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# Glacial Archaeology in the Pennine Alps, Switzerland/Italy, 2011–2014

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This report summarizes a glacial archaeology project funded by the Swiss National Science Foundation (SNSF) which took place between 2011 and 2014. This interdisciplinary project integrated methods from archaeology, history, and geography and resulted in the collection of more than one hundred objects of archaeological interest. Until now, 37 of those objects have been dated using radiocarbon analysis and range from the Bronze Age to modern times. The final results are presented and discussed and perspectives are offered in regard to future regional scale, interdisciplinary, glacial archaeological projects.

## Introduction

The subject of glacial archaeology is a consequence of climate change; high-altitude and -latitude environments, which have been covered in ice and snow for hundreds to thousands of years, have been recently subject to increased melting due to augmented global temperatures, leading to the discovery of archaeological artefacts and remains in these areas (Dixon *et al.* 2014). The glacial-archaeological phenomenon was brought to light after the discovery of Ötzi in 1991 (Seidler *et al.* 1992) and has since developed into a legitimate field of research for scientists all over the world (c.f. Reckin 2013). With glaciers, ice patches, and snow levels at their lowest point in recent history (IPCC 2013), Archaeologists now have access to unexplored landscapes, allowing us to better understand how humans interacted with high-altitude and -latitude environments in the past.

Keywords: glacial archaeology, GIS, interdisciplinary, Bronze Age, Pennine Alps, Valais

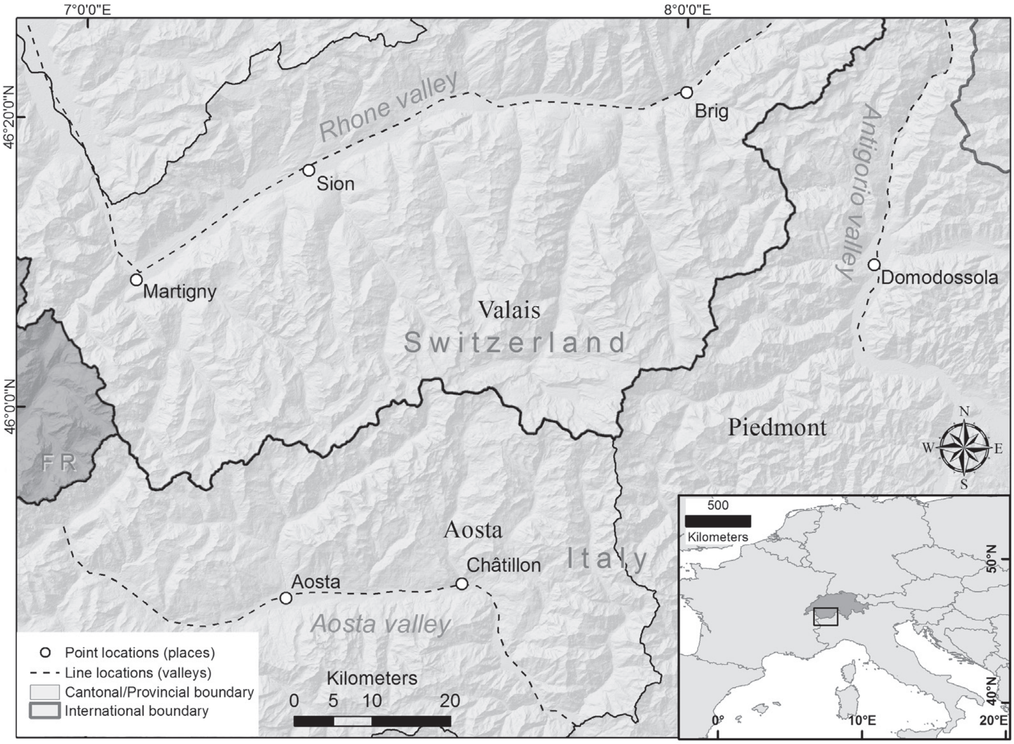


Figure 1 Overview of the Pennine Alps study area (Rogers and Curdy 2015).

Over centuries, changing climatic patterns have caused fluctuations in the amount of ice and snow cover at high-altitudes and -latitudes in the European Alps (Holzhauser 2007; Nussbaumer *et al.* 2011); this factor has greatly influenced whether or not humans were able to access certain regions over time. Therefore, these fluctuations are an integral piece in the complicated puzzle of predicting glacial-archaeological potential (c.f. Rogers 2014a). This multifaceted problem requires us to look at the subject from a holistic standpoint, taking into account both the geographic (e.g. topography, climate) as well as human aspects (e.g. historical and archaeological evidence) of the terrain. Current research suggests that we can expect continued melting at high-altitudes and –latitudes at the global scale (Zemp *et al.* 2015), thus we can assume that further glacial-archaeological objects will be discovered for years to come.

An interdisciplinary project including historians, archaeologists, and geographers, was undertaken between 2011 and 2014 (with archaeological prospection continuing until 2016) in the Pennine Alps. The objective was to gain a better understanding about the factors influencing glacial-archaeological potential in this region; a mountainous area located between Switzerland and Italy (Figure 1). This article describes the interdisciplinary analysis methods used, and reports on the final results of the project entitled "Modelling the archaeological potential of high-altitude passes and trails in the Pennine Alps using GIS tools" funded by the Swiss National Science Foundation (SNSF). The Pennine Alps are a unique study area due to their rich and extended cultural history dating back to the Mesolithic period and extending to historic times (Curdy 2007, 2015). Thus, the main goal of this project was to protect cultural heritage by identifying prospection-size areas of high glacial-archaeological potential in a study area of about 4,500 km$^2$. This was the first regional-scale, interdisciplinary, glacial-archaeological study in Switzerland. Its success is due greatly to the unique collaboration across disciplines and the combination of methods from the respective domains, which proved to be crucial for the successful implementation of the project.

