The Iceman's fungi

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The iceman's fungi

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Among the numerous items of equipment with the 'Iceman', who died more than 5000 years ago on an alpine glacier, were three fungal objects: two different shaped fruitbody pieces of the polypore *Piptoporus betulinus*, each mounted separately on a leather thong, and, found in his girdle bag, a relatively large quantity of tinder material prepared from the 'true tinder bracket' *Fomes fomentarius*. A full description of these items and a chronological report on their identification is given. The question about the possible use of the fungi is discussed on the basis of a comprehensive collection of ethnomycological and pharmacological literature data.

The discovery of a Neolithic corpse in September 1991 in an alpine glacier at the Hauslabjoch, 92 m south of the Austrian/Italian border (Neubauer, 1995), attracted widespread attention. The real age of the Iceman (we prefer this name, one of more than 500 names for this unique find since autumn 1991 (Ortner, 1995)) ranges according to nine independent radiocarbon measurements between 3350 and 3100 BC (Prinoth-Fornwagner & Niklaus, 1995). Among the numerous items of equipment which were found with the mummified and frozen body there were three fungal objects.

Two of these objects were first mentioned by the archaeologists Lippert & Spindler (1991) as polypore like structures the size of walnuts, each mounted separately on a leather strap. Referring to other parts of the Iceman's equipment they thought that these fungal objects might represent a kind of tinder used for making fire.

The third object, a mysterious 'Black Matter', was discovered by X-ray analysis of an elaborate girdle bag made of leather. While the bag contained several flint tools, a great part of it was filled up with the black material, which was first thought to be resin representing part of a prehistoric repair kit (Lippert & Spindler, 1991; Egg & Spindler, 1993). In the course of the first chemical analysis at the Institute of Organic Chemistry in Vienna, Sauter & Stachelberger (1992) found that the material consisted predominantly of 'a felt-like biological matter, built up of different thread-like filaments which probably came from German felt (*Fomes fomentarius*)'.

In winter 1991 we received the first piece of the polypore-like material from the Römisch-Germanisches Zentralmuseum Mainz, Germany. The object was still in the condition in which it had been found on the glacier: a whitish structure of corky, leathery consistency, shaped like a Scots pine cone, threaded on a leather strap. The whole material was water saturated, and most surprisingly to us, after more than 5000 years the leather strap liberated a beastly smell, difficult to describe but well known by successful hunters. A quick microscopical examination of the whitish structure clearly demonstrated the presence of skeletal hyphae confirming its polypore nature. Since no additional basidiomatal structures, such as spores or cystidia, have been found the type of these skeletal hyphae and the shape and size of the fruitbody fragment were the only basis for further taxonomical investigations. Moreover, the situation was complicated by the fact that we were not authorized to remove larger quantities from this unique object. Nevertheless, within a few months we were able to identify this object (the methods applied are described below) as a fruitbody fragment of the polypore *Piptoporus betulinus* (Bull. ex Fr.) P. Karst. Our opinion (Pöder, Peintner & Pümpel, 1992) is that the 'razor strop fungus' does not provide a good tinder and, therefore, might have served some purpose other than making fire – we indicated a possible medicinal-spiritual use – and this has prompted a flurry of controversial discussion both in newspapers and scientific journals (e.g. Nieszery, 1992; Grant, 1993; Denman, 1993; Chapela & Lizon, 1993).

To find out whether or not the Iceman used the *Piptoporus* fruitbody fragment as fire-starting tinder, an accurate mycological re-examination of the 'Black Matter' revealed more information: It has been clearly identified as 'classical tinder' prepared from *F. fomentarius* (L. ex Fr.) Fr. (Pöder, 1993; Pöder, Pümpel & Peintner, 1995) thus confirming the idea proposed by Sauter & Stachelberger (1992).

The above mentioned studies were followed by the examination of the other (more spheroidal) piece of white polypore, which was like the first one mounted on a leather thong, but more elaborately decorated with a kind of three-lobed leather tassel. Its identity (it also represents a fruitbody

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fragment of *P. betulinus*) is published here for the first time. By giving comprehensive information about ethnomycological and pharmacological aspects of the fungi involved, it is an additional aim of the present article to provide a framework for a meaningful discussion of their possible use.

MATERIALS AND METHODS

Material examined

Two fungal objects on leather thongs from the 'Iceman' labelled 91/133 a and 91/133 b; 'Black Matter' found in the 'Leather Bag'. These materials are now kept at the Südtiroler Landesmuseum für Archäologie in Bozen, Italy. Reference material: *Laricifomes officinalis* (Vill.: Fr.) Kotl. & Pouzar, IB 73/112, 24 Aug. 1973, Ochsenkopf near Poschach, Ötz valley, Tyrol, Austria, on *Larix*, leg. B. Brader, det. M. Moser; *L. officinalis*, IB 88/701, 27 May 1988, Tiefentalalm St. Leonhard, Pitz valley, Tyrol, Austria, on *Larix*, leg. et det. M. Moser; *Piptoporus betulinus* (Bull.: Fr.) P. Karst., IB 91/932, 6 Oct. 1991, Eberstein, Görschitz valley, Carintia, Austria, on *Betula*, leg. et det. U. Peintner; *P. betulinus*, IB 91/933, 15 Oct. 1991, Christlum, Achenkirch, Achen valley, Tyrol, Austria, on *Betula* stem on the ground, leg. et det. U. Peintner; *Trametes gibbosa* (Pers.: Fr.) Fr., IB 73/139, 23 Sep. 1973, Engi, Lake Brienz, Switzerland, on *Fagus*, leg. et det. M. Moser; *Fomes fomentarius* (L. ex Fr.) Fr., IB 91/934, 26 Aug. 1991, Christlum, Achen valley, Tyrol, Austria, on *Fagus*, leg. et det. U. Peintner; '*F. fomentarius* leather': a piece of a hat produced in Poland, kindly provided by J. Klima, Innsbruck (IB 91/936); *Ganoderma lipsiense* (Batsch) G. F. Atk. (= *G. applanatum* (Pers.) Pat.), IB 91/935, 26 Aug. 1991, Achenkirch, Achen valley, Tyrol, Austria on *Fagus*, leg. et det. U. Peintner; *G. lipsiense*, IB 91/48, 1 May 1991, Gnadenwald near Innsbruck, Tyrol, Austria, on *Fagus*, leg. et det. U. Peintner; *Gleophyllum odoratum* (Wulfen: Fr.) Imazeki, 27 Jul. 1992, Lans near Innsbruck, Tyrol, Austria, on *Picea*, leg. et det. U. Peintner.

