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EVIDENCE FOR EARLY HUMAN PRESENCE AT HIGH ALTITUDES IN THE ÖTZTAL ALPS (AUSTRIA/ITALY)

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ABSTRACT. The present article reports on the results and interpretation of a total of 235 radiocarbon dates from Alpine sites in the Ötztal region. Out of these, 88 age determinations were performed on equipment and artifacts associated with the Neolithic Iceman (discovered in 1991), and on a variety of plant and animal specimens collected at his discovery site. Since the material was dispersed over a larger area, ^{14}C dates were important to establish the deposition time of the respective samples. About half of the samples fall into the time period where the Iceman lived, documenting synchronous deposition, whereas the others spread out over several thousand years before and after his lifetime. The other set of samples (147) were collected along the Ötztal Valley to the north, with a few samples collected also south of the Alpine watershed. The samples were mainly from soil profiles and peat bogs above the present-day timberline. Overall, the analysis of the data indicates human presence in these high regions of the Alps throughout the Holocene. While the older botanical and archaeological finds indicate activities of hunting and foraging, the younger ones (after ~5000 BC) point to an intensification of pasturing. This suggests that early human activity was concentrated at altitudes where natural pastures were found, which were probably more favorable than locations at the bottom of the valleys where flooding and other hazards existed. Early users may have come from south of the water divide spreading into the northern regions, particularly during the summer season. It is possible that the Iceman perished at one of his crossings over the probably well-known high-altitude mountain pass due to reasons not yet fully resolved.

INTRODUCTION

During the last glacial period some 22,000 yr ago, the European Alps were covered by a thick layer of ice (Ivy-Ochs et al. 2008). In the ensuing warm period starting around 12,000 yr ago (Holocene), which lasts until today, a large fraction of the ice disappeared, eventually allowing plants to move into regions previously covered with ice (Bortenschlager 2000). In the Alps, an interesting question is, where and when early humans appeared at high altitudes. This topic clearly received a big boost with the accidental discovery of the famous Iceman "Ötzi" in 1991, who was found locked up in a shallow ice patch at an altitude of 3210 m above sea level (asl) on a mountain pass in the Ötztal Alps (Höpfel et al. 1992). Radiocarbon measurements of bone and tissue samples revealed that the Iceman had died between 5350 and 5100 before present (BP = AD 1950) (Bonani et al. 1992, 1994; Hedges et al. 1992). This date was confirmed later by ^{14}C dating of material associated with the Iceman (Kutschera and Müller 2003). The multiplicity of ^{14}C dates from the Iceman site and other regions of the Ötztal Alps presented in the current work allow us to draw conclusions about (i) the material, which most likely belonged to the Iceman, and (ii) human presence at high altitude over a large time period. Although the place of the Iceman find was most likely never inhabitable during the past 10,000 yr, natural pastures above the timberline (2000–2500 m asl) may have existed for thousands of years. They offered favorable conditions, especially during summer months. It was thus of interest to search for evidence of human presence at these altitudes.

The present work concentrates on the Ötztal (Ötz Valley), which runs from the water divide at the main Alpine ridge for about 60 km to the north, draining into the Inn-Danube River system. In order to explore the question of an early appearance of humans in this valley, the area was surveyed over many years, with particular attention paid to finding clues for the presence of humans at high

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altitudes, and to retrieving material at these sites that can be ^{14}C dated. Most of the sampled material was charcoal, but occasionally peat samples were also used. A possible old-wood effect of charcoal, a well-known phenomenon in ^{14}C dating, may in some cases cause a slight shift to older ages. However, since the range of the calibrated ages in Table 3 are generally 200 yr or larger, such (unknown) shifts are neglected and are considered insignificant for the overall picture drawn from the ^{14}C results. Various traces of human activities were identified including indoor and outdoor fireplaces, fire horizons, irrigation sediments, and silex finds. The collected material and the ^{14}C dates provide an approximate overview of human presence at high altitudes covering the past 10,000 yr, and is the first assessment of such activities over a large timespan throughout one of the main high-altitude valleys in the Alps. It therefore contributes to the interesting question of why, how, and when humans started to move into these high-altitude regions after the end of the last glacial period.

The main part of the present work is the description of the evidence for early human presence in regions that may have been habitable at least during the summer months. A total of 147 samples were collected for radiocarbon dating mainly along the Ötztal Valley (Figure 1), but a few also south of the Alpine water divide. The Iceman site at the Tisenjoch (3120 m asl) on the Alpine ridge is marked with a triangle in Figure 1. It may have been used by ancient humans to cross the Alps from south to north and vice versa. Before describing the various sites of human activities and their chronological order, we will first summarize the ^{14}C results from the Iceman site in some detail. Preliminary reports of these findings have been published earlier (Kutschera et al. 2000; Kutschera and Müller 2003).

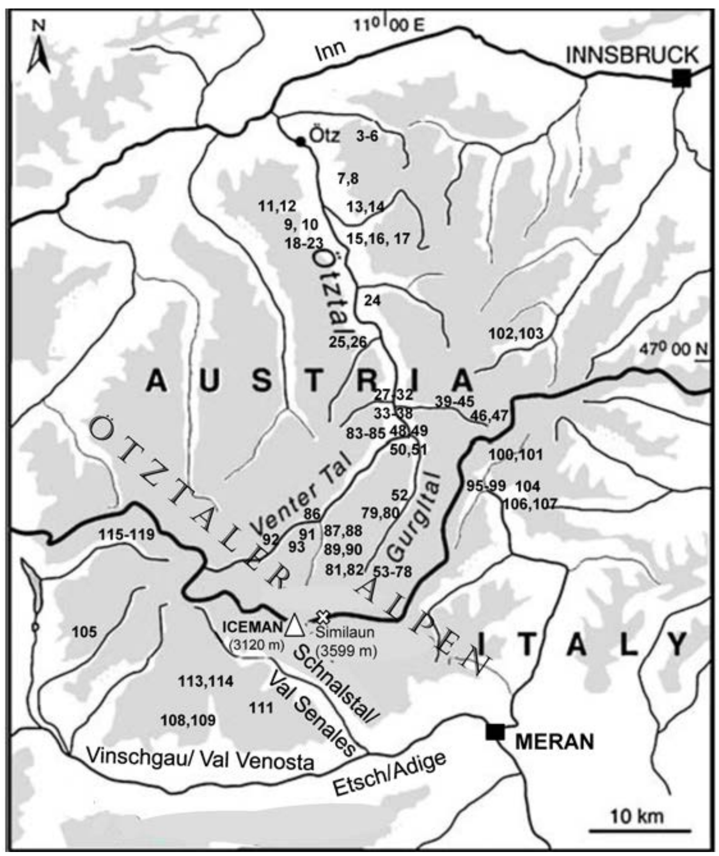

Figure 1 Simplified map of the Ötztal Alps and adjacent regions, modified from Figure 1 of Heiss and Oeggl (2009). The approximate sample locations are marked with numbers and refer to Table 3, where the ^{14}C results are listed. The Iceman site is marked with the triangle. The heavy line across the lower part of the figure marks the main Alpine ridge and the border between Austria and Italy. It also constitutes the water divide. A detailed topographical map of the area can be viewed online, which allows one to identify the location of the sample sites with good resolution.

RADIOCARBON DATING AT THE ICEMAN SITE

The accidental discovery of the Iceman in 1991 was a stroke of luck for archaeology. The circumstances of the discovery and its consequences have been described in many publications (e.g. Höpfel et al. 1992; Spindler 1993; Spindler et al. 1995, 1996; Baroni und Orombelli 1996; Bortenschlager and Oeggl 2000; Fowler 2000; Dickson et al. 2003; Müller et al. 2003; Rastbichler Zissernig 2006; Ruff et al. 2006; Rollo et al. 2007; Ermini et al. 2008; Vanzetti et al. 2010; Paterlini 2011; Keller et al. 2012). First, archaeological inspections of the artifacts found together with the Iceman indicated a Bronze Age context, but ^{14}C measurements revealed that he had lived even earlier, around 5200 yr ago (Bonani et al. 1992, 1994; Hedges et al. 1992). Never before had a human body been found from the Late Neolithic period fully preserved under natural conditions. In addition, it was not a burial find (Zink et al. 2011) but a snapshot from life. Apparently, the Iceman had been preserved for 5000 yr in the shallow patch of ice at the find site shortly after he had died from violent causes (Lippert et al. 2007; Pernter et al. 2007; Nerlich et al. 2009). Although the ice may have melted briefly in warm spells somewhere between 5300 and 2800 yr ago (Acs et al. 2005; Heiss and Oeggl 2009), this apparently had little effect on the excellent state of preservation.

Radiocarbon Dating of the Iceman

It is well known that the varying ^{14}C content in the atmosphere limits the precision of absolute (calendar) ages obtained using ^{14}C dating (Guilderson et al. 2005). This was also the case for the dating of the Iceman. The original ^{14}C measurements were performed with accelerator mass spectrometry (AMS) at the AMS laboratories of Zürich (Bonani et al. 1992, 1994) and Oxford (Hedges et al. 1992). The combined, uncalibrated ^{14}C age with the 1σ uncertainty (68.2% confidence limit) is 4550 ± 19 yr BP. However, due to the wiggles in the calibration curve the uncertainty increases by more than a factor of 10, and the absolute calendar time ranges span from 5310 to 5080 BP (3360–3130 BC) for the 68.2% confidence limit, and from 5320 to 5050 BP (3370–3100 BC) for the 95.4% confidence (Kutschera and Müller 2003). We can therefore conclude that the Iceman died somewhere between 5320 and 5050 yr ago. Even though the uncertainty is large, the result is clearly relevant, as it attributes the remains of the Iceman to the end of the Neolithic Age, which is generally also called the Copper Age, and not into the Bronze Age as originally estimated from evaluating the artifacts found with the Iceman.

Radiocarbon Dating of Material from the Iceman Site

After the date of the Iceman was established to be around 5200 BP, it was interesting to find out whether this period was particularly warm, and thus implying that the finding place of the Iceman may have been ice-free. One year after the Iceman was found, a systematic archaeological excavation was performed (Bagolini et al. 1995). The ice of the rocky depression was completely melted including the thin (approximately 20 cm thick) pristine ice layer at the bottom, where the Iceman was embedded when he was discovered. A large variety of materials was collected, partly by sieving also the meltwater, and after careful inspection at the Institute of Botany of the University of Innsbruck a project was started at the Vienna Environmental Research Accelerator (VERA) to ^{14}C date a variety of selected materials (Jettmar 2003).