## Geographical methods

Geographical applications, specifically those related to the use of spatial analysis in Geographic Information Systems (GIS), later referred to as geospatial analysis, have been used in archaeology for decades (Kvamme 1999) and continue to be developed (Forte and Campana 2017). One of the main benefits of using GIS in archaeological research is that it allows data from multiple geographic scales, time scales, and research areas to be visualized, analyzed, and mapped together. Thus, GIS methods have been widely adopted in the field of archaeology, allowing archaeologists to obtain a better understanding about the spatial relationship that humans have with each another and their surrounding environment (Kantner 2008).

In the relatively new field of glacial archaeology, several studies have already integrated GIS into their work (Andrews, MacKay, and Andrew 2012; Dixon, Manley, and Lee 2005; Goossens *et al*. 2007; Reitmaier-Naef and Reitmaier 2016; Rogers, Collet, and Lugon 2014; Rogers and Curdy 2015), and ideas for different analysis types are provided in Rogers (2014b). For this project, several geospatial methods were employed to determine the archaeological potential of the Pennine Alps and are presented below. The main objectives of this part of the project were to:

1. Analyze where people could have travelled based on the slope and landcover of the terrain using Least Cost Path Analysis (LCPA);
2. Determine where archaeological remains might be best preserved based on terrain characteristics using locational analysis;
3. Determine the level of importance of each identified area with respect to its potential for containing glacial archaeological objects based on current and future glacier extents using glaciological modelling.

### *Data collection*

One of the most crucial tasks in any GIS project is the process of obtaining geographic data. This process is substantially more difficult when working across disciplines and international borders. Fortunately, Switzerland has well established geographic, archaeological, and historical datasets which suited the needs of this project (Table 1), so data did not need to be created nor purchased. Collection of these datasets took approximately six months, and ranged from simple downloads from online sources, delivery of data via external hard drive, and contacting authors to obtain their results (e.g. for glacier extents). Some datasets were impossible to obtain, including the equivalent ones for the Italian side of the border, thus global scale, lower-resolu-

Table 1 Geographic data sources used in the project.

| Type | Dataset | Obtained from | Year | Spatial scale | Used for |
|---|---|---|---|---|---|
| Geographical | Digital Elevation Model (DEM) 25m | Swisstopo | 2010 | Switzerland | Least cost path analysis (LCPA) within Switzerland |
| | DEM 30m | NASA ASTER GDEM | 2011 | Global | LCPA between Switzerland and Italy |
| | Glacier extents | Maisch (2000) | 1850 | Switzerland | Glaciological modelling |
| | | Paul *et al.* (2002) | 1973 | | |
| | | Paul *et al.* (2011) | 2003 | | |
| | | Fischer *et al.* (2014) | 2011 | | |
| | Primary Surfaces Landcover 25m | Swisstopo | 2010 | Switzerland | LCPA within Switzerland |
| | Corine Landcover 100m | European Environment Agency | 2006 | Europe | LCPA between Switzerland and Italy |
| | SwissNames | Swisstopo | 2010 | Switzerland | |
| Archaeological | Archaeological finds database | Etat du Valais, Service des Bâtiments, Monuments et Archéologie | 2011 | Valais, Switzerland | Determining the relationship between discoveries and physical conditions in those locations |
| Historical | Inventaire fédéral des voies de communication historiques de la Suisse (IVS – Inventory of Historical Traffic Routes) | Swiss Confederation | 2010 | Switzerland | Supplementary information for archival text analysis |

tion datasets were needed to perform the cross-border analyses.

### *Least-cost path analysis (LCPA)*

LCPA was used to determine travel routes between locations of interest based on the principle that a person wishes to expel the least amount of time or energy to travel from one place to another. This method has been used in various archaeological applications and has proved to be beneficial for obtaining an initial idea about possible travel paths across a terrain (c.f. Verhagen and Jeneson 2012). In the first application of LCPA for this project (Rogers, Collet, and Lugon 2014), least-cost paths (LCPs) were calculated between places of archaeological interest, represented as point locations, on each side of the Pennine Alps. The LCPA model was further investigated by analyzing results from multiple points as well as lines, and the effects of changing input parameters on the resulting LCPs which helped to validate and improve the model (Rogers and Curdy 2015). LCPA was used in a third study from which to calculate LCPs between passes on the border between Switzerland and Italy which were glacierized in 1973, to the nearest respective valleys (Rogers, Fischer, and Huss 2014).

### *Locational analysis*

Locational analysis in archaeology is based on locating areas of high archaeological potential using various input data layers and weighting schemes. It is particularly beneficial for assembling data layers of varying type, geographic scale, and time period into one comprehensive index so that criteria can be evaluated based on their shared or varying characteristics (Kvamme 1999). It has been successfully integrated into glacial-archaeological studies and also in glacial archaeology (Dixon, Manley, and Lee 2005; Andrews, MacKay, and Andrew 2012; Reitmaier-Naef and Reitmaier 2016). In this Pennine Alps project, locational analysis was used in conjunction with

LCPA and glaciological modelling, with results published in Rogers, Fischer and Huss (2014). Criteria based on distances from LCPs, slope of the terrain, and glacial ice thickness were multiplied together to obtain one layer containing all possible value combinations. The values were reclassified into categories based on their respective archaeological potential levels. The resulting archaeological potential model was used in conjunction with results of glaciological modelling to assist in the selection of prospection sites.

