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The omnivorous Tyrolean Iceman: colon contents (meat, cereals, pollen, moss and whipworm) and stable isotope analyses

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The contents of the colon of the Tyrolean Iceman who lived *ca*. 5300 years ago include muscle fibres, cereal remains, a diversity of pollen, and most notably that of the hop hornbeam (*Ostrya carpinifolia*) retaining cellular contents, as well as a moss leaf (*Neckera complanata*) and eggs of the parasitic whipworm (*Trichuris trichiura*). Based almost solely on stable isotope analyses and ignoring the work on the colon contents, two recently published papers on the Iceman's diet draw ill-founded conclusions about vegetarianism and even veganism. Neither the pollen nor the moss is likely to have been deliberately consumed as food by the Iceman. All the available evidence concerning the Iceman's broad-based diet is reviewed and the significance of the colon contents for matters other than assessment of food intake is outlined.

Keywords: Tyrolean Iceman; palynology; bryology; stable isotopes; human diet; archaeology

1. INTRODUCTION

In 1991, high in the Ötztal Alps, the melting from the ice of the beautifully preserved, tattooed, arthritic corpse of a prehistoric man, with his clothes and gear, was a world-wide sensation. By many methods never before possible, here was the chance to investigate the way of life of a human who had lived *ca*. 5300 calibrated radiocarbon years ago (Late Neolithic period). Numerous publications, including papers and books, have been made and three official volumes out of nine scheduled have already appeared, and now there is a fourth (Bortenschlager & Oeggl 2000). Now known as the Iceman, the man had stood about 159 cm tall. Post-mortem, all of his hair and finger and toe nails had fallen out and the outermost layers of his skin had sloughed off (Bereuter *et al*. 1996). Some of his hair (up to 9 cm long) and one of his finger nails were found. There has been disagreement about the location of the Iceman's home area. Was it to the north or south of the death site? Almost all now accept the southern provenance (Dickson *et al*. 1996; Oeggl 1996). Wherever he lived, there is no disagreement that he belonged to an agricultural community and indeed cereal grains were found adhering to his upper garment. These were einkorn (*Triticum monococcum* L.), one of the first wheats to be cultivated, and barley (*Hordeum vulgare* L.), another cereal among the first to have been grown. He was well clad with three layers of clothes of goat, deerskin and bark fibre, well-made shoes and a bearskin hat. With the corpse were found a hafted copper axe, an unfinished longbow, a quiver full of mostly unusable arrows, the fragmentary remains of a backpack (contents unknown), a tinder kit inside a pouch, two birch (*Betula*) bark containers and other gear. Study of the Beau's lines on the only one of his fingernails to have been recovered showed that he had been badly ill three times during the last six months of his life which lasted almost 46 years (Capasso 1999; Gaber 1999).

Analyses of plant remains from both outside and inside the corpse have directly produced much data concerning the interpretation of the Iceman's precise foodstuffs, his exploitation of plants and fungi for purposes other than food, and also concerning his environment (Bortenschlager & Oeggl 2000; Dickson *et al*. 1996; Dickson 1997, 2000; Holden 1996; Oeggl 1996, 1999, 2000; Oeggl & Schoch 1995; Pöder *et al*. 1992, 1995).

Stable carbon and nitrogen isotope analyses of body tissues are now widely used in the assessment of the composition of the diet of ancient populations (Ambrose 1993). The tissue most often investigated is the bone protein collagen. However, the isotopic values of hair keratin have also been shown to correlate well with dietary isotopic values (O'Connell & Hedges 1999).

On the basis of such analyses of the Iceman's hair, as well as a sample of 'goat hair' and a 'grass-like plant' found with the corpse, a surprising evaluation of the