Sensitive proxies of climate change are plants that grow at their respective altitude limit. Since precipitation in the Alps is always plentiful, the temperature is the main determining factor for the existence of plants at a particular altitude. A well-known example is the timberline, which moves by about 100 m up or down when the summer temperature raises or falls by about 0.6°C, respectively (Patzelt 2000). This correlation has some relevance for human activities around the timberline in the Ötztal (2000–2500 m asl), discussed below. On the other hand, one would not expect any trees to grow at the Iceman site at 3210 m asl, even at the highest temperatures imaginable during the Holocene. However, some grass species may have made it up to that altitude during favorable climatic conditions. Mosses, on the other hand, seem to be less temperature-sensitive, and grow also in more hostile conditions at this altitude (Dickson et al. 1996). An extensive analysis of plant macroremains from the Iceman site can be found in Heiss and Oeggl (2009). Besides plant and animal remains, a variety of artifacts and pieces of equipment supposedly belonging to the Iceman were ^{14}C dated. Figure 2 shows the distribution of the samples collected at the Iceman site that have been ^{14}C dated.

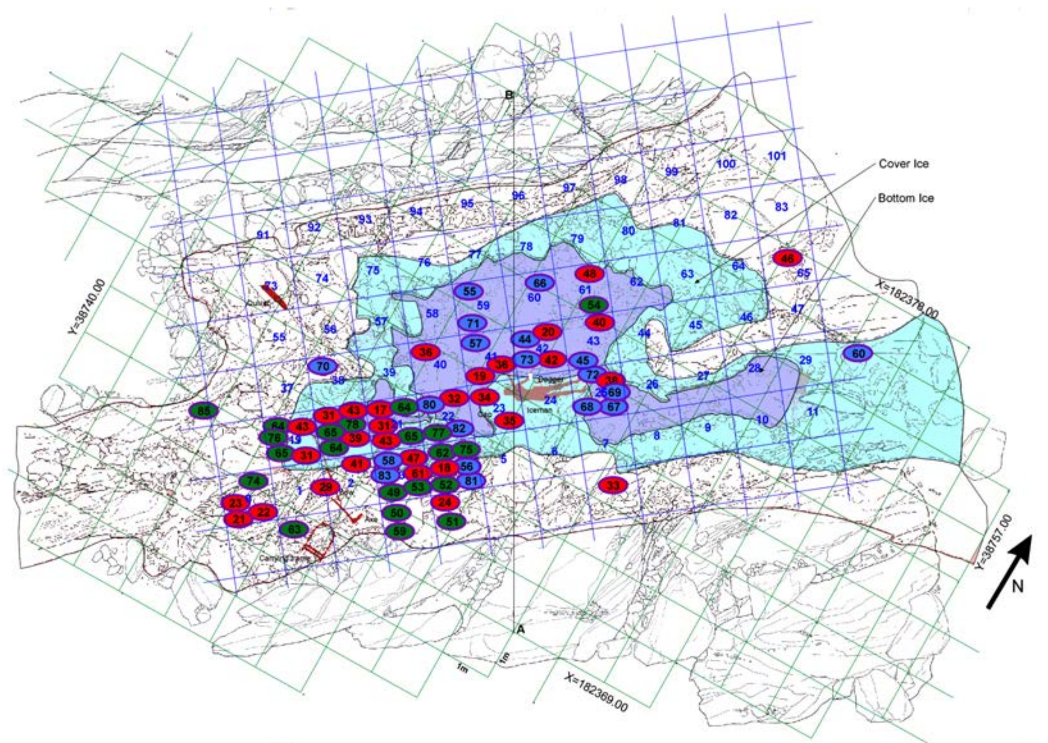

Figure 2 Detailed topography of the Iceman site with the location and numbers of the samples (circled symbols) listed in Table 1, and displayed in Figures 3 and 4. The color code indicates samples that fall into the time period of the Iceman (red), of earlier times (blue), and of later times (green), respectively. The extent of the bottom ice is marked in violet, while the extent of the cover ice added in 1991 (Lippert 1992) to protect the bottom part is marked in light blue. The pink area indicates the largest extent of the rocky depression that can hold water without overflowing. The two grids are the result of the excavation campaign in 1992 (Bagolini et al. 1995). Each quadrant is 1 × 1 m.

Most of the ^{14}C measurements listed in Tables 1 and 2 were performed at VERA using standard procedures for AMS measurements (Jettmar 2003; Steier et al. 2004; Wild et al. 2008). For completeness, ^{14}C measurements from other AMS laboratories are also listed, as far as we are aware of them. This results in 88 ^{14}C dates, which are labeled with a running number in column 2 of the tables. Table 1 summarizes samples that gave dates matching the Iceman time period, whereas Table 2 summarizes those materials that gave dates outside the Iceman time range. In addition, the samples are grouped according to their common origin as belonging to a particular species or other characteristics. In order to assess the sample distribution somewhat more easily, the dates from Tables 1 and 2 are displayed in Figures 3 and 4, respectively. In these figures, the time period from 6000 BC to 1/1 BC/AD is covered. The time period of the Iceman is marked in red, and all other sample dates are shown as black bars covering the age range of the 94.5% confidence level. ^{14}C ages were calculated from the measured $^{14}C/^{12}C$ atom ratios normalized by $\delta^{13}C$ (Stuiver and Polach 1977). Calibration was performed with the OxCal v 4.2 program (Bronk Ramsey 2001, 2009) using the IntCal13 calibration curve (Reimer et al. 2013).

DISCUSSION OF THE RESULTS

All ^{14}C dates displayed in Figure 3 fall into the period of the Iceman. This suggests an association with the Iceman, which is supported by the fact that these materials could not possibly originate from the find place itself, and confirm a contemporaneous deposition of the artifacts and the body. For example, the bast or grass samples of his cape belong to species that cannot grow at this altitude (Acs et al. 2005; Heiss and Oeggl 2009). The assignment of the various materials to the Iceman is a good example of the power of ^{14}C dating, even though the uncertainties of individual results are in the 200-yr range due to the well-known problem of "wiggles" in the calibration curve (Guilderson et al. 2005).

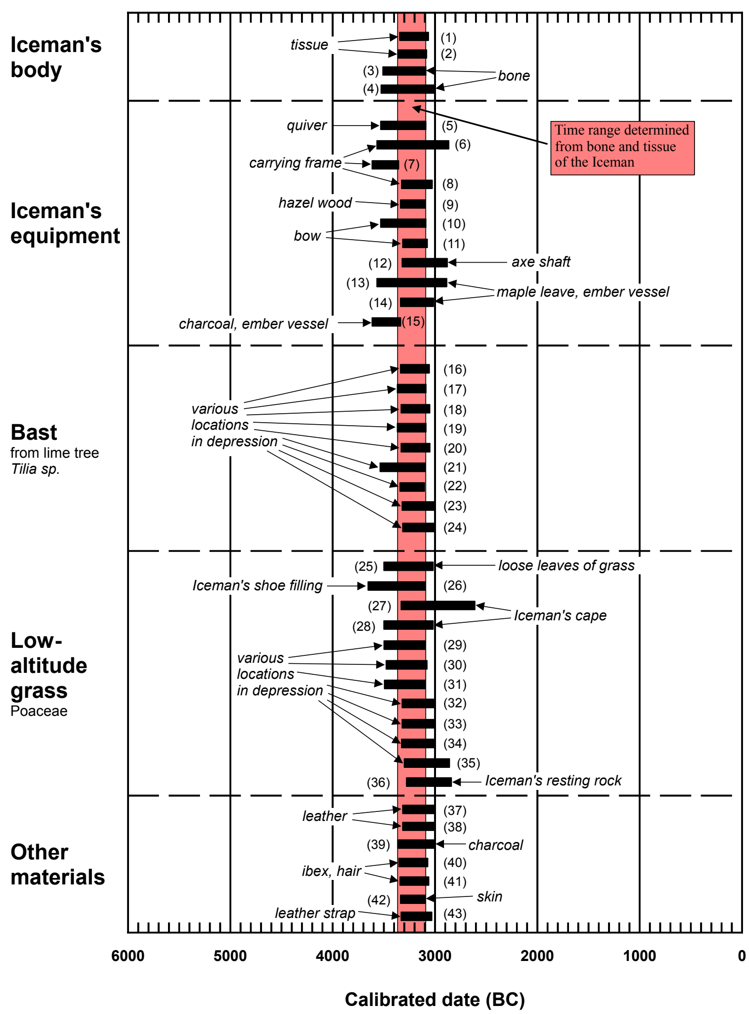

Figure 3 Summary of ^{14}C measurements on materials that are most likely directly associated with the Iceman. The red band indicates the calibrated time range (95.4% probability) obtained from bone and tissue of the Iceman's body (Bonani et al. 1992, 1994; Hedges et al. 1992; Kutschera and Müller 2003). All additional dates are shown with filled block symbols for calibrated time ranges (95.4% probability) of the respective materials. Numbers in parentheses refer to Table 1.

Figure 4 displays a variety of materials whose ^{14}C dates clearly fall outside the time period of the Iceman. They belong to mosses and grasses thriving in the near vicinity of the gully. Leaves and needles of woody species grow in the wider vicinity as well as wood. The presence of animal droppings over a larger time period is not surprising since the results of the coprolite analyses (Oeggl et al. 2009) suggest that the droppings originate from game (*Capra ibex*, *Rupicapra rupicapra*) rather than from livestock (*Ovis/Capra*), and it can be expected that caprine animals used to high altitudes were crossing the mountain pass at all times. Most interesting are various pieces of wood of a size that had to be carried by man to the discovery site, indicating the local presence of humans up to 2000 yr before the Iceman. Such an early presence of humans in the Ötztal region is confirmed by the findings discussed in the following section.

