Least Cost Path Analysis for Predicting Glacial Archaeological Site Potential in Central Europe

Stephanie R. Rogers, Claude Collet
University of Fribourg, Switzerland

Ralph Lugon
University of Applied Sciences, Switzerland

Abstract:
Recent changes in climate have led to an increased exposure of glacial archaeological artefacts due to the melting of glaciers and ice patches. Here we calculated Least Cost Paths (LCPs) between archaeologically significant locations in Switzerland and Italy using a Least Cost Path Analysis (LCPA) method in which cost rasters were first calibrated at a study site near Haut-Val de Réchy, Switzerland to develop a prehistoric cost raster. Tools were used to calculate the LCPs based on DEM-derived slope using Tobler's anisotropic hiking function and landcover. Our results have since provided a focus for prehistoric glacial archaeological prospection in the Pennine Alps of central Europe, as well as led to the discovery of an artefact from the Bronze Age (~2,800 years BP). This methodology could be used as an example for identifying additional sites of prehistoric glacial archaeological remains around the world.

Keywords:
Glacial Archaeology, GIS, Least Cost Path Analysis

1. Introduction

The current warming period is leading to a rise in the exposure of archaeological artefacts due to increased melting in the cryosphere (Dixon, Manley, and Lee 2005; Molyneaux and Reay 2010). As a result, prehistoric and historic archaeological remains have been discovered near the margins of melting glaciers, ice patches, and permafrost in various places around the world (Krajick 2002). The frozen setting in which these artefacts have been found provides a unique preservation environment that withstands decomposition and allows organic biological and cultural materials to remain intact, enabling the collection and scientific analysis of rare and irreplaceable objects (Andrews and MacKay 2012; Molyneaux and Reay 2010). For example, one of the most complete prehistoric finds, Ötzi the Tyrolean Iceman, was found protruding from a high-altitude ice patch near the border of Austria and Italy in 1991 (Prinoth-Fornwagner and Niklaus 1994; Seidler et al. 1992). Because the corpse was so well-preserved for the last ~5,300 years, the study of this specimen has provided unique information about the place of origin, ancestry, genetics, diet, and diseases that inflicted prehistoric people from this region (Janko, Stark and Zink 2012; Keller et al. 2012; Shouse 2001). The accidental discovery of Ötzi led to the stark realisation that similar finds could be expected as temperatures continue to rise. As a result, archaeologists in North America (Andrews et al. 2012; Andrews and MacKay 2012; Dixon, Manley and Lee 2005; Farnell et al. 2004; Hare et al. 2004; Lee 2012; VanderHoek, Tedor and McMahan 2007), Asia (Goossens et al. 2007), and Europe, specifically Norway (Callanan 2012; Farbregd 1972;) and Switzerland (Hafner 2012; Swiss National Science Foundation 2014) have increased efforts to investigate high altitudes with the aspirations of intercepting materials which have been, or will soon be, exposed in order to protect and conserve cultural heritage before it decomposes or becomes destroyed by the current environment or anthropogenic causes. Some interesting finds include prehistoric hunting materials in Alaska and northern Canada (c.f. Dixon, Manley and Lee 2005; Hare et al. 2012; VanderHoek, Tedor and McMahan 2007;) and a 6,000 year record of archaeological remains from an ice patch in the Bernese Alps in Switzerland (Hafner 2012), which attests to the use of high mountain passes by humans in the Swiss Alps for thousands of years.

The Pennine Alps (sometimes referred to as the Valais Alps) located along the Swiss-Italian

---

Corresponding author: stephrogers5@gmail.com border, are an area of glacial archaeological interest due to their topographic location, rich cultural past, and prominent glaciated territory. The Pennine Alps are characterised by their high peaks; the highest being the Dufour peak (4,634 m above sea level) and the most well-known, the Matterhorn (4,478 m asl). High mountain passes connect Switzerland's canton of Valais to northern Italy's provinces of Aosta and Piedmont. Archaeological finds have demonstrated that mountain passes between Switzerland and Italy have been used as trade and travel routes for thousands of years (Coolidge 1912; Curdy 2007; Harriss 1970; 1971), with the earliest indication of human usage originating from the Mesolithic period (Curdy, Leuzinger-Piccand and Leuzinger 2003). Numerous written documents from medieval times attest to the existence of close ties between the Swiss and Italian sides of the Pennine Alps through small alpine passes. For example the exchange of wine and sheep between the Aosta and Zermatt valleys was important for the commercial development in those areas (Ammann 1992). However, navigating through mountainous terrain is often a difficult task, especially when travelling with goods for trade or commerce, or a large number of people for migration. For this reason, many archaeologists have assumed that these remote, high altitude regions were marginal and not used excessively by humans (Walsh, Richer, and de Beaulieu 2006). Due to recent accidental finds in high altitude locations around the world, there is increased interest in the archaeology of glaciated and frozen regions, especially in the Pennine Alps, whose geographical and cultural attributes make them a region of great archaeological interest.

In the Pennine Alps, numerous glaciated mountain passes exist which allow the passage between Switzerland and Italy. However, the vast glaciated surface area and high altitudes pose problems for archaeological investigation. Due to the size of the study area and the inaccessibility of some passes, it is impossible to visit all of the potential sites of interest due to time and cost constraints. Therefore, Least Cost Path Analysis (LCPA), a Geographic Information Systems (GIS) method, was used to aid in glacial archaeological investigations by narrowing down potential site locations based on the principle that people want to take the least physically demanding route possible to get from one location to another. LCPA is one of a variety of predictive methodologies developed in GIS that has been adapted for archaeological investigations and has been increasingly applied in research along with the expansion and ease of access to GIS data, tools and software (Anderson and Gillam 2000; Bell and Lock 2000; Egeland, Nicholson and Gasparian 2010; Gaffney and Stančič 1991; Gorenflo and Gale 1990; Herzog and Posluschny 2011; Howey 2007; Kondo and Seino 2011; Madry and Rakos 1996; Verhagen and Jeneson 2012). It has been used to link together archaeological site locations (Bell, Wilson and Wickham 2002; Gorenflo and Gale 1990; Tripcevich 2008), to track prehistoric migration patterns (Egeland, Nicholson, and Gasparian 2010; Krist and Brown 1994), and also as a first step in research to predict potential travel routes (c.f. Anderson and Gillam 2000; Verhagen and Jeneson 2012). Here, we followed the latter approach and used LCPA as a decision support tool and a stepping stone for further archaeological investigation in remote high altitude regions of the Pennine Alps.