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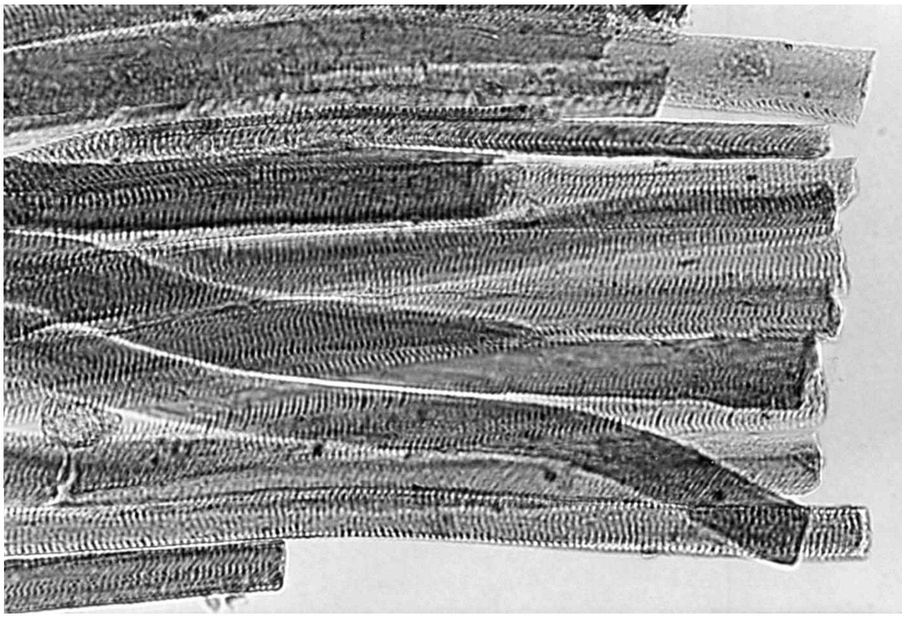

Figure 1. Muscle fibres in the food residue from the Iceman's colon. The frame width is 350 μm. From Holden (1996).

Iceman's diet has recently been made by Macko *et al.* (1999*a*,*b*) who compared him with present day vegans in Austria and England. In their summary (Macko *et al.* 1999*a*) they state 'We have recognized a primary vegetarian component in the diet of the Neolithic Ice Man'. In the case of δ^{15}N, they state 'δ^{15}N value of 7.0% for the Ice Man clearly points to diet which is essentially vegan' (Macko *et al.* 1999*a*, p. 72). For carbon they state 'the δ^{13}C value ... reflects a high percentage of grains in the diet which can be attributed to plants which used the C_3 pathway for photosynthesis ...' (Macko *et al.* 1999*a*, p. 74).

In neither of their papers did these authors consider the matter further by discussing the microscopic studies of the Iceman's colon contents and indeed the papers are written as if they were unaware that there have been such studies (Dickson 1997; Groenman-Van Wateringe 1997; Oeggl 1996, 2000).

2. THE CONTENTS OF THE COLON

On the microscope slides prepared from minute quantities of the Iceman's colon contents are muscle fibres, the remains of meat (figure 1) (Holden 1996; Oeggl 1999, 2000). The fibres have not been identified as to species of origin but two small bone splinters (from neck vertebrae of a male alpine ibex, *Capra ibex*) were associated with the corpse (Spindler 1994; Von Den Dreisch & Peters 1995). Following Spindler (1994), Fleckinger & Steiner (1998, p. 45) claim that the Iceman 'had probably taken smoked or dried ibex meat with him on his journey'.

In his botanical work on the colon contents, Oeggl (1996, 1999) has identified bran and other remains of einkorn and barley and he considered that plant tissue fragments made up 45%, pollen 22% and charcoal particles (of coniferous wood) 25%, leaving mineral particles, *Trichuris* eggs and diatoms as minor components (figure 2). Of the tissue fragments, 82% were cereals, mostly of the wheat–rye type (figure 3); these remains must be of einkorn wheat because rye (*Secale cereale* L.) was not in central Europe at that remote period.

There were other probable though not precisely identified food plants represented by microscopic fragments, as well as a moss leaf and eggs of the intestinal parasite whipworm (*Trichuris trichiura* L.) (Aspöck *et al.* 1995, 1996). Holden (1996) undertook an independent analysis of the colon contents (other than of pollen and *Trichuris*). The results are essentially the same as those of Oeggl, i.e. abundant bran of wheat (but with two spikelet forks confirming that the wheat was einkorn), two bran fragments of barley, occasional muscle fibres, possible connective tissue and a hair of animal origin as well as charcoal and mineral particles.

