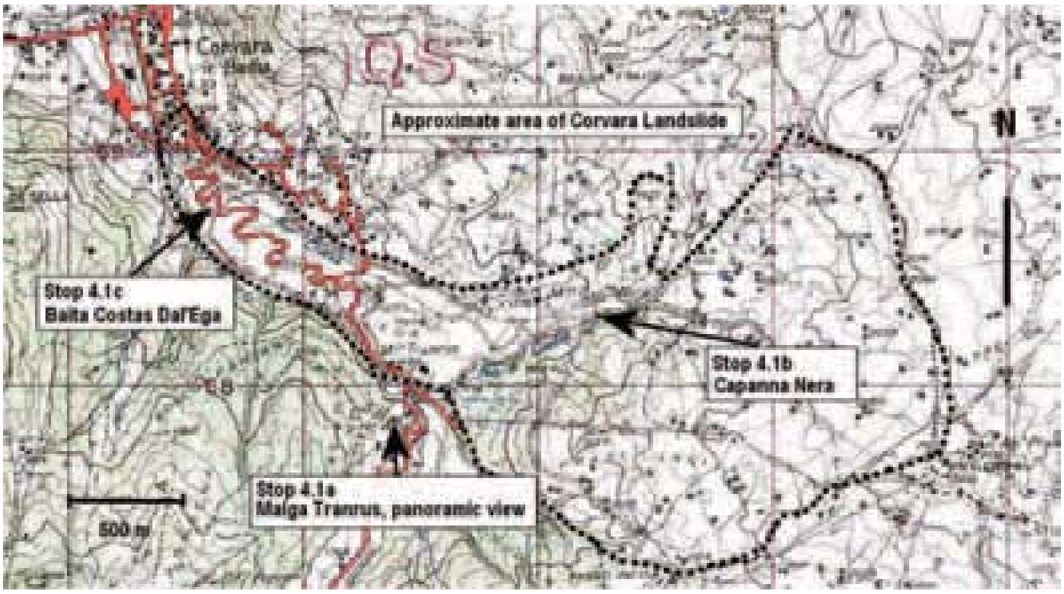


Figure 51 - Excerpt of the Corvara topographic map. Landslide approximative area and field trip stops are indicated.

as a complex movement (rotational rock slide - earth flow) showing evidence of movement in many sectors. In particular its terminal portion around the "Costes da L'Ega" area, evolving as an earth flow, extends up to the south-east edge of the inhabited area. Driving along the SS 244 road connecting Brunico to Arabba, immediately after the inhabited area of Corvara, the road is built exactly on the landslide accumulation zone, approximately between the 33rd km and 36th km. This part of the landslide body flows between the Rutorto and the Rio Chiesa streams, that run nearly parallel to the left and right sides of the earth flow. The two streams erode the flanks of the accumulation body and they flow together at its toe (Figure 52). The mass movement, belonging to a wider landslide unity (Pasuto et al., 1999), originates on the western slope of the Mt. Pralongi by a series of rotational slides which involve both La Valle and S. Cassiano formations (Corsini et al., 1999). In the source area, where three depletion sectors separated by crests can be distinguished, the rotational slides have probably affected the bedrock up to a depth of about 40-50 m. In this area, owing to the retrogressive rotational slide phenomena, the crown has by now reached about 2000 m asl, while the foot is located at about 1550 m asl. The landslide stretches over an area of about 3 km^2 involving approximately 120-150 million m^3 of clay-rich material with an average thickness of about 40 - 45 m. The maximum length is 3600 m and the maximum width is 1250 m. As just said, the landslide evolves in an earth flow of notable dimensions which spreads into the Rutorto river bed. The recovery of lacustrine deposits at the back of the accumulation zone witnesses the temporary damming of the stream in the past. The landslide has suffered some reactivations in the past, of which it is possible to track testimonies not only in historical age.

In fact, for example, wood remnants found at about 26 m of depth in a borehole drilled in the landslide foot area, witness an event referable to about 8800 years B.P. (^{14}C age). In the Capanna Nera zone, the present landslide's track zone, another drilling has recovered at 22 m of depth wood remnants dated to about 7900 (^{14}C age) (Corsini et al., 2001). Moreover, a sample collected at about - 37 m in a borehole drilled in the source area, allows us to date to about 2260 years B.P. (^{14}C age) an intense development phase of retrogressive rotational slides, which interested the upper part of the slope. In more recent eras, there is evidence of new slides and reactivations that have affected the landslide area in different ways, since 1930 and up to the present.

The presence of a dextral strike slip fault, which extends for about 12-15 Km in NNW-SSE direction (alignment Rio Freina Maradagn - Braida Fraida scarp – Incisa Pass - see Figure 49) appears to have played an important role in the landslide activity. The fault was active during the quaternary, probably also in coincidence with seismic events (Corsini et al.,1998; Castaldini and Panizza, 1991; Corsini, 2000).

Figure 52 - Southward view of the accumulation zone of Corvara landslide (from Bosellini , 1996).

As final remarks, multitemporal analysis of aerial photographs (from 1954 to 1996) has pointed out an increase in landslide phenomena in the source and track areas, whilst a substantial stability has been recorded at the foot of the landslide, in proximity of the inhabited area (Corsini et al., 1998; Corsini, 2000). This stability is probably due to the erosive activity of the Rutorto and Rio Chiesa streams on the accumulation body; thanks to it, a substantial equilibrium is maintained between the feeding process operated by materials coming from the source and track areas and the dismantlement of the accumulation area worked out by the two streams.

On the basis of the most recent studies, the evolution of the Corvara landslide can be hypothesized according to this general scheme: reactivation phenomena and/or new further rotational slide and slide – earth flows in the source area, with damage to the ski, electric and water infrastructures; slide/earth-flows in the track zone (Capanna Nera – golf course – SS 244 – Rutorto stream), with strong displacements of up to 10 meters/year, and damage also to the road infrastructures; and finally, intensification of the lateral reactivation phenomena and superficial deformations in the accumulation area, with damage to road SS 244 and to the ski-lifts and ski-runs. Advancement of the landslide toe toward the urbanized area is also possible.

An instrumental monitoring network, constituted by inclinometers, piezometers and TDR (coaxial) cables, is at present operating to control the evolution of the slide. A network of GPS measure points is associated

