

# Glacial Geomorphosites and Related Landforms: A Proposal for a Dendrogeomorphological Approach and Educational Trails

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**Abstract** The educational value is an attribute characterising glacial geomorphosites and it can be classified as additional value or part of the scientific one. In recent years, Alpine geomorphosites—including glaciers, whose role as palaeogeomorphic landforms, models of evolution and climatic indicators is evident—are becoming increasingly common locations for excursions, hiking trails and educational trips. Two educational trails are presented here in order to (a) enhance the role of glacial and Alpine geomorphosites in education; (b) underline the importance of dating methods such as dendrochronology for assessing the ecological value of geomorphosites and for educational purposes; (c) outline the importance of fieldwork activities in improving knowledge of landscape evolution. The first trail itinerary leads to a debris-covered glacier used for winter skiing, explaining in ‘stops’ the geomorphological processes observable on the slope and in the surrounding landscape. It also introduces dendrochronology as a tool for dating past events and climatic variations. This includes providing examples of dendrochronological exercises related to the reconstruction of a mixed fan (debris-flow and avalanche fan) located near the trail, with the aim of reinforcing the theoretical method previously learned. The second trail itinerary leads to a glacial geomorphosite where dendrogeomorphological investigations were carried out in dating an ancient moraine system colonised by trees, with the aim of showing students the importance of tree rings as a natural archive of environmental and climatic data. Testing part of the first trail on 14-year-old students confirmed the usefulness of the associated fieldwork

and provided evidence of the educational potential of glacial geomorphosites and dendrochronology.

**Keywords** Geomorphosites · Dendrogeomorphology · Educational trail · Central Italian Alps

## Introduction

Educational value is defined in literature as “the importance of a site for education (school, universities)” (Reynard et al. 2007) and as such is said to increase the value of geomorphosites either in terms of their scientific importance (Panizza 2001; Zouros 2007; Pereira et al. 2008) or as a separate additional educational value (González Trueba and Serrano Cañadas 2008).

Mountain regions are particularly suitable for educational purposes; here limited climatic variations may induce great changes in the surrounding landscape (in this work, we refer to landscape sensu Panizza 1988: “the integrated geodynamic expression of several cultural and anthropic components”), resulting in spectacular sites of great value and interest. As important components of high-altitude mountain environments, glaciers represent geomorphosites of great educational value, whose importance has already been highlighted by Diolaiuti et al. (2003), Pelfini and Smiraglia (2003) and Diolaiuti and Smiraglia (2010).

Indeed, glacial systems contain all the attributes necessary to define a geomorphosite (aesthetic, cultural/historical, socio/economic, scientific; Panizza and Piacente 2003). More specifically: (a) their aesthetic value is an undeniable characteristic of glaciers; (b) from a cultural point of view, some Alpine glaciated areas were the sites of several First World War battles (e.g. Ortles Cevedale, Marmolada); (c) the socio/economic value of glaciers is reflected by their

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role as an important tourist destination and source of meltwater for supplying hydroelectric power stations; (d) some organisms are highly specialised at surviving in these habitats, highlighting the ecological importance of glaciers (Pelfini and Gobbi 2005). Besides documenting glacier history, moraine ridges are also palaeogeomorphological and palaeoclimatic indicators (Panizza 1988; Panizza and Piacente 2003; Pelfini and Smiraglia 2003). Glacier-related processes (e.g. glacial stream activity, debris flows transporting glacial deposits, etc.) may also create other landforms suitable for educational purposes. For instance, complex and debris-flow fans represent potential study areas for analysing the effects of hazardous processes and for reconstructing previous events.

In such studies, biological dating methods like dendrochronology are useful techniques and as such increase the ecological value of glacial geomorphosites (Garavaglia and Pelfini 2008; Garavaglia et al. 2010). This method easily enables the establishment of the minimum age of moraines and recently deglaciated areas (Pelfini 1999), as well as being able to date trees buried under glacial deposits in order to retrace the path of glacier advance. Tree rings also play an educational role in helping to describe geomorphological processes (Stoffel and Bollschweiler 2009), landscape evolution (Sheppard 2002) and climate change (McCormik 2007).

In the Alps, wide valley glaciers are easily accessible thanks to the presence of cable cars and walkable trails and huts, and they are the focus of many scientific investigations producing large amounts of data. Considering these facts, the thematic paths in the region that are of increasing interest to tourists, may also represent a useful tool for educational purposes. Indeed, the new role of hiking trails as part of educational itineraries is reflected by their appearance in nature guides, geo-tourist maps and brochures (Coratza et al. 2004). Fieldwork is an important instrument for disseminating scientific knowledge to students, for developing their ability to observe the landscape (“not only the *what’s* and *where’s*, but also the *why’s* and *how’s*”—Golledge 2002; Lewis 2007) and the environmental responses to global climate change.

The importance of direct observation and fieldwork is reflected by the great number of recent studies focussing on educational approaches and applications, e.g. the effect of fieldwork on the affective domain (Boyle et al. 2007) or its implication for disabled students (Hall et al. 2004).