Microscopy

Light microscopy (LM) was carried out with a Leitz Diaplan with DIC-Nomarski equipment, and an automatic photosystem (Leitz Vario-Orthomat 2). Video prints (Sony CCD-videocamera CK-23 and a Sony Videoprinter UP-930) were used for measurements of hyphal diameters (all sample sizes > 30). Samples from the surface and the context of the different fungal objects were taken for squash mounts in water and 3% KOH.

Samples for SEM were sputter coated with gold without previous treatment. Micrographs were taken by using a Zeiss DSM 950 scanning electron microscope.

HPLC fingerprints of cell wall extracts

Five mg of dried context material (4 h at 105 °C) were ground down with quartz-sand in 0·5 ml 4% sodium-dodecylsulphate solution with a pestle and mortar. Suspensions were heated for 15 min to 100°, centrifuged (10000 ***g***, 10 min) and the sediment washed three times with 1 ml distilled water. The hydrolysation was done in three succeeding steps. Step 1, 1 ml 100 mM H_2SO_4 for 60 min at 100°. Step 2, 1 ml 1 M H_2SO_4 for 30 min at 100°. Step 3; 1 ml 10 M H_2SO_4, short boiling, diluted 1:5 with distilled water. After centrifugation the supernatant of each step was analysed: 10 µl of each hydrolysate was separated with an Aminex-HPX87H column (Bio Rad) with 0·5 ml min^{-1} 10 mM H_2SO_4 at 30°. Refractive-index and uv-extinction chromatograms (213 nm) were recorded and analysed on a computer.

HPLC fingerprints of methanolic extracts

Samples were ground down with methanol and quartz-sand with a pestle and mortar and heated. After centrifugation (10000 ***g***, 10 min) the supernatants were ultrafiltered (10000 D) and separated with a Hypersil ODS 5 µm column (1 ml min^{-1} 60% methanol at 25°). UV-extinction chromatograms (213 nm, 254 nm) were recorded and analysed on a computer.

TLC fingerprints of ethanolic extracts

100 mg of dried fungal material was ground down with 2 g quartz-sand with a pestle and mortar, extracted for 24 h in 10 ml 50% ethanol at room temperature and then heated in a boiling water bath for 3–4 h. Before centrifugation the volume was adjusted to 10 ml with 50% ethanol. The supernatant was evaporated to dryness, the residues obtained were dissolved in 1 ml 50% ethanol. TLC was carried out on silica gel DC plates 60 F254, 0·2 mm, Merck 5554, with a modified solvent system for triterpenic acids (Stahl, 1967) composed of 75 ml diisopropylether, 30 ml acetone and 25 µl glacial acetic acid. Chromatograms were examined in daylight, in uv light (254 nm, 365 nm), after treatment with iodine and after spraying with a 1:1 mixture of 96% sulphuric acid and 96% ethanol. After the latter treatment it was necessary to heat the TLC-plates to 110° for several minutes.

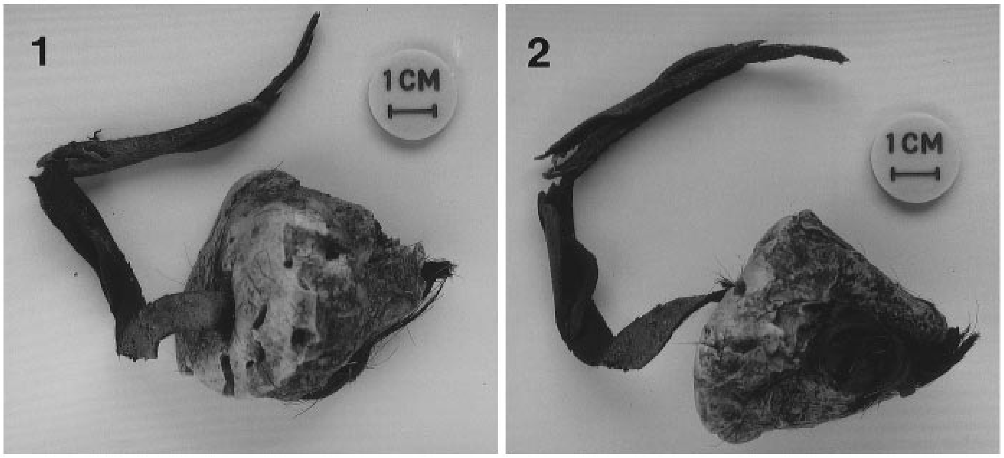
Detection of agaricine

The detection of agaricine (hydroxynonadecan-1,2,3-tricarbonic acid) was carried out following Fürth & Hermann (1935) and Casares-Lopez (1936): 1–4 mg of the dried context were extracted in 0·6 ml boiling glacial acetic acid. The solution was then evaporated to dryness and the residues dissolved in 0·2 ml acetic anhydride. After sedimentation of insoluble particles 0·15 ml were transferred into a test-tube before adding 0·8 ml of pyridine. After 30 min an orange-red colour reaction could be observed. Pure agaricine (Sigma A-7384) was used for calibration and for photometric quantification at 500 nm. This modified, simple method, allows the detection of at least 0·1–10 µg agaricine.