to the previous one, to control the surface movements. It consists of 48 benchmarks set on the landslide body and 3 external control points located outside the landslide area for references.
The first stop of the day (stop 4.1a) will be in the zone of Malga Tranrus (at the start of the Crep de Mont Ski-lift), reached by a rural road on the right of the SS 244. From there it is possible to have a panoramic view of the landslide phenomena affecting the Col Alto – Pralongi slopes and to discuss the morphological features and related implications.
The second stop (stop 4.1b) will be in the area of Capanna Nera, close to both the track and the alimentation areas, for a direct observation of the local geological asset and of the peculiar geomorphological structures.
Finally stop 4.1c will take place on the landslide accumulation body, along the SS 244, at Baita Costas Dal'Ega locality. In the area where TDR instruments record movements up to 80 meters deep, the geological implications connected to the evolution of this part of the landslide, as well as the monitoring system setting, will be illustrated.
From Corvara in Badia, the field trip continues along the SS 244 in direction of Arabba, where we will arrive crossing the Campolongo Pass (1875m asl). Then we will drive to the Pordoi Pass (2239 meters asl) along the SS 48 road of the Dolomites. Just beyond the Pass we enter the territory of Trento Province and we start to go downhill toward Val di Fassa to reach Canazei. The last 12 Km of the road run along 28 hairpin bends to reach the valley at 1435 m asl. Along the way, splendid sights of the Sasso Piatto and Sasso Lungo as well as of Sella Massifs can be enjoyed.
The Val di Fassa, so named up to Moena, is cut by the upper course of the Avisio stream that rises at Fedaia Pass (2057m a.s.l.) from Marmolada glaciers. The Avisio stream is a left tributary of the Adige river; their confluence is near Lavis, north of Trento. The median course of the Avisio flows along Val di Fiemme (local name of the Avisio valley from Moena until over Cavalese), whilst its final course runs in Val di Cembra.
The stream is already dammed, forming an artificial lake (Fedaia Lake, 2028 m) just a few hundred meters downstream from the spring. In proximity of Pezz it gives origin to another artificial basin about 1 Km long and it is again dammed at 787m a.s.l., forming the lake of Stramentizzo. The fluvial habitat is various and this is the kingdom of the "*marmorata* trout" that here can reach notable sizes (up to 7-8 kilos).
During the excursion we will follow a great part the course of the Avisio stream, driving along the SS 48 and the SP 71 roads.
From Val di Fassa, the Roda di Vael tops, the Catinaccio Group, the Rose Garden, which, according to popular tradition, was the abode of king Laurino, the Sassolungo massif, the Sella Group and the Marmolada, can be admired. According to some recent archaeological recoveries, the first traces of human presence in Val di Fassa are referred to the Mesolithic period (8000 - 5000 years B.C.); they mainly consist of hunters' traces which from the Po plain climbed the alpine passes searching for game.
The Val di Fassa and the Val di Fiemme represent fundamental stages in the development of the history of geology. Starting at the beginning of the XIX century famous geologists from many European countries have in fact used this peculiar geologic environment, where it is possible to observe the evidence of geological processes datable up to 250 million years ago, for their studies. In particular Predazzo became famous all over the geological world in 1821, when the observations carried out in the area brought new contributions to the dispute between Plutonists and Neptunists, testifying the possibility that plutonic rocks could be more recent than sedimentary ones.
Joseph Marzari Pencati (1779-1836), illustrious mining inspector of the epoch, observed in fact that in the Canzoccoli Plain, inside the Predazzo basin, granitoid rocks (in reality monzonites) overlapped Mesozoic sediments, while till that time all the intrusive rocks were thought to be more ancient than the sedimentary ones.
Near Canazei it is possible to see the contact between the sedimentary rocks (Marmolada Conglomerate - medium Trias) and the volcanic ones (shoshonitic basalts - medium trias).
This is one of the typical geological assets of the region where the imposing and articulated development of carbonatic platforms is associated to an intense magmatic activity, both intrusive and effusive. In particular two eruptive centres, one situated in Val di Fassa and the other in the area of Predazzo are well known.

Stop 4.2:

Forte Buso Landslide

Near Predazzo, we will leave the SS 48 road, turning to the left to get for the SS 50 road (Road of the Grappa and Passo Rolle), towards S.Martino di Castrozza.

A few kilometers (about 15) will take us into the Paneveggio natural park where, in correspondence with the homonym artificial basin, the second stop of the day will take place, to visit the "*Forte Buso*" landslide area (Figure 53). The Paneveggio Park is famous for its forest (about 2,700 hectares), whose lumber results of particular value in the construction of musical instruments, so much as to be sought after by Stradivari himself and by the most famous schools of lutists.

Figure 53 - Excerpt of the Paneveggio area topographic map. Landslide approximative area and field trip stops are indicated.

The rocks cropping out in this area belong to the formation of the "*Base Porfirica Atesina auct*.", better described today in literature as *Distretto Vulcanico Atesino*. The age of these rocks ranges approximately between 280 and 260 My and they crop out in an area of about 2000 Km^2 with a thickness up to 2000 meters; they are mainly constituted by ignimbrites (about 60%) and subordinately by lavas and domes.

From a stratigraphic point of view, volcanic rocks lie on the metamorphic basement or on the base conglomerate (*Conglomerato di Ponte Gardena*) while at the roof they are followed by the continental formation of the *Arenarie di Val Gardena*. In the southern sector, a lower group (andesitic-dacitic) and an upper group (rhyodacitic-rhyolitic) can be distinguished. In the northern sector an intermediate group constituted by rhyodacitic rocks with discontinuous sedimentary intercalation is present.

The "*Forte Buso*" landslide (Figure 54 and figure 55) is located on the southern slope of monte Dossaccio (1838 m asl) and develops entirely in the porphyry of the upper ignimbritic unit, impending on the SS 50 road at about Km 105. The crown is about at 1778 m asl and extends for more then 100 meters. The depth of the rock movement is esteemed to be about 100 meters too. The spatial distribution of the rock boulders, as big as 100 m^3, is chaotic.

Movement kinematics indicates that the blocks slowly slip in mass on a sliding surface, not well identified, but surely emerging above the foot of the slope, and finally collapse.

To mitigate rockfall risk along the SS 50 road, the Provincia Autonoma has designed a passive defence work consisting of a large wall made of gigantic boulders and earth.

To guarantee safety to the workers, a monitoring system is active along the slope. It consists of estensimeters (Figure 56) that transmit the measured data to the Fire department and the Geological Survey of the Provincia Autonoma di Trento, where the alert and alarm phases are managed, with the possibility to stop traffic on the road.

The monitoring system is completed by satellite GPS observations, conducted on a monthly basis, in the crown zone and accurate theodolite measurements to control the targets directly set on the moving blocks.

Stop 4.2a will be approximately at Km 105.3 of the SS 50 road, close to the rockfall protection wall, for a general description of the phenomenon. Subsequently, using a rural road starting at about km 103.4, close to the beginning of the Oxen Valley, where just 4wd cars can go, we will reach the crown of the landslide (Stop 4.2b). Here the fracture systems cracking the ignimbritic rock mass can be observed, as well as the degree of disarticulation of the volcanic rocks and the monitoring system set by the Geologic Survey of the Provincia di Trento.

After the stop we will go back along road SS 50 to Predazzo, where we will turn left along the SS 48 road towards Cavalese, to visit the quarrying area of

Figure 54 - Panoramic view of the southern slope of Monte Dossaccio before the building of the wall to protect the road.

Lases.

The object of the second part of the 4th day of the excursion will be the sliding and rockfall phenomena connected to porphyry extraction.

A journey of about 31 Km on Provincial Road n. 71 Fersina Avisio, that runs along the left-hand side of the Avisio stream, will take us to Lases.

Between Km 17 and 16 of SP 71, just after the villages of Scancio and Saletto, at the crossing of the Regnana brook, on the left, it is possible to see the area of the famous earth pyramids of Segonzano. This is a geological phenomenon linked to differential erosion in glaciofluvial material, where large boulders protect underlying materials from erosion, enabling the formation of pinnacles that may reach even tens of meters in height (Figure 57).