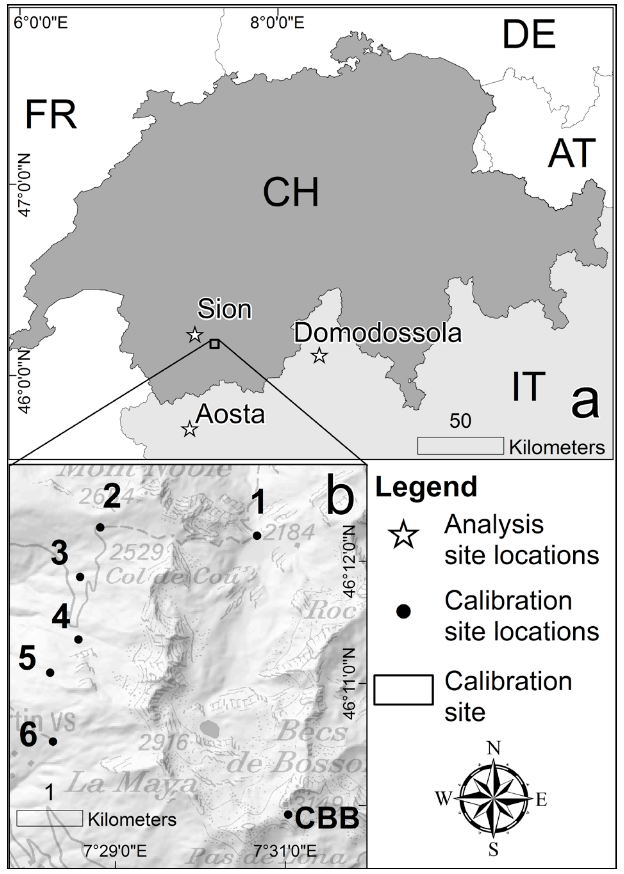

***Figure 1**. Overview of study areas.*

Using LCPAs, we attempted to predict which high mountain passes were most-likely travelled in prehistoric times based on topographic properties and landcover characteristics. Our main objective was to aid in understanding the effects of the slope of the terrain and differing landcover types on travel routes through mountainous terrain using a calibration site and later applying those results to two analysis sites in order to aid archaeologists in high altitude investigations. By first implementing a series of LCPAs on a calibration site in the Haut-Val de Réchy (HVR), Switzerland, a prehistoric cost raster weighting scheme was established and later applied to two analysis sites between Sion, Switzerland and both Aosta and Domodossola, Italy (Fig. 1). The region around Sion has an archaeological record dating back to the Mesolithic (Curdy 2007) while northern Italy has a record dating back to the Epipaleolithic, although the Ossola and Aosta Valleys have provided few artefacts (Crotti, Pignat, and Rachoud-Schneider 2002; Di Maio 2007). From these archaeologically significant locations, we determined potential travel routes between sites and discovered a previously unstudied mountain pass from which an archaeological artefact was retrieved, thus showing the possibility to use LCPA as a first step in glacial archaeological investigations by narrowing down potential travel routes across mountainous terrain in order to ultimately find, protect, and conserve archaeological remains.

2. Methods

In ArcGIS 10.1, the process of creating Least Cost Paths (LCPs) requires two steps: 1) the creation of the accumulative cost distance raster (ACDR) using the Path Distance tool and 2) the calculation of the LCP with the aforementioned ACDR as an input into the Cost Path tool. The ACDR defines the cost value for each cell in the raster initiating from the point of interest. The cost grows as the distance from the source location increases, thus each cell in the resulting ACDR represents the cost of travel back to the source location (ESRI 2013; Whitley and Hicks 2003). Along with the surface distance, landcover and slope were also included in the Path Distance calculation in order to account for the impeding costs of differing landcovers and slope values when traversing terrains. Landcover can be modelled isotropically as the direction of travel does not affect the cost of crossing a certain landcover type (van Leusen 1999; Wheatley and Gillings 2002). However, when incorporating slope into travel calculations, anisotropic modelling should be implemented to account for the changes in cost incurred when travelling up, down, or perpendicular to the slope (Bell and Lock 2000; Eastman 2003; van Leusen 2002). For this reason, Tobler's hiking function for undulating terrain (Tobler 1993), which was elaborated from Imhof (1968), was used to calculate walking times based on DEM-derived slope value calculations. Tobler's original equation:

$$v = 6 \exp(-3.5 * \mathrm{abs}(s + 0.05)), \quad \text{where:}$$

v, the walking velocity in km/h

s, the dh/dx = slope = tan (theta)

calculates walking on flat terrain at approximately 5 km/h. The walking speed is greatest when travelling downslope at a slight decline, with speeds progressively declining as slopes decrease and increase (Gorenflo and Gale 1990). To facilitate the integration of the algorithm into the Path Distance tool in ArcGIS, the reciprocal of the equation was used as suggested by Tripcevich (2008; 2009) in order to directly calculate walking times:

$$\mathrm{Time\ (hrs)/m} = 0.000166666 * (\exp(3.5 * \mathrm{abs}(s + 0.05)))$$

Thus the time in hours/m was calculated as the vertical factor for each slope value and multiplied by the surface distance and isotropic friction values to obtain the ACDRs. The Cost Path tool was then used to calculate the LCPs from the ACDRs and the cost backlink rasters. The backlink raster, which is also an output of the Path Distance tool, defines the neighbouring raster cell which is the next on the least accumulative cost path back to the source, while also accounting for the surface distance and the vertical factor (ESRI 2013).

2.1 Calibration site

The Haut-Val de Réchy (HVR), Switzerland was used as the calibration site for this study and is located at the southern end of the Val de Réchy (46° 11' N, 7° 30' E – World Geodetic System 1984 (WGS84)) (Fig. 1b). This relatively small (~40 km²) calibration site was used as a control site to create a prehistoric cost raster which was later integrated into the LCPA between the larger study area (~4,500 km^2) between Switzerland and Italy. This calibration site was chosen based on its topographic features, including various mountain passes, its altitude range (~1,000 m), its differing landcovers, its geomorphologic familiarity (Gardaz 1998; Lugon and Delaloye 2001; Tenthorey 1993), and its accessibility for future ground-truthing purposes. The HVR is distinguished by its flat bottomed U-shaped valley and steep surrounding ridge formed by glacial activity (Tenthorey 1993). Six starting locations were strategically chosen from which walking times to and from the Cabin de Becs de Bosson (CBB) were calculated (Fig. 1b). The CBB is located at an elevation of 2,988 m asl on the southern side of the ridge that surrounds the HVR, and is adjacent to the Becs de Bosson mountain (3,129 m asl). The starting locations for the LCPs were selected based on their geographic locations (i.e. near mountain passes or swamps) to investigate how different landcovers and slopes affected the corresponding LCPs. Five of the six starting locations were situated on the western side of the ridge to test the effects of varying topography on paths, while one starting location (number 1, Fig. 1b) was situated to the north of the valley directly behind a swamp to test the effects of varying landcover characteristics.

