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On a Mountain High: Finding and Documenting Glacial Archaeological Sites During the Anthropocene

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ABSTRACT

Glacial archaeology is a developing field, brought on by climate change. High mountain ice is melting, which has led to the exposure of artifacts in North America, Mongolia, the Alps, and Scandinavia. The highest number of finds and sites in the world are reported from Innlandet County, Norway. We present our methods of finding and documenting glacial archaeological sites in Innlandet based on 15 years of experience. Sites are found using a combination of local information on the ground and remote sensing. Fieldwork takes place in three steps: an exploratory survey for assessment, systematic surveys for documentation, and monitoring in case of further ice retreat. The harsh environment makes the logistics very different from regular archaeology at lower elevations. Fieldwork methods are described in detail. The continuing retreat of mountain ice worldwide makes the Innlandet experience increasingly pertinent to the practice of field archaeology.

KEYWORDS
ice patch archaeology; glacier; fieldwork methods; survey; hunting sites; mountain passes; remote sensing; climate change

Introduction

Glacial archaeology is a developing field brought on by climate change (Andrews and MacKay 2012; Reckin 2013; Dixon et al. 2014). Glaciers and ice patches are melting in the high mountains around the world, and human influence on the climate is very likely the main driver of this melt (IPCC 2021). As the ice retreats, artifacts and faunal materials are melting out in North America, the Alps, Scandinavia, and Mongolia. Glacial archaeologists in these regions are surveying along the edges of melting ice to discover and document emerging finds. Many are of organic materials rarely preserved elsewhere. The unique finds from the ice and the intersection with climate change have created a lot of interest for this new field in archaeology, both scientifically and publicly. The melting of glacial ice is part of a wider process which endangers the preservation of frozen cultural heritage in general (Hollesen et al. 2018; Clark et al. 2021; Reitmaier 2021).

In this context, we present our experience of more than a decade of systematic work discovering and documenting glacial archaeological sites in Innlandet County, Norway. Our work started in 2006 and has received permanent funding since 2011. After 15 years, we have located 62 archaeological ice sites (Figure 1). Ten can be described as large, complex sites with hundreds of finds spanning several thousand years. More than 3500 finds have been collected in total. To our knowledge, this makes Innlandet the region with the most ice sites and most ice finds in the world. The finds date from 4000 B.C. to recent times (Pilø et al. 2018).

In this paper, we describe how these archaeological ice sites have been found and recorded. There is little dedicated literature on the basics of glacial archaeology. We thus explain how our fieldwork is conducted, especially the surveying and find documentation. We also discuss the challenging logistics of glacial archaeology and how they can be overcome. Our practices and methods are of present and increasing relevance to world archaeology, given that global warming is now exposing artifacts and faunal material from melting ice masses in several places internationally. Glacial archaeology is a field which is bound to expand in scope and importance. It is also one where remote sites will only be found with a targeted effort. Where pertinent, we compare our approach to efforts elsewhere by our colleagues in the glacial archaeology community.

The Discovery of Finds from Mountain Ice

The first known find of a prehistoric or medieval artifact from the ice worldwide was an arrow recovered from an ice patch in Oppdal, Trøndelag County in Norway in 1914 (Callanan 2012). Unsurprisingly, it was a very hot summer that year—the early finds are generally linked to such circumstances. Finds also appeared elsewhere: a 1925 newspaper clip from British Columbia, Canada, describes an arrow found on ice (Keddie and Nelson 2005). Even more finds appeared in Oppdal during the very warm summers of the 1930s (Farbregd 1972; Callanan 2012), when a few finds were also reported from the neighboring county of Oppland, now part of Innlandet County (Hougen 1937). Things then quieted down until the 1990s, even though there were occasional finds from the ice in Innlandet County in the 1970s (Dagsgard 1977).

Ötzi was found in the Tyrolean Alps in 1991 (Spindler 1993) and became the starting gun for the second wave of ice finds. Six years later, arrows, atlatl darts, and

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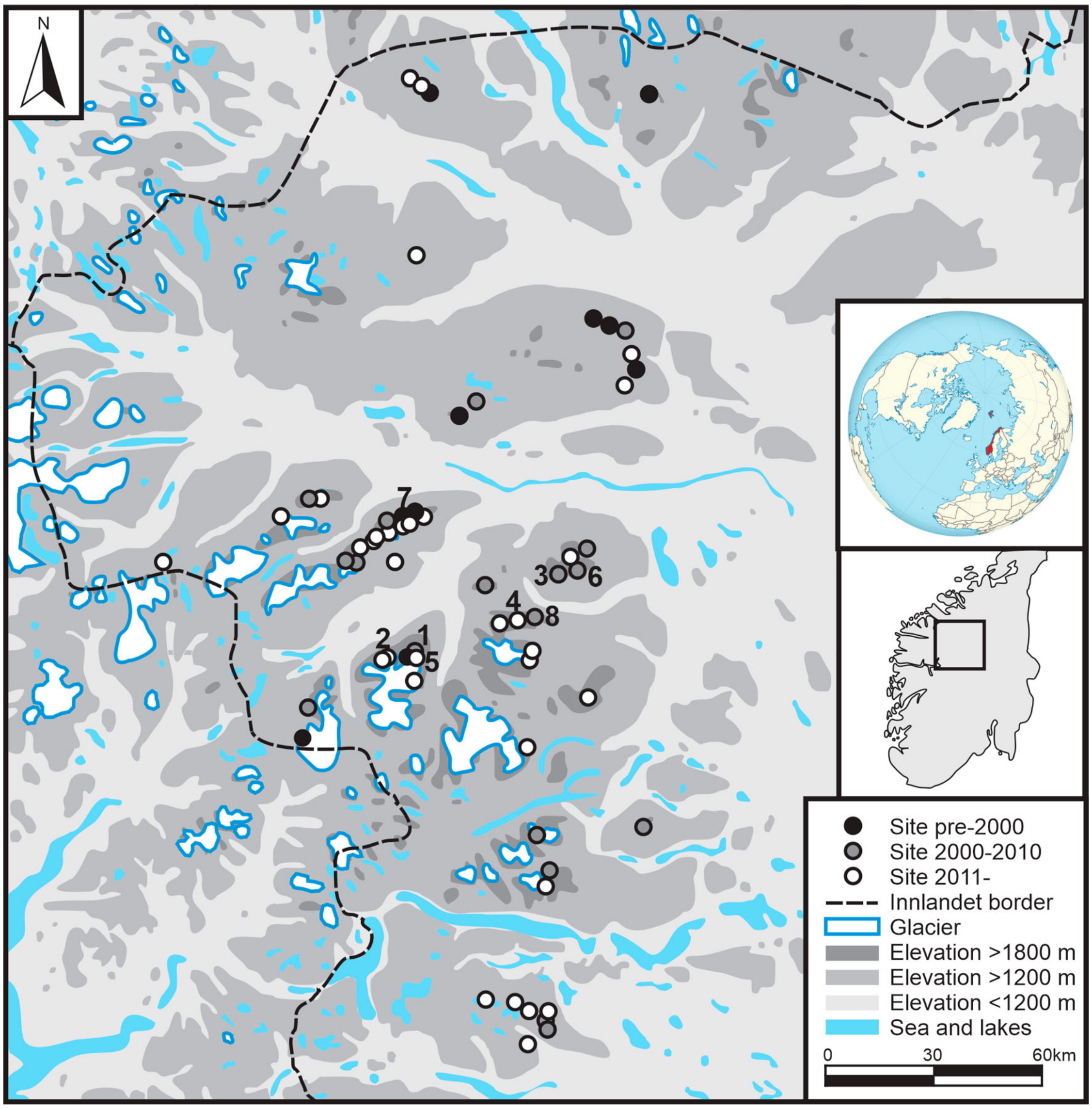

Figure 1. Site distribution according to date of discovery. Sites mentioned in text: 1) Juvfonne, 2) Storgrovbrean, 3) Storfonne, 4) unnamed ice patch at Trollsteinhøe, 5) unnamed ice patch south of Juvfonne, 6) Langfonne, 7) Lendbreen, and 8) Austre Trollsteinhøe. Map: Lars Pilø/Espen Finstad.

paleozoological material were reported from Yukon ice patches (Farnell et al. 2004), and a long-term program was initiated to rescue these finds. Pretty soon, similar finds, but fewer in number, appeared elsewhere in western Canada (Northwest Territories [Andrews, MacKay, and Andrew 2012] and British Columbia [Hebda, Greer, and Mackie 2017]), in Alaska (Dixon, Manley, and Lee 2005; VanderHoek et al. 2012), and in the U.S. part of the Rocky Mountains (Lee 2012). More finds appeared in the Alps, as well (Hafner 2015). A dramatic melting episode in Norway in 2006 led to a sharp increase in the number of finds here, including in Innlandet County. Recently, artifacts have also emerged from ice patches in Mongolia (Taylor et al. 2021).