Proceeding towards the south-west, the Avisio stream leads us increasingly into the southern sector of the Atesino Volcanic District, whose effusive rocks extend for about 750 Km^2 in the province of Trento. As already mentioned, the rocks of this complex appear highly differentiated both in terms of

Figure 55 - Highest part of Monte Dossaccio slope. In the upper part of the picture the main scarp of the landslide can be seen, while the ingnimbritic boulders in the foreground are slowly sliding down.

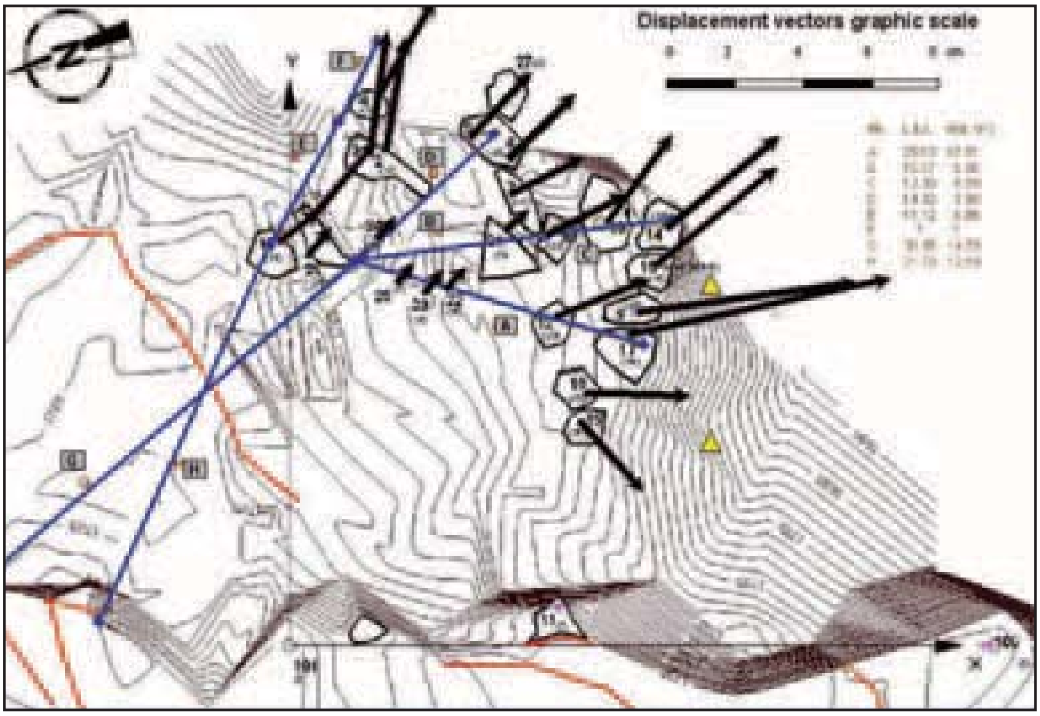


Figure 56 - Monitoring network on Forte Buso Landslide. Letters from A to H are referred to extensometers. Poligons with numbers represent rock blocks under topographic control: arrows are cumulative displacements on horizontal plane and Triangles are inclinometers.

chemical composition and in terms of formation. In particular, those of ignimbritic formation and rhyolitic composition form a type of porphyry that displays peculiar lithotechnical and structural characteristics that facilitate its extraction and processing, making it "ready to use" and available for the market.

In this case, it consists of flows of liquid-gaseous mixes, that are extremely fluid owing to the very high temperature and high gas content, whose thickness can vary from 5 to 20 metres, and that have formed by overlapping, at times before the previous flow had cooled down. The common denominator of these flows is their chemical composition, which can remain practically unvaried for hundreds of metres of thickness, enabling to group the various flows together in a single Ignimbritic Unit.

In the case studied, the extraction unit is the Ignimbritic Rhyolitic Unit belonging to the Upper Group, widely extended in the area of Lases, in Val di Cembra and on the high plain of Pin.

In the afternoon, therefore, it will be possible to visit the greatest porphyry mining district in Italy and Europe, second in economic importance only to the Carrara marble quarry district. It will be possible to assess environmental problems and view both the emergency measures adopted and later slope safety and stabilization measures, in particular those implemented on the northern and north-eastern slopes of Mount Gorsa.

The main structural characteristic of this Unit, which makes it valuable from a market point of view, is its sub-vertical fissuring, due both to cooling and to the mechanical response of the rock to tectonic stimuli; a combination that facilitates its mining and processing. On the quarry walls, the typical "hooked" structure of the sub-vertical fissures, that is due to systems of transversal fractures of later age, may be observed. The system of joints interests the Ignimbritic Rhyolitic Unit for a thickness of about 100 - 200 metres with breaks in the lateral direction that limit its extraction potential in areas.

This characteristic, which enables the material to be processed in slabs, together with excellent lithotechnical properties, such as the high compressive failure load and high resistance to chemical agents, makes porphyry one of the best quality flooring and panelling materials. **Table 5** shows a comparison between the physical and mechanical characteristic of various types of porphyry found in the Province.

Figure 57 - The suggestive earth pyramids of Segonzano

Socioeconomic Aspects

From the socioeconomic point of view, the porphyry sector is the most important mining activity in the Province. The exploitation of porphyry deposits in the area of Albiano and Fornace began in the 1920s, when a number of quarries producing cubes, slabs, kerbstones, etc, were opened.

Since the Second World War the number of quarries has increased gradually, so much so that in the 1970s there were more than one hundred. Over this period the sector recorded a significant expansion, due above all to advances in excavation technologies and the transition from manual processing to mechanical processing with the use of special stone-crushing machines. The product is almost entirely sold outside the province, and 40% abroad, especially in northern European countries. The overall turnover for the sector, excluding side-line activities, is assessed at over 100 million euro per year. Deposits of significant potential are exploited, as shown in **table 6**, through a mining activity that involves about one hundred active quarries (including those of porphyry rubble), to which are added about 200 companies that process the raw material. At least 1900 persons are employed for the mining and processing of this material. In addition, side-line

Caratteristiche fisico-meccaniche di alcuni porfidi estratti nella Provincia di Trento								
MATERIALE	Carico di rottura a compressione	Carico di rottura a Compressione dopo gelività	Coefficiente di imbibizione (in peso)	Resistenza a flessione	Prova d'urto: altezza minima di caduta	Coefficiente di Dilatazione lineare termica	Usura per attrito radente	Peso per unità di volume
	kg/cm2	kg/cm2		kg/cm2		mm/m/°C	mm	kg/m3
Porfido di Albiano (Monte Gorsa)	2.830	2.847	0,765	243	61	0,002965	0,36	2.543
Porfido di Albiano (Tassaiole)	2.602	2.556	0,525	286	60	0,007565	0,60	2.563
Porfido di Predazzo (Forte Buso)	2.923	2.879	0,575	205	71	0,006705	0,70	2.613

Table 5 - Physical-mechanical properties of some porphyries from Provincia di Trento.

activities provide employment for a few hundred people, giving a total number of about 2300 jobs (source: Servizio Minerario della Provincia di Trento - October 2003).

Environmental Aspects

The impact of the mining activity is obviously significant and results in a profound alteration of the environment, including the need to assign certain grounds for the dumping of inert materials, and in any case affecting forestry and hydrogeological aspects.

