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ORIGINAL ARTICLE

The plant macro-remains from the Iceman site (Tisenjoch, Italian–Austrian border, eastern Alps): new results on the glacier mummy's environment

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Abstract Archaeobotanical studies are currently being carried out on all the plant remains retrieved from the high alpine site where the Iceman "Ötzi" was found (3,210 m a.s.l.). Preliminary results already show a great diversity of species (121 taxa) mainly originating from lower regions, which must have been transported to the Tisenjoch site by a number of vectors. Spatial modelling has been carried out for one part of the plant remains unequivocally assignable to the Iceman. The resulting patterns indicate that post-depositional displacement processes have affected the material, and even the mummified body itself. It is demonstrated that the influence of cross-contamination resulting from the recovery attempts preceding the excavations can be ruled out by thorough selection of sampled areas and layers. The archaeobotanical results, together with current data from other research fields, strongly suggest that the Iceman had died in an area about 5 m south-west of the position where he was discovered in 1991.

Keywords Neolithic · Alps · Iceman · Archaeobotany · Taphonomy · Palaeo-forensics

Introduction

The Iceman "Ötzi" represents the unique find of a perfectly preserved corpse dating back to the late Neolithic. Radiocarbon data (3370–3100 cal B.C.; see Bonani et al. 1994; Hedges et al. 1992; Kutschera 2002) suggest that he was a contemporary of the Cham and Horgen cultures north of the Alps (Jacomet 2006).

The body has been subject to detailed multidisciplinary scientific research for more than a decade, dealing with issues as different as his geographical and cultural backgrounds, health and state of nutrition, and many more. Various results on plant remains have already been published, such as analyses of the wooden artefacts (Oeggl and Schoch 1995, 2000), the binding material (Pfeifer and Oeggl 2000), the remains of retrieved mosses and liverworts (Dickson 2003; Dickson et al. 1996, 2000, 2005), or of the grasses used (Acs et al. 2005). Even the body's intestine contents (Oeggl 1998, 2000, 2001; Rollo et al. 2002) have successfully been examined for plant and animal remains, and resulted in valuable data on the living conditions of Ötzi.

The discovery site of the Neolithic glacier mummy is located in a flat and rocky area of the Tisenjoch (3,210 m a.s.l.), a pass in the Ötztal Alps, in the municipality of Schnals/Senales in Italy, close to the Austrian border (Fig. 1). The rocky hollow where the body has been found lies in a level part of the pass, in the accumulation area of the Niederjoch glacier. The flat local topography and the orientation of the rocky hollow, crosswise to the ice flow's direction (Baroni and Orombelli 1996), were conditions decreasing the influence of glacial movement (Bagolini et al. 1995). Also, the only slight deformations of the corpse's soft tissues suggested that the find assemblage had probably not been subject to massive ice-flow (Seidler et al. 1992a), as to be expected in steeper areas of the glacier.

The gully is orientated in a southwest–northeast direction, and about 40 m long, but only the southern part of the gully, in which the mummy had been discovered, was excavated. Its width varies from 3.5 m at the western end

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Fig. 1 The location of the Iceman site south of the Ötztal

to about 8 m in the centre of the gully, its depth being about 2.5 m (Figs. 2, 3). In the centre of the gully, to the south-east, the limiting rock ridge is lower and becomes an overflow for melt-water, which in case of melting allows water levels of up to about 1.4 m in the gully (Bagolini et al. 1995).

During two archaeological excavations (see the "Materials and methods") at the Iceman's discovery site a huge amount of plant material, which had been embedded in the ice and sediments of the gully, was collected and taken to the Botanical Institute of Innsbruck University for analysis following the excavations in 1992. Unfortunately, a comprehensive study of all plant remains from the Iceman's discovery site has not been done until now: this kind of analysis could contribute essential information on the post-mortem fate of the organic remains and on the formation of the find assemblage (the taphonomy) in the gully at the Tisenjoch. Furthermore, the results of this study could also help with a scientific interpretation of the last moments in the life of the Iceman. Both topics are still under controversial discussion. Originally, Spindler (1993, 1996; see also Zur Nedden et al. 1994) suggested that the extraordinarily good preservation of the body and the other finds was due to an immediate incorporation in the snow slowly transforming into ice after years, and then never thawing again until the glacier mummy's discovery in 1991. Anyhow, first studies on the wooden artefacts and their positions in the gully indicated that they had possibly been displaced by wind or water (Oeggl and Schoch 1995). This suggestion was corroborated by further detailed analyses of the wooden artefacts found in the gully (Oeggl and Schoch 2000; Oeggl 2003), as well as by a pedological investigation of the soils at the Tisenjoch site carried out by Baroni and Orombelli (1996). Climatological interpretation of the latter study implied that the ice in the gully, where the Iceman had been discovered, had melted several times since the late Neolithic.

Once more it has to be stressed that the cause of Ötzi's death is still ambiguous. The original suggestion that he had possibly died from exhaustion and hypothermia (Seidler et al. 1992a) is seriously opposed by the recent discovery of a fresh arrow wound in his back, with the arrowhead still trapped between the rib cage and the left shoulder blade which it had perforated (Gostner and Egarter-Vigl 2002; Murphy et al. 2003). This severe injury indicates a trauma of the large axilla (armpit) vessels caused by the arrow, the resulting haemorrhage leading to death within a short time (P. Gostner, personal communication). Where the attack had taken place—either in the gully at the Tisenjoch or elsewhere—is still a subject of speculation.

Anyway, knowledge of the taphonomy of the find assemblage can contribute data to clarify whether the find positions of the corpse and the other finds correspond to their original positions at the time of Ötzi's death, and thus provide cogent evidence of the last moments of his life.

The reconstruction of the Iceman's death is hampered by the indication that parts of the find assemblage were displaced on freezing/thawing cycles which took place post-mortem, as already suggested by archaeologists during the excavation in 1992 (Bagolini et al. 1995). However, precise data on the site's taphonomy has been scarce up to now, although there is some evidence of the processes which took place there:

- The Iceman's equipment was scattered across the whole rock gully where he had been lying (Fig. 2) which does not seem to be a typical situation to be expected at a resting place or at a camp site. Nevertheless, the possibly violent death of the Iceman might constitute exceptional circumstances.
- The corpse was lying in a prone position on a stone slab (Fig. 3), left arm beneath him, right hand trapped under a stone. This has initially been interpreted as a "resting position" (Lippert 1992). In consideration of the arrowhead in his left shoulder, this position might also be explained as resulting from the pain caused by the injury (Gostner and Egarter-Vigl 2002).