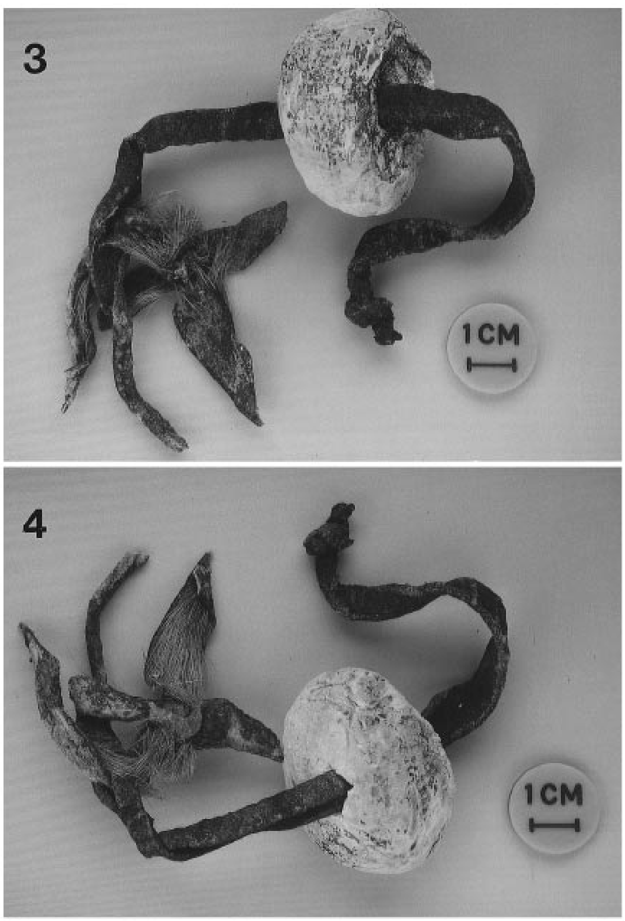
RESULTS

The fungi on the leather thongs

The fruitbody fragment officially labelled as 'object 91/133 a', is shaped more or less like a Scots pine cone with a maximum



Figs 1–2. The cone-like *Piptoporus betulinus* basidiome fragment (91/133 a) mounted on a leather thong, in its original, water-saturated condition.



Figs 3–4. The spheroidal *Piptoporus betulinus* fragment (91/133 b) mounted on a leather thong which bears an elaborated three-lobed leather tassel (pictures taken after lyophilization).

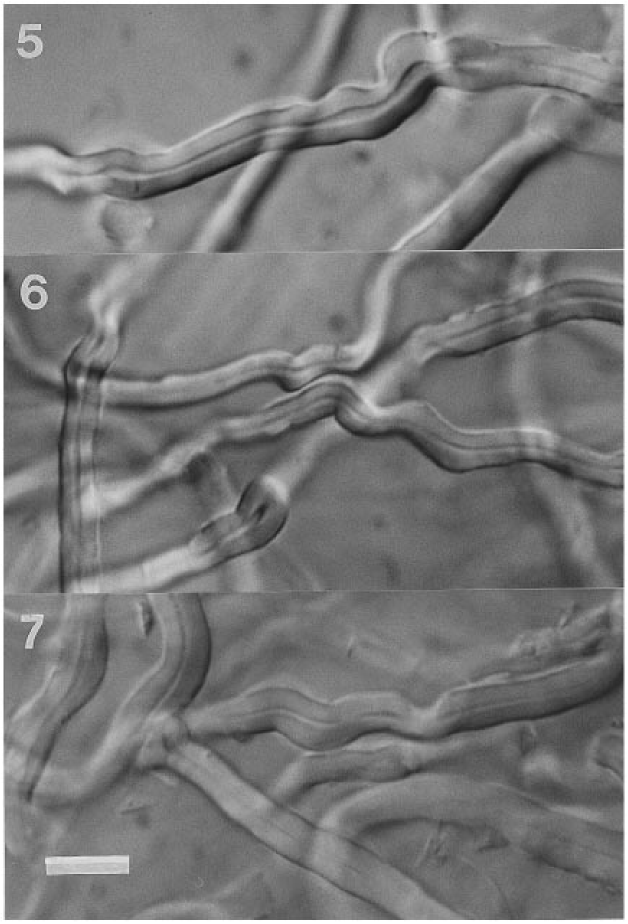
dimension of 4·5 to 5 cm (Figs 1–2). It is punched along its longitudinal axis and mounted on a leather thong which is tied into a quite complicated knot near the apical end of the fungal cone. The leather thong consists of two parts: the main thong, ruptured at its free end, is about 14 cm long, 0·9 cm broad, and 0·1 cm thick, with five perforations at irregular intervals (1·5–3 cm); through these perforations a second narrower thong (12 cm long, 0·5 cm broad 0·1–0·2 cm thick) is threaded. Fine blackish tufts of hair adhering to the knot and hole exit of the fungal fragment indicate that these thongs originally were fur strips ('the ones bearing the mushrooms … are possibly made of goat skin'; Groenman-van Waateringe & Goedecker-Ciolek, 1992). The context and surface of the corky, leathery object are whitish. The irregularly structured (wrinkled, folded, cracked) surface is partly covered with sooty speckles, some animal hair and remains of plant fibres. The total weight of the water saturated objects was about 42 g; the leather strap weighs approximately 4 g.