In the past, the economic aspects prevailed in the approach to mining, resulting in a significant expansion of extraction and dumping areas, sometimes even near inhabited areas and creating a host of safety problems, also from the point of view of geological stability and environmental impact. There has been news of "projectiles" (boulders up to 50 kg) which have actually reached town centres from the quarries.

ESTENSIONE DELLE AREE ESTRATTIVE VOLUME DELLE RISERVE PROBABILI - RELATIVA RESA PRESUNTA						
COMUNE	LOCALITA	SUPERFICIE	RISERVE PROBABILI	RESA PRESUNTA IN PRODOTTO GREZZO		PRODOTTO PREVALENTE
		$m^2/10^3$	$m^3/10^3$	$m^3/10^3$		
Albiano	Monte Gaggio - Rio	1.354	17.000	7.650	45%	cubetti
Albiano	Monte Gorsa	264	4.000	1.400	35%	lastre
Baselga di Pinè	Lastari - Sacco	338	4.700	1.645	35%	lastre
Capriana	Bus della Vecia	67	350	140	40%	cubetti
Cembra 7	Val Scorzai	345	2.000	700	35%	cubetti
Fornace	Pianacci - Slopi S.Stefano -Val dei Sari	683	7.950	2.782	35%	lastre
Fornace	Monte Gorsa	6	50	17	35%	lastre
Giovo	Ceola	100	500	175	35%	cubetti
Lisignago	Spedena	39	100	35	35%	cubetti
Lona –Lases	Caolago - Monte Gorsa - Pianacci	376	3.600	1.260	35%	lastre
Predazzo	Forte Buso	42	90	18	20%	blocchi
Trento	Camparta - Rio Secco	568	4.000	1.600	40%	cubetti
TOTALE		**4.285**	**44.250**	**17.405**	**39%**	

Table 6 - Data related to the extension of the active mining area and to the estimated amount of material to be mined

More recently, the introduction of planning tools, such as the "Provincial Plan for the Use of Mineral Substances", has resulted in quarry activities being regulated by strict exploitation plans and their being contained within well-defined mining zones. Municipal planning (P.R.G.) also adapts to forecasts of the "Provincial Plan". Today, therefore, also following the introduction of the environmental impact assessment (E.I.A.), porphyry is mined with greater rationality and safety and environmental recovery operations are increasingly being carried out.

Stop 4.3:

Lases area landslides

Once in the area of Lases (Figure 58), the first stop (4.3a) will be at the small village of S. Mauro, at an altitude of 807 m. The village is in a strategic position to gain an overview of the mining activities in the area and of geological – environmental challenges and problems linked to the stability of slopes and quarry walls.

The next stop (4.3b) will be to view the landslide that interests a portion of the eastern slope of Mount Gorsa, reported in the news as the Lases or Slavinac landslide, from the name of the locality. The landslide threatens the underlying SP 71, at Km 9.5, and if it were to undergo a paroxysmal evolution it could reach the small lake of Lases that lies parallel to the provincial road (depth of about

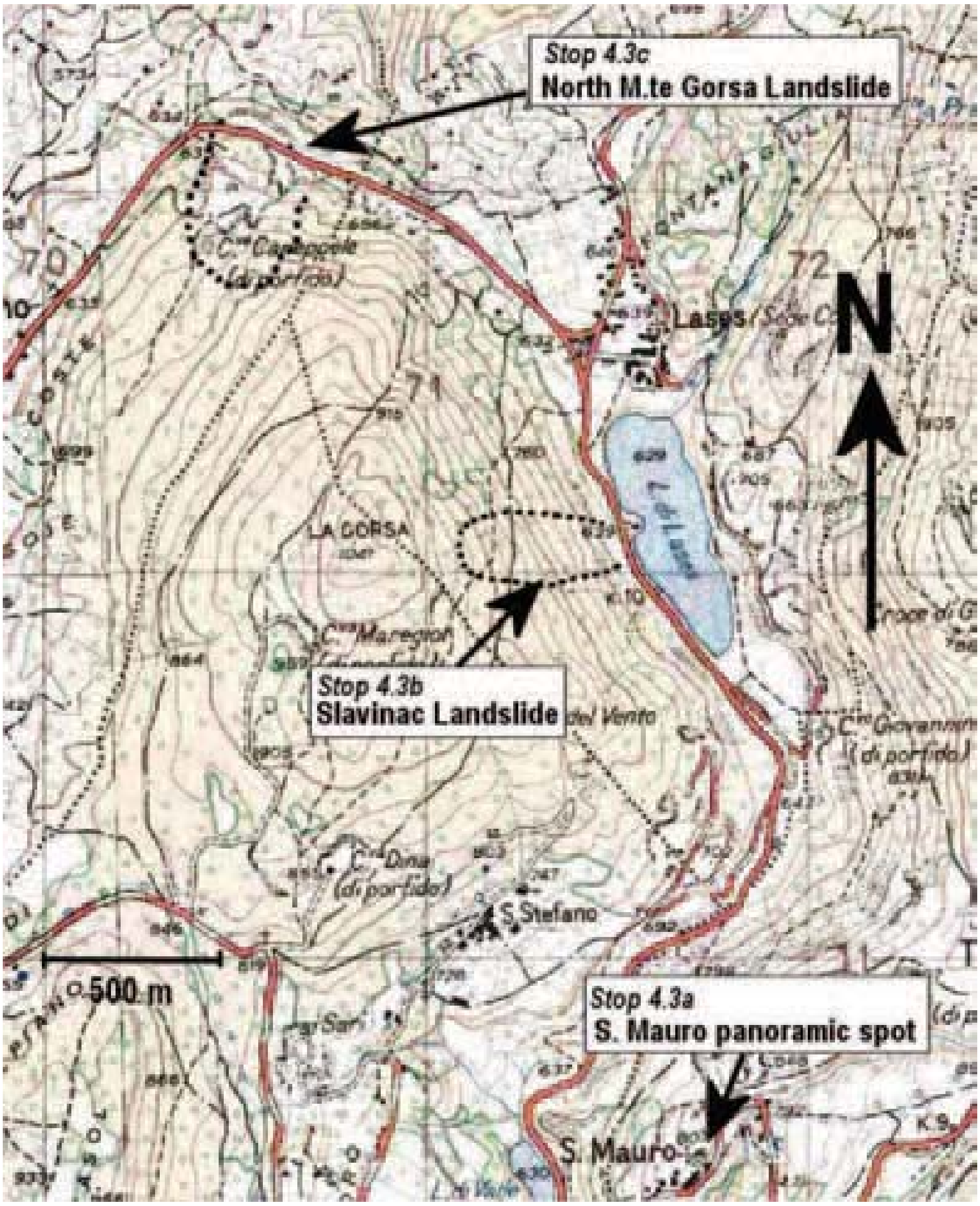


Figure 58 - Excerpt of the Lases area topographic map.
Approximative extent of the visited landslides and field trip stops are indicated

30 metres, length about 800m), resulting in a tidal wave that would hit the town of Lases, situated immediately downhill from the lake basin. The crown area extends into the wooded area, above an altitude of about 850 m. According to geognostic studies, the slip plane reaches a depth of 30-40 m. Signs of instability in this portion of slope were noted starting in the summer of 1976, and later on more than one