These results are very important in a variety of respects and in broad terms do not bear more than one interpretation. Shortly before his demise, the whipworm-infested Iceman had ingested both animal and vegetable material. The use of the verb 'ingest' is deliberate because in this context a distinction has to be drawn between intentional and unintentional swallowing. The discovery of a single moss leaf in the colon contents makes that point cogently. The moss leaf, a mere 0.6 mm long, has been identified as *Neckera complanata* Hedw. This is the low to moderate altitude woodland moss, which had already been found as a mass of leafy stems up to 6.5 cm long that came from sample 124 (of the 1991 gatherings). That sample had been catalogued as 'grass, pieces of leather or hide (upper body clothing and leggings)'. There are photographs of the mass in Dickson *et al.* (1996) and Dickson (2000).

3. DISCUSSION

(a) *Colon contents*

Work on the archaeobotany of the Tyrolean Iceman has brought to the fore in particularly intriguing ways the uses to which the prehistoric inhabitants of Europe put both flowering plants and mosses. Pollen can be eaten deliberately as food. The Navajo Indians of North

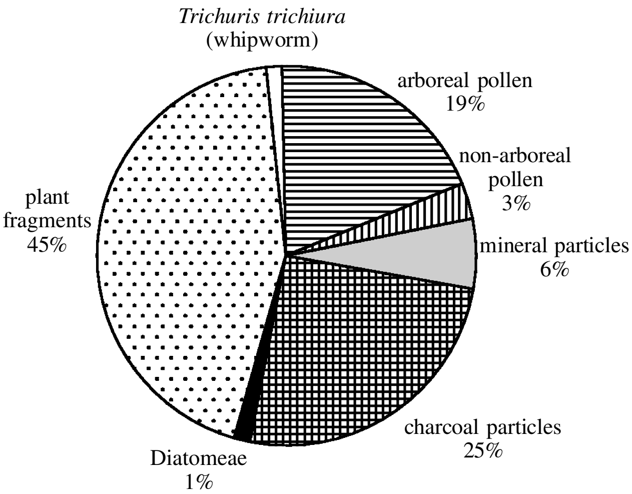

Figure 2. The colon contents. The analysis was made by K. Oeggl as part of a botanical investigation and meat remains were noticed but not counted. Translated from Oeggl (1999).

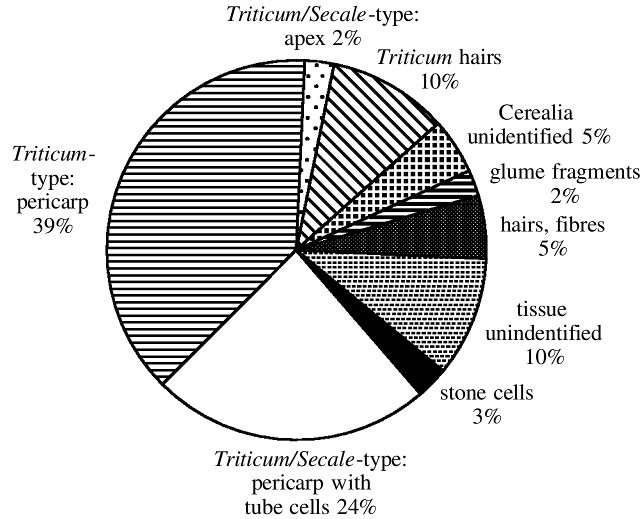

Figure 3. The detailed proportions among the plant tissue fragments as identified by K. Oeggl. Translated from Oeggl (1999).

America collected pollen of maize (*Zea*) as food (Linskens & Jorde 1997) and the Indians of California collected the pollen of *Typha* (cat-tail or reed-mace) and made it into a kind of bread (Balls 1962). The Yuma of Arizona ate *Typha* pollen raw or stored it for further use, boiled it to make thin gruel, baked it into cakes and used it as flavouring (Moerman 1998). On the other side of the Pacific, the Maoris of New Zealand ate pollen as food (Cranwell 1953). Cranwell stated (p. 9) 'considerable use was once made of *Typha* pollen by the primitive New Zealanders. Bucketsful were beaten out gently from the spikes... mixed up with water into cakes and baked'. The natives of Scinde in India did exactly the same, as reported by Sir Joseph Hooker (Cranwell 1953).

