Rosone landslide - Orco Valley, Piedmont, Italy

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1 INTRODUCTION

The Rosone landslide is placed on the left hydrographic slope of the Locana Valley (near Turin, Piedmont) with an areal extension of about 5.5 km^2. The landslide has been interpreted as a Deep Seated Gravitational Deformation (DSGD) affecting the southern side of the Orco - Piantonetto ridge modeled on lythotypes of the Gran Paradiso Massif. The slope morpho-structural features allow to distinguish three adjacent sectors corresponding to three different evolution stages of the DSGD.

Rosone hamlet and the 99 MWh hydroelectric power plant of Azienda Energetica Metropolitana of Turin (AEM) are located at the confluence of the Orco and Piantonetto torrents. Coming from Ceresole Reale dam, the water reaches the AEM facilities through a 17 km long after spanning the entire length of the gravitational deformation up to the reservoirs of Perebella, where it falls towards the power plant via a penstock with a drop of 813 m. At the toe of the slope the only national road n.460 from Turin to Ceresole Reale runs.

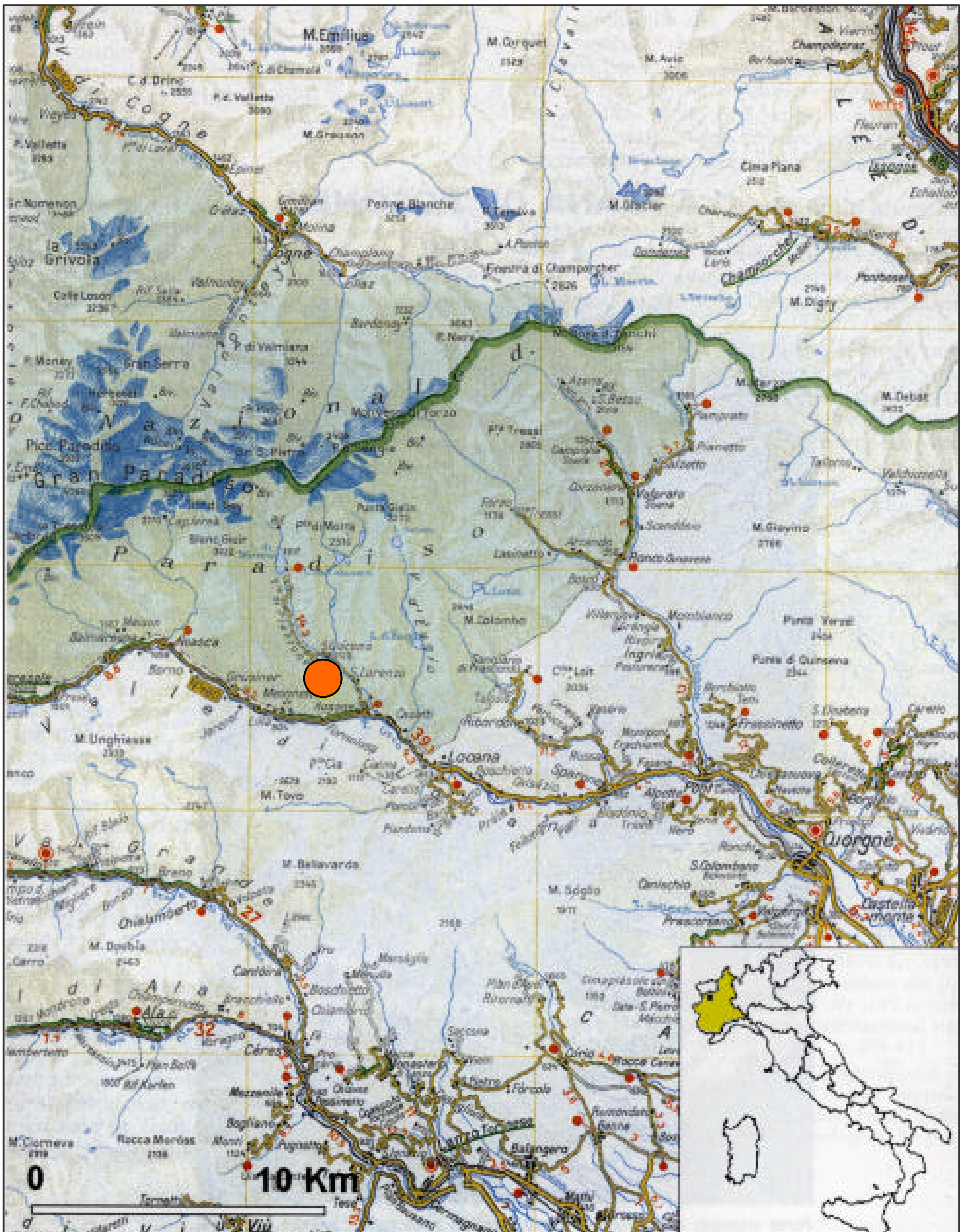

Figure 1 - Location map of Rosone landslide, Locana Valley (Piedmont).

2 REGIONAL FRAMEWORK

2.1 *Climate*

The climate is characterized by a pre-alpine regime (“c” type) and in according to the Thornthwaite classification (in BIANCOTTI & BOVO, 1998a) the area can be classified as AB1're3'. Region: cold axeric; Subregion: cold temperate.

The thermometric regime is characterized by 4-6 frost months per year. Ceresole Reale station, located at an altitude of 1600 m, registered 184 frost days (1950-1986) with a probability of 80 -100 % of frost days since December to March. Bertodasco station is the reference for the period 1990-2001.

On Graie Alps the pluviometric rate is pre-alpine type and the average annual number of rainy days varies from 90 to 110 days per year. On Orco basin the average annual precipitations is about 1224 mm/year and average annual rainy days is of 96. The average daily intensity is about 12.8 mm/day.

