Analysis of morphometric indexes to evaluate tectonic activity and slope instabilities: a case study in the Germanasca valley (NW-Alps, Italy)

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Abstract— **Possible interactions between recent tectonic activity and the evolution of mountain relief have been investigated in the Germanasca Valley (Cottian Alps, NW-Italy), an area of strong heterogeneity of drainage features and slope instabilities. Analyses by remote sensing (satellite/aerial DEM and orthophoto) and field survey allowed creation of a geodatabase managed by standardized procedures into a GIS environment. Morphometric analyses have been performed for interpreting the particular geomorphological setting. Alignment and/or coincidence of significant structural and morphological features (ridges, incisions, scarps) and preferred stream orientations indicates possible structural/tectonic controls on the onset and evolution of the drainage network.**

I. Introduction

The aim of this study is the characterization of the drainage basin system of the Germanasca River (NW Italy) through the use of morphometrics and morphotectonics indexes. In order to evaluate neotectonic activity and slope instabilities of the internal sector of the Western Alps. This area is affected by a diffuse low-magnitude seismicity (ML> 3), although in the past there have been some events of greater magnitude (1980 ML=4, 8 and 1808 MS=5.5). The framework of active structures, capable of generating earthquakes of this magnitude, is not yet fully known in this Inner sector of the Cottians Alps (Western Alps).

A DEM (5x5 meters) supplied by the Piemonte Region has been imported into the GIS environment in order to evaluate the basin and river network's geomorphometry. The workflow followed can be summarized in different steps: a) drainage network extraction and hierarchization; b) evaluation of linear and areal indexes; c) analysis of azimuthal distribution of drainage pattern and lineament features. The values of these parameters have been interpolated by means of geostatistical algorithms for the creation of a serie of thematic maps.

II. Geological and geomorphological setting

A. *Present day geomorphology*

In the central sector of the Western Alp, the Chisone and Germanasca valleys (Figure 1) are part of the Chisone Basin, a water-drainage system (area: 590 Km^2) developed between Susa valley (to the North) and Pellice Valley (to the South).

Both Chisone and Germanasca valleys lack of a major glacial cirque at the main valley head [1; 2]. On the contrary,

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tributary valleys are divided by high ridges (above 3000 m a.s.l.) with evident traces of alpine glacial modelling (i.e. cirques and moraines). In contrast with previous geological literature [3; 4], studies by the Earth Sciences Department of the University of Torino demonstrate that during LGM no unique valley glacier developed along the entire Chisone and Germanasca valleys. Tributary glaciers reached the main valley bottom and sometimes joined, but never overtopped the main valley's axis.

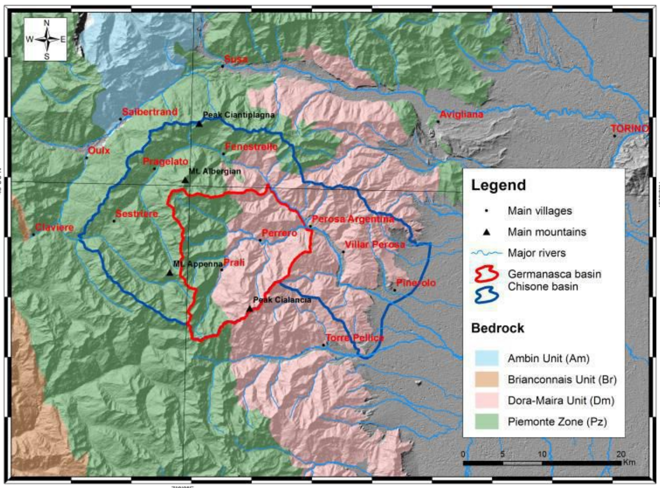

Figure 1 - View of central sector of Western Alps (Inner Cottian Alps).

Slope instabilities locally obliterated Pleistocene glacial and Holocene fluvial landforms. Many traces of large deep-seated gravitational slope deformation (DSGSD), such as counterslope scarps and trenches have been surveyed in the higher part of the valleys [5].

B. Neogene kinematics evolution

The arc of the Western Alps results from late collisional phase after convergence of the Adria plate and the European margin of the Tethys. Neogene Alpine tectonics was characterized by widespread orogen-parallel extension in the internal zones, coeval with westward propagation of the compressive front in the external zones [6]. Two main faulting stages can be distinguished within the post-metamorphic tectonic evolution of the inner Western Alps [7]: the first (late Oligocene-Early Miocene) is related to the dextral movements along the most important deformation zones; in the second (post- Early Miocene), major structures are reactivated as transtensive/normal faults. This complex kinematic evolution fits in a model of dextral transtension at the scale of the Western Alps, induced by the coexistence of two different driving forces active since the late Oligocene: the counterclockwise rotation of the Adria plate and the body forces acting inside the chain [7; 8]. This coexistence may have induced strain partitioning and, subsequently, complex spatial and chronological relations between transcurrent and extensional movements on a regional scale [7; 9].

As indicated before, the central sector of the Western Alpine Arc is an area of low-to-moderate magnitude seismic activity; however, since a few strong historical earthquakes have occurred, causing significant damage, and paleoseismic features have been recognized [10].

III. MATERIALS AND METHODS

The Germanasca basin has been classified following Strahler [11], 11 sub-basins and drainage features extracted by DEM analysis and digitized, relief proprieties and geomorphometric parameters spatially analyzed by means of the SAGA (System for Automated Geoscientific Analyses) extension of ArcGIS, and by MATLAB.

Satellite lineaments have been identified [12], then statistically classified according to their azimuthal frequencies, cumulative lengths and length (3 classes of frequencies: > 2500 m, 2500 to 5000 m, and > 5000 m.

