

Ceppo Morelli Landslide - Anzasca Valley, Piedmont, Italy

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1 INTRODUCTION

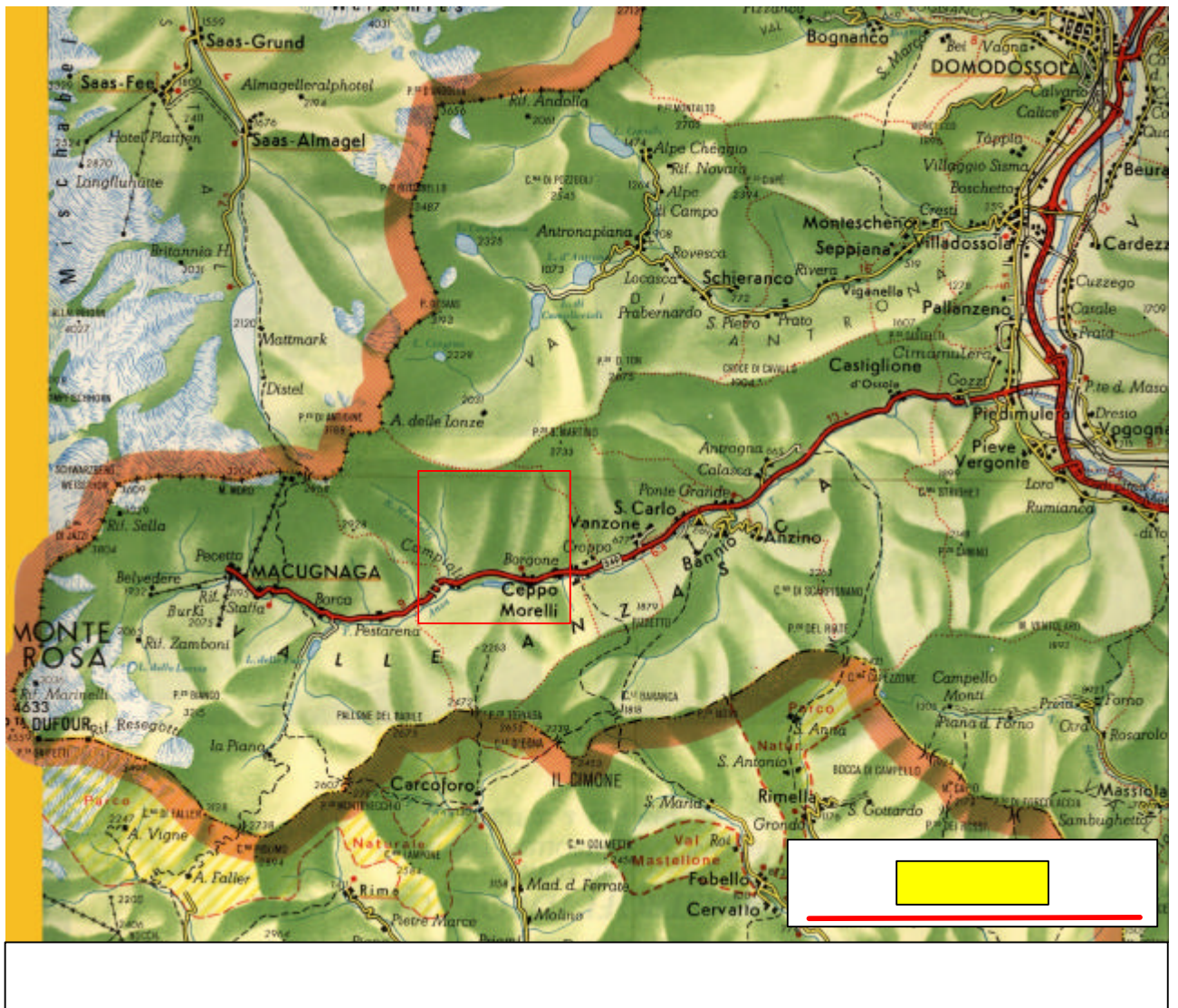


Figure 1: regional framework; Ceppo Morelli landslide (red point) is located in northern Piedmont (yellow area).

The *Ceppo Morelli* rockslide extends on the left side of the middle *Anzasca* valley in Pennine Alps, northern Piedmont (Italy), few kilometres from the border with Switzerland (Fig.1). The valley is drained by the *Anza* river. The national road SS 549 runs along the *Anzasca* valley for about 30 km, from *Piedimulera* village (*Toce* river plane) to *Pecetto di Macugnaga* hamlet (at the foot of the *Monte Rosa* massif). This is one of the Italian Walser valleys as well as *Sesia*, *Lys* and *Ayas* valleys. The Walser are German people that settled in this area during the 13th century.

The *Ceppo Morelli* landslide is located between *Prequartera* and *Campioli* hamlets, close to *Ceppo Morelli* village (Fig.2). It affects the middle-lower part of the slope until the valley bottom at about 800 m amsl; the crown is located close to a secondary slope ridge at about 1.850 m amsl. The slide affects a massive gneiss formation along a cataclinal over dip slope and may be regarded as a *quasi-planar* rock slide. The overall surface of the slide is in the order of 150.000 m²; the volume estimation is between 4 and 6 * 10⁶ m³.