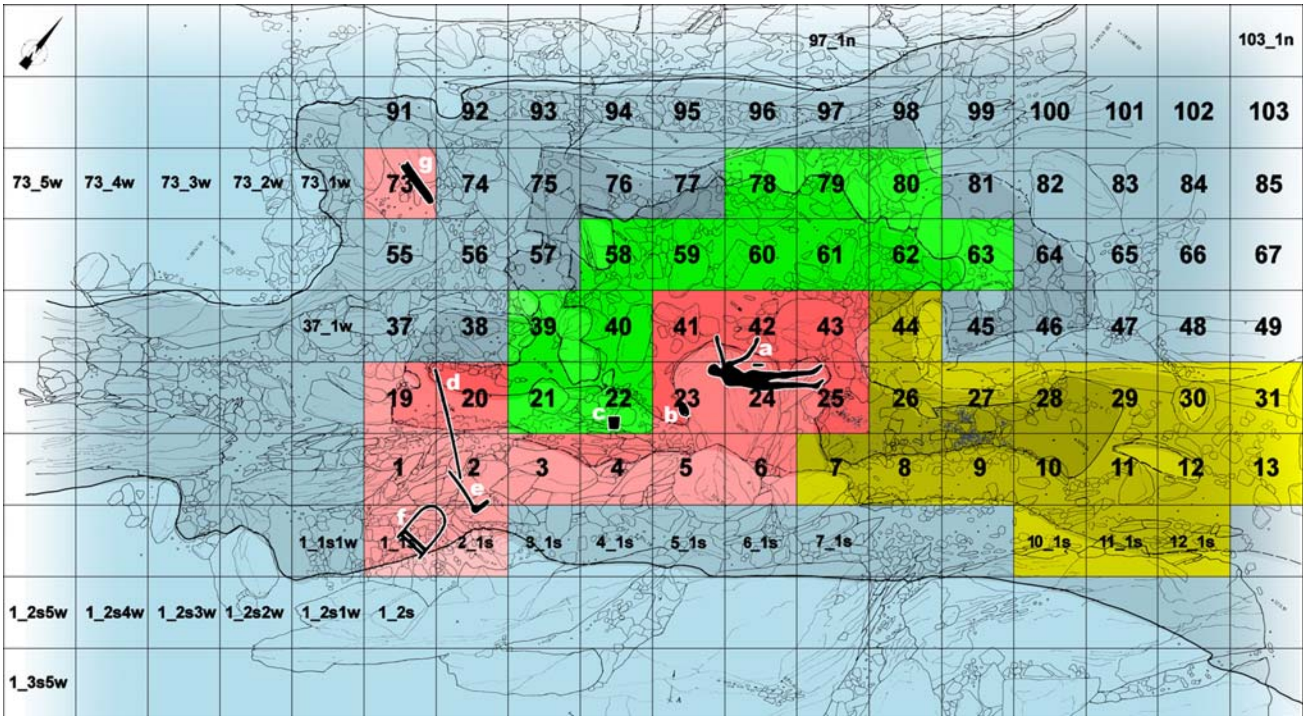

Fig. 2 The Iceman site with the 1 m^2 grid. Additional quadrant numbers in the west and east (indicated with "*s*", "*w*" or "*n*") were added as supplements to the original plan. Marginal areas are not displayed. *Darker shades* of blue indicate deeper areas of the rocky hollow. *Red* area excavated during the 1991 campaign. *Yellow* quadrants within the melt-water stream of the 1992 excavation. *Green* quadrants with undisturbed sediments selected for preliminary assessment of spatial distribution. **a** Iceman body and dagger, **b** bearskin cap, **c** birch bark container, **d** bow, **e** axe, **f** backpack frame, **g** quiver

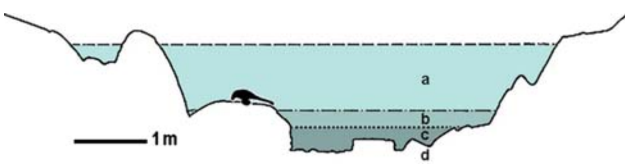

Fig. 3 North–south transect of the Iceman site. **a** Maximum depth of water, flooded after the excavation in 1991, **b** upper ice layer excavated in 1992, **c** lower, "dirty" ice layer incorporating the find assemblage, **d** bedrock (Bagolini et al. 1995, modified)

- The body's outermost epidermis layers had come off due to the body having been submerged in water for short episodes (Bereuter et al. 1996; Murphy et al. 2003), causing a loss of epidermal appendages such as hair, fingernails and toenails.

All this evidence remains isolated at the moment and can only be corroborated (or vitiated) by an integrated and large-scale study of plant remains in the gully. The current archaeobotanical study deals with the features of how the find assemblage at the discovery site had been formed by evaluating the distribution patterns of plant remains in the ice and sediments inside the gully, to reconstruct the circumstances of deposition and possible post-depositional alterations of the Iceman's find assemblage.

Materials and methods

Field work and sampling

The archaeological excavations at the site of the Iceman's discovery were conducted by Andreas Lippert (University of Vienna) under exceptional conditions (Lippert 1992; Lippert and Spindler 1992; Bagolini et al. 1995). The first excavation, immediately after the discovery in autumn 1991, was restricted to the south-eastern part of the gully, in the immediate vicinity of the body and the artefacts. The campaign lasted only three days and had to be abandoned because of the late season. Finally, the gully was flooded with water to create a sterile ice layer sealing the site, and thus avoiding unauthorized interference.

An extensive second excavation campaign then took place in the summer of 1992, aiming to study the complete southern part of the gully. Before, tons of snow and the sterile ice layer had to be removed. The snow and ice were mainly melted by the sun; only in the case of artefacts visible in the ice was a steam blower used to melt the objects from the ice. All melt-water was siphoned from the gully and brought via a system of tubes and gutters into a set of sieves with defined mesh sizes to collect all finds from the site. Precise spatial information was obtained using GPS and theodolite coordinates: at the beginning of the excavation, a 1 m grid was calibrated and projected onto the site to ensure the precise location of all material retrieved from the site and consequently to allow detailed documentation and analysis. The main focus of the excavation campaign was the "dirty" bottom ice layer which contained most of the finds (Bagolini et al. 1995). After all of this ice had been removed, the sediment of each quadrant was also sampled and taken to the Institute of Botany in Innsbruck for further analysis.