Finally, by involving walking trails under safe conditions, fieldwork enables the introduction of concepts of hazard and risk (*sensu* Bell 2001), with students able at the same time to observe the effects of slope instability processes that can rapidly modify the shape of landforms and damage trees, converting them into data repositories with which to reconstruct past geomorphological events (Pelfini and Santilli 2008; Rickenmann and Chen 2003; Pelfini et al. 2007).

Through direct observation of the landscape it is easier to explain how landforms may be classified as geomorphosites.

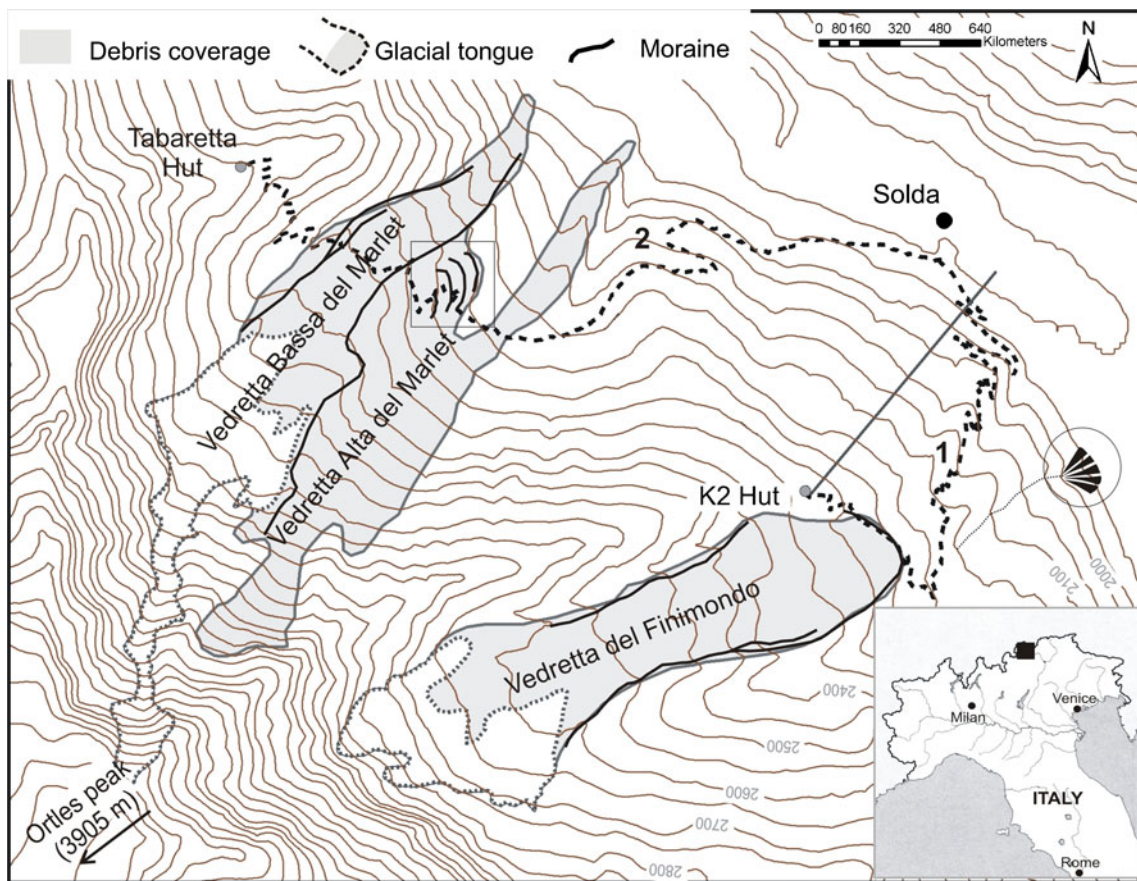
This paper presents two examples of educational trails in an Italian glacial valley, focussing on the use of dendrochronology to study landscape. The first is associated with an anthropic glacier (i.e. a glacier where “the presence of man has influenced the glacial system and its evolution over time, and on the other hand, the change in climate ... have limited the influx of tourists and man’s use of the glacier”; Diolaiuti et al., 2001) with a panoramic vista, where a glacial geomorphosite is observable and where dendrochronological investigations have been carried out. Along this trail, dendrochronology is introduced as a dating method used to reconstruct local landscape evolution and the geomorphological processes affecting the slope. Part of this first educational trail provides examples of practical dendrochronological exercises for studying the colonisation of a mixed fan (debris-flow and avalanche fan) by trees.

The second trail presents dendrochronology as a method for reconstructing glacial history, leading as it does to a glacial geomorphosite crossing its proglacial area which has already been studied by dendrochronology. In this case, tree rings are also presented as a tool for improving the ecological value of the geomorphosite, connecting its biotic and abiotic components.

The main aim of this study is to highlight the potential of geomorphosites as part of teaching approaches based on fieldtrips and fieldwork along mountain paths. The paper also aims to underline how dendrogeomorphological analysis may be helpful for: (a) environmental reconstructions, (b) geomorphosite promotion (Garavaglia and Pelfini 2008) and (c) educational activities.

