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Neolithic and Bronze Age Archery Equipment from Alpine Ice-Patches: A Review on Components, Construction Techniques and Functionality

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Abstract

The alpine ice-patch sites of Tisenjoch (I), Schnidejoch and Loetschenpass (CH) brought to light the most complete archery equipment known from European Prehistory.

From the end of the last glaciation until the Middle Ages, bows and arrows were the most important weapons for hunting and warfare. The first verified artefacts of archery equipment are the arrows from Stellmoor, Northern Germany, which date to 10,000 BC, while the oldest bows found so far are still the two elm bows from Holmegard in Southern Denmark, dated to ca. 8000–6500 BC (Junkmanns 2013).

During the Neolithic, bows were made almost exclusively from yew wood (*Taxus baccata*). Despite their different shapes, all prehistoric bows found in Europe are simple man-tall bows made from a single piece of wood with a more or less D-shaped cross-section and a flat belly side. Arrows were made from split wood or thin saplings and equipped with different types of points made from stone, bone/antler material or the wood itself, according to their specific intended purpose. The manufacturing process can be described from several finds of unfinished bow blanks, as in the case of the Tisenjoch finds.

Neolithic arrows were made from shoots of hazel (*Corylus avellana*), guelder rose (*Viburnum* sp.) or other hardwoods. They were straightened by heat and are generally longer and thicker than modern sporting arrows for increased weight and penetration power. Their fletching with three split feathers is practically the same as fletching used today. Bowstrings are extremely rare in European archaeological sites. Only two assured samples, stemming from the Tisenjoch and the Schnidejoch ice-patches, are known to date. They were made from animal sinew fibres, which are not preserved in non-frozen sites. Although there was almost certainly a need for a cover to protect a bow against bad weather, there is only one example of a Neolithic bow case known to date. The cover, made from water resistant birch bark measuring a little longer than the bow carried inside it, was found on Schnidejoch. It incorporates a carrying system of leather straps, which enabled the user to wear it over the shoulder, keeping the hands free for other tasks. It is supposed that other bow cases, which very probably existed in the Neolithic, were made from animal hide or leather which did not survive in waterlogged sites. That there were protective carrying devices for archery gear is also generally testified by the leather arrow quiver found on Tisenjoch and by numerous other ethnographic and historic examples.

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1. Introduction

Excavations and surveys in alpine ice-patches (Fig. 1) at Tisenjoch (South Tyrolean Alps, Italy), Schnidejoch and Loetschenpass (Bernese Alps, Switzerland) have yielded the most complete examples of Neolithic archery equipment known to date (Egg 1992; Junkmanns et al. 2015). While archery material finds are quite abundant, they are mostly quite isolated. Finds, which belong to a functional unit, are very rare, but they give us the chance to study the entire weapon system.

Archery equipment consists of three structural components: the bow with its bow string is the core element of the weapon, the arrow shaft mounted with arrow fletching and an arrowhead forms the missile, whereas the quiver and the bow case are transport containers. Quivers serve for a comfortable and safe handling of fragile arrows either in action or during transport. Bow cases protect the bow and the bow string from humidity, shocks and other damages during transport.

