Applied Geological Sciences Master Thesis Summary **Federico Tognetto**
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GEOMORPHOLOGICAL ANALYSIS AND ASSESSMENT OF LANDFORMS, PROCESSES AND RESOURCES FOR A SUSTAINABLE MANAGEMENT OF A HIGH-ALTITUDE ALPINE AREA: THE INDREN-CIMALEGNA SECTOR IN THE MONTEROSA SKI RESORT.

1. Introduction and study area framework

With the rise of about 1°C in the mean global temperature since 1850s, impacts of climate change are evident on different environments of our planet. Particularly, in the Alpine region, highest mountain areas are intensely affected by warming, which almost double the global average. The consequent rapid environmental change creates opportunities and risks to human activity in the alpine landscapes. Therefore, both theory and practice suggest to analyse the dynamic geodiversity of alpine fragile environments in order to understand their peculiarities in a sustainable development perspective.

With this in mind, a geomorphological analysis has been performed in a sector of Western Alps, between the Indren glacier and the Cimalegna plateau (Monte Rosa, Italy), within the Monterosa Ski resort: a location where the development of new high-altitude services goes hand in hand with the need to safeguard natural resources. Analysis and classification of the geosystem services offered by the physical environment to life and human activities, have been carried out to meet the above mentioned needs

The analysed territory is located in Gressoney-La-Trinité and Alagna Valsesia municipalities, in the highest portion of the Monterosa Ski resort, at the watershed between Aosta Valley and Piemonte regions (NW Italy). The mapped area is about 7 km^2 at an altitude range from the 2505 m a.s.l. (Endre Gaveno plain) to the 4212 m a.s.l. (Piramide Vincent peak).

All the area is characterised by a strong anthropic footprint, mainly linked to ski resort facilities, with the presence of four ropeways, two bar/restaurants, three mountain huts and the Angelo Mosso Scientific Institute.

From the geological-structural point of view, the study area is placed on the inner side of the Alpine belt, in the Western Alps, within the Pennidic domain. The Monte Rosa nappe, that widely outcrops in the thesis sector, represents continental crust units and belong to the Upper Pennidic Domain. Oceanic crust units derive from the Ligure-Piemontese ocean. The fold and thrust setting due to the alpine convergence and continental collision phases (STECK *et al.*, 2015) has been overlapped by the late-alpine brittle deformation with typical high-angle faults (BISTACCHI *et al.*, 2000). The geomorphological framework is defined by the Indren glacial catchment and the Cimalegna periglacial plateau. Both represent a high mountain environment deeply shaped by Holocene and Pleistocene glaciers activity. In sectors abandoned from glaciers, present-day geomorphological setting is linked to processes and landforms of gravity-induced, cryogenic-nival and torrential morphogenetic agents.

2. Methodology

Geomorphological map is a basic tool for analyzing and representing Earth's surface landforms and natural and anthropic processes (DRAMIS & BISCI, 1998). Particularly, "maps of active morphogenetic processes" takes into account phenomenon connected to actual geodynamic conditions and the anthropic exploitation of the territory. Aiming at a correct assessment, protection, promotion, management and planning of the landscape, it is necessary to figure out its different components. Geomorphology plays an important role in this domain (GRIFFITH & ABRAHAM, 2008). The realization of the geomorphological map of the study area is based on the "guidelines of the Italian Geomorphological Map" by CAMPOBASSO et al., 2018. The

classification and representation of anthropic landforms has been done taking into account and comparing methods used for the Italian and British (FORD *et al.*, 2014) geomorphological mapping.

The concept of geosystem services (GRAY, 2013) was used to prove and identify geodiversity values, allowing for proper conservation and management. It has been developed specifically for glacial and periglacial environments enabling its cartographic representation.

3. Analyses and tests

This thesis enables the realization of a geomorphological map in a GIS environment and the recognition and mapping of geosystem services of the Indren Glacier – Cimalegna plateau sector. The final objective is to create a tool useful for the management and the sustainable development of such a complex and fragile environment. In order to reach this goal, we decided to apply a geomorphological approach, using computer tools to collect, elaborate and represent data. The GIS processing required the creation of a legend based on the one suggested for the Italian geomorphological map, except for anthropic landforms for which two alternative methods have been proposed. The detection, classification and mapping of geosystem services necessitated a geological data collection but also cultural and historical data retrieval that allowed extending and completing the analysis.