## Study Area

Research was carried out in the Valle di Solda, on the boundary between Lombardy and Trentino Alto Adige in Stelvio National Park (Central Italian Alps). This is a glacial valley deeply reworked by glacier fluctuations and where clear signals of their activity are recorded in moraine systems (19 according to the Italian Glacier Inventory, CGI-CNR 1961) bordering the glaciers, which are now rapidly receding or already extinguished. The studied trail itineraries cross the side of the valley where three glaciers are located: Vedretta Alta del Marlet, Vedretta Bassa del Marlet and Vedretta del Finimondo (Fig. 1). The Vedretta Alta del Marlet is located at the bottom of a steep valley; it is fed mainly by avalanches from Ortles peak (3,905 m) and is topographically very steep, uneven and debris-covered. It is currently classified as a debris-covered glacier. The Vedretta Bassa del Marlet moves eastwards down a valley originating from the northern ridge of Ortles peak. The valley it occupies is steep



**Fig. 1** Morphological sketch of the study area and glacier locations. The proposed educational trails are indicated by the numbers 1 and 2. The dated moraine system is shown in the *square* and the mixed

(debris-flow and avalanche) fan in the *circle*. The *arrow* shows the approximate off-map location of the Ortles peak

and narrow, the tongue is extremely crevassed and the lower part is half-covered with debris (CGI-CNR 1961). These two glaciers will hereupon be referred to as the ‘Marlet glaciers’. The Marlet glaciers deposited a complex moraine system during the Little Ice Age (LIA) climatic fluctuations (Porter 1986; Grove 1988; Orombelli and Mason 1997), characterised by ‘recent’ LIA moraines without a vegetation layer and other ancient ridges completely colonised by grasses, shrubs, living trees and stumps of *Larix decidua* Mill. and *Pinus cembra* L. (Fig. 2).

The third glacier is the Vedretta del Finimondo, located in a short, narrow valley on the eastern side of Ortles peak; snow accumulation is mainly derived from avalanches, while in this case the tongue is also covered by supraglacial debris.

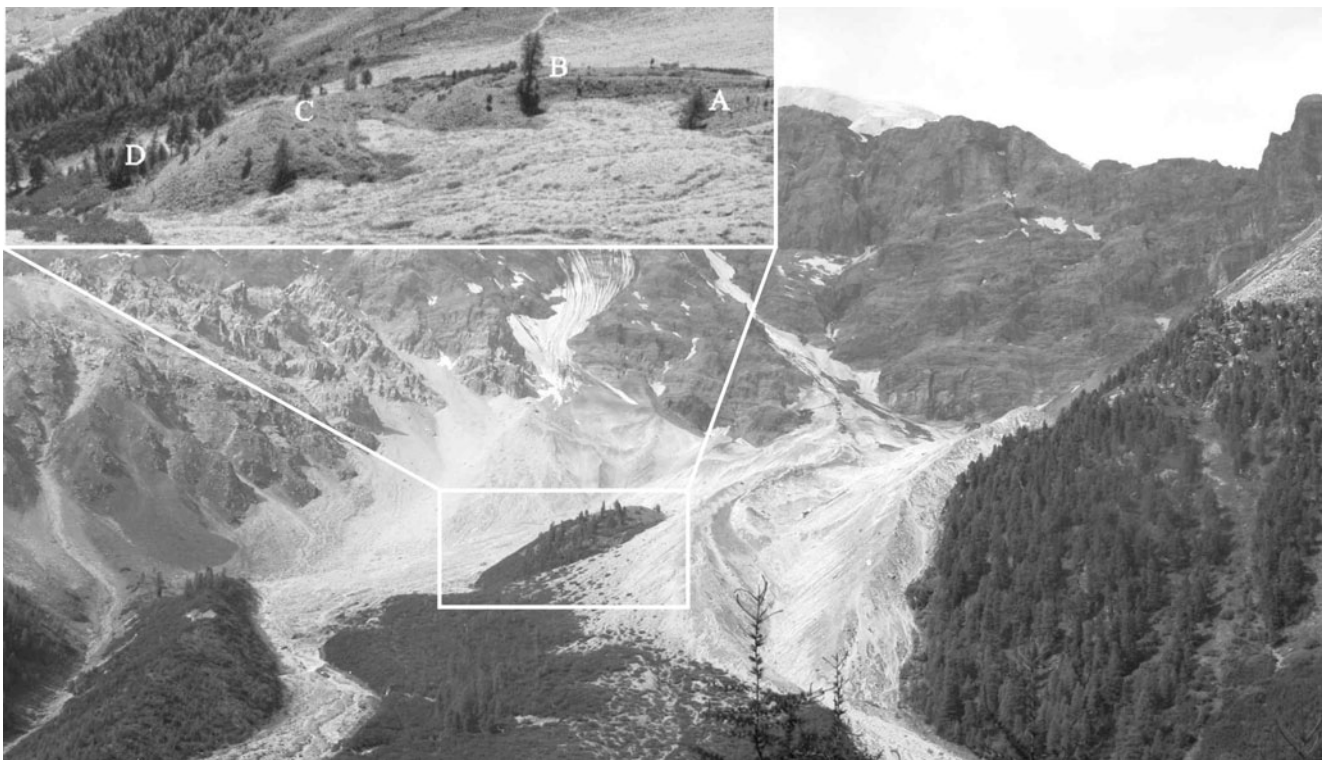
**Methods**

**Trail and Geomorphosite Selection**

The local trail system located on the western side of the Valle di Solda consists of nine official tourist paths. Each trail was carefully analysed, paying particular attention to