The more or less globose fruitbody fragment with somewhat flattened poles (object 92/133 b, it had been lyophilized by the Römisch-Germanisches Zentralmuseum) is 3·5–4·7 cm diam. and 2·4 cm high (Figs 3–4). Both the more or less smooth surface and the context of this polypore fragment are whitish. A 23 cm long and on average 1 cm broad leather thong is pulled through it. In contrast to the above mentioned piece, the leather thong bears an elaborated three lobed tassel inserted in a 1·5 cm long slit near one end, the other end is tied to a simple knot.

Microscopical examinations revealed that both fungal objects consist only of sterile tissue formed by typically waved and knobbed skeletal hyphae (Figs 5–7). The diameter of these thick-walled, unpigmented, mostly aseptate and very rarely branched hyphae is 4 ± 1 µm ($n = 55$). No generative hyphae or true binding hyphae could be observed. Because of the lack of binding hyphae the context structure of the two basidiomatal fragments must be considered as 'dimitic'.

The identification process was based on the following facts: (i) the objects in question had originally a white or unpigmented context (10000 years old, brown-pigmented polypores found in various archaeological sites had not lost their pigmentation; Kreisel, 1956/57; Kreisel, 1977; Göpfert, 1982; Terberger, 1996); (ii) the context structure of the species is dimitic; and (iii) the thickness of the original basidiomata was at least 4 cm or 2·5 cm, respectively.

Based on these three features, our comparative anatomical studies on recent European material could finally be restricted to *Piptoporus betulinus* and *Laricifomes officinalis*. A striking similarity of the hyphae from the 5000 years old basidiomata



Figs 5–7. Fig. 5. Typically waved and knobbed skeletal hyphae from the sterile tissue of recent *Piptoporus betulinus* material. **Figs 6–7.** Skeletal hyphae from the ancient *P. betulinus* fruitbody fragment (object 91/133 a). Bar, 10 µm.

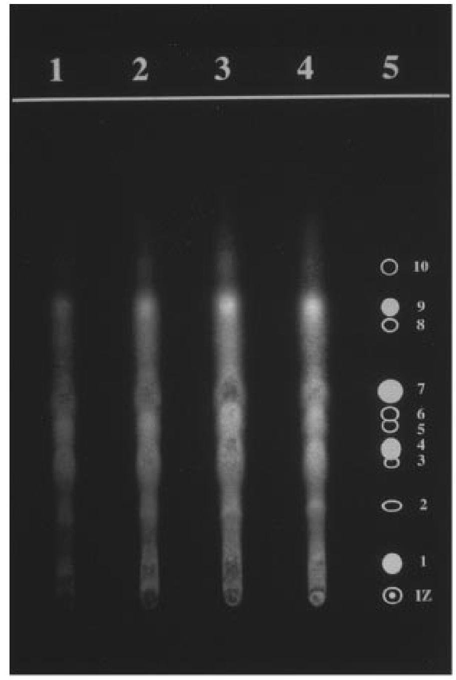


Fig. 8. Black and white reproduction of a TL-chromatogram after development with sulphuric acid, seen in uv light (254 nm). Ethanolic fruitbody extracts of recent material of *Piptoporus betulinus* (lane 1, 5 µl and lane 3, 10 µl) and ancient material (object 91/133 a: lane 2, 15 µl and lane 4, 30 µl). Lane 5 indicates 10 well distinguishable spots of unidentified, lipophilic substances, which appear in all lanes (full circles = pronounced spots; empty circles = weak but distinct spots; IZ = initial zone). The comparison of these fingerprints was facilitated by the different fluorescent behaviour of single spots (e.g. spots 1, 4, 7 were pinkish, spot 9 showed a bright turquoise colour). The original colour slide was electronically processed.

with that of recent *P. betulinus* could be observed: the whitish dimitic trauma, the typically waved and knobbed skeletal hyphae as well as their dimensions correspond with the detailed descriptions given by Corner (1953, 1984, 1994). He pointed out that in the diphasic development of *P. betulinus*, the initially monomitic flesh secondarily becomes dimitic, being infiltrated with many thick-walled, aseptate and rarely branched hyphae of 2·5–3·5 µm diam. During this 'intrusive skeletal processes' generative hyphae disappear.

To ensure that the fungi on the leather thongs were fruitbody fragments of *P. betulinus* and not of *L. officinalis* we scanned for other identification methods: *L. officinalis* was known to the ancient Greeks (Buller, 1914; Killermann, 1936; Thoen, 1982; Vaidya & Rabba, 1993) and has been used as a purgative or as medicine against pulmonary diseases right up to the 20th century. It contains the pharmacologically active agaricine (2-hydroxy-nonadecan-tricarbonic acid (1, 2, 3)) which is insoluble in cold water. Consequently agaricine should have been detectable in the material which had been 'put on ice' for more than 5000 years. Our method for the detection of agaricine enabled us to detect and quantify this substance in small quantities of dried fungal material: more than 20 years old basidiomata of *L. officinalis* showed an average content of 2% agaricine on a dry weight basis, but no agaricine could be detected in the two fungi of the Iceman nor in recent material of *P. betulinus*.

This result also supported our idea that the two objects with the Iceman were fruitbody fragments of *P. betulinus*, but as an additional positive control we looked for the presence of polyporenic acid C (dihydroxymonobasic acid with a terminal methylene group), which is a substance specific to *P. betulinus* (Cross *et al*., 1940; Birkinshaw, Morgan & Findlay, 1952). The detection of this acid, however, requires rather larger amounts of fungal material. We therefore tried to apply analytical fingerprint methods to obtain specific patterns of hydrophobic components: chromatographical patterns (TLC) of the ancient sample and recent material of *P. betulinus* were nearly identical (Fig. 8). HPLC fingerprints also showed a much higher similarity of the fungal fragments to *P. betulinus* than to *L. officinalis*. So, with nearly identical chromatographical fingerprints as well as a corresponding morphology we have a reliable identification of objects 91/133 a and 91/133 b as fruitbody fragments of *P. betulinus*.