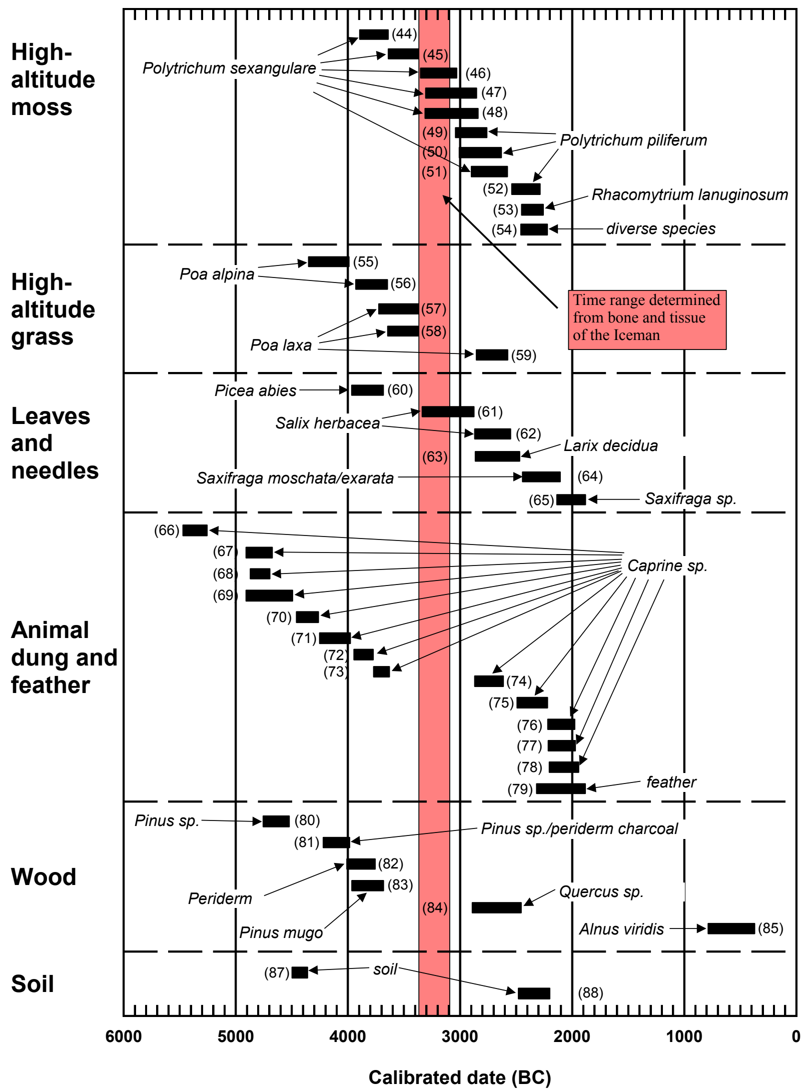

Figure 4 Summary of ^{14}C measurements that fall outside the range of the Iceman. As in Figure 3, the red band indicates the calibrated time range (95.4% probability) obtained from bone and tissue of the Iceman's body. All additional dates are shown with filled block symbols for calibrated time ranges (95.4% probability) of the respective materials. Numbers in parentheses refer to Table 2. Note that with one exception no samples younger than 2000 BC were found.

Table 1 Radiocarbon dating results for materials matching the time period of the Iceman.

^{14}C lab nr[a]	Sample nr[b]	Material	Species	Location	^{14}C age (yr BP)	Calibrated time range (yr BC)[c]
Iceman's body						
OxA-**1[d]	619/91/O5 WT (1)	Tissue	human, *Homo sapiens sapiens*	Iceman's left hip	4500 ± 30	3350–3095
ETH-8345.1-2[e]	619/91/Z5 WT (2)	Tissue	human, *H. s. sapiens*	Iceman's left hip	4555 ± 34	3485–3100
Ox A-**2[d]	619/91/O2 KN (3)	Bone	human, *H. s. sapiens*	Iceman's left hip	4580 ± 30	3500–3115
ETH-8342[e]	619/91/Z2 KN (4)	Bone	human, *H. s. sapiens*	Iceman's left hip	4560 ± 65	3520–3020
Iceman's equipment						
GifA-94**[f]	B-91/32 (5)	Wood	hazel, *Corylus avellana*	Stiffening rod of the quiver	4605 ± 40	3520–3120
GifA-94**2[f]	B-91/33 (6)	Wood	hazel, *Corylus avellana*	Carrying frame, broken end of hazel rod	4540 ± 70	3510–3010
GifA-94**3[f]	B-91/34 (7)	Wood	hazel, *Corylus avellana*	Carrying frame, broken end of hazel rod	4645 ± 40	3620–3350
GifA-94**6[f]	B-91/37 (8)	Wood	hazel, *Corylus avellana*	Carrying frame, splinter from broken end	4480 ± 40	3350–3025
VERA-0051[f]	91/96 (9)	Wood	hazel, *Corylus avellana*	Recovered during sample washing	4520 ± 30	3360–3100
GifA-94**4[f]	B-91/35 (10)	Wood	yew, *Taxus baccata*	Bow, splinter from broken end	4595 ± 40	3515–3110
VERA-0050[f]	B-91/35(11)	Wood	yew, *Taxus baccata*	Bow, parallel sample to GIFA-94**5	4500 ± 30	3350–3095
GifA-94**5[f]	B-91/36 (12)	Wood	yew, *Taxus baccata*	Axe shaft, wood from the inner side of branch retaining the blade	4460 ± 40	3350–2940
GifA-93047[f]	B-91/38 (13)	Leave	maple, *Acer platanoides*	Ember vessel found near the quiver	4540 ± 70	3510–3010
VERA-0049[f]	91/139 (14)	Leave	maple, *Acer platanoides*	Ember vessel, paral. sample to GIFA-93047	4510 ± 40	3365–3090
VERA-0053[f]	91/139 (15)	Charcoal	conifer	Ember vessel, recovered from meltwater	4690 ± 40	3630–3365
Bast						
VERA-0593	92/52 (16)	Bast	lime, *Tilia sp.*	Recovered from meltwater	4505 ± 43	3360–3030
VERA-0594	92/79 (17)	Bast	lime, *Tilia sp.*	Sieve sample from bottom ice, quadrant 21	4550 ± 40	3485–3095
VERA-0605	92/184 (18)	Bast	lime, *Tilia sp.*	Sediment, quadrant 4	4480 ± 40	3350–3025
VERA-0611	92/236 (19)	Bast	lime, *Tilia sp.*	Quadrant 41	4545 ± 40	3370–3095
VERA-0614	92/255 (20)	Bast	lime, *Tilia sp.*	Sediment from ice at quadrant 42	4490 ± 35	3350–3030
VERA-0628	92/357 (21)	Bast	lime, *Tilia sp.*	West at southern ridge, quadrant 0	4570 ± 45	3500–3100
VERA-0633	92/357 (22)	Bast	lime, *Tilia sp.*	Sediment from bottom of quadrant 0	4520 ± 40	3365–3095
VERA-0637	92/357 (23)	Bast	lime, *Tilia sp.*	Sediment from bottom of quadrant 0	4490 ± 35	3350–3030
VERA-0641	92/370 (24)	Bast	lime, *Tilia sp.*	Sediment south of quadrant 4	4505 ± 45	3360–3030
Low-altitude grass						
ETH-8345-3[e]	619/91/Z5 G (25)	Grass	grass, *Poaceae*	Loose grass leaf blades	4535 ± 60	3500–3020

Table 1 Radiocarbon dating results for materials matching the time period of the Iceman.

^{14}C lab nr[a]	Sample nr[b]	Material	Species	Location	^{14}C age (yr BP)	Calibrated time range (yr BC)[c]
Ua-2373[f]	B-91/3 (26)	Grass	grass, *Poaceae*	From filling of Iceman's left shoe	4610 ± 50	3630–3110
Ua-2374[f]	B-91/16a (27)	Grass	grass, *Poaceae*	From Iceman's grass cape	4345 ± 100	3360–2690
GifA-91413[f]	B-91/16b (28)	Grass	grass, *Poaceae*	From Iceman's grass cape	4550 ± 60	3500–3030
VERA-0599	92/117 (29)	Grass	grass, *Poaceae*	At broken bow location, from the ice	4570 ± 45	3500–3100
GX-18504-AMS[g]	92/27 (30)	Grass	grass, *Poaceae*	Waterdrain, from frozen meltwater of 1991	4555 ± 50	3500–3090
VERA-0607	92/185 (31)	Grass	grass, *Poaceae*	Quadrant 19, 20, 21, meltwater	4580 ± 55	3520–3090
VERA-0626	92/306 (32)	Grass	grass, *Poaceae*	Sediment, quadrant 22, bottom	4485 ± 45	3355–3025
VERA-0604	92/175 (33)	Grass	grass, *Poaceae*	South of quadrant 7	4475 ± 45	3355–3020
VERA-0592	92/44 (34)	Grass	grass, *Poaceae*	Quadrant 23	4465 ± 40	3350–3015
VERA-0619	92/263 (35)	Grass	grass, *Poaceae*	Sediment, quadrant 23	4440 ± 60	3340–2920
VERA-0612	92/240 (36)	Grass	grass, *Poaceae*	Resting rock of the Iceman, quadrants 40, 41	4405 ± 45	3330–2905
Other materials						
VERA-0054	92/181 (37)	Leather		Recovered from water drain	4480 ± 40	3350–3025
VERA-0609	92/215 (38)	Leather		Sediment from bedrock of quadrant 25	4490 ± 35	3350–3030
VERA-0596	92/80 (39)	Charcoal	conifer	Sieve sample from bottom ice, quadrant 20	4510 ± 60	3380–3010
VERA-0056	92/283 (40)	Hair	ibex, *Capra ibex*	Sediment from bottom of quadrant 43	4510 ± 30	3355–3095
VERA-0635	92/332 (41)	Hair		Sediment south of quadrant 20	4525 ± 35	3365–3095
VERA-0615	92/255 (42)	Skin		Sediment from ice in quadrant 42	4505 ± 35	3355–3095
VERA-0606	92/185 (43)	Leather strap		Sieve sample from quadrants 19, 20, 21	4485 ± 40	3350–3025

[a] For results obtained from other sources, the superscript given on the ^{14}C lab nr indicates the corresponding reference listed below. The lab numbers refer to the following AMS laboratories: OxA = University of Oxford, ETH = ETH Zürich, GifA = Gif-sur-Yvette, Ua = Uppsala, VERA = VERA Lab Vienna, GX = Geochron Boston.
[b] Origin of sample, e.g. all samples with 92/xxx refer to the excavation of Bagolini et al. 1995. (#) is a running number to identify the samples in Figures 3 and 4.
[c] The true date lies with 95.4% probability within the given time range.
[d] Hedges et al. 1992.
[e] Bonani et al. 1994.
[f] Rom et al. 1999.
[g] Prinoth-Fornwagner and Niklaus 1994.

Table 2 Radiocarbon dating results for materials not matching the time period of the Iceman.