### *Glaciological modelling*

Another major objective of this project was to use glaciological modelling to determine what glaciers in this study area could look like in the future, in order to assess the degree of urgency for archeological prospection. In collaboration with glaciologists at the University of Fribourg, Switzerland, glaciers were modelled in 10-year increments from 2010 until 2100. This process integrated a combination of different glaciological models at high spatial resolution. In summary: first, glacier ice thickness was calculated from glacier inventories in Switzerland (Fischer *et al.* 2014) and Italy (Paul, Frey, and Le Bris 2011) using the method developed by Farninotti *et al.* (2012); next, surface mass balance and 3D glacier geometry change were modelled transiently for 50 Swiss glaciers from 2010 to 2100 based on a detailed glacier model (Huss *et al.* 2010); these future extents were calculated based on the A1B $CO_2$-emission scenario (Nakićenović 2000) which estimates a temperature rise of +4.7°C relative to 1980-2009 temperatures; finally the mass balances determined from the 50 glaciers discussed above were extrapolated to all of the glaciers in the Pennine Alps (Huss 2012) resulting in glacier extent information in 10-year increments for each glacier in our study area. These extents were then used in conjunction with results from locational analysis in GIS to predict where archaeological remains could be found in the future based on future glacier geometries and the topography of the terrain.

## Geographical results

Results from individual studies for LCPA, locational analysis and glacial modelling are described in detail in their respective publications and will not be presented again here, however the overall results of geospatial analyses will be summarized. The geographical aspect of the project led to the selection of 31 passes for archaeological prospection and produced a glacial archaeological potential map for archaeologists to use in the coming years. A breakdown of the overall geographic results from the methods described above are summarized in relation to archaeological prospection in the future, were provided in Rogers (2014a). Each pass identified as a potential area of interest using a geospatial method was categorized into one of three groups based on its current or future archaeological potential determined using glacier inventories from 1850 (Maisch 2000), 1973 (Paul, Frey, and Le Bris 2011), and 2010 (Fischer *et al.* 2014):

- Group A: no current or future glacial archaeological potential—pass not glacierized in 1850, 1973, or 2010 (12/31 passes);

- Group B: pass recently deglacierized, current and future glacial archaeological potential—pass glacierized in 1850 and 1973 but not 2010 (5/31 passes);
- Group C: pass currently glacierized, no current potential, possible future potential—pass glacierized in 1850, 1973, and 2010 (14/31 passes).

Perhaps a crude grouping method, from a practical sense, it is logical that any glacial archaeological remnants which have been exposed to the current environment degrade and decompose quickly, leaving a short time window to locate them while they are still intact.

## Historical methods

The main goal of this part of the project was to create an inventory of how often various high-altitude passes in the Pennine Alps were mentioned in historical documents. Numerous studies have examined how the Alps were crossed using major mountain passes such as the Grand St. Bernard (~2,500 masl), often referred to as a "primary pass" (Swiss Confederation 2006). However, smaller passes, often at higher altitudes, have received much less attention from historians. These are often referred "to as secondary passes." These secondary passes were thought to be used to bypass primary ones in times of political and commercial tension, or due to obstructions caused by natural phenomena (avalanches, glaciers, etc.). However, these secondary passes have lacked attention in historical documents with the striking exception of the work of Aerni (e.g. 1963, 1979). Others have referenced, or have conducted intermittent research on, secondary passes (e.g. Röthlisberger 1973; Schneebeli and Röthlisberger 1976). This lack of information about secondary passes in historical documents merited a thorough investigation. Compared to the considerable amount of effort undertaken at the national level to compile information about major routes, the Inventory of Historical Traffic Routes in Switzerland—IVS (Swiss Confederation 2006), lacks considerable information about regional, secondary passes. This directly corresponds to the lack of publications alluding to such secondary passes. Knowing this, it was evident that there was a lack of historical information about secondary passes and merited further investigation for this project. Thus, we hypothesized that we would be able to identify archaeologically-interesting secondary passes based on their proximity to major routes and primary passes, and conducted a thorough archival text analysis to try to prove this.

The historical analysis was conducted in two steps: (1) a thorough investigation of texts published by earlier historians from the end of the eighteenth century to the middle of the twentieth century and, (2) an analysis of the minutes (procès-verbaux) of the former Valaisan Parliament, ranging from the fifteenth century to the *Ancien Régime*, i.e. until the French Revolution. The minutes frequently alluded to the obstruction of various sections of the Swiss/Italian border in times of epidemics, epizootic disease, or war (or rumors of war). Each historic publication had to be critically scrutinized as early historians often had a romanticized view of the events that took place, lacked scientific evidence, or neglected to differentiate between reality and legend (Eschmann Richon 2014).

**Historical results**

Unfortunately, after the critical analysis of historical sources, it was determined that most were unreliable as they were based on unverifiable assumptions. For example, it seemed that the glaciated Col d'Hérens (3,457 masl) was used for numerous journeys between Zermatt and Sion until the seventeenth century. However, there were no written documents supporting this fact, thus discrediting the information. The minutes of the Valaisan Parliament identified geographic areas at the regional scale, but rarely provided precise place-based information. For example, during periods of high tension, the minutes indicated that high-altitude passes between Lombardy (Italy) and the Valais, or between Savoy (Italy and France) and the Valais, were closed. However, specific place names or the high-altitude passes themselves were not mentioned. It is also important to note that before the nineteenth century, the names of certain passes changed over time, which made it difficult to search for pass names in historical documents. Furthermore, the historical research did not allow us to discover previously unknown secondary passes, that is, those frequently visited over history but currently absent from collective memory. For example, the case of the Schnidejoch pass, (2,755 masl) in the Bernese Alps (Hafner 2012). Additionally, this research was not able to furnish any information regarding the passes identified by the geographical methods used in this project. For example, the Col de Cleuson, where artifacts dating back to the Bronze Age were collected after field prospection, was not mentioned in the literature until the nineteenth century, where it then only appeared in tourist guides.