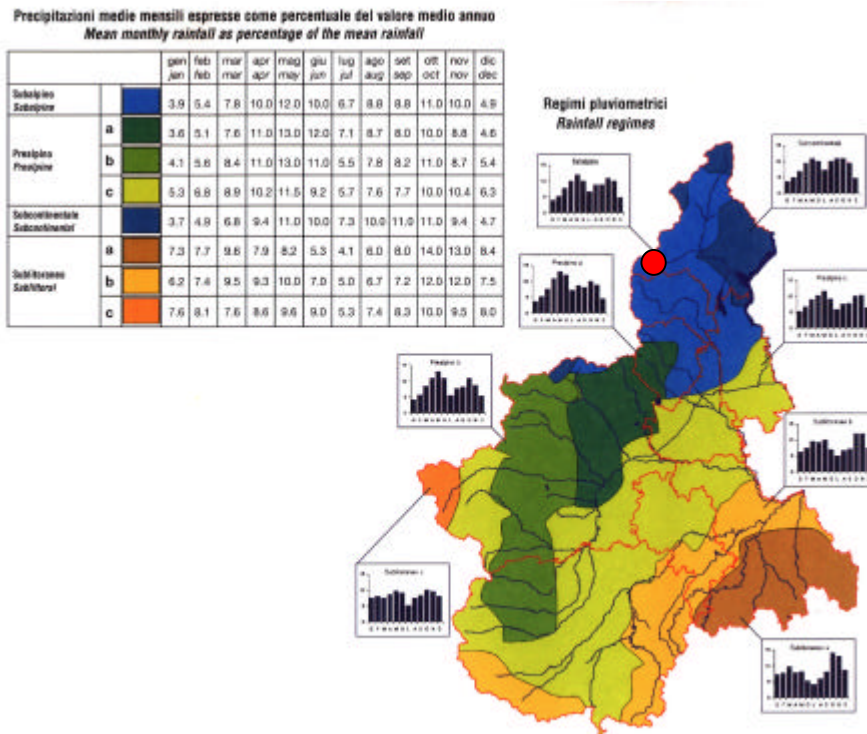
Where the main sliding surface probably daylights, 400 m about above the talweg, the slope sector produces several rockfalls reaching the *Anza* river. Boulders up to 1.000 m³ are not uncommon.



2 REGIONAL FRAMEWORK

2.1 Climate

The climate of the considered area is characterized by a Subalpine regime. According to Thornthwaite (BIANCOTTI & BOVO, 1998a e b) this area can be classified as AB1'rb3'. Region: cold axeric. Subregion: cold temperate (Fig.3).



Meteorologic information derived from 14 stations pertaining to the *Idrografico e Mareografico* National Service indicate for the period 1951-1986 an annual average rainfall of 1.594 mm with 119 raining days by year and average intensity 13,4 mm/day. Monthly rainfall peaks have been recorded in *Ban-nio-Anzino* station in correspondence of May and October, with 198 mm and 190 mm (BIANCOTTI & BOVO, 1998a e b).

Figure 3: Piedmont climate map (BIANCOTTI & BOVO, 1998a e b). Red point shows the investigated area.

Since 1990 is active *Macugnaga* station and since 2000 is active *Alpe Colla* station, both pertaining to the Regional Meteorological Service.

The monthly mean temperatures are (in °C): Jan -0,2; Feb 0,9; Mar 3,9; Apr 7,5; May 11,5; Jun 15,2; Jul 17,9; Aug 17; Sep 13,8; Oct 9,4; Nov 4,2; Dec 1,2. Annual mean temperature is 9°C. There are an average of 93 frost days by year (data refers to a square grid sized 1 km round *Ceppo Morelli* landslide).

Snow information derive from *Alpe Cavalli* gauges (1.510 m amsl, *Antrona* Valley); data refer to 1966-1996 continuous measures (in cm): max. snow level 785 (1971-72), min. 137 (1985-86), average 438; monthly mean snow level: Nov 49; Dec 61; Jan 89; Feb 86; Mar 80; Apr 67; May 1 (BIANCOTTI & BOVO, 1998a e b).

Data sources are the *Idrografico e Mareografico* National Service and the Regional Meteorological Service.

Tab 1 - Idrografico e Mareografico National Service gauges: rain, snow and temperature gauges around the studied area (BIANCOTTI & BOVO, 1998a e b).

Station	Altitude (m amsl)	Recording period
<i>Antronapiana</i>	902	1913-1941
<i>Alpe Cavalli</i>	1.510	1928-1986
<i>Bannio-Anzino</i>	670	1914-1985
<i>Campello Monti</i>	1.300	1914-1967
<i>Campliccioli</i>	1.310	1928-1986
<i>Camposecco</i>	2.308	1937-1986
<i>Cingino</i>	2.192	1937-1986
<i>Forno</i>	892	1923-1986
<i>Macugnaga</i>	1.300	1914-1985
<i>Marmo Sambughetto</i>	765	1921-1986
<i>Domodossola</i>	277	1913-1986
<i>Montescheno</i>	709	1924-1941
<i>Ornavasso</i>	208	1913-1964
<i>Piedimulera</i>	243	1914-1976
<i>Rivasco</i>	860	1916-1928
<i>Rovesca</i>	760	1935-1986
<i>Alagna</i>	1.205	1913-1986
<i>Boccioleto</i>	667	1917-1986
<i>Camasco</i>	752	1921-1978
<i>Campertogno</i>	815	1922-1986
<i>Carcoforo-Ferrate</i>	1.150	1915-1986
<i>Fobello</i>	800	1913-1986
<i>Miniera d'oro</i>	1.300	1913-1913
<i>Piana di Rassa</i>	1.139	1922-1941
<i>Rima</i>	1.417	1915-1941
<i>Rimasco</i>	905	1915-1986
<i>Rimella</i>	1.181	1920-1941
<i>Riva Valdobbia</i>	1.117	1913-1963
<i>Sabbia</i>	726	1917-1986
<i>Varallo</i>	453	1913-1986
<i>Belvedere</i>	1.842	1919-1920

Tab 2 - Regional Meteorologic Service: rain, snow and temperature gauges around the studied area.