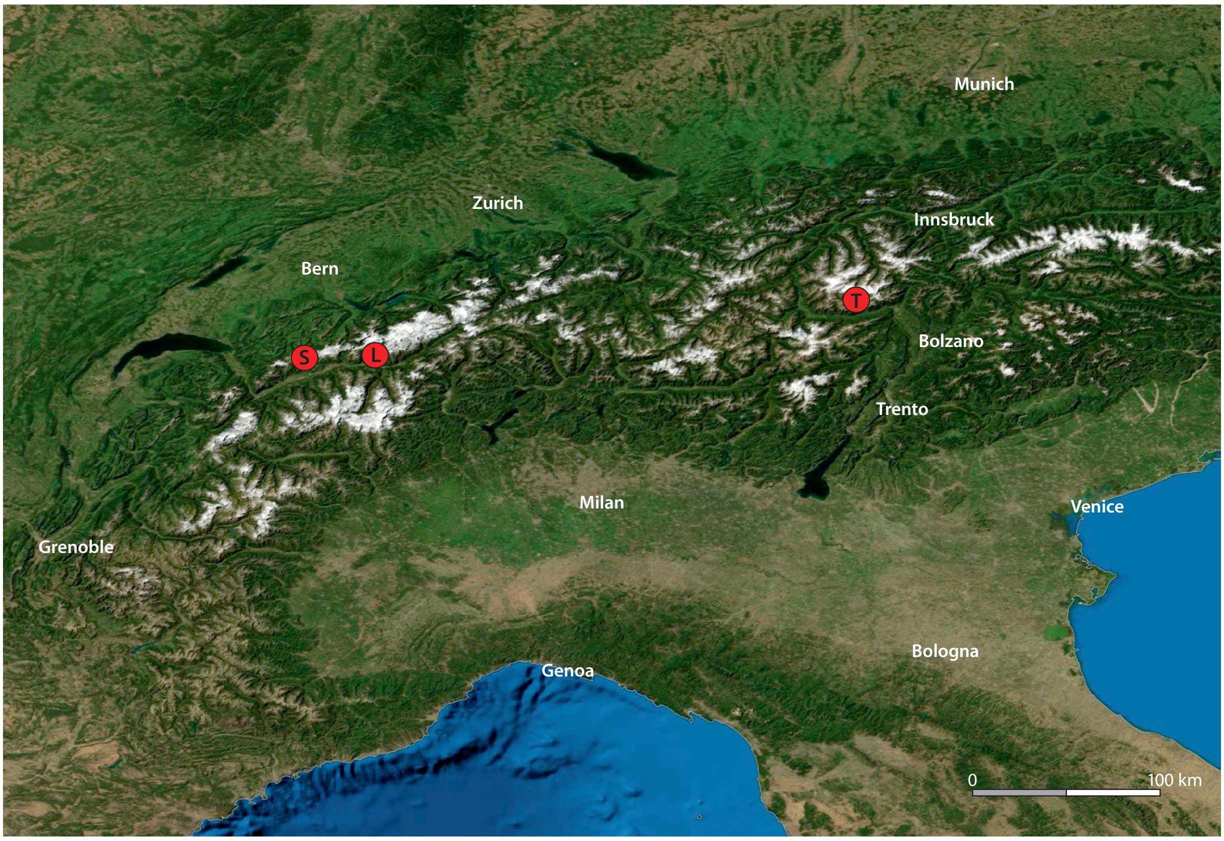

Fig. 1. Map of the Alpine ice-patch sites mentioned in the text.

Most of the surviving archaeological finds from Neolithic archery equipment are arrowheads made of durable material, such as flint, stone and bone, which survive under nearly all possible soil conditions. Wooden Neolithic bow and arrow fragments are much less frequent. Nevertheless, ca. 200 pieces have been counted for Europe (Junkmanns 2013). The preservation of these archaeological finds is mainly related to wetland sites in lakes and bogs. In comparison to arrow projectiles, wooden bows and arrows, the occurrence of quivers, bow cases and possible bow strings are extremely rare. From this group of items exclusively made from organic materials, such as leather, birch bark and animal sinew, only a handful of specimens are known from Neolithic Europe. Outside temperate Europe, extremely dry conditions in arid desert climates or ice cores in grave mounds allow organic material to survive for millennia as well. Up to now, all known examples of quivers, bow cases and possible bow strings are related to alpine ice-patches of Europe. Their rarity makes them objects of special interest for knowledge about prehistoric hunting equipment.

2. Material

2.1 Tisenjoch, Schnidejoch and Lötschenpass: Alpine ice-patches with archery finds

All three sites, situated at or near old alpine passages, exhibit excellent preservation of organic artefacts due to the ice cover. Artefacts were left there by travelling, hunting or herding prehistoric people (Hafner et al. 2015), or, in the case of Tisenjoch, due to a deadly incident (Pernter et al. 2007). While in the case of the Iceman from Tisenjoch, where all artefacts from the site belong to a single incident, at Schnidejoch and Lötschenpass several events led to the composition of the finds. For the archery equipment from these sites, ^{14}C data suggest that they are at least partly contemporaneous. The archery artefacts from Schnidejoch dated to ca. 2800 BC are very likely parts of one functional unit, as they were partly found close to each other and the bow fits the bow case in size.

Tisenjoch, 3208 m a.s.l., South Tyrol, Italy

In 1991, a human body was discovered by hikers in a melting ice-patch near Tisenjoch in the Ötztal Alps (46°46'26.39" N, 10°50'13.79" E). For the first time, a fully equipped archer from the Neolithic was found (Egg 1992; Spindler et al. 1995; Oberhuber/Knapp 2000; Egg/Spindler 2009). Radiocarbon dating of the ice-mummy revealed an age between 3350–3100 cal BC (Bonani et al. 1992, 1994; Kutschera et al. 2000). Apart from personal belongings, leather clothing, a bear fur cap and a grass cape, the man was carrying a copper axe and archery equipment. The latter consisted of an unfinished yew bow stave, an arrow quiver, 14 arrows and arrow shafts as well as a possible bowstring (Egg 1992).

Schnidejoch, 2756 m a.s.l., Canton of Bern, Switzerland

The first archaeological finds from the Schnidejoch pass (46°22'09.10" N, 7°23'19.70") in the Bernese Alps were discovered in 2003 by hikers. First finds were a yew bow, which was found in one piece, together with some arrow fragments. In the same year, hikers also found the upper part of a bow container. Further finds belonging to archery include the complete bow case, a potential bow string, 15 Neolithic and three Bronze Age arrows and two flint arrowheads. Although no human body was found at Schnidejoch, it seems that an accident might be at the origin of the findings of clothes such as leather leggings, shoes and a grass cape. The site was intensively researched between 2004 and 2012 (Suter et al. 2005; Hafner 2009; Hafner 2012). Radiocarbon dating determined an age of 2800 cal BC for most of the Neolithic archery equipment and clothing (Hafner et al. 2015).

Loetschenpass, 2690 m a.s.l., Canton of Bern, Switzerland

Already between 1934 and 1944, some nearly complete bows and fragments (a total of at least 6 bows), medieval crossbow bolts, Roman coins and other items were discovered in the Bernese Alps on the Loetschenpass, (46°24′58″N, 7°42′59″E) by the artist and painter Albert Nyfeler (1883–1969) (Bellwald 1992; Meyer 1992; Hafner 2008). In 1989, the bows were rediscovered in the former workshop of the finder and radiocarbon dating confirmed Bronze Age (2400–1800 BC) origin of this complex. This very homogenous group of bows, so similar in their appearance, are presumably contemporaneous. Their ^{14}C dates do not correspond exactly, but their wide range does not necessarily imply different absolute ages for them. Arrows from the same period have not been found on the site so far.