Mountain Ice and the Preservation of Artifacts

When our work started in Innlandet County in 2006, only a few of our high mountain ice masses had previously reported artifact finds which pointed to their status as archaeological sites (see Figure 1). Therefore, the first step was to actively survey along the edges of the ice masses to gain an impression of the number of glacial archaeological sites and the number of finds on these sites. However, the high mountains of Innlandet County cover a large area (ca. 10000 km^2), and there are hundreds of ice masses, large and small. Where to begin?

The search for glacial archaeological sites starts by understanding that not all mountain ice preserves artifacts for millennia. A basic distinction is often made between stationary ice patches preserving artifacts and moving glaciers destroying them. However, this is too simple. Instead of this dichotomy, it is better to look at the different types of mountain ice as steps on a ladder. At the bottom, there are intermittent snow patches without a permanent ice core. At the top, there are large glaciers. All glaciers started as snow patches, before developing into semi-stationary ice patches with permanent ice cores. When the ice patch has accumulated enough mass, it will start moving and become a glacier. Such glaciers can be frozen to the bed (cold-based) or basally sliding (warm-based). Artifacts, paleozoological, and paleobotanical material can be preserved along the various steps on this ladder of snow and ice accumulations, though the degree of preservation and the age varies according to the type of ice mass.

At the lowest step of the ladder, even intermittent snow patches/extinct ice patches can preserve organic material

(VanderHoek et al. 2007, 2012). At our Langfonne site, we found artifacts and bones more than 100 m from the current ice edge, in areas where there is unlikely to have been permanent ice cover after the finds were deposited (Pilø et al. 2021). While such objects are not as well preserved as objects found closer to the ice, they still survive in an identifiable state. We also have isolated finds of organic objects from non-ice contexts in our high mountains, such as a medieval wooden spade found in a pitfall trap at ca. 1500 m.

Ice patches are the next step on the ladder. These are where most glacial archaeological finds are recovered. Ice patches are semi-stationary bodies of ice, often developing in hollows on the northern/northeastern side of mountain tops or ridges or sometimes in canyons/gullies (Ødegård et al. 2017; Chellman et al. 2021). They mainly accumulate from wind-deposited snow. As they grow, meltwater trickles through the snow and re-freezes further down, leading (together with compression) to the development of an ice core (Meulendyk et al. 2012; Ødegård et al. 2017; Chellman et al. 2021). While small ice patches are stationary, larger ice patches may show slow ice deformation, which affects the artifacts (Pilø et al. 2021). Large ice patches may even become cold-based glaciers during periods of expansion. Due to the slowness of ice movement, such large ice patches may still preserve ancient ice and artifacts dating back millennia.

The greatest age of the ice also determines the greatest age of the organic finds found associated with the ice patches. The earliest ice date in Norway is at the bottom of the Juvfonne ice patch in Innlandet County with a date of ca. 7600 CAL B.P. (see Figure 1: 1; Ødegård et al. 2017). The Rocky Mountains and Yukon have provided even earlier ice patch dates (Farnell et al. 2004; Chellman et al. 2021) and correspondingly early artifact dates (Hare et al. 2012; Lee 2012). So far, there are no ice patches that have been shown to preserve ice from the Pleistocene. This is due to the early- and mid-Holocene warming that followed the end of the Ice Age.

Glaciers are at the top of the ladder. The ice in glaciers is in constant renewal, accumulating at the top, moving downhill, and melting away in the ablation zone. In most cases, this prohibits the preservation of finds older than ca. 500 years inside the ice. The movement of glaciers leads to stress and strain, which tears apart human bodies and artifacts. However, it does not necessarily completely destroy the objects. There are several examples from the Alps of damaged human bodies with associated artifacts found on the surface of the lower parts of glaciers (e.g. the post-medieval bodies from the Porchabella and Theodul glaciers [Alterauge et al. 2015; Providoli, Curdy, and Elsig 2016]). It should also be noted that a moving glacier may be connected to non-moving ice fields at the top and/or along the sides (Figure 2). Such stationary ice fields may preserve artifacts and/or faunal materials of considerable age.

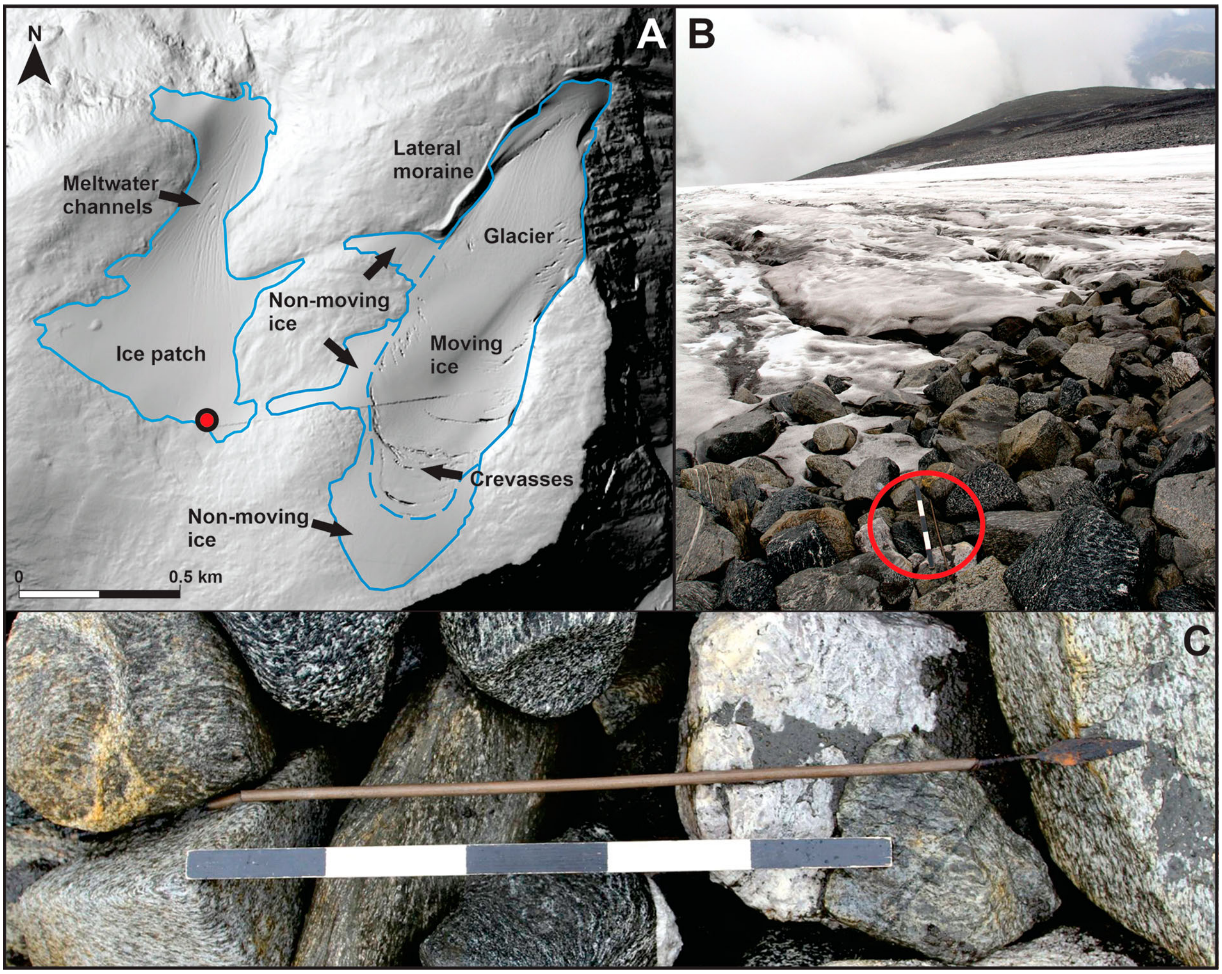

Figure 2. Storgrovbrean—a large double ice mass in Lom municipality, Innlandet County, Norway (Figure 1: 2). A) Digital terrain model showing a glacier to the east with crevasses and a lateral moraine in the lower part showing the moving ice, but with non-moving ice at the top and along the upper western edge. Ice patch to the west with meltwater channels and no crevasses. Red point shows findspot for arrow, dated to ca. 500 A.D. B) Same arrow, found lying on the ground close to the retreating ice. C) Detail of arrow. Map: Lars Pilø, background map from https://hoydedata.no/LaserInnsyn/. Photos: Glacier Archaeology Program.

The only ice areas that are excluded from survey at the outset are areas with burrowing glaciers with crevasses. As mentioned above, even such glaciers may produce interesting, albeit more recent, finds. However, chances are very small of locating such finds during an archaeological survey, as there is a poor "survey time" to "find discovery" ratio, due to the large size of the glaciers. In addition, crevasses may stop finds appearing on the ice surface from being washed downslope and ending up on the ground in front of the ice, as happens in the case of ice patches. The basal sliding of glaciers will also bury artifacts lying in front of the ice during advances. Usually, reports of archaeological finds from glaciers have so far been chance discoveries by mountain hikers, not archaeologists (e.g. Hebda, Greer, and Mackie 2017; but see Dixon, Manley, and Lee 2005).