The 'Black Matter' found in the 'Leather Bag'

The 'Black Matter' was found in a small pouch together with several sharpened flintstones, a small drill like piece of flint and

Fig. 9. The Iceman's girdle bag and its content: A part of the 'Black Matter' is shown on the right hand below. This material, originally filling up the major part of the bag, represents a mass of clumped hyphae of *Fomes fomentarius*. Next to the sample of the 'Black Matter' a 6·2 cm long bone-awl can be seen above which three flint objects are depicted (from left to right: great silex blade, silex drill, small silex blade). The wooden tack, right above, was not part of the bag content (photograph reproduced by permission of Römisch-Germanisches Zentralmuseum, Mainz, Germany).

a slender bone-tool (Fig. 9). This clotted, water saturated mass filled out the major part of the leather bag. The dark brown to blackish colour changed to a lighter brown during drying and the shiny wrinkled surface became faint showing a fibrous consistency. Using forceps it was easy to loosen up the dried material to a wad like consistency. The 'Black Matter' had been treated with boric acid by the Römisch–Germanisches Zentralmuseum Mainz to prevent growth of micro-organisms.

The microscopical investigation showed that the 'Black Matter' predominantly consisted of brown pigmented hyphae: thick-walled, straight and very rarely branched skeletal hyphae $5{\cdot}5 \pm 2$ µm ($n = 88$) diam., and sinuous-tortuous, often branched, $2{\cdot}5 \pm 1$ µm ($n = 50$) wide binding hyphae (Fig. 10). Besides accidental impurities like some hairs, traces of pyrite could be detected (Sauter & Stachelberger, 1992).

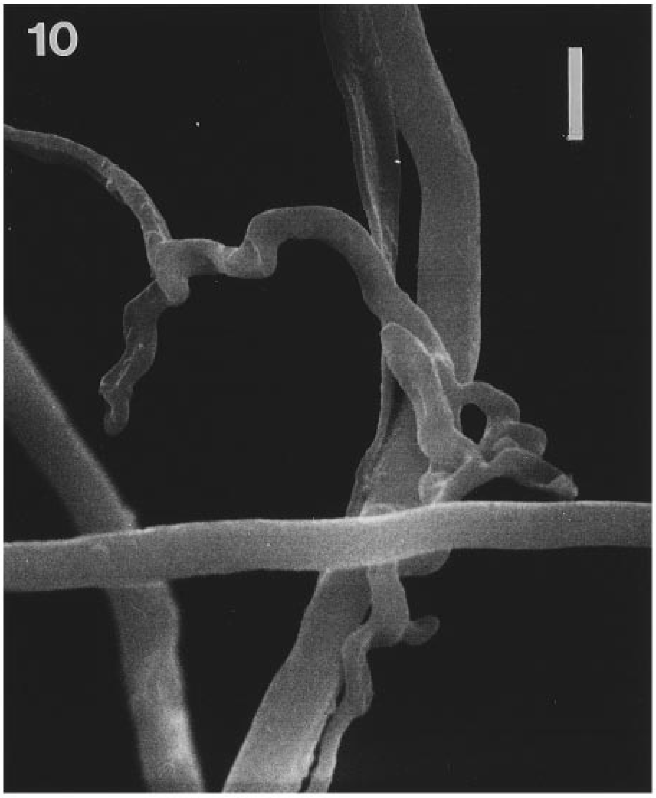
Based on the presupposition that the original fungal material had a brown context and was trimitic, we compared this part of the Iceman's equipment with other trimitic and brown pigmented polypores. The way in which it had been kept safe strongly indicates its use as tinder, but in ancient times many different polypores were used for this purpose (Killermann, 1936, 1938; Champion, 1976; Nieszery, 1992). An exact identification, therefore, provides new perspectives not only about the use and role of fungi, but (as polypores are generally host specific) also supplies interesting information about the environment of our ancestors. European polypores with rather robust basidiomata and a pigmented, trimitic trauma all belong to *Fomes*, *Ganoderma* and *Gloeophyllum*. Like the 'Black Matter' *Ganoderma lipsiense* has a rather high ratio of binding hyphae in the context but in contrast to our material they are mostly dichotomous branched. *Gloeophyllum odoratum*, on the other hand, has rather few binding hyphae. *Phellinus* species, although also used as tinder, were excluded due to their pure dimitic trama. Hyphal structures of *F. fomentarius* showed the most striking similarities with our 'Black Matter'. Also the data available in the literature (Jahn, 1963; Ryvarden, 1978; Jülich, 1984) correspond with our measurements of the hyphae. Moreover, we succeeded in confirming the results of our anatomical-morphological comparisons with chemical-analytical methods: The HPLC fingerprints of the methanolic extracts as well as the fingerprints of the cell wall hydrolysates showed a surprising high similarity between the 'Black Matter' and recent material of *F. fomentarius* (Figs 11–12). Thus, the 'Black Matter' was shown to consist of loosely interwoven hyphae of the 'true tinder bracket' *F. fomentarius* (Pöder, 1993; Pöder *et al.*, 1995).