Identified geomorphological features have been classified in five main categories representing the main morphogenetic agents. Features belonging to the gravitational, glacial and periglacial environments are the main representative and distinctive elements of the study area.

Among gravitational landforms, a high number is related to rock falls and debris flows (Fig. 1b). Distinctive features of Deep Seated Gravitation Slope Deformation are visible within the Passo dei Salati and Punta Indren sectors. Glacial landforms, typically moraine deposits and smoothed surfaces, testify the intense glaciers reshaping activity at different altitudes (Fig. 1a). Nowadays, glaciers are represented by: the Indren Glacier, with its lowest part characterised by a thickening debris cover, and the Garstelet Glacier. Numerous glacial lakes are widespread in the study area. A great number of periglacial landforms are evidence of permafrost presence and of the continuous action of freeze-thaw cycles. Between them the most significant are rock glaciers (Fig. 1c), block streams and block fields. Anthropic landforms have been classified either with the national geomorphological mapping method or with the one proposed and used by the British Geological Survey to understand their versatility and their possible application in a high mountain modified by human activity. Examples are stripping surfaces (Fig. 1d) classified as worked grounds, embankments classified as made grounds and remodeled surfaces classified as landscaped grounds.

General geomorphological interpretation enables to highlight the strong shaping activity made by the big glacial masses during the Last Glacial Maximum. It is therefore possible to separate sectors characterised by strong differences in the recent geomorphologic evolution. The Indren catchment, between the Piramide Vincent (4.212 m a.s.l.) and the glacier front (3.120 m a.s.l.), is deeply modeled by actual glacial features thus indicating the rapid evolution of this sector. Downstream, dominates morphogenetic agents such as gravitational, periglacial and nival, fluvial, fluvio-glacial and run-off, all activated after the LGM and until the end of the Little Ice Age (ca. 1850) glaciers retreat. On the Cimalegna plateau it is possible to identify two different geomorphologic-evolutionary phases. The first, linked to glacial modeling, lead to the creation of a high number of glacial erosion landforms. In the second phase, the isolation of the plateau from glacier dynamics, lead to the development of cryogenic features.

Identified geosystem services appear on the territory in different ways. Some have been simply described, others can be mapped and overlap different geomorphological features, some others find a direct link with well-defined geomorphological elements. Among regulating services, we find terrestrial processes (debris production and transport; Fig. 2a) and flood control (Fig 2b). Most significant supporting services are those related to habitat provision and platform for human activities (Fig 2b e 2d); glaciers and lakes plays an important role as water reservoirs. The primary provisioning service is the hydroelectric power production

(Fig. 2b). Cultural and knowledge services are really important and they are linked to geotourism (Fig. 2d) and leisure activities, research (Fig. 2f) and environmental monitoring in historic and modern times (Fig. 2e).

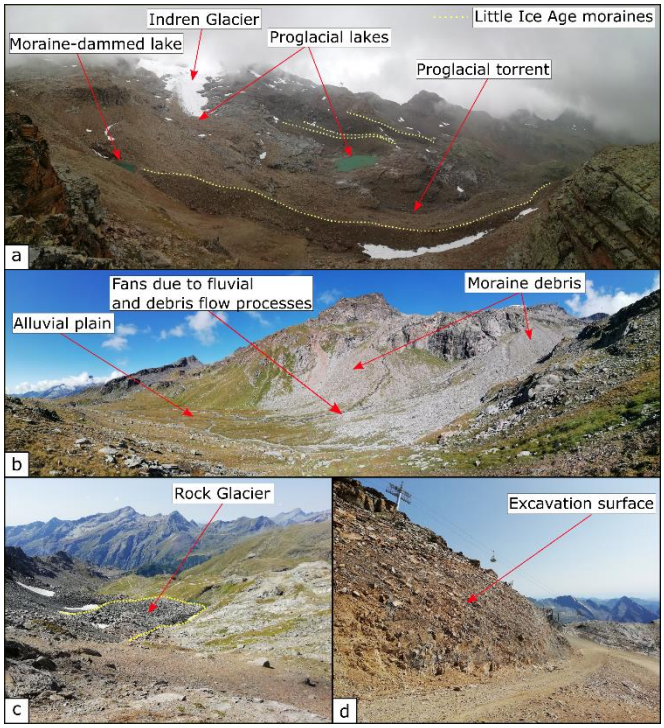

Figure 1 – examples of geomorphological elements present in the study area.