The Nature of Glacial Archaeological Sites

Glacial archaeological sites are situated in the high mountains, in an extreme environment very different from lower elevations. The sites are covered in snow and ice for much of the year and are heavily influenced by natural glacial and peri-glacial processes, in contrast to the ploughing and/or bioturbation typically found on lowland sites. Understanding the nature of the glacial archaeological sites is a key to both finding and understanding them.

Glacial archaeological sites in Innlandet County typically consist of a semi-stationary ice mass surrounded by a well-defined lichen-free zone (LFZ) (Figure 3). The LFZ shows the area which has been recently exposed by retreating ice and snow. In Innlandet, the extent of the LFZ normally shows the extent of ice and snow in the late 1990s (Grønås 2019) after several winters of heavy snowfall, due to a prevailing positive North Atlantic Oscillation (NAO) winter weather mode (Nesje and Matthews 2012). Outside the LFZ, there is typically a zone with less well-developed lichen and moss growth, which delimits the extent of the ice and snow during the Little Ice Age (LIA; 1450–1850 A.D.) (Grønås 2019).

The LFZ contains artifacts and paleozoological materials and sometimes ancient monuments such as stone markers/cairns or hunting blinds (semi-circular or circular stone walls where hunters can hide). Such ancient monuments may also be found outside the LFZ (and far away from any ice), while artifacts of organic materials are only very rarely recovered outside the LFZ. Finds are normally recovered on the surface of the LFZ and, on occasion (ca. 2%), on the ice surface.

Figure 3. The Storfonne ice patch in September 2014—a typical glacial archaeological site in Innlandet County (Figure 1: 3). The ice is surrounded by a large lichen-free zone, which contained hundreds of artifacts and paleozoological materials. Ice stratification is seen as wavy lines on the ice surface. First finds were reported here in 2002. Large-scale systematic surveys were conducted in 2017 and 2018. Photo: Glacier Archaeology Program.

Most finds were originally lost in the snow but are now found on the ground during survey. This is because small ice masses like ice patches are sensitive to changes in climate and weather (Ødegård et al. 2017). They expand and contract quickly, and this leads to the melt out of many finds. The ice surface is normally a slope, and this means that light finds (e.g. wood) are quickly transported downslope by meltwater, ending up on the ground in front of the ice. Here, the finds may be covered by ice again (and later re-exposed, sometimes repeatedly). The strong winds of the high mountains also play a role in the displacement of finds. The distribution of finds on the ground surrounding the ice is thus mainly a result of natural site formation processes (Pilø et al. 2021). Nearly all finds are displaced from their original point of deposition, some by hundreds of meters (Finstad et al. 2018).

The peculiar nature of the glacial archaeological sites makes it difficult to derive paleoclimatic inferences from the find distributions. Only when dated ancient monuments melt out, such as a hunting blind with datable finds, can it be stated that there was no ice here when the hunting blind was built. However, this would just be a moment in time. There could have been snow and ice in the same spot just before and/or just after, since the ice patches expand and contract so quickly. The peri-glacial landscape surrounding the ice is quite active. This can lead to the burial of finds lying on the surface through movement in the active permafrost layer and through solifluction.

It is often possible to see ice stratification on the exposed surface (see Figure 3). This stratification extends into the deeper parts of the ice mass, as demonstrated by ground penetrating radar (Ødegård et al. 2017; Pilø et al. 2021) or ice tunneling (Ødegård et al. 2017). Ice stratification is a very dynamic process, including melting episodes, leading to parts of the stratigraphic record disappearing and/or being combined into composite dark horizons.

Glacial archaeological sites in Innlandet are similar to those in western Canada (Farnell et al. 2004; Andrews, MacKay, and Andrew 2012; Hare et al. 2012), both in topography and their function as reindeer/caribou hunting locations. Sites in the Alps also share common features such as LFZs and ancient monuments, but their topographical expressions differ markedly, due to a more peaked topography (Hafner 2015) and their typical function as transport routes. Ice patches are also rarer in the Alps, where glaciers dominate.

Locating the Glacial Archaeological Sites

The first step before initiating survey is to get an overview of where the mountain ice is located. A general overview of ice masses in a mountain region can be established in several ways, depending on the availability and quality of maps and aerial/satellite photos (for an overview of remote sensing applied to glacial archaeological and permafrost sites, see Caspari 2021). Larger ice masses are normally drawn on maps, while smaller ice bodies may not be marked and are only found on orthophotos or satellite imagery. One such small ice body not on the map, an unnamed ice patch at Trollsteinhøe in the Jotunheimen Mountains (see Figure 1: 4; Figure 4), has yielded more than 200 finds. Thus, a

Figure 4. Scaring sticks for reindeer hunting found at the edge of the ice during exploratory fieldwork of an unnamed ice patch at Trollsteinhøe in the Jotunheimen Mountains (Figure 1: 4) in August 2011. Scaring sticks are ca. 1 m long wooden poles with a movable object attached to the top. They are set up in lines and used for leading the reindeer towards the hiding hunters. Photo: Glacier Archaeology Program.

combination of maps and aerial/satellite photos is preferable. Google Earth is an easy option and is instinctively appealing, as one can view potential ice sites in 3D and in different years. Many countries have higher resolution orthophotos taken in different years available online. Orthophotos and satellite imagery are available online at no cost in Norway—orthophotos at https://norgeibilder.no/ (mostly ca. 0.25 m resolution) and Sentinel satellite imagery (10 m resolution) at http://www.xgeo.no/ (within a day of images being taken).

The high mountains of Innlandet County are now in the process of being covered by a very detailed elevation model. The surface model can be viewed at https://hoydedata.no/LaserInnsyn/, where the data can also be downloaded for free. The areas below the tree line are mapped using lidar, while the high mountains have their elevation model mostly produced by photogrammetry based on vertical aerial photographs. The resolution of the digital terrain model (DTM) of the high mountains is ca. 1 point/m^2. This is enough to identify the ice-covered areas and areas with non-moving ice or very slow ice deformation (Figure 2A), but not enough to map ancient monuments.

Prior to the huge increase of finds in 2006, there were reported finds from ice patches by local mountain hikers, which later turned out to be large, complex archaeological sites (e.g. Dagsgard 1977; Pilø, Finstad, and Barrett 2020). Seeking advice among local reindeer herders, hunters, and researchers about regions where the reindeer stay during summer and which ice patches are most frequently used by the animals in the summer months is valuable information for locating potential hunting sites. We had a report made by a reindeer researcher summarizing the current knowledge regarding how and where reindeer used the ice patches (Jordhøy 2007). Commonly, this applies to ice patches with a short distance to good feeding vegetation for the animals. The information on reindeer behavior made it possible for us to target our surveys towards the most promising sites. It was also an advantage that, from the outset, members of our team had an intimate knowledge of the relevant areas due to their interest in mountain hiking.

A variety of other information can be of value when prioritizing potential sites for survey. Previously registered ancient monuments, such as stone-built hunting blinds and/or stone markers close to the ice, indicate where reindeer hunting took place in the past. This could potentially lead to the loss of artifacts in the snow. Most of our glacial archaeological sites have associated hunting blinds and stone markers. We also have ice masses with hunting blinds and/or stone markers but no finds. In some cases, this is because the melt has not reached deep enough levels for the finds to emerge. An example is ca. 1 km south of our large Juvfonne site (see Figure 1: 5), where hunting blinds were found along the edge of a small ice patch in 2007, but no finds were reported until 2018 when the ice patch melted back substantially. We currently have 151 unchecked ice masses in our high mountains that we deem to have a potential for finds, while 16 have been checked without finds so far.

GIS/spatial analysis to narrow the search

Glacial archaeological sites are commonly situated in remote mountain regions, which can cover very large areas. To narrow down the most promising areas, GIS and/or spatial analysis have been implemented, for example in North America and the Alps (e.g. Dixon, Manley, and Lee 2005; Andrews, MacKay, and Andrew 2012; Rogers et al. 2018).

One option for locating ice areas with a high potential for finds is to predict where ancient mountain trails may have crossed ice. Such trails can be known from historical sources, or their potential presence may be indicated by least-cost-path (LCP) analysis. LCP analysis was conducted in the Jotunheimen Mountains here in Innlandet (Fossåskaret 2017), which pointed at both known historical routes (some with ice finds) and other possible pathways. The predicted routes mostly crossed glaciers, with the increased challenges of recovering finds noted above, so only limited fieldwork has been prioritized to check them in Innlandet. This type of approach is better developed in the Alps (Reitmaier-Naef and Reitmaier 2015; Rogers et al. 2018).

After checking many potential ice sites in Innlandet, we can see a pattern in that large sites are relatively close to settled valleys. They are typically within a 2–3 hour hike from present-day farms or summer farms in much the same locations as those from the Viking Age (800–1066 A.D.) and perhaps earlier (Pilø, Finstad, and Barrett 2020). Sites farther away may also have finds, but they are fewer in number. Within the logistical limits provided by our funding and short field seasons (see below), this has led to a concentration of fieldwork on sites within a day's hike of present-day settlements.