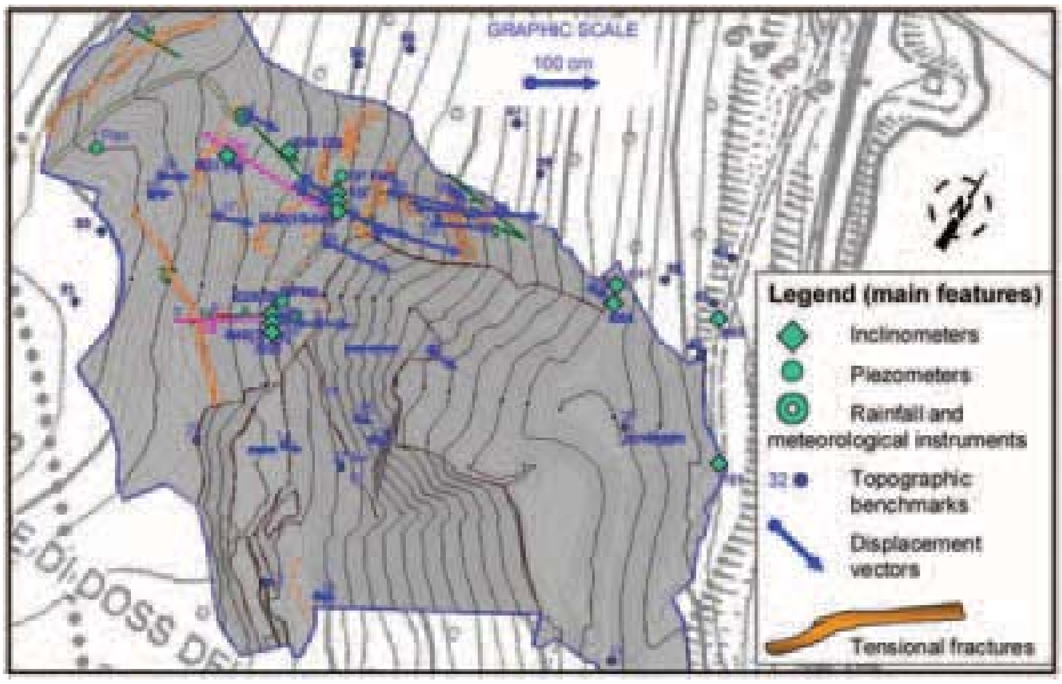


Figure 59 - Monitoring network on Slavinac Landslide.

occasion, in particular in November 2000, when, in concurrence with the exceptional meteorological events of the autumn, an acceleration in the landslide was recorded so that the evacuation plan for the village of Lases (involving about 40 houses and 300 people) was activated. Since 1997, the monitoring of the landslide is conducted by the Geological Survey of the Provincia di Trento (Figure 59).

The first operations involved an emergency monitoring network, also having warning service functions, basically consisting of strain gauge cables (manual reading and then transducer wire strain gauges,) which allowed to better define the extension of the slide (about 50,000 square metres) and its mechanism, as well as the geometry of the fractures.

A survey control network was added to this measurement network, which, from two stations located at the foot of the opposite slope to that of the landslide, monitors the movement of the bench marks distributed over the unstable slope. The monitoring network is today integrated with GPS and meteorological and rain gauge instruments, piezometers, dip needles and horizontal multiple-base strain gauges.

As part of the emergency measures, it should be noted that waterproof tarpaulins were placed over the fractures opened in the area of the landslide, completed with the control of runoff water from the sector uphill from the crown. These measures have resulted in effectively slowing down the kinematics of the phenomenon, and permitted the planning of stabilisation operations which will consist mainly in the removal of about 300,000 cubic metres of slide debris, re-profiling the slope in suitably dimensioned steps, surcharging the foot of the landslide and putting in place a network of drains to replace the waterproof tarpaulins.

The stop area will be reached from SP 71, by taking the service road that crosses the mining area and leads to a terrace on the northernmost limit of the quarry, at an altitude of about 850. The clearing opens near the crown area, where this leads into the present right side of the slide. Walking along a short path, it will be possible to inspect some of the morphostructural and geometric elements of the landslide body, and view the waterproofing work and instruments installed for warning and monitoring, as preparatory measures for the planning of stabilization operations.

Resuming the journey once more along SP 71 towards Lases, just after the lake of the same name, we turn left on SP 76 Gardolo-Lases. Stop 4.3c is about 1 Km away, in the mining area on the northern

Figure 60 - M.te Marzola DSGSD viewed from A22 highway.

slope of Mount Gorsa, where in September 2003 a sudden slide affected an active quarry front and also interested the upper sectors of the slope. The extraction front is about 300 m wide and about 400 m in height, with terraces of about 15-20 m. The upper terraces have collapsed onto the underlying ones, with little evidence of the beginning of the phenomena, and in a particularly dry period, preceded by six months of very little rainfall. The debris mobilised by the landslide is estimated to amount to at least 400,000 cubic metres. During the emergency stage, it was necessary to validate the model hypothesised for the landslide by acquiring the data relative to the deformation field of the quarry front. Therefore, a SAR interpherometric ground based reconstruction of the wall deformations was carried out, monitoring these in time and space. Acquisitions were conducted at intervals of 65.5 hours without interruption. The model validation enabled to later carry out safety work on the slope, mainly consisting of lightening the lithostatic load in the crown area.

DAY 5

Mezzocorona - Trento - Rovereto - Marco, Lavini di Marco (Stop 5.1) - Mori - Loppio - Tenno (Stop 5.2) - Riva del Garda - Malcesine - Peschiera - Verona.

Our itinerary on the last day will begin in Mezzocorona (TN) and proceed first southward and then towards the west to visit two types of slides, a planar landslide ("Lavini di Marco" landslide near Rovereto) and a rotational landslide ("Tenno", north of the lake Garda) respectively. Along highway A22, before Trento, it will be possible to see on the right the area of the Zambiana locality that is subject to collapse. Here in the past a rock prism of about 200,000 m^3 was recorded to have detached. A "twin" prism is currently unstable and is being monitored, not without difficulty, as the area is particularly prone to lightening strikes and the resulting high voltage discharge into the ground frequently damages the installed instruments.

Beyond Trento, the structure of Mount Marzola can be seen on the left, showing morphological evidence typical of Deep-Seated Gravitational Slope Deformations (DSGSD) (Figure 60). The movement would involve the Triassic competent carbonate formations and underlying sedimentary land with a high terrigenous component, consisting mainly of alternating dolomites and marly limestone with siltstone-arenaceous levels (Werfen Formation).

Certain complex landslide phenomena can be related to the evolution of the DSGSD, one of which is certainly Pre-Glacial, as moraine material overlies it, and the other Post-Glacial.

