The analysis of geomorphic indicators for the definition of the extension of Pleistocenic glaciers within alpine valleys

Method and applications

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Abstract— **The paper explains the use of geomorphic indicators (such as erratic blocks and tors) as indicators of presence/absence of glacier passage during the Pleistocene. Thanks to a census of over 600 erratic blocks, and their distinction from the tors, the reconstruction of glacier extension is possible also inside the alpine valleys. As example, the paper shows the reconstruction of Pleistocene glacier extension within the Lanzo Valleys (Western Alps, Italy). The reconstruction of the Pleistocene glaciers is enough accurate for applications to geology or biology. As example, we show the application of method to the problem of origin of endemic species living in caves: thanks to the definition of the relationships between caves and glaciers during the Pleistocene, it is possible subdivide the caves in five groups with different history of habitat and of climatic changes.**

Keywords: glaciers; geomorphic indicators; erratic blocks; tors; Western Alps

I. Aims of work

The extension maps of glaciers in the Pleistocene are very commons, but generally they have only purpose of disclosure, so they represent well only the glacial tongues at the mouth of the glacial valleys in lowlands. These maps often reconstruct the ice-covered part of the Alps more on the basis of the imagination than on geological evidences, especially where the glaciers are never arrived as far as the Po Plain.

However, a better reconstruction would have significant importance, e.g. for the biogeography studies. One of these is the study of areas where fauna can survive during the ice ages and the interglacial stages. For example, the "jardin des glaciers" hypothesis as the Orrido di Chianocco (Susa Valley) where can surviving species of thermophilic plants would not hold if we reconstruct, even approximately, the extent of glaciers.

In some modern studies, as the project CaveLab [17], the biologists study the speciation of the subterranean fauna. In fact, the glacier extension in the area surrounding the caves should influence the speciation: the cold climate and the deposition of glacial till (that is rich of interstices) can promote the spread of cryophilic species, or on the contrary the obstruction with ice of entrances of the caves and the cover of interstitial environments can isolate some species. A precise reconstruction of the ice cover during the Pleistocene is therefore always more useful.

The aim of this work is provide an objective tool to determine which areas have never had ice cover, and the contrary.

II. Introduction

The geologists have faced the problem of the extension of Alpine glaciers during the Pleistocene, immediately after the recognition of the validity of the theory of Ice Ages. Initially, with the recognition of morainic amphitheatres and erratic boulders, geologists have implicitly assumed that the Alpine glaciers during the ice ages were so large that their tongues have reached the Po Plain [10]. The current idea was a single ice cap from which outlet glaciers protruded. Within alpine valleys, Gastaldi [13], [14] and Sacco [27], [28], [29] have explained the moraines that lie below those of the "Little Ice Age", with periods of stop or glacial advance (“Dauniano”, “Gleitzschiano”) who have interrupting the slow and gradual retreat of the glaciers, at the end of the last ice age (“Würm”).

The lack of certain glacial evidences in some valleys, the lack of morainic amphitheatre at the mouth of many alpine valleys (in Piedmont, particularly, the Cuneo, Lanzo and Sesia valleys), the discovery that the glacial retreat has been nearly instantaneous at geological time scale, have removed the theory of a single ice cap, at least as far as the Italian side of the

This study is part of the CaveLab project “From microclimate to climate change: caves as a laboratory for the study of the effects of temperature on ecosystems and biodiversity”, funded by the University of Turin and Compagnia di San Paolo (Progetti di Ateneo 2011 - ORTO11T92F).

This study is partially funded also by University of Turin project “Contrasti termici e umidità in microclimi di grotte di particolare interesse naturalistico" (MOTMRIL013).

The Piedmont Region in agreement with University of Turin (coordinator Michele Motta) has funded the census of erratic blocks for implementing the Regional Law n. 23 of 21.10.2010 “Development and preservation of erratic blocks that have high landscape, environment and history value”.

Alps, in favour of the idea of large compound glaciers [26], [12] and [1].

With regard to the Piedmont, the papers of Sacco are even today in many valleys the best maps available for the glacial landforms, although Sacco has mistaken some accumulation of landslide or rock glacier for moraines. E.g. the blocks between Mondrone and Martassina (Lanzo Valleys, fig. 8), actually deposits of debris flow [10]; the group of blocks near Exilles (Susa Valley), believed of glacial origin still in the draft of Geological Map of Italy 1:50,000; actually, some rockfalls have deposed these blocks in historical age [6]. Roughly speaking, the recent mapping of the glaciers during the Pleistocene has still as basis, the moraines arrangement that Sacco has surveyed, and the distribution of glacial drift on the geological maps. Unfortunately, sometimes the geological maps are older of the Sacco works (Susa, 1890-1910, Oulx, 1910-11 ...) and all maps are inaccurate in the assignment of surface formations (e.g., the maps classify the deposits that are dubious as "moraine and debris mixed ").

In literature the identification of areas never covered by glaciers has focused almost exclusively on lowland areas (e.g. [11]). In particular the highly evolved soils are materials easily removable by the glaciers, so they mark absence of glacial passage after their developing age (almost always during Middle Pleistocene). In literature, the highly weathered rocks (grus, clays rich in kaolin) of certain pre-Alpine areas as Biella and Belmonte (Cuorgné), with a weathering that is starting in early Pleistocene (Gelasian), have the same meaning.

The main purpose of most recent research projects, such as PROGEO [15], [16], is the exact attribution of each moraine to its age, or glaciation. The recent works have used for this purpose: stratigraphy of wells, absolute dating... This work is almost always limited to morainic amphiteatres in plain. In the few cases in which papers have examined the alpine valleys (e.g. [8]), the main purpose was almost always chronological reconstruction of the glacial retreat at the end of the last Ice Age (e.g. in Aosta Valley [1], p. 25). This work (which led to the abolition of the late stages of Ice Age, proposed by Sacco) does not require the determination of the overall extension of the glacier, but only the position of the end moraines ([1], p. 29).