Such preparation of pollen of *Typha* or of any other plant appears to be unrecorded from Europe, present or past, according to Linskens & Jorde (1997, p. 78), who state that pollen is 'a concentrated, energy and vitamin rich food'. Humans have consumed honey since very ancient times (Clark 1942) and honey contains pollen but eating honey is not deliberately to eat pollen. Humans also occasionally eat flowers and flower buds but again that is not intentional eating of pollen.

A great deal of interest and some controversy attaches to the significance of the pollen recovered from the Iceman's colon samples. There is a wide variety of pollen types: Oeggl (1996, 1999, 2000) recognized 30 types as well as two types of spores. Much of the pollen is hop hornbeam (*Ostrya carpinifolia* Scop.) and hazel (*Corylus avellana* L.). The disagreement concerns the well-preserved pollen of hop hornbeam, a small catkin-bearing low-altitude tree of Southern Europe. It is wind pollinated so its pollen is not a component of honey and therefore that consideration does not apply. Was this ingestion of pollen deliberate or accidental? Groenman-Van Waateringe (1997) has argued that it was deliberate in that the pollen had been sticking to the bark of the tree used to make medicine. Moerman (1998) cites three North American tribes that used the bark of Eastern hop hornbeam (*Ostrya virginiana* (P.Mill.) K. Koch) to make infusions against weak blood, toothache, cancer, tuberculosis and diarrhoea. There is no record of the medicinal use of hop hornbeam in these or other ways in Europe, present or past. Furthermore there are no remains of bark in the colon samples though no bark fragments would necessarily have been swallowed with an infusion.

In contrast, Oeggl (1996, 1999, 2000) considered that the pollen grains, some most notably of hop hornbeam with the cellular contents remaining, were swallowed unintentionally in drinking water while the Iceman was in or near his home valley. Pollen of pine (*Pinus*), birch (*Betula*) and *Vaccinium* type (bilberry or rhododendron) was also found in the colon samples. In late spring or early summer (the flowering period of hop hornbeam) this ingestion had taken place prior to or during the Iceman's swift and final ascent from the south through deciduous and coniferous woodlands to the great height of 3210 m above sea level, where he died in a rocky hollow of the Ötztal Alps just inside Italy. Subsequently his corpse was preserved frozen for more than 5000 years in what became a stationary part of the Niederjoch glacier. If this last interpretation is accepted then the Iceman's death took place much earlier in the year than the autumnal demise claimed by Spindler (1994). Whatever the interpretation of the pollen analyses of the colon sample, because of the low pollen concentration (9700 grains g^{-1}) it is very improbable that the Iceman had intentionally eaten the pollen of hop hornbeam or of that of any other plant as food.

Though there are instances of the deliberate eating of pollen, there are virtually no instances of the consumption of mosses (class: Musci) as food. It has been well known for a long time that mosses are often encountered during archaeological excavations especially where there had been waterlogging. There have been many plausible explanations put forward such as packing, stuffing, wiping and caulking and indeed the precise contexts in some cases have left no room for doubt about selective use.

On his last journey the Iceman carried mosses that came from low to moderate altitudes where in Vinschgau and nearby elsewhere in Südtirol they now grow in local abundance, especially on shady, limy rocks, and would have grown in at least as great—probably greater—abundance in the Late Neolithic period before there had been much woodland clearance (Dickson *et al.* 1996). The crucial species are the already mentioned *Neckera complanata* and also *Neckera crispa* Hedw.

If it is accepted that the Iceman deliberately carried the mosses—notably *N. complanata*—what had been his purpose in doing so? The details of the recovery of the *Neckera* given above are regrettably insufficient to allow any single explanation to be advanced to the exclusion of others. The theories offered by Dickson (2000) are as follows: padding or decoration for the clothes, food, medicine, hygiene and wrapping. The last two are the favoured ones while the others are discounted. On the basis of present knowledge from archaeological excavations and ethnobotany on a worldwide basis, what seems very likely is the following. The Iceman had not intended to consume the mosses as food. That statement can be made with confidence despite the leaf found in the colon sample. This solitary leaf can be readily explained as an unintentional ingestion, just as is the case for the few, sparse remains of mosses recovered from the intestines of the famous Iron Age bog bodies from Denmark and England (Dickson 1997).