^{14}C lab nr[a]	Sample nr[b]	Material	Species	Location	^{14}C age (yr BP)	Calibrated time range (yr BC)[c]
High-altitude moss						
VERA-0627	92/307 (44)	Moss	moss, *Polytrichum sexangulare*	Sediment from ice of quadrant 42	4970 ± 35	3910–3655
VERA-0055[d]	92/283 (45)	Moss	moss, *P. sexangulare*	Sediment from bottom of quadrant 43	4700 ± 40	3635–3370
VERA-0608	92/210 (46)	Moss	moss, *P. sexangulare*	Sediment from bedrock of quadrant 65	4510 ± 45	3365–3030
VERA-1695	92/402a (47)	Moss	moss, *P. sexangulare*	From cracks between rocks of quadrant 3	4420 ± 35	3325–2915
VERA-0622	92/300 (48)	Moss	moss, *P. sexangulare*	Sediment from ice and bottom of quadrant 61	4360 ± 65	3330–2880
VERA-1694	92/402a (49)	Moss	moss, *P. sexangulare*	From cracks between rocks of quadrant 3	4325 ± 30	3020–2890
VERA-1698	92/371 (50)	Moss	moss, *P. sexangulare*	At quadratmeter south of quadrant 3	4260 ± 45	3015–2690
VERA-0642	92/409 (51)	Moss	moss, *P. sexangulare*	Quadratmeter south of quadrant 4	4220 ± 60	2930–2610
VERA-1692	92/409a (52)	Moss	moss, *P. sexangulare*	Quadrant 4	3960 ± 30	2575–2345
VERA-1690	92/402b (53)	Moss	moss, *Rhacomytrium lanuginosum*	From cracks between rocks of quadrant 3	3925 ± 30	2490–2295
VERA-0623	92/300 (54)	Moss	moss, diverse species	Sediment from ice & rocks of quadrant 61	3905 ± 35	2480–2285
High-altitude grass						
VERA-0621	92/299 (55)	Grass	Alpine meadow grass, *Poa alpina*	Sediment from ice of quadrant 59	5375 ± 85	4360–3990
VERA-1691	92/409a (56)	Grass	tufted meadow grass, *Poa laxa*	Quadrant 4	4980 ± 35	3930–3660
VERA-0625	92/305 (57)	Grass	Alpine meadow grass, *P. alpina*	Sediment from ice of quadrant 41	4785 ± 65	3700–3370
VERA-1693	92/402a (58)	Grass	tufted meadow grass, *P. laxa*	From cracks between rocks at quadrant 3	4670 ± 35	3625–3365
VERA-1699	92/371 (59)	Grass	tufted meadow grass, *P. laxa*	From square meter south of quadrant 3		4190 ± 40
Leaves and needles						
VERA-0630	92/315 (60)	Needles	spruce, *Picea abies*	Sediment from quadrant 30	5070 ± 65	3990–3700

Table 2 Radiocarbon dating results for materials not matching the time period of the Iceman.

^{14}C lab nr[a]	Sample nr[b]	Material	Species	Location	^{14}C age (yr BP)	Calibrated time range (yr BC)[c]
VERA-1696	92/402a (61)	Leaves	dwarf willow, *Salix herbacea*	From cracks between rocks of quadrant 3	4420 ± 35	3325–2915
VERA-1688	92/409a (62)	Leaves	dwarf willow, *Salix herbacea*	Quadrant 4	4120 ± 30	2870–2575
VERA-0639	92/358 (63)	Needles	larch, *Larix decidua*	Sediment at sqm. south of quadrant 1	4110 ± 70	2880–2490
VERA-0601	92/134 (64)	Leaves	saxifrage, *Sax. moschata/exarata*	Sieve sample, quadrants 19, 20, 21	3840 ± 50	2470–2140
VERA-0600	92/134 (65)	Leaves	saxifrage, *Saxifraga* sp.	Sieve sample, quadrants 19, 20, 21	3635 ± 45	2140–1890
Animal dung and feather						
VERA-0632	92/317 (66)	Dung	goat-antelope, *Caprine*	Sediment from bottom ice of quadrant 60	6365 ± 40	5470–5230
VERA-0610	92/215 (67)	Dung	goat-antelope, *Caprine*	Sediment from bedrock of quadrant 25	5955 ± 40	4940–4725
VERA-0616	92/215 (68)	Dung	goat-antelope, *Caprine*	Sediment from bedrock of quadrant 25	5940 ± 35	4935–4720
ETH-13038[e]	92/313 (69)	Dung	goat-antelope, *Caprine*	East of Iceman resting rock, quadrant 25	5890 ± 70	4950–4580
VERA-0620	92/264 (70)	Dung	goat-antelope, *Caprine*	Sediment from bottom of quadrant 38	5505 ± 35	4450–4265
VERA-0631	92/316 (71)	Dung	goat-antelope, *Caprine*	Sediment on the bottom ice of quadrant 59	5235 ± 40	4230–3965
VERA-0613	92/249 (72)	Dung	goat-antelope, *Caprine*	Sediment from bottom (below ice) of quadrant 25	5035 ± 25	3950–3765
VERA-0617	92/255 (73)	Dung	goat-antelope, *Caprine*	Sediment from ice of quadrant 42	4965 ± 35	3905–3650
VERA-0638	92/357 (74)	Dung	goat-antelope, *Caprine*	Sediment from bottom of quadrant 0	4170 ± 35	2885–2630
VERA-0634	92/331 (75)	Dung	goat-antelope, *Caprine*	Sediment from sqm. South of quadrant 22	3900 ± 40	2485–2210

Table 2 Radiocarbon dating results for materials not matching the time period of the Iceman.

^{14}C lab nr[a]	Sample nr[b]	Material	Species	Location	^{14}C age (yr BP)	Calibrated time range (yr BC)[c]
VERA-0597	92/81 (76)	Dung	goat-antelope, *Caprine*	Sieve sample from bottom ice, quadrant 19	3715 ± 35	2210–1980
VERA-0618	92/262 (77)	Dung	goat-antelope, *Caprine*	Sediment from quadrant 22	3705 ± 35	2205–1980
VERA-0595	92/80 (78)	Dung	goat-antelope, *Caprine*	Sieve sample from bottom ice, quadrant 20	3675 ± 35	2195–1950
ETH-13037[f]	92/29 (79)	Feather	bird	Waterdrain, from frozen meltwater of 1991	3695 ± 65	2290–1910
Wood						
VERA-0052[d]	92/292 (80)	Wood	pine, *Pinus* sp.	On the southern ridge	5820 ± 40	4785–4555
VERA-1689	92/409a (81)	Charcoal	pine, *Pinus* sp./*periderm*	Quadrant 4	5280 ± 30	4235–3995
VERA-0636	92/348 (82)	Wood	conifer, *periderm*	Meltwater from quadrant 22	5135 ± 45	4040–3795
VERA-1697	92/402a (83)	Wood	dwarf pine, *Pinus mugo/sylvestris*	From cracks between rocks of quadrant 3	5070 ± 50	3970–3710
ETH-19096	92/402a (84)	Wood	oak, *Quercus* sp.	Axe shaft, found ~100 m from Iceman site	4060 ± 55	2870–2470
VERA-0048[d]	B-92/275 (85)	Wood	green alder, *Alnus viridis*	In western part of depression	2500 ± 40	795–485
VERA-1687	00/411 (86)	Wood	deciduous tree, *Prunus* sp.	Stray find from western ridge	>modern	
Soil						
GX-20678-AMS[g]	(87)	Soil	whole organic fraction	Rocky depression ~100 m from Iceman site	5615 ± 55	4550–4340
GX-20677-AMS[g]	(88)	Soil	whole organic fraction	Rocky depression ~100 m from Iceman site	3885 ± 60	2570–2190

[a] For results obtained from other sources, the superscript given on the ^{14}C lab nr indicates the corresponding reference listed below. The lab numbers refer to the following AMS laboratories: OxA = University of Oxford, ETH = ETH Zürich, GifA = Gif-sur-Yvette, Ua = Uppsala, VERA = VERA Lab Vienna, GX = Geochron Boston.
[b] Origin of sample, e.g. all samples with 92/xxx refer to the excavation of Bagolini et al. 1995. (#) is a running number to identify the samples in Figures 3 and 4.
[c] The true date lies with 95.4% probability within the given time range.
[d] Rom et al. 1999.
[e] G Bonani, private communication to R Fornwagner, 9 December 1994.
[f] Prinoth-Fornwagner and Niklaus 1994.
[g] Baroni and Orombelli 1996.

Table 3 Results of ^{14}C dating for samples indicating human activity in locations of the Ötztaler Alps and surrounding regions.

ID #	^{14}C lab #[a]	Sample #	Material	Location	Altitude (m asl)	Comment	^{14}C age (yr BP)	Calibrated time range (yr BC)[b]
^{14}C dates from soil profiles								
1	VERA-3844	AF 1-1	Wood	Feldalm-Alpach	1775	1st clearing	5940 ± 40	4935 BC–4720 BC
2	VERA-3845	AF 2-1	Wood	Feldalm-Alpach	1780	2nd clearing	2255 ± 40	400 BC–200 BC
3	VERA-2887	WT 1-2	Charcoal	Wörgetal	2180	indoor fireplace	2795 ± 30	1020 BC–845 BC
4	VRI-2146	WT 2-2	Charcoal	Wörgetal	2180	indoor fireplace	2270 ± 40	405 BC–205 BC
5	VERA-2847	WT 3-2	Charcoal	Wörgetal	2265	indoor fireplace	1730 ± 40	220 AD–405 AD
6	VERA-3846	WT 3-1	Charcoal	Wörgetal	2265	indoor fireplace	3450 ± 40	1885 BC–1665 BC
7	VRI-1988	Farst-1	Charcoal	Farst	1670	fire horizon	3010 ± 50	1410 BC–1110 BC
8	VRI-1998	Farst-2	Charcoal	Farst	1550	fire horizon	3910 ± 50	2570 BC–2200 BC
9	VERA-0015	FA-4	Charcoal	Vordere Fundusalm	1610	irrigation	1580 ± 35	400 AD–555 AD
10	VRI-1516	Fundus-1	Charcoal	Hintere Fundusalm	1940	fireplace	8300 ± 80	7530 BC–7080 BC
11	VRI-1654	LA-1	Charcoal	Leiersalm	2020	1st fire clearing	1460 ± 50	430 AD–670 AD
12	VERA-0016	LA-5	Charcoal	Hintere Leiersalm	2060	fire clearing	5705 ± 40	4685 BC–4455 BC
13	VRI-2112	NSH-1	Peat	Niederthai-Sennhof	1540	fertilized meadow	1480 ± 50	420 AD–660 AD
14	VERA-2574	NSH-2	Charcoal	Niederthai-Sennhof	1540	fire clearing	2475 ± 35	775 BC–430 BC
15	VERA-2079	NT-2	Charcoal	Niederthai	1565	fire horizon	1570 ± 30	415 AD–560 AD
16	VERA-2080	NT-3	Charcoal	Niederthai	1560	fire horizon	3035 ± 30	1400 BC–1210 BC
17	VERA-2078	NT-1	Charcoal	Niederthai	1565	1st fire clearing	3295 ± 35	1660 BC–1495 BC
18	VERA-1311	KO-1	Charcoal	Köfels	1410	irrigation	1240 ± 35	680 AD–885 AD
19	VERA-1312	KO-2	Charcoal	Köfels	1398	fire horizon	1590 ± 40	390 AD–560 AD
20	VERA-2889	KO-3	Charcoal	Köfels	1350	1st fire clearing	2490 ± 35	790 BC–485 BC
21	VRI-2097	KW-1	Charcoal	Köfels	1460	irrigation	1100 ± 50	770 AD–1030 AD
22	VERA-2515	KW-2	Charcoal	Köfels	1460	farmed soil	720 ± 40	1220 AD–1390 AD
23	VERA-2516	KW-3	Charcoal	Köfels	1460	1st fire clearing	1620 ± 30	380 AD–540 AD
24	VRI-1731	BST-2	Charcoal	Burgstein	1410	1st fire clearing	2500 ± 50	800 BC–430 BC
25	VERA-2885	EA-1	Charcoal	Ebenalm-Huben	2070	fire clearing	1935 ± 35	40 BC–135 AD
26	VERA-3848	EA-2	Charcoal	Ebenalm-Huben	2070	1st fire clearing	2550 ± 40	810 BC–540 BC
27	VERA-2367	SH-1	Charcoal	Sölden-Höfle	1360	1st fire clearing	945 ± 40	1015 AD–1185 AD
28	VRI-1734	SB-1	Charcoal	Sölden-Brandl	1410	1st fire clearing	1060 ± 40	890 AD–1030 AD
29	VRI-1720	SSW-1	Charcoal	Sölden-Sonnwinkel	1380	1st fire clearing	1320 ± 50	610 AD–860 AD

Table 3 Results of ^{14}C dating for samples indicating human activity in locations of the Ötztaler Alps and surrounding regions.