The study on the boulders of the morainic amphitheatre of Rivoli-Avigliana [3], and the subsequent surveys for the Piedmont register of the erratic blocks [19] have had the need to distinguish between tors [9] and erratic blocks. Therefore, their results have provided new elements for the delimitation of the areas covered by glaciers in the nearby mountains to the Po Plain. The tor distribution is clearly separate from that of the erratic blocks, suggesting a slope evolution entirely without glacial processes. The tors are small blocks easily removable by glaciers, and requiring a long period of shaping [2]: so, certainly they are among the oldest landforms in the Alps.

III. INDICATORS

The method employed start with the identification of forms and deposits that are indicators of a glacier passage or, conversely, that are indicators of the lack of glacial processes in the past. Indicators generally extend their information geometrically in an area, with limits defined according to the type of indicator (fig. 1). The limits of this area are:

- for the indicators of glacial passage, the part of mountain slope that is limited upstream by the contour line at the same altitude of the indicator, and that is limited downstream by the bottom of the valley and by line of maximum gradient between indicator and thalweg (i.e. the bottom of the valley).

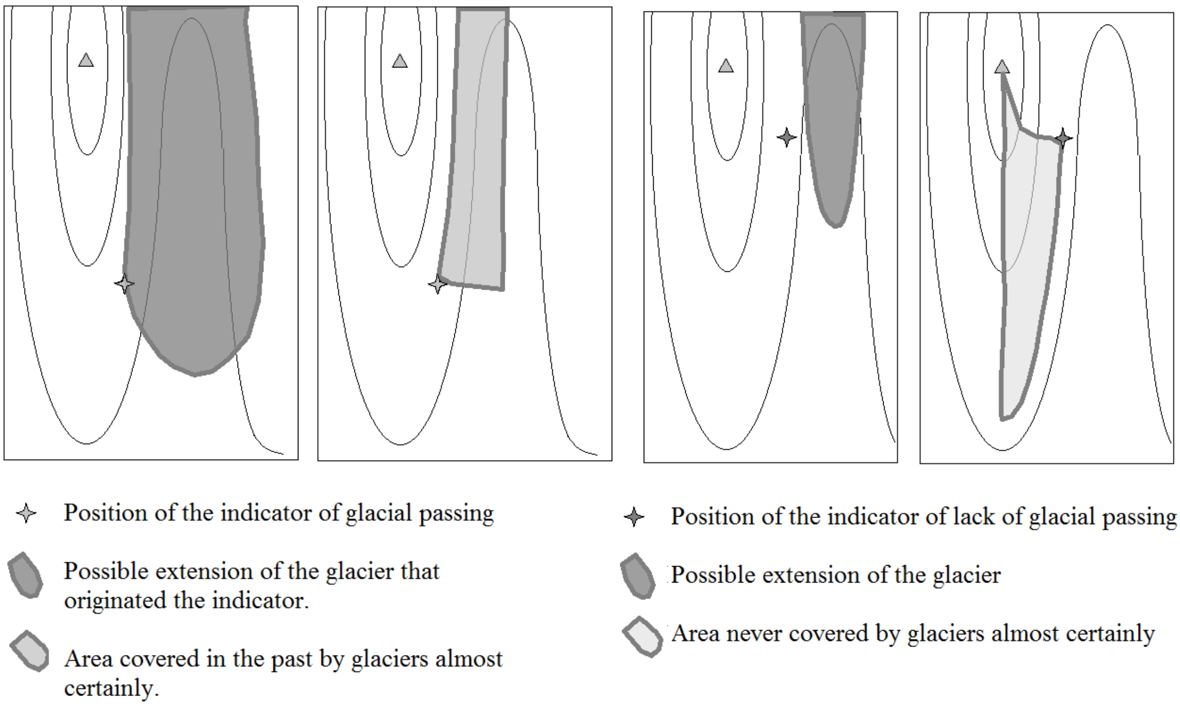

Figure 1. Extension criteria for the area subtended by an indicator.

– for the indicators of lack of glacial passage, the area that has the contour line at the same altitude of the indicator as downstream limit, the watershed and the line of maximum gradient between indicator and watershed as upstream limit.

Some indicators are unquestionable, because they may result solely from the presence (or absence) of glacial processes. Other indicators are doubts, because they may be interpretable, as well with low probability, as resulting from other geomorphic processes.

The indicators used are as follows.

A. *Unquestionable glacial indicators:*

– *Erratic blocks*, boulders transported by glaciers (fig. 2). The recognition criteria for the distinguishing between erratic blocks and others big blocks are [20]: lithology different from the bedrock; position independent from the bedrock structure; surfaces with traces of glacial transport (i.e. faceted rocks and glacial striae). The register created for the Piedmont Region by [22] lists the major erratic blocks of Piedmont: it contains the description of more than 600 blocks, or boulder groups.

Figure 2. Pera Aguà (Susa Valley) has all the characteristic of an erratic block: this block of amphibolite is resting on a base of white marble, the contact surface is irregular and with lenses of till, the lower part of boulder has glacial striae. This block shows that the ancient Susa Glacier in this point is arrived as high as the altitude of the block, a hundred of meters above the bottom of the valley.

– *Glacial till* and *Moraines*, deposits and forms of glacial accumulation that are obtained (with the limitations described above) from the Geological Map of Italy 1:100,000 or 1:50,000 (if available) and from the works of Sacco.

– *Faceted rocks* and *Polished bedrock surfaces with glacial striae* (fig. 3), forms of glacial abrasion. They have only some quotations in the works of Sacco and of Motta & Motta [18], [20], [22].

B. *Questionable glacial indicators:*

– *Diamicton* is a deposit with texture similar to the till, but of questionable origin. This list cites the diamicton for completeness, but the geological maps of Piedmont not report this term. These maps report sometimes the equivalent terms of “moraines mixed with debris” or “questionable moraines”.

– *Truncated spur*. The main glacier of the valley often has shaped several rocky walls on the arêtes of secondary watersheds. A database in [23] collects partly these landforms. Similar landforms are present in fluvial landscape, such as a triangular wall that interrupts a secondary watershed, because of the presence of a fault line, or due to linear erosion of a watercourse. Therefore, for the recognition is mandatory a complete analysis of the local geology, and of the landscape.