Exploratory Surveys

After making a priority list of ice masses with find potential, the next step is exploratory survey of the individual ice masses. Such surveys, and fieldwork in general, takes place in August and September each year, in the short period between the melt of the previous winter snow and the arrival of new snow from the coming winter. This narrow window of opportunity for glacial archaeological fieldwork is roughly the same elsewhere in the northern hemisphere, both in North America and in Europe (e.g. Andrews, MacKay, and Andrew 2012; Glauser 2015).

In Innlandet County, exploratory surveys invariably mean a visit on foot, hiking in from the nearest road. Normally only up to three people undertake an exploratory survey.

This is a one-day visit including substantial uphill hiking, so we travel light, bringing with us only rudimentary equipment, such as conservation supplies to pack fragile finds and a small hand-held GPS. In Canada, the distance from roads to the ice is too long for day-hikes, so helicopters are used (Hare et al. 2012; Hebda, Greer, and Mackie 2017). This allows the archaeologists to hop from site to site, covering many potential find areas in one day. This is an approach that we have discussed implementing in Innlandet, as well, as we struggle to find the time to visit more remote areas. However, helicopter time is very expensive in Norway, and current funding limits have not yet allowed this approach. We also try to keep our carbon footprint as low as possible.

Once we arrive at the ice, we conduct a visual survey of the LFZ, looking for artifacts and/or paleozoological material lying on the surface (see Figure 4). We do not necessarily conduct intensive systematic surveys with lines of evenly spaced surveyors in this phase. The distance between the surveyors may vary from 3–10 m, and we focus on checking parts of the terrain which are known empirically to contain more finds, like areas close to the ice edge and depressions. During exploratory surveys, the focus is on locating artifacts to determine whether the ice mass is an archaeological site. Paleozoological material is not collected during the exploratory surveys but is noted, as it is an indicator that the ice may preserve old organic material.

If there are only a few artifacts, they are collected and recorded using hand-held GPS for geo-positioning. If the artifacts are numerous, we collect a few (leaving markers for more precise georeferencing later) to sample the evidence before a large systematic survey can be conducted. If especially vulnerable finds are discovered, they are also collected, as they may not preserve well until the next survey takes place.

Depending on time, the terrain close to the ice is inspected to check for hunting blinds. Blinds indicate hunting, so even if artifacts are not discovered during an initial visit, chances are that they may still be preserved in the ice. Moreover, ice patches traversed by transport routes can be indicated by rows of cairns to and from the ice. Such structures, as well as a general assessment of the surrounding terrain's suitability for walkers and pack-horses, is noted during initial surveying. It is hard to completely dismiss an ice patch as a non-site based on one visit. A lack of observable artifacts may simply be a consequence of limited melting or a year with a lot of snow covering most of the LFZ (see above). Associated stone features such as blinds and cairns are important clues in these instances. To lay the groundwork for future systematic survey, the first visit should also check out the availability of suitable ground for a basecamp.

Systematic Survey—Choosing Sites

After finding a site, it is added to the potential fieldwork list. Which sites are chosen in a given year, and the scale of the fieldwork, depends on the melting situation. Since there are many sites and both funding and fieldwork time are limited, it is of paramount importance to choose carefully. Ideally, one conducts systematic surveys on sites with a minimum of snow left from the previous winter and with marked ice retreat.

During summer, we use various methods to monitor the melt. The most reliable information is provided by local mountain hikers—acting as "citizen scientists." They visit relevant areas in late winter, spring, and summer, providing ground intelligence on snow conditions at individual sites. From such visits, we gather information on snow depth and drifting. Subsequent visits during the summer provide information on the progression of snow melt. On some sites, this information can also be gained from long-distance ground observations, using binoculars or even telephoto lenses (Figure 5A).

The Juvfonne site (see Figure 1: 1) is situated near a paved road and is open for public outreach in the summer. It also has a weather station close to the ice which records snow depth. This site thus yields important information of general value to the surrounding mountains throughout the summer.

Satellite photos are a valuable tool for following the snow melt both generally and on specific sites in summers with little cloud coverage. In recent years, we have used Sentinel-2 imagery for this purpose. Winter snow is easily visible on the satellite photos. The exposure of darker old ice is normally also easy to see (Figure 5B). When a site is singled out for fieldwork in a given year purely based on remote sensing or long-distance ground observations, it may be visited on foot prior to fieldwork to obtain ground information.

Systematic Survey of Large, Complex Sites

When a site has been discovered to contain many finds, a large-scale systematic survey is the next step. More personnel

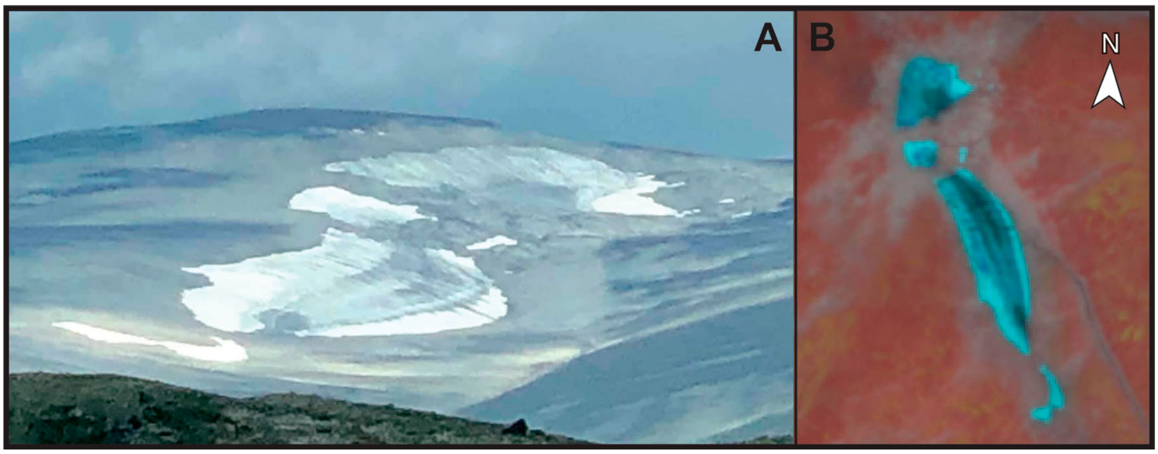

Figure 5. The Langfonne ice patch (Figure 1: 6) in late August 2019. A) Ground photo from ca. 7 km distance, facing northwest (photo: Espen Finstad/Glacier Archaeology Program). B) Sentinel-2 imagery (source: xgeo.no/Copernicus Sentinel data 2019).

Figure 6. A) Packhorses with field equipment and food in the Lendbreen basecamp. B) Helicopter lifting equipment to the Lendbreen basecamp. C) The field crew with heavy packs on their way out from the Trollsteinhøe massif. Notice the long perimeter markers with black flags and the shorter find markers with blue flags strapped to the backpack on the right. D) Basecamp near the Storfonne ice patch after heavy snowfall in August 2018. Photos: Glacier Archaeology Program.

and equipment are needed, and fieldwork takes place over longer periods. In such cases, we set up a basecamp (Figure 6). Some sites are so large that repeated fieldwork over multiple field seasons is necessary. As an example, the Lendbreen site (see Figure 1: 7) was systematically surveyed in five field campaigns from 2011–2015, with a total survey coverage of 250,000 m^2 (Pilø, Finstad, and Barrett 2020). If possible, the basecamp is placed close to the ice to avoid having to start the day with a tiring uphill hike. We use sturdy, inflatable sleeping mats, which allow us to sleep on rough ground and permafrost. Usually, we have a tent for each team member and a common mess tent.

On longer and larger surveys, we have on occasion used a helicopter to lift crew and equipment to basecamp (Figure 6B). In recent years, we have relied on packhorses (Figure 6A) or human helpers for this job to reduce the carbon footprint of the project. Even when transport help is available, we try to keep equipment weight low. Transport help back out may not be available (e.g. helicopter transport is weather dependent), and the recovered finds add additional weight (Figure 6C). In general, we try to rely on low-cost, low-tech equipment, such as bamboo markers with flags instead of the usual survey measuring metal rods.

Survey method

In general, our systematic surveys start at the edge of the ice. The normal survey team is 5–6 people. The team members survey along the ice, following the curve of the edge (Figure 7). There is a ca. 2 m interval between each surveyor, forming a line from the ice edge at 90° outwards in the terrain. The short distance between the individual surveyors is necessary due to the small size of many finds and the uneven nature of the rough and stony ground. These circumstances can easily hide finds from view unless the surveyor is immediately on top of them. Even then, objects may still be obscured from view and recovery if they are deeper in the scree. Such finds may only be recovered if others located on the surface lead to a closer examination of the spot.