Station	Altitude (m amsl)	Acquiring data since
<i>Alpe Cheggio</i>	1.460	6/11/96
<i>Anzino</i>		25/11/00
<i>Ceppo Morelli</i>	2.030	25/11/00
<i>Domodossola</i>	252	4/5/88
<i>Macugnaga Pecetto</i>	1.360	10/11/99
<i>Passo del Moro</i>	2.820	4/11/88
<i>Sambughetto</i>	742	28/11/89
<i>Carcoforo</i>	1.290	6/11/96
<i>Bocchetta della Pisse</i>	2.410	21/10/87
<i>Fobello</i>	873	29/5/96
<i>Boccioleto</i>	800	25/11/99
<i>Sabbia</i>	600	29/5/96
<i>Varallo</i>	470	1/3/89
<i>Rassa</i>	950	20/7/93

2.2 Regional Morphology

The *Anzasca* valley is drained by the *Anza* river. It is the last lateral right valley of the *Ossola* main valley. The *Anza* river joins the *Toce* river on the lower *Ossola* valley plane.

The *Anzasca* valley is mainly characterized by fluvial and glacial morphogenesis and by landslide activity. Subglacial features are also present (*Calasca* gorge). The *Anzasca* valley is steeper and impervious and the valley altitude ranges from 247 m amsl (*Piedimulera* village) to 1.378 m amsl (*Pecetto di Macugnaga* hamlet) just along a 30 km length. Just beyond *Ceppo Morelli* village the stream profile is interrupted by the *Morghen* rocky step that bounds the *Macugnaga* plane.

2.3 Regional Geology and Structural Setting

The landslide site is placed in the *Monte Rosa* basement nappe (Upper Pennine Units). The *Monte Rosa* basement nappe is represented by polymetamorphic augengneisses and paraschists (Fig.4). This basement is characterized by several Alpine ductile deformation phases.