Average annual rainfall is determined in a period of 42 years, from 1938 to 1980. The result of about 1200 mm refers to a station placed at an altitude of 700 m, at the bottom of the referred slope. Since 1990 a new pluviometric and thermometric station has been activated at Bertodasco (1120 m) in the average altitude of landslide body.

The seasonal distribution of rainfall can be summarized as follows:

May: the highest monthly rainfall value (160 mm), the greatest average number of rainy days (12 days) and the highest cumulative rainfall values are reached in three or four days (up to nearly 195 mm).

September: heavy downpours of relatively short duration.

October: the monthly average is similar to that of May (155mm-160 mm), but the average number of rainy days is modest.

On a regional scale snow rates mainly vary according to altitude. On Graie Alps snowfalls are frequent at an altitude between 2000 m and 2300 m and they have their maximum in April and a secondary maximum in February (Lago Serrù at 2296 m). At an altitude beyond 2300 m snow rates have a single maximum in April (Valsoera at 2412 m). At an altitude between 1200 m and 1700 m snow rates are unimodal, showing a maximum in February (Ceresole Reale at 1573 m). The maximum snow level recorded at Rosone is about 2 m (1994-1995), the minimum level 0.1 m (1966), the average 0.35 m. In Orco Valley maximum snow level is recorded a in 1989-1990 winter, preceded by the minimum recorded in 1986-1987 winter. The absolute maximum monthly in the last thirty years has been measured in January in Rosone station, located at 700 m of altitude.

Temperatures raising (10° - 15°) have been recorded in the last decade of February, testified by a rapid snow melting.

Available data come from Hydrographic and Mareographic National Service (1951-1986) and Regional Meteorological Service (since 1980); the first one with 5 stations (Pont C.se 461 m, Rosone 714 m, Ingria 827 m, Piamprato 1550 m, Ceresole R. 1600 m); the second one with 4 stations (Ceresole R.-Ceresole Villa; Ceresole Reale - Lago Agnel 2304 m, Locana-Bertodasco 1120 m e Locana - Lago di Valsoera 2365 m, Valprato Soana-Piamprato 1555 m).

2.2 *Regional Morphology*

The Orco Valley features testify a fluvial-glacial morphogenesis. The original distribution of superficial deposits and forms have been modified by gravity deformations. The slopes are characterized by high difference in height; ridge orientations and stream channels correspond to main regional lineament systems.

2.3 *Regional Geology and Structural Setting*

The Orco Valley is located in the central part of the Gran Paradiso Massif (Figure 2). This complex belongs to the Upper Pennine Units (Pennine Nappe System) and it consists of a composite crystalline basement and a Permo-Liassic cover, locally preserved in the peripheral areas. In detail the Massif is constituted by three different complexes:

- Augen Gneiss Complex: augen gneisses and fine-grained gneisses with inter-bedded metabasics;
- Money Monometamorphic Complex: albite micaschists and gneisses, frequently graphite-bearing, with inter-bedded quartzose meta-conglomerates.
- Erfaulet Ortogneiss Complex: ortogneiss at leucogranitic composition.

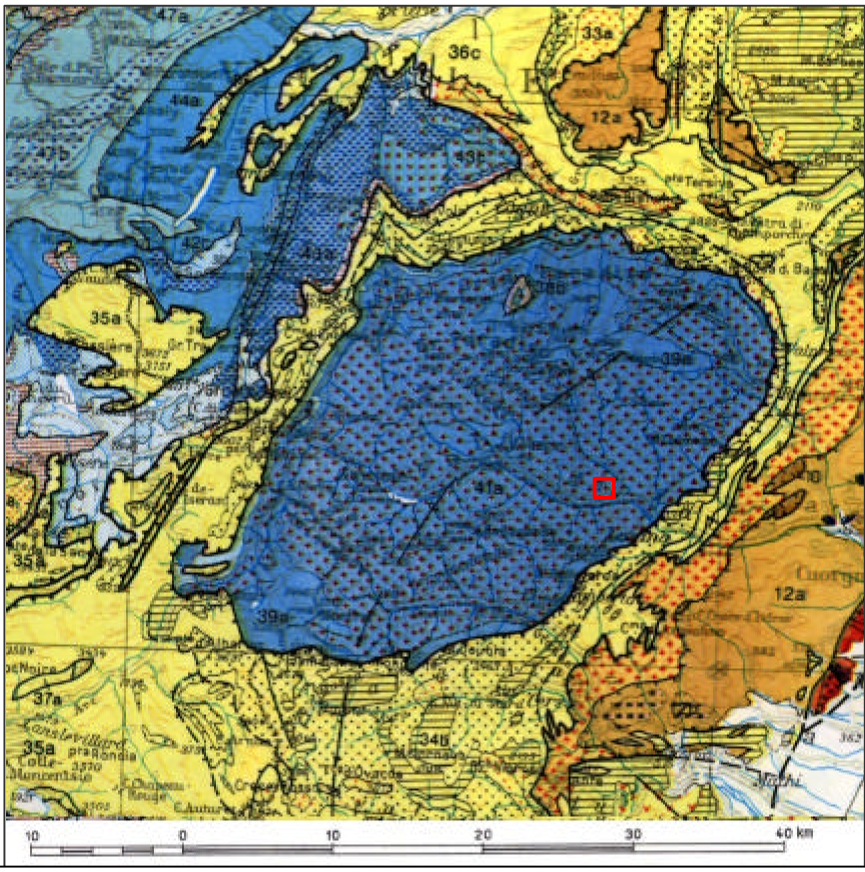

Figure 2 - Extract of Structural Model of Italy (CNR, 1990).