2.2 Bows

Tisenjoch bow stave

The 183.5 cm long Tisenjoch bow stave (Fig. 2) was prepared from an approximately 8–9 cm thick yew stem. It was recovered in two pieces measuring 142 and 41.5 cm (Oberhuber/Knapp 2000). As the surface is entirely covered by tiny cut marks, the bow is clearly unfinished. The Tisenjoch bow stave is surprisingly long, compared to the body size of 159–163 cm of the potential owner, the Tisenjoch Iceman (Table 1).

Its section is a wide oval with a flattened "belly" side, while the front side or "back" of the bow is roundish. The bow stave is still extremely thick. From a 3.7 cm wide and 3.1 cm thick centre, the limbs gradually taper to 1.1 x 0.9 cm at the tips. It is a common characteristic of the prehistoric bows of Europe that they are more or less flat, or even slightly concave on the belly side, while the back is rounded. Technically, they are flatbows.

The surface of the Tisenjoch bow is completely covered by very regular, tiny negatives of hatchet cuts about 0.5 to 1 cm large. As these negatives are very flat, most likely a transversely hafted blade, a so-called adze, would have been used for this work. Changes of the direction of the adze blows indicate that the maker of the bow turned the stave several times for convenient working during the process of shaping (Spindler 2004). One of the tips was cut to length and shows no other traces of wear. The other end was damaged after recovery. Sapwood and heartwood, normally used in a specific way in bow making, cannot be distinguished in the stave due to the dark brown colour of the whole artefact in its present state. About 60 annual rings could be counted near the centre, which translates into ca. 20 rings per cm. Thus, the wood is very fine grained.

Table 1. Dimensions of the Tisenjoch bow stave. Effective Length: ca. 180 cm, yew (*Taxus baccata*)

cm		width	thickness
91,0	tip	1,10	0,90
81,0		2,20	1,75
71,0		2,10	2,30
...	...	...	...
0	centre	3,70	3,10

Schnidejoch bow

For the manufacturing of the 160.5 cm long yew bow (Fig. 3), a 45–50-year-old stem of approx. 5 cm in diameter was used. Impressions of a 3 mm thick twined cord on the nocks prove that the Schnidejoch bow is a completed weapon and was apparently in use. The wood is very fine-grained with growth ring widths of max. 20 rings per cm. The back of the bow is nearly free from knots as was necessary for maximum tensile strength. Sapwood and heartwood cannot be distinguished in the bow as its colour is currently a uniform yellowish brown.

Fig. 2. Neolithic bow blank from Tisenjoch and comparison find. (a) Tisenjoch (South Tyrol, Italy); (b) Egolzwil 4 (Switzerland) (Fig. 2 a © Südtiroler Archäologiemuseum/ Harald Wisthaler. www.iceman.it).

Some three or four annual rings were cut during the preparation of the bow's back. This should be avoided because it weakens the tensile strength. As the growth rings are quite thin, this can happen during smoothing. Thus, it obviously produced no problem.

The straight-sided Schnidejoch bow does not show any narrowing or thickening in the centre. In this respect, it looks quite similar to what would have been intended for Oetzi's bow stave when finished, although it is a bit narrower in general than typical bows from the end of the Neolithic (Type Onstwedde; Junkmanns 2013). The cross-section of the Schnidejoch bow is a narrow D with a nearly flat belly side and slightly rounded corners. From nock to nock, the effective or working length of the bow is 156.3 cm. Both nocks are of different shape. One features a simple pin on a retracted shoulder, while the other one possesses two protruding pegs, which serve as string support. It is likely that the simple nock was used for the temporary bracing of the bow, while the peg type nock could have been used to

Fig. 3. Neolithic bow from Schnidejoch and comparison finds. (a) Schnidejoch (Bernese Alps, Switzerland) (© Archaeological Service Canton of Bern; (b) Onstwedde (Netherlands); (c) Cambridge Fens (UK); (d) Vrees (Germany).

secure the other end of the string permanently. Sliding a string loop up to the tip would have been easier this way. If this hypothesis is true, the pin type nock would probably have been the upper end of the bow. But, of course, the bow could be used either end up.

Loetschenpass bows

A group of at least eight Early Bronze Age bows (Fig. 4) resp. bow fragments of the same type have been found to date on the Loetschenpass (Bellwald 1992; Junkmanns 2013; Junkmanns et al. 2015). The latest finds from 2017 are still in the conservation process. All bows and fragments belong to the Loetschenpass type, which is characterized by flat limbs widening towards the tips and an extremely narrow but high handle. Judging from the best-preserved bows, their length varied roughly between 166 and 177 cm. The limb's cross-sections are lens or trough-shaped, and sometimes develop a keel on the belly towards the handle. In the handle of the bows, the cross-section is shaped like an egg with the thicker side up. Eye-catching elements are the very long and slender tips. The three more or less completely preserved bows as well as the numerous smaller fragments were partially heavily damaged by glacial pressure.

Bow a: About three-fourths of the yew bow are preserved, now 118.5 cm long. The original length was about 168–173 cm. The very slender, but highly stacked handle is 10 cm long. The fades into the limbs are lightly keeled on the belly, whereas the limbs are lens shaped and widest in the last third before the tips, which are missing. The wood used from a stem at least 7 cm thick is very fine grained with a count of about 20 rings per cm. Sapwood is optically not discernible. Radiocarbon date: 3535 ± 70 BP (ETH-6698), calibrated 2038–1688 cal BC (2σ, 94.5 %).