For the calibration site, the inputs to the Path Distance tool included the following (Table 1): point locations for each site, four reclassified landcover layers, the 25 m DEM from Swisstopo, and Tobler's value table. The original landcover layer was the Swisstopo Vector25 Primary Surfaces shapefile (Federal Office of Topography 2014) which, in this specific study region, had 12 different landcover classes of which some could be amalgamated for the purposes of this analysis (e.g. the four differing types of scree were grouped into the same category). Subsequently, four different weighting schemes were used to represent four different scenarios: current landcover, prehistoric landcover (with two different weighting schemes), and the topographic landcover (Table 2). Weights were established and assigned after a consensus between the authors and other research group members was reached regarding the ease or difficulty to traverse respective landcover classes. For example, for the current landcover raster, the "Other" category, which incorporates open spaces and grassy areas, was assumed to be the easiest to traverse and was therefore assigned a weight of 1. The "Forest, Bushes" category was decided to be three times more difficult to traverse and was therefore assigned a weight of 3. The "Scree" category was given a weight of 4 as it was deemed more difficult to cross than forest, although less difficult to cross than "Residential/Rock", which was given a weight of 5. The "Swamp" category was given a weight of 10 as it was assumed that people would avoid these, however they were not deemed impossible to cross. The "Water" category was given a weight of 999 assuming that people would not be willing to swim across a water body, but instead go around it. For both prehistoric landcover weighting schemes a treeline of 2,000 m was assumed (Colombaroli et al. 2010), therefore everything below that level was covered with trees. The first prehistoric landcover weighting scheme was similar to the current landcover, except that the treeline was a determining factor for forest cover. The "Other" and "Forest, Bush" categories were given values of 3 or 4 depending on whether they were located above or below the treeline, respectively. The weights of the remaining categories stayed the same as the current landcover weighting scheme. After some preliminary testing, it was decided that travel times were highly exaggerated when these weights were applied so a second prehistoric landcover weighting scheme was created which divided each weight in half. The final weighting scheme, representing the topographic landcover, was used to test the effects of the slope of the terrain on LCPs. Thus, each class was given a weight of 1, except "Water" which remained at 999. The respective landcover layers were used as the cost raster input to the Path Distance tool to model isotropic friction across the surface. The resulting LCPs were analysed and visually compared with current hiking trails on the 1:25,000 topographic map and their respective travel times. The control travel times were calculated using the Switzerland Mobility Wanderland website (Suisse Rando 2013a) which computes walking times based on the calculation used by the Swiss Hiking trail network, Suisse Rando (Suisse Rando 2013b). Suisse Rando calculates path travel times based on the horizontal distance, height difference, and slope between start and end locations (Suisse Rando 2013b). Henceforth, these paths will be referred to as the Wanderland Paths (WPs).

Input to Path Distance tool	Function	Layers used: calibration site	Layers used: analysis sites
Feature source data	Start point; cost distance raster will be created based on this point	Sites 1 to 6, Cabin de Becs de Bosson (CBB)	Sion, Aosta, Domodossola
Input cost raster (Isotropic friction layer)	Landcover raster which denotes the weight of each landcover type	Swisstopo's Vector 25 m Primary Surfaces layer reclassified as: Current LC, Prehistoric LC (first and second weightings), Topographic LC (see Table 2 for reclassification schemes)	Corine 2006 100 m landcover layer reclassified (Table 3) using the Prehistoric LC second weighting scheme and resampled to 25 m
Input surface raster	The raster from which the true distance is calculated	25 m DEM from Swisstopo	30 m ASTER DEM resampled to 25 m
Input vertical raster	The layer used to calculate the slope. The slope value is then multiplied by the vertical factor	25 m DEM from Swisstopo	30 m ASTER DEM resampled to 25 m
Vertical factor (Anisotropic friction table)	The input table which defines the walking speeds required to traverse each degree of slope	Values calculated from Tobler's walking function in table format	Values calculated from Tobler's hiking function in table format

***Table 1**. Inputs into the Path Distance tool.*

Original LC class	Current LC	Weight	Prehistoric LC		Weight 1	Weight 2	Topo LC	Weight
Other	Other	1	Other, Forest	Above 2000 m	3	1.5	Other	1
			Other, Forest, Bush, Residential, All Scree	Below 2000 m	4	2		
Forest	Forest, Bushes	3	Other, Forest	Above 2000 m	3	1.5		1
			Other, Forest, Bush, Residential, All Scree	Below 2000 m	4	2		
Sparse forest		3	Other, Forest	Above 2000 m	3	1.5		1
Bush		3	Other, Forest, Bush, Residential, All Scree	Below 2000 m	4	2		1
Scree	Scree	4	Other, Forest, Bush, Residential, All Scree		4	2		1
Scree in forest		4			4	2		1
Scree with bushes		4			4	2		1
Scree in sparse forest		4			4	2		1
Residential Zone	Residential, Rock	5	Other, Forest, Bush, Residential, All Scree		4	2		1
Rock		5	Rock		5	2.5		1
Swamp	Swamp	10	Swamp		10	5		1
Lake	Water	999	Water		999	499.5	Water	999
Resulting path name	Current LC Path (CLP)		Prehistoric LC Path (PLP)*				Topographic LC Path (TLP)	

***Table 2**. Calibration site reclassification table.*

Original CORINE Landcover class	Reclassification categories	Prehistoric LC 2nd weight
Pastures (above 2000 m)	Open space above 2000 m	1.5
Coniferous forest (above 2000 m)		1.5
Natural grasslands (above 2000 m)		1.5
Moors and heathland (above 2000 m)		1.5
Sparsely vegetated areas (above 2000 m)		1.5
Glaciers and perpetual snow		1.5
Continuous urban fabric	Everything below 2000 m	2
Discontinuous urban fabric		2
Industrial or commercial units		2
Road and rail networks and associated land		2
Port areas		2
Airports		2
Mineral extraction sites		2
Construction sites		2
Green urban areas		2
Sport and leisure facilities		2
Non-irrigated arable land		2
Rice fields		2
Vineyards		2
Fruit trees and berry plantations		2
Pastures (below 2000 m)		2
Complex cultivation patterns		2
Land principally occupied by agriculture		2
Broad-leaved forest		2
Coniferous forest (below 2000 m)		2
Mixed forest (below 2000 m)		2
Natural grasslands (below 2000 m)		2
Moors and heathland (below 2000 m)		2
Transitional woodland-shrub		2
Beaches, dunes, sands		2
Sparsely vegetated areas (below 2000 m)		2
Burnt areas		2
Bare rocks	Rock	2.5
Inland marshes	Swamp, watercourse	5
Peat bogs		5
Water courses		5
Water bodies	Water body	499.5

***Table 3**. Analysis site reclassification table.*

2.2 Analysis sites

Based on the results from the calibration site (section 3.1), the second weighting of the prehistoric landcover cost raster was used as the isotropic input to calculate the LCPs between the analysis sites. The inputs to the Path Distance tool varied slightly due to the lack of availability of data layers for this cross-border study. The landcover layer and DEM were downloaded from free sources online; the 2006 version of the Coordination of Information on the Environment (European Environment Agency 2012) 100 m resolution landcover layer (European Environment Agency 2012) and the research grade Advanced Spaceborne Thermal Emission Radiometer Global DEM (ASTER GDEM V2) (NASA Jet Propulsion Laboratory 2004) of 30 m resolution, respectively. Each layer was resampled to 25 m for analysis. The landcover layer was reclassified into five categories and weighted based on the results from the calibration site: open space above 2,000 m (assuming a treeline of 2,000 m), everything below 2,000 m (except rock, swamp, and water), rock, swamp/watercourse, and water body (Table 3).