When surveying, the person farthest away from the ice places an outer corridor perimeter marker at regular intervals, 1 m outside his/her route. When the group reaches the end of the survey corridor, they make a return survey, using the perimeter markers as an inner guide line. Once an inner perimeter marker is reached, it is passed down the line of surveyors and placed 1 m outside the outermost surveyor.

The terrain surrounding ice patches is uneven and covered in stones. Surveys are usually limited to the LFZ, which shows areas recently exposed by retreating ice. Surveyors walk slowly, stopping and looking around at regular intervals to spot artifacts hidden between the rocks. When a find is located, a marker with a blue flag is used to mark the findspot.

In recent years, finds have started to appear on the surface of the ice (Figure 8B, D), not only on the lichen-free ground surrounding the ice. This is a sign that the melt is reaching layers previously untouched by melt. On such sites, surveys are extended to the ice surface.

The ice edge is not always straight or slightly curved. Sharp turns, ice tongues, and corners appear regularly. Therefore, the survey should be well planned and flexible. During the first run, we often cut over ice tongues. The surveyor closest to the ice often must also cover tongues of bare ground extending into the ice patch, while the rest of the crew wait until this extra ground is covered. This is done

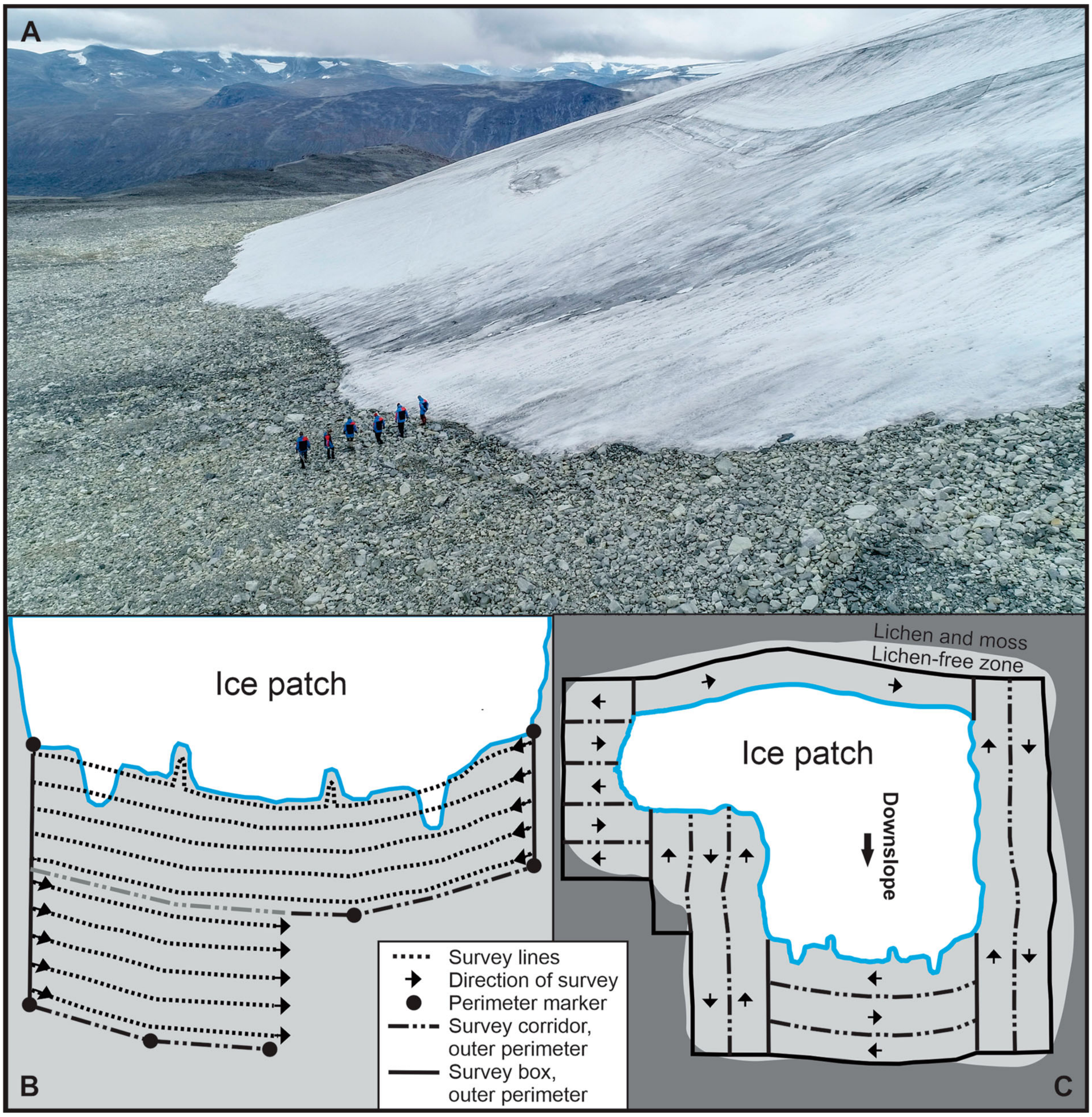

Figure 7: Survey techniques. A) Systematic survey along the curved ice edge of Storfonne ice patch (photo: NRK/Torje Bjellaas). B) Schematic representation of how systematic surveys along the ice are conducted. C) Schematic representation of survey corridors and boxes around an ice patch (drawings B and C: Elling Utvik Wammer/Lars Pilø).

to straighten up the corridors for the following runs. In this way, we avoid unnecessary and problematic corridor turns. Survey does not extend all the way around an ice patch in one go but is divided into survey boxes at different angles on the sides of the ice, forming a large patchwork.

This is a version of systematic survey (Banning 2002) as often used in contexts such as ploughed agricultural land or desert sands, adapted for a very different environment. There are no field furrows to follow, and the line nearly always follows the shape of the ice edge to some extent. The perimeter markers make sure that all surveyed ground is covered evenly, even without straight survey lines or visible footprints in the soil, as is commonly the case in ploughed fields. In our first large-scale systematic survey, at Juvfonne in 2009, we instead did transects extending from the ice outwards (see Taylor et al. 2021), but we find the "follow the ice" technique to be quicker and simpler. It also allows time-limited surveys to start with the areas closest to the ice where most well-preserved objects are found. The only exception to this rule is in steep sections along the sides of an ice patch, where a survey along the ice edge would imply going up and down the steep slope several times. In such cases, we survey in transects along the slope and at a right angle to the ice.

Our systematic surveys with 2 m distance have been practiced at all ice patch sites in Innlandet since 2007. This makes our results inter-comparable. However, some general and site-specific source critical concerns should be kept in mind. For example, some scree (with larger stones) hides archaeological objects more than others. This varies not only from mountain to mountain or site to site but also around one single ice patch and influences the recovery rate of finds. Weather conditions during survey can also influence the surveyor's ability to see finds. Sunglasses are a necessity when working close to the ice on sunny days. Under such conditions, it is hard to see finds in the dark shadows between stones in the scree. We normally slow down the survey tempo in such cases, but this does not fully compensate for the