Late and post-orogenic deposits and magmatic rocks: (1) Undifferentiated continental deposits. **Alpine units**– *Canavese system*: (8) rhyolites and metaclastic deposits; (9) high– grade to retrogressed paragneisses and metabasites. **Austroalpine system of the Western Alps**–*Valpelline and 2nd Diorite-Kinzingite Upper Units*: (10) Rootless sheets of granulite to amphibolite facies. *Lower units*:(12) Eclogitic Micaschists Complex; (12a) eclogitic para- and orthogneisses; (12b) metagabbros; (12c) marbles; (12d) orthogneisses. **Piedmont-Ligurian ophiolite nappe system and related Flysch Units**–*Oceanic Units:* (33a) supraophiolitic pre-flysch metasedimentary cover; (33c) metagabbros; (34a) mantle lherzolites; (34b) antigorite serpentinites;. **Undifferentiated calcschists Units**: (35a) undifferentiated calcschists. *Cover units of ocean facing continental edges:* (36c) paraconformable flysch; (37a) dolostone , marbles and minor sedimentary breccias. **Pennine nappe system**–*Upper Pennine Units (Gran Paradiso)*: (38b) Money clastic schists; (39a) undifferentiated micaschists and minor relics of HT paragneisses; (41a) augengneisses and massive metagranitoids. *Middle - Pennine Units (Gran San Bernardo)*: (42a) undifferentiated sedimentary cover; (42b) evaporites; (42c) metamorphic clastic and volcanic sequences; (43) Metamorphic "Permian –Carboniferous schists;(43a) metaconglomerate and coal-bearing beds; (43b) metagranophyre; (43c) metaquartzdiorite;

All these units are cut by two main joint sets, mutually orthogonal, corresponding to E-W and N-S striking sub-vertical normal fault.

Glacial deposits (*upper Pleistocene*) are represented by silt and gravel.

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

The regional ductile tectonic deformation is characterized by a foliation (S1) recognized in rare relics (Alpine first folding phase) which is refolded by a second folding phase represented by folds P2 and by the development of crenulation cleavage S2. The second foliation corresponds to the main Alpine regional schistosity (S2 = SR). The P2 folds are refolded by a third folding phase that give P3 folds and associated crenulation cleavage (S3). At local scale, a crenulation cleavage not comparable to regional structures has been surveyed (BROVERO et al., 1996). Small thrusts have been developed on the short limbs of asymmetric P3 folds.

Three remote sensed lineament on satellite images striking E-W, NW-SE and NE-SW has been recognized. They mutually intersect in the landslide area. These lineaments belong to regional lineament systems widely distributed in the whole region. In the adjoining region they correspond to regional fault systems.

3 LOCAL FRAMEWORK

3.1 *Local Geology and structural setting*

Rosone landslide is modeled on the Augen Gneiss Complex (unit volume weight $g > 25$ kN/m^3; uniaxial compressive strength $C_0 > 100$ MPa); in detail it is represented by intensively laminated augen gneiss with band interlayer of silvery micaschists of quartz-chlorite-chloritoid-talc-phengite and rare chloritoschists They are characterized by several Alpine ductile deformation phases as described in the paragraph 1.3.

Quaternary *eluvial-colluvium* deposits (heterogeneous and incoherent masses of soil material and rock fragments) are present.

The geological-structural configuration of the studied area is relatively simple: mostly outcrops of granite and occhiadini gneiss, with big feldspar idioblasts. Locally it is possible to observe *facies* with a more marked schistosity, as revealed by an increase in common mica and black mica; micaschist levels are also present and a few chloritoschists. The main schistosity (**SR**) is affected by the periclinal orientation of the massif, which, in this area, displays an average dip direction of about 150°, with 35° dip (BROVERO et al. 1996a, ISMES 2001, SGI 2001).

The brittle structural attitude is defined by three main discontinuity systems: a KS system parallel to main schistosity (SR) and two subvertical lineaments corresponding to E-W (K1) and N-S (K2) striking normal fault conjugate system.

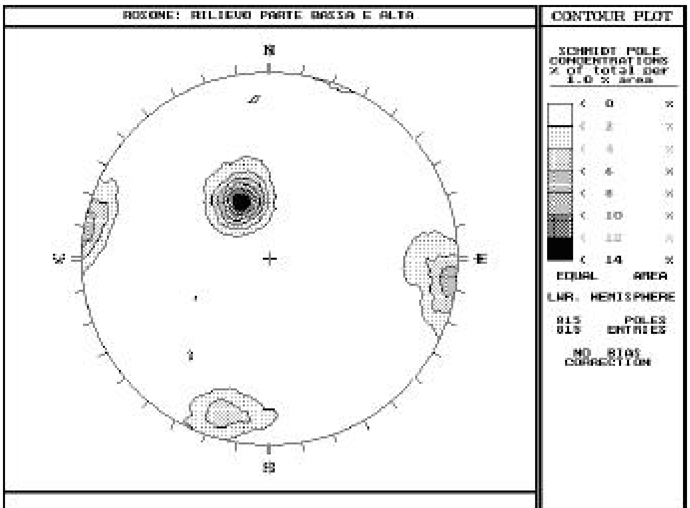

Figure 3 - Stereographic representation of the mainly discontinuity systems (BROVERO et al., 1996).

The **KS** system dips to N135 with an inclination of about 28°; in the upper part of the slope the joint system dips to N156 with inclination of 27° while at the bottom the dip is N129 with inclination of 26°. The KS average features are: length major than 20 m; no aperture; roughness JRC = 7; no gouge and rare presence of laminated altered rock filling; spacing 2 m-6 m and subordinate 0.6-2 m.

The **K1** sub-vertical lineament dips to N282 and it is characterized by an average length of 3 m-10 m, no separation, except in the heavily deformed section, where the aperture exceeds 1 m; roughness average value JRC = 10; no gouge, nearly no alteration; average spacing 2 m-6 m. Several joints show a length over 20 m and widely open. In general these joints have great spacing and create large blocks.