Bow b: Roughly four-fifths of the bow are preserved. One ca. 32 cm long end piece is missing. The bow is badly flattened on one limb by glacier action, the preserved tip is split. The handle is less narrow than those of the other Loetschenpass bows and measures 8 cm long. The flat limbs are widest in the outer third and lens-shaped in the cross-section. The innermost third of the limbs have a pronounced keel on the belly. The surviving bow tip is 6.5 cm long. The elegant and beautifully made bow was originally about 176 cm long and made from an exceptional clean piece of yew of extremely dense growth (ca. 40 rings per cm). The stem measured at least 5.6 cm in thickness. Sapwood is not distinguishable. Radiocarbon date: 3795 ± 55 BP (ETH-6983), calibrated 2410–2042 cal BC (2σ, 95.4 %).

Bow c: The best-preserved bow from the site is at present 166 cm long; only one ca. 6 cm long tip is missing (original length 172 cm). It features an extremely narrow (1.85 cm) and highly stacked ca. 16 cm long handle area. The limbs are of roundish cross-section near the centre and become wider, flatter and trough-shaped towards the ends. The centre line of the back seems to follow the outermost year ring of the tree, judging by characteristic small channels and furrows in the surface, which appear when the bark is completely removed. The preserved bow tip is about 6 cm long and 1.2 cm wide. This bow, too, is of excellent workmanship and is made from fine-grained quality yew wood with a stem diameter of min. 6 cm. In this bow, sapwood is very probably present, although it is optically not distinguishable. Radiocarbon date: 3555 ± 55 BP (ETH-7542), calibrated 2124–1696 cal BC (2σ 95.4 %).

Fig. 4. Early Bronze Age bows from Lötschenpass (Bernese Alps, Switzerland). (a – d): Yew (*Taxus baccata*); e – f): Elm (*Ulmus* sp.) (© Archaeological Service Canton of Bern).

Smaller bow fragments (Fig. 4 d–f): As well as the bigger fragments or complete finds mentioned above, smaller pieces of 6 or more bows were found here, the last one during field work in 2017. As some of them can be joined to other pieces, while others cannot, it is not possible to determine the exact number of bows. The fragments share more or less the characteristics of the more complete bows. The radiocarbon dates of the smaller bow fragments fall into the same time span (roughly between 2200–1700 cal BC).

2.3 Bow strings

Tisenjoch bow string

Inside the quiver of the Tisenjoch Iceman, some items were discovered that could be related to bowstrings. A bundle of some 26 cm long, unprocessed leg sinews was probably intended for bowstring production. In comparison, a clew of a twisted cord of undetermined fibre measuring approx. between 1.75 and 2 m long (Egg 1992; Egg/Spindler 1993) aroused suspicion that it could represent a possible finished bowstring (Fig. 5 a). The mostly ca. 4 mm thick cord is composed of three strands joined in a tightly wound S-twine. One end of the string is knotted. The nature of the knot was not investigated. Interestingly, the fibres, despite being described several times briefly as "presumably tree bast" (Egg 1992; Egg/Spindler 1993; Fleckinger/Steiner 2003), never underwent scientific analysis.

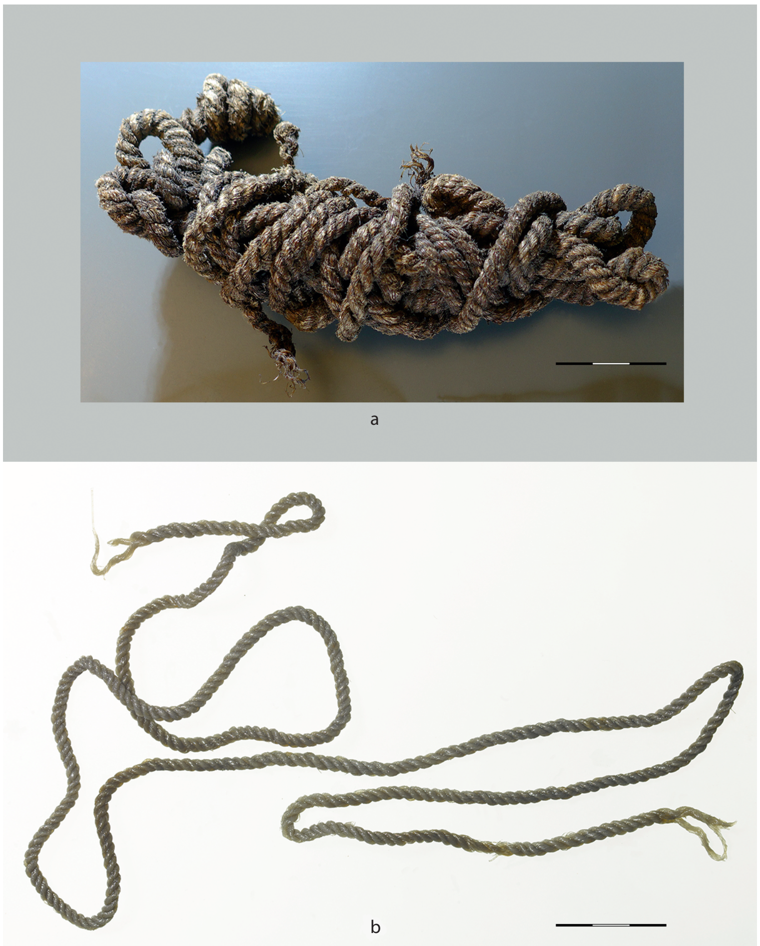

Fig. 5. Probable Neolithic bow strings. (a) Tisenjoch (South Tyrol, Italy); (b) Schnidejoch (Bernese Alps, Switzerland) (© Archaeological Service Canton of Bern).