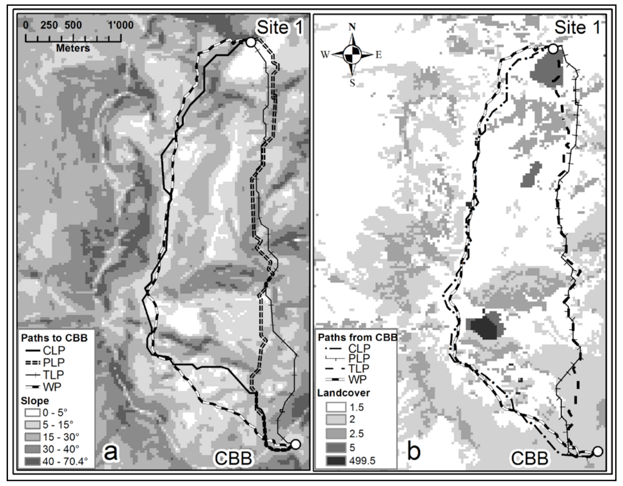

***Figure 2**. Results of LCPA for Site 1 at calibration site.*

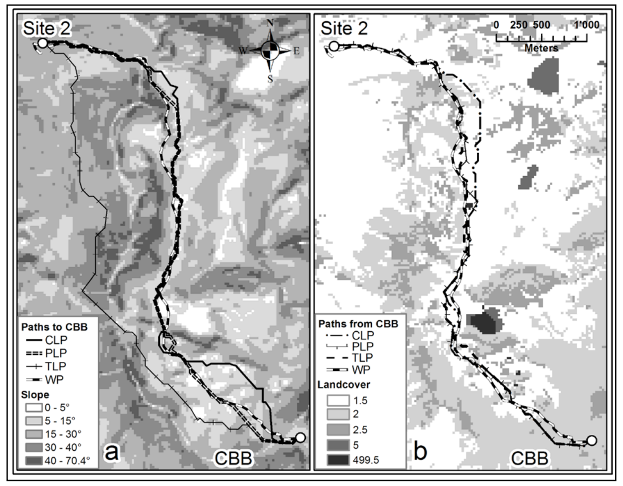

***Figure 3**. Results of LCPA for Site 2 at calibration site.*

Sion/Domodossola

The first analysis site was located between Sion (46º 14‘ N, 7º 22‘ E, 500 m asl), situated in the canton of Valais in the southwest corner of Switzerland, and Domodossola (46º 07‘ N, 8º 17‘ E, 272 m asl), located in the northwest of the province of Piedmont, Italy (Fig. 1a). The straight line distance between these two locations is approximately 74 km.

Sion/Aosta

The second analysis site was between Sion and Aosta (45º 44‘ N, 7º 19‘ E, 583 m asl), which is the name of the town, but also the province, in the northwestern part of Italy (Fig. 1a). The straight-line distance between the two locations is approximately 55 km.

Archaeological prospection

After the LCPs for the analysis sites were analysed and discussed with archaeologists and historians familiar with the area, various passes were selected for archaeological prospection. From the Sion/Domodossola LCP, archaeological prospection was undertaken at the Forca d'Aurona on September 20th, 2012. From the Sion/Aosta site, the region surrounding the Col de Cleuson and the Grand Désert glacier were investigated on July 30th, 2012 from the north side of the Col de Cleuson and September 11th, 2012 from the south side. A handheld Garmin GPS receiver was used to mark the location of finds.

3. Results

3.1 Calibration site

At each site, paths created using the topographic landcover raster resulted in the shortest walking times. At Site 1 (Fig. 2), the topographic landcover path (TLP) was the only path which went through the swamp located directly south of the starting location (Fig. 2b). At Site 2 (Fig. 3), all paths followed similar routes by travelling along the valley bottom, except the TLP stayed outside of the valley until the Pas de Lovégno, avoiding the multiple slope changes (Fig. 3a). The majority of the other paths followed the lowest landcover weightings (Fig. 3b) while the TLP was unaffected by those values. Consequently, in comparison to the times calculated by the Wanderland Paths (WPs), the

				CLP		PLP (1st)		PLP (2nd)	
Site	**Lat**	**Lon**	**Alt(m)**	**Away**	**Return**	**Away**	**Return**	**Away**	**Return**
1	46° 12‘12" N	7° 30‘40" E	2,184	03:06:40	02:13:06	06:27:00	04:38:36	03:13:30	02:19:18
2	46° 12‘17" N	7° 28‘49" E	2,326	03:12:21	02:26:56	06:39:29	05:14:49	03:19:44	02:37:24
3	46° 11‘52" N	7° 28‘35" E	2,126	03:27:33	02:33:32	07:08:15	05:17:09	03:34:08	02:38:34
4	46° 11‘22" N	7° 28‘34" E	2,190	03:12:35	02:21:46	06:29:32	04:48:59	03:14:46	02:24:30
5	46° 11‘5" N	7° 28‘14" E	2,240	03:02:40	02:16:06	06:05:50	04:32:46	03:02:55	02:16:22
6	46° 10‘31" N	7° 28‘16" E	2,171	02:52:11	02:12:46	05:56:32	04:17:20	02:58:23	02:08:40

				TLP		WP	
Site	**Lat**	**Lon**	**Alt(m)**	**Away**	**Return**	**Away**	**Return**
1	46° 12‘12" N	7° 30‘40" E	2,184	01:54:11	01:19:58	02:38:00	01:47:00
2	46° 12‘17" N	7° 28‘49" E	2,326	02:02:16	01:36:11	02:41:00	01:54:00
3	46° 11‘52" N	7° 28‘35" E	2,126	02:08:56	01:34:38	02:48:00	01:53:00
4	46° 11‘22" N	7° 28‘34" E	2,190	01:56:53	01:25:48	03:10:00	02:16:00
5	46° 11‘5" N	7° 28‘14" E	2,240	01:49:42	01:20:50	02:40:00	01:52:00
6	46° 10‘31" N	7° 28‘16" E	2,171	01:49:14	01:18:44	02:28:00	01:34:00

***Table 4**. Calibration site calculated walking times.*

TLPs underestimated the walking times required.

The paths created using the current landcover cost raster (CLPs) took into account the reclassified landcover types both above and below the treeline. At the majority of sites, the CLPs followed a similar path as the WPs (Fig. 2 and Fig. 3). In general, CLP walking times were on average about 20 minutes more than the walking times calculated by the WPs (Table 4), therefore slightly overestimating the walking times required.

The paths created using the Prehistoric landcover cost raster were identical for both the first and second weighting schemes. Visually, the prehistoric landcover paths (PLPs) were similar to the majority of other calculated paths. In terms of time, the first weighting for the prehistoric landcover produced very long walking times, often three times longer than the rest. The paths created using the second weighting scheme better estimated the walking times compared to the WPs but still slightly overestimated walking times by about 30 minutes on average.

Based on these results, paths created with the prehistoric landcover cost raster using the second weighting scheme were most similar to both the hiking trails on the 1:25,000 topographic map and the walking times calculated by Suisse Rando. Therefore, the prehistoric landcover cost raster with the second weighting scheme was used as the input to the Path Distance tool for the analysis site between Sion and Aosta.

3.2 Analysis sites

Sion/Domodossola

From Sion to Domodossola (Fig. 4), the LCP travelled firstly through the Rhône valley in a northeast direction and continued through the valley on low-weighted landcover values (Fig. 4b) and flat terrain (Fig. 4c) for approximately 50 km before reaching the town of Brig. From Brig, the path ascended to the Forca d'Aurona (2,686 m asl) which is a currently unglaciated mountain pass south of the Punta d'Aurona (2,985 m asl). From the pass, the LCP descended into Italy in a southeast direction toward Varzo and then continued following the Val Divedro until reaching Domodossola in 48:54:39. The return path from Domodossola to Sion was visually similar but was calculated to take 48:34:00 in total.