K2 subvertical joint dip N 19 and is characterized by an average length of 3-10 m, no separation, except in the heavily deformed section, where the aperture exceeds 1 m; roughness average JRC = 10; no gouge, nearly no alteration. Several joints show a length over 20 m and widely open. In general these joints have great spacing and create large blocks.

minimum RMR = 22-40 (5 cases), maximum RMR = 50-58, average RMR = 43-53.

Furthermore two minor sub-vertical joints systems have been recognized: **K3** system dipping to N240 and **K4** system dipping to N40 (GEOENGINEERING 1984, SGI 1984).

3.2 *Water Conditions*

No surface waters has been observed on landslide area; some drainage lines are present on the eastern margin.

Early piezometric measurements (2 cells at -41.5 m and –29 m depth, near Bertodasco) reveal the presence of two aquifers (preliminary interpretation); pressure trend (first measure 21/06/92) shows a late spring peak (rainfall and snow melting). Two perpetual springs are located near Perebella and Bertodasco (B portion); some temporary springs are present on the landslide toe and near the right flank of Bertodasco sector.

Data about groundwater circulation are not available. Springs alignment along inferior boundary in B and C sectors lets presume that groundwater circulation occurs preferably along slide surface.

Permeability is essentially of secondary type and the infiltration comes mainly along the discontinuities systems, generally open and persistent.

In the Ronchi sector the coarse debris (rock blocks) is characterized by high permeability.

The Perebella sector presents high infiltration in the upper portion due to the presence of debris.

In the Bertodasco sector the secondary permeability increases in the lower part of landslide mass (BROVERO M. et al.,1996).

4 LANDSLIDE

4.1 *Landslide Identification*

Rosone landslide has been interpreted as a deep seated gravitational deformation (DSGD) which affects the middle part of the slope.

Trough detailed geo-structural analysis three different geomorphologic evolution stages could be identified: “Ronchi”, “Bertodasco” and “Perebella”.

4.2 *Landslide Detail*

The scheme in figure 4 shows the different sectors identified. The Ronchi sector corresponds to the western portion and is characterized by a highly advanced evolution stage of deformation, which caused the disruption of original rock mass. This portion of slope has been interpreted as an ancient rockslide.

The Perebella sector shows a preliminary stage of evolution.

The eastern sector (Bertodasco) is most likely to undergo a catastrophic evolution. The interpretation of aerial photographs reveals in Bertodasco sector the presence of three areas with different degrees of mobility: from the top to the valley floor, referred to A, B and C zone (see details in 3.4).

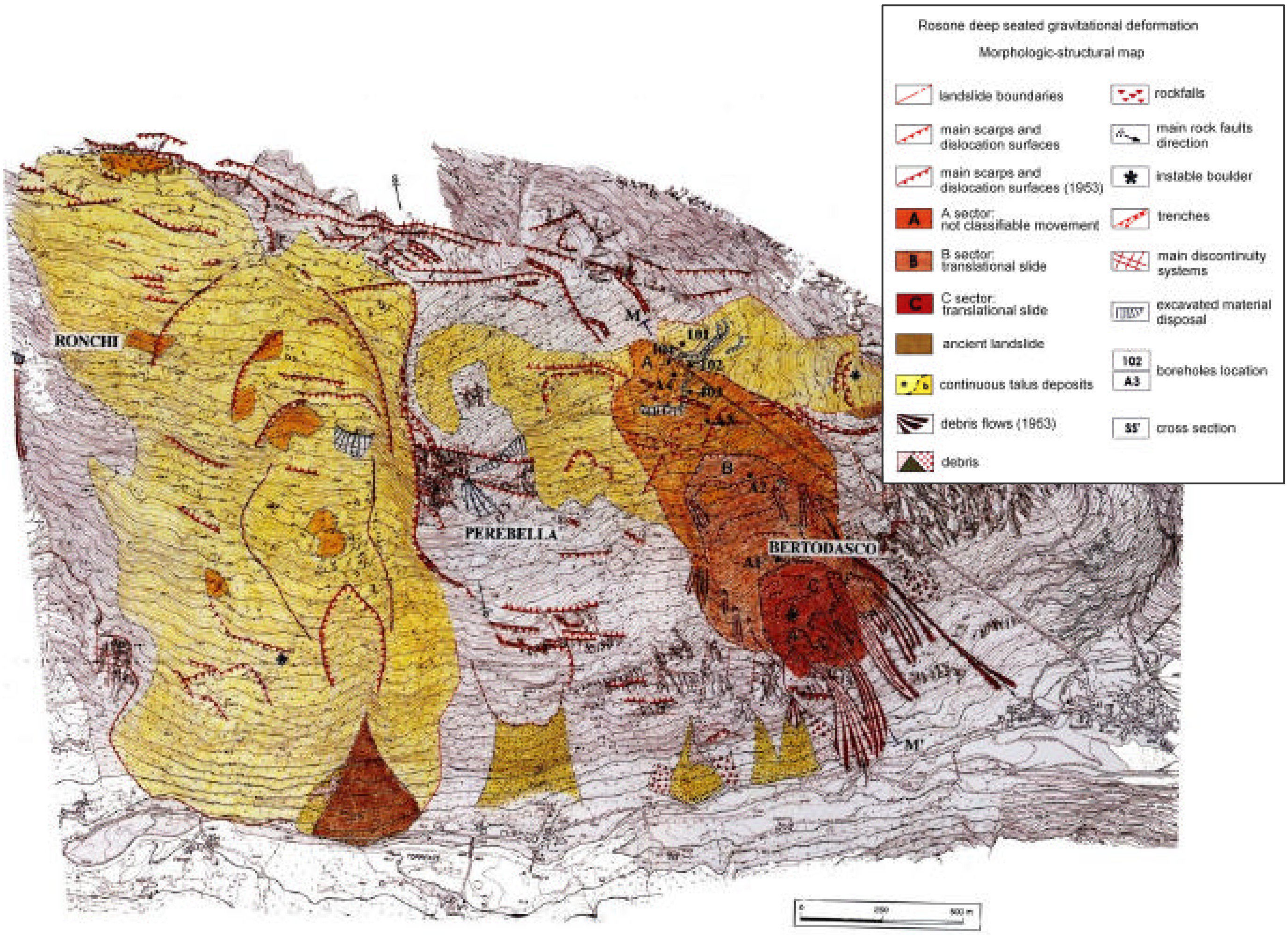

Figure 4 - The Rosone deep seated gravitational deformation: morphologic-structural map (Ramasco et al, 1990).