Sample types and their processing

The plant material analysed originated from a variety of sources:

1. The Iceman's equipment itself: clothing components made of plant material, such as the grass cape/mat and shoe insulating material, or the wooden tools and weapons, such as the bow and the axe shaft, both made of yew wood.
2. Plant macro-remains picked from and washed off the Iceman's clothes and implements. This material had been retrieved at the Römisch-Germanisches Zentralmuseum in Mainz (RGZM) and was later sent to the Botanical Institute at Innsbruck University for further studies.
3. The botanical material melted from the surrounding ice layers in the gully by using a steam blower.
4. Plant fragments extracted from the sediment at the bottom of the gully by using wet-sieving and flotation techniques (Jacomet and Kreuz 1999). The mesh sizes used for fractioning the material were 7.0, 5.0, 3.15, 2.0, 0.71, 0.5, 0.25, and 0.125 mm.

All extracted plant material was stored at the institute's refrigerator chamber at a constant temperature of +4°C, immersed in Strasburger's preserving agent (Gerlach 1969), a 1:1:1 solution of distilled water, ethanol 96%, and glycerine. A small amount of phenol (0.4–0.6% by weight), serving as a fungicide, had also been added.

Identification of the plant remains was carried out using standard literature on diaspores (Anderberg 1994; Berggren 1969, 1981), leaf surfaces (Westerkamp and Demmelmeyer 1997) and wood (Schweingruber 1990; Heiss 2000 onwards) as well as the comprehensive reference collection of Alpine plant material at the Institute of Botany in Innsbruck. Nomenclature follows Fischer et al. (2005).

Spatial modelling

After the identification of the plant remains, the exact topographic sample positions first had to be allocated by integrating the find positions from the 1991 excavation into the coordinate system used in the 1992 campaign (Lippert and Spindler 1992; Lippert 1992; Bagolini et al. 1995; Zissernig 1992), and by placing the 1991 data in the 1 m^2 grid (Fig. 4).

In order to ensure sufficient reliability of the spatial modelling, it was crucial to make a deliberate selection of the areas and layers to be assessed. Consequently, all events after the Iceman's discovery that might have affected possible distribution patterns of the finds had to be considered:

- The events prior to the archaeological excavation, when laymen tried to recover the glacier mummy from the ice, as well as the rescue of the body by the official medico-legal expert (Zissernig 1992), increasing the chance of distortions in the distribution of plant remains in the immediate vicinity of the Iceman's body.
- The 1991 rescue excavation conducted by Lippert (1992) focused on the stone slab where the body had been lying, as well as on areas in the south of the gully where the Iceman's weapons and carrying frame were retrieved from the ice. The quadrants lying within this excavation area are displayed in Figs. 2 and 4 (red areas).
- After the 1991 campaign, the gully was flooded with water to seal unexcavated parts and the remaining find material from access. This ice was removed before the excavation campaign in 1992. The original ice layers beneath were only a 50–80 cm thick, with a clearly distinguishable upper (bright, sterile) and lower (grey, "dirty") layer (Fig. 3b), the latter containing the Iceman artefacts (Bagolini et al. 1995). Thus, it was reasonable to primarily focus on the plant material from the lower ("dirty") ice and the sediment layers below this level (Fig. 3c).
- During the 1992 excavation campaign the north-eastern parts of the gully served as a drain for the melt-water. Possible material movements and cross-contamination between the quadrants could have occurred in these places (Fig. 2, yellow areas).

Bearing in mind these determining factors, the preliminary study for spatial distribution patterns was focused on the undisturbed layers in the quadrants 21, 22, 39, 40, 58–63, and 78–80 (Figs. 2, 4, green areas).

As the immediate vicinity of the mummy had been sampled more intensively by the archaeological teams, the resulting sample frequencies varied from 1 to 17 samples per m^2. Neither were the sampled amounts constant, with sample volumes per m^2 ranging from 55 to 9,855 ml (average 1,106 ml). To compensate these biases, the total sample volume per m^2 will have to be standardised prior to