Sion/Aosta

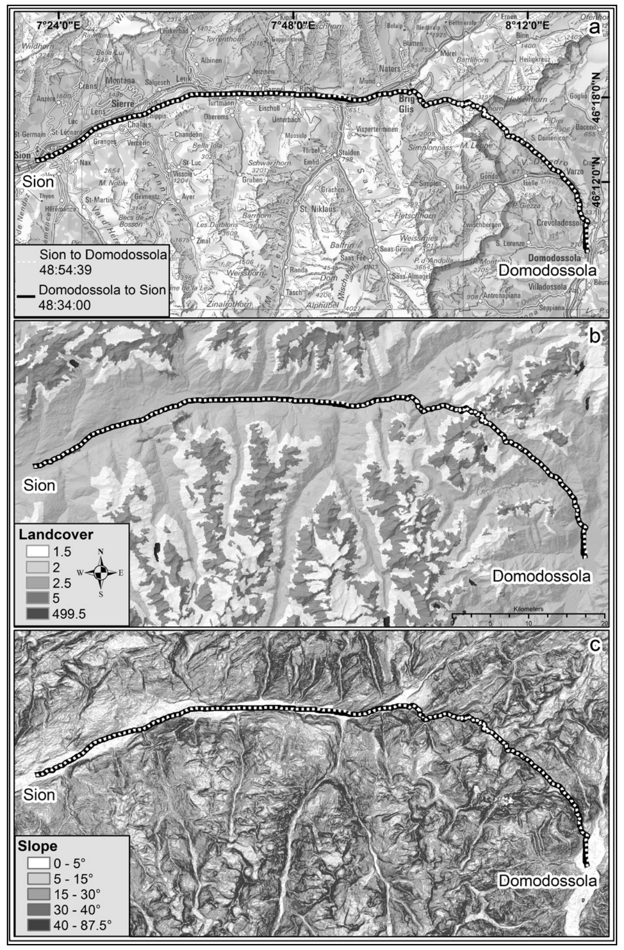

***Figure 4**. Results of LCPA for first analysis site between Sion and Domodossola.*

The LCPs from Sion to Aosta and Aosta to Sion also followed similar routes in both directions. From Sion, the LCP moved in a southerly direction through the Val de Nendaz, continuing on flat terrain below 2,000 m asl, depicted by the landcover value change, until it made an ascent to the west of the Rosablanche mountain (3,336 m asl) (Fig. 5a). To cross this mountain pass, the LCP passed over the Grand Désert glacier and through the Col de Cleuson (3,018 m asl) (Figs. 5 and 6). After passing the col, the path descended into the Val de Bagnes and continued on a southeast route perpendicular to the slope, across an area of low landcover values, past the Lac de Mauvoisin (Fig. 5b, c). After the lake, the path remained along the flat slopes and lowly-weighted landcover values until turning southwest near the Grand Charmotane and began the ascent to the Fenêtre de Durand (2,805 m asl) along the northwest side of the Glacier de Fenêtre. After crossing the Fenêtre de Durand mountain pass, the LCP descended into Italy's Valle d'Aosta in a southwest direction. The path moved southwest around an area of steep slopes before heading directly south, continuing on the low slopes and low-valued landcover regions, until reaching Aosta. The journey in the southern direction took a total of 39:56:08. The path from Aosta to Sion differed only significantly in a few places, namely just south of the Col de Cleuson (Fig. 5) and near the Grand Charmotane. The path from Aosta to Sion took a total of 39:56:40.

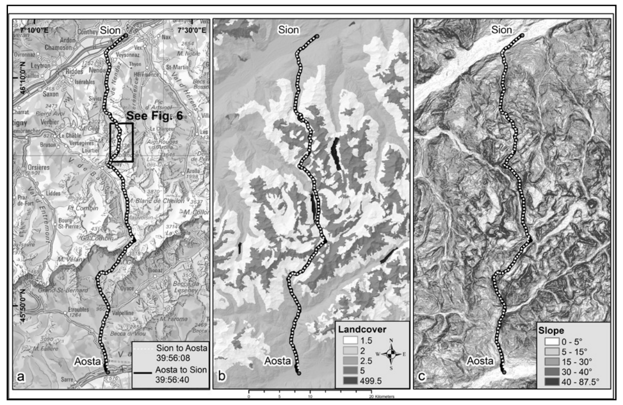

***Figure 5**. Results of LCPA for first analysis site between Sion and Aosta.*

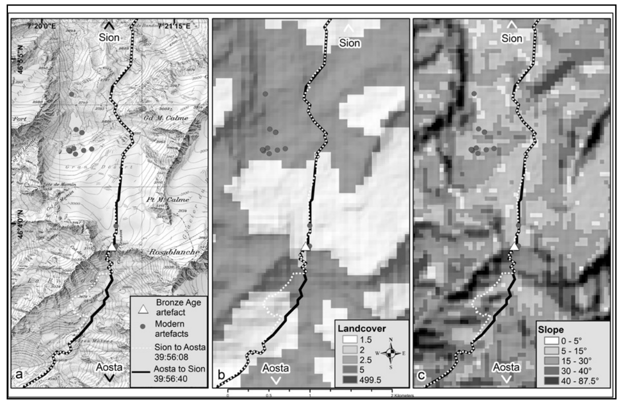

***Figure 6**. Zoomed in section of the results of LCPA between Sion and Aosta at Col de Cleuson.*

Archaeological prospection

As a result of the Sion/Domodossola LCPA, the mountain pass of Forca d'Aurona (Fig. 4) which separates Switzerland and Italy, was archaeologically investigated. The recent construction of a cabin on this currently non-glaciated pass made the retrieval of archaeological remains impossible as the original landcover had been destroyed. Only modern artefacts were found at the remaining ice patches.

The LCP from Sion/Aosta led to two days of prospection at the Col de Cleuson (Fig. 6). A total of 16 items, all pieces of wood, were discovered at the margin of the Grand Désert glacier, on the pass of the Col de Cleuson, or directly on the glacier (Fig. 6). Five of the six dated items were modern (~180 – 125 BP), but one piece of wood, which was found directly on the Col de Cleuson (3,018 m asl), partially concealed under rocks, was dated to 2,795 ± 35 BP (Poz-52269). This piece of wood was approximately 40 cm long and 3 cm in diameter. The presence of this artefact attests to the use of this pass in prehistoric times.

4. Discussion

In this study we found a Bronze Age piece of wood on top of a previously unstudied mountain pass by using least cost path analyses in conjunction with Tobler's hiking function and by testing the effects of differing landcover weights on paths at a calibration site. In doing so, certain assumptions and estimations had to be made in order to gain a better general understanding of movement through mountainous terrain. Tobler's hiking function, which was calibrated from empirical data of soldiers walking through varying topography, assumes that topography affects the walking speeds of people travelling through it (Gorenflo and Gale 1990; Imhof 1968; Tobler 1993). Although it has been criticised for not being based on scientific experiments (Herzog 2012), it is still the most used algorithm for LCPA in archaeological studies (Bell and Lock 2000; Gorenflo and Gale 1990; Verhagen and Jeneson 2012; Whitley and Hicks 2003). The integration of this algorithm into GIS and LCPA is useful for the estimation of time required and potential paths taken when traversing undulating terrains. Another algorithm which calculates walking times is the *r.walk* function from GRASS (GRASS Development Team 2013; Neteler and Mitasova, 2008). Research using this function has also shown interesting results (Madry and Rakos 1996; Ullah and Bergin 2012). However, a greater body of literature supports the use of Tobler's hiking function, therefore it was deemed most suitable for this study (e.g. Bell and Lock 2000; Gorenflo and Gale 1990; Verhagen and Jeneson 2012; Whitley and Hicks 2003). Furthermore, instead of using time as the measure, it has been stated that perhaps energy is a better indicator of human travel as time can be perceived differently in different cultures and time-periods (Herzog and Posluschny 2011; Kondo and Seino 2011; Llobera and Sluckin 2007; van Leusen 2002;). Some researchers have developed and implemented energy based algorithms into their calculations (Kondo and Seino 2011; van Leusen 2002), which would be interesting to adapt and implement in this study area.

