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Combining glaciological and archaeological methods for gauging glacial archaeological potential

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ABSTRACT

Recent climate changes have led to an increase in the exposure of archaeological remains in frozen environments due to the melting of glaciers and ice patches, and the thawing of permafrost. In some cases, the discovery of glacial archaeological findings has occurred due to chance. In order to avoid the risk of losing exceptional, often organic, cultural remains due to decomposition, systematic and predictive methods should be employed to locate areas of high glacial archaeological potential. Here, we merged archaeological and glaciological methods to create a new type of archaeological prediction model in the field of glacial archaeology. Locational analysis and glaciological modelling were used to highlight current and future areas of archaeological potential in the Pennine Alps, located between Switzerland and Italy. Future glacier area was calculated in 10 year increments until 2100. By 2090, 93% of glacier area is expected to have disappeared. The results from the final model, GlaciArch, provide new insights into future glacial archaeological prospection in the Pennine Alps by narrowing down a study region of 4500 km^2 into several manageable square kilometre sites.

1. Introduction

Due to the alternation of various warm and cold periods, glacier extents and ice volume storage have fluctuated in the entire European Alps during the Holocene (10.5 ka to present). Compared to the Last Glacial Maximum (LGM) (19–20 ka BP) and latest Pleistocene, when large piedmont lobes of vast valley glaciers reached the Alpine foreland (Clark et al., 2009; Ivy-Ochs et al., 2008), glacier changes have been rather minor during the Holocene. The glacierized area varied between the stage of the Little Ice Age (LIA) maximum, around 1850, and a minimum which was significantly smaller than the present day extents (Grosjean et al., 2007; Holzhauser, 2007; Joerin et al., 2006, 2008).

Glacier-climate interactions have affected humans for millennia. In the European Alps, glacier fluctuations directly influenced human interaction with Alpine areas (Benedict and Olson, 1978; Wiegandt and Lugon, 2008). For example, as glaciers receded after the LGM, humans took advantage of the newly ice-free Alpine biome which offered plenty of food and resources during the Paleolithic period (Pacher, 2003; Tagliacozzo and Fiore, 2000). The present atmospheric warming has caused shrinkage of glaciers and ice caps all over the world (IPCC, 2013). In consequence, melting ice and snow has uncovered archaeological remains in Arctic and Alpine environments (Andrews et al., 2012; Beattie et al., 2000; Callanan, 2012, 2013; Dixon et al., 2005; Farbregd, 1972; Farnell et al., 2004; Hafner, 2012; Hare et al., 2004, 2012; Lee, 2012; Rogers et al., 2014; VanderHoek et al., 2007) which further attests to the use of frozen regions on a global scale. These artefacts which have melted out of ice patches and glaciers, and thawed out of permafrost, have created a new sub-discipline of archaeology: glacial archaeology. “Glacial archaeology” has also been referred to as ice patch archaeology (c.f. Andrews and MacKay, 2012; Reckin, 2013) and frozen archaeology (Molyneaux and Reay, 2010). Perhaps one of the most famous examples of a glacial archaeological find is that of Ötzi the Tyrolean Iceman who was accidentally discovered by hikers in 1991 on the Italian/Austrian border, protruding from an ice patch (Prinoth-Fornwagner and Niklaus, 1994; Seidler et al., 1992). The uniqueness of Ötzi and other glacial archaeological discoveries is that they have often been preserved by ice for thousands of years, thus protecting them and providing scientists with unparalleled information about past cultures and climates (Dixon et al., 2005; Reckin, 2013). There is urgency to collect these delicate, often organic, glacial archaeological remains before, or soon after, they melt out of the ice and become destroyed

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by decomposition (Andrews and MacKay, 2012; Dixon et al., 2005; Molyneaux and Reay, 2010). As melting in high altitudes and latitudes is not anticipated to halt in the near future (c.f. Radić et al., 2014), more glacial archaeological finds can be expected and there is a need to further develop predictive methods in this research domain.

In this paper, archaeological and glaciological methods are merged together to create a new type of predictive model to determine areas of glacial archaeological potential. The results will be used as a decision support tool for future prospection of archaeological findings in high mountain environments. Our approach, referred to as "GlaciArch" in the following, is based on current ice thickness distribution, future evolution of glacierized areas, and topographic characteristics of the terrain which could have influenced past human accessibility. First, currently glacierized or recently deglacierized high altitude mountain passes located on the border of Switzerland and Italy are selected to be used as sites on which to perform the locational analysis. Next, least cost paths (LCPs) are calculated between valleys and respective passes. Then, locational analysis is used to determine areas of glacial archaeological potential based on the physical characteristics of the terrain. After, the future evolution of glaciers is modelled for the Pennine Alps using a glacier evolution model (Huss et al., 2010a). Finally, the results of glacier modelling are combined with the results of locational analysis to create GlaciArch, a predictive model which ultimately defines regions of highest archaeological interest for now and the future. This paper highlights how the intersection of glaciological and archaeological methods provides a new approach for looking at glacial archaeological prospection.