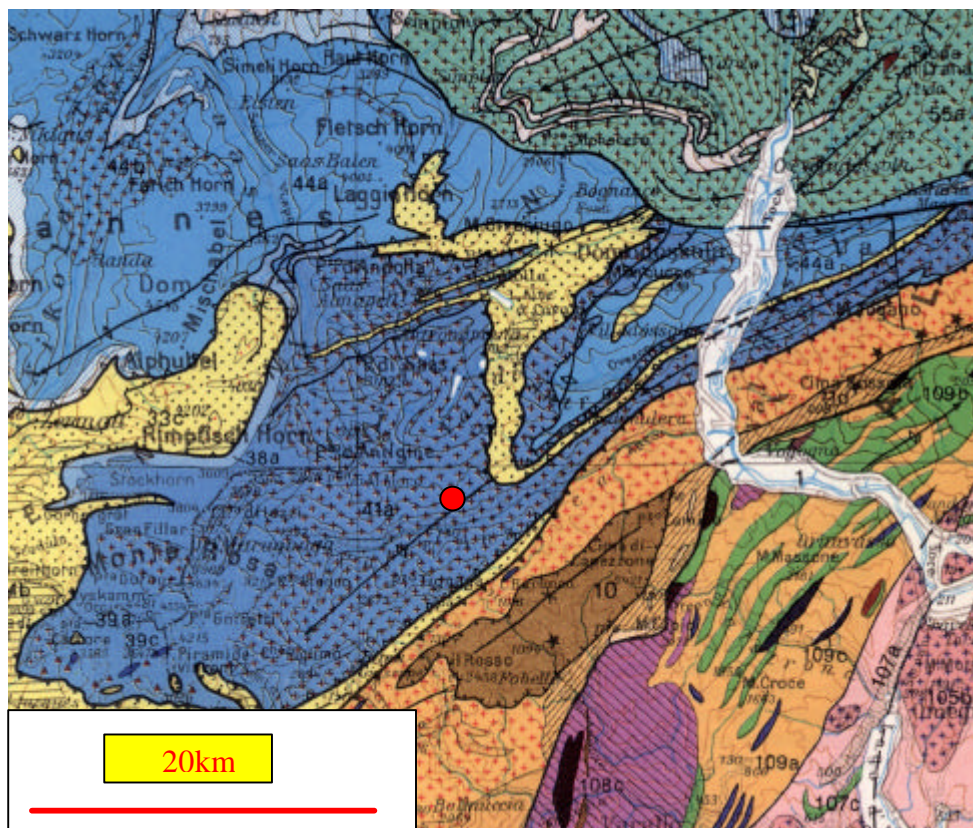


Figure 4: geologic and structural framework (CNR, 1990). Quaternary: 1 Undifferentiated continual deposits. - Austroalpine system: - 10 Rootless sheets of granulite to amphibolite facies. - 11b *Arolla-Gneiss Minuti* basement complex. - 11d *Fobello-Rimella* mylonitic schists. - 12a Eclogitic Micaschists complex. Piemont-Ligurian ophiolite nappe system: 33c Metabasalts. - 35a Undifferentiated calcschists. Pennine nappe system: 38a Post-Hercynian metasedimentary cover. - 39a Undifferentiated micaschists. - 39c marbles. - 41a Augengneiss and massive metagranitoids. - 42c metamorphic clastic and volcanic sequences. - 44a micaschists. - 44b orthogneiss. - 45b undifferentiated sedimentary cover - 52b *Tarentaise* unit. - 53a *Valais* calcschists unit. - 55a Lower Pennine nappes, mainly Alpine orthogneiss. - 56a undifferentiated *Baceno-Verampio* micaschists and *Lucomagno* metasedimentary cover. Southern Alps: 105b granitoids. - 106 Phyllites, micaschists and minor paragneiss. - 107a Hercynian orthogneiss. - 107c metabasites in greenschists and amphibolite facies. - 108b cumulus gabbros. - 109a metapelites. - 109b metabasites. Red point shows the investigated area.

At regional scale the basement is deformed by the *Vanzone* antiform characterized by a SW plunging axis and NW dipping axial plane.

The regional ductile deformation is characterized by:

- S1 foliation parallel to the axial planes of the P1 folds (first folding phase); the S1 is re-folded by a second fold phase that gave origin to isoclinal P2 folds (among which is the *Vanzone* antiform) and associated crenulation cleavage S2 (corresponding to SR in chapter 2.1). P2 are re-folded (third folding phase) by open folds (P3) and associated crenulation cleavage S3.

The regional brittle tectonic deformation is characterized by mesofaults and joint systems, partially parallel to the axial planes of the *Vanzone* antiform.

Recent eluvial-colluvium deposits are represented by heterogeneous and incoherent mass of soil material and rock fragments deposits.

3 LOCAL FRAMEWORK

No systematic studies are conducted in the area.

The slide affects a massive gneissic rock mass which is intersected by several joint sets.

3.1 Local Geology and structural setting

The main discontinuities observed (Fig.5), mainly from field investigation (October/November 2000), are listed below:

SR - ($225^{\circ}/35^{\circ}$): schistosity; highly persistent system with small spacing. Average JRC = 2. Average JCS = 22 MPa and average base shear resistance angle = 28° - 30° .

K - ($225^{\circ}/55^{\circ}$ - 60°): fracture system; highly persistent system. SR and K systems merge at depth.

K1 - ($115^{\circ}/85^{\circ}$): fracture system; highly persistent system (>100 m) spacing 10-100 m. This system is disposed towards E by step geometry and it borders the landslide right side.

K2 - ($70^{\circ}/85^{\circ}$): fracture system; highly persistent system (50 m) spacing more than 20 m. Minor persistence and spacing than K1.

K3 - ($44^{\circ}/88^{\circ}$): fracture system. Geometrically similar to system K2; due to the small number of measures, K2 and K3 could belong to the same scattered joint system.

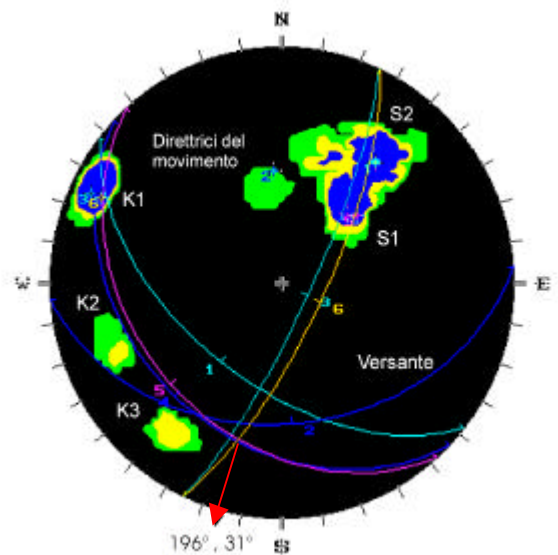


Figure 5: Schmidt's equal-area diagram; stereographic projection of main discontinuities (lower hemisphere). S1 and S2 correspond in text to SR and K respectively. Red arrow shows the lineation of intersection between SR schistosity and K1 cleavage which represents the dip direction and dip ($196^{\circ}/31^{\circ}$) of the landslide main movement.

4 LANDSLIDE

The *Ceppo Morelli* rockslide lays on a S-SE exposed slope.

4.1 Landslide Identification

The slides affects a massive gneissic formation along a cataclinal over-dip slope and may be regarded as a *quasi*-planar rock slide.

Probably the main movement is governed by a plain parallel to master continuous surface, strongly defined by mica layer with low shear resistance and dipping about 35°. Moreover it seems extremely likely that, the sliding surface follows a stepped path which involves both the main foliation system (SR) and the steeper K system.

Where the main sliding surface may daylight (400 m about above the talweg), the slope produces rock-falls reaching the *Anza* river. Boulders up to 1.000 m³ are not uncommon (Fig.6).

The lower part of the main slide body is apparently strongly instable and may well give origin to mass-falls or even to a rock avalanche.

Four main structural lineations define the landslide body: two subvertical systems (with NNE-SSW and ESE-WNW directions,) and two SW dip directed systems dipping 35° and 60° respectively.