When conducting any type of prehistoric analysis in GIS, it is important to take into account the paleoenvironment, or past environmental characteristics (Wheatley and Gillings 2002). In this study, a prehistoric landcover raster was created by experimenting at the calibration site. The landcover reclassification schemes used at the calibration site were based on discussions between archaeologists, historians, and geographers to obtain a consensus about friction levels for each type of terrain. The 2,000 m asl treeline level was an estimation of the upper limit of the forest influenced by the first important prehistoric human impact (Colombaroli et al. 2010). Although this method was relatively crude, it was important to acknowledge that landcover is constantly evolving due to natural and anthropogenic reasons and this should be taken into account when conducting GIS analysis (Wheatley and Gillings 2000).

The analysis of the results from the calibration site indicated that the walking times and routes taken by the LCP varied depending on the inputs to the LCPA model. For example, the paths calculated using the topographic landcover cost raster were the shortest in terms of time, because they were influenced only by the slope of the terrain and did not take into effect the landcover weights. The use of the topographic landcover cost raster allowed visualisation of the effects of both the isotropic and anisotropic inputs into the model. The majority of past archaeological studies using LCPA have relied solely on the slope of the terrain, thus anisotropic friction, in LCPA models (Bell and Lock 2000; Egeland, Nicholson, and Gasparian 2010; Gaffney and Stančič 1991; Gorenflo and Gale 1990; Herzog and Posluschny 2011; Kondo and Seino 2011; Tripcevich 2008; Verhagen and Jeneson 2012), therefore neglected the isotropic aspect. The incorporation of both isotropic and anisotropic frictions integrates both the magnitude and force of frictions across the cost surface (Bell and Lock 2000) and thus results in a more representative model of the terrain (van Leusen 2002). Similar to Howey (2007), in this study land cover was integrated as the isotropic friction along with slope as the anisotropic friction. However, it was not assumed that landcover and slope of the terrain were the only factors affecting the travel patterns of prehistoric people. In fact, it has been suggested that numerous social and cultural factors affected their travel decisions (Llobera 2000; Lock and Pouncett 2010; Murrieta-Flores 2010; 2012). Times calculated by the first weighting scheme of the prehistoric landcover cost raster were highly exaggerated, and took approximately three times longer than the paths calculated by the WPs. However, visually they seemed to be most consistent with the trails on the current topographic map. When each weight was divided in half to create the second prehistoric weighting scheme, the resulting paths were visually the same but had more accurate walking times compared to the WPs calculated by Suisse Rando. Thus, the prehistoric landcover with the second weighting scheme was adopted for the analysis between Sion and Aosta. The comparison of the LCP with present day walking trails was based on the assumption that the walking trails that exist today are based upon the same principle that people desire to take the easiest route possible when walking over mountainous terrain. The model could be further strengthened through ground-truth validation of walking times at the calibration site and it should be reiterated that the concept of time was not necessarily the same in the past as it is today.

The LCPA at the analysis sites narrowed down vast, mountainous study regions to aid glacial archaeological prospection and proved to be beneficial for discovering a previously unknown archaeological site with the detection of a prehistoric artefact at the Sion/Aosta site. Because of high elevations and low-accessibility in mountainous regions, it was physically impossible to visit every site of interest within the Pennine Alps. Thus, LCPA enabled a focused study area to be more thoroughly investigated with field recognisance and site visitation. With the aid of archaeologists and historians, the Forca d'Aurona and Col de Cleuson were chosen for further investigation based on the outcomes of the LCPA. The Forca d'Aurona was once a glaciated pass, but with the current climate situation, there was no ice or snow on the pass in the late summer of 2012 when archaeological prospection was conducted. From a glacial archaeological perspective, sites free of ice and snow yield fewer archaeological remains because the majority have decomposed or been destroyed by anthropogenic causes, as was the case at this site. Conversely, the region surrounding the Col de Cleuson is currently glaciated and had not been previously studied, archaeologically nor historically. Thus a new location of interest was discovered. The 16 pieces of wood retrieved from the Col de Cleuson and near the margin of the Grand Désert glacier attest to the fact that people have used this pass for thousands of years and could be of future interest to archaeologists. It should be noted that any piece of wood found at such high elevation (almost 1,000 m above the current treeline) was not a natural phenomenon, but had to be transported there by someone or something. According to Verhagen and Jeneson (2012), despite being a popular research technique LCPA does not usually result in predictive success. The Forca d'Aurona showed the limit to this method, and perhaps for the future, more emphasis should be placed on passes which are still glaciated or surrounded by snow and ice. On the other hand, the results at the Col de Cleuson showed that in a region rich in cultural occurrences and terrain which often determines travel routes, that this method was effective as a decision support tool for the purposes of finding new sites for glacial archaeological investigation.

Acknowledgements

This research has been supported by the Swiss National Science Foundation (grant CR21I2 130279), by the Service des bâtiments, monuments et archéologie, (Canton du Valais, Switzerland) and by the History Museum of Valais (Switzerland). Thanks to Philippe Curdy, curator at the History Museum of Valais, for all of his inputs and assistance with the model and fieldwork and also thanks to the project group for their inputs, including historians Muriel Eschmann-Richon and Pierre Dubuis, and geomorphologist Reynald Delaloye. Also, thank you to the three anonymous reviewers who helped strengthen this paper.

References

Ammann, H.-R. 1992. "Quelques aspects de l'importation du vin valdôtain en Valais au XVIe siècle." In *Vigne e vini nel Piemonte moderno*, edited by R. Comba, 461–480.

Alba-Cuneo: L'Arcière.

Anderson, D. G., and J. C. Gillam. 2000. "Paleoindian Colonization of the Americas: Implications from an Examination of Physiography, Demography, and Artifact Distribution." *American Antiquity* 65:43–66.

Andrews, T. D., and G. MacKay. 2012. "The Archaeology and Paleoecology of Alpine Ice Patches: A Global Perspective." *ARCTIC* 65:iii–vi.

Andrews, T. D., Glen MacKay, L. Andrew, W. Stephenson, A. Barker, C. Alix, and Shútagot'ine Elders of Tulita. 2012. "Alpine Ice Patches and Shúhtagot'ine Land Use in the Mackenzie and Selwyn Mountains, Northwest Territories, Canada." *ARCTIC* 65:22–42.

Bell, T., and G. R. Lock. 2000. "Topographic and Cultural Influences on Walking the Ridgeway in Later Prehistoric Times." In *Beyond the Map: Archaeology and Spatial Technologies*, edited by G.R. Lock, 85–100. Oxford: IOS Press.

Bell, T., A. Wilson, and A. Wickham. 2002. "Tracking the Samnites: Landscape and Communications Routes in the Sangro Valley, Italy." *American Journal of Archaeology*106:169–186.

Callanan, M. 2012. "Central Norwegian Snow Patch Archaeology: Patterns Past and Present." *ARCTIC* 65:178–188.

Colombaroli, D., P. D. Henne, P. Kaltenrieder, E. Gobet, and W. Tinner. 2010."Species Responses to Fire, Climate and Human Impact at Tree Line in the Alps as Evidenced by Palaeo-environmental Records and a Dynamic Simulation Model." *Journal of Ecology* 98:1346–1357.