morphological features and potential geomorphological hazards (according to Bell 2001; Panizza 2005). The Marlet glaciers geomorphosite was surveyed on the basis of particular attributes and values (sensu Panizza and Piacente 2003). This preliminary analysis allowed the identification of the most suitable itineraries for realising desired teaching outcomes. Each track was recorded by mobile devices, GPS and GIS software. During the first investigation phase, each trail was divided into homogeneous sections on the basis of morphological data such as path course, length, inclination, mean altitude, ground characteristics, the presence of anthropogenic structures and type of underlying slope (according to Bozzoni and Pelfini 2007). Using a topographic map derived from a digital elevation model of the study area, it was possible to identify track segments with inclinations suitable for inexperienced walkers, as well as many parts with severe or high inclinations but where the trail was wider than 50 cm. This allowed the identification of ‘difficult walking sections’ and also the selection of the most accessible ones suitable for educational purposes.

The data obtained were processed in order to establish where to place trail ‘stops’ along the itinerary, with their scientific significance recorded on study sheets (one for each



**Fig. 2** Slope panorama showing a detail of the moraine amphitheatre studied in the dendrochronological survey. In the *top square* the four moraines are marked **a**, **b**, **c** and **d**

stop). Each stop represents the opportunity of making an educational step in which it is possible to observe the results of simple dendrochronological research and to explain how dendrochronology is used in reconstructing climatic signals.

In terms of geomorphosites, we selected the glacial system composed of the Vedretta Alta del Marlet, the Vedretta Bassa del Marlet (the Marlet glaciers) and their vegetated moraines.

The Vedretta del Finimondo, as an example of an ‘anthropic glacier’ and a small fan formed by repeated debris flows and avalanches at the foot of the valley side, is proposed as very appropriate for involvement in field activities. This fan was used as a potential study area with which to test the dendrochronological method and reconstruct past avalanche and debris-flow activity.

#### Dendrochronological Analysis

The dendrogeomorphological reconstructions outlined here are extremely simplified and clearly do not represent complete geomorphological or dendrochronological research investigations. However, such an approach does make it possible to demonstrate to students how to carry out research on glacial history reconstruction and mass wasting processes, as well as outlining the use of tree vegetation as a natural data archive. Tree-ring widths were measured (accurate to 0.01 mm) using the LINTAB and TSAP

systems (Rinn 1996) and image analysis was carried out with WinDENDRO software (Regent Instruments 2001). Cross-dating of the dendrochronological series was statistically processed using the COFECHA programme (Holmes et al. 1986) and visually with TSAP.

Twenty-nine *Larix decidua* Mill. were sampled to establish the minimum age of the older well-vegetated moraines (the Vedretta Bassa del Marlet moraine system). A mean tree-ring chronology was created from 12 living trees, with 13 successive stump samples cross-dated using local reference chronologies and others available in the International Tree-Ring Data Bank (Grissino-Mayer and Fritts 1997).

The obtained dates represent only a minimum tree cambial age, since the results can be affected by errors such as a delay between moraine stabilisation and tree colonisation, sampling height, cores not reaching the stem pith, damaged or decomposed wood etc. (Heikkinen 1994).

On the debris-flow fan 27 trees (5 *Pinus cembra* L. and 22 *Larix decidua* Mill.) were sampled, extracting one core from the base of each with the aim of dating them. The sampled trees were accurately located on a 1:10,000 map and parameters such as height, diameter, circumference and crown status collected. The extracted cores were prepared and tree rings measured as described above. Ring counting enabled the reconstruction of a minimum age of both the tree layer and colonisation process.

Dendrochronological and dendrogeomorphological study sheets were created for educational purposes.

## Results

### Educational Trail Number 1

#### *Choice of Stops and Formulation of Study Sheets*

Two itineraries are proposed. The first (1 in Fig. 1) is a trail consisting of stops for educational purposes, directing participants' attention to the geomorphological and dendrochronological aspects of the Valle di Solda. The desired learning outcomes are the selection of suitable trees, the collection of tree cores, formulation of growth curves and the use of dendrochronology for geomorphological event reconstruction. At the same time, students are trained to recognise geomorphological processes and landforms and as such learn to 'read' the surrounding landscape.

The route extends from Solda village (at an altitude of 1,900 m) to hut K2 (2,350 m), crossing the Solda forest and running alongside the terminal moraine of the Vedretta del Finimondo. The path is easily navigable and is therefore suitable for pupils. As a result of the impact of human activity, the Vedretta del Finimondo can be considered as an anthropic glacier (Diolaiuti et al. 2001; Belò et al. 2002; Leroux et al. 2008), with glacial deposits being reworked and modified for the creation of ski slopes as well as a ski lift on the lateral moraines.