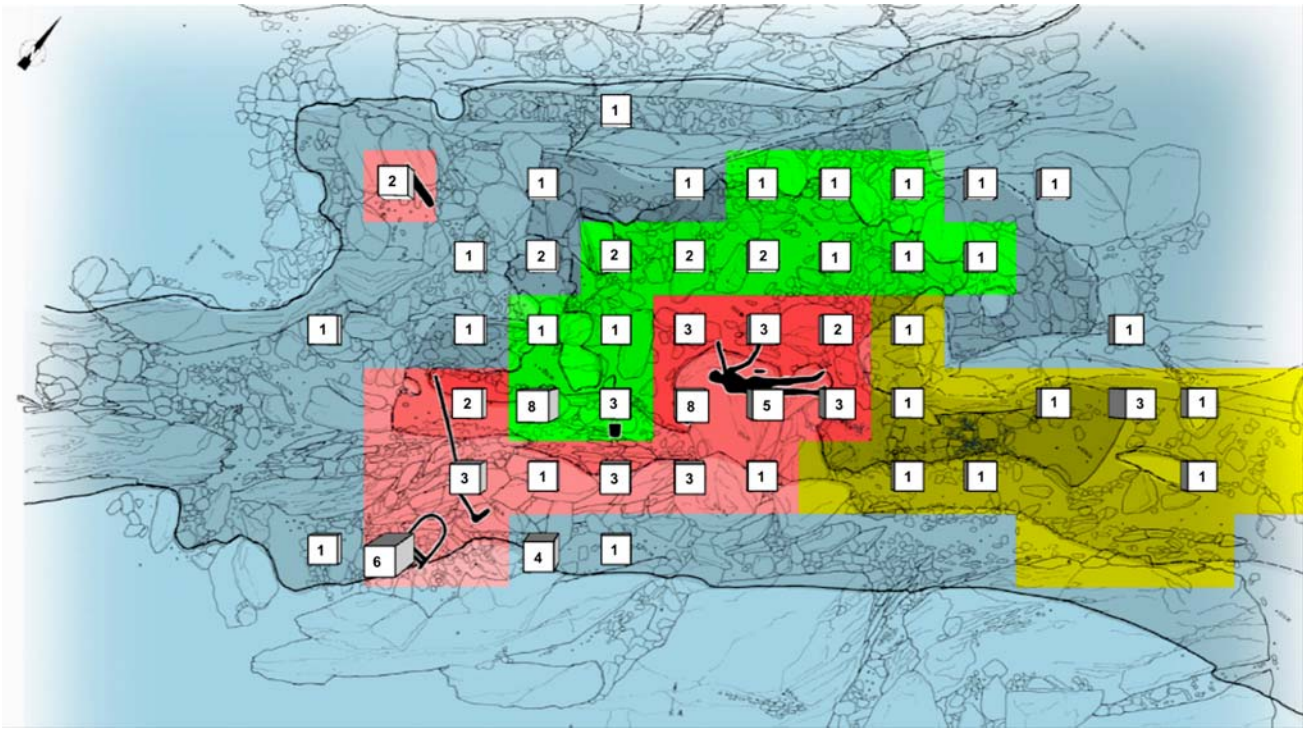

Fig. 4 Current state of archaeobotanical analysis. The *numbers* in the bars show the analysed samples per square metre. For meanings of colours, see Fig. 2

quantification and statistical analysis of the data. Consequently, these operations are postponed until the complete dataset of the plant remains from the gully sediments is available.

Up to now, 107 samples out of 291 have already been analysed, 97 of which were assignable to precise positions within the grid. Ten samples originated from the melt-water obtained from whole site sectors, which are larger units representing north–south transects through the site, with widths of 2–3 m.

Results

The 107 samples analysed up to now have resulted in a total of 40,612 plant remains from 121 vascular plant taxa. These were attributable to 32 families and a minimum of 66 species. Together with at least 80 species of mosses and liverworts identified by Dickson (2003), the Iceman site has up to now yielded the highest plant diversity ever found from an archaeological site above the tree line (Tables 1, 2).

It has to be stressed that a whole variety of ecosystems ranging from the valley bottoms up to the snow line is represented in the plant material from the site. Considering the fact that six of the identified vascular plant taxa have the ecophysiological potential to grow on-site (grey bar in Table 1; Fig. 5), it becomes evident that the vast majority of the plant material originated from lower altitudes (see also under "taphonomical considerations" below). Figure 5 displays an overview of all plant taxa found in the samples, assigned to phytosociological class groups (Oberdorfer 1990).

A detailed account of the recovered cultivated plants is shown in Table 1. Two cereals, *Hordeum vulgare* (hulled barley) and *Triticum monococcum* (einkorn), have already been found before, adhering to the body's garments (Oeggl and Schoch 1995; Oeggl 2000). Two new finds of millet caryopses were discovered in the sediments of quadrants 82 and 42, the latter one within immediate vicinity of the corpse (Figs. 2, 4): the carbonised grains could not be identified with certainty as they were in a very bad state of preservation, and no chaff remains were found. Thus, their identification has to remain cf. *Panicum miliaceum* (cf. broomcorn millet).

However, another two cultivated crops have newly been discovered: two seeds of *Papaver somniferum* (opium poppy) were retrieved from the ice (sample no 92/166 which comes from sector 4/5, a north–south transect through the site). Also a single seed of *Linum usitatissimum* (flax) was found, embedded in the sediments of quadrant 21, 2 m west of the Iceman's corpse. As for the literature (Kroll 2004), these can be considered the earliest oilseed finds in this central part of the Alps.

Table 1 Plant remains, in phytosociological class groups (Oberdorfer 1990)

		Se, Fr	Wood	Charc	Bast	Le, Ne	Other	Total
Rocky meadows and rock crevices								
sn	*Achillea moschata* Wulfen	2						**2**
sn	*Cerastium uniflorum* Clairv.	24						**24**
sn	*Kobresia myosuroides* (Vill.) Fiori	41						**41**
*sn	*Poa laxa* Haenke	874					8	**882**
sn	*Poa* cf. *laxa* Haenke						3	**3**
*sn-n	*Ranunculus glacialis* L.	129						**129**
sn-n	*Salix herbacea* L.					85	1	**86**
a	*Salix* cf. *reticulata* L.			1				**1**
a	*Hieracium intybaceum* All.	9						**9**
a	*Leucanthemopsis alpina* (L.) Heywood	11						**11**
a	*Luzula spicata* (L.) DC.	2						**2**
a	*Saxifraga bryoides* L.	1						**1**
a	*Sibbaldia procumbens* L.	6						**6**
a	*Silene acaulis* (L.) Jacq. s.l.	6						**6**
a	*Silene acaulis* (L.) Jacq. subsp. *exscapa* (All.) Braun-Blanq.	23						**23**
Anthropogenic/zoogenic heaths and meadows								
a	*Achillea millefolium* L. agg.	23						**23**
a	*Alchemilla vulgaris* L. agg.	1						**1**
m	*Aster linosyris* (L.) Bernh.	1						**1**
m	*Brachypodium pinnatum* (L.) P. Beauv. s.l.	14				125	2cf.	**141**
m	*Bromus hordeaceus* L.	12						**12**
sa	*Dactylis glomerata* L.	3						**3**
a	*Hieracium aurantiacum/pilosella* L./L.	2						**2**
a	*Leontodon helveticus* Mérat	16						**16**
sa	*Molinia caerulea* (L.) Moench					16		**16**
a	*Nardus stricta* L.					9		**9**
sa	*Taraxacum officinale* Weber agg.	8						**8**
sa	*Trifolium montanum* L.						1	**1**
Herbaceous and shrubby vegetation of woodland margins								
sa	*Alnus viridis* (Chaix) DC.	29	1	7			2	**39**
m	*Bromus ramosus* Huds. agg.	2						**2**
m	*Sambucus racemosa* L.	6						**6**
Coniferous woods and associated heathland								
a	*Arctostaphylos uva-ursi* (L.) Spreng.	9					1	**10**
m	*Betula pubescens* Ehrh.	1						**1**
a	*Empetrum nigrum* L. s.l.	7						**7**
sa	*Erica carnea* L.					1		**1**
sa	*Larix decidua* Mill.		18			1,314		**1,332**
sa	cf. *Larix decidua* Mill.		1					**1**
a	*Loiseleuria procumbens* (L.) Desv.	2				1		**3**
a	*Picea abies* (L.) H. Karst.	4				235	10	**249**
a	cf. *Picea abies* (L.) H. Karst.		12	201				**213**
a/sa	*Picea* sp./*Larix* sp.		5	1				6
sa	*Pinus cembra* L.		1			17		**18**
a	*Vaccinium vitis-idaea* L.	8				1		**9**
Deciduous woods and associated brushwood								
m	*Abies alba* Mill.					9		**9**
m	*Acer platanoides* L.					3		**3**
m	*Cornus* sp.		1					**1**
m	*Corylus avellana* L.		11					**11**
sa	*Deschampsia* cf. *flexuosa* Trin.	5						**5**
m	*Fraxinus* cf. *excelsior* L.		1					**1**
sa	*Luzula sylvatica* (Huds.) Gaudin	1						**1**
m	*Sanicula europaea* L.	1						**1**
m	*Taxus baccata* L.		5					**5**
m	*Viburnum lantana* L.		17					**17**
Herbaceous plants in frequently disturbed habitats								
m	*Carduus nutans* L.	3						**3**
m	*Cirsium arvense* (L.) Scop.	1						**1**
a	*Cirsium spinosissimum* (L.) Scop.	1						**1**
m	*Lappula squarrosa* (Retz.) Dum.	1						**1**
m	*Picris hieracioides* L.	1						**1**
Cultivated crops								
	Hordeum vulgare L.	5						**5**
	Hordeum vulgare L. var. *nudum*	14						**14**
	Linum usitatissimum L.	1						**1**
	cf. *Panicum miliaceum*	2						**2**
	Papaver somniferum L.	2						**2**
	Triticum dicoccon Schrank	2						**2**
	Triticum monococcum L.	9						**9**
Total		**1,325**	**73**	**210**		**1,816**	**26**	**3,452**