In summary, the main findings from the historical text analysis were: written sources relating to high-altitude secondary passes in the Pennine Alps were often incomplete, scattered, or inconsistent; the number of written testimonies increased during periods of political tension and commercial conflict between the Italian and Valaisian valleys; and the majority of sources consulted attested to local, short-distance travel (long-distance travel did exist, but these particular sources did not report on this type of information). Overall, the consulted sources provided evidence for intra-Alpine connections between the neighboring valleys of the Pennine Alps, however, they did not make it possible to draw conclusions about how often certain passes were visited or during which time periods. In general, the collection and synthesis of these historical documents reiterated what was already known about the investigated passes and did not provide any new information (Eschmann Richon 2014). However, the historical text analysis did enable the identification of frequently used passes, namely the Theodulpass (3,293 masl) from the sixteenth century, Col Collon (3,068 masl) from the fourteenth century, and Antrona pass (2,837 masl) from the thirteenth century (Eschmann Richon 2014). The Theodulpass was mentioned the most frequently and indeed, did play a significant role in commercial exchanges between the Valais and the Aosta Valley; wine was traded by mule train, herds were transported, and individuals also crossed this pass on foot (Providoli, Curdy and Elsig 2016). On the high-altitude passes studied more in detail, the glacial advance which occurred during the Little Ice Age (1300–1850 AD), did not seem to have a lasting effect on the crossing of these passes.

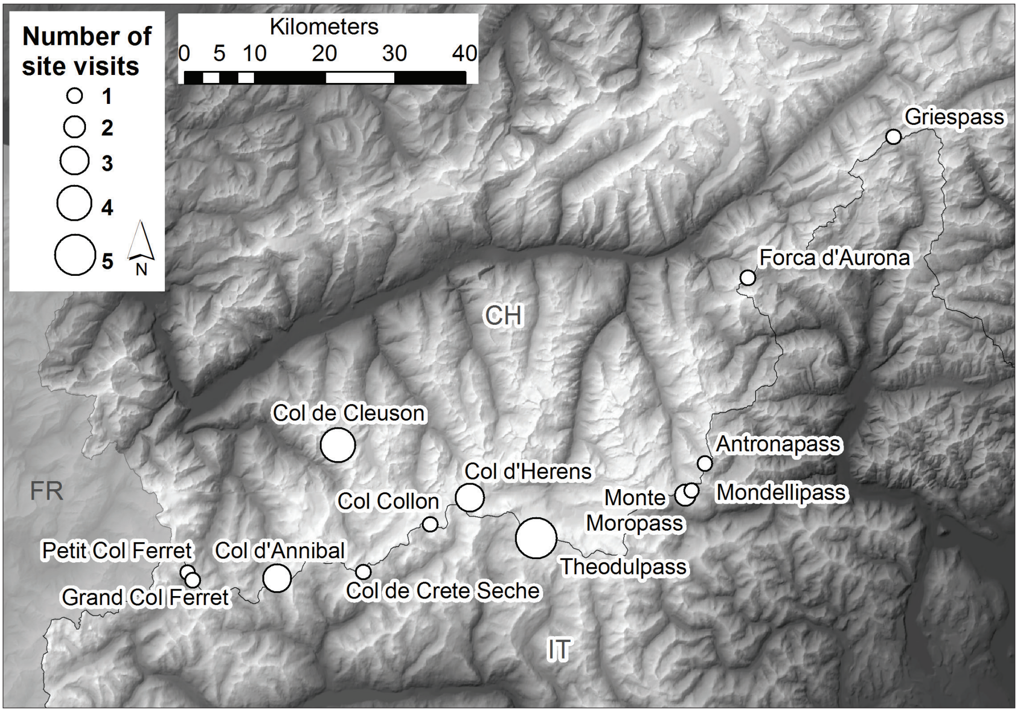


Figure 2 Map of high-altitude passes visited for archaeological prospection. The size of the circle indicates the number of times visited between 2011 and 2016.

## Archaeological methods

In the Alps, optimal glacial archaeological prospection conditions are brief and vary from year to year. The time window usually ranges from a number of days to a couple of weeks in late August or September depending on weather conditions. A layer of fresh snow destroys all hope of locating archaeological remnants, thus, in some cases, prospection can often not be conducted until the following year. The first step of archaeological investigation was to obtain the existing database of sites and locations of findings from previous prospection activities in the Canton of Valais (Table 1). These data were integrated into geospatial modelling and used to complement the results of field surveys. Archaeological field prospection took place in the autumns of 2011, 2012 and 2013 on the passes identified as archaeologically interesting from:

- the results of historical text analyses;
- the results of geospatial analyses;
- those passes not indicated in either of the previous results but based on the location of an ice patch or glacier located close to a LCP (Figure 2).

The applied field method was based on a visual inspection of the surface; a metal detector was used in some instances. Between 2011 and 2013, 12 high-altitude passes were visited over 22 days with 12 different people involved. Supplementary prospections were conducted during the autumns of 2014, 2015 and 2016 on the most promising sites, i.e. Col d'Annibal, Theodulpass or Col de Cleuson, three glaciated passes located above 3,000 masl.