Figure 3. Polished bedrock with glacial striae and the typical triangular-shaped scars of the plucking. Susa Valley.

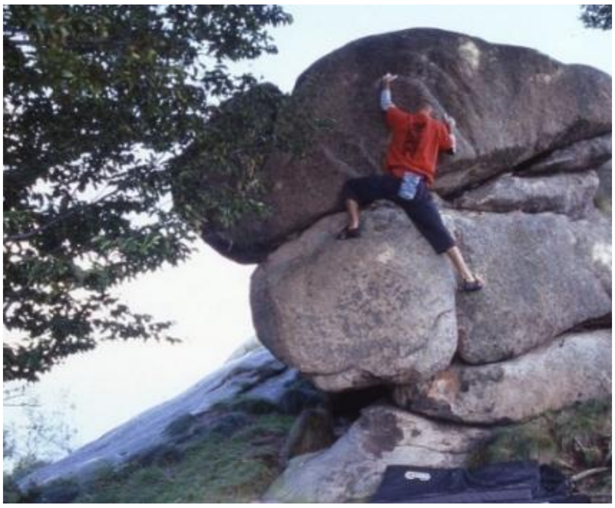

Figure 4. Typical (summit) tor: a pile of round blocks separated, but still closely in contact one another. Mottarone Mt., on the watershed between the glacial lakes of Orta and Maggiore.

- *Rocky steps* are on gentle slopes (e.g., bottom of the valleys). They are landforms of the subglacial environment [25]. If this landform not has glacial microforms, it is quite similar to a landform due to difference in rock resistance.
- *Cirques* are deep depressions on the upper part of mountain slope, under a steep wall. In Piedmont, they are relict landforms, developed almost only during the Pleistocene glaciations [5]. A range of mountains arranged by chance in semi-circle can (rarely) be confused with this landform.

C. *Unquestionable indicators of lack of glacial processes:*

- *"Vetusuoli"* are much evolved (under warm climate) soils. In the climate of Piedmont (temperate), they rest only on rocks of Middle or Lower Pleistocene: so, they are indicators of lack of glacial passage during the Upper Pleistocene (last glaciation). The vetusuoli of Piedmont are mapped in [31].
- *Tors* are piles of rounded blocks, born from the breaking up of a single rocky outcrop (fig. 4). The selective weathering has shaped these landforms [2]. Reference [9] has proposed a classification depending from the tor location: summit tor, on hill and ridge crests; spur tor, at the ends of ridges or spurs; valleyside tor, along valley sides. In Piedmont climate, the weathering can shape a tor only in a very long time. When a glacier overcame a tor, it removes easily the small blocks of the tor, and the bedrock becomes polished. Therefore, in the Alps the tors are only or in minor valleys that are flowing directly to Po Plain, or on the mountains close to the mouth of the glacial valleys in lowlands. The tor can be confused with an erratic block (fig. 5). For the recognition criteria, see [20]; the more important are the spacing frequency of the joints similar to that of the bedrock, and the parallelism of the fractures of tor and bedrock. A tor can be confused as well with the pillars resulting from landslides (e.g. in Piedmont the famous Torre delle Giavine, i.e. Landslides Tower, in Sermenza Valley), or ancient quarrying works (e.g. in Susa Valley the Roc di Pera Piana, near Avigliana). In Piedmont, the studies for the realization of the register of erratic blocks have faced largely the recognition of the tors. Reference [23] has reported a partial list of them.

Figure 5. The spur tor near Borna del Servaj (Ala Valley) very resembles an erratic block: it is located within an alpine valley, at 1450 m a.s.l., and on a rounded outcrop of the bedrock. Actually, a joint plane separates the block from the bedrock. Besides, this surface and the main sets of joints inside the block, and within the bedrock, are parallel one another; the bedrock surface has many weathering microforms; the rock texture of the boulder and of the bedrock is parallel.

D. Questionable indicators of the lack of glacial processes:

– Weathered debris. The geological maps report often these deposits, sometimes for filling of zones little known because of a lack of outcrops. The presence of thick layers of weathered debris (if in place, and if they are actually weathered debris!) has the same meaning of tors, but it is harder to define their age. In Northern Piedmont, the rocky hills around Biella have often thick layers of very weathered debris, containing kaolin, that are missing in the near Aosta Valley, because of glacial erosion [11]. In Southern Piedmont, the weathered debris are common on the pediments between Alps and Po Plain, underneath of slopes with tors. Some terraces covered by weathered debris are also on the summit of the mountains closer to lowlands; the authors consider them relicts of a large pediment of the "Plio-Pleistocene" (before of the glaciations, corresponding to current Gelasian) [4].

IV. IS THE ERRATIC BLOCK RECOGNIZABLE FROM THE TORS FOR ITS HONEYCOMB WEATHERING GRADE?

An example of an area where the glacial indicators are very close one another is the part of the Susa Valley closer to Po Plains. In this area, the higher slopes of the mountains were higher of the tongue of the glacier. However, these mountains are no very high, so they not had their glaciers at the top. Thus, the glacial forms are only down, near the bottom of the Valley, while the tors are on the higher slopes.

In this area, the position of the lateral moraines, which are all well preserved, also those of the Middle Pleistocene, well outlines the extension of the glacier. This situation is perfect to check if the weathering is stronger on the oldest surfaces, i.e.:

– rocks never covered by glaciers, versus rocks covered;

– rocks that a glacier has shaped during the last ice age (Upper Pleistocene), versus rocks modelled in previous glaciations (Middle Pleistocene).

Of course, the weathering has a variable speed of development in the different rocks. Therefore, we chose to compare the prasinite stone (albite-chlorite-epidote-actinolite schist), the most common rock in this area. To assess the weathering we used the scale of [24].

The fig. 6 is a cross section along the famous abbey of Sacra di S. Michele, the symbol of Piedmont.