The *A* zone shows minor movements in the upper portion, while in the lower part gravitational movements are more evident. The slide movement rate is of 6.7 mm/year (average value along 68 months for the period 1981-1993).

In the *B* zone the main movement is a translational slide. A secondary movement is represented by topple of few blocks of large dimensions that interest the superficial deposits (debris). A 3 m-4 m high scarp testifies a movement occurred in 1953.

In the *C* zone a slide movement (quite slow and continuous) triggers along circular and complex rupture surfaces. Displacements occur along main scarps high from a few meters to ten meters. The lower portion of the deformed slope is characterised by the triggering of several rock falls and debris flows which sometimes involved the floor valley.

4.3 *Landslide Morphometry*

Rosone landslide affects an area of about 5.5 km^2 and a depth of over 100 m. The total height corresponds to 1300 m (from an altitude of 2000 m amsl to 700 m amsl, on the valley bottom).

The landslide extends for a total length of about 2400 m and a maximum width of about 1900 m. The mobilized mass involved a volume of 50 millions cubic meters.

The more active area (Bertodasco) affects a length of 1200 m and a width of 500 m; the involved volume is of about 22-35 millions cubic meters. In detail the upper zone (*A* zone) extends from an altitude of 1500 m to 1400, while *B* zone extends from an altitude of 1400 m to 1150 m and involves an area of about 180.000 m^2. The lower zone or *C* zone extents from an altitude of 1160 m to 900 m and involves an area of about 90.000 m^2 The rupture surface has been estimated at a depth variable from 30 m to 72 m for *A* zone, 46 m for *B* zone and 39 m for *C* zone. The involved volume corresponds to $22 \cdot 10^6$ m^3 - $35.11 \cdot 10^6$ m^3; more in detail: $9.3 \cdot 10^6$ m^3 – 12.1 10^6 m^3 for *A* zone, $8.2 \cdot 10^6$ m^3 – $14.5 \cdot 10^6$ m^3 for *B* zone and $4.5 \cdot 10^6$ m^3– $8.5 \cdot 10^6$ m^3 for C zone.

4.4 *Landslide Morphology*

The slope morpho-structural features allowed to distinguish three adjacent sectors corresponding to different evolution stages of the DSGD (BROVERO et al. 1996, FORLATI et al. 1991). The slope is characterized by trenches and double ridges (typical of DSGD), with a total length of 2 km striking E-W, WNW-ESE.

- The western sector (Ronchi) is characterized by huge gravitational deformation and consequent obliteration of the original geomorphologic features. This portion of slope is characterized by a concave-convex slope profile, by the presence of large undulations, a large depression in the upper and a wide thick cover of coarse debris with big rock blocks whose dimensions reach the order of thousands cubic meters. In the lower eastern part (from 1000 m height to floor valley) an ancient accumulation zone of a stabilized landslide is recognizable.

- Perebella sector represents an early stage of the deformation process. It is clearly divided from the Ronchi sector by a striking N-S hectometric discontinuity that corresponds to a well - defined scarp (height 50 m–90 m). Furthermore, this sector is characterized by the presence of multiple ridge spreading of the crests. The western part is characterized by a bedrock intensely fractured. In proximity of the lateral western margin (1575 m– 1375 m) a large trench striking NNW-SSE fixes the boundary of a large area of exposure of very fractured rock mass.

- The eastern sector (Bertodasco, figure 5) is characterized by intermediate evolution conditions. The longitudinal profile of the slope side is characterized by large-scale undulations. Derived data from local surveys, measuring instruments and historical evidences, allowed to subdivide the area into three minor zones named *A*, *B* and *C* zone. In Bertodasco area two types of movement have been recognized, rotational (*C* zone) and translational slide (*B* zone).

Figure 5 - Rosone landslide: Bertodasco sector.

The upper portion (*A* zone) is characterized by a wavy longitudinal profile and shows two main trenches developing along E-W direction. Scarps related to the main movements are not always well evident and continuous. The *A* sector is characterized by an intermediate evolution stage, which caused the disruption of the original rock mass. The middle portion called *B* zone is bounded by scarps generally set according to the main joint sets. There are some analogies with Ronchi sector, as the presence of a wide thick covered by coarse debris. The *C* zone is the lower part of Bertodasco sector and it shows the major evidence of deformation. This sector is characterized by very disengaged rocks and by the development of debris flow and rockfalls.

4.5 *Landslide History*

The Rosone landslide underwent two major paroxysmal stages, one in the early 18th century and another in the fall-winter of 1953, whilst two minor movements were recorded in the course of this century.

The first significant event well-know dates back to 1705-06: from an inspection report ("Atto di visita") we learn that the phenomenon was similar to the paroxysmal stage of 1953 and it caused severe damage to many buildings and the disruption of cultivated fields.