ID #	^{14}C lab #[a]	Sample #	Material	Location	Altitude (m asl)	Comment	^{14}C age (yr BP)	Calibrated time range (yr BC)[b]
30	VRI-2000	SBB-1	Charcoal	Sölden-Brunnberg	1915	1st fire clearing	1350 ± 50	600 AD–770 AD
31	VRI-2001	SBB-2	Charcoal	Sölden-Brunnberg	1890	1st fire clearing	1380 ± 50	570 AD–770 AD
32	VRI-1999	STH-1	Charcoal	Sölden-Tyrolerhof	1360	1st fire clearing	1760 ± 50	130 AD–390 AD
33	VRI-1972	SIW-2	Charcoal	Sölden-Innerwald	1495	2nd fire clearing	1030 ± 50	890 AD–1160 AD
34	VRI-1971	SIW-1	Charcoal	Sölden-Innerwald	1495	1st fire clearing	2210 ± 50	400 BC–160 BC
35	VERA-121	GA-2	Charcoal	Gampa Alm	1980	1st fire clearing	4975 ± 30	3910 BC–3660 BC
36	VRI-1806	GA-3	Charcoal	Gampa Alm	1980	2nd fire clearing	2420 ± 50	760 BC–390 BC
37	VERA-2517	KA-2	Charcoal	Kleble Alm	1980	mountain pasture	575 ± 35	1295 AD–1425 AD
38	VERA-2229	KA-1	Charcoal	Kleble Alm	2210	1st fire clearing	1070 ± 40	885 AD–1025 AD
39	VRI-2144	WL-1	Charcoal	Windach-Loobkar	2410	fire horizon	3300 ± 50	1730 BC–1450 BC
40	GrN-21993	WB-5	Charcoal	Windach-Bruggen	1870	fire horizon	1980 ± 20	40 BC–70 AD
41	VERA-1628	WDA-3	Charcoal	Windachalm	1960	irrigation	760 ± 30	1215 AD–1285 AD
42	VERA-1627	WDA-1	Charcoal	Windachalm	1960	reclaimed land	1080 ± 30	890 AD–1020 AD
43	VERA-2200	WH-2/1	Charcoal	Windach-Haeche	2510	indoor fireplace	1895 ± 40	25 AD–230 AD
44	VERA-2096	WH-1/4	Charcoal	Windach-Haeche	2490	indoor fireplace	680 ± 35	1265 AD–1395 AD
45	VERA-2987	WH-1/5	Charcoal	Windach Haeche	2490	indoor fireplace	3375 ± 30	1750 BC–1610 BC
46	VERA-1309	WS-1	Charcoal	Windach-Silex	2260	silex	6590 ± 60	5640 BC–5470 BC
47	VRI-1625	WK-1	Charcoal	Windach-Sumpf	2280	fireplace	6340 ± 60	5470 BC–5210 BC
48	VRI-2178	ZG-4	Charcoal	Zwieselstein	1475	fire clearing	1020 ± 50	890 AD–1160 AD
49	VERA-3288	ZG-2	Charcoal	Zwieselstein	1475	1st fire horizon	2785 ± 40	1030 BC–830 BC
50	VRI-1721	ZWU-2	Charcoal	Zwieselstein-Unterberg	1475	reclaimed land	1110 ± 50	770 AD–1020 AD
51	VRI-1722	ZWU-3	Charcoal	Zwieselstein-Unterberg	1475	1st fire horizon	2050 ± 50	200 BC–60 AD
52	VRI-2041	UA-1	Charcoal	Untergurgl-Angern	1785	reclaimed land	1140 ± 50	770 AD–1020 AD
53	VRI-1598	PW-1	Charcoal	Poschachwald	2070	1st fire horizon	3130 ± 50	1510 BC–1270 BC
54	VRI-2085	OGG-1	Charcoal	Obergurgl-Grüner	1920	1st fire horizon	4460 ± 50	3350 BC–2930 BC
55	VRI-2084	OGB-2	Charcoal	Obergurgl-Broser	1900	reclaimed land	1880 ± 50	10 AD–250 AD
56	HD-10855-10766	OG-1	Charcoal	Obergurgl-Grüner	1910	1st fire clearing	2870 ± 25	1125 BC–940 BC
57	VRI-1632	OM-2	Charcoal	Obergurgl-Mahdstuhl 2	1920	2nd fire clearing	2380 ± 60	760 BC–360 BC
58	VRI-1631	OM-1	Charcoal	Obergurgl-Mahdstuhl 1	1920	1st fire clearing	7760 ± 70	6770 BC–6450 BC
59	VRI-1674	OG-1	Charcoal	Obergurgl-Gaisberg	1940	1st fire clearing	1660 ± 50	250 AD–540 AD
60	VRI-1597	NH-1	Charcoal	Obergurgl-Nederhütte	2100	fire horizon	1300 ± 50	640 AD–870 AD
61	VRI-1983	BST-3	Wood	Beilstein	2117	indoor floor board	440 ± 50	1400 AD–1640 AD

Table 3 Results of ^{14}C dating for samples indicating human activity in locations of the Ötztaler Alps and surrounding regions.

ID #	^{14}C lab #[a]	Sample #	Material	Location	Altitude (m asl)	Comment	^{14}C age (yr BP)	Calibrated time range (yr BC)[b]
62	VERA-3388	BST-11[c]	Charcoal	Beilstein	2117	fire horizon	880 ± 50	1030 AD–1250 AD
63	VERA-2674	BST-10AB	Charcoal	Beilstein	2117	fireplace and silex	4110 ± 35	2870 BC–2570 BC
64	VERA-2675	BST-10EF	Charcoal	Beilstein	2117	fireplace and silex	4980 ± 35	3930 BC–3660 BC
65	VERA-3857	BST-19	Charcoal	Beilstein	2117	fireplace	5605 ± 40	4520 BC–4350 BC
66	VERA-1625	BST-1	Charcoal	Beilstein	2117	fireplace	5690 ± 30	4605 BC–4455 BC
67	VRI-1982	BST-2	Charcoal	Beilstein	2117	fire horizon	5890 ± 70	4950 BC–4580 BC
68	VERA-2082	BST-7	Charcoal	Beilstein	2117	fire horizon	5870 ± 35	4840 BC–4615 BC
69	VRI-2027	BS-6	Charcoal	Beilstein	2117	fire horizon	5920 ± 70	4990 BC–4610 BC
70	VERA-3838	BST-21	Charcoal	Beilstein	2117	post-hole	8020 ± 35	7065 BC–6815 BC
71	VERA-3390	BST-13	Charcoal	Beilstein	2117	fireplace	8025 ± 45	7075 BC–6770 BC
72	VERA-3890	BST-24	Charcoal	Beilstein	2117	fireplace	8180 ± 35	7310 BC–7070 BC
73	VERA-3890	BST-25	Charcoal	Beilstein	2117	oldest fireplace	8670 ± 40	7785 BC–7590 BC
74	VRI-1515	Löble-2	Humus	Obergurgl-Löble	2150	irrigation	3260 ± 50	1650 BC–1430 BC
75	VERA-3841	KU-1	Peat	Obergurgl-Küppele	2325	irrigation	2100 ± 35	345 BC–35 BC
76	VERA-3843	KU-3	Peat	Obergurgl-Küppele	2325	irrigation	2390 ± 30	730 BC–395 BC
77	VRI-2145	OS-1/1	Charcoal	Obergurgl-Soom	2520	indoor fireplace	2610 ± 50	900 BC–550 BC
78	VERA-2886	OS-2/1	Charcoal	Obergurgl-Soom	2530	indoor fireplace	3075 ± 35	1425 BC–1230 BC
79	VERA-4076	SS-1	Charcoal	Obergurgl-Soom	2480	1st indoor fireplace	3240 ± 35	1615 BC–1435 BC
80	VERA-4412	SS-5	Charcoal	Obergurgl-Soom	2480	2nd indoor fireplace	3125 ± 35	1495 BC–1285 BC
81	VRI-1729	KA-8	Charcoal	Kleinalbl[a]	2185	1st fire horizon	2190 ± 50	390 BC–110 BC
82	VRI-1728	KA-7	Charcoal	Kleinalbl[a]	2185	2nd fire horizon	2120 ± 50	360 BC–1 BC
83	VRI-1596	Gaislach-1	Charcoal	Gaislach	1860	irrigation	3190 ± 50	1620 BC–1310 BC
84	VERA-1626	GA-1	Charcoal	Gaislach Alm	1940	1st fire horizon	5810 ± 35	4770 BC–4550 BC
85	VRI-1998	GA-2	Charcoal	Gaislach Alm	1940	2nd fire horizon	5440 ± 60	4450 BC–4060 BC
86	VRI-1663	Vent 1	Charcoal	Vent	2100	fire clearing	1780 ± 50	120 AD–390 AD
87	VRI-1661	RA-2/2	Charcoal	Ramolalm	2220	1st fire horizon	4780 ± 80	3710 BC–3370 BC
88	VRI-1660	RA-2/1	Charcoal	Ramolalm	2220	2nd fire horizon	1950 ± 50	60 BC–210 AD
89	VERA-0013	SM-2	Charcoal	Spiegelmahd	2050	1st fire horizon	3505 ± 45	1945 BC–1695 BC
90	VRI-1662	SM-1	Charcoal	Spiegelmahd	2050	fire horizon	2970 ± 50	1390 BC–1020 BC
91	VERA-0011	Rofen-2	Charcoal	Rofenhöfe	2100	irrigation	2955 ± 50	1380 BC–1010 BC