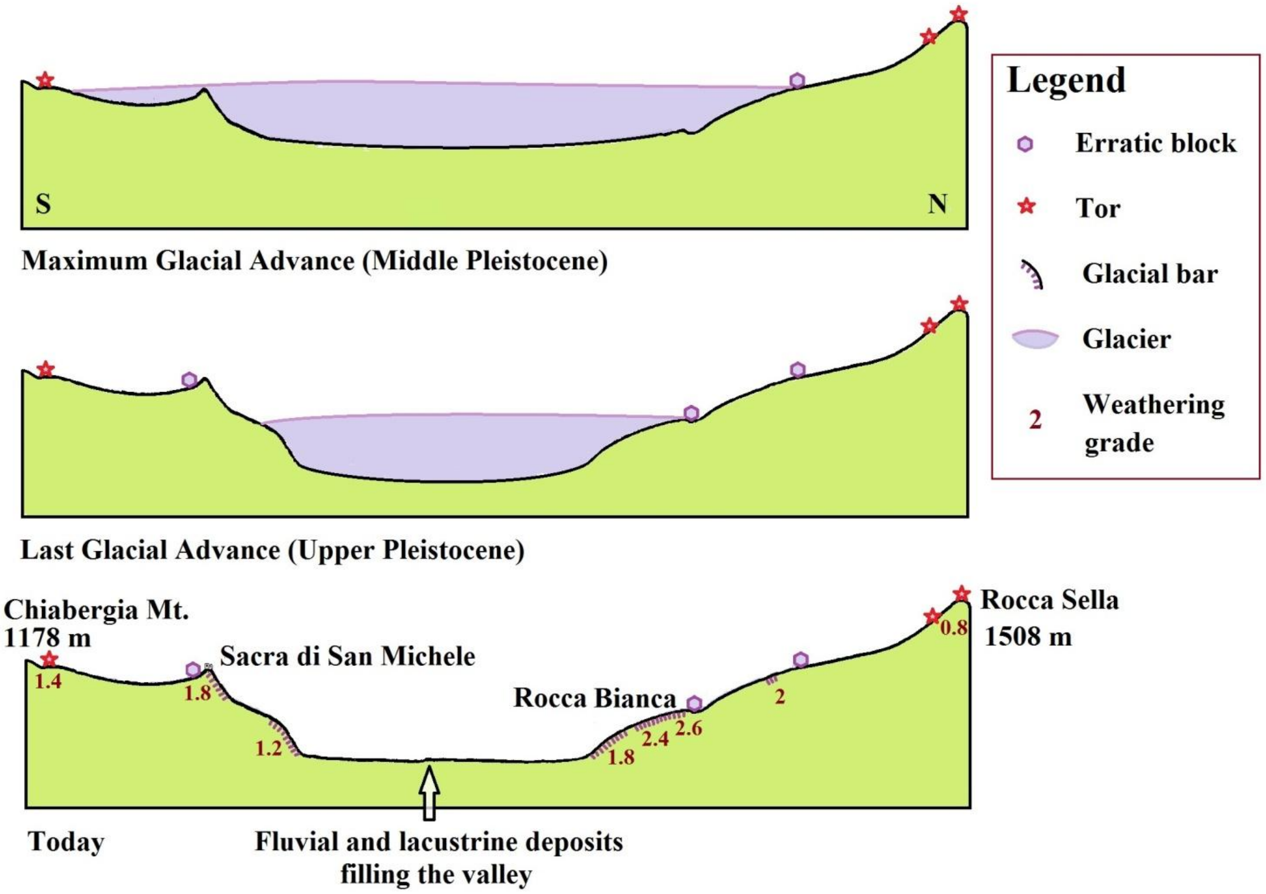

Figure 6. Cross section of the Susa Valley. According to [24], we have done an average of the weathering grade values of five walls that are at the same altitude. Honeycomb weathering grades employed in this study: 0: no visible weathering forms; 1: isolated circular pits; 2: pitting > 50% of area; 3: honeycomb present; 4: honeycomb > 50% of area; 5: honeycomb with some wall breakdown. The section shows that the weathering grade is independent of the geomorphic position or altitude.

The results suggest that the ranking of alveolar weathering grade is unsuitable for recognise the glacial landforms.

In the climate of Piedmont, the weathering process is quite slow. The honeycomb weathering of the blocks of prasinite cutted for building, including those used a thousand years ago for the Sacra di San Michele, is not very developed (honeycomb weathering grade in the Mottershead classification = 1). However, the little time spent by the last ice age, is clearly sufficient to a stronger weathering of natural surfaces (grade 1-3). Probably, the difference of the weathering grade from one wall to another is due only to a local detachment of slabs from the surface, with the exposition of new rock surfaces without weathering forms.

V. Delimitation of area subtended by an indicator

We have extended the area subtended by the indicators, depending on the meaning of the indicators, upstream or downstream (fig. 1). In the valleys that hold the indicators, we have made always the extension. We extend the area subtended by indicators in tributary valleys only if we can exclude in these valleys the presence of minor glaciers in the past. Therefore in the tributary valleys have to be missing the following indicators:

- altitude of valley head over the 2000 m a.s.l.;
- glacial cirques, also if they are dubious;
- glacial drift and diamicton.

VI. Results of the application of the method to the Alps

Fig. 7 and 8 are reporting the distribution of major geomorphic indicators in Lanzo Valleys, and fig. 9 the consequent reconstruction of ancient Lanzo Glacier during the Pleistocene.

The extension of the weathered debris is not analysed (even if they are abundant near to tors), since their distribution is badly known in some parts of the area. However, the proximity between the areas subtended by the opposite indicators, allows a very good reconstruction of the major glaciers. Instead, the quality of the reconstruction is less for the small glaciers at high altitudes. The glacial deposits of small glaciers are not very extended, whereby frequently are not mapped on the geological maps; moreover, these deposits are often completely eroded or covered by recent deposits, such as landslides or talus cones. Even the count of the numbers of erratic blocks in these zones gives a number very less than the actual. In fact, the register of boulders had as objective to identify and protect the boulders of particular scenic interest, historical or natural: a boulder of high altitude hardly has features that fall between those of the boulders protected by law, while it is likely that a boulder near the bottom of the Valley, easily seen and appreciated by many people, has high historical value or landscaping.

A survey specifically dedicated to research of geomorphologic indicators would obtain definitely a high precision in the definition of the extension of the Pleistocene glaciers in higher altitude areas.