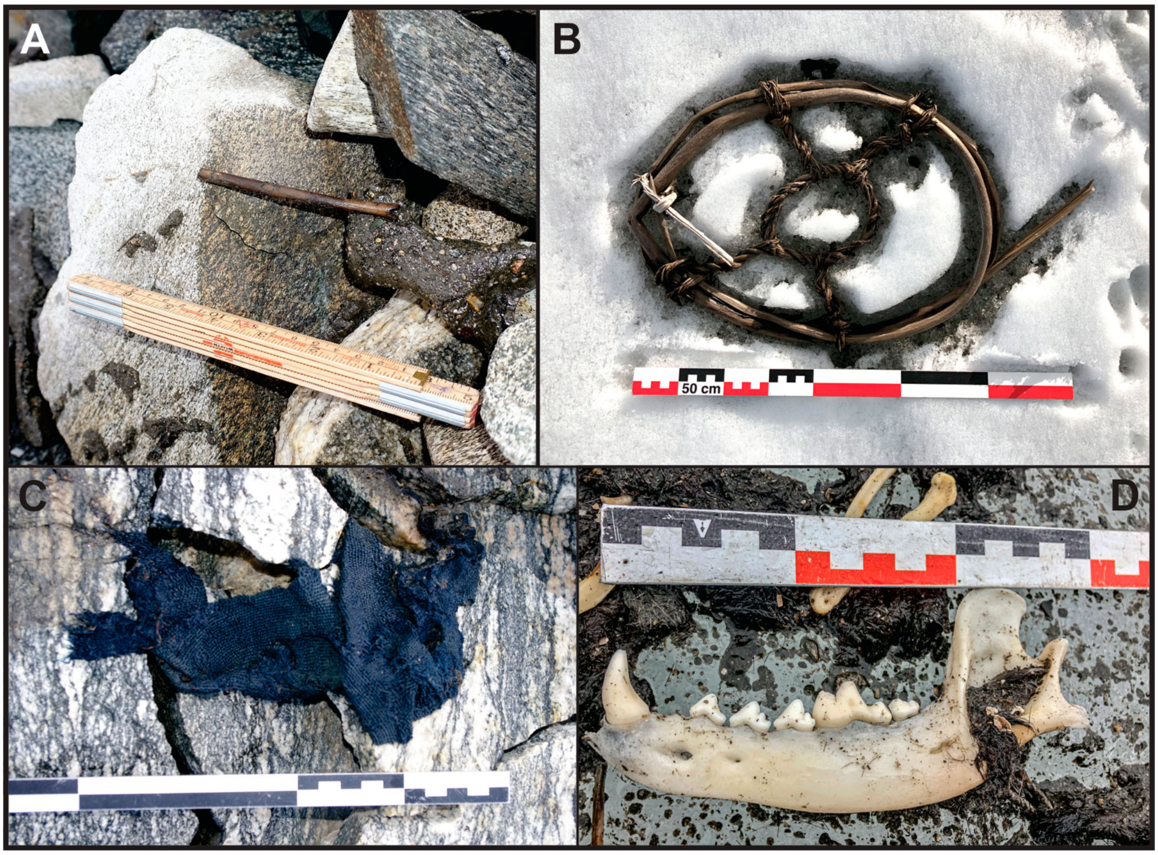

Figure 8. Four examples of finds. A) Short fragment of the proximal end of an arrowshaft, found on the scree at Langfonne (find no. R1B, 6180–5928 CAL B.P., viburnum wood). B) Horse snowshoe, found on the ice at Lendbreen (find no. 1595, 1741–1632 CAL B.P., birch wood). C) Fabric with a blue color still preserved, found on a rock at Lendbreen (find no. 556, 1055–933 CAL B.P., wool). D) Mandible, other bones, and remains of fur from a dog, found with collar and leash on the ice at Lendbreen (find no. 1681, 451–312 CAL B.P.). All radiocarbon dates with 95.4% certainty. Photos: A) Reidar Marstein; B–D) Glacier Archaeology Program.

increased blind spots. The state of the surface and the weather are thus important factors that are relevant to note in the field diary, as repeat survey may be merited.

Documentation of finds

When 10–20 finds have been made, a finds team will separate from the survey group and begin documenting and collecting the objects. The location of each is measured using a high-precision GPS (Figure 9A)—a GNSS receiver using the GPS/GLONASS satellite constellation in combination with a Real Time Kinematic (RTK) system—giving the measurements an accuracy within centimeters where there is cell phone coverage. Without such coverage, precision is 1–2 m. Information about the finds is added to a water-resistant notebook. The artifacts are photographed before they are taken up (Figure 9B), have their ID-labels attached using inorganic string, and are packed in bags or within acid-free paper in cardboard boxes (Figure 9C). For fragile finds such as arrow shafts with arrowheads and sinew attached, foam mats are cut to secure the artifact in the box. Textiles and leather/hide artifacts are stored in snow on-site so they are kept stable. Iron artifacts in this environment hardly have any active corrosion and do not need special care. During fieldwork, artifacts of the same type are repackaged together on-site for ease of transport. Paleozoological material (e.g. reindeer bones or antlers) have their ID-labels attached (Figure 9D) and are normally packed in large plastic bags, as they are sturdier than the artifacts.

All artifact finds and bones/antlers are normally collected during systematic surveys; however, at the Lendbreen site, there were so many finds that pieces of wood smaller than 10 cm, which were not immediately identifiable objects, were not recovered or measured due to time limits.

Excavation

Taphonomic processes on the ice sites lead to the break-up of objects (Pilø et al. 2021). This is especially the case with arrows, where the arrowhead, the fletching, and parts of the shaft may be preserved deeper in the scree below where an arrow shaft is lying visible on the surface. It is thus a regular procedure to remove stones below an arrow find to check for more parts deeper in the scree. Such additional small parts are not always preserved, as they may have already separated from the shaft inside the ice (due to ice movement) or on the ice surface during downslope transport by meltwater.

Objects are sometimes trapped in depressions in the terrain after being released from the ice. In such depressions, silt can accumulate and be covered with moss, even within the otherwise LFZ. It has happened on quite a few occasions that arrows and other finds have been found in pockets like this. Subsequent small excavations in such mud have been fruitful on a few occasions but are not undertaken without prior artifact finds on the mud surface.

Excavating objects still stuck in the ice is a difficult task. If ice axes or chainsaws are used, there is a danger of damaging remains, as happened with Ötzi (see Mackie et al. 2017 for a successful implementation of chainsaws and ice axes). A better way is to thaw out objects using lukewarm water (Figure 10). In our experience, this is nevertheless laborious

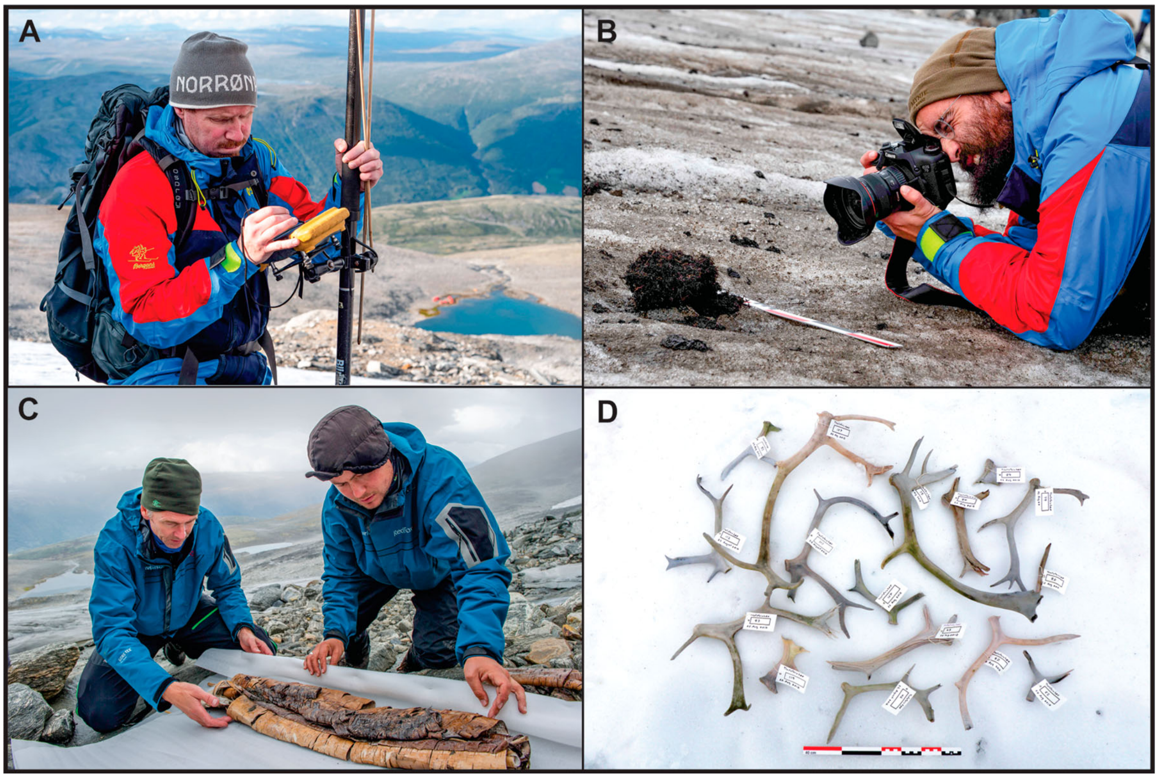

Figure 9: Documentation of finds. A) Measuring the location of a find at Lendbreen, using a high precision GPS. B) Photographing a find on the ice at Lendbreen. C) Packing a container of birch bark, found at Lendbreen. D) Reindeer antler found at the unnamed ice patch at Trollsteinhøe, marked with find labels. Photos: A–B) Glacier Archaeology Program; C) Johan Wildhagen/Palookaville; and, D) James H. Barrett.

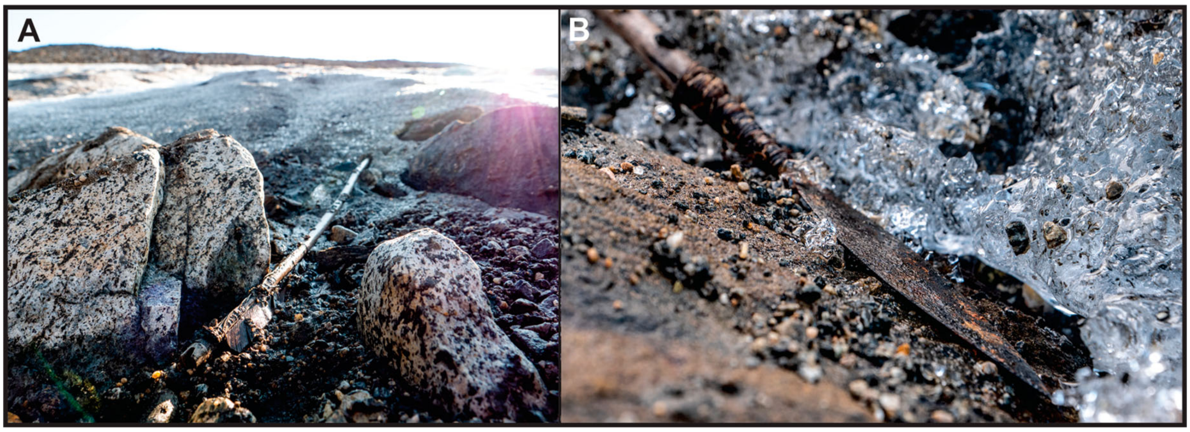

Figure 10: Arrow from ca. 500 A.D., found at an ice patch at Austre Trollsteinhøe (Figure 1: 8) in Jotunheimen in 2019. A) The arrow as found, with the distal end still buried in the ice. B) After thawing out the distal end, using lukewarm water. Photos: Glacier Archaeology Program.