Fig. 6. Neolithic arrows from Alpine ice-patch sites. Tisenjoch (South Tyrol, Italy) (© Südtiroler Archäologiemuseum/ Harald Wisthaler. www.iceman.it).

Fig. 7. Neolithic and Bronze Age arrows from Alpine ice-patch sites. Schnidejoch (Bernese Alps, Switzerland) (© Archaeological Service Canton of Bern).

Schnidejoch bow string

A cord measuring ca. 3.6 mm thick and twisted in a tight three-ply S-twine (Fig. 5) was found just beneath the Schnidejoch bow case (Junkmanns et al. 2015). The translucent fibres were analysed as animal sinew fibre (Report Rast-Eicher 2009), but the animal species could not be determined. The string fragment is 97 cm long in its present state, with both ends damaged.

2.4 Arrows

Tisenjoch arrows

Inside the Tisenjoch quiver, 12 unfinished arrow shafts, 84–87 cm in length, and two finished ready-to-shoot arrows, 85 and 90 cm long, were found (Fig. 6). All were made from shoots of mealy guelder rose (*Viburnum lantana*). One of the finished arrows has a dogwood foreshaft.

Schnidejoch arrows

On the Schnidejoch site, numerous arrows and their fragments were recovered (Fig. 7). At least nine of them are from the Neolithic Age, whereas Bronze Age origin could be verified for two arrows (Table 2 and 3). All arrows were made from shoots of guelder rose (*Viburnum* sp.), honeysuckle (*Lonicera* sp.) or hazel (*Corylus avellana*).

2.5 Transport containers

Tisenjoch arrow quiver

The only known European Neolithic quiver was found on Tisenjoch together with the famous iceman. The approximately 86 cm long quiver (Fig. 8) is a flat trapezoidal bag made from the hide or fur of chamois (*Rupicapra rupicapra*). It is sewn together on the bottom and on one side with a 3 mm wide strip of leather (Groenman-van Waateringe/Goedecker-Ciolek 1992). While a simple saddle stitch was used on the side, a whipstitch allowed a flatter bottom (Egg 1992). The upper part with two flaps – one to close the quiver and another for easy arrow extraction – is made of stiffer bovine leather (Hollemeyer et al. 2012). The quiver mouth is approximately twice as wide as the 9 cm wide bottom. Into the sewn lateral edge, a 92 cm long and 1.4 cm thick sapling of hazel (*Corylus avellana*) is inserted as a stiffener. The stick was slotted for that purpose and attached by sewing with a leather strip through 20 holes cut into it (Egg 1992). The stick protrudes approximately 4.5 cm from the bottom of the quiver bag. The lower tip ends with an angle. When found, it was filled with a total of 14 arrows, which was roughly maximum capacity.

Judging by a distinctive crease in the upper lid, the maximum arrow length with a closed lid can be estimated to ca. 85 cm. However, one of the arrows was considerably longer (90 cm). The quiver shows damage at the upper part, where the stick is broken into three pieces. Apparently, one of the pieces was attached again, but upside down (Egg 1992), while the second piece was found some distance from it. The uppermost leather parts are also damaged. Probably this part was already thawed from the ice once before discovery. Nonetheless, the reconstruction of the quiver mouth is still possible. The quiver could be closed by a leather flap extending from the

Fig. 8. The Tisenjoch arrow quiver (© Südtiroler Archäologiemuseum/Harald Wisthaler. www.iceman.it).

Table 2. Neolithic arrows from Schnidejoch.