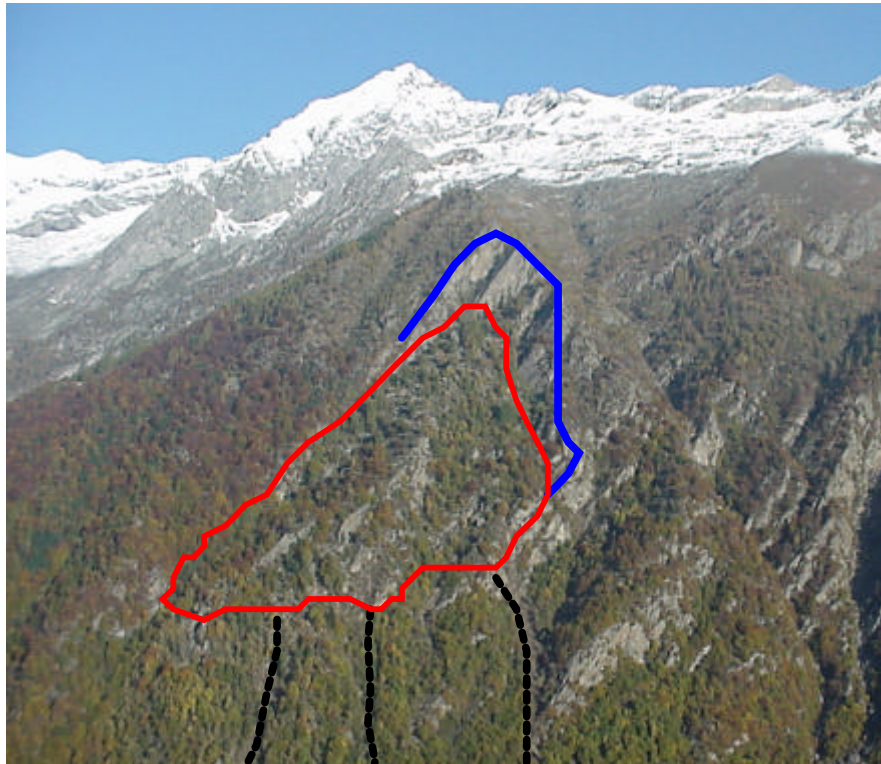


Figure 6: Ceppo Morelli landslide. It's shown the crown (blue line), the main sliding body (red line) and the main rockfall tracks (black dots).

4.2 Landslide Detail

Three distinct sectors are recognizable (Fig.7):

A: crown. Upper part and upper left side of landslide. It corresponds to the scar zone of the landslide. As consequence of the October 2000 event, a continuous tension crack developed in this sector bounding the upper part of the slide body (B sector).

B: slide body. Central part of landslide: it could be divided in B1 (coarse debris; upper and lateral right edges of B2), B2 (translated body with preserved structural assessment) and B3 (debris with uncommon preserved rock masses; lower edge of B2).

C: involved area. It involves the overall slope from B sector to bottom valley. It could be divided in C2 (western C area involved in ancient and recent rockfalls) and C1 (eastern C area, probably an old rock avalanche; *Pestarena* hamlet rises on it).

The October 2000 flood represents the last paroxysmal event.

Displacement dates for C sector are: 1816 (engraved on a 1.000 m³ boulder close to the *Anza* river), 1940, 1971-1977, 16/10/2000, 18-19/10/2000, 27/10/2000, 6/11/2000, 10/11/2000, 18/11/2000. In detail: in 6/11/2000 rockfalls at 6.30, 9.00, 15.30 have been recorded; in 27/10/2000 rockfall at 12,30 has been recorded; in 6/11/2000 rockfall at 13.30 has been recorded; in 10/11/2000 rockfall at 15.00 has been recorded.

4.3 Landslide Morphometry

The overall surface of the slide is in the order of 150.000 m²; the volume estimation is between 4 and 6 millions m³.

The A sector extends from 1.750 m amsl to 1.400 m asmsl.

The B sector extends from 1.660 m amsl to 1.200 m amsl.

The C sector extends from 1.200 m amsl to 800 m amsl.

The surveys carried out after the October 2000 event indicated an overall downward movement of the main slide body of about 5 m (measured from striations on the right scarp of the landslide) and a relative subsiding of about 1,2 m. Measures on tension crack along the crown shows a downward movement ranging from 2 m to 6 m and a 190°-210° slide direction. The direction of sliding seems to be influenced by the main foliation rather than by the slope morphology, and seems to follow the line of intersection between K1 and SR (196°/31°; red arrow in figure 5). The surveys also indicated that the movement seems to occur along a deep slide surface and that the right scarp actually represents the right limit of the slide.