Coolidge, W. A. B. 1912. *Alpine Studies*. London: Longmans, Green and co.

Crotti, P., G. Pignat, and A.-M. Rachoud-Schneider, eds. 2002. *Premiers Hommes Dans Les Alpes de 50 000 à 5 000 Avant Jésus-Christ*. Lausanne: Éditions Payot/Sion, Musées cantonaux du Valais.

Curdy, P. 2007. "Prehistoric Settlement in Middle and High Altitudes in the Upper Rhone Valley (Valais-Vaud, Switzerland): A Summary of Twenty Years of Research." *Preistoria Alpina* 42:99–108.

Curdy, P, C. Leuzinger-Piccand, and U. Leuzinger. 2003. "Zermatt Alp Hermettji et les cols secondaires du Valais." In *ConstellaSion. Hommage à Alain Gallay*, edited by M. Besse, L.-I. Stahl Gretsch, and P. Curdy, 73–88. Lausanne: Cahiers d'ardhéologie romande.

Di Maio, P. 2007. *Prime Impronte Dell'uomo Nella Regione Sempione-Arbola*. Torino: Celid.

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* 70:129–143.

Eastman, J. R. 2003. *IDRISI Kilimanjaro: Guide to GIS and Image Processing*.City: Clark Labs, Clark University.

Egeland, C. P., C. M. Nicholson, and B. Gasparian. 2010. "Using GIS and Ecological Variables to Identify High Potential Areas for Paleoanthropological Survey: An Example from Northern Armenia." *Journal of Ecological Anthropology* 14:89–98.

ESRI. 2013. "Environmental System Research Institute." ArcGIS Online. Accessed May 16. http://www.arcgis.com/home/.

European Environment Agency. 2012. "Corine Land Cover 2006." Last modified 29 November. http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-100-m-version-12-2009.

Farbregd, O. 1972. "Pilefunn fra Oppdalsfjella (arrow finds from the Oppdal mountains)." *Det Kgl. Norske Videnskabers Selskab, Muskeet, Miscellanea* 5:105-117.

Farnell, R., P. G. Hare, E. Blake, V. Bowyer, C. Schweger, S. Greer, and R. Gotthardt. 2004. "Multidisciplinary Investigations of Alpine Ice Patches in Southwest Yukon, Canada: Paleoenvironmental and Paleobiological Investigations." *Arctic* 57:247–259.

Federal Office of Topography Swisstopo. 2014. "VECTOR25." Accessed January 15. http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/landscape/vector25.html.

Gaffney, V. L., and Z. Stančič. 1991. *Gis Approaches to Regional Analysis: A Case Study of the Island of Hvar*. Ljubljana: Znanstveni inštitut.

Gardaz, J.-M. 1998. *Permafrost Prospecting, Periglacial and Rock Glacier Hydrology in Mountain Areas. Case Studies in the Valais Alps, Switzerland*. City: University of Fribourg.

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*, edited by editors, pages. City: publisher.

Gorenflo, L. J., and N. Gale. 1990. "Mapping Regional Settlement in Information Space." *Journal of Anthropological Archaeology* 9:240–274.

GRASS Development Team. 2013. "GRASS GIS Reference Manual." Accessed October 2. http://grass.osgeo.org/grass70/manuals/index.html..

Hafner, A. 2012. "Archaeological Discoveries on Schnidejoch and at Other Ice Sites in the European Alps." *ARCTIC* 65:189–202.

Hare, P. G., S. Greer, R. Gotthardt, R. Farnell, V.Bowyer, C. Schweger, and D. Strand. 2004. "Ethnographic and Archaeological Investigations of Alpine Ice Patches in Southwest Yukon, Canada." *Arctic* 57:260–272.

Hare, P. G, C. D. Thomas, T. N. Topper, and R. M. Gotthardt. 2012. "The Archaeology of Yukon Ice Patches: New Artifacts, Observations, and Insights." ARCTIC 65:118–135.

Harriss, B. 1970. "The Theodulpass: a History." *Alpine Journal* 75:87–94.

Harriss, B. 1971. "The Monte Moro Pass and the Col D'Herens." *Alpine Journal* 76:127–132.

Herzog, I. 2012. "The Potential and Limits of Optimal Path Analysis." In *Computational Approaches to Archaeological Spaces*, edited by A. Bevan and M. Lake, pages. London: Left Coast Press.

Herzog, I., and A. Posluschny. 2011. "Tilt – Slope-dependent Least Cost Path Calculations Revisited." In *On the Road to Reconstructing the Past, Computer Applications and Quantitative Methods in Archaeology (CAA). Proceedings of the 36th International Conference, Budapest, April 2008*, edited by editors, 236–242. Budapest: Archaeolingua

Howey, M. C. L. 2007. "Using Multi-criteria Cost Surface Analysis to Explore Past Regional Landscapes: a Case Study of Ritual Activity and Social Interaction in Michigan, AD 1200–1600." *Journal of Archaeological Science* 34:1830–1846.

Imhof, E. 1968. *Gelände und Karte*. City: Eugen Rentsch Verlag.

Janko, M., R. W. Stark, and A. Zink. 2012. "Preservation of 5300 Year Old Red Blood Cells in the Iceman." *Journal of the Royal Society Interface* 9:2581–2590.

Keller, A., A. Graefen, M. Ball, M. Matzas, V. Boisguerin, F. Maixner, and P. Leidinger. 2012. "New Insights into the Tyrolean Iceman's Origin and Phenotype as Inferred by Whole-genome Sequencing." *Nature Communications* 3:698–706.

Kondo, Y., and Y. Seino. 2011. "GPS-aided Walking Experiments and Data-driven Travel Cost Modeling on the Historical Road of Nakasendō-Kisoji (Central Highland Japan)." In *Making History Interactive, Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 2009*, edited by editors, 158–165. Oxford: Archaeopress.

Krajick, K. 2002. "Melting Glaciers Release Ancient Relics." Science 296:454–456.

Krist, F. J., and D. G. Brown. 1994. "GIS Modeling of Paleo-indian Period Caribou Migrations and Viewsheds in Northeastern Lower Michigan." *Photogrammetric Engineering and Remote Sensing* 60:1129–1138.

Lee, C. M. 2012. "Withering Snow and Ice in the Mid-latitudes: A New Archaeological and Paleobiological Record for the Rocky Mountain Region." *ARCTIC* 65:165–177.

Llobera, M. P. 2000. "Understanding Movement: A Pilot Model Towards the Sociology of Movement." In *Beyond the Map: Archaeology and Spatial Technologies*, edited by G.R. Lock, 65–84. Oxford: IOS Press.

Llobera, M., and T. J. Sluckin. 2007. "Zigzagging: Theoretical Insights on Climbing Strategies." *Journal of Theoretical Biology* 249:206–217.

Lock, G., and J. Pouncett. 2010. "Walking the Ridgeway Revisited: The Methodological and Theoretical Implications of Scale Dependency for the Derivation of Slope and Calculation of Least-cost Pathways." In *Making History Interactive, Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 2009*, edited by editors, 191–202. Oxford: Archaeopress.

Lugon, R., and R. Delaloye. 2001. "Modelling Alpine Permafrost Distribution, Val de Réchy, Valais Alps (Switzerland)." *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography* 55: 224–229.