Number	¹⁴C date	Wood species	description	length	diameter	front end	rear end	tar/binding traces
112151, fig. 8.1	4.716–4.546 cal BC (2δ, 95,4%), ETH-38877/ UZ-5768: 5.785 ± 35 BP	Hazel (*Corylus* sp.)	rear end	30.7 cm	ca. 7 mm at front/ 6.5 mm at rear end	–	2–4 mm wide, 4 mm deep, V-shaped, probably ground notch. Pointed laterally	–
102453, fig. 8.2	4.720–4.458 cal BC (2δ, 95,4%), ETH-37756/ UZ-5705: 5.745 ± 60 BP	Hazel (*Corylus* sp.)	rear end	13.3 cm	7.5 mm/ at front 5.5 mm at rear end	–	half round, ca. 4 mm wide, 3 mm long notch, probably ground in	tiny tar spots at rear end
109501.a, fig. 8.3	4.746–4.552 cal BC (2δ, 91,3%), ETH-39474/ UZ-5780: 5.815 ± 35 BP	Hazel (*Corylus* sp.)	front end	38.2 cm	ca. 7 mm	2 mm deep, laterally grooved 7–8 mm long (for winged arrowhead?)	–	–
109504, fig. 8.4	4.778–4.548 cal BC (2δ, 95,4%), ETH-39475/ UZ-5781: 5.815 ± 40 BP	Hazel (*Corylus* sp.)	rear end	38.8 cm	7.5 mm	–	ca. 4 mm deep, 2.5 mm wide, V-shaped notch, probably ground in	–
100990, fig. 8.5	2.916–3.335 cal BC (2δ, 95,4%), ETH-37760/ UZ-5709: 4.425 ± 55 BP	Guelder Rose (*Viburnum* sp.)	complete	81.4 cm	9 mm at front/ 6 mm at rear end	10 mm deep, 3 mm wide, parallel split notch, front conically shaped	16 mm long, 2.5 mm wide, parallel split notch	sinew fibres at front end, black tar spot at rear end
84688/ 101028, fig. 8.6	2.888–2.580 calBC (2δ, 95,4%), ETH-31143/ UZ-5254: 4.160 ± 60 BP	Guelder Rose (*Viburnum* sp.)	complete	79.0 cm	9 mm at front/ 6.6 mm at rear end	6 mm deep, 2.5 mm wide, parallel split notch	17 mm deep, 2 mm wide, parallel split notch	–
100998, fig. 8.7	2.882–2.573 calBC (2δ, 95,4%), ETH-32040/ UZ-5341: 4.135 ± 55 BP	Guelder Rose (*Viburnum* sp.)	complete	82.4 cm	10 mm constantly	10 cm long quite dull point, no notch	15.5 mm deep, 3 mm wide, parallel split notch	–
100976, fig. 8.8	2.882–2.573 calBC (2δ, 95,4%), ETH-32039/ UZ-5340: 4.135 ± 55 BP	Guelder Rose (*Viburnum* sp.)	nearly complete, both ends broken	82.7 cm	10 mm 10 cm behind slightly thinned front end, 6 mm at rear end	–	–	2 small tar spots at rear end
101020, fig. 8.9	2.864–2.466 calBC (2δ, 95,4%), ETH-32044/ UZ-5345: 4.050 ± 55 BP	Guelder Rose (*Viburnum* sp.)	Nearly complete, front slightly damaged	82.0 cm	9.5 mm at front end/7 mm at rear end	4 mm wide, parallel split notch	V-shaped, 15 mm deep, 1–3 mm wide notch, probably ground in, flattened laterally, edges rounded	Inside front notch and around tar traces and impressions of delicate binding behind. Rear end tar spots with impressions of binding
101702, fig. 8.10	2.888–2.620 calBC (2δ, 94,3%), ETH-35570/ UZ-5635: 4.165 ± 50 BP	Honeysuckle (*Lonicera* sp.)	complete	88.0 cm	10x7 mm tip/ 7.5 mm rear end	front parallel shaped, hollowed out 10 mm deep and ca. 6–8 mm wide	9 mm deep/ 3 mm wide parallel split notch	Front hollow part and foremost 4 cm contain tar traces with impressions of binding. No tar at rear end, but traces of coarse binding in 8 cm long fletching zone
84697, fig. 8.11	2.891–2.618 calBC (2δ, 93,4%), ETH-31145/ UZ-5256: 4.170 ± 55 BP	Guelder Rose (*Viburnum* sp.)	complete	91.0 cm	front 8 x 5 mm, centre 9.5 mm, rear end 6.5 mm	foremost 13 cm flattened and tip 12 mm deep hollowed out	7 mm long, 2.5 mm wide, parallel split notch	spots of tar with impressions of very fine binding at rear notch
100977, fig. 8.12	2.880–2.627 calBC (2δ, 95,4%), ETH-37925/ UZ-5710: 4.160 ± 35 BP	Guelder Rose (*Viburnum* sp.)	nearly complete, both ends broken	87.4 cm	both ends thinned to 7–8 mm, centre 9.5 mm, 10.5 mm at 22 cm from broken tip	–	–	ca. 12 cm long fletching zone with several tar spots. Impressions of fine binding

Table 3. Bronze Age arrows from Schnidejoch.

Number	¹⁴C-date	Wood species	description	length	diameter	front end	rear end	tar/ binding traces
84687, fig. 8.13	2.138 – 1.770 cal BC (2δ, 95,4 %), ETH-31142/ UZ-5253: 3.600 ± 65 BP	Hazel (*Corylus* sp.)	complete	102.2 cm	9.5 mm max. (15 cm from front end), 7.5 mm at rear end	Dull conus 1.5 cm long, probably for socketed arrowhead, but no traces of hafting	U-shaped, 4.5 mm wide and 3 – 4 mm wide notch, probably ground in	–
107260, fig. 8.14	1.896 – 1.634 cal BC (2δ, 95,4 %), ETH-34934/ UZ-5600: 3.455 ± 50 BP	Hazel (*Corylus* sp.)	rear end	26 cm	5 mm, nock widened to 7.5 mm	–	shallow 2.5 mm deep, 3 mm wide V-shaped notch, probably ground in	–

lower leather by folding it around to the quiver front. The tip of the flap could probably be fastened to the quiver front by a leather strip which was attached ca. 6 cm below the top of the main quiver body (Junkmanns 2013). Additionally, a leather piece of approximately 15 by 15 cm was sewn sideways to the quiver bag. This piece, stiffened by leather strips woven into it, could be opened laterally for easy access to the arrows.