The grey bar highlights taxa from the potentially local flora (in subnival and nival zones). Asterisks indicate plants growing on-site, observed by the authors on a recent survey (21 September 2005). Letters in leftmost row indicate maximum altitudinal zones of the taxa: *sn–n* subnival to nival (above 2,500 m a.s.l.), *a* alpine (ca. 1,800–2,500 m a.s.l.), *sa* subalpine (ca. 1,500–1,800 m a.s.l.), *m* montane (ca. 500–1,500 m a.s.l.); data from Fischer et al. (2005); *Se, Fr* seeds, fruits (+ chaff, cone scales); *Wood* wood fragments (mainly of artefacts); *Charc* charcoal; *Bast* lime bast; *Le, Ne* leaves, needles (+ bud scales), *Other* other remains (flowers, periderm...)

Table 2 Plant remains not assignable to phytosociological class groups

		Se, Fr	Wood	Charc	Bast	Le, Ne	Other	Total
Asteraceae								
	Achillea sp.	1						**1**
m	*Bidens* sp.	1						**1**
	Cirsium sp.	1						**1**
	Leontodon sp.	2						**2**
sa	*Solidago virgaurea* L.	1						**1**
	Taraxacum sp.	2						**2**
	Asteraceae Subfam. Asteroideae						1	**1**
	Asteraceae indet.	17						**17**
Betulaceae								
	Alnus sp.	15						**15**
sa	*Betula pendula* Roth	3						**3**
sa	*Betula* Sect. Albae	12		1				**13**
	Betula sp.	40	3			2	2	**47**
Pinaceae								
sa	*Pinus mugo* Turra/*P. sylvestris* L.					4		**4**
sa	*Pinus* cf. *mugo* Turra			22				**22**
sa	*Pinus* sp. (*P.* non *cembra*)		1	2				**3**
sa	*Pinus* sp.		1			1	1	**3**
	Pinaceae indet.		1			2		**3**
Poaceae								
	Agrostis sp.	1						**1**
a	*Anthoxanthum alpinum* A. & D. Löve	1						**1**
a	*Avenula pubescens/versicolor* (Huds.) Dumort./(Vill.) M. Laínz	5						**5**
a	cf. *Bellardiochloa violacea* (Bellardi) Chiov.						2	**2**
	Brachypodium sp./*Molinia* sp.					3		**3**
	Bromus sp.	7						**7**
	Festuca sp.	7						**7**
a	*Poa annua* L. agg.	1						**1**
a	*Poa chaixii* Vill.	2						**2**
a	*Poa* cf. *chaixii* Vill.	7						**7**
	Poa sp.	41						**41**
	Poaceae indet.	32				18	1,906	**1,956**
Rosaceae								
m	cf. *Amelanchier ovalis*			4				**4**
a	*Dryas octopetala* L./*Geum montanum* L.	6						**6**
	Maloideae			1				**1**
a	*Potentilla aurea/crantzii* L./(Crantz) Beck ex Fritsch	3						**3**
	Rosa sp.	1						**1**
Mosses								
	Hydrogrimmia mollis (Bruch & Schimp.) Loeske						2	**2**
	Neckera complanata (Hedw.) Hüb.						5	**5**
	Paraleucobryum enerve (Thedenius) Loeske						2	**2**
	Polytrichum piliferum Schreb. ex Hedw.					1	47	**48**
	Polytrichum sexangulare Brid.						43	**43**
	Racomitrium lanuginosum (Hedw.) Brid.						14	**14**
	Musci indet.						39	**39**
Others								
m	*Acer* sp.			2				**2**
m	cf. *Acer* sp.			1		3		**4**
	Carex sp.	4						**4**
	Epilobium sp.	7						**7**
	Epilobium Subgen. *Epilobium*	1						**1**
a	*Juniperus communis* L.	1				9		**10**
	Rumex sp.						1	**1**
	Salix sp.	1	6					**7**
	cf. *Salix* sp.		1					**1**
m	*Sambucus nigra* L.	1						**1**
m	*Sambucus* sp.	5						**5**
a	*Saxifraga oppositifolia* L.					37	17	**54**
m	*Tilia* sp.		8		12,033		1	**12,042**
m	*Ulmus* sp.			22				**22**
	Apiaceae indet.	2						**2**
	Cyperaceae indet.	156				21		**177**
	Dryopteridaceae indet.						1	**1**
	Juncaceae indet.	3						**3**
	Broad-leaved wood indet.		1				1	**2**
	Coniferous wood indet.		1	29				**30**
	Grasses (Poaceae/Cyperaceae/Juncaceae) indet.					20,484		**20,484**
	indet.	9	2	292		191	1,463	**1,957**
Total		**399**	**25**	**376**	**12,033**	**20,776**	**3,548**	**37,157**