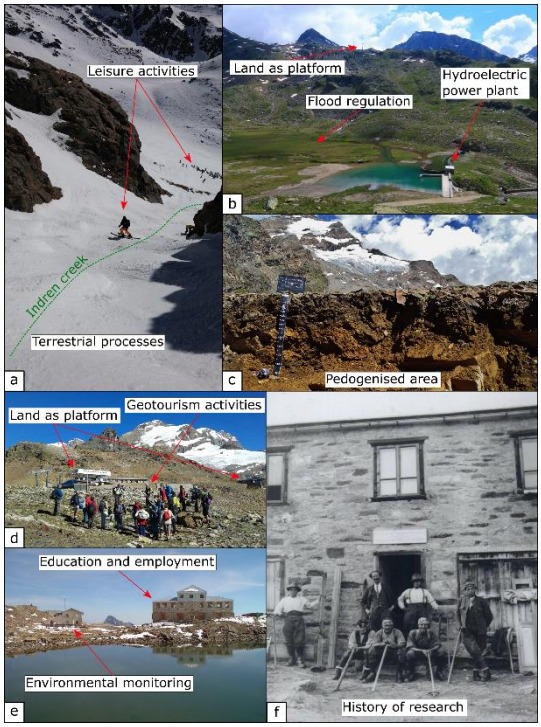

Figure 2 – examples of geosystem services present in the study area.

QGIS open source software has been used to realise cartographic products, allowing the integration of remote sensing data and traditional survey data with GPS (Avenza Maps). The main elaborate is the geomorphological map at 1:5.000 in scale, associated with a simplified geo-lithological map. The second document is represented by the anthropic landform map classified with the British system; a map at the 1:5.000 in scale, centered on the Passo dei Salati sector where ski resort infrastructures are highly concentrated. The third elaborate is the geosystem services interpretative map of the entire area, at a scale 1:10.000.

4. Results and conclusions

The thesis work allowed reaching different results useful for the study of relations between man and geomorphological environment, in a high altitude alpine sector highly sensitive to climate change effects. In particular, problems during the realization of the thesis included complicated GIS comparison due to different geographic data and database at the administrative border between Aosta Valley and Piemonte Regions.

A possible implication on the scientific and environmental domain is the practical outcome on the development of a complete geomorphological legend in the QGIS environment, promoting cartographic product consistency. Innovations deriving from the geomorphological mapping appears to be useful also in the geosystem services context. The present test represents one of the first application, with a high detail, of an interpretative methodology for assessing services related to geodiversity in a high altitude alpine environment on the Italian territory. Thus it has been demonstrated the close connection between geomorphology and the sustainable development of the environment, with the design of a method applicable in different planning context and at different scales.

Finally, a possible development of this work regards the promotion of a sustainable, active and conscious mountain tourism through the use of data and maps of the thesis for the creation of geo-hiking routes,

exhibitions and dissemination activities on climate change, glacial dynamics and geological-geomorphological risks in high mountains.

References

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STECK A., MASSON H. & ROBYR M. (2015) - *Tectonics of the Monte Rosa and surrounding nappes (Switzerland and Italy): tertiary phases of subduction, thrusting and folding in the Pennine Alps*. Swiss Journal of Geosciences, 108, 3-34.

Annexes

1. Detailed geomorphological map of the Indren - Cimalegna area (Monterosa Ski)
2. Anthropic landforms map of the Passo dei Salati –Cimalegna plateau sector (Monterosa Ski)
3. Geosystem services map of the Indren – Cimalegna area (Monterosa Ski)

Scientific publications

The following paper has been published based on this master thesis work.

F. Tognetto, L. Perotti, C. Viani, N. Colombo & M. Giardino (2021) - *Geomorphology and geosystem services of the Indren-Cimalegna area (Monte Rosa massif – Western Italian Alps)*, Journal of Maps, 17:2, 161-172, DOI: 10.1080/17445647.2021.1898484.

The QGIS legend has been made available at the following link: https://www.geositlab.unito.it/jom/