There is no trace left of a carrying strap, which should be expected with an arrow quiver. Presumably, there would have been some carrying system to avoid having to hold it in one's hands all the time. There is a possibility that leather strips could have been fastened to the stiffening hazel stick. We can only speculate if the quiver was intended to be carried on the back by a shoulder strap, attached to the hip or simply held in the hand. As the backpack frame that was part of the Iceman's equipment was most likely carried on the back, it seems reasonable that the quiver was likely attached to the hips.

Besides the 14 arrows, respectively, arrow shafts, several objects that probably could be archery-related were found inside the quiver. A bundle of four, pointed antler slivers, ca. 15 cm long and bound with bast strips, could have been raw material for the manufacturing of arrowheads.

Schnidejoch bow case

The only known European Neolithic bow case was found in several pieces at the Schnidejoch ice-patch site in the years 2003–2005. The exceptional find (Fig. 9) is made from birch bark, lime bast, wood and leather. With its overall length of ca. 170 cm, the bow case fits the size of the 160.5 cm bow, which was found near to it. As the container was not found in one piece, but rather in three pieces, it is not surprising that the bow was not resting inside the case anymore. By the finds of two flint arrowheads inside the bottom part of the case, it can be assumed that not only the bow, but also the arrows were carried inside it. However, it would not have been easy to withdraw the arrows from the bow case quickly. A probable bow string was found just beside the case and may also have been stored in it.

Basically, the Schnidejoch bow case consists of two parts. A main part, measuring about 137 cm long, can be closed by sliding a 37 cm long lid or cap onto it. Both parts are made from two or more layers of birch bark. The inner structure is made of rectangular strips measuring approx. 45 x 30 cm, folded lengthwise and sewn together to form an elongated 14 cm wide sleeve. An outer mantle of folded strips, 5–10 cm wide, was added in a way like overlapping roofing shingles, sometimes reinforced by additional layers. Opposite to the fold, all pieces were sewn together with lime bast strips. Inner and outer bark strips show a different orientation. While the inner pieces

Fig. 9. The Schnidejoch bow case (© Archaeological Service Canton of Bern).

are used horizontally relative to the position of a tree, the outer shell is aligned vertically. Moreover, the inner strips are used with the exterior white part of the bark to the outside, while the outer shingles are inversed. This makes sense because the exterior of birch bark is more prone to damage by peeling than its inside. In the way it was used, the inside where the bow was slid in and out, and the outer surface, which is exposed to impact damage, were resistant to abrasion. Due to the way that the outer shingles overlap, it can be stated that the whole bow container was nearly waterproof when held in a vertical or slightly oblique position as would have been the case when it was carried over one shoulder.

The whole structure was reinforced in the centre by two stiffening rods of split hardwood shoots of honeysuckle (*Lonicera* sp.) and guelder rose (*Viburnum* sp.), which were simply inserted into slits cut in the outside of the fold. Narrow leather straps were fastened to these and also to the base of the lid piece. A small remaining piece of a wider leather strip is still attached to the narrower strip in the centre. Presumably this was intended as a carrying strap when still intact.

3. Results/ discussion

3.1 Neolithic bow technology

Construction

The unfinished bow made from yew wood (*Taxus baccata*), which was found with the Tisenjoch Iceman, is an important source of information on Neolithic bow building technology (Fig. 2). Several similar unfinished bows or bow blanks are known from the Neolithic, all of which, except for the one from Tisenjoch, were found in Switzerland (Junkmanns 2013). Like most of them, the Tisenjoch Iceman bow workpiece is entirely covered by tiny and very regular scars of wood removal by a fine hatchet. The roughed-out shape of the bow is already recognizable, but it is still way too thick. In a well-preserved bow blank from Feldmeilen-Vorderfeld (Canton Zurich, Switzerland), more stages of the workflow can be observed (Fig. 10 a – d). Characteristic splitting surface areas show that after felling the chosen yew tree, it was split into two halves (Fig. 10 a). The clean surface of the outside wood, the wane, shows that the remaining bark and cambium layers on the back of the future bow were simply stripped off, which is easy when still full of sap (Fig. 10 b). Subsequently, the bow blank was sculpted to its gross shape most probably using a small hatchet or adze. The clean appearance of the cutmarks in the Feldmeilen bow as well as the Tisenjoch bow shows that this work was executed while the wood was still green (Fig. 10 c – d). In comparison, dry wood would show splintering because it could not be worked so cleanly with stone tools. During shaping, the future bow was probably already cautiously test bent. This was done to find and reduce any stiff spots. Another bow blank from Zurich, Mozartstrasse (Fig. 10 e; Canton of Zurich, Switzerland) already broke due to an irregularity inside the wood during this process (Junkmanns 1999). In any case, too much bending in this stadium must be avoided, as it ruins a bow. A still green bow would develop “string follow”, a permanently bent shape, which would seriously affect the bow’s performance. The bow blank would then have to be put aside for a while to let it dry thoroughly. Final “tillering” or adjusting of the bow could then only be done on a dry blank. This would have been done best by scraping with flint tools, because they produce a very clean