The lineaments were identified on the satellite images according to the methodologies, proposed by [8]. The detected lineaments were, moreover, statistically analyzed according to their azimuthal frequencies, azimuthal frequencies for cumulative lengths and length classes. Frequencies were divided into three classes from the statistical distribution: less than 2500 m, 2500 to 5000 m, and more than 5000 m.

IV. RESULTS

A. Evaluation of linear and areal indexes

The Germanasca is a complex drainage network of the sixth order; 11 sub-basins have been characterized by their drainage linear and areal parameters: Hmax, Hmin, Hmean, Square, Perimeter, Hypsometric index (Hi), Strahler stream order, bifurcation ratio (Rbm), weighted bifurcation ratio (Rbw), direct bifurcation ratio (Rbd), index of bifurcation (Ir), Stream frequency, number and indexes of hierarchic anomaly (Ga, Δa, Da).

The difference between the maximum and the minimum height has been calculated in order to evaluate the energy of relief. A moving window with search radius of 250 meters has been used, and a geothematic map has been created.

The Stream Length-gradient index (SL: slope normalized to length of river segments) provided comparisons between reaches of streams of different sizes [13], in order to investigate a possible morphogenetic role of recent tectonic activity. The results have been summarized in a second geothematic map, by using the natural neighbor interpolator (ArcGis by ESRI). The longitudinal profiles of the main rivers have been investigated in order to detect concavity and steepness indexes as well as knickpoints (Figure 2). These has been interpreted as geomorphological anomalies potentially related to surface and sub-surface deformational processes.

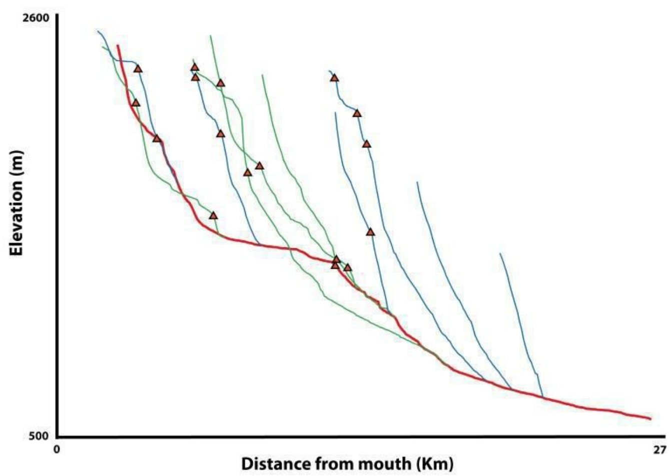

Figure 2 – Stream profile of Germanasca basin. Red: major river, blue: left tributaries, green: right tributaries. Yellow: knickpoint distribution.

B. Azimuthal distribution of lineament features and drainage patterns

Field data shows the post-metamorphic structural setting mainly consists of a tectonic network of faults and fractures formed within brittle-ductile to brittle deformation conditions.S patial and hierarchic relations derived from both field and remote sensing lineament interpretation indicates three main systems: Ln1 (N0°-N30°E), Ln2 (N55°-N70°E), Ln3 (N80°-N100°E). No differences in the lineament distribution and characteristics have been detected at the different scales and methods of analyses.

The drainage pattern of the Germanasca basin has been analyzed for assessing the azimuthal distribution of its segments. Figure 3 shows that the river change directions from N-S to W-E as the increase of the order of its stream segment.

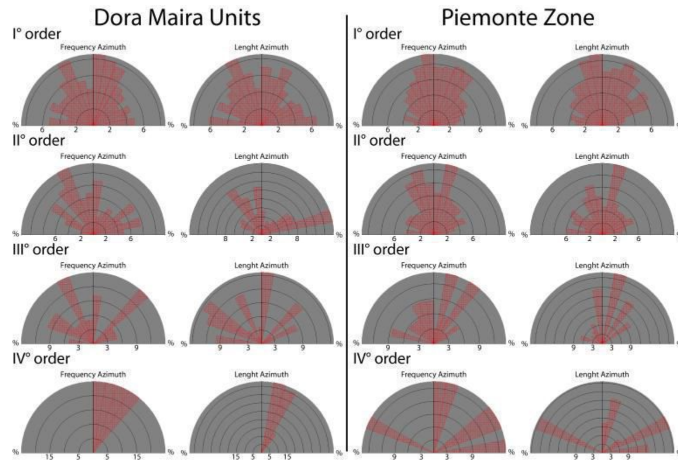

Figure 3 – Azimuthal distribution of the Germanasca drainage pattern.

V. Discussion and conclusion

Analyses of structural and morphometric data within the Germanasca Valley allowed preliminary interpretation of geomorphological anomalies in the investigated area.

The stream network is characterized by straight deep incisions, asymmetric cross-profiles and stepped longitudinal profiles, sharp changes of channel directions and progressive river captures associated with retrogressive erosion. Higher concentrations of geomorphological anomalies are located in the upper part of drainage basin.

Alignment and/or coincidence of significant structural (faults and fractures) and morphological features (ridges, incisions, scarps) and preferred stream orientations indicates possible structural/tectonic controls on the onset and evolution of the drainage network, particularly in the middle and lower parts of Faetto Valley.

Morphometric analyses allowed identification of sectors characterized by higher frequency of nick points, SL anomalies and high values of energy relief. These coexists with increased frequencies of iso-oriented neotectonic lineaments, thus suggesting target areas of stronger morphotectonics influence on the evolution the mountain relief.

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