The gravitational movement could be linked to the presence at the base of the mountainside of a deep, ancient riverbed formed by the Fersina Stream which is now completely blocked by Quaternary deposits which were brought to light by the recent geophysical investigations. The geological problems related to the presence and development of this structure are particularly important with regard to the design of the new high-speed railway line, the route of which could pass through this geological situation. Carrying on southwards, the route of SS12 road can be seen from the motorway as it winds along at the base of

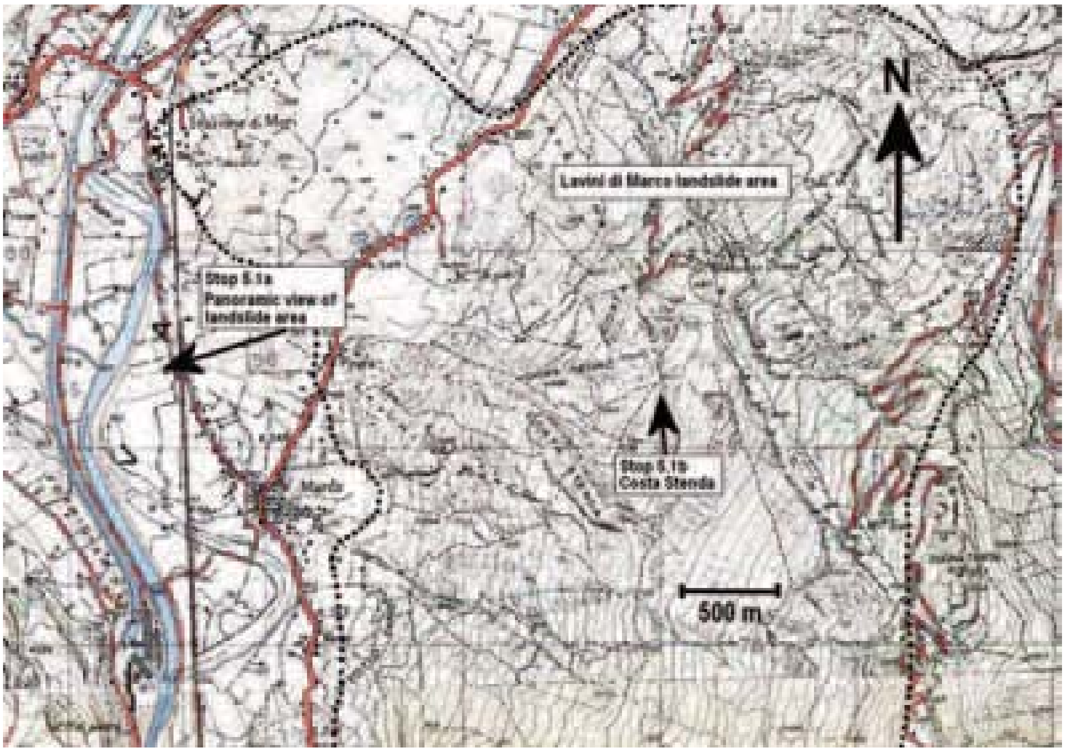


Figure 61 - Excerpt of the Lavini di Marco topographic map. Approximative area affected by landslides (dotted line) and field trip stops are indicated.

the calcareous cliffs (mainly Triassic Dolomites and Jurassic Grey Limestone), which are often jutting out and with evident presence of landslides. The replacement of the old rockfall barriers with new dips to retain the fallen material can be seen in various stretches (this operation also enables its reuse for various types of "sub-base" in civil and engineering works).

At Castel Beseno, on the left, the morphology clearly shows the monoclinal structure of Mount Finonchio, which is constituted by the formation of Grey Limestone on the roof of the main dolomites, with a S-SW dip. This structure gives rise to slope instability phenomena, which are very extensive at Castel Pietra, just after Castel Beseno.

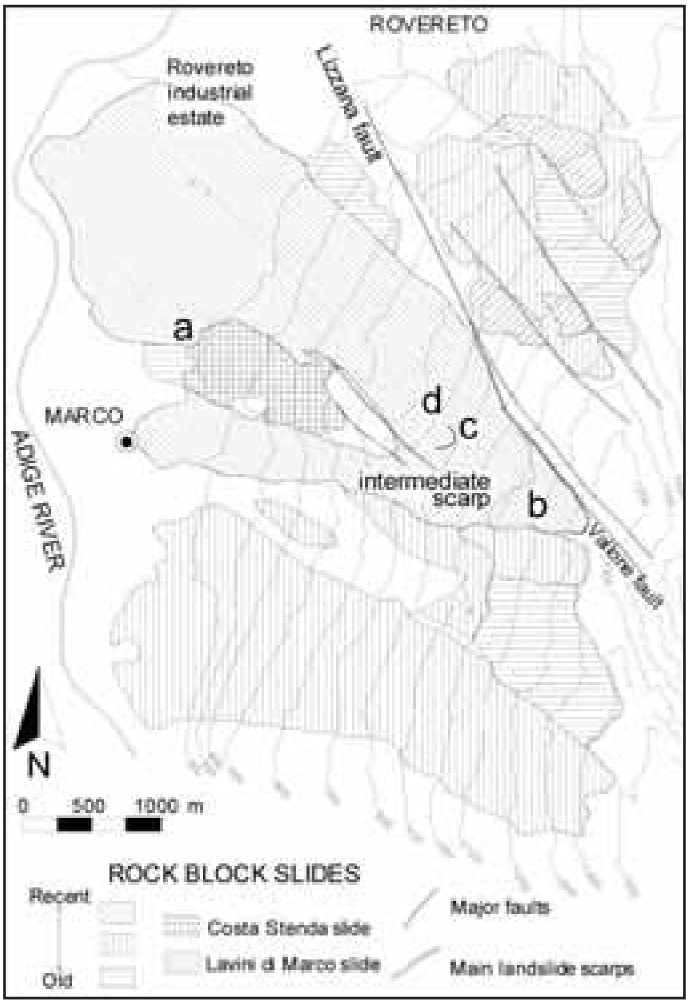
A few kilometres further on, to the right, near the village of Nomi, a series of recently constructed rockfall dips are visible, as defence against events which had threatened the village in the past (1997-98). The marks left in the woods by the fall of an enormous rock mass, which even reached some houses, can still be seen.

Stop 5.1:

Lavini di marco landslides and dinosaurs steps.

We have now reached the start of Val Lagarina, the final stretch of the Adige Valley before it enters the plain. Immediately after leaving the motorway turnoff to Rovereto Sud we reach the first stop (5.1a) of the day (Figure 61). It is possible from here to obtain an overall view of the geological structure to the left of the River Adige, at about 2 km to the south of Rovereto, which has clearly visible landslide phenomena. This area is well known in the literature for the dinosaur tracks which have been discovered here. The area in question (Figure 62) is called "Lavini di Marco", where the first dinosaurs fossil footsteps were found during the 1980s and where, subsequently, during the 1990s, following a systematic search by the Tridentino Museum of Natural Sciences, traces of more than 200 dinosaurs were found. The morphological characteristics of the west face of Mount Zugna Torta (1257 m asl) immediately show the types of instability present in the area, which is geologically formed by carbonaceous rocks of the Mesozoic series (Main dolomites of the Upper Triassic; Grey

Figure 62 - Lavini di Marco landslide area, viewed eastward from A22 highway. Costa Stenda ridge is clearly visible. The main detachment area is also shown.



Limestone *di Noriglio* of the Lower Jurassic; Oolitic Limestone – San Vigilio Group of the Middle-Lower Jurassic; Red Ammonitic Veronese of the Upper-Middle Jurassic) which form a monoclinal structure dipping mainly to the NW with a slope of approximately 20°.