(see also Glauser 2015), and we prefer to wait for natural melting when possible.

Other field documentation of the sites

In addition to measuring the location of the finds, other survey data are also recorded (Figure 11). We measure the ice edge at the time of survey. This makes it possible to determine when the ice has retreated between field seasons and thus if there is need for additional survey close to the ice.

The LFZ is so large on many sites that it is not possible to survey all of it during one expedition, even if it is a basecamp survey of a week or more. When survey stops, we measure the outer perimeter of the area covered to allow us to focus on unsurveyed areas in subsequent fieldwork.

As noted above, hunting blinds and cairns are often associated with ice sites. These are documented (using GPS measurements, photos, and written descriptions) if time permits. We have only made limited use of metal detectors on two sites so far (see Glauser 2015 and Kristensen 2017 for metal detector surveys on glacial archaeological sites).

Documenting the ice

The age of the preserved ice can give valuable information, for example if there is preserved ice from a period with few or no finds. On ice patch sites in Canada and the United States, it has been possible to extract ice cores that contain enough organic carbon (from animal dung and plant material blown onto the ice) to allow for radiocarbon

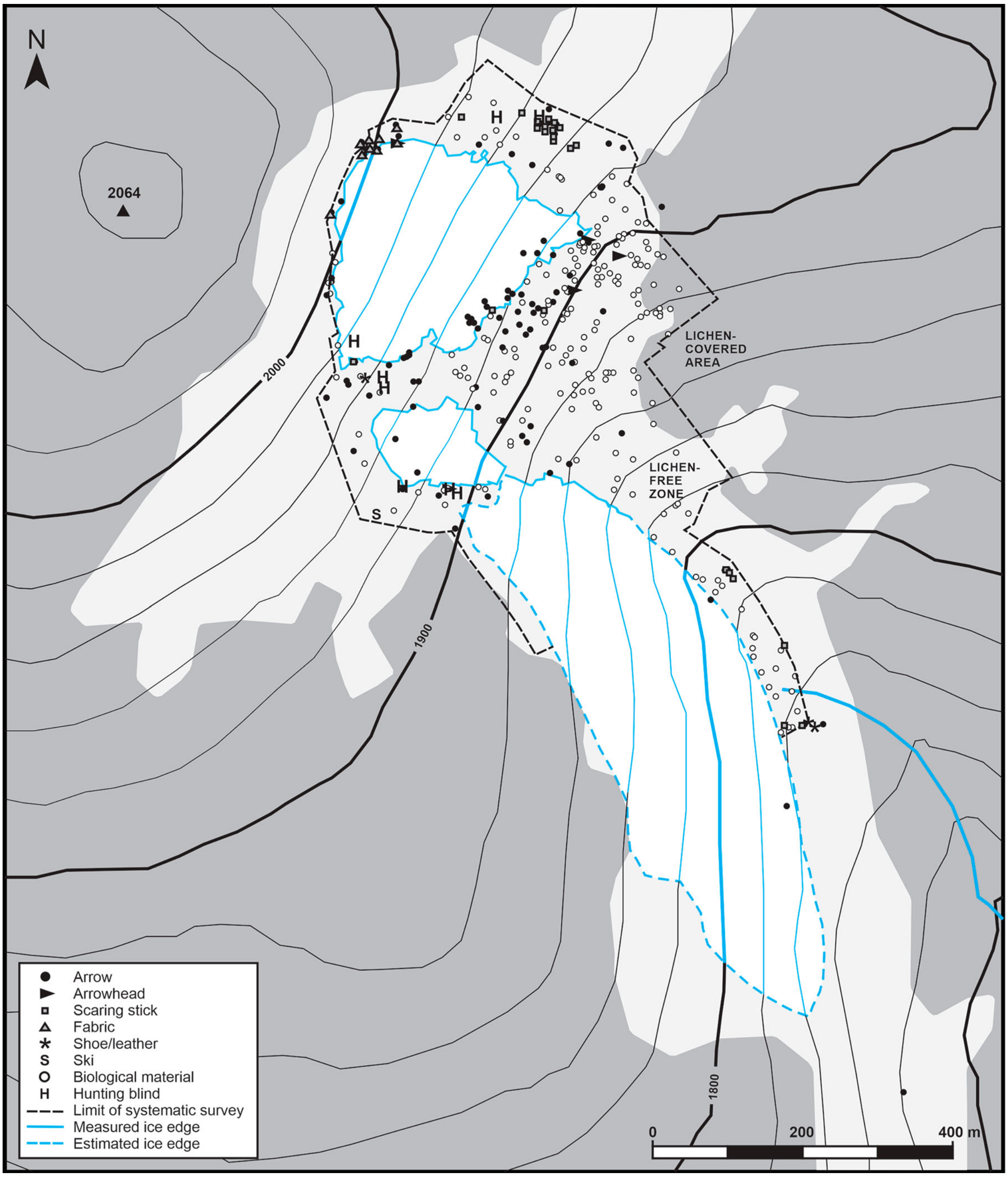

Figure 11. Map of the Langfonne site (Figure 1: 6). First fieldwork in 2006, with two major field campaigns in 2014 and 2016 (Pilø et al. 2021).

dating (Meulendyk et al. 2012; Chellman et al. 2021). In our fieldwork, we have extracted datable material near the melting surface where stratified ice is visible (Pilø et al. 2021; see also Jarrett 2019). Radiocarbon dates have also been obtained from organic material collected from the walls of the ice tunnel in the Juvfonne ice patch and even on carbon in air bubbles in "pure" ice (Ødegård et al. 2017).

Ground penetrating radar (GPR) has been applied at Langfonne and Juvfonne. This type of mapping yields valuable information on ice depth and on ice stratification and deformation. At Langfonne, we succeeded in linking early arrow shafts found on the ice surface to ice layering visible in the GPR section extending from the surface into the core of the ice patch (Pilø et al. 2021). GPR mapping of an ice patch has also recently been conducted in the Rocky Mountains (Ackermann et al. 2021).

The core of thousands-of-years-old ice in ice patches contains important information on regional climate history, as demonstrated by Chellman and colleagues (2021). Such information may not be available from a region's glaciers, due to the limited age of the glacier ice. This type of climate archive is endangered by the current melting and ideally should be documented by coring samples from a selection of the remaining ice patches before they melt away. It must be noted, however, that ice patches are characterized by repeated episodes of accumulation and melting, rather than continuous accretion. Thus, they will seldom provide a continuous climate record.

Safety issues

Due to the high-alpine environment, safety issues must be planned for in advance. Typical fieldwork risk assessments will identify and mitigate pertinent issues, but a few aspects of glacial archaeology merit special mention. When survey takes place on an ice patch itself, crampons or spiked boots are essential. Surveying on glaciers is even more dangerous due to crevasses. In such cases, the crew needs to be roped, use crampons, and carry ice-axes and other safety equipment. The weather in the high mountains can be very unpredictable. We have experienced snow blizzards, strong winds, and temperatures of -10°C at night during fieldwork. The tents used must be specifically designed for these adverse weather conditions. The crew must have proper clothing and winter sleeping bags. Once, at Langfonne in 2016, we had to stop the survey and evacuate the base camp due to a storm. On other occasions, it has been safe enough to hunker down in basecamps during bad weather. There is also a risk of being hit by falling stones when surveying on steep slopes with loose scree. In such cases, surveyors move in a line at a ca. 45° angle to the direction of survey, with the uppermost surveyor leading the line. This way, stones sent downslope by a surveyor will not hit the surveyor below.

Drone survey

Mapping of ice patches can be done in several ways in addition to tracking the ice edge on the ground using a GPS. We have constructed photogrammetric 3D models based on photos taken from a helicopter. We have also created such models from video filmed from a belly-mounted camera on a helicopter. Terrestrial laser scanning is another possibility (Jarrett 2019).