Modern civilization depends on the consumption of cereals, and many other flowering plants are eaten either as staples or in minor ways. Also consumed are algae (seaweeds), lichens, fungi, pteridophytes (the fronds of ferns such as bracken, *Pteridium aquilinum* (L.) Kuhn) and gymnosperms (seeds of both conifers and cycads and tubers and stem starch of the latter; Palmer 1878). The authors know of no evidence from any place, anywhere in the world, at any time, present, recent or distant past, that shows the regular consumption of mosses as food, not even as famine food. In his summary of American ethnobotany, Moerman (1998) lists bryophytes many times but not once their use as food. Though mosses are not known to be toxic, neither are they especially palatable nor nutritious (Crumb 1973; Richardson 1981). The lack of palatability of mosses may well relate to the large amounts of lignin-like substances present in the tissues. Lignin (the chemical basis of wood) is itself indigestible and furthermore may inhibit the digestibility of carbohydrates.

Infection by the colonic nematode *Trichuris* takes place under conditions of poor sanitation and hygiene by ingestion of infective eggs which contaminate the environment where poor sanitation and inadequate hygiene prevail. The discovery of the eggs of the whipworm with the Iceman is not surprising. Now having been recovered so many times from European archaeological contexts, including prehistoric ones, the recognition of these eggs is routine, though care has to be taken in distinguishing those of the species which parasitize humans from those of other large mammals (Aspöck *et al.* 1995, 1996). If he had harboured a heavy whipworm infection, the importance with regard to the Iceman is that he might well have suffered from overt trichuriasis, including either chronic diarrhoea or dysentery and the accompanying debilitating effects (Little 1985).

In the samples examined by both Oeggl and Holden, the bulk of the colon contents was bran of einkorn of sufficiently small size as to indicate fine grinding on a saddle quern. Such processing would have been carried out for baking bread rather than gruel for which pounding would have been enough, with coarser cereal fragments resulting. Mineral particles could have adulterated the flour during the milling and baking could have led to contamination by charcoal particles.

(b) *Isotopic analyses of the Iceman's hair*

Both carbon and nitrogen isotopic analyses are useful in determining the dietary composition of humans, indicating whether an individual obtains most of their food from a C_3 or C_4 ecosystem, whether they are primarily dependent on terrestrial or marine foods, and whether the individual was more dependent on animal or plant sources for their protein intake. The isotopic results from the Iceman's hair (Macko *et al.* 1999*a*,*b*) are of interest but need further evaluation and discussion. Evidence of the Iceman's diet from sources other than isotopic analyses, as detailed in this paper, do not support the interpretation that he was primarily a 'vegetarian' or 'vegan' (Macko *et al.* 1999*a*,*b*).

When using isotopic analyses to reconstruct diet, the results should not be interpreted in isolation from their wider context. The reconstruction of an individual's diet must be based on the isotopic values of both the individual of interest and possible food sources. In addition, the likely composition of the diet must be considered in the light of what else is known of the site and individual at the time of living.

With regard to the carbon isotopic signature of the Iceman's hair ($\delta^{13}C = -21.2$), Macko *et al.* (1999*a*,*b*) conclude that the Iceman was consuming a (C_3) 'grain' diet. As no C_4 plants were consumed by humans in Central Europe when the Iceman lived, the observation that his diet was derived from a C_3 food chain (as opposed to C_4) is trivial. The colon contents would support the contention that his diet was cereal based, but the $\delta^{13}C$ value of his hair cannot be interpreted specifically as reflecting a 'grain' diet because the $\delta^{13}C$ of bulk consumer tissues cannot be used to distinguish between different types of C_3 plants.