The structure is cut by faults lying roughly NW-SE, such as, for example, that of Lizzana. This structural layout, with *franapoggio* alignment of the strata (i.e. dipping of the strata in the same direction as the topographical slope), has favoured the development of a series of large landslides (Figure 63), some

Figure 63 - Landslides map of the Lavini di Marco area (from Tommasi et al., 2003). The area is located on the left flank of the Adige Valley, south of Rovereto. Letter a refers to Costa Stenda slide; letters from b to d refer to potential slide areas. The main faults (NNW-SSE trending faults) are indicated; the Vallone one gives origin to the high lateral scarp of the Marco landslide. Two accumulation bodies have been produced by Lavini di Marco slide event while Costa Stenda Ridge probably caused the splitting of the landslide. The Costa Stenda slide is another planar rock slide, detached from the Costa Stenda ridge.

of which have resulted in debris avalanches, part of which were probably triggered by seismic events (Orombelli and Sauro 1988; Tommasi, Campedelli et al, 1999 and 2002).
They are therefore translational slides along stratum planes, which are represented by the marly and clayey-marly film skins of the Grey Limestone formation. It is thanks to these slide surfaces that it is possible to see the dinosaur tracks and footprints. The mountain side we are looking at has at least seven large and medium-sizes landslides (Orombelli and Sauro 1988), the largest of which is known as "Lavini di Marco", which covered an area of about 6 km^2. The debris accumulation area of this landslide (the so-called "*macereto*") mainly covers the Adige valley floor for about 4 km^2, where the particular morphology with humps and dips gives an idea of the flow direction and the deposition process. A second debris accumulation area which is smaller but formed by enormous blocks, lies near the village of Marco, at the foot of the slope. The structure of Costa Stenda is clearly visible on the mountainside, with a ridge running along the NW-SE direction, not involved in the instability phenomena, which conditioned the direction of the landslide movement.
It is believed that the poet Dante Alighieri referred to this landslide in his famous Canto XII of the inferno:

"*qual quella ruina che nel fianco*
di qua da Trento l'Adice percosse
o per tremoto o per sostegno manco,
che da cima del monte, onde si mosse,
al piano s la roccia discoscesa
ch'alcuna via darebbe a chi su fosse..."

The poet assumes that the event was caused either by an earthquake ("*tremoto") or by erosion at the toe of the slope *("sostegno manco")*.

Recent studies, carried out with the help of interferometric satellite techniques (Permanent Scatters) confirm that the entire sector referred to is slowly deforming, as also shown by the findings of some inclinometer and extensometer stations.
At the end of the first stop we continue on towards SS 12 ("Abetone" and "Brennero" road) crossing the village of Marco (at approx. km 347), which lies on the Lavini landslides, on an area of debris from an ancient landslide.
This area was the subject of a detailed geological study by the Provincia di Trento with regard to the use of a former explosives store for Civil Protection activities. The study confirmed the geological stability of Marco village with respect to the feared instability phenomena. We continue along SS 12 until (approx.) km 352 and at the village of Lizzana we turn off towards Ossario di Castel Dante. We then enter *artillerymen road*, so-called because it is edged by the tombstones of artillerymen who died during all the wars and were awarded the gold medal for military valour. After 3 to 4 km we reach the area of Costa Stenda where we take the second stop of the day (stop 5.1b). This will enable us to visit some dinosaur tracks and more directly observe the shapes and structures related to the Lavini di Marco landslides (Figure 64 and figure 65).
The trip continues by returning to SS 240 in the direction of Lake Garda until we reach the last location to be visited during the field trip, which is the village of Tenno - to study the landslide bearing the same name. After passing the village of Mori, at about 10 km on the national road, the road runs alongside a morphological dip for about 2 km which corresponds to the bed of Lake Loppio. This is a transient lake. Its temporary existence is linked to high rainfalls which boost the lake's old springs, currently dry, feeding the lake for a certain length of time. The story of the lake

Figure 64 - Partial view of the detachment area of the Lavini di Marco Landslide, taken from stop 5.1b zone.

Figure 65 - a) An example of tension crack affecting the outcropping limestone formation. The instability phenomena are mainly related to the low shear strength of the clayey-marly interbeds. b) Buckling structure in the slide surface of Lavini di Marco landslide, involving a package of plane layers (about five meters thick).

is related to the construction of a diversion tunnel aimed at diverting part of its waters, in the case of flooding of the Adige River, into Lake Garda. The tunnel was started in 1940, interrupted during World War II and completed in 1955. It is 10 km long, with a section of 50 m^2. The difference in level between the Mori inlet and the Torbole outlet is 100m. The tunnel actually formed a structure which drained the aquifer contained within the limestone mass of Baldo mountain with the consequent drying out of the springs, both those used by the neighboring municipalities and those of the lake. The drained flow is approximately 400-600 l/s, with peaks of about 1m3/s.

At the village of Nago we join SS 244, at the junction for Arco, and continue along to Lake Tenno. The area of the landslide is reached at approximately km 53-54 of SS 421 *dei laghi di Molveno-Tenno*.

Figure 66 - Tenno landslide panoramic view. The houses damaged by the landslide can be seen on the right of the accumulation body while the main scarp is visible on the upper left. The length of the landslide is about 400 m and its width is more then 200 m. The estimated volume of the displaced material is about 4 M m3