Letters in leftmost row indicate maximum altitudinal zones of the taxa: *sn–n* subnival to nival (above 2,500 m a.s.l.), *a* alpine (ca. 1,800–2,500 m a.s.l.), *sa* subalpine (ca. 1,500–1,800 m a.s.l.), *m* montane (ca. 500–1,500 m a.s.l.); data from Fischer et al. (2005)

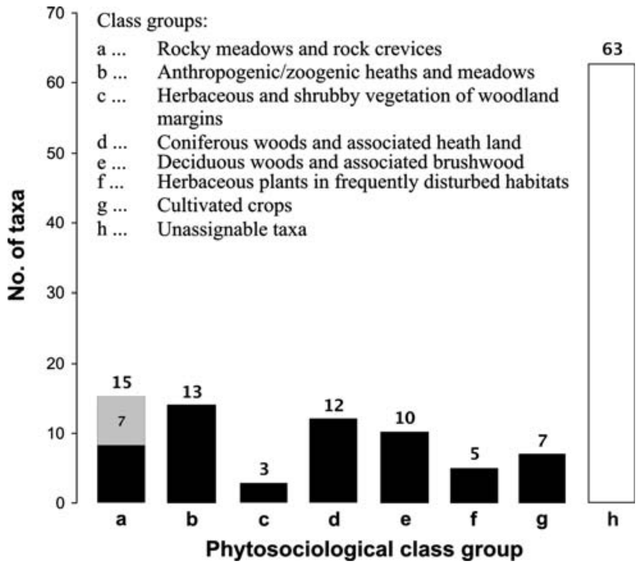

Fig. 5 Overview of the identified taxa, in phytosociological class groups (Oberdorfer 1990). The *grey bar* shows taxa growing in subnival and nival altitudinal zones

Discussion

Taphonomical considerations

A crucial question within the scope of this study was the origin of the plant material. In spite of the site's location in the nival zone above 3,200 m a.s.l., with only isolated plants occurring locally in the surroundings, the numerous remains from non-local plants required the consideration of alternative reasons for their deposition in the gully. As the excavators had paid special attention to remove the covering fresh snow and ice layers during ice and sediment sampling before taking any samples of the original ice layers beneath (Bagolini et al. 1995; Fig. 3), at least the presence of modern plant remains could be excluded. Even in such a remote place as the ice-covered Tisenjoch at an altitude above 3,200 m, several possible sources for the plant materials have to be taken into account to avoid misleading conclusions in the interpretation of the finds. This is especially so, when considering that the gully in which the Iceman was discovered forms a sediment trap due to its micro-topography and position at the lee side of the Tisen pass. Additionally, this investigation does not only concentrate on plant material unambiguously assignable to the Iceman's equipment, but also includes the complete spectrum of plant material found in the rocky hollow. The possible sources for the identified plant materials are as follows:

(a) Local vegetation: the remains of locally growing plants are an important factor influencing the species composition in the Iceman's discovery place. As mentioned above, there are only six taxa recorded up to now which grow in the altitude of the discovery site (Fig. 5; Table 1). Small stands of *Poa laxa* and *Ranunculus glacialis* are still found around the gully (Fig. 6). The arctic–alpine species *R. glacialis*, being the vascular plant growing at the highest altitude in the Alps (Fischer et al. 2005), even grows a few hundred metres above the site, on the slopes of the adjacent Finailspitze (3,514 m a.s.l.) as observed in a recent survey by the authors (on 21 September 2005). Currently, investigations on the range of local and extra-local diaspore and plant debris transport are being carried out by analysing modern glacier snow samples from the Niederjoch along an altitudinal gradient, and comparing their contents with the positions of modern stands of *Ranunculus glacialis* and *Poa laxa*.

(b) Extra-local and regional vegetation: most of the recovered plant remains belong to the extra-local or regional vegetation from lower altitudes and could have been transported to the gully by the following different vectors:

- Wind: nutlets of *Betula* spp. (birch) and *Alnus* spp. (alder) as well as several fruits of pappus-bearing Asteraceae were discovered. Although epizoochory (transport on animals) of these types of diaspores is also quite common (Römermann et al. 2005), wind transport is the principal means of their dispersal. The ongoing analyses of modern snow samples at these altitudes also indicate wind transport of other plant remains, like of the identified needles of *Larix decidua* (larch), *Picea abies* (spruce) and *Pinus cembra* (Arolla pine).
- Birds: since the seeds of most moderate-sized fleshy fruits (such as drupes and berries) are dispersed endozoochorously, predominantly by birds, the seed/kernel finds of *Empetrum nigrum* (crowberry), *Arctostaphylos uva-ursi* (bearberry), *Vaccinium vitis-idaea* (cowberry), *Sambucus* spp. (elder) and *Juniperus* spp. (juniper) most probably will have to be interpreted as deriving from bird droppings (Fig. 7). This interpretation is also corroborated by the missing pericarps of these diaspores, which should have been preserved under the special conditions of the site. Consequently, the fruit pulp must have decomposed before deposition, or been removed by other processes such as digestion. Besides, some bird carcasses were also found in the gully.
- Caprids: the numerous caprine droppings retrieved from the site had to be considered as

Fig. 6 Stand of *Ranunculus glacialis* and *Poa laxa* in a rock crevice on the southern slope of the Hauslabjoch (ca. 3,250 m a.s.l.)

an additional potential source of plant material. According to Oeggl et al. 2008 (this volume), macrofossils of *Leucanthemopsis alpina* (alpine daisy), *Ranunculus glacialis* (glacier buttercup), *Salix herbacea* (dwarf willow), and *Saxifraga oppositifolia* (purple saxifrage) are recorded from these droppings. Furthermore, faecal material has to be considered a source for the identified fragmented needles of *Juniperus communis* (juniper), *Larix decidua* (larch) and *Picea abies* (spruce), as well as for a minor part of grass remains. These grass fragments can be differentiated from other grassy material by their poor preservation, supposedly caused by the effects of ruminant digestion, while the major part of Poaceae leaf remains is clearly assignable to the Iceman's equipment.