Although the Neolithic period saw the introduction of domesticated cereals to human diet, there is no reason to suppose that this eliminated the importance of seasonally abundant wild plants as food sources for the Iceman's community—some of these which are still commonly consumed across Europe are blackberry (*Rubus fruticosus* L.) and raspberry (*R. idaeus* L.), crab-apple (*Malus sylvestris* (L.) Miller), elder (*Sambucus nigra* L.), hazel (*Corylus avellana* L.), sloe (*Prunus spinosa* L.), strawberry (*Fragaria vesca* L.) and wild garlic (*Allium ursinum* L.). In the absence of evidence to the contrary, it is an unparsimonious argument to suggest that a people living close to nature among this edible abundance should entirely restrict themselves to 'cereal'. The cited species are all well known from prehistoric sites across Europe and grow in the South Tyrol, the Iceman's homeland. In the colon samples there were several different tissue remains of plants not precisely recognized but which show the consumption of a variety of plants apart from the cereals. A well-preserved fruit of sloe was found beside the Iceman's body (Oeggl & Schoch 1995). Sloes (structurally identical with plums) keep well after drying, a process which much reduces the bitterness of the fresh fruit. Remains of sloe have turned up again and again in archaeological layers from prehistoric times onwards throughout Europe.

Carbon isotopic values of an individual's body tissues indicate the plant type (C_3, C_4) at the base of that individual's food-chain, but cannot discriminate between consumption of C_3 plants and consumption of meat taken from animals consuming C_3 plants. Nitrogen isotopic values can indicate the relative amounts of animal or plant protein in the diet due to the trophic level effect. The trophic level effect is an observed average enrichment in δ^{15}N between a mammal's diet and their body tissues, of *ca*. 3% (De Niro & Epstein 1981; Hare *et al.* 1991), which equates to a jump of 3% between plants and herbivores, and between herbivores and carnivores. Comparison of δ^{15}N results from three specimens—the Iceman's hair (δ^{15}N = +7.0%), a sample of goat fur (δ^{15}N = +5.9%), and a sample of a 'grass-like' plant (δ^{15}N = +4.0%)—led Macko *et al.* (1999*a*,*b*) to conclude that the primary source of the Iceman's diet was the grass-like plant, or other similar species owing to the 3% difference between the Iceman and plant sample.

We contend that one sample of a grass-like plant is insufficient to document the δ^{15}N of the plant component of the Iceman's diet. Plant δ^{15}N is extremely variable: δ^{15}N differences among plant parts have been routinely measured as 0–6% (roots, stems, leaves, fruits and flowers). The δ^{15}N of a single plant species may vary within a site and the average δ^{15}N of different plant taxa may vary systematically within a site (Handley & Scrimgeour 1997). Among sites, site-averaged plant δ^{15}N for all co-concurring species has been shown to vary in relation to rainfall (Handley *et al.* 1999), past fires (Chang & Handley 2000) or grazing pressures (Schulze *et al.* 1999).

In spite of this known variability in plant δ^{15}N, and the observation that nitrogen isotopic values of mammals are less variable than plant δ^{15}N, due to the averaging of all the N of an individual's diet over time (Ambrose 1993), Macko *et al.* (1999*a*,*b*) appear to make their judgement about the Iceman's diet more on the nitrogen isotopic values of the 'grass-like' plant than the goat fur δ^{15}N.

However, if the plant δ^{15}N is ignored, and if the δ^{15}N of the goat fur is taken as representative of herbivore δ^{15}N, then the 1% enrichment of the Iceman relative to the goat implies that he was not a complete 'herbivore', but did consume a proportion of animal protein. A 1% shift is equivalent to one-third of a trophic level shift, suggesting that the Iceman is one third of the way between herbivore and carnivore. In comparison, the !Kung bushmen, a contemporary hunter–gatherer group, have been observed to derive about 35–40% of their dietary protein from animal sources (Lee 1968), and such a group is not considered as vegetarian or vegan. In discussions of these observations, Lee writes 'the basis for Bushman diet is derived from sources other than meat. This emphasis . . . appears to be a common feature of among hunter–gatherers in general. Since a 30–40% input of meat is such a consistent target for modern hunters in a variety of habitats, is it not reasonable to postulate a similar percentage for prehistoric hunters?' (Lee 1968, p. 43). The fragments of muscle fibres found in the Iceman's colon confirm that he did consume animal protein, and the finding of small bone splinters beside him make it likely that alpine ibex formed part of his diet.