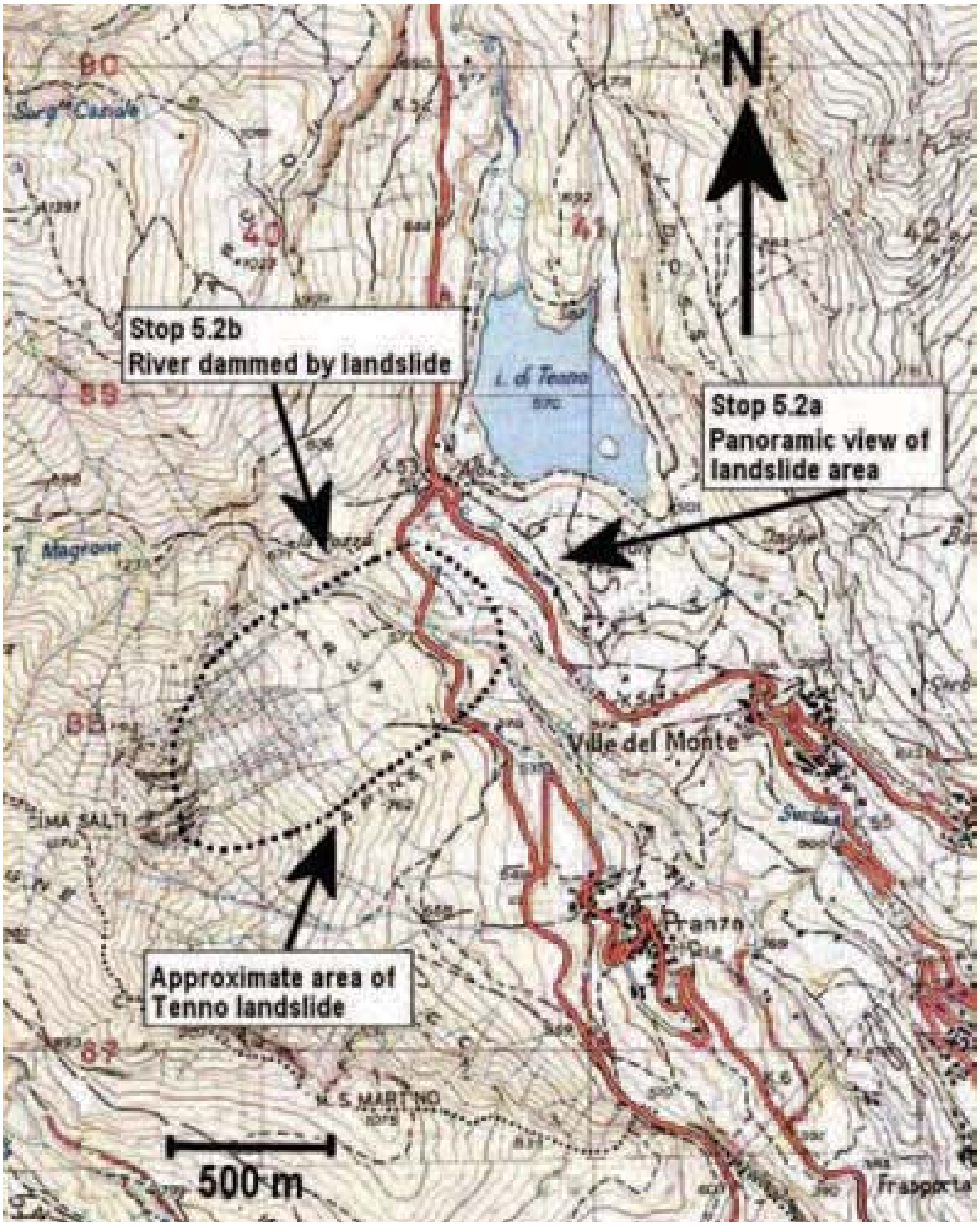


Figure 67 - Excerpt of the Tenno area topographic map. Approximative area affected by the landslide (dotted line) and field trip stops are indicated.

The landslide was probably extremely active during historical times (between the 1000s and 1200s). There has been an extremely large slide on the eastern slopes of Cima Salti, formed by fractured limestone of the Maiolica formation (lower Cretaceous), falling to the valley floor and contributing to the formation of the current Lake Tenno – which may stem also from a moraine embankment (PAT – Geological Survey, 2003).

Stop 5.2:

Tenno landslide

The most important event during very recent times occurred after the exceptional rainfall of November 2000, when – at 4 p.m. on 27 November 2000 – one of the largest landslides in Trentino in the last 40 years occurred (Figure 66).

The landslide covered the previous debris material, interrupted SP 37, blocked the bed of the Magnone Stream for a stretch of more than 400 m, destroyed a house, without causing any victims, and came very close to a second house. The area of the landslide was approximately 120,000 m^2 with 3 million m^3 of material mobilized.

The geological and geotechnical studies carried out by PAT-Geological Survey after the event, with piezometric monitoring, clarified the geological conditions which caused the landslide. It was caused both by the deep-down presence of silt deposits with clay (lacustrine environment, maximum thickness unknown, but more than 40m), which acted as a slip plane, and by the increase in the water table level in the fractured limestone rock mass which saturated the detrital deposits with a considerable increase in pressure.

The reclamation project is based on a re-profiling of the landslide debris and diversion of the Magnone stream to prevent erosion at the foot of the debris. The first stop (Stop 5.2a) (Figure 67) will be made along the national road to obtain a general overview of the phenomenon and of the reclamation work in progress, as well as to describe the event. The next stop (Stop 5.2b) will actually take place at the foot of the landslide, near the temporary intake work which currently collects the water from the Magnone stream and discharges it downstream, bypassing the foot of the landslide (Figure 68).

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Figure 68 - The intake construction built after the event to allow a safe remedial work realization. The work is located at the left edge of the accumulation body, which has dammed the river bed. The water are collected from the Magnone stream and discharged downstream to avoid the erosion of the landslide foot.

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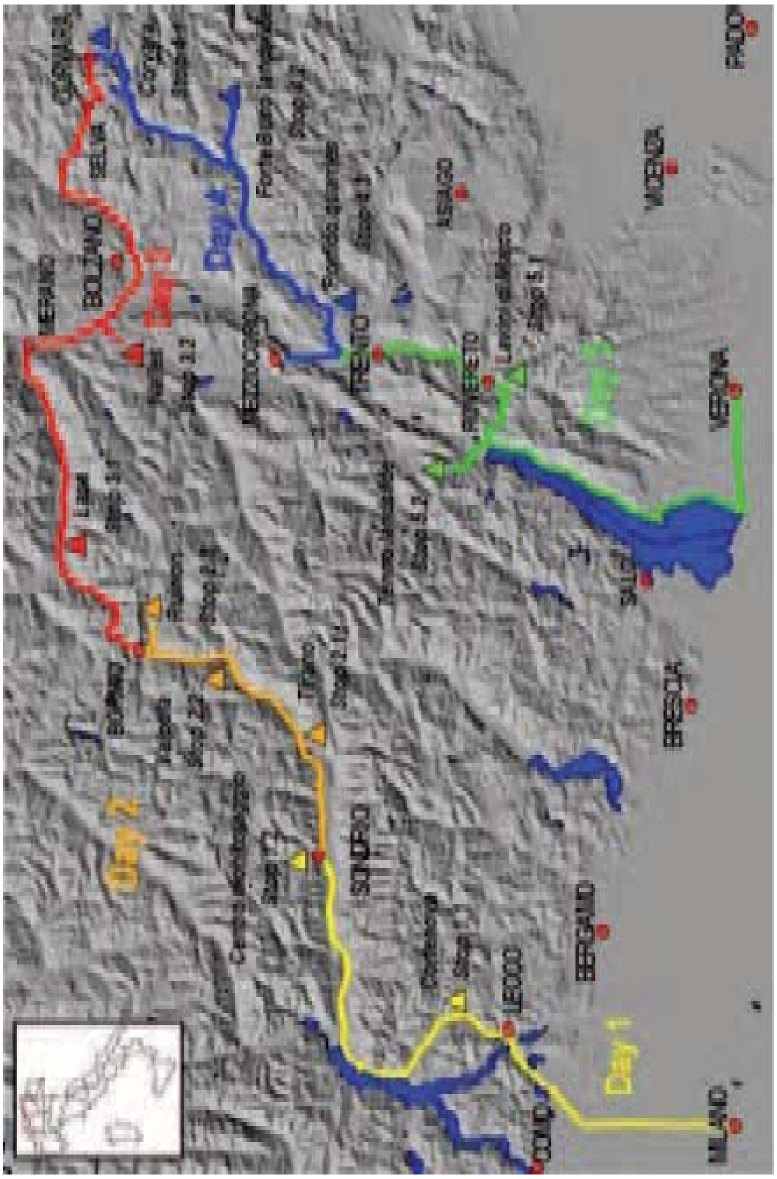
Back Cover:
field trip itinerary

FIELD TRIP MAP



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