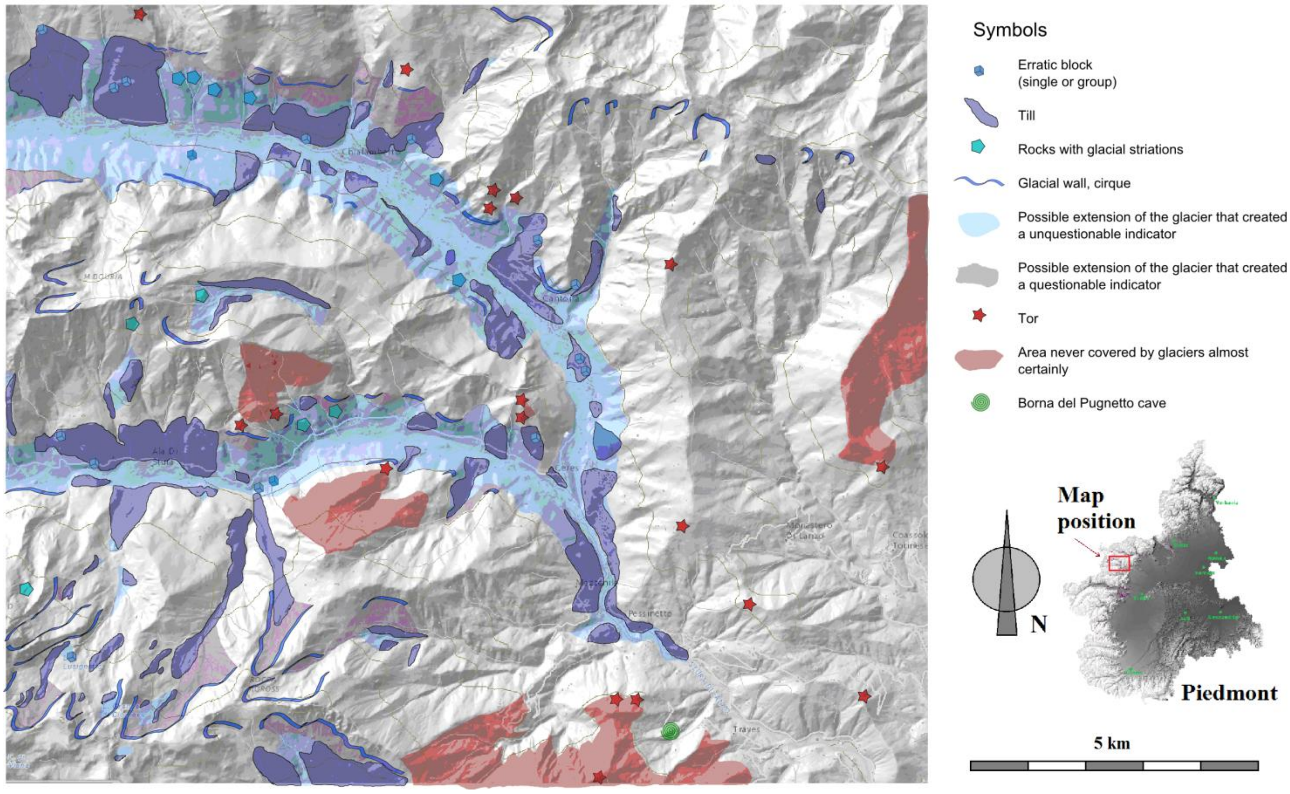

Figure 7. Distribution of geomorphic indicators of glacial passage (erratic blocks, till, rocks with glacial striae, glacial walls, such as truncated spur and rock step, cirques) and indicators of lack of glacial processes (tors) in Lanzo Valleys. Cartography of Arpa Piemonte.

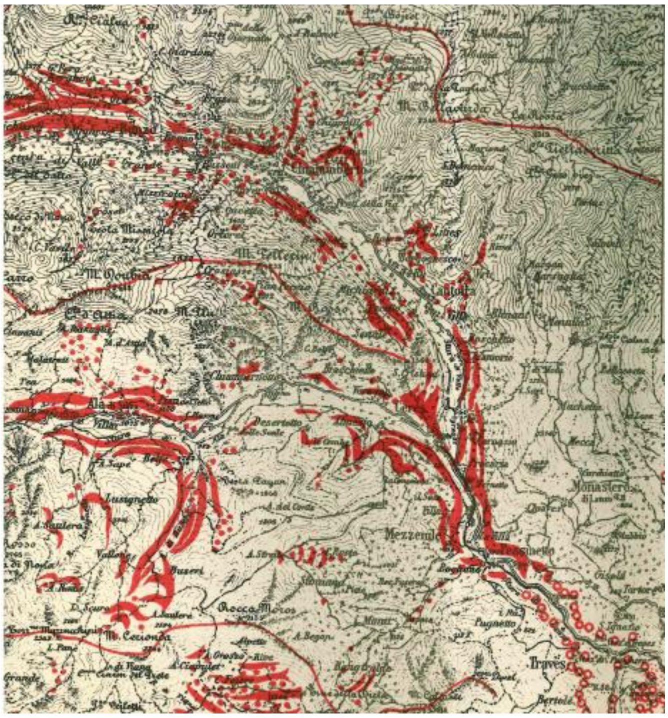

Figure 8. The “morenico sparso” (i.e., glacial deposits scattered, that are marked by dotted areas), the moraines (red lines) and fluvial deposits (red circles) in the Sacco survey of the Lanzo Valleys [28]

Despite the limits mentioned above, the card well highlights the difference in development of glacial processes between the two western valleys (Ala and Grande Valley) and the minor eastern valleys (Tesso and Malone) that are lower (only a few summits exceed 2000 m a.s.l.) and closer to the Po plain. In the major valleys, the only areas covered by glaciers are the slopes directly above the glacial tongues. In contrast, within the smaller valleys, the glacial traces are restricted to areas more shaded and high of the valley heads. At first glance, most of all the Lanzo valleys have the summits pointed and rocky ; but in the West, that is because these summits are a pyramidal peak surrounded by glacial cirques, while near to Po Plain (SE) the top of the rocky mountains is a summit tor.