Along this trail, 13 stops were selected and 13 study sheets (Table 1, Fig. 3) prepared, describing geomorphological processes, the effects of small catastrophic events (e. g. debris flows, avalanches) and landforms directly observable along the path or on the opposite valley side. Trees are also presented as research tools for climatic and environmental reconstructions, with the aim of introducing students to the method in the hope that it will increase the educational value of the Marlet glaciers geomorphosite, which is observable at the end of the trail.

#### *Tree Recolonisation of a Complex Fan (Debris-Flow and Avalanche Fan)*

A debris-flow and avalanche fan (Figs. 1 and 4) was analysed and appropriate educational exercises proposed. The fan is situated at the foot of the valley side of the Valle di Solda, at between 1,850 m and 1,900 m a.s.l. near the starting point of educational trail number 1. The stream characterising the fan, a tributary of the Rio Solda which presents well-developed lateral levees, is fed by rainfall and glacial meltwater from the Vedretta del Finimondo. In addition to seasonal debris flow events,

the fan is also intersected by avalanches that affect trees and shrubs, with the vegetation in general appearing disturbed and discontinuous.

Sampling was carried out in order to reconstruct colonisation of the fan by trees. It is highly probable that previous catastrophic events removed the forest coverage (denudation), resulting in the current sparse state of the vegetation.

The oldest sampled tree dates back to 1965 AD (1958 AD, taking into account estimated missing rings) and the youngest to 1993 AD (1988 AD considering missing rings). Looking at the tree-age spatial distribution map (Fig. 5), the oldest vegetation occurs in sector A (Fig. 4), an area less affected by avalanche and debris-flow events, while an undisturbed group of trees is found in sector B, probably protected by lateral levees.

However, in general, the study area does not present any clear patterns in terms of tree-age distribution, confirming the high frequency of processes affecting tree growth. The simple dendrochronological analysis presented here is useful for highlighting the effect of high-frequency geomorphological events on trees in Alpine environments, as well as emphasising the information recorded in tree rings.

In order to facilitate the repeatability of this dendrogeomorphological research without extracting new cores, the collected and investigated samples have been reproduced and all tree rings made visible (Fig. 6). During their fieldwork, students can identify tree ages simply by knowing the sampling date and can trace growth curves using graph paper and a ruler.

Using a topographic map of the study area showing the location of the sampled trees (Fig. 5), it is also possible to teach basic cartographic concepts, stimulating both landscape observation and orientation. The trees studied are in fact marked on their trunks with numbers corresponding to the extracted samples.

The educational programme proposed here has been tested on two classes (about fifty 14-year-old pupils) who carried out the dendrochronology and landscape reconstruction exercises during a one-day field trip in June 2008. In fact, considering the importance of selecting a public audience (Reynard and Berrebi 2008) and when the possibility of collaborating with two classes of 14-year-old students was made known, all the study sheets outlined here were in fact devised explicitly for them.

Before their field trip took place, 25 pupils attended lessons on Alpine environment evolution and the use of dendrochronology to reconstruct its history (Group A); the other 25 students participated only in the field trip, listening to brief explanations about high mountain landscapes directly in the field (Group B).

**Table 1** Topics related to the 13 stops

| Stop n. | Altitude(m) | Study sheet   | Topic/location/methods  |
|---------|-------------|---|---|
| 1       | 1,909       | The dendrochronology  | Conifer structure—introduction to dendrochronology  |
| 2       | 1,947       | Avalanche channel   | Avalanche channel on eastern slope/avalanche detachment mechanisms/defence works  |
| 3       | 1,989       | Rock glaciers   | Rock glacier on the eastern slope/genesis and evolution   |
| 4       | 2,003       | Tree colonisation (dendrochronology)                        | Trees close to the trail/minimum colonisation ages/dendrochronological analysis   |
| 5       | 2,012       | Stabilisation works on a slope                              | Unstable slope (landslides) close to the trail/stabilisation works  |
| 6       | 2,166       | Climatic signal in growing plants                           | Climatic signal/dendrochronological research  |
| 7       | 2,179       | Tree colonisation study (application of dendrochronology)   | Trees close to the trail/attribution of minimum colonisation ages/dendrochronological surveys   |
| 8       | 2,186       | Tree colonisation study (application of dendrochronology)   | Trees close to the trail/attribution of minimum colonisation ages/comparison with the previous surveys (sheet no.4)/dendrochronological surveys |
| 9       | 2,200       | Debris flows  | Debris flow close to the trail/triggering mechanisms and forms of deposit   |
| 10      | 2,223       | Moraine   | Moraines close to the trail/spatial and temporal classification, origin and evolution   |
| 11      | 2,282       | Reaction wood   | Trees close to the trail/plant response methods to disturbance phenomena/dendrochronological research   |
| 12      | 2,329       | Avalanche defence works                                     | Avalanches on the eastern slope and close to the trail/avalanche classification and detachment methods/kinds of defence works                   |
| 13      | 2,332       | Anthropic impact on a glacier: the “Vedretta del Finimondo” | Anthropic impact on the western slope/historical reconstruction   |