Madry, S., and L. Rakos. 1996. "Line-of-sight and Cost-surface Techniques for Regional Research in the Arroux River Valley." In *New Methods, Old Problems. Geographic Information Systems in Modern Archaeological Research*, edited by H. Maschner, 104–126. Carbondale: Southern Illinois University.

Molyneaux, K., and D. S. Reay. 2010. "Frozen Archaeology Meltdown." *Nature Geoscience* 4: 2–2.

Murrieta-Flores, P. A. 2010. "Travelling in a Prehistoric Landscape: Exploring the Influences That Shaped Human Movement." In *Making History Interactive, Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 2009*, edited by editors, 249–267. Oxford: Archaeopress.

Murrieta-Flores, P. A. 2012. "Understanding Human Movement through Spatial Technologies. The Role of Natural Areas of Transit in the Late Prehistory of South-western Iberia." *Trabajos de Prehistoria* 69: 103–122.

NASA Jet Propulsion Laboratory. 2004. "ASTER Global Digital Elevation Map Announcement." Last modified September 7.http://asterweb.jpl.nasa.gov/gdem.asp.

Neteler, M., and H. Mitasova. 2008. *Open Source GIS: A Grass GIS Approach.* London: Springer.

Prinoth-Fornwagner, R., and T. R. Niklaus. 1994. "The Man in the Ice: Results from Radiocarbon Dating." *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 92: 282–290.

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: 455–457.

Shouse, B. 2001. "For Ice Man, the Band Plays On." *Science* 293: 2373–2373.

Suisse R. 2013a. "SwitzerlandMobility - Hiking in Switzerland." Accessed May 31. www.wanderland.ch.

Suisse R. 2013b. "Suisse Rando." Accessed May 31. http://www.wandern.ch.

Swiss National Science Foundation. 2014. "Glacial Archaeology, Valais, Swiss Alps. Modelling Archaeological Potential of High Altitude Passes and Trails, Pennine Alps, Valais and Borders." Accessed January 15. www.glacialarchaeology.com.

Tenthorey, G. 1993. *Paysage géomorphologique du Haut-Val de Réchy (Valais, Suisse) et hydrologie liée aux glaciers rocheux.* City: Université de Fribourg.

Tobler, W. 1993. "Three Presentations on Geographical Analysis and Modeling." National Center for Geographic Information and Analysis (NCGIA) Technical Report 93–1. Accessed February 13. http://www.ncgia.ucsb.edu/Publications/Tech_Reports/93/93-1.PDF.

Tripcevich, N. 2008. "Estimating Llama Caravan Travel Speeds." Poster presented at the *UC Santa Barbara Geography, California*. Accessed May 14, 2013. http://works.bepress.com/tripcevich/23.

Tripcevich, N. 2009. "Workshop 2009, No. 1 - Viewshed and Cost Distance." Accessed May 13, 2013. http://mapaspects.org/courses/gis-and-anthropology/workshop-2009-viewshed-and-cost-distance.

Ullah, I. I., and S. M. Bergin. 2012. "Modeling the Consequences of Village Site Location." In *Least Cost Analysis of Social Landscapes: Archaeological Case Studies*, edited by D. A. White and S. L. Surface-Evans, 155–173. Salt Lake City: University of Utah Press.

van Leusen, M. 1999. "Viewshed and Cost Surface Analysis Using GIS (Cartographic Modelling in a Cell-Based GIS II)." In *New Techniques for Old Times. CAA98. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 26th Conference, Barcelona, March 1998,* edited by J.A. Barceló, I. Briz and A. Vila, 215–224. Oxford: Archaeopress.

van Leusen, M. 2002. "Pattern to Process: Methodological Investigations Into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes." PhD Diss. University of Groningen.

VanderHoek, R., R. M. Tedor, and J. D. McMahan. 2007. "Cultural Materials Recovered From Ice Patches In The Denali Highway Region, Central Alaska, 2003–2005." *Alaska Journal of Anthropology* 5:185–200.

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, 123–130. Oxford: Archaeopress.

Walsh, K., S. Richer, and J.-L. de Beaulieu. 2006. "Attitudes to Altitude: Changing Meanings and Perceptions Within a 'marginal' Alpine Landscape – the Integration of Palaeoecological and Archaeological Data in a High-altitude Landscape in the French Alps." *World Archaeology* 38: 436–454.

Wheatley, D., and M. Gillings. 2000. "Vision, Perception and GIS: Developing Enriched Approaches to the Study of Archaeological Visibility." In *Beyond the Map: Archaeology and Spatial Technologies*, edited by G.R. Lock, 1–26. Oxford: IOS Press.

Wheatley, D., and M. Gillings. 2002. *Spatial Technology and Archaeology: The Archaeological Applications of GIS.* London: Taylor & Francis Group.

Whitley, T. G., and L. M. Hicks. 2003. "A Geographic Information Systems approach to understanding potential prehistoric and historic travel corridors." *Southeastern Archaeology* 22: 77–91.

- *Is there a reason why Andrews, T. D., and G. MacKay. 2012 in ARTIC has pages expresses as Roman numbers while Andrews et al. 2012 has pages expressed in Arabic numbers?*
- *Eastman, J. R: missing place of publication*
- *European Environment Agency. 2012. "Corine Land Cover 2006.." was changed in " European Environment Agency. 2012. "Corine Land Cover 2006." Last modified 29 November." Pls check and confirm you are ok with the change*
- *in Farbregd, Oddmunn. 1972.: is' Det Kgl.' part of the title? If so must be in italics*
- *Farnell,et al: the journal name Arctic is used in lower case here (as well as hare and al), while before appears in upper case. Please confirm which one is correct so that they can all be consistent*
- *(Corine 2012) was changed in (European Environment Agency 2012)*
- *"Federal Office of Topography 2007 Swisstopo" was changed in "Federal Office of Topography Swisstopo. 2014. "VECTOR25." Accessed January15. http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/landscape/vector25.html.*

Pls check and confirm you are ok with the change The change affected also the in-text reference

- *Gaffney, V. L., and Z. Stančič. 1991.: pls check publication place. We added Ljubljana: please confirm.*
- *Gardaz, J.-M. 1998.: please indicate town, not country of publication*
- *Goossens, R.,: missing place of publication and publisher; please double check also the title*
- *Herzog, I., and A. Posluschny. 2011: Budapest was added as publication place: please check and confirm*
- *Imhof, E. 1968: please check publisher and place of publication*
- *Keller, A., A. Graefen etc: a 'et al.' at the end of the list of authors has been removed. If other authors are included please add all of them*
- *Lugon, R. 2011. "Modelling Archaeological Potential of High Altitude Passes and Trails, Pennine Alps, Valais and Borders." Glacial Archaeology, Valais, Swiss Alps. Accessed June 18, 2013.www.glacialarchaeology.com was changed in "Swiss National Science Foundation. 2014. "Glacial Archaeology, Valais, Swiss Alps. Modelling Archaeological Potential of High Altitude Passes and Trails, Pennine Alps, Valais and Borders." Accessed January 15" to match the Chicago web site citation style. Pls check and confirm you are ok with the change. The change affected also the in-text reference*
- *"NASA (National Aeronautics and Space Administration). 2012. "ASTER Global Digital Elevation Map." ASTER GDEM. Accessed May 22, 2013". was changed in " NASA Jet Propulsion Laboratory. 2004. "ASTER Global Digital Elevation Map Announcement." Last modified September 7." to match the Chicago web site citation style. Pls check and confirm you are ok with the change. The change affected also the in- text reference*