From reports dated back to the beginning of this century we find that in 1916 Rosone was classified as a man-made structure to be consolidated according to Law No 455 of 1908. In 1933-34, the inhabitants were evacuated for about 7 months. In the early '40s, a landslide occurred at the altitude of 1300 m: vast earth blocks and huge boulders toppled downhill and threatened Rosone, Grumel and the eastern part of Bertodasco. In 1940 the *C* zone (Bertodasco sector) has been interested by increasing slide movements with triggering of flows.

The landslide showed signs of re-activation in 1948 and 1951. In the fall-winter of 1953, following abundant precipitations, a portion of the slope collapsed. The movement of the ground in the Bertodasco area damaged or even destroyed some houses. The fall of debris and boulders from the slope overhanging Rosone caused evacuation of the 250 inhabitants and their cattle.

Between 1953 and 1957, these movements gradually slowed down, as confirmed by topographic measurements carried out by AEM. In 1957, the three villages: Rosone, Grumel and Bertodasco were evacuated.

Between 1957 and early 1960s, the movements accelerated and phenomena similar to those recorded in 1953 were observed, albeit less severe.

Further phenomena were recorded in the fall of 1963 and in the spring of 1964 and 1969, 1988. At present, significant movements continue to take place in the upper part of the landslide zone, as born out by the topographic measurements performed on the anchoring blocks of penstock. investigation, monitoring and modelling.

5 INVESTIGATION AND MONITORING

5.1 *Survey and monitoring of landslide activity*

In order to survey the displacements around the Bertodasco sector, an integrated monitoring system has been installed , with automatic data recording.

Since 1960 percussion and rotary drillings with continuous coring (maxim depth reach: 120 m) have been carried out. Between 1960 and 1980 boreholes have been instrumented with inclinometers; the investigations have been carried out near penstocks (western part of the slope). Since 1985 studies have been focused in particularly on the Bertodasco sector (geomechanical survey, topographic, inclinometric and piezometric measurements). The survey allowed to individualize the shear surfaces depth in *B* and in *C* zones (BROVERO et al. 1996, SGI 1984, FORLATI et al, 1993, SGI 2000, ISMES 2001).

Geophysics survey includes a vertical deep geophone (*A3* borehole), two three-directional deep geophones (*B1* and *B2* boreholes), three-directional surface geophones and a vertical surface micro-seismic detector.

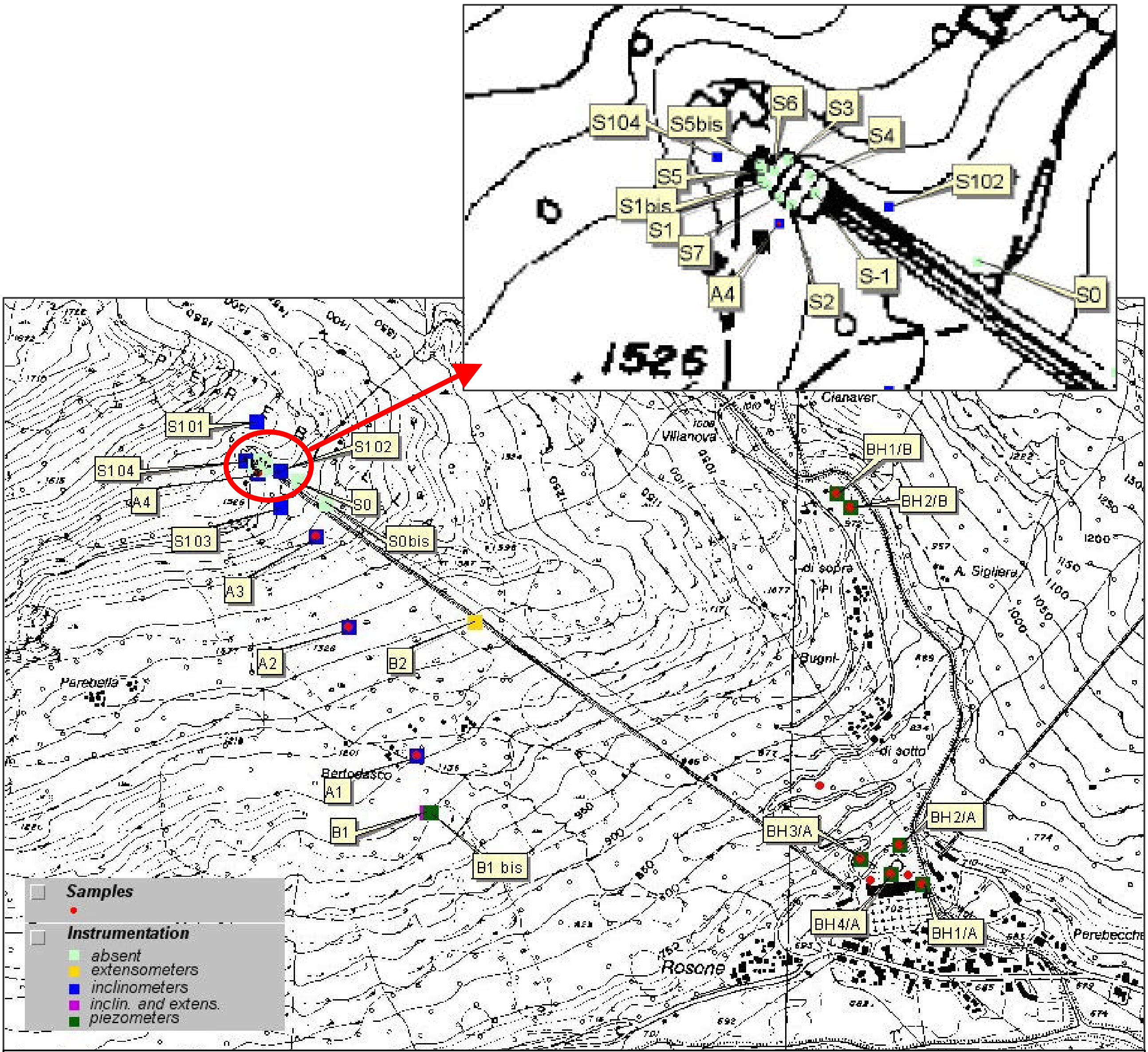

Figure 6 - Boreholes location map.