## Archaeological results

Over the duration of the project, more than one hundred pieces of wood were collected on seven high-altitude passes. To date, 37 of these pieces have been dated using radiocarbon analysis (Table 2); five pieces were dated to modern time (later than 1900 AD); 16 were from the period between 1400 and 1900 which corresponds to the Little Ice Age and adds a level of uncertainty of several centuries in the radiocarbon calibration; four pieces were dated to the Middle Age (approx. 500–1400 AD); six pieces were dated to Roman time (approx. 0–500 AD); and finally, six pieces were dated to prehistoric time (earlier than 1 BC). The majority of the ancient wood pieces were non-worked stakes, probably used as route markers and found mainly on the Col d'Annibal. Of note was the presence of a 2,300 year old (Celtic time) sickle handle, in perfect condition, found above the Theodulpass, which is located in the accumulation zone of the Gorner Glacier system (Curdy *et al.* 2016). This significant discovery shows how archaeological objects can be preserved for thousands of years even in harsh mountain environments. In comparison, most wood pieces found at the Col de Cleuson (Bronze Age and Early Middle Ages) were highly distorted due to ice movement and their function could not be interpreted, but a nice iron hook was found with part of the wooden handle conserved (1000–1200 AD). All pieces located at the Theodulpass have been recently published (Providoli, Curdy and Elsig 2016). In addition to the wood pieces, many iron objects have been found, predominantly with the use of a metal detector. Surprisingly, among the numerous fragments collected, very few roman shoe nails were discovered on the paths to and from the main passes, in particular for the Theodulpass where many roman coins had been found at the end of the nineteenth century (Providoli, Curdy and Elsig 2016). The oldest pieces were nails from horse shoes dated between the twelfth to sixteenth centuries.

To validate the reliability of the models used in this project, it was also necessary to visit sites deemed to have a low archaeological potential. A total of nine such sites were visited, from which some positive results were obtained leading us to make the following conclusion about the models: the parameters included in the LCPA did not allow the LCP to make any detours, only a direct line from point A to point B. Due to those parameters, some significant, well-known passes, such as the Col Collon (where prospection led to the collection of wood dated to the Early Iron Age), was neglected.

## Discussion and conclusion

Historical data, and especially those dating before the sixteenth century, rarely permitted us to obtain precise geographic locations for this project, making it impossible to integrate historical data into our GIS database. However, the historical and geospatial information gathered from the methods described above, did lead to significant archaeological results. For example, the glaciated Col Collon, not identified in geospatial analyses, appeared in literature dating back to the fourteenth century.

Table 2 List of radiocarbon dates reflecting the use of passes proposed by LCPA. Some objects could be dated by their typology, in particular the coins (often ancient finds) dated to the Roman Period and some shoe nails (Roman or dated to nineteenth/twentieth centuries) or from horseshoes (after 1400 AD) (From Curdy *et al.* 2016, updated).

| Site | code | object | Wood species | lab code | BP | cal |
|---|---|---|---|---|---|---|
| Forca d'Aurona | AUR12-1 | Wood, stick | picea abies | Poz-86366 | 165±30 | 1662–1990 AD |
| Col Collon | COL13-01.01 | Wood, stick | salix | Poz-62503 | 2425±35 | 751–403 BC |
| Col Collon | COL13-01.02 | Wood, stick | maloideae | Poz-68695 | 2405±30 | 733–400 BC |
| Col Collon | COL13-01.03 | Wood, stick | maloideae | Poz-86365 | 2440±30 | 751–408 BC |
| Gd Désert | GD12-01 | Wood, fragment | corylus avellana± | Poz-52268 | -3346±25 pb | >1957 AD |
| Gd Désert | GD12-02 | Wood, fragment | Fraxinus + corylus avellana, | Poz-52272 | -1770±27 pb | 1957–1987 AD |
| Gd Désert | GD12-04 | Wood, fragment | corylus avellana | Poz-52273 | -3139±23 pb | 1964–1978 AD |
| Gd Désert | GD12-08 | Wood, fragment | corylus avellana | Poz-52274 | -4810±20 pb | 1961–1969 AD |
| Gd Désert/Col Cleuson | GD12-13 | Wood, fragment | corylus avellana | Poz-59851 | 1225±30 | 690–885 AD |
| Gd Désert/Col Cleuson | GD12-15 | Wood, fragment | salix sp. | Poz-52269 | 2795±35 | 1025–842 BC |
| Gd Désert | GD12-16 | Wood, stick | | Poz-52270 | -1897±24 pb | 1957–1985 AD |
| Gd Désert/Col Cleuson | GD14-01 | Wood, hook handle | fraxinus sp. | Poz-68700 | 845±30 | 1058–1261 AD |
| Gd Désert/Col Cleuson | GD14-02 | Wood, stake | salix sp. | Poz-68701 | 870±30 | 1045–1248 AD |
| Col d'Annibal | HANN13-01.01 | Wood, stake | picea abies | Poz-59850 | 1960±30 | 39 BC–120 AD |
| Col d'Annibal | HANN13-02 | Wood, stake | picea abies | Poz-62500 | 2050±30 | 164 BC–18 AD |
| Col d'Annibal | HANN13-04.01 | Wood, stake | picea abies | Poz-62499 | 2020±35 | 152 BC–63 AD |
| Col d'Annibal | HANN14-16 | Wood, stake | picea abies | Poz-68697 | 1965±30 | 42 BC–116 AD |
| Col d'Annibal | HANN14-19 | Wood, stake | picea abies | Poz-68699 | 1990±30 | 48 BC–71 AD |
| Col d'Annibal | HANN14-22 | Wood, fragment | picea abies | Poz-68696 | 2010±30 | 91 BC–65 AD |
| Theodulpass | MV11388 | Wood, small cup | alnus viridis | Poz-52276 | 680±30 | 1270–1389 AD |