In the valleys with numerous and generally unquestionable indicators, as Lanzo Valleys, Susa Valley or Aosta Valley, we never found contradictory indicators. In other words, the areas subtended by glacial flow indicators do not overlap ever, even partially, to the areas subtended by the indicators of lack of glacial passage.

In theory, then, in areas where the indicators are many but most of them are questionable indicators, the method might work to backwards. In other words, deposits of uncertain origin could be classified of glacial origin or not, depending on whether they are in areas subtended by the indicators of glacial passage or less.

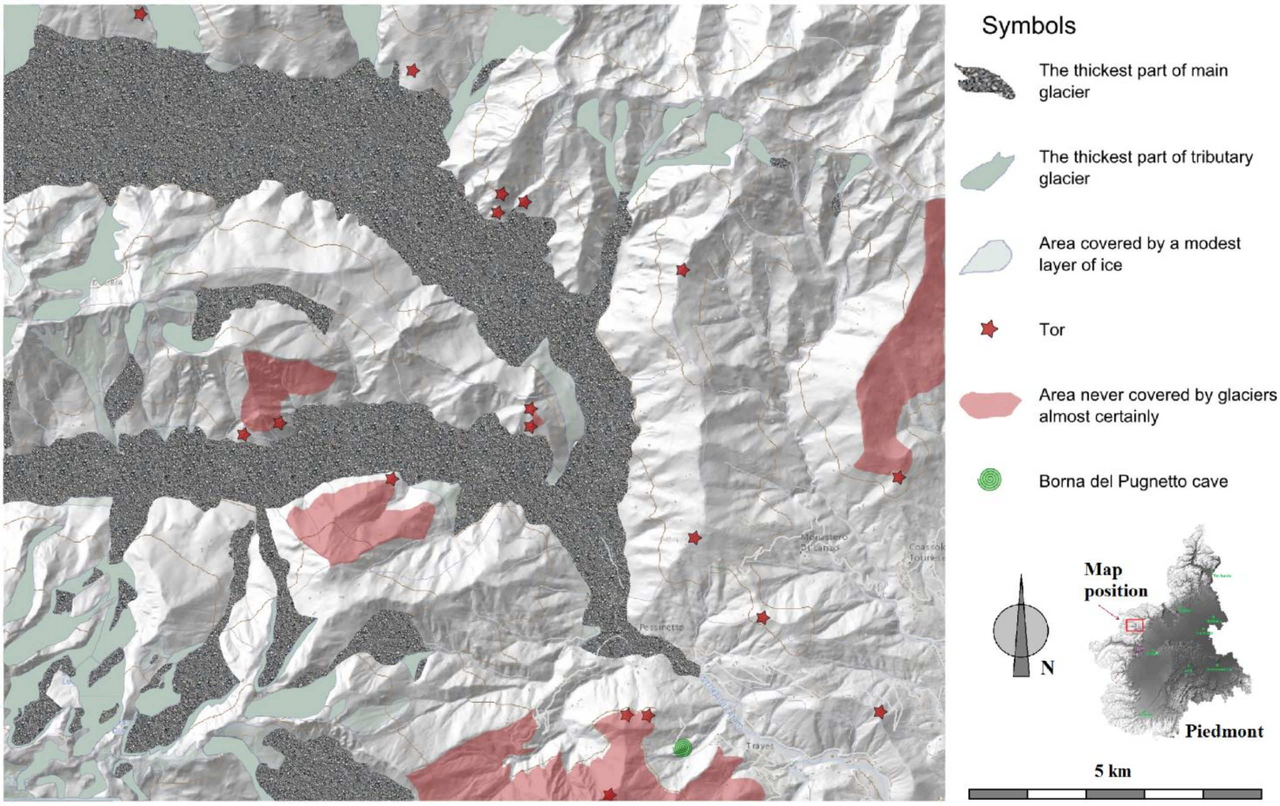

Figure 9. Reconstruction of ancient Lanzo Glacier during the Pleistocene, based on the analysis of glacial morphological indicators of fig. 7.

ISSN: 1339-5491, Volume 2, Issue 1, 2015

TABLE I. CAVES STUDIED BY CAVELAB [21].

N° register	Cave	Municipality	Altitude	UTMED50_X	UTMED50_Y
118 Pi/CN	Grotta dell'Orso di Ponte di Nava	Ponte di Nava	808	410027	4885936
105 Pi/CN	Grotta delle Camoscere	Chiusa Pesio	1057	392974	4896975
108 Pi/CN	Grotta di Bossea	Frabosa Soprana	836	407374	4899582
art Pi/CN	Sotterranei del Forte A di Tetti Ruinas	Vernante	800	382565	4901169
1214 Pi/CN	Barun Litrun	Valdieri	1050	373117	4902365
122 Pi/CN	Grotte del Caudano	Frabosa Sottana	780	403537	4905362
1003 Pi/CN	Grotta Occidentale del Bandito	Roaschia	714	374716	4905527
151 Pi/CN	Tana della Dronera	Vicoforte Mondovì	525	408066	4910960
1102 Pi/CN	Buco dell'Aria Calda	Vignolo	840	377406	4911834
1239 Pi/CN	Grotta 1 di Argentera	Argentera	1795	335864	4918268
nc Pi/CN	Buco del Partigiano	Roccabruna	1170	364416	4929787
1024 Pi/CN	Grotta dei Partigiani	Rossana	615	375493	4932782
1019Pi/CN	Tana dell'Orso di Casteldelfino	Sampeyre	2357	349107	4935896
1148Pi/CN	Buco del Maestro	Paesana	750	360333	4949624
1538Pi/TO	Ghieisa d'la Tana	Angrogna	835	359634	4967937
1621Pi/TO	Tuna del Diau, Chiabrano	Perrero	1080	350672	4979013
1591Pi/TO	Tana del Diavolo, Roure	Roreto Chisone	1414	352140	4987790
1569 Pi/TO	Grotta Testa di Napoleone	Borgone	450	363263	4997329
1597 Pi/TO	Balma Fumarella	Gravere	864	345315	4999142
1501Pi/TO	Borna Maggiore del Pugnetto	Mezzenile	742	375551	5014621
art Pi/CN	Borna del Servais B	Ceres	1420	369011	5020340
1593Pi/TO	Grotta La Custreta	Sparone	1386	386340	5033760
1609 Pi/TO	Buca del Ghiaccio della Cavallaria	Brosso	1548	405988	5041429
2048Ao/AO	Grotta A di Ivery	Ivery	773	407363	5049504
2624Pi/BI	Caverna dell'Om Salvej	Sordevolo	1025	417306	5050186
2503Pi/BI	Grotta di Bergovei	Sostegno	415	442855	5056806
2509Pi/VC	Grotta delle Arenarie	Valduggia	780	446644	5062402
2001Ao/AO	Borna d'la Glace	Chabodey	1605	348747	5066007
2017Ao/AO	Fessura di Verrogne	Verrogne	1536	360703	5066012
2501Pi/VB	Caverna delle Streghe di Sambughetto	Sambughetto	670	446956	5084248