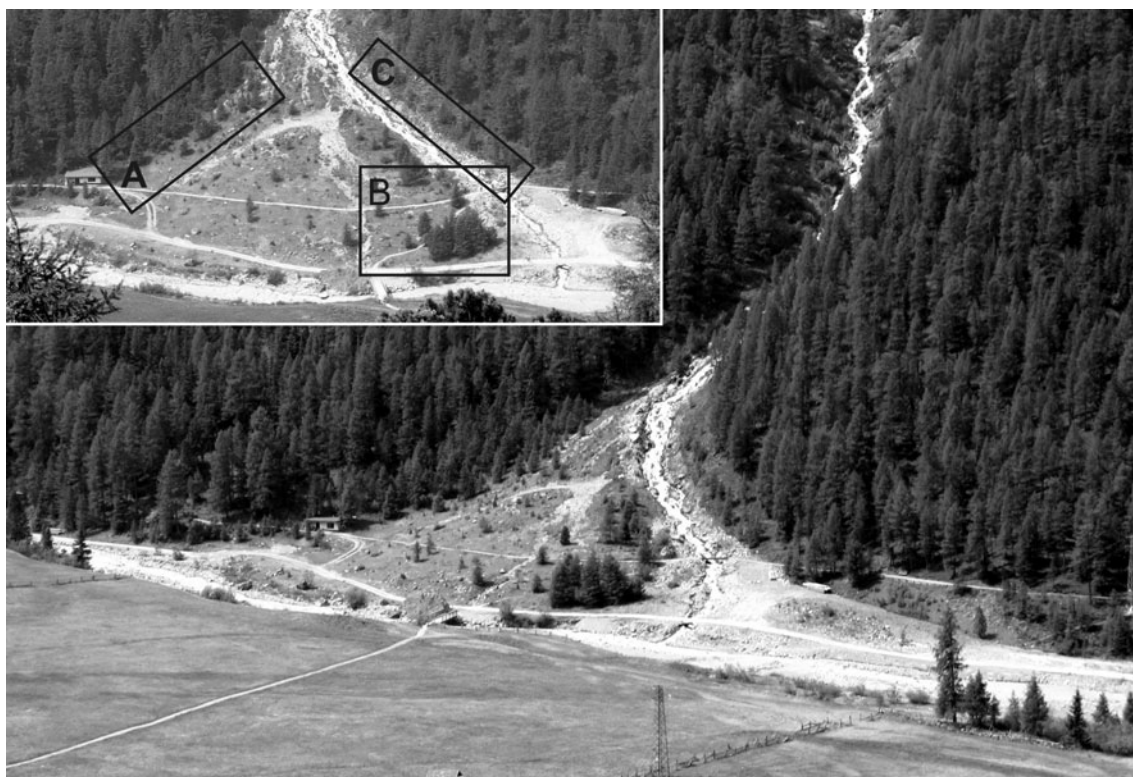
The results of the dendrochronology exercises are shown in Table 2. Group A, with 21 students completing the exercise, made less errors than Group B (22 students completed the exercise), suggesting that theory is a fundamental part of

fieldwork. Mistakes made in drawing growth curves were related to other school subjects, such as errors in measuring ring width or in counting millimetres on graph paper, and as such are not counted as being specifically geographical.



**Fig. 3** Photographs of stops 5, 9, 12 and 13 (details in Table 1), with their relative positions on the trail shown on the right. On the panoramic view of the slope dominated by the Ortles peak (3,905 m),

the teaching trail route is shown in white with the stop associated with the ‘Climatic signal and plant growth’ study sheet marked with a star. The other teaching stops are indicated by the (black circle) symbol



**Fig. 4** Panoramic view of the studied cone, showing the discontinuous tree vegetation cover. In the *top square*, sampling areas with major concentrations of trees are represented in the *smaller squares*

Educational Trail Number 2

*General Characteristics*

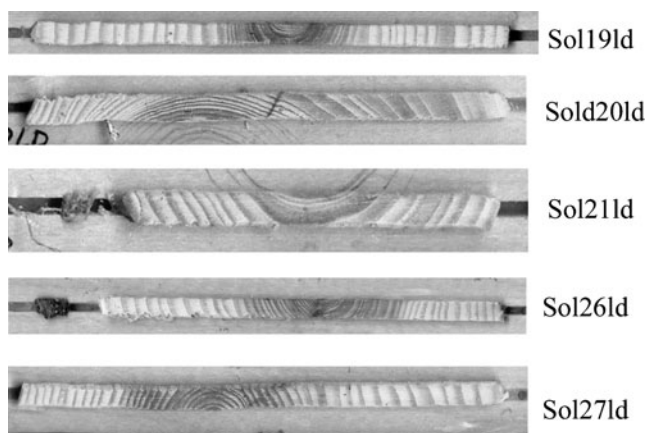
The aim of the second itinerary (2 in Fig. 1) is to appreciate geomorphological features that could be considered glacial geomorphosites. Both glaciers, the Vedretta Alta del Marlet and the Vedretta Bassa del Marlet, represent examples of glacial response to global warming, highlighted by their transformation from clean to debris-covered glaciers. The

moraine system of the Marlet glaciers is used to introduce students to glacier dynamics in relation to climate change, while the dendrochronological dating method highlights the importance of tree vegetation in reconstructing glacial fluctuations.