| | | | | | | |
|---|---|---|---|---|---|---|
| Theodulpass | MV11647b | Wood, packsaddle | fraxinus | Poz-52277 | 105±30 | 1681–1937 AD |
| Theodulpass | MV11647d | Wood, packsaddle | picea abies | Poz-52278 | 365±30 | 1449–1634 AD |
| Theodulpass | MV12493 | Leather, shoe sole | | Poz-59840 | 280±30 | 1498–1795 AD |
| Theodulpass | TH2010-7 | Bone, mule | | Poz-52279 | 415±30 | 1429–1618 AD |
| Theodulpass | TH2011-7 | Leather, belt | | Poz-52280 | 255±30 | 1521–1949 AD |
| Theodulpass | TH2011Kronig-1 | Wood, handle | acer | Poz-59841 | 2165±30 | 358–113 BC |
| Theodulpass | TH2011Kro-nig-1b | Wood, handle (2$^{nd}$) | acer | Poz-62498 | 2215±30 | 372–201 BC |
| Theodulpass | TH2012Kronig-2 | Wood, walking stick | maloideae | Poz-59842 | 85±30 | 1687–1926 AD |
| Theodulpass | TH2013-12.2 | Wood, barrel hoop | betula | Poz-59843 | 180±30 | 1653–1949 AD |
| Theodulpass | TH2013-13 | Cherry stone | | Poz-59276 | 130±30 | 1675–1941 AD |
| Theodulpass | TH2013-14 | Leather, fragment | | Poz-59845 | 270±70 | 1449–1949 AD |
| Theodulpass | TH2013-16.501 | Horsehair | | Poz-59848 | 100±30 | 1682–1935 AD |
| Theodulpass | TH2013-28 | Wood & leather belt | salix sp. | Poz-59846 | 105±30 | 1681–1937 AD |
| Theodulpass | TH2013-3.1 | Wood, stick | | Poz-59275 | 65±30 | 1691–1921 AD |
| Theodulpass | TH2013-4.2 | Wood, walking stick | picea sp. | Poz-59344 | 90±30 | 1685–1928 AD |
| Theodulpass | TH2013-9.2 | Wood, stick | quercus | Poz-59847 | 165±30 | 1662–1949 AD |
| Theodulpass | TH2013Kronig_2 | Wood, barrel hoop | picea abies | Poz-59345 | 155±30 | 1666–1949 AD |
| Petit Col Ferret | Interreg n0 085 | Wood, stick | | Poz-67887 | 370±30 | 1447–1634 AD |
| Petit Col Ferret | Interreg n0 195 | Wood, knife handle | | Poz-67973 | 830±30 | 1161–1264 AD |

OxCal 2017: H. Cheng, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, H. Haflidason, I. Hajdas, C. Hatté, T. J. Heaton, A. G. Hogg, K. A. Hughen, K. F. Kaiser, B. Kromer, S. W. Manning, M. Niu, R. W. Reimer, D. A. Richards, E. M. Scott, J. R. Southon, C.S.M. Turney and J. van der Plicht.

IntCal13 and MARINE13 radiocarbon age calibration curves 0-50000 years calBP *Radiocarbon* 55(4) 2013: 1869–1887. https://doi.org/10.2458/azu_js_rc.55.16947

pb: Post-bomb atmospheric NH1 curve (Hua and Barbetti 2004)

Sources specified a "Good Neighbor" treaty which indicated a strong relationship between the inhabitants of the Val d'Hérens (Switzerland) and Bionaz on the Italian side of the pass (Eschmann-Richon 2014). During a one-day visit to the site, multiple wood pieces were collected on the pass, which is now almost completely deglaciated. These findings demonstrate the use of this pass dating back to at least the Iron Age (Table 2). Unfortunately, most of the passes identified using geospatial methods could not be found in historic literature. However, the Col de Cleuson, which was previously unknown from an archaeological stand-point, was identified as a pass of interest by geographical methods. Although it could not be historically verified, we discovered wood pieces dating back to the Bronze Age (Table 2), thus, uncovering a new archaeological, and potentially historical, site. The historical and geographical aspects of the project were both integral to the final archaeological outcomes of the project, thus interdisciplinarity was key.

Throughout this project, GIS and the related geospatial analyses were used as a decision-support system for archaeologists. First, the LCPA allowed us to compare all possible routes over the high-altitude passes between Switzerland and Italy across the Pennine Alps. From those results, we could choose the solutions which seemed the most efficient in terms of cost, in this case, time. As with any "out-of-the-box" GIS software packages, the tools and their parameters are often predefined and do not permit fine-tuned alterations. In this regard, users are confined by the functionality of the tool and this often leads to reductionist models, as was the case in using LCPA throughout this project. Although the criteria and parameters in each GIS application were determined by the group of experts from the project, the GIS user only has a certain flexibility when using predefined tools. In the end, the choice of the "correct path" still belongs to the experts, scientists or mountaineers, who ultimately evaluate the credibility of the paths simulated by computer models. To avoid this technical annoyances in the future, open-source GIS software packages, which are becoming increasing available and reliable, can and should be used to fine-tune the exact type of analysis you want to perform.

The archaeological potential maps created from glaciological modelling results were constructed on the basis of quantitative variables and on a choice of detailed weighting criteria in Rogers, Fischer, and Huss (2014). It should also be noted here that the term "potential" does not mean "prediction." It is always possible to discuss the relevance of the variables and the parameters chosen. As in the case of the LCPA, it is the responsibility of experts, here archaeologists, to ultimately decide on the validity of the proposed models. Indeed, spatial analysis produces maps that are not and should not be considered as "the definitive truth." This spatial information is constrained by the choice of weighting criteria, by the precision of the parameters that simulate the physical recession of glaciers, and, of course, by the uncertainties associated with the climate change scenario used in the simulations. These maps therefore remain provisional. They should be considered as a simple decision-support tool for the management of our frozen heritage, awaiting validation on the ground.