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ID #	^{14}C lab #[a]	Sample #	Material	Location	Altitude (m asl)	Comment	^{14}C age (yr BP)	Calibrated time range (yr BC)[b]
92	VRI-1320	Rofen Alm 1	Charcoal	Rofen Alm	2105	irrigation	520 ± 60	1290 AD–1470 AD
93	GrN-22767	Rofen Alm 2	Charcoal	Rofen Alm	2095	1st fire clearing	3535 ± 35	1960 BC–1750 BC
94	VERA-4134	TG-1	Charcoal	Taschach-Grubrig	2330	indoor fireplace	620 ± 30	1290 AD–1405 AD
95	VRI-2179	SS-2	Charcoal	Schmiedhof[d]	1680	indoor fireplace	850 ± 50	1040 AD–1270 AD
96	VERA-3290	SS-3	Charcoal	Schmiedhof[d]	1680	indoor fireplace	1230 ± 40	680 AD–890 AD
97	VERA-2890	SS-1	Charcoal	Schmiedhof[d]	1680	fireplace under hut	8395 ± 35	7545 BC–7355 BC
98	VRI-1792	SchA-1	Charcoal	Schönauer Alm	1790	fire horizon	5530 ± 60	4500 BC–4260 BC
99	VRI-1793	SchA-2	Wood	Schönauer Alm	1790	fire clearing	5890 ± 60	4940 BC–4600 BC
100	VERA-0657	TA-9	Wood	Timmelsalm	2190	fire horizon	5900 ± 35	4850 BC–4695 BC
101	VRI-1879	TA-8	Charcoal	Timmelsalm	2232	fire horizon	7570 ± 70	6590 BC–6250 BC
102	VERA-4414	RK-2	Charcoal	Ruderhofkar	2240	1st indoor fireplace	2225 ± 35	385 BC–200 BC
103	VERA-4413	RK-1	Charcoal	Ruderhofkar	2240	2nd indoor fireplace	1770 ± 40	130 AD–380 AD
104	VERA-1307	SM-2	Charcoal	Schneeberg-Seemoos	2140	silex	2590 ± 35	830 BC–585 BC
105	VERA-3218	Planail-1	Charcoal	Planail[c]	2390	fire horizon	4295 ± 40	3025 BC–2870 BC
106	VERA-2519	OGA-2b	Charcoal	Obere Gost-Alm	1950	1st fire horizon	2775 ± 35	1005 BC–835 BC
107	VERA-2519	OGA-1b	Charcoal	Obere Gost-Alm	1950	2nd fire horizon	2600 ± 35	840 BC–590 BC
108	VERA-2676	GS-1	Charcoal	Grubensee[e,f]	2400	fire offering place	2090 ± 35	205 BC–1 BC
109	VERA-2677	GS-2	Charcoal	Grubensee[e,f]	2400	1st mountain pasture	5345 ± 40	4325 BC–4050 BC
110	VERA-3200	Finail-Grub	Charcoal	Finailtal[e]	2480	fire clearing	3380 ± 35	1765 BC–1560 BC
111	VERA-3823	Mastaun-1	Charcoal	Mastaun[e]	2340	fireplace	3450 ± 35	1885 BC–1680 BC
112	VERA-3824	Peder-1	Charcoal	Peder[c]	2420	fire horizon	2990 ± 40	1390 BC–1080 BC
113	VERA-3821	KA-2c	Charcoal	Schlandraun[e]	2435	1st fire horizon	3325 ± 40	1730 BC–1505 BC
114	VERA-3822	KA-1	Charcoal	Schlandraun[e]	2435	2nd fire horizon	3365 ± 35	1750 BC–1535 BC
115	VERA-1317	LKP-2	Charcoal	Pratzenkar	2470	indoor fireplace	2765 ± 35	1005 BC–830 BC
116	VERA-1316	LKP-1	Charcoal	Pratzenkar	2470	1st fire clearing	2870 ± 40	1200 BC–920 BC
117	VRI-2177	LFB-1	Charcoal	Falginboden	2340	1st fire clearing	4010 ± 50	2850 BC–2340 BC
118	VERA-4094	Melag-1	Charcoal	Melag	2140	irrigation	3585 ± 35	2040 BC–1780 BC
119	VERA-4410	Melag-2	Charcoal	Melag	2140	irrigation	3640 ± 40	2140 BC–1900 BC
120	VRI-1992	FT-3	Charcoal	Futschöl	2165	fire horizon	4450 ± 60	3340 BC–2920 BC

Table 3 Results of ^{14}C dating for samples indicating human activity in locations of the Ötztaler Alps and surrounding regions.

ID #	^{14}C lab #[a]	Sample #	Material	Location	Altitude (m asl)	Comment	^{14}C age (yr BP)	Calibrated time range (yr BC)[b]
^{14}C dates from sediments with pollen profiles								
121	VERA-0091	FA-6 P	Peat	Vord. Fundusalm, 56 cm	1590	irrigation	725 ± 45	1210 AD–1390 AD
122	VERA00-94	LA-5 P	Charcoal	Leiersalm, 90 cm	2020	clearing onset	1510 ± 80	390 AD–670 AD
123	GrN-21989	WB-1 P	Peat	Windach-Bruggen, 32 cm	1865	intensified use	780 ± 20	1215 AD–1275 AD
124	GrN-21990	WB-2 P	Charcoal	Windach-Bruggen, 58 cm	1865	fire clearing	1940 ± 30	20 BC–130 AD
125	GrN-21991	WB-3 P	Charcoal	Windach-Bruggen, 79 cm	1865	1st human impact	3100 ± 30	1440 BC–1290 BC
126	VERA-1308	WK-5 P	Peat	Warrenkar, 32.5 cm	2380	intensitied pasturing	1660 ± 60	240 AD–540 AD
127	VERA-1305	WK-4 P	Peat	Warrenkar, 55 cm	2380	onset of pasturing	4425 ± 40	3330 BC–2910 BC
128	VERA-1304	WK-3 P	Peat	Warrenkar, 62.5 cm	2380	1st human impact	4470 ± 70	3360 BC–2920 BC
129	VERA-0123	WG-4 P	Peat	Windach-G.[g], 22.5 cm	2115	intensified pasturing	1100 ± 45	810 AD–1030 AD
130	VERA-0122	WG-3 P	Peat	Windach-G.[g], 37.5 cm	2115	1st clearing	3375 ± 40	1760 BC–1530 BC
131	VERA-0652	ZW-4 P	Peat	O-G, Zirbenw.[h], 20 cm	2085	intensified pasturing	1135 ± 30	780 AD–990 AD
132	VRI-1590	ZW-1 P	Charcoal	O-G, Zirbenw.[h], 28 cm	2085	fire clearing	2370 ± 50	750 BC–360 BC
133	VRI-1591	ZW-2 P	Peat + charc.	O-G, Zirbenw.[h] 38 cm	2085	1st human impact	5300 ± 60	4320 BC–3980 BC
134	VRI-1595	BS-I/3 P	Peat	Beilstein I, 12.5 cm	2115	irrigation	380 ± 50	1440 AD–1640 AD
135	VERA-650	BS-4 P	Peat	Beilstein I, 30 cm	2115	intensified pasturing	1970 ± 35	50 BC–130 AD
136	VERA-2893	BS-II/5 P	Peat	Beilstein II, 22.5 cm	2115	intens. livestock farming	380 ± 30	1440 AD–1640 AD
137	VERA-2892	BS-II/4 P	Peat	Beilstein II, 33.5 cm	2115	intensified pasturing	1985 ± 35	60 BC–90 AD
138	VERA-2891	BS-II/3 P	Peat	Beilstein II, 41.5 cm	2115	onset of pasturing	3435 ± 35	1880 BC–1640 BC
139	Beta-44517	GurglerAlm P	Peat	Gurgler Alm, 69 cm[i]	2240	onset of pasturing	5450 ± 80	4460 BC–4050 BC
140	VRI-1315	GF-14/3 P	Peat	Langtaler Eck, 90 cm[c]	2420	onset of pasturing	5610 ± 60	4560 BC–4330 BC
141	GrN-22215	RA-3/1 P	Charcoal	Ramolalm, 44 cm	2220	intensified pasturing	3660 ± 50	2200 BC–1890 BC
142	GrN-21987	RA-3/2 P	Charcoal	Ramolalm, 89 cm	2220	pasturing	4500 ± 100	3500 BC–2900 BC
143	VRI-1733	RA-3/4 P	Peat	Ramolalm, 93 cm	2220	onset of pasturing	4790 ± 60	3700 BC–3370 BC
144	VRI-1724	RM-1 P	Peat + charc.	Rofenmoos, 36 cm[j]	2015	peak of land use	2980 ± 50	1390 BC–1050 BC
145	VRI-1725	RM-2 P	Charc. + wood	Rofenmoos, 52 cm[j]	2015	2nd period of use	4040 ± 100	2900 BC–2300 BC
146	VRI-1726	RM-3 P	Peat + charc.	Rofenmoos, 63 cm[j]	2015	1st period of use	5100 ± 60	4040 BC–3760 BC
147	VERA-2247	Pedros 45 P	Peat	Pedros, 45 cm	2510	onset of pasturing	4115 ± 30	2870 BC–2570 BC

[a]Lab numbers refer to the following AMS laboratories: VERA = VERA Lab Vienna; VRI = Vienna Radium Institute; GrN = Groningen Centre for Isotope Research; HD = Heidelberg Academy of Sciences; Beta = Beta Analytic Miami. [b]The true date lies with 95.4% probability within the given time range. [c]Bortenschlager 2000. [d]Zanesco 2006. [e]Staffler H, 2008, personal communication. [f]Mahlknecht 2005. [g]Windach-G. = Windach-Gaisstabl; [h]O-G, Zirbenw. = Obergurgl, Zirbenwald. [i]Vorren et al. 1993. [j]Tschisner 1998.