a. "art" in first column means man-made cavity, and obviously these "caves" not existed in Pleistocene. Also Buca del Ghiaccio della Cavallaria, Ghieisa d'la Tana, and Borna d'la Glace, tectonic caves formed by landsliding, probably not were existing before the Holocene. Tana dell'Orso di Casteldelfino, Buco del Maestro, Grotta 1 di Argentera, Tana del Diavolo, Tuna del Diau, Testa di Napoleone, Caverna dell'Om Salvej and Buco del Partigiano are tectonic caves, and perhaps not were existing during Pleistocene (or they exist only since the Upper Pleistocene).

b. UTMED50_X and Y are the UTM coordinates, European Datum 1950.

VII. APPLICATION OF THE METHOD TO THE STUDY OF SUBTERRANEAN FAUNA

The interdisciplinary project CaveLab "From microclimate to climate change: Caves as laboratories for the study of the effects of temperature on ecosystems and biodiversity" was born in 2013 at the University of Turin, with a team of several members of the departments of Life Sciences and Biology of the Systems, Earth Sciences, General Physics, Plant Biology and Analytical Chemistry [17].

The ultimate goal of the project is: from a scientific point of view, a better knowledge of the impact on ecosystems of sudden variations (in time of the evolution of species) of climate such as the deglaciation, or in a future scenario, the global warming; from a practical point of view, give advice on the good management of the tourism inside caves containing sensitive species.

The project begins with the characterization of the cave environment. The next step takes into account the influence direct and indirect of factors such as availability of trophic resources, the human disturbance, the structure of the biocoenosis and habitats, the Pleistocene climate, and, exactly, the extension of Quaternary glaciers.

Reference [7] has formerly analysed some of these caves, solely on the basis of the position in relation to glacial drift distribution on geological map of Italy 1: 100,000 (tab. 2).

Depending on the location of caves respect to position of glaciers, we can list different ecological conditions.

Caves at low altitude, without important flow of water and with the entrance on a sunny slope (e.g. Buco dell'Aria Calda): during glaciations the inner climate remains warm, so the interglacial fauna survives (nowadays they are become endemic and thermophilic species?).

TABLE II. CONDITIONS OF THE CAVES DURING PLEISTOCENE, ACCORDING TO [7].

Condition during Pleistocene	Caves
Covered by glacier	Abisso Artesinera, Balmovra, Barma di Grange Torre, Buco di Valenza, Caverna delle Streghe di Sambughetto, Elva Grotta dei Folletti di Novalesa, Grotta del Tiro a Volo, Grotta delle Meta (Borgone), Grotta di Bossea Grotta Testa di Napoleone, Rio Martino, Tana dell'Orso (Casteldelfino)
Maybe covered by glacier	La Custreta, Pertus dal Drai, Tana del Diavolo, Tumba d'Cucitt
Perhaps without a glacier covering	Fascette, Grotta dell'Orso di Ponte di Nava, Grotta di Candoglia
Certainly without a glacier covering	Barma dell'Argilla, Barma Scura, Buca del Ghiaccio della Cavallaria, Buco del Maestro (Paesana), Buco della Bondaccia Buco Dell'Aria Calda, Dronera, Garbo della Donna Selvaggia, Ghieisa d'la Tana, Grotta del Bandito Grotta del Pugnetto, Grotta della Marmorera, Grotta di Bergovei (Sostegno), Grotta di Levone, Grotta di Rio dei Corvi Grotta di Rossana, Grotta Superiore dei Dossi, Tana di Camplass, Tana of S.Luigi (Roburent)

Caves of the valleys without glaciers (e.g. Tana della Dronera) or caves at considerable distance from the glaciers, with important variations in the water and air temperature: only the little sensitive species can survive to thermic variations.

Caves that have been all the time without a glacier cover, but very close to a debris-covered glacier: during glaciations, the fauna that lives in the interstices of the moraine can colonize the cave. In the caves at high altitudes, survive glacial relicts; also at a lower altitude, on a shaded slope (e.g. Borna Maggiore di Pugnetto), several endemic species of cryophilic type, may living nowadays.

Animals that are living in the interstices of the moraine can colonize during the last glacial retreat a cave as soon as discovered by the glacier (e. g. The Custreta): so, these caves may contain the same fauna of the previous group, without however glacial relicts of the Middle Pleistocene.

Tectonic caves borne after the glacial retreat (e.g. Ghieisa of the Tana), man-made caves (e.g. Borna of Servais): the fauna can only have the species that live in the environment surrounding interstitial or that are able to spread rapidly.

VIII. CONCLUSIONS

The analysis of geomorphic indicators supplies an objective method for define the extension of Quaternary glaciers within alpine valleys. In normal conditions, in other words if the valley has a sufficient number of unquestionable indicators, the definition of the glacier extension is quite precise for the application of the results to other fields, such as biology. In the study case of relationship between caves and glaciers, the results are very improved compared with a former study, recent and well done. In fact, on the basis of the method proposed, we can change, or specify, the condition during Pleistocene of some caves formerly analysed by [7]:

– Grotta di Bossea: from covered to uncovered

– La Custreta: from maybe covered to certainly covered

– Buca del Ghiaccio della Cavallaria, Borna Maggiore del Pugnetto: the analysis with the method proposed has confirmed the condition during Pleistocene, and has specified the exact distance between cave and glacier.