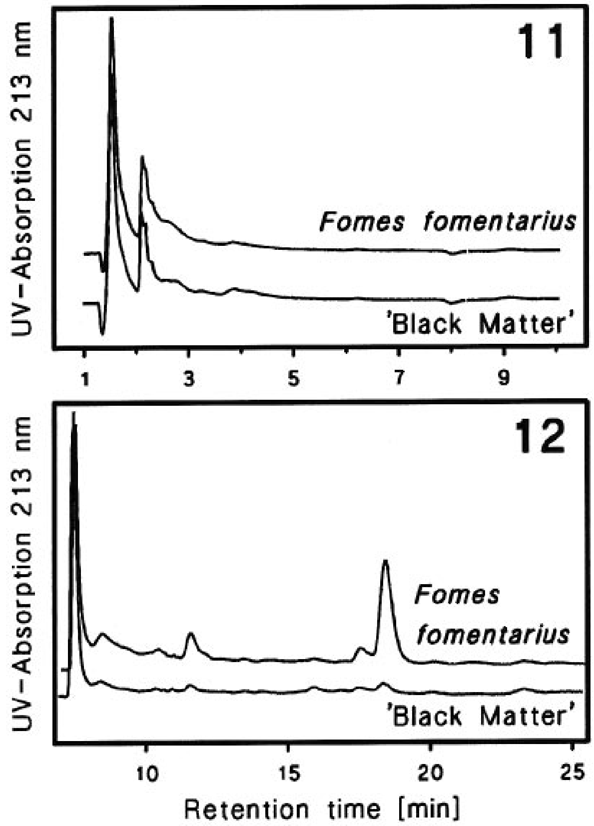
Piptoporus betulinus: ethnomycological remarks

A screening of the available ethnomycological literature demonstrated only a comparatively recent use of *P. betulinus* for nutritional purposes, in folk medicine and for various commodities, but no indications on archaeological findings or prehistorical uses of this striking fungus could be found.

P. betulinus fruitbodies are edible, at least when they are young. Wasson (1968, pp. 238, 239) mentions that the Kamchadal, a people living in Kamchatka (western Siberia, Russia) used *P. betulinus* for nutritional purposes. He cites Steller (1774), who reported that 'the Kamchadal knock them off birches with sticks, break them up with axes, and eat them frozen'. In this context Wasson refers to a passage in Krasheninnikov (1755), where the latter speaks of the Kamchadal as 'omnivorous creatures, for they pass by neither *zhagra* nor *mukhumor*, though the former has no taste and does not satisfy hunger, and the latter is obviously harmful'. *Zhagra* means primarily 'punk', 'touchwood' but also 'tree fungus' or 'polypore' in general; referring to Krasheninnikov's text Wasson interprets *zhagra* as 'the white polypore on birch trees', (= *P. betulinus*); *Mukhumor*, without doubt, means the hallucinogenic fly agaric *Amanita muscaria*.

Various polypores were used for medical purposes before modern medicines superseded them (Cochran, 1978; Thoen, 1982; Ying *et al.*, 1987; Hobbs, 1996): mushroom teas, for instance prepared of 'Tchaga' (= *Inonotus obliquus*), were very popular in Russian folk medicine as a remedy against cancer. Species used for mushroom teas include also *P. betulinus* (Golubjatnikov, cited by Cochran, 1978). Stamets (1993)





Figs 10–12. Fig. 10. SEM micrograph of the 'Black Matter' showing typical elements of the trimitic context of *Fomes fomentarius*: thick-walled, straight skeletal hyphae and sinuous-tortuous, often branched binding hyphae. Bar, 5 µm. **Fig. 11.** RP-HPL chromatogram of methanolic extracts of recent *F. fomentarius* reference material and 'Black Matter' samples (baseline shifted). **Fig. 12.** RP-HPL Chromatogram of cell wall hydrolysates of recent *F. fomentarius* reference material and 'Black Matter' samples (baseline shifted).

described the effect of *P. betulinus* teas as anti-fatiguing, immuno-enhancing and soothing.

People in south west Surrey (Great Britain) cut the context of *P. betulinus* basidiomata into small strips and used them as styptic; similar strips with a central perforation were employed as corn pads, while *P. betulinus*-charcoal was very appreciated as an antiseptic material (Swanton, 1916; Thoen, 1982). Hilton (1987), an Australian paediatrician, packed fruitbody pieces of *P. betulinus* behind ingrowing toenails leading to 'excellent results'.

Basidomata of *P. betulinus* have also been made into different utilitarian commodities: fruitbodies of *P. betulinus* have been processed into razor strops (Swanton, 1916; Rolfe & Rolfe, 1925; Gilbertson, 1980; Grant, 1993), used to make sweat pads in hats, the Swiss watch industry has used them for polishing the metal parts of watches (Thoen, 1982) and entomologists have made mounting blocks for insects from them (Grant, 1993). Furthermore, after a special treatment fruitbodies of *P. betulinus* have been used to manufacture drawing-charcoal (Bondartsev, 1986), while apiarists in England used smouldering *P. betulinus* and *Daedalea quercina* fruitbodies for anaesthetizing bees (Swanton, 1916; Gilbetson, 1980; Tyler, 1977). In Austria (Styria) basidiomata of *P. betulinus* have also been used for decorative carvings (Lohwag, 1965). No indication could be found concerning the use of *P. betulinus* as tinder material, except Swanton (1916) who reports that it was used for renewing or duplicating fires by placing it in a tin with restricted ventilation. For more detailed ethnomycological information regarding *P. betulinus* see Peintner & Pöder (1998).

Piptoporus betulinus: *pharmacologically active substances*

Between the 1940s and late 1970s the pharmacologically active substances of polypores attracted the attention of many scientists. Among many polyporaceous fungi (Ying *et al.* (1987) report 77 medicinal species from China only) *P. betulinus* was also screened for its medical properties.