The Iceman project was started also with the hope to use some of the plant material as proxies for the climatic conditions 5000 yr ago. The high altitude of the Iceman site (3210 m asl) is clearly above the timberline of the Alps (2000–2500 m), but certain species—e.g. *Poa alpina* and *Poa laxa*, which thrive at the site today—may actually have grown there under climatically favorable conditions. Since, in general, there is plenty of precipitation (rain and snow) in Alpine regions, average summer temperature determines the upper growth limit. The dates of the high-altitudinal grass in Figure 4 give some indication that there may have been a warmer period around the Iceman time, similar to recent times, but due to lack of samples the evidence is poor. Hair-cup mosses (*Polytrichum*), on the other hand, are not particularly sensitive to climate as they grow also under harsher climatic conditions, which is reflected in the distribution of samples displayed in Figure 4. However, two soil samples dated adjacent to the Iceman site (Baroni and Orombelli 1996) support the existence of a warmer climate at this period (bottom of Figure 4). In fact, the authors of the corresponding paper (Baroni and Orombelli 1996) argue that these findings are indicative of climatic conditions prevailing during the climatic optimum of the Holocene (9000–5000 BP), and the Iceman lived just before Neoglaciation started around 5000 yr ago. This may also be reflected by the investigation of Magny and Haas (2004).

HUMAN PRESENCE AT HIGH ALTITUDES IN THE ÖTZTAL ALPS

Until the discovery of the Iceman, the area of the Ötztal Alps was archaeologically a void region, without evidence of human presence in prehistoric times. The discovery of the Iceman triggered a period of intense research, as a result of which the Ötztal Alps became an archaeologically well-investigated region. Human presence and activity, stretching back to the early Mesolithic period, were found (Bagolini and Pedrotti 1992; Schäfer 1998, 2011; Leitner 1999; Zanesco 2006).

Archaeological excavations over a large mountainous region are expensive and time consuming. Due to weather conditions in elevated areas, only a few weeks per year are available for such excavations. Projects of this kind can rarely be undertaken with the rigor of a usual archaeological excavation (see, however, Schäfer 2011; Reitmaier et al. 2013). Therefore, an alternative method was chosen, which lies somewhere between simple prospection and large-area excavation. Soil profiles were investigated, and those containing charcoal were selected. Charcoal samples that indicated fire clearance—confirmed by pollen analyses wherever possible—were used for ^{14}C dating. This information was complemented by ^{14}C dating of charcoal from fireplaces in dwellings of shepherds.

Human activities sometimes also clearly show up in pollen profiles from peat bogs. Stratigraphically determined fire horizons, and the simultaneous rise in pollen from pasture indicators accompanied by characteristic plant forms, are clear evidence of human activity (Bortenschlager 2000). Pollen analysis also allows one to clearly distinguish between fire clearance and natural occurrences of fire. This investigation indicated that large-scale fires caused by lightning were very rare events.

In connection with the present work, 16 pollen profiles were analyzed by W Kofler, W Wahlmüller, Chr. Tschisner (personal communications, 1998–2005). Five of these have been published (Bortenschlager 2000); the remainder are being prepared for publication. ^{14}C data from pollen profiles relevant to the current work are given in Table 3. In total, the table contains 120 ^{14}C data from soil profiles and 27 from pollen profiles. Calibrated ages were obtained in a similar way as described above for the Iceman site. Figure 1 shows the location of the soil profile data in the Ötztal region.

The current investigation is mainly concerned with the spread of human activities, both in terms of spatial and elevation distribution, as well as the temporal development of land use in the mountains. It should complement the few stand-alone archaeological excavations. The primary task was to obtain absolute dates for indicators of prehistoric human presence in the Ötztal region. In this way, the Iceman is assessed in a larger temporal framework. A summary of the results of Table 3 is displayed in Figure 5. Only samples up to the beginning of the modern time period (AD 1500) have been considered in this work.

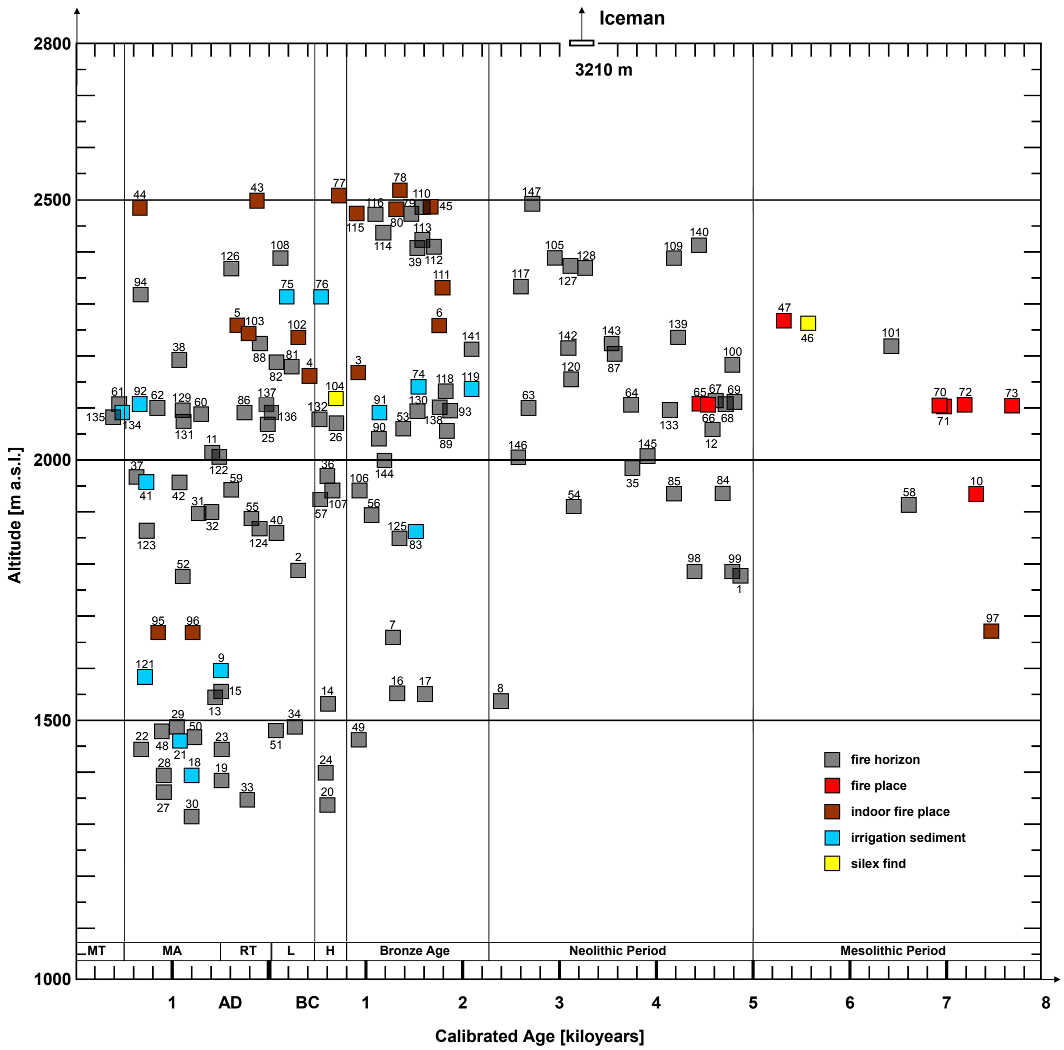

Figure 5 Altitude versus time display of the ^{14}C data (squares) from the Ötztal Alps and surrounding areas (cf. Table 3). The numbers at the squares refer to the ID # of Table 3. The meaning of the color codes is described at the right bottom corner of the figure. The date of the Iceman is also included in the figure. The time ranges of archaeological periods are marked with thin vertical lines (MT = Modern times; MA = Middle Ages; RT = Roman times; L = La Tène period; H = Hallstatt period; L + H = Iron Age). This figure can be also viewed online with high resolution, where the length of the block bars corresponds to the calibrated time range (95.4% confidence).

DISCUSSION OF THE RESULTS

Mesolithic Period

Some 500–600 yr after the end of the Younger Dryas period, i.e. ~9000 BC, the high valleys in the Alps were ice-free in front of the forefields of the modern glaciers (Weihrich and Bortenschlager

1980; Bortenschlager 1984; Nothegger 1997; Ivy-Ochs et al. 2009). In the same time period, human presence has been firmly determined at the Jagdstation (hunting station) Ullafels located at 1870 m asl in the Fotschertal, Stubaier Alps, and rich with artifacts (Schäfer 1998, 1999, 2011). The idea that hunters preyed on game in the elevated areas very soon after the area became ice-free has thus been confirmed (Fedele 1981). ^{14}C dating of logs recently freed from glacier ice revealed that already between 8000 to 7000 BC the glaciers were smaller than today (Nicolussi and Patzelt 2000, 2001). Thus, climatic conditions at that time must have been as warm or even warmer than today. As a result, feeding grounds for wild animals and hunting have probably reached up to higher altitudes.

In the Ötztal Alps, six fireplaces were dated that were in use between 7900 and 7000 BC. Four of these were found during a dig at a Jagdstation at Beilstein near Obergurgl, which lies at 2117 m asl (Figure 5, ID #70–73). Silex artifacts and a posthole provide evidence of wooden constructions (Zanesco 2006). The oldest fireplace so far (ID #73) was dated to around 7700 BC. A fireplace at another location (Fundusalm) at 1940 m asl was dated to around 7200 BC (Figure 6, ID #10). A discovery of silex from the end of the Mesolithic period found in a fireplace at 2260 m asl has been dated to ~5500 BC (ID #46).

Figure 6 A Mesolithic fireplace at the Fundusalm (1940 m asl, 7527–7085 BC). The profile depth can be assessed from the length of the manual shovel, which is approximately 20 cm.

Neolithic Period

Eight ^{14}C data from fire clearances at altitudes between 1750 and 2200 m asl show that around 4600–4800 BC human interventions into the forested area became noticeably frequent (Figure 5). This can be considered as the beginning of the regular use of mountain pastures.

Thanks to pollen analysis in the higher Ötz Valley, it has been proved that animals were grazing in the Gurglertal at altitudes of 2400 m asl from about 4500 BC on (Table 3, Figure 5, ID #140. Bortenschlager 2000; ID #139. Vorren et al. 1993). At the Grubensee, south of the main Alp ridge, an archaeological excavation determined that the use of mountain pastures at an altitude of 2400 m asl had begun in around 4200 BC (Table 3, Figure 5, ID #109, Mahlknecht 2005). In contrast, recent archaeological and palynological studies from sites south of the main Alpine crest provide evidence for the beginning of Alpine farming not before the Early Bronze Age, 2200 to 1600 BC (Festi et al. 2013). However, these contradicting results need further interdisciplinary studies for clarification.