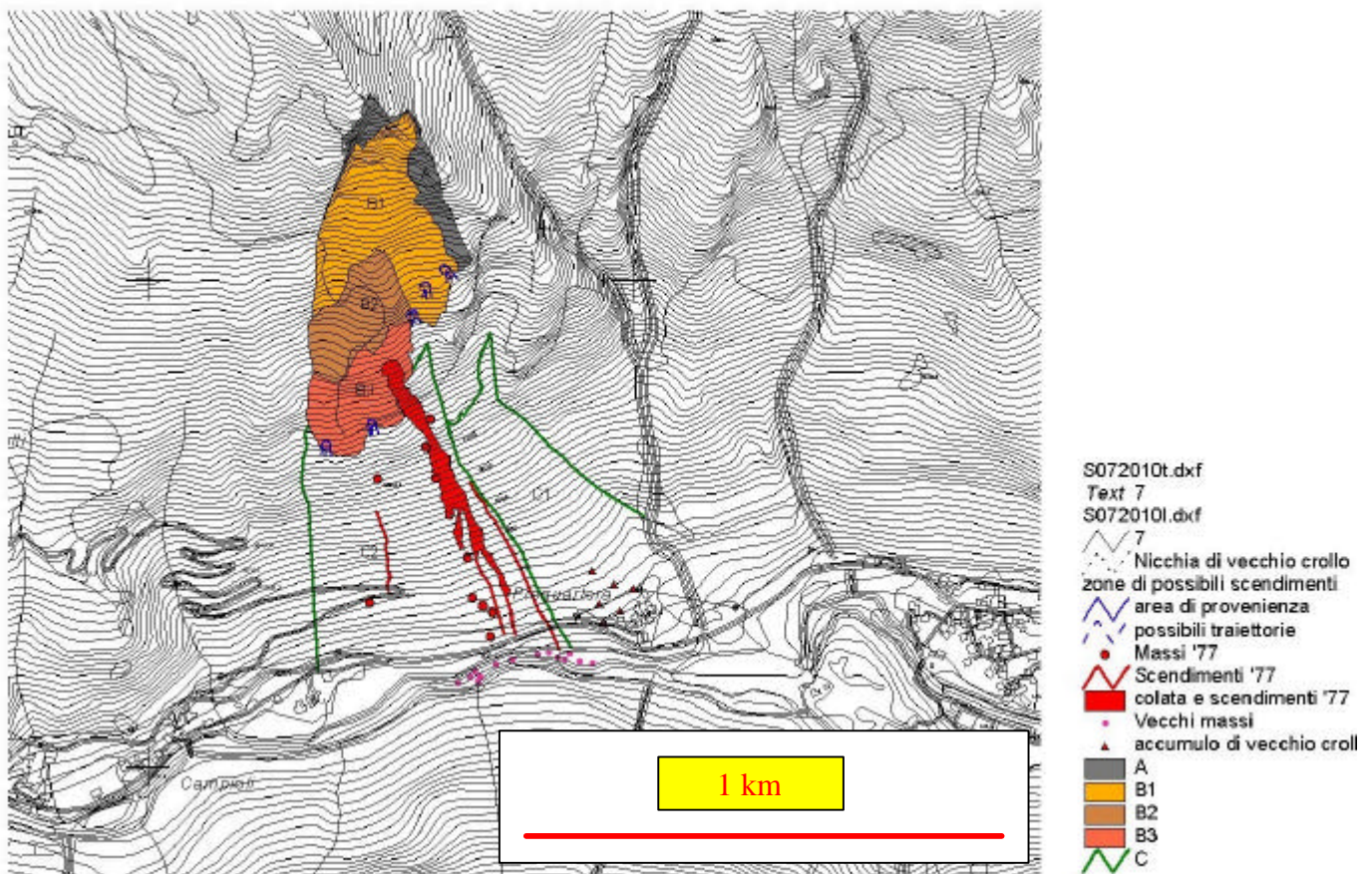


Figure 7: Ceppo Morelli landslide sectors. Legend translation: Nicchia di vecchio crollo, zone di possibili scendimenti - Ancient rockfall crown, probable rockfall tracks; aree di provenienza - source area; possibili traiettorie - probable rockfall tracks; Massi '77 - 1977 rockfall boulders; Scendimenti '77 - 1977 rockfall traks; colata e scendimenti '77 - 1977 flow and flow traks; Vecchi massi - ancient rockfall boulders; accumulo di vecchio crollo - ancient rockfall zone of accumulation.

During the flood of October 2000 several boulders, up to 300 m³, reached the river and the National Road (Fig.9).



Figure 8: April 1977: rockfall involves the national road.



Figure 9: rock fall triggered during the October 2000 flood. The boulder (right red arrow) damaged the national road (red line) and stopped near a house (left red arrow).

5 INVESTIGATION AND MONITORING

After the October 2000 flood, slide was monitored also to provide some information about the risk for the national road and the hamlets.

5.1 Survey and monitoring of landslide activity

From November 2000 the slide is monitored by means of an automated data recording and transmission system which includes: 32 topographic bench-marks (above the crown and on the landslide main body) controlled by an automated theodolite; 10 wire extensometers (7 extensometers on the landslide crown 3 extensometers along the fracture of the landslide body); 10 distometers with 3 reference bolts each, associated with all the extensometers (7 distometers on the landslide crown and 3 distometers along the fracture of the landslide body); 3 uniaxial surface geophones and 2 triaxial surface (prox. install.).

All the data are transmitted by means of GSM modules. Up to now no relevant displacements were detected. Future investigation will define the geologic setting, the precise geometry of the slide body and the probability of major failures.

5.2 Monitoring of meteorological and Hydraulic conditions

A rain-gauge with a thermometer was installed at *Alpe Colla (Ceppo Morelli)* 2.030 m amsl (25/11/00). Not meaningful data are available up to present.

6 MODELLING

Three numeric model had been developed by *Politecnico di Torino* to evaluate landslide runout:

1 - Lagrangian rheologic approach using a frictional fluid model: blocks with constant volume.