Inexpensive drone mapping is now becoming an attractive alternative. For example, we have tested using a drone for mapping a small unnamed ice patch near Trollsteinhøe in the Jotunheimen Mountains (see Figure 1: 4; Rømer 2020), which has yielded finds from ca. 2000 B.C.–600 A.D. It worked well, producing high-quality survey data (Figure 12). The drone was pre-programmed to fly a planned route and take vertical nadir photos over the ice patch, followed by oblique photos from the sides. The images were processed in AgiSoft Metashape, and a photogrammetric model produced. It was precisely georeferenced using a combination of measured fixpoints in the field and distinctive terrain formations visible on high-precision orthophotos, available at https://norgeibilder.no.

A comparison between the RTK-measured ice edge and the orthophoto generated from the drone images shows an almost complete match. The drone images provide a visual depiction of the ice surface, showing where old ice is present on the surface at the time when fieldwork was conducted. The drone images also show the ice stratification and color. In addition, the 3D model provides information on the height of the ice surface.

A 3D dense point cloud produced in connection with the 3D model could be processed in the same way as lidar data. In this way, it was possible to visualize structures such as hunting blinds in the foreland of the small Trollsteinhøe ice patch. This method is appropriate for mapping structures inside, as well as outside, our foot survey area.

Drone mapping is less practicable on very large sites, such as Lendbreen, where the combination of ice and surveyed terrain is around 600,000 m^2, ten times that at Trollsteinhøe. Here in Norway, drones are only allowed to be flown in line-of-sight, making it impossible to solve the problem of mapping large ice areas by flying higher with a lower resolution.

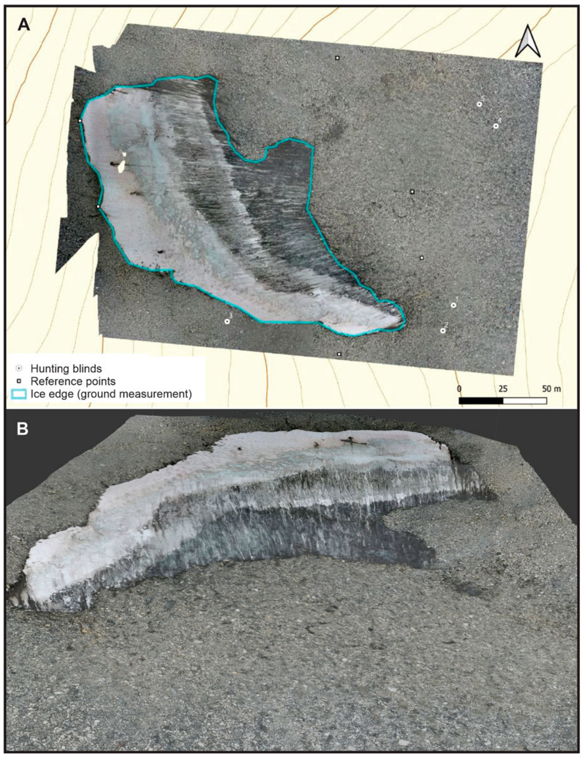

Figure 12: Drone survey. A) Orthophoto produced from drone photos, with the ground-measured ice edge shown. B) 3D model of the same ice patch, seen from east. Orthophoto and 3D model: Axel Hee Rømer.

Our current conclusion is that drone mapping is a valuable part of the survey tool box for glacial archaeology. It sometimes provides higher-quality data than ground measurements and terrestrial photos. In addition, drone mapping can provide high-quality data for documenting natural formation processes of ice melting and accumulation over time if data is collected at the same site on multiple occasions. However, due to the practical limitations of the harsh environment (limiting when flying can occur) and piloting rules, drone mapping is currently not a substitute for traditional low-tech ground mapping.

Monitoring of Already Surveyed Sites during Melt Episodes

Once the LFZ of a site has been systematically surveyed and all finds in surveyed areas have been recorded and removed, work at the site moves into the monitoring phase. No further fieldwork takes place then, until the site sees further ice retreat. When that happens, the previous ice edge is marked in the field using bamboo perimeter markers, defining the inner limit of the previous survey. Previously collected data and measurements of the ice edge are carried in the GPS controller for an accurate positioning of the perimeter markers. A systematic survey will then cover the newly exposed ground for additional finds. Sometimes, a simpler solution is chosen—surveying from the edge of the ice until there are no further finds and one is certain that one is well beyond the previous ice limit. The methods employed are otherwise the same as described previously.

Extinct ice patches only marked by their LFZ can yield finds as the sediments left by the ice erode (VanderHoek et al. 2007). This could warrant further surveys on a site even after all the ice is gone. However, ice patches in Innlandet County contain little sediment, unlike some in North America. Thus, this issue is less prominent here.

Post-Fieldwork

After the completion of survey, the packed finds are transported to the Norwegian Mountain Center in Lom, which serves as a hub for our fieldwork. Here, finds are stored until fieldwork is over. Artifacts of wood are dried slowly in the open, while finds of hide, leather, textile, and samples of other organic materials such as horse dung are deposited in a deep freezer. Some artifacts are exhibited for public viewing in a refrigerated "shopping display" unit during the field season. When snow arrives and fieldwork is over, the artifacts and ecofacts are transported to the Museum of Cultural History in Oslo, who are curating the finds. Paleozoological material which appears to be unmodified and not linked to human use of the sites is stored at the University Museum of Bergen, Department of Natural History. Post-recovery research then begins in cooperation with these museums. The excellent preservation of organic materials opens up avenues for study that are not accessible to other archaeological research (e.g. Vedeler and Jørgensen 2013; Hebda, Greer, and Mackie 2017; Helwig et al. 2021; Pilø et al. 2021).

Discussion and Conclusions

The ongoing melting of mountain glaciers has led to the development of glacial archaeology. We are still at an early stage in this field. Insights gained from the finds melting out of the ice indicate that human use of high-alpine areas was more intensive than previously believed (e.g. Hafner 2015; Pilø, Finstad, and Barrett 2020). As the melting continues, glacial archaeology is bound to expand in scope chronologically, geographically, and in the research questions it can address.

In this paper, we have presented the methods we have used to find and document glacial archaeological sites in our 15 years of work in Innlandet County, Norway. We have adapted survey methods normally used at lower elevations for glacial archaeological sites in the high mountains. Our approach is predominantly low-tech, but nevertheless effective.

We publish our methods and experiences because they will be helpful to an inevitably growing subdiscipline. Global warming is now inexorable (IPCC 2021). Much of the ice in the high mountains of Norway is going to melt away in this century, based on the current climate prognosis (Hanssen-Bauer et al. 2015). The discovery of finds emerging from the retreating ice is a stark reminder of the realities of climate change. As glacial archaeologists, we collect pieces of the past that emerge from the retreating ice. As the ice melts ever further, the finds get progressively older (Callanan 2015; Pilø et al. 2021).

As archaeologists, our immediate focus must be on documenting the melting sites and rescuing the emerging finds before they perish. However, in doing so, we use mainly walk-in methods to reduce the carbon footprint of the program and minimize our contribution to the problem of anthropogenic climate change. This is an option that may not be possible for glacial archaeologists working in more remote areas, where helicopter transport is the only practical solution to reach sites. Our methods will inevitably be adopted with modifications to suit local conditions internationally.

Glacial ice and permafrost have accumulated artifacts and environmental evidence for thousands of years. Climate change is now threatening this record. For the archaeological finds encased in high mountain ice, the threat of melting out is imminent. At the same time, the ongoing melt provides a limited time-window for archaeologists to recover an important archaeological record of human activities in the high mountains. Recovering this record requires an immediate and targeted effort before it is lost.

One of the greatest challenges in glacial archaeology is getting funding to do fieldwork. The sites are situated in the high mountains, outside areas that are being developed, except for the occasional ski lift in Norway and in the Alps. Thus, normal archaeological rescue funding associated with developmental work is not available. Securing funding to undertake fieldwork outside the development framework can be challenging. Moreover, if one acquires funding for pilot research to document needs and scope, unpredictable weather (and year-to-year variability in melting) in the high mountains makes it difficult to guarantee results within typical project timetables.

We conducted our first surveys in 2006, after reports from the public about finds from melting ice. We persevered with fieldwork over the next five years on intermittent and very limited funding. In 2010, we produced a report laying out the number of sites and finds in Oppland County (now part of Innlandet County) and a plan to handle these issues (Finstad and Pilø 2010). We also did substantial public outreach to make our work visible. Having documented the scale and importance of the archaeology, in 2011, we received permanent funding from the Norwegian Ministry of Environment and our own employers. This funding is enough for fieldwork and curating the finds in normal melt years (up to 150 artifact finds). In years of heavy melting and many finds, we apply for extra funding from the Directorate of Cultural Heritage. Nevertheless, we have not yet been able to expand the surveys to cover more remote areas. Due to the long distance from valleys settled with agrarian settlements in the last two millennia, finds are probably fewer here. However, for earlier periods when hunting was of greater importance, the distance to the settled valleys of today is less relevant. Limited exploratory fieldwork has shown that the potential for finds in more remote regions is there. Even with all the effort put in during the last 15 years, the work has only just started.

Acknowledgements

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