Since 2000, boreholes have been instrumented with vertical deep geophones (*A1*, *A3*, *B1*, *B2* boreholes). Furthermore monitoring data obtained through acoustic monitoring system and GPS instruments. The GPS (Global Positioning System) net activated in 2001 uses 5 satellite receivers: these data are elaborated every six months; nineteen bench marks are controlled with manual GPS measures.

Laboratory tests carried out on samples has been made possible to determine some parameters as grain size distribution, Atterberg Limits, USCS and Casagrande Classification, unit volume weight (gamma = 26.2 kN/m^3), triaxial, uniaxial compressive strength (Co average = 74.9MPa), tensile strength (average = 7.1 MPa), *p* wave velocity (average = 3794 m/s).

Furthermore in situ test on bedrock has been carried out to obtain base shear resistance by means of tilt test (angle: 35.1° +/- 2.9°; 120 measures), joint compression strength (JCS = 110 MPa; 320 measures), Barton joint roughness coefficient (JRC= 11; 420 measures). Furthermore a seismic reflection profiling and a down hole allowed to obtain data about rock mass physical properties and landslide body thickness.

From the top to the bottom of Bertodasco sector a progressive increase of the displacement speeds recorded by the inclinometers (from about 1 cm/year in A zone to about 2.4 cm/year in C zone) and an increase in the disorder of the rock mass as revealed by drilling tests have been observed. The bottom zone displays greater activity with variations in the direction of displacement, which is always very close to the direction of maximum inclination of the slope (for example displacements in the lower part of the Bertodasco sector are about 12 cm in six years). Local increase in speed or acceleration deriving from exceptional meteoric events are possible.

5.2 *Monitoring of meteorological and Hydraulic conditions*

Boreholes A1 bis and B1 bis have been instrumented with piezometric cells, respectively in 1991 and in 2000. In A1 bis borehole the cells are located at a depth of 29.0 m (PZ5131) and 41.5 m (PZ5129); groundwater pressures measured are: 30-50 kPa (PZ5131) and 80-200 kPa (PZ5129).

In B1 bis borehole the cells are placed at a depth of 36.6 m and 59.0 m; groundwater pressure is 90 kPa (36.6 m) and 180 kPa (59.0 m) (SGI 2000).

As described in par.2.1, on the slope meteorological stations have been installed (at Rosone 700 m amsl, at Bertodasco 1120 m amsl and at Perebella 1520 m amsl). Since December the measurement frequency is daily, with one measure every six hours. An hydrometer is placed near Orco torrent, in proximity of the bridge for Fornetti locality; the station consists of an ultrasound hydrometer, a thermo–hygrometer, a rain-gauge and a nivometer.

6 MODELLING

Three kinds of geo-mechanical models were used in order to investigate different aspects of hazard related to Rosone landslide:

1 Triggering aspects have been modeled by means of:
- a parametric study of safety factor depending on strength parameters and pore pressure distribution, carried out by limit equilibrium analysis (Studio Geotecnico Italiano, 2001) with Mohr-Coulomb effective stress failure envelope;
- 2D finite difference method with a lagrangian approach (Itasca FLAC 2D© code) using elasto-plastic Mohr Coulomb in conjunction with Maxwell creep constitutive models. Gravity (Odasso, 1996) and gravity plus water table (Studio Geotecnico Italiano, 2001) were the triggering factors considered;
- 2D finite element method using Drucker Prager elasto-visco-plastic constitutive model with strain softening (Forlati *et al.*, in printing) considering gravity plus water table as triggering factors.

Displacement and velocity field calculated were compared with those measured by inclinometers;

2. Runouts has been modeled by empirical methods:
   - Landslide runout distance and subsequent basin filling time (Forlati *et al.* 1991) have been evaluated by relations among involved debris volumes and the "equivalent friction coefficient" (Scheidegger 1973, Li Tianchi 1983);
   - Runout axial length, symmetric and asymmetric lateral expansion, hydraulic hazards have been evaluated by a “rock avalanche” approach (ISMES 2001): three scenarios are pointed out according to different hypothesis about the extension of unstable sectors.

3. Rockfalls of several shape and volume bodies along selected significant slope profiles (with statistical variation of geometric and mechanical parameters) have been modeled by 2D “lumped mass” approach (ISMES 2001). Limits of propagation, kinematic and dynamic quantities of bodies have been calculated.

7 STABILISATION/PROTECTION WORKS AND REGULATION

In order to protect from rockfalls the National Road SS460 a tunnel (about 400 m long) was realized in the late 70's.

In 1916 Rosone was classified as a man-made structure to be consolidated in according to D.L. n.299 2nd March 1916. In 1956 Rosone, Grumel and Bertodasco hamlets were evacuated (D.P.R. n.772 8th June 1956).

8 LAND USE AND RISK ASSESSMENT/MANAGEMENT

8.1 *Land Use*

On landslide area man-made structures include Perebella and Bertodasco hamlets and the structures of hydroelectric power plant.

Outside landslide area man-made structures include a secondary road in the eastern sector and hamlets and the national road in the floor plain.

Pastures extend on overall Rosone landslide (Perebella, Ronchi and Bertodasco sectors) and in the floor plain.

Shrubs grow in the middle-low portion of the slope of Ronchi sector. Shrubs area constitute also the Perebella middle-high portion and parts of Bertodasco *A* and *B* zone.

Deciduous forests extend in the lower part of Ronchi sector, in the middle-low portion Perebella sector and in Bertodasco A sector (along penstocks), in B and in C zone.