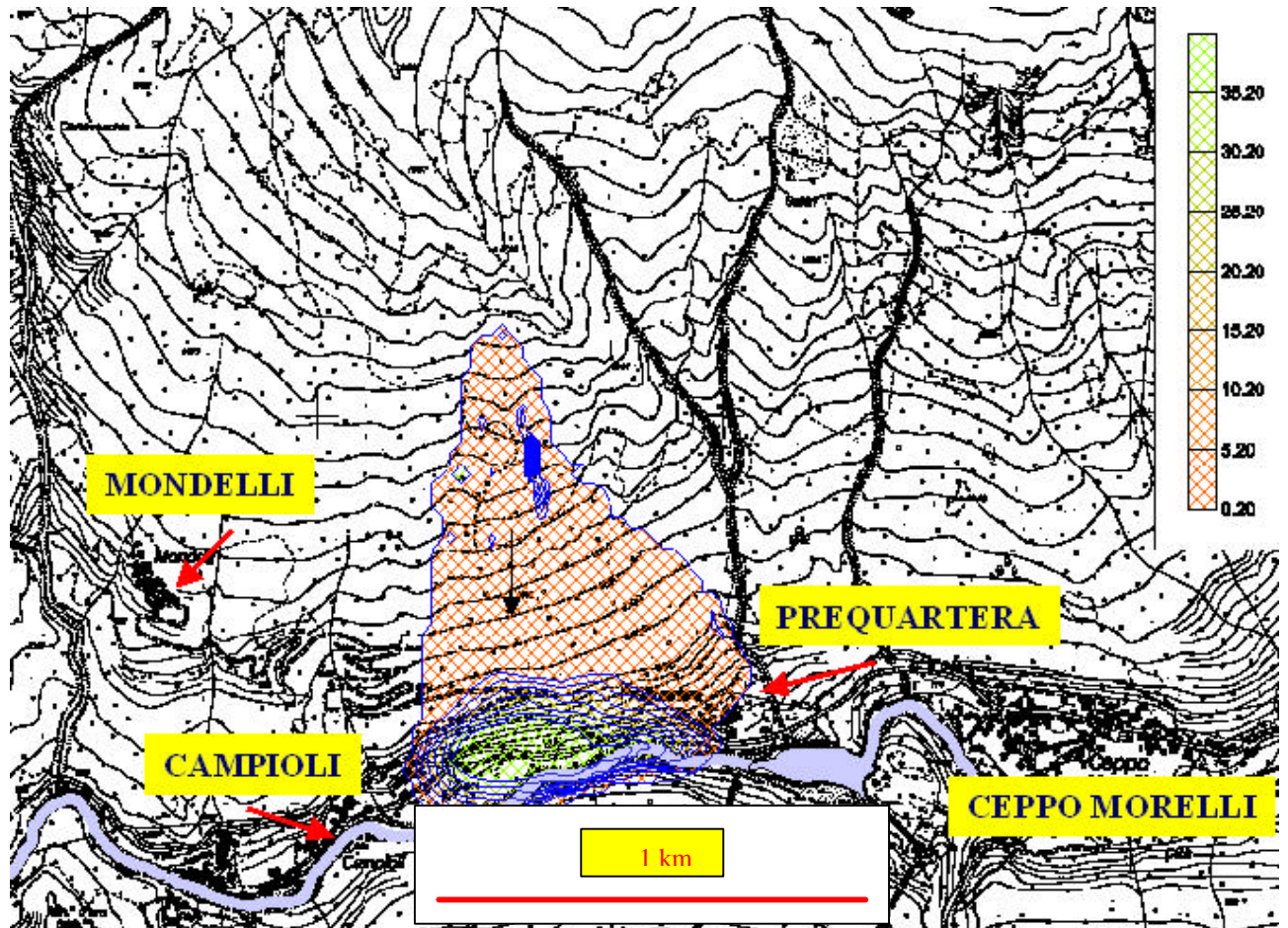


Figure 10: results of 3D cellular automaton modelling.

2 - 3D cellular automaton model (Segre & Deangeli 1995, Deangeli 1997) (Fig.10). The state of a cellular automaton is defined by values of all the variables (space, time and physical quantities). The evolution occurring in timestep n is calculated in each cell according to values in adjacent cells at timestep $n-1$. A 5 million (conservative) unstable volume is considered for the dynamic analysis, on the basis of K1 and S2 joint systems (*Regione Piemonte*, 2000).

3 - One-dimensional lagrangian analysis (DAN), able to take into account rheologic and mass variations occurring during the landslide. The runout path is part of the analysis input. Several scenarios are considered, according to different hypothesis on the unstable volume involved. Investigation of the input parameters influence is provided. The output are: runout distance, landslide velocity and expiring time; limits of propagation. (Hungr, 1995; Hungr & Evans, 1997; Pirulli, 2001).

Another modeling has been pointed out for rockfalls by *Regione Piemonte* using the software: *ISOMAP & ROTOMAP*, Geo&Soft, Torino, Italy. Blocks are represented by material points defined by mass and velocity (lumped mass). Sliding is characterized by a friction coefficient; rebound by normal and tangent reaction coefficient. The output are path, stop probability area and kinetic energy of blocks (Fig.11).