In fact, the small moraine amphitheatre (Fig. 2) documents a glacial phase during which the tongues were different than they are today. The small frontal moraines are located between the sharp LIA moraines that are different in terms of both vegetation coverage and soil development.

**Fig. 5** Spatial distribution of sampled trees (*black circles*) on the studied debris-flow fan. On the *left-hand map* they are represented by *sampling numbers* and on the *right-hand map* by *symbols* of size proportional to tree age. Evident is the concentration of the oldest trees in marginal areas, probably in those parts of the cone less affected by geomorphological processes. During fieldwork, similar maps permit students to locate the sampled trees as well as learn some aspects of cartography





**Fig. 6** Picture of some of the increment cores extracted from trees growing on the studied fan. Each sample is shown accompanied by its respective code: this number (for example 19 in Sol19ld) corresponds to the location of the tree in the *left-hand map* in Fig. 5

The moraine geometries and their differences with respect to the ridges deposited during the Little Ice Age highlight that they developed in a more ancient time.

The trail starts in Solda village and reaches the Tabaretta hut (2,556 m) before subsequently crossing the Solda forest, the proglacial area of the Marlet glaciers, with an average altitude of 2,200 m and arriving at the starting point for climbing the Ortles peak (3,905 m). Along the trail, morphological features generated by geomorphological processes, including debris-flow channels and avalanche paths, can be observed in perfect safety.

#### *Dendrochronological Study of the Marlet Glaciers' Ancient Moraines*

Here a dendrochronological investigation of the Marlet glaciers' moraine system is presented, with the aim of highlighting the educational value of the geomorphosite and the possibility of improving it using tree rings.

This older moraine system (Fig. 2)—colonised by trees, in contrast with the main LIA moraine system—documents a past phase when the morphology of the Vedretta Bassa del

Marlet differed from its present configuration. The spatial distribution of the moraines suggests their age progressively increases down-valley (from A to D in Fig. 7a and b). In order to better approximate real tree ages, the number of lacking rings was estimated based on the distance to the pith and the sampling height (Villalba and Veblen 1997). A previously constructed mean tree-ring chronology, covering the period 1396–2004 (for details see Leonelli et al. 2008), was used for cross-dating samples from stumps which were alive between at least 1411 AD and 1947 AD. The germination period is certainly older, since some samples from dead trees are decayed in their inner parts. The obtained ages do not increase down-valley, while the moraines minimum ages are probably underestimated. In any case, their formation seems to date back to before 1300 AD for the most ancient (D) and before 1430 AD for the youngest (A). Considering the time interval between deposition and colonisation, this moraine system could potentially have been deposited during the initial stages of the LIA or perhaps even earlier, as suggested for other locations in the Alps by Grove (1988), Pelfini and Smiraglia (1994) and Pelfini et al. (2002). Despite this uncertainty, colonisation seems to have taken place within a small time interval (of about 130 years) and therefore the phases of advance probably occurred in relatively rapid succession.

#### **Discussion**

This paper has presented two hiking trails adapted to meet educational goals, with the ultimate aim of demonstrating the possibility for promoting the Marlet glaciers as glacial geomorphosites. This wonderful landscape, with its debris-covered glacier and impressive moraine system deposited during the LIA or more probably even earlier, are unique features, with all the values characterising a classic geomorphosite.

Two hiking paths have been accurately analysed, identifying all geomorphological processes and panoramic vistas to help meet the goal of increasing trail users'

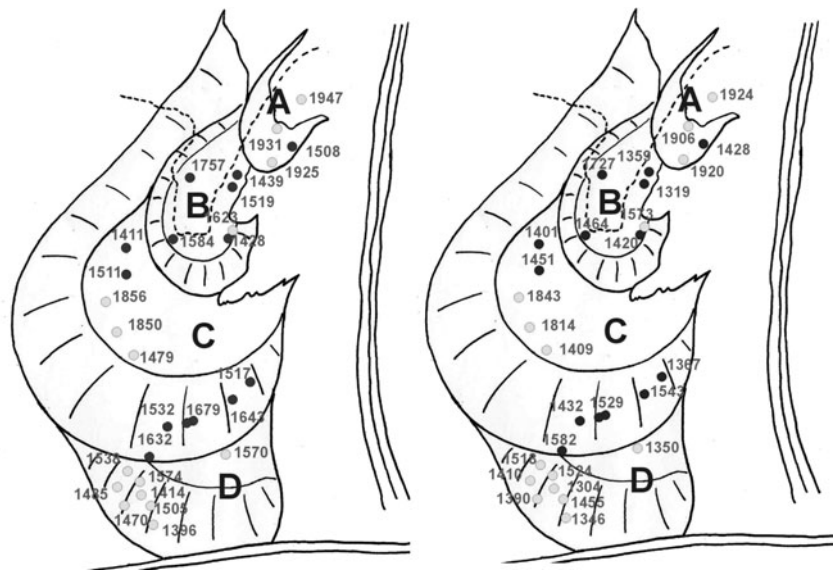
**Table 2** Mistakes in completing the dendrochronology exercise after fieldwork

| Sample code | Group A                       |                               | Group B                       |                               |
|-------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|             | Error in tree age attribution | Error in growth curve drawing | Error in tree age attribution | Error in growth curve drawing |
| sol02       | 0                             | 3                             | 0                             | 2                             |
| sol13       | 0                             | 3                             | 4                             | 5                             |
| sol15       | 3                             | 7                             | 2                             | 4                             |
| Tot         | 3                             | 13                            | 6                             | 11                            |