Concerning the prehistoric periods indicated by radiocarbon dating of the collected objects: there were very few ancient dates (Bronze and Iron Age) and no dates from the Neolithic, which seems unusual when we think of Ötzi (3,000 BC, Seidler *et al.* 1992) or the Schnidejoch pass, from 4,500 to 2,000 BC (Hafner 2015; Hafner and Schwörer 2017). We believe that these are certainly shortcomings due to limited surveys in the study area, as Neolithic discoveries in high-mountain areas (above 2,000 m) are well documented in the Alps (Curdy 2007, 2015; Hafner 2015). In conclusion, the archaeological data collected during this project has led to significant discoveries which demonstrate the use of certain high-altitude passes since, at least, the Bronze Age. Surprisingly, no Neolithic objects were discovered, even though the most spectacular finds of the Alpine arc are from this period (Hauslabjoch, Schnidejoch, Hafner 2015). In regard to the geospatial models, high-altitude passes deemed as both interesting and uninteresting, furnished significant archaeological objects. This leads us to conclude that these models were a starting point for discussion on archaeological prospection, but it was ultimately up to the archaeologists to decide which sites to visits in the end.

## References


Aerni, K. 1963. "Beobachtung Zum Verlauf der alten Passwege Grimsel, Gries, Albrun, Simplon und Monte Moro." *Geographica Helvetica* 18: 288–289.

———. 1979. "Die Entwicklung des Gemmipasses. Ergebnisse aus Der Erfor- Schung von Gelände und historischen Quellen." *Schweizerische Zeit- Schrift Für Geschichte* 29: 53–83.

Andrews, T. D., G. MacKay, and L. Andrew. 2012. "Archaeological investigations of alpine ice patches in the Selwyn Mountains, Northwest Territories, Canada." *Arctic* 65(5): 1–21. https://doi.org/10.14430/arctic4182

Curdy, P. 2007. "Prehistoric settlement in middle and high altitudes in the Upper Rhone Valley." *Preistoria Alpina 42:* 99–108.

———. 2015. "Prehistoric settlement evolution in the Upper Rhone Valley (Western Swiss Alps): An upgraded vision." *Predicting Prehistory: Predictive Models and Field Research Methods for Detecting Prehistoric Contexts*, edited by G. Pizziolo and L. Sarti, 85–96. Millenni Studi di Archeologica preistorica 11. Firenze: Museo e Istituto Fiorentino di Preistoria "Paolo Graziosi."

Curdy, P., M. Eschmann Richon, R. Lugon and S. Rogers. 2016. "Evaluation du potentiel archéologique sur les cols des Alpes pennines et lépontines (Canton du Valais, Suisse)." *Bulletin d'Etudes préhistoriques et archéologiques alpines* 17: 247–262.

Dixon, E. J., W. F. Manley and C. M. Lee. 2005. "The emerging archaeology of glaciers and ice patches: Examples from Alaska's Wrangell-St. Elias National Park and Preserve." *American Antiquity* 70(1): 129–143. https://doi.org/10.2307/40035272

Dixon, E. J., M. E. Callanan, A. Hafner and P. G. Hare. 2014. "The emergence of glacial archaeology." *Journal of Glacial Archaeology* 1(1): 1–9. https://doi.org/10.1558/jga.v1i1.1

Eschmann Richon, M. 2014. "Cols Secondaires Des Alpes Valaisannes, entre le Col de Cleuson et Le Griespass." *Vallesia* 69: 453–521.

Farinotti, D., S. Usselmann, M. Huss, A. Bauder and M. Funk. 2012. "Runoff Evolution in the Swiss Alps: projections for selected high-alpine catchments based on ENSEMBLES scenarios." *Hydrological Processes* 26(13): 1909–1924. https://doi.org/10.1002/hyp.8276

Fischer, M., M. Huss, C. Barboux and M. Hoelzle. 2014. "The new Swiss Glacier inventory SGI2010: Relevance of using high-resolution source data in areas dominated by very small glaciers." *Arctic, Antarctic, and Alpine Research* 46(4): 933–945. https://doi.org/10.1657/1938-4246-46.4.933

Forte, M. and S. Campana. 2017. *Digital Methods and Remote Sensing in Archaeology: Archaeology in the Age of Sensing.* Berlin: Springer.

Goossens, R., A. De Wulf, J. Bourgeois, W. Gheyle, B. Van Bever, M. Vanommeslaeghe, D. Dossche and D. Devriendt. 2007. "The frozen tombs of the Altai Mountains inventarisation and conservation." In *Proceedings XXI International CIPA Symposium*. Athens, Greece. http://hdl.handle.net/1854/LU-695917.

Hafner, A. 2012. "Archaeological discoveries on Schnidejoch and at other ice sites in the European Alps." *Arctic* 65(5): 189–202. https://doi.org/10.14430/arctic4193

———. 2015. *Schnidejoch und Lötschenpass: Archäologische Forschungen in der Berner Alpen = Schnidejoch et Lötschenpass: Investigations archéologiques dans les Alpes bernoises*. Bern: Archäologischer Dienst des Kantons Bern.

Hafner, A. and C. Schwörer. 2018. "Vertical mobility around the high-alpine Schnidejoch Pass: Indications of Neolithic and Bronze Age pastoralism in the Swiss Alps from paleoecological and archaeological sources." *Quaternary International* 484: 3–18. https://doi.org/10.1016/j.quaint.2016.12.049

Holzhauser, H. 2007. "Holocene glacier fluctuations in the Swiss Alps." In *Environnements et cultures à l'âge du bronze en Europe occidentale*, edited by Hervé Richard, Michel Magny and Claude Mordant, 29–43. Paris: Editions du Comité des travaux historiques et scientifiques.

Huss, M. 2012. "Extrapolating Glacier Mass Balance to the Mountain-Range Scale: The European Alps 1900–2100." *The Cryosphere* 6(4): 713–727. https://doi.org/10.5194/tc-6-713-2012

Huss, M., G. Jouvet, D. Farinotti and A. Bauder. 2010. "Future high-mountain hydrology: A new parameterization of glacier retreat." *Hydrology and Earth System Sciences Discussions* 7(1): 345–387. https://doi.org/10.5194/hessd-7-345-2010

IPCC. 2013. *Climate Change 2013: The Physical Science Basis*. WMO/UNEP, Cambridge University Press. http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.