The pharmacologically active substances of *P. betulinus* are ergosta-7,22-dien-3-β-ol, fungisterol, ergosterol, tumulosic acid (Efimenko, 1961*b*) and a group of triterpenes. Among the latter, Cross *et al.* (1940) separated three triterpenoid acids, polyporenic acid A, B and C. Animal studies have shown polyporenic acid A (= ungulininc acid; Loquin, Loquin & Prevot, 1948) to have antimicrobial and antiphlogistic activities (Efimenko *et al.*, 1961*a*; Ying *et al.*, 1987). Polyporenic acid B is a mixture of tumulosic acid and dehydrogenated substances (Ying *et al.*, 1987). Polyporenic acid C (called 'triterpenoid acid' by Birkinshaw *et al.*, 1952) was found to have a high activity against species of *Mycobacterium* (Marcus, 1952). According to Ying *et al.* (1987) this substance also inhibits the growth of '*Bacterium racemosum*'.

The five-cyclic triterpenes obtained from *P. betulinus* inhibit the growth of plants and malignant neoplastic cells. Thus, this polypore shows action on spontaneous tumours in dogs including cancers of the vagina as well as on sarcoma S37 in mice (Utzig & Saborski, 1957; Wandokanty, Utzig & Klotz, 1958; Blumenberg & Kessel, 1962). Shibata *et al.* (1968) tested the inhibition rate of *P. betulinus* extracts against the growth of sarcoma 180 in white mice. The alkaline extract was more effective than the aqueous extract. The hot water extract showed an inhibition rate of 42%, the alkaline extract of 72%. *P. betulinus* has also been found capable of preventing poliomyelitis in white mice and monkeys (Cochran, 1978). Furthermore, RNA isolated from *P. betulinus* fruitbodies can be used as interferon inducers in mice (Kawecki *et al.*, 1978).

Fomes fomentarius: ethnomycological remarks

Many species of polypores have been used as primary tinder for making fire, but as 'touchwood' or 'punk' *F. fomentarius* has enjoyed primacy from the beginning (Buller, 1914; Wasson, 1968). There is evidence that this polypore, the true tinder bracket, has been used for millennia, as both native fruitbodies and also fruitbodies bearing traces of human handling have frequently been found in archaeological sites, the oldest ones dating back to 11555 ± 100 BP (Killermann, 1936, 1938; Göpfert, 1979; Neuweiler cited in Göpfert, 1982; Thoen, 1982; Kreisel, 1996).

Various authors (for instance Buller, 1914; Herrmann, 1962; Champion, 1976; Weiner, 1981; Göpfert, 1982) describe in detail how tinder or 'amadou' was prepared and used for making fire with flint and steel. Moreover, dried and partly hollowed basidiomata of *F. fomentarius* were used to transport fire (Cordier, 1870 cited in Thoen, 1982; Walter, 1982).

Apart from its widespread use as classical tinder and as the basis for utilitarian articles *F. fomentarius* has been used for medical and even spiritual purposes (Buller, 1914; Sponheimer, 1936; Herrmann, 1962; Champion, 1976; Thoen, 1982; Saar, 1991; Vaidya & Rabba, 1993). The first historical reference seems to come from Hippocrates in the fifth century BC. Hippocrates, writing about the practice of medicine, advised cauterisation with amadou for the cure of certain complaints. The cauterization was accomplished by lighting the tinder and applying it, as it was smouldering, to the skin on the outside of the affected organ (Buller, 1914; Rolfe & Rolfe, 1925). Following Rolfe & Rolfe (1925) the practice of cauterization by means of fungi has survived among the Laplanders, Chinese and Japanese to the present day.

Furthermore, *F. fomentarius* was widely used as styptic by surgeons, barbers and dentists and therefore called 'agaric of the chirurges' or 'surgeon's agaric' (Cordier, 1870 cited in Thoen, 1982; Buller, 1914; Rolfe & Rolfe, 1925; Göpfert, 1982). A kind of absorbing cotton made of tinder was externally applied on wounds and burnings, or used as warming compresses (Wasson, 1968; Saar, 1991; Vaidya & Rabba, 1993).

Moreover, in Europe *F. fomentarius* was used as remedy against dysmenorrhoea, haemorrhoids and bladder disorders (Killermann, 1938), while in Indic folk medicine it was used as a diuretic, a laxative and as a tonic for nerves (Chopra & Chopra, 1956 cited in Vaidya & Bhor, 1991). In China cancer of the oesophagus as well as gastric and uterine carcinoma were treated with *F. fomentarius* (Ying *et al.*, 1987).

When natural people discovered the medical power of polypores in preserving and improving human health, they often conferred the origin of these properties to spiritual sources.

Smoking rituals with *F. fomentarius* are reported from the Khanty, a people living in western Siberia, and the Ainu people of Hokkaido, Japan. These peoples, in the case of illnesses or epidemics, which they believed to be caused by demons, burned *F. fomentarius* around their houses throughout the whole night, with the aim of banishing the bad spirits or demons (Yokohama, 1975, cited in Thoen, 1982; Saar, 1991).

The fruitbodies of *F. fomentarius* were also used for other purposes: as the soft material processed from the context has insulating and drying capacities, this polypore was often used for making caps, chest protectors and other articles of clothing (Buller, 1914; Ramsbottom, 1923; Rolfe & Rolfe, 1925; Broendegaard, 1981; Walter, 1982). Furthermore, this material has been used as pin-cushions to prevent needles from rusting (Broendegaard, 1981), and served entomologists for mounting their delicate insects (Thoen, 1982). A recent use of *F. fomentarius* concerns the art of fly fishing: fishing tackle manufacturers offer pads of 'amadou' as excellent absorbent material for drying water-logged flies.

Finally, Siberian peoples like the Khanty used powders ground from dried *F. fomentarius* and *Phellinus igniarius* fruitbodies as snuff (Wasson, 1968; Thoen, 1982), while the Athapaska Indians, the Eyak, Tanaina and other Eskimo people of Eastern America used to smoke ashes of the true tinder bracket on its own or after mixing it with tobacco (Thoen, 1982). For more detailed ethnomycological information regarding *F. fomentarius* see Peintner & Pöder (1998).