Members of Group A, who attended preparatory lessons beforehand, committed fewer errors (3) in the tree dating exercise compared to Group B, who participated in only the fieldwork



**Fig. 7** Spatial distribution of sampled trees on moraine amphitheatre lobes. *Black circles* represent dead trees, *grey circles* living ones. The *left-hand diagram* shows tree ages obtained by counting rings; the *right-hand diagram* shows ages estimated on the basis of sampling height and distance from stem pith



knowledge of landscape evolution. Prepared study sheets have been adapted for and tested by a group of 14-year-old students, confirming the increasing interest of schools in fieldwork activities. Study sheets associated with different stops along the trails gradually reinforce the notion of ‘tree rings as a dating method’, guiding the learning process and teaching students to both make detailed observations and understand the Marlet glaciers’ moraine system as well as other landforms characterising the surrounding landscape.

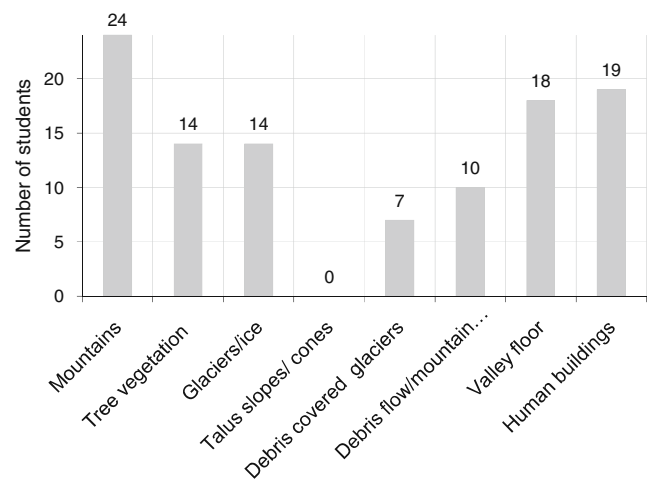
Finally, the simple exercises introducing examples of dendrochronological reconstructions on the mixed fan produced great interest in students, confirming the importance of learning by doing.

Nevertheless, a previous study (De Paulis 2008) has underlined the necessity of introductory lessons about mountain landscapes, especially if students are aware of the Alpine environment. Indeed, with respect to the pupils involved in this study who came from an urban background, their landscape perception was quite lacking. This was demonstrated by their individual descriptions of an Alpine panorama, in which they tended to include anthropogenic components (Fig. 8) and not common natural environmental features and processes.

**Conclusions**

The findings outlined in this paper suggest (a) how Alpine geomorphosites may be used as instruments with which to teach about Alpine landscape modelling and evolution (answering not only questions of *what?* and *where?*, but also *how?*); (b) how simple exercises carried out in the field may represent useful methodologies with which to consolidate students’ understanding of the time scale of geomor-

phological processes (answering the question of *when?*); (c) how using tree rings allows comprehension of landscape modifications (the question *why?* e.g. why may dated moraine ridges located at higher altitudes be older than others located down-valley?). From an educational point of view, the presence of geomorphosites such as debris-covered glaciers can be used to explain the concept of glacial evolution, which does not simply involve glacial tongue retreat but is also a strategy introducing the concept of conservation. This should allow the introduction of physical concepts, including differential ablation, mass balance, radiation and albedo, which are also reproducible in the laboratory (see Pelfini et al. 2010). In this sense, observation of the Vedretta del Finimondo also provides the ability to promote the concepts of the integrity and conservation of glacial geomorphosites.



**Fig. 8** Students ability to recognise Alpine landscape processes and landforms, after observation of a panoramic image

Although tested on only two class groups, this study enhances the educational potential of hiking trails, thanks to the integration of fieldwork activities, classical geomorphological topics, dating techniques and geomorphosite observation. Students, in direct contact with the mountain landscape and with the opportunity to verify and test genuine academic research methods, are encouraged to think independently and critically, experiencing complete ‘critical learning’ (Di Palma 2009).

The choice of an appropriate trail is critical, with the presence of anthropogenic structures (local hiking trails and huts), constantly controlled and managed by local authorities, in fact facilitating this approach.

Finally, an educational approach that includes dating methods such as dendrochronology is useful not only for introducing palaeoclimatic and palaeoenvironmental reconstruction techniques, but also for demonstrating the role of trees as a natural data archive.

Although the sample size was small, the preliminary results of the students’ study sheet test show the importance of fieldwork in education (Davis 2002), as well as highlighting the educational potential of geomorphosites and dendrochronology.

Considering these findings and the students’ general lack of landscape knowledge, it is clearly desirable to promote geomorphology as a way of understanding the surrounding environment (Lewis 2007).

Through educational projects it should be possible to disseminate physical geography topics via non-traditional methods, and also to introduce classical academic subjects such as landscape complexity, valuation and conservation, including the concept of the ‘geomorphosite’.

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