Kantner, J. 2008. "The archaeology of regions: From discrete analytical toolkit to ubiquitous spatial perspective." *Journal of Archaeological Research* 16(1): 37–81. https://doi.org/10.1007/s10814-007-9017-8

Kvamme, K.L. 1999. "Recent directions and developments in geographical information systems." *Journal of Archaeological Research* 7(2): 153–201. https://doi.org/10.1007/BF02446276

Maisch, M. 2000. *Die Gletscher der Schweizer Alpen: Gletscherhochstand 1850, aktuelle Vergletscherung, Gletscherschwund-Szenarien*. Vdf, Hochschulverlag AG an der ETH.

Nakićenović, N. 2000. *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Nussbaumer, S. U., F. Steinhilber, M. Trachsel, P. Breitenmoser, J. Beer, A. Blass, M. Grosjean, A. Hafner, H. Holzhauser and H. Wanner. 2011. "Alpine climate during the Holocene: A comparison between records of glaciers, lake sediments and solar activity." *Journal of Quaternary Science* 26(7): 703–713. https://doi.org/10.1002/jqs.1495

Paul, F., A. Kaab, M. Maisch, T. Kellenberger and W. Haeberli. 2002. "The New Remote-Sensing-Derived Swiss Glacier Inventory: I. Methods." In *Annals of Glaciology 34*, edited by J. G. Winther and R. Solberg, 355–361. Cambridge: International Glaciological Society. https://doi.org/10.3189/172756402781817473

Paul, F., H. Frey and R. Le Bris. 2011. "A new glacier inventory for the European Alps from Landsat TM Scenes of 2003: Challenges and results." *Annals of Glaciology* 52(59): 144–152.

Providoli, S., P. Curdy and P. Elsig, eds. 2016. *400 Jahre Im Gletschereis*. Sion: Kantonsmuseen Wallis.

Reckin, R. 2013. "Ice patch archaeology in global perspective: Archaeological discoveries from Alpine ice patches worldwide and their relationship with paleoclimates." *Journal of World Prehistory* 26(4): 323–385. https://doi.org/10.1007/s10963-013-9068-3

Reitmaier-Naef, L. and T. Reitmaier. 2016. "cOld Ice: A survey and monitoring programme of high-alpine cultural heritage in the Central Alps, Switzerland." *Journal of Glacial Archaeology ISSN (Print)* 2050: 3407.

Rogers, S. R. 2014a. "Geospatial modelling of the glacial archaeological potential of the Pennine Alps." Université de Fribourg. http://doc.rero.ch/record/260823?ln=fr.

———. 2014b. "An overview of selected GIS Methods available for use in glacial archaeology." *Journal of Glacial Archaeology* 1(1): 99–115. https://doi.org/10.1558/jga.v1i1.99

Rogers, S. R., C. Collet and R. Lugon. 2014. "Least cost path analysis for predicting glacial archaeological site potential in central Europe." In *Across Time and Space: Selected Papers from the 41st Computer Applications and Quantitative Methods in Archaeology Conference*, Perth 23–25 March 2013, edited by Arianna Traviglia, 261–275. Amsterdam: Amsterdam University Press.

Rogers, S. R. and P. Curdy. 2015. "Least cost path analysis for predicting glacial archaeological site potential: Scale and parameter investigations." *Predicting Prehistory: Predictive Models and Field Research Methods for Detecting Prehistoric Contexts*, 49–64. Millenni Studi di Archeologica preistorica 11. Firenze: Museo e Istituto Fiorentino di Preistoria "Paolo Graziosi."

Rogers, S. R., M. Fischer and M. Huss. 2014. "Combining glaciological and archaeological methods for gauging glacial archaeological potential." *Journal of Archaeological Science* 52 (December): 410–420. https://doi.org/10.1016/j.jas.2014.09.010

Röthlisberger, F. 1973. "Blümlisalpsagen und Gletscherpässe im Raume Zer- Matt - Ferpècle - Arolla: Ein Beitrag zu Klimaschwankungen im Postglazial mit einem Anhang über Holzfunde aus Gletschern." Unpublished PhD thesis, Zürich Georaphisches Institut.

Schneebeli, W. and F. Röthlisberger. 1976. "8000 Jahre Walliser Gletschergeschichte: Ein Beitrag Zur Erforschung Des Klimaverlaufs in Der Nacheiszeit," 59–152. Luzern: Verlag Schweizer Alpen-Club.

Seidler, H, W. Bernhard, M. Teschler-Nicola, W. Platzer, D. zur Nedden, R. Henn, A. Oberhauser and T. Sjøvold. 1992. "Some anthropological aspects of the prehistoric Tyrolean Ice Man." *Science* 258 (5081): 455–457. https://doi.org/10.1126/science.1411539

Swiss Confederation. 2006. "Inventaire des voies de communication historiques de la Suisse IVS." http://www.ivs.admin.ch/index.php?id=128&L=3.

Verhagen, P. and K. Jeneson. 2012. "A Roman puzzle: Trying to find the Via Belgica with GIS." In *Thinking Beyond the Tool: Archaeological Computing and the Interpretive Process*, edited by A. Chrysanthi, P. Murrieta-Flores and C. Papadopoulus. Oxford: Archaeopress.

Zemp, Michael, Holger Frey, Isabelle Gärtner-Roer, Samuel U. Nussbaumer, Martin Hoelzle, Frank Paul, Wilfried Haeberli, *et al.* 2015. "Historically Unprecedented Global Glacier Decline in the Early 21st Century." *Journal of Glaciology* 61(228): 745–762. http://doi.org/10.3189/2015JoG15J017