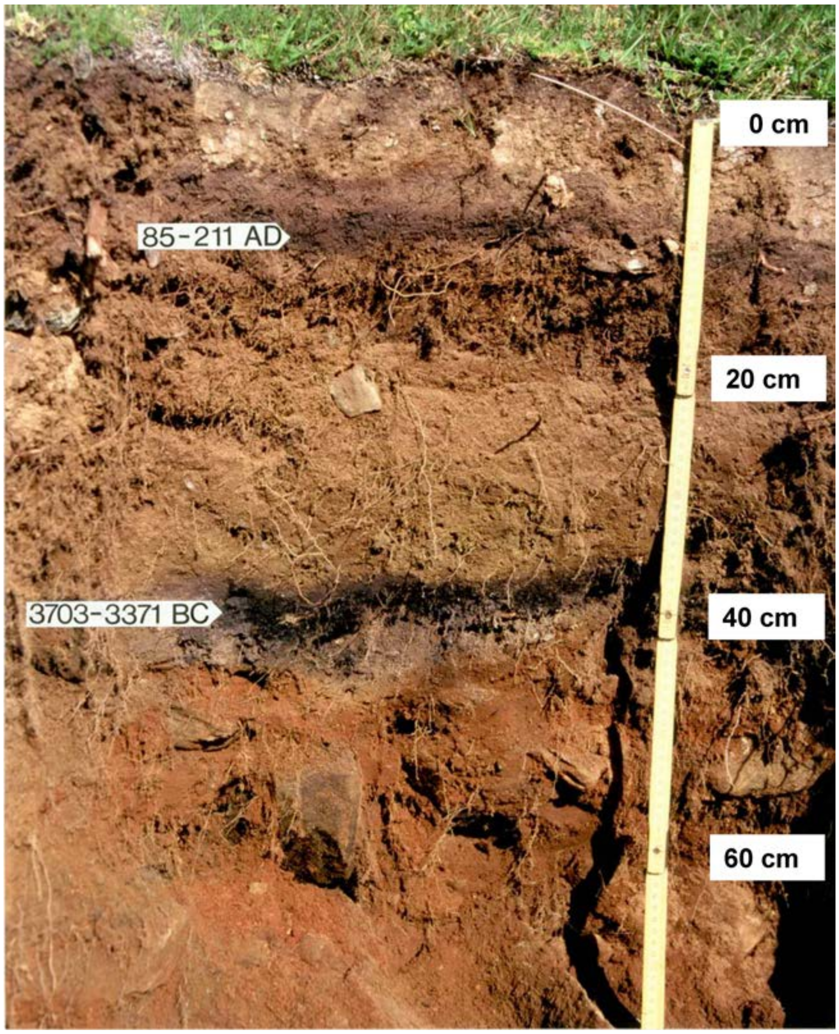

Figure 7 Soil profile at the Ramolalm (2220 m asl). Charcoal samples from the indicated layers were carefully separated from any root material.

Concerning the period before the lifetime of the Iceman, 21 ^{14}C data from fire clearances and fireplaces between 4800 and 3200 BC (Figure 5) show that Alpine grassland during the Middle Neolithic Age was already in use. For the lifetime period of the Iceman, five ^{14}C data taken from different areas indicate the use of areas at high altitudes. Four of these originate from the Ötztal region. Figure 7 is a characteristic soil profile from which it can be inferred that the area had been in continuous use since the end of the Neolithic period (Copper Age). A fully developed Podsol is terminated by a fire horizon, which has been dated to 3703–3371 BC (Table 3, ID #87), which therefore precedes the Iceman. Above this, a sandy colluvium follows a long period of use. Between 85 and 211 BC, it is covered by a fire horizon from the Roman period (Table 3, ID #88). This is superimposed by approximately 10 cm of stony colluvium with the current grass growth. The profile was opened at 2220 m asl on a pasture in the Ramolalm in the currently forested area. The location may be reached by foot in 4 hr from the place where the Iceman was found, and is almost within view.

The dating (Table 3, Figure 5, ID #120) of an extensive fire horizon in Futschöltal, Silvrettagruppe, at 2165 m asl shows that for this time similar evidence of use is also to be found outside of the small area under investigation. Overall, the frequency of data and its distribution at altitude seem to determine that elevated areas were used in the Neolithic period from around 4800 BC.

Bronze Age

At the beginning of the Bronze Age, around 2200 BC (Figure 5), there is a ^{14}C data gap of approximately 100 yr. Whether this is accidental or actually indicates an interruption of the use of land at high altitudes—perhaps linked with the well-known 4.2kyr BP climate episode when, for one example, tree growth at high elevation in the SW United States was notably affected (Salzer et al. 2014)—cannot be determined at present.

Around 1800 BC, land use intensified including areas between 2000 and 2500 m asl, indicated by an increase in ^{14}C data. Between 2400 and 2500 m asl, there is a remarkable cluster of ^{14}C dates for fire horizons and fireplaces (Figure 5). The highest fireplaces in shepherd huts at over 2500 m asl were found at Obergurgl, originating from the time between 1400 BC and the end of the Bronze Age in 800 BC. At this time, there must have been sources of firewood at these elevated areas. At an altitude of 2470 m asl, a fire horizon was discovered in the open terrain of the Pratzenkar, Langtauferer Tal, south of the main crest of the Alps (ID #116). This is about 70 m higher than the current timberline. In addition, at the same location the first fireplace in a shepherd hut was ^{14}C dated to 1000–830 BC (Table 3, Figure 5, ID #115).

The intense cultivation of areas at high altitude during the Bronze Age is supported by the first evidence for meadow irrigation (Table 3, Figure 5, ID #74, 83, 91, 118, 119). This was unequivocally proved by the stratigraphy of a soil profile at Melag (ID #118, 119) at an altitude of 2140 m asl. Here, the charcoal from the dated fire horizon was mixed into the lowest part of overlaying irrigation sediments. Just as today, meadows were probably only irrigated artificially to improve the harvest of hay. Hay is primarily used for animal food in the winter. This is likely to have allowed permanent settlements in the upper areas of the valley.

Hallstatt Period to Modern Times

There is also plenty of evidence that land use and human presence in high-altitude areas persisted during the Hallstatt, however with a slight decline around the 8th century BC, possibly reflecting a global cooling effect at that time (Salzer et al. 2014). The density of ^{14}C data between 0 and AD 300 indicates intensified use of the pastures during the time of the Roman Empire. In contrast to regions outside the Alps, there seems to be a continuous use in the 5th century during the change from Roman times to the Early Middle Ages. The second high point in the use of elevated areas was reached in the High Middle Ages (11th–13th century AD) with historically well-documented expansions of land use, however, at somewhat lower altitudes. This may be indicative of the much-discussed Medieval Climate Anomaly (Mann et al. 2009; Diaz et al. 2011).

It is interesting to note that after Roman times there is a decline of ^{14}C data with altitude. This indicates that the cultivation of pastures and meadows penetrated into forested areas from top to bottom.

Paths and Changes

The Alps are a high mountain range that can be crossed on foot with relatively little difficulty. In general, crossing high-altitude mountain ridges and passes was less of an obstacle than the gorges located lower down the valley. Furthermore, paths and settlements were often cut off by rockslides, which spread across the valley.

An example is the Köfels landslide in the Ötztal that happened around 8000 BC (Heuberger 1975; Ivy-Ochs et al. 1998), resulting in a dammed lake in the modern-day basin of Längenfeld. This hindrance blocked the valley. Upstream into the valley, an impassable stretch of gorges begins. In prehistoric times, a total of 17 km of the Ötztal was impassable or only passable with difficulty. As a result, in the northern and southern valley separate settlements developed. The inner, higher areas of the valley were reached by crossing the main crest of the Alps from the south. Of the 11 passes that run from the south into the Ötztal, the Timmelsjoch at an elevation of 2474 m asl (Figure 1) is the lowest one. A prehistoric use of this pass was assumed, and it has now been proved by the discovery of a brooch from the La Tène period at the highest point of the pass (Museum Passeier, St. Leonhard, Italy, unpublished).

All of the remaining passes lie at over 2700 m asl and were covered in prehistoric times with glaciers on the northern side. However, they were frequently crossed by humans and livestock. The Hochjoch (2770 m asl) and the Niederjoch (3019 m asl) were both used for the herding of sheep to the summer pastures north of the main watershed. Until the 20th century, sheep crossing of the Tisenjoch at an altitude of 3210 m asl must have been quite common too (Fowler 2000).

The Tisenjoch is the place where the Iceman was discovered (Figure 1). The Tisenjoch is a high but relatively easy crossing, which is also possible without artificial pathways. The surrounding area, which is exposed to the wind, was consistently free of ice both during the Iceman's lifetime, as well as for a long time before and after. This can be inferred from the ^{14}C data from grasses and moss in the area (Figure 4). The Iceman probably remained covered with snow and ice in the rocky depression from the day of his death until the discovery, which explains the excellent state of preservation in which he was found, and the lack of any traces of animal attack on his body. The possibility that the body of the Iceman was not moved from the spot where he was killed was discussed by Lippert et al. (2007). However, other investigators come to different conclusions and suggest a possible movement of the Iceman during warmer periods (Dickson et al. 2003; Acs et al. 2005). Therefore, this question currently remains open, and needs further research.

CONCLUSION

The ^{14}C results from the Iceman site clearly show that most artifacts recovered likely belong to the Iceman and were deposited contemporaneously with him. A few artifacts (wood) are older and some are younger, indicating that the Tisenjoch was used by humans also before and after the lifetime of the Iceman. Overall, a large-scale use of the mountainous Ötztal Alps has been demonstrated by the collected ^{14}C data (Figures 1 and 5). The existence of Jagdstationen (hunting sites) from 7800 BC on has been established, as has the exploitation of the Alpine grass mats by man at high elevations from ~4800 BC on. This supplements the results of archaeological excavations (Schäfer 1998, 2011; Leitner 1999; Zanesco 2006), and expands them through the addition of spatial components. The dating of the Iceman (Figure 3) fits well into this picture. That he was found on the Tisenjoch pass at 3210 m asl shows that this pass was known and represented a link between the pasture areas to the south and north of the main Alpine ridge. Additionally, the temporal distribution of data proves a continuous use of high-altitude areas since the early Neolithic period (~4800 BC). Recently, a variety of artifacts were found at a high-altitude pass in the Swiss Alps (Schnidejoch, 2756 m asl), covering the time period from the 5th millennium BC to Roman times (Grosjean et al. 2007; Hafner 2012). Although no human body was found, it indicates early human presence at high altitudes also at other locations in the European Alps (Holden 2008).

It is obvious that the discovery of the Iceman triggered the interest of researchers from many different fields to explore the evidence for the presence of early humans at high altitudes in the Ötztal region. As a result, an area in which hitherto no archaeological discoveries had been made was turned into a thoroughly examined mountain area within the last 20 years. With most Alpine glaciers continuing to recede, it is likely that additional clues for human activities at high altitudes in the Alps will be discovered. This will allow us to learn more about early humans who apparently did not shy away from areas nowadays considered to be hostile for the majority of people living in low-lands outside the Alps.

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