2. Study area and data

2.1. Study area

The Pennine Alps (centered at approximately 45°57′N, 7°32′E) are located between the canton of Valais, Switzerland, and the provinces of Aosta and Piedmont, Italy (Fig. 1). The whole region is of particular glacial archaeological interest due to its large glacierized area and rich cultural heritage. The Pennine Alps cover approximately 4500 km^2 and reach altitudes above 4000 m a.s.l. The main valleys to the north, south, and east of the Pennine Alps, the Rhone valley (Switzerland), and the Aosta and Antigorio valleys (Italy) respectively, are scattered with archaeological remains dating from Mesolithic (9.5 ka to5.5 ka BC) to historic times (Curdy, 2007; Radmilli, 1963). Although most travellers reached these valleys from lower altitudes, each valley could also be reached by crossing the Pennine Alps between them. This relatively short distance was often traversed for commercial purposes. Archaeological remains collected on the way to, and on top of, mountain passes between Switzerland and Italy demonstrate the use of these passes as trade and travel routes for thousands of years (Bezinge

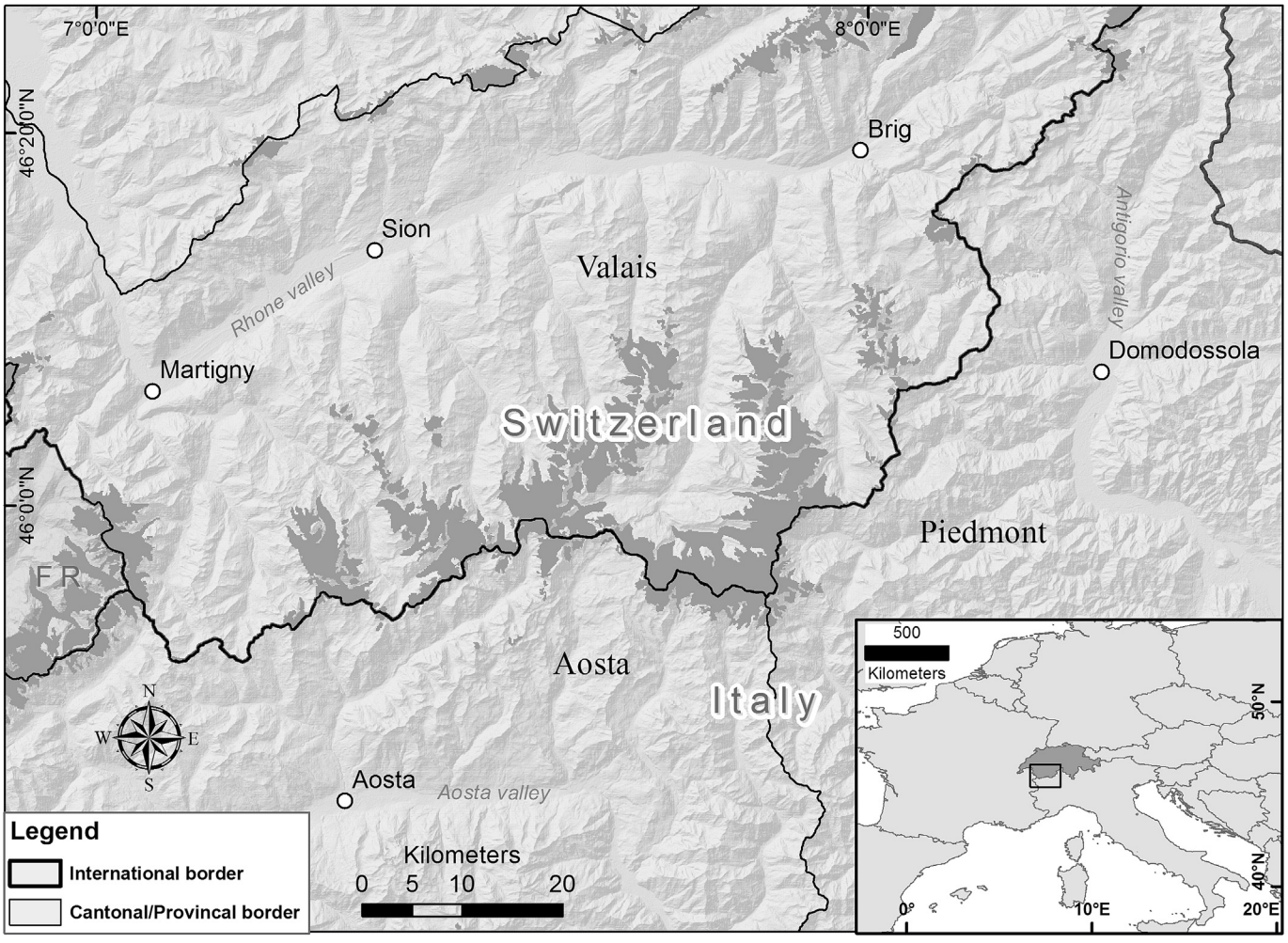

Fig. 1. Overview of study area. Glacierized areas are shaded in dark grey.