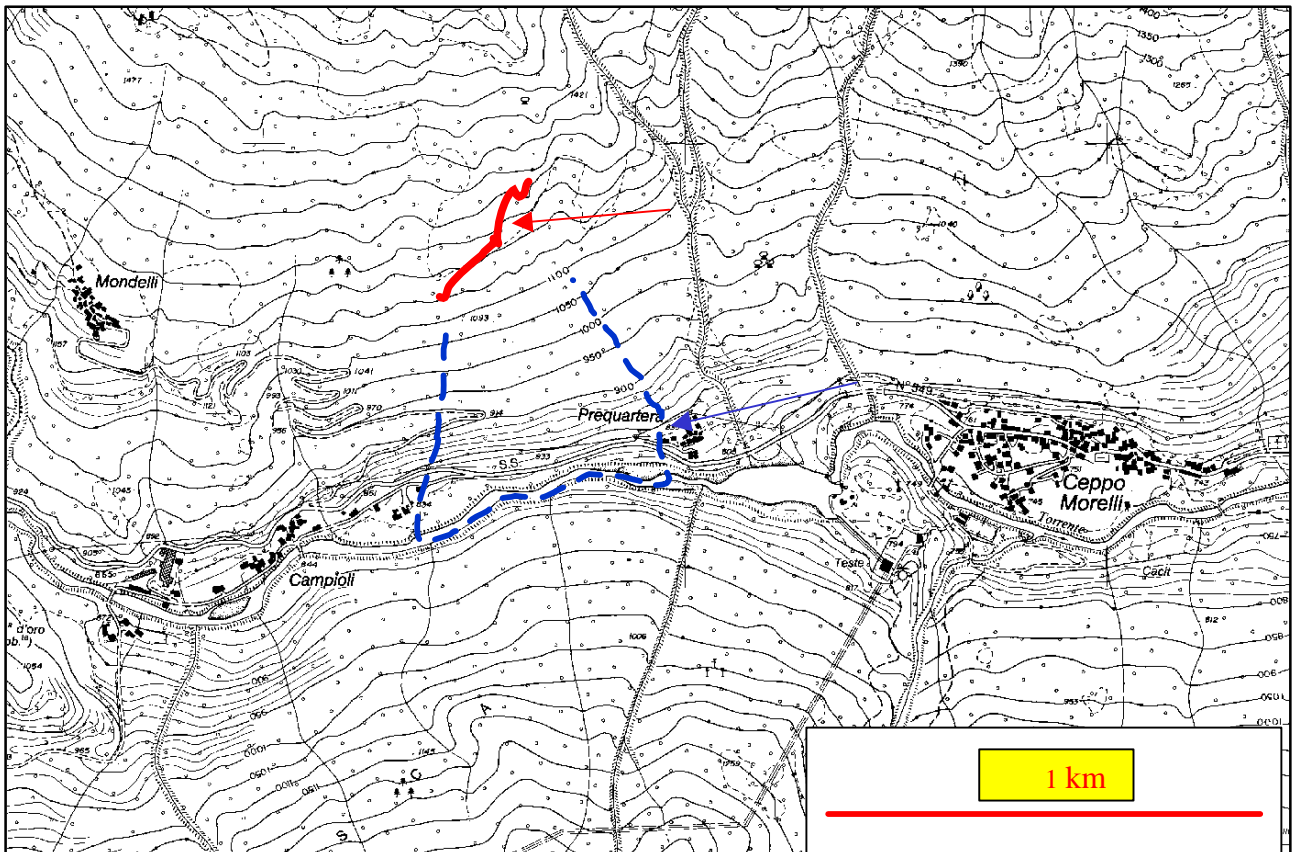


Figure 11: rockfalls modelling result. Red line shows rockfalls source; dashed blue line shows the involved area in rockfalls modeling.

7 STABILISATION/PROTECTION WORKS AND REGULATION

A provisional by-bass for the National Road was realized in December 2000 on the opposite valley flank. As consequence the National Road SS 549 has been interdicted between Prequartera and Campioli hamlets. A Tunnel for the National Road is under project. *Prequartera* will be protected by means of a reinforced-earth rockfalls protection wall.

8 LAND USE AND RISK ASSESSMENT/MANAGEMENT

8.1 Land Use

Man-made structures are concentrated along the talweg; they includes two hamlets, the national road and part of a hydroelectric power plant. Meadow extends along floor plane and along higher level grounds.

Pasture extends above 1.400 m amsl associated to rock masses.

Deciduous forest grows on the left slope of the valley; they extends from bottom valley up to conifer forest and pasture boundaries.

Conifer forests extend on overall right slope of the valley and from 1.100 m amsl up to 2.000 m amsl on the left slope.

8.2 Elements at Risk

The National Road SS 549 runs on the valley bottom. The road is the only connection to *Macugnaga*, a popular tourist resort close to the *Monte Rosa* massif. In order to avoid the sector at risk (800 m about) a provisional by-pass road was prepared in December 2000. Since this solution will protect from rockfalls but not from a mass-fall, a by-pass tunnel is under project.

Two hamlets dating back to the XVI century, *Prequartera* and *Campioli*, could be involved in rockfalls or rock avalanche. *Prequartera* will be protected by means of a reinforced-earth rockfalls protection wall. The situation of *Campioli* is still under examination. The hamlet will be either protected by a rockfalls protection wall or relocated elsewhere.

9 FIRST SCENARIOS

High probability: movements of the main slide body trigger several rockfalls starting from the daylight line. Major boulders reach the talweg, affecting *Campioli*, the national road and, possibly, *Prequartera*.

Low probability: mass-fall or rock avalanche. Volumes of rocks ranging from 600.000 m³ to some millions of cubic meters (up to 6*10⁶ m³) may dam the Anza river and destroy *Campioli*. *Prequartera* hamlet could be interested and SS 549 national road could be destroyed.

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