The example demonstrates that the method employed gets better results than a traditional study based solely on analysis of geological maps [7] and allows, as shown in fig. 10 and 11, a very detailed and precise reconstruction of the glaciers extension during the Pleistocene.

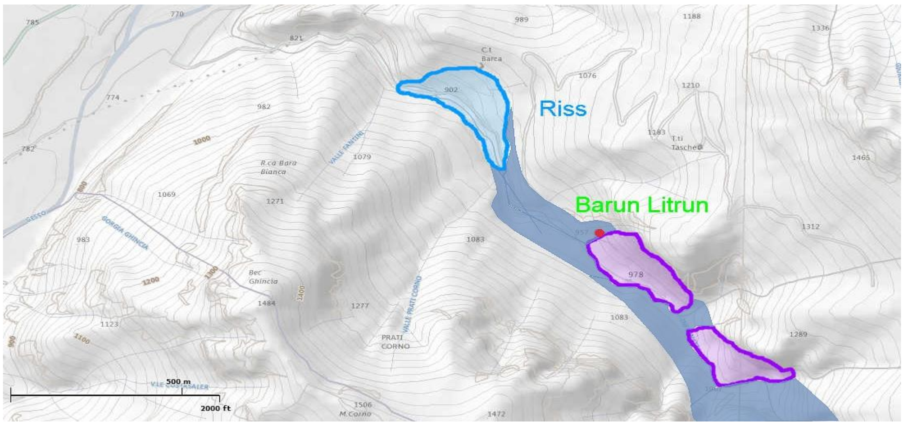

Figure 10. The Barun Litrun cave is between the glacial deposits of the Middle Pleistocene (pale blue) and the ones of the Upper Pleistocene (violet). The gray-blue area is the zone definitely covered by a glacier during Pleistocene.

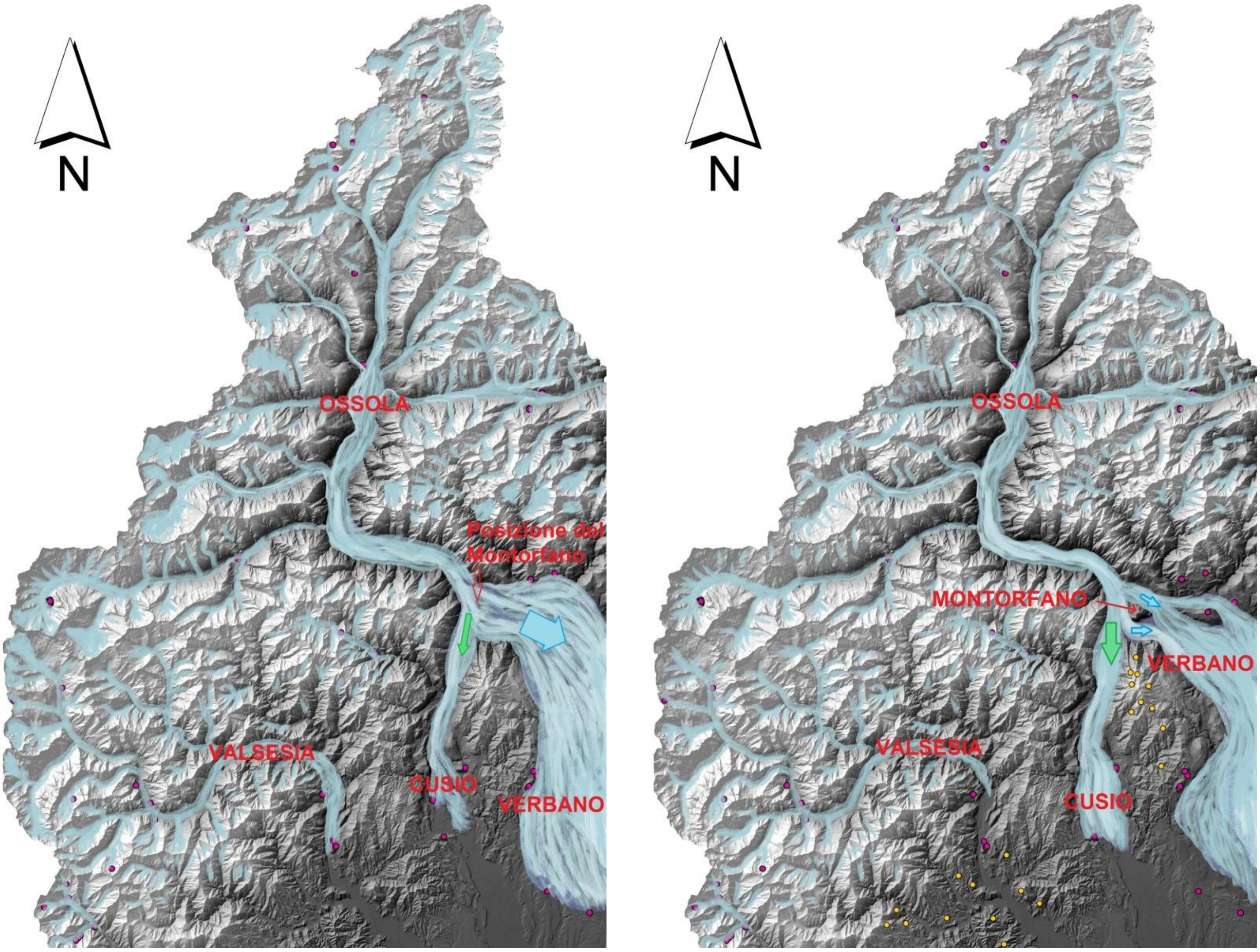

Figure 11. Reconstruction of the extension of glaciers (pale blue areas) in northern Piedmont during the Maximum Glacial Advance of Middle Pleistocene (left), and during the Last Glacial Advance of Upper Pleistocene (right), based on the analysis of glacial morphological indicators. Out of all these indicators, only the main erratic blocks and the tors (map on the right) are drawn (violet and orange circles). Width of map: 50 km.

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