As well as considering isotopic analyses within the context of food sources, it is also important to place the analyses within a time-period. Macko *et al.* (1999*a*,*b*) support their theory of a 'vegetarian' Iceman by making a direct comparison between δ^{15}N then and now. This is not possible, since δ^{15}N are not absolute, but can be affected by climate and geology (Heaton *et al.* 1986; Gröcke *et al.* 1997) and are known to have fluctuated to a small extent within single species of mammals over the last 30 000 years (M. P. Richards, unpublished data). Therefore although the Iceman's δ^{15}N value is equal to that of a modern human consuming no animal protein, this equivalence does not imply that he himself had a diet similar to that of a modern vegetarian individual.

From a technical standpoint, the isotopic analysis of the Iceman's hair has to be viewed with caution. When analysing the stable isotope natural abundance of proteins from archaeological sites, it is advisable to establish and report purity criteria of the samples analysed, such as total nitrogen content, carbon-to-nitrogen ratio and amino-acid content. Macko *et al.* (1999*a*,*b*) reported the latter criterion, but neither of the former. Although samples of the Iceman's hair showed similar relative fractional amino-acid contents, they showed consistently lower absolute amino-acid contents ($\mu M\ mg^{-1}$) when compared with hair from Coptic mummies and contemporaneous samples. Nitrogenous loss from, or contamination of, the Iceman's hair could have a large effect on the remaining hair δ^{15}N. Individual amino acids have a wide range of δ^{15}N values relative to bulk sample. Hare *et al.* (1991) found a range of 13.1% among common amino acids in bone collagen samples taken from a pig reared on an exclusively C_3-plant-based diet. NH_4^+ lost from the degradation of organic matter can differ from bulk source by 40% (Handley *et al.* 1996). Unfortunately, these data do not allow an assessment of the likely scale of any contamination by non-protein nitrogen, which may have introduced a bias in the bulk analysis.

Overall, the evidence suggests that the Iceman had an omnivorous diet, including both plant and animal material.

4. CONCLUSION

The microscopic analyses of the Iceman's colon contents revealed pollen which, though very probably not consumed as food, is of great interest in revealing his environment and season of death. The Iceman had carried the moss *Neckera complanata* for some purpose which remains unknown and a single leaf of that species recovered from the colon sample is, like the pollen, likely to have been an accidental ingestion.

In making the comparison with modern vegans, Macko *et al.* (1999*a*) do not consider that such an attitude might have been foreign to the attitudes of prehistoric people. Veganism, which developed in Europe in the 1940s, may be defined as 'a way of living that seeks to exclude, as far as is possible and practical, all forms of exploitation of animals for food, clothing or any other purpose' (The Vegan Society, UK). Had the Iceman been a dietary vegan, then he would have deliberately avoided the consumption of all foodstuffs of animal origin. The presence of fragments of meat in his colon would indicate that he was not a vegan as defined above, however much he may have depended on a plant-based diet. We would suggest that the term 'vegan' implies a lifestyle choice and is best avoided when discussing the habits of ancient populations or individuals.

Although taboos concerning the consumption of animal flesh are extensive and well known (for an excellent review of food avoidances, see Simoons (1994)), prior to the 20th century, there is little evidence of individuals or societies who choose to avoid eating all animal products. Even historic populations considered to be vegetarians consume dairy products, such as the Jains of India (Simoons 1994). Using nitrogen isotopic values, it is not possible to distinguish between the consumption of primary or secondary animal products, i.e. meat or milk, since all protein sources from the same animal are isotopically indistinguishable (Katzenberg & Krouse 1989; Minagawa 1992; Schoeller *et al*. 1986). This means that lacto-vegetarians have similar values to omnivores (Webb *et al*. 1980; O'Connell & Hedges 1999). Therefore, if the Iceman were a vegetarian consuming plant foods and some dairy produce, isotopic values alone would be insufficient to identify him as such.

The Iceman came from a cereal growing community. Stable isotope studies as so far published are inadequate to draw firm conclusions on the exact composition of his diet. However, a combination of the archaeological and biological evidence with the isotopic results strongly support the conclusion that he was omnivorous, with a diet of both animal and vegetable material. Fleckinger & Steiner (1998, p. 45) stated that the Iceman's 'last meal had consisted of a gruel made of einkorn, meat and unidentifiable plants'. These main components are correct but it is more likely that the einkorn was consumed as bread.

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