Conifer forests extend above 1500 m of altitude, in Ronchi, Perebella and Bertodasco sectors.

8.2 *Elements at Risk*

Elements at risk are Rosone hamlet and floor plain between Locana and Rosone hamlets. Furthermore the National Road n. 460 which runs on the valley bottom could be interested by rockfalls. The road represents the only connection with Ceresole Reale hamlet.

In Bertodasco sector the elements at risk are represented by infrastructures of the hydroelectric plant of the Azienda Energetica Metropolitana of Turin (AEM) which interests the whole length of the Deep Seated Gravitational Deformation.

9 FIRST SCENARIOS

On the basis of the morpho-structural considerations and of the geo-mechanical model it has been possible to draft some instability scenarios according to the following scheme:

1 rockfalls;
2 instability of the Bertodasco *C* sector, of the *B* and *C* zones simultaneously or not and of the *A*, *B* and *C* zones also simultaneously or not. (figure 7);
3 Perebella slope evolvement following the previous scheme.

Considering the highest distance of ancient rockfalls it is possible that the entire bottom valley up to Torrente Orco is involved by rockfalls, with probable involving of Rosone Vecchio, Fornolosa hamlets and the National Road n. 460.

The second scenario considers a rapid movement of the Bertodasco instable mass and its consequent evolution in rock avalanche. The result would be the destruction of hamlets and infrastructures. The collapsed materials would dam the Orco Valley and generate a temporary lake. Three different scenarios can be supposed according to the involved sectors (valuation of involved area has been made using Perla model, 1980):

C sector - the Bertodasco sector would develop as a rock avalanche, mobilizing a volume of about $1.5 \cdot 10^6$ m^3 -$2 \cdot 10^6$ m^3. The result would be the Orco valley occlusion, with formation of a temporary lake (upstream basin of a volume of $1 \cdot 10^6$ m^3 -$1.2 \cdot 10^6$ m^3, extends to Moglia and Biole localities would be formed), due to a dam high about 35 m on floor valley. Time of basing filling estimated of about 24 hours.

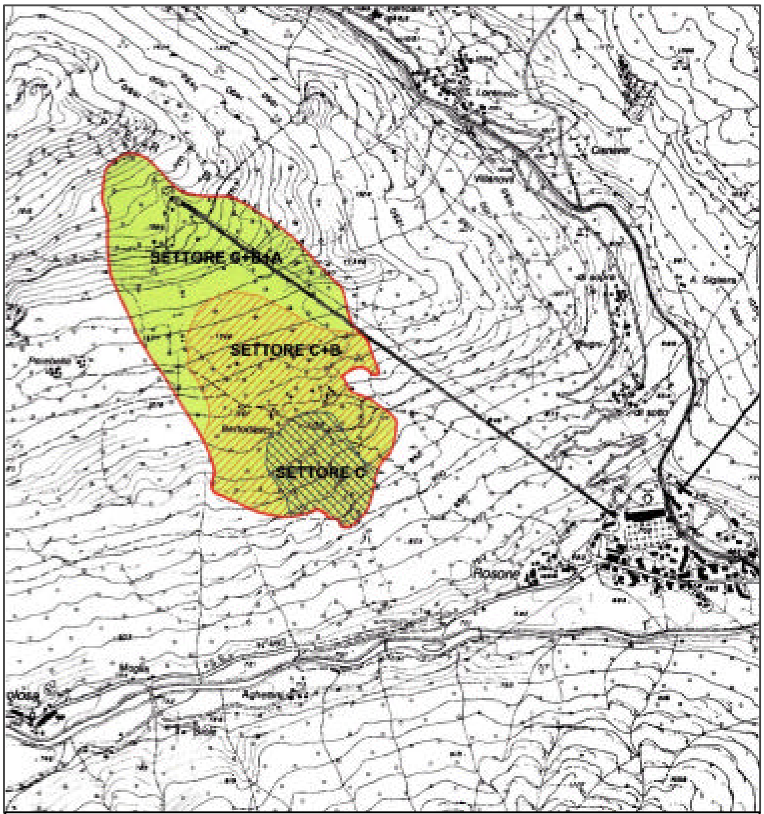

Figure 7 - Bertodasco sector: A, B and C zone.

The phenomenon would interest a floor valley sector very close to Rosone hamlet (presumably some buildings involved), and the National Road n. 460 for a length of about 600 m would be destroyed.

C + B sectors - The second scenario contemplates the collapse of *B* and *C* sectors with a volume estimated of about $9 \cdot 10^6$ m^3.

The result would be the Orco valley occlusion, with formation of a temporary lake (upstream basin of a volume of $7 \cdot 10^6$ m^3, extends to Moglia and Biole localities would be formed), due to a dam high about 65 m on floor valley. Time of basing filling estimated of about 5 days.

A floor valley sector would be interested, including the southern portion of Rosone (involving almost half of the urbanized area) and the National Road n. for a length of about 1500 m would be destroyed.

A + B + C sectors - This case supposes the simultaneously collapse of the *A*, *B* and *C* sectors; the volume estimated is of about $20 \cdot 10^6$ m^3 -$25 \cdot 10^6$ m^3.

The effect of the movement would be the Orco Valley occlusion with formation of a temporary lake (upstream basin of a volume of $22 \cdot 10^6$ m^3, extends to Moglia and Biole localities would be formed) due to a dam high about 95 m on floor valley. Time of basin filling ha been estimated of about 17 days. A floor valley sector would be interested, including almost totality of Rosone Hamlet along the National Road till Perebecche and Casetti localities, downstream of Piantonetto - Orco confluence. As occurred in October 2000 flood even hydroelectric plant would be involved and the National Road n. 460 for a length of about 1500 m would be destroyed.

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11 PICTURES