Fomes fomentarius: pharmacologically active substances

It has already been mentioned (Buller, 1914) that the styptic cotton prepared from *F. fomentarius* contains some iodine. Moreover, basidiomata of *F. fomentarius* contain the red-brown purpurogallin derivate fomentariol, which is concentrated in the hard crust of the basidiomata and is responsible for the intense blood red colour produced when this fungus is treated with alkali. The occurrence of this purpurogallin derivate seems to be restricted to *F. fomentarius* (Gill & Steglich, 1987). Fomentariol shows limited bacteriostatic action (Arpin & Favre-Bonvin, 1977).

The lipid fraction of *F. fomentarius* extracts contains ergosterols, fungisterol, and isoergosterone (Singh & Rangaswami, 1965; Yokoyama, Natori & Aoshima, 1975) as well as ergosta-7,22-dien-3-one (Arthur, Halsall & Smith, 1958). The liquid extract of *F. fomentarius* reached an 80% effective rate against sarcoma 180 in mice (Ying *et al.*, 1987). Isolated polysaccharides from a mycelium culture were tumour inhibiting in mice (Ito, Sugiura & Miyazaki, 1976).

DISCUSSION

As far as it is known, the discovery of the 5000 years old Iceman represents the only case where fungi were obviously part of a prehistoric person's equipment. Because of the uniqueness of this finding and the condition of the fungal items, identification methods had to be applied that are not commonly used for the identification of single species. Methods like HPLC, TLC or the detection of agaricine require very little material and may, therefore, be useful in similar cases, e.g. for the identification of fungal objects deposited in various museums around the world. The reliable identification of a fungus inevitably opens a window to ecological and other data, thus providing a source of new and valuable information, for instance about the way prehistoric people lived.

From an ethnomycological point of view, one of the most striking facts is that the Iceman carried two different species of fungi on his journey, which were treated and kept by him in different ways. Clumps of the 'Black Matter' filled up the greatest part of the Iceman's girdle bag. This mass, consisting of loosely interwoven context hyphae of *Fomes fomentarius*, did not show the compactness and organization of untreated or native fungal context because it could easily be loosened up by using forceps. Obviously, it had been treated mechanically in order to gain a material of a wad-like consistency. Consequently, we have to assume that the Iceman's girdle bag was more or less tightly stuffed with dry tinder material before his death. Furthermore, traces of pyrite could be found among the hyphae. The special consistency of the material and its safe storage in the bag strongly indicate its use as classical fire starting tinder. It can, however, never be proven whether or not it was additionally used for other purposes, for instance as a styptic or wound compress.

These considerations strongly support the assumption that the two *Piptoporus betulinus* fragments, each mounted separately on elaborate leather thongs, served some purpose other than making fire. Moreover, material scraped off from basidiomata of *P. betulinus* burns like paper, but compared to that of *F. fomentarius* it smoulders badly.

Screening ethnomycological literature, no indications could be found regarding a prehistoric use of this striking polypore. It is, however, not surprising that the birch polypore has never been found in archaeological sites, since under normal environmental conditions the annual fruitbodies are degraded within a short time. The Iceman noticed this strikingly shaped, whitish polypore growing on birch-trees. But what did he use it for?

A merely nutritional use seems not very reasonable to us for two reasons: (i) the corky consistency of *P. betulinus* is accompanied by a rather unpleasant taste; (ii) the storage of two small portions of simple food on elaborated leather thongs seems not very reasonable. Nor may these two fungal fragments be considered as commodities because of their shape and size, which do not give us any hint as to their possible practical application. Also an exclusively ornamentative or decorative function seems not very likely, whereas it seems more reasonable to associate the significance of these pieces with a 'medical-spiritual' background. The medical properties and various spiritual applications of polypores have been described many times: medical and spiritual qualities were often mixed up by native peoples, therefore they have often regarded polypores with medical properties as spiritual sources, for instance as a source of eternal strength or wisdom (Buller, 1914; Wasson, 1968; Cochran, 1976; Thoen, 1982; Saar, 1991; Blanchette *et al*., 1992; Hoobs, 1996; Blanchette, 1997).

In this context, a recent publication by Blanchette (1997) is particularly interesting: He reports that various North American indigenous people used *Haploporus odorus* as a component of sacred objects up to the 20th century. According to him 'the frequent use of *H. odorus* basidiocarps on sacred robes and in shaman or other medicine bundles demonstrates the reverence and spiritual uses the Plains Indians attributed to this fungus'. Older people wore fruitbody necklaces 'to ward off illness', and fruitbodies were 'burnt to produce a performed smoke in case of sickness'. Besides this merely spiritual use *H. odorus* probably was also applied medically: Blanchette argues that *H. odorus* is identical to the '*Polyporus*' with medical properties mentioned by Hellson (1974). The latter reported that this fungus was used by the Indians as remedy against various diseases.

The macromorphological analogy of the *H. odorus* objects illustrated by Blanchette (1997) to the Iceman's *P. betulinus* fragments is, however, remarkable. A further hint for a possible medical–spiritual use of *P. betulinus* arises from the fact that it grows exclusively on birch-trees, a tree regarded as the tree of life and fertility in many European and Siberian myths (e.g. Heeger, 1936; Wasson, 1968).

Summarizing the above considerations, what can be said about the significance of the Iceman's fungi? Concerning the 'Black Matter', its interpretation as classical fire starting tinder seems well confirmed by the current body of evidence. Regarding the *P. betulinus* objects, it seems very likely to us to ascribe their importance to a medical-spiritual field. In the latter context, however, the prospects for finding a non-speculative answer to this key issue look considerably more remote.

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