Fig. 7 Bird droppings on a rock on the peak of Hauslabjoch (3,280 m a.s.l.), with protruding seeds of *Juniperus* sp.

– Other mammals or humans: the vectors for the discovered epizoochorously propagated diaspores are unclear. The spiny fruits of *Lappula squarrosa* (bur forget-me-not) and *Sanicula europaea* (sanicle) may have been transported attached to the Iceman's clothes or hair, but maybe also to some animal's fur.

Taking these considerations into account, only the remains of cultivated plants and the plant material belonging to the Iceman's equipment were regarded as (a) being contemporary with "Ötzi" and (b) with a high probability of having been brought to the find place by the Iceman himself (cf. extensive radiocarbon data of the implements: Kutschera et al. 2000; Kutschera and Müller 2003).

Distribution patterns

The gully on the Tisen pass is small and shallow and is fed by melt-water from the south-eastern slopes of the Hauslabjoch. Over a ridge it drains to the southeast into the Ötztal. Usually the water depth in the gully is low, but when all the ice is melted, water levels may reach about 1.4 m. The current energy as well as the sedimentation rates are low to moderate inside the gully, and bioturbation virtually does not exist at such altitudes. According to this, a dislocation of organic remains is possible by wind, water, and/or glacier movement. The latter seems to have had little impact due to the topography of the site, as shown by the intact state and the excellent preservation of the Iceman (Barfield et al. 1992; Seidler et al. 1992b; Bagolini et al. 1995).

Nevertheless, the Iceman find assemblage clearly displays an impact of various mechanical processes like fragmentation, dispersion and re-orientation, which took place at the time of his death and/or in the long period between the deposition and the archaeological excavation: for example the torn quiver cap, the broken quiver strut, the fractured arrow shafts, and the distant location of some of their pieces well away from the quiver suggest that considerable mechanical forces were involved. It is a fact that the conditions for an excavation at such altitudes are difficult and also that the first attempted recovery carried out by laymen involved the use of force. Still, there can be no doubt that the artefacts must have been broken at the time of deposition because they were recovered in that damaged condition from the undisturbed ice (cf. Zissernig 1992; Lippert 1992; Egg et al. 1992; Bagolini et al. 1995; Spindler 1996).

The dispersed distribution pattern of the artefacts can also be observed in other plant remains of the find assemblage. For the time being, distribution patterns were generated and analysed only for two categories of plant remains: the *Tilia* sp. (lime) bast used as a binding material throughout the Iceman's equipment (Pfeifer and Oeggl 2000), and the *Taxus baccata* (yew) wood of which the Iceman's bow was made (Oeggl and Schoch 2000).

The distribution of lime bast fragments shows two distinct peaks: the highest concentrations of these were observed in the quadrants where the backpack frame, axe and bow were found, followed by a second peak at the find place of the glacier mummy itself (Fig. 8), originating from bast remains adhering to the Iceman's clothes. Together with these two peaks in lime bast concentration, the accumulation of several heavier pieces of the Iceman's equipment (bow, axe, backpack frame, leather fragments) on the rock ridge south of the gully suggests that Ötzi's body had originally been deposited in this place, well away from where it was discovered.

Small amounts of bast fragments were found scattered across the whole investigated area, even in places rather far away from their potential sources. The probability of displacement of plant material caused by activities of the excavators is high in certain areas of the rock gully, indicated by different colours in the figures (Figs. 2, 3c, 4, 8, 9). The occurrence of lime fragments in the green areas (Fig. 8) suggests that the deposition pattern of lime bast is a result of natural causes and not one biased by excavation activities.

The remains of *Taxus baccata* (yew) wood were analysed in order to test the amount of possible material displaced by excavation activities. The bow may contribute to this matter because it was broken during an attempted rescue by laymen, about a week before the first excavation. The splinters resulting from this damage were recovered from the ice both in the 1991 and 1992 campaigns. Figure 9 shows that all the splinters had stayed within the same quadrant as the bow. This suggests that archaeological and rescue activities have had little effect on the distribution pattern of the find assemblage.

Anyhow, due to the fact that the Iceman was hit by an arrow and most probably died within a short time (P. Gostner, personal communication), it seems unlikely that he had enough time to arrange his equipment in such a scattered way. The distribution patterns of the artefacts and the plant remains in the rocky hollow were thus most probably caused by a dislocation either by wind, by melting snow and/or by water in a resulting melting water pool (Oeggl 2003). It has to be considered that Ötzi died in late spring (Oeggl 2000), at a time when the gully was presumably covered with several metres of snow. Thus the body must have lain in or on the snow at first and then, during the following thawing, sank to the bottom of the gully. Forensic investigations corroborate this hypothesis, basing on the skin alterations observed in the body: these indicate that the Iceman was not embedded in ice immediately, but rather was first submerged in water for one to

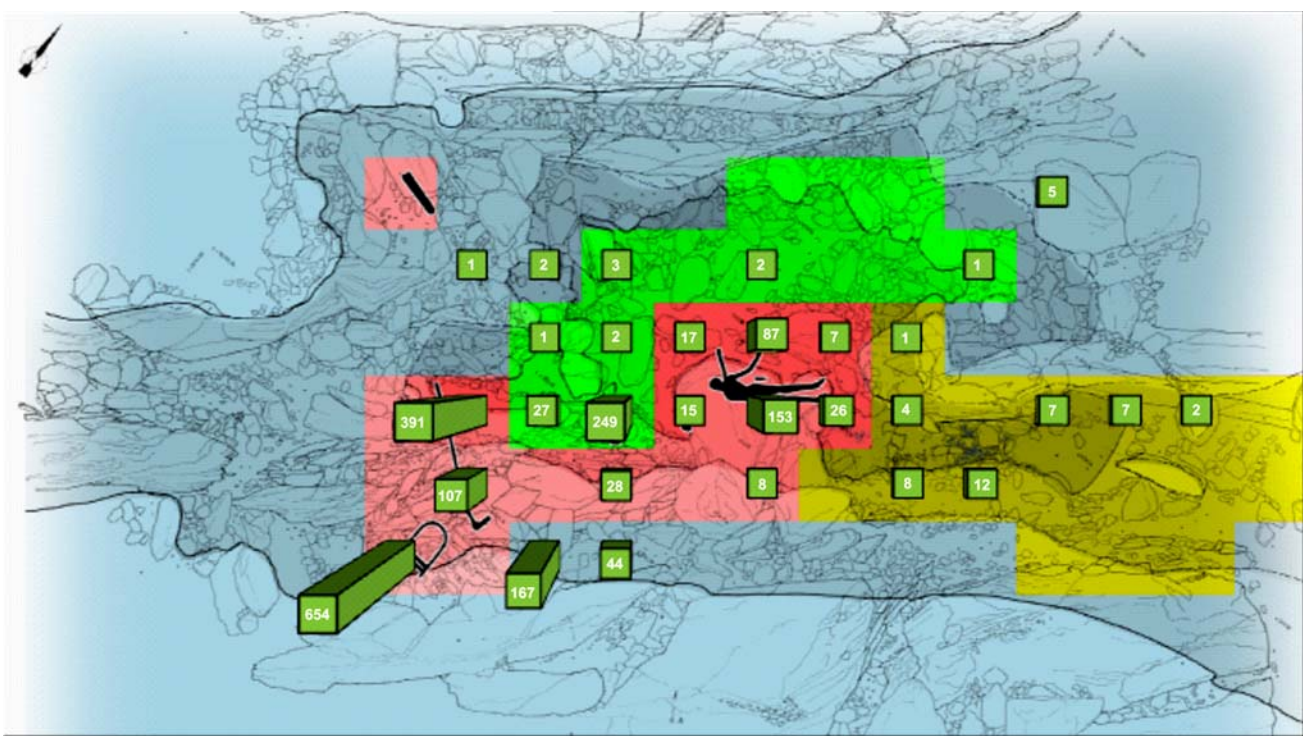

Fig. 8 Distribution of lime bast. The *numbers* in the bars represent the total fragments. For meanings of colours, see Fig. 2

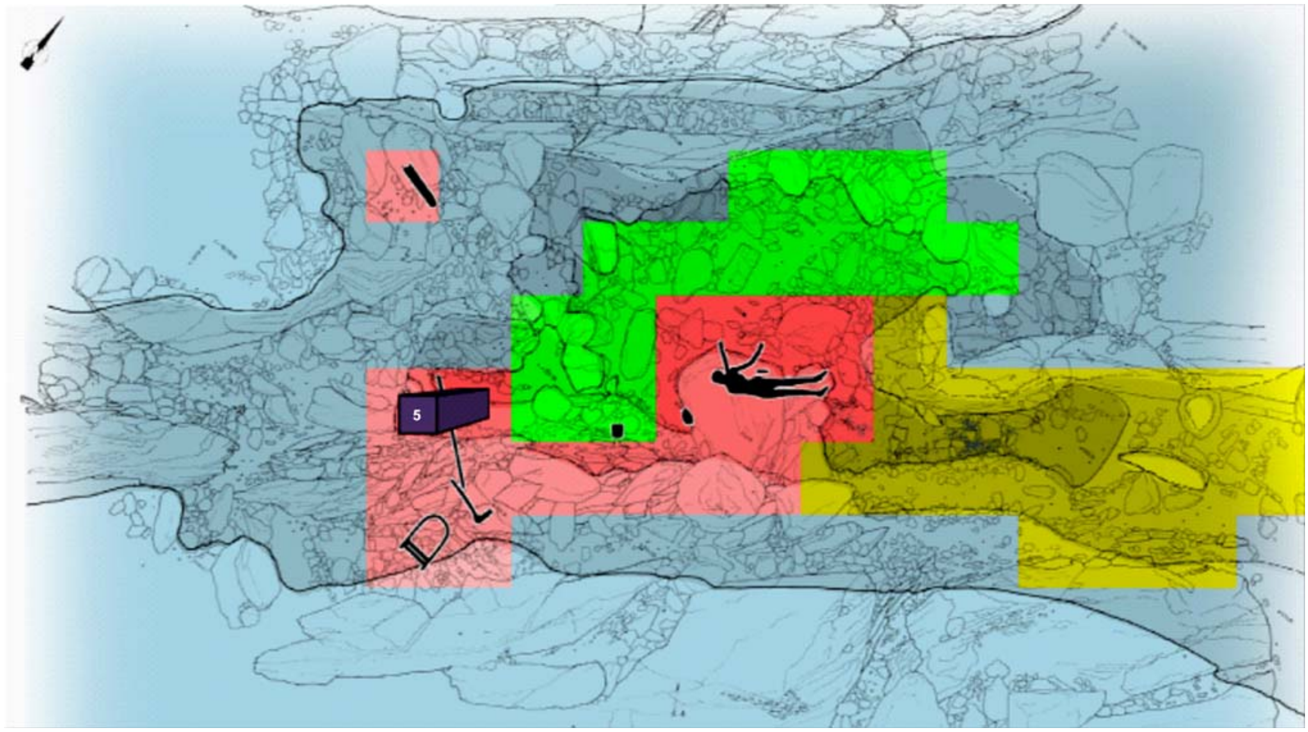

Fig. 9 Distribution of *Taxus baccata* (yew) splinters. For meanings of colours, see Fig. 2

three months, and only then was exposed to drying winds causing mummification (Bereuter et al. 1997). This again means that either the Iceman must have floated in the melting snow and water of the gully immediately after his death or that the ice melted at least once between his death and final discovery in 1991. This assumption is strengthened by the fact that several fragments of artefacts were discovered on the boulders outside the gully (Zissernigg 1992) and that some of the Iceman's equipment is still missing, such as parts of the birch-bark containers, fragments of the wooden backpack frame, pieces of leather from the quiver cap, etc.

Conclusions

Analysis of more than 40,000 plant remains from the find site of the Tyrolean Iceman has yielded plants from a great variety of ecosystems from different altitudes, and also from many taxonomic groups. Most of these plants were transported to their find place by long-distance transport either by wind or by human/animal action. The spectrum of identified cultivated Neolithic plants has now been extended by the cereal cf. *Panicum miliaceum*, as well as by the two oilseeds *Papaver somniferum* and *Linum usitatissimum*, so far the oldest finds in the Eastern Alps.

The first analyses of plant remain distribution patterns carried out for the "Ötzi" site suggest that plant remains have been subject to movement by snow and/or melting water, but most probably not resulting from excavation activities. It is to be expected that a clearer image of the site's taphonomy and of the processes involved is going to be gained from the ongoing full analysis of the remains.

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