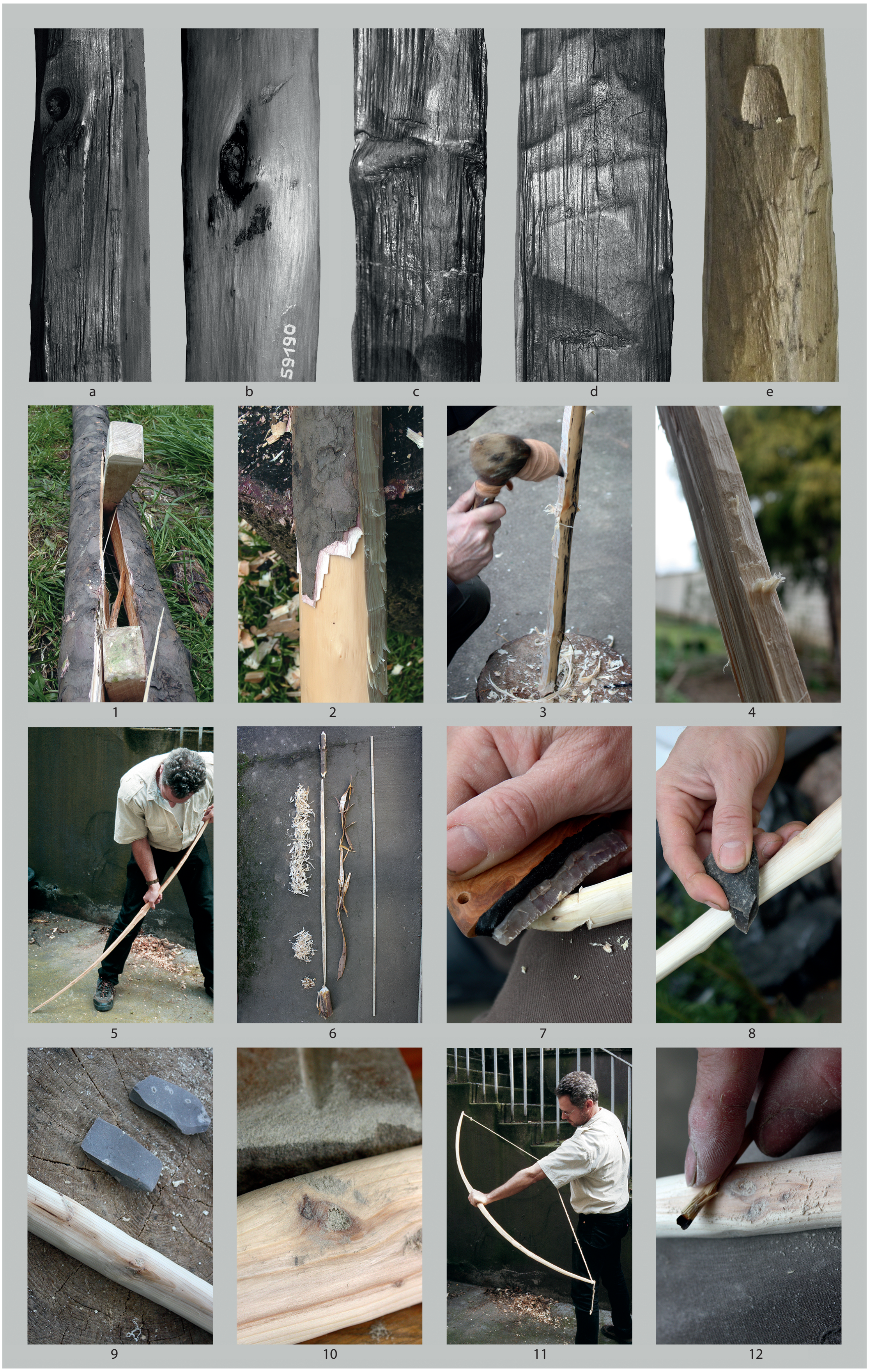

Fig. 10. Neolithic bow-making technology. (a–b) Bow blank from Feldmeilen-Vorderfeld; (e) bow blank from Zurich-Mozartstrasse; (1–12) experimental bow making process: (1) splitting; (2) debarking; (3–4) adzing; (5) test bending; (6) finished bow blank with remains; (7) cutting the string nock; (8–9) scraping; (10) grinding with sandstone; (11) testing the bend; (12) polishing with Common horsetail.

surface (Fig. 10.8–9). The drying time of such a pre-shaped bow blank can be as short as two or three weeks, but only in summer (Junkmanns 2001). A piece of soft sandstone can be used like a modern rasp (Fig. 10.10), as probably used for a child's bow from Zurich, Seefeld (Junkmanns 2013). This can be very efficient on spots with difficult grain. After the bow was adjusted to bend and function properly, a polished surface (which can be observed on many Neolithic bow finds) could be achieved by finally sanding it with common horsetail (*Equisetum arvense*) or another abrasive material (Fig. 10.12). Neolithic adult bows rarely show any remaining traces of work, while smaller youth and kids bows are not smoothed very well (Junkmanns 2013). The Schnidejoch bow was not smoothed very thoroughly. To observe distinct work marks on a prehistoric adult bow is quite unusual. In most of the known examples, great efforts were put into smoothing and polishing. On one of the sides, a shallow 10 cm long splintered negative is present, developed very probably by an adze working against the grain of the wood. In many spots, rippled structures are still visible and represent characteristic traces of scraping with flint edges. Thus, the Schnidejoch bow was not a very gracious bow, but rather a bow for duty.

The total working time needed to make a Neolithic hunting bow with stone tools is estimated at ca. 6–10 hours (Paulsen 1990; Junkmanns 2001).

Typology

As the bow blank of the Tisenjoch Iceman and the finished bow from Schnidejoch have straight sides and no narrowed handles, they can be classified to the straight stave type family. By the D-shaped cross-section with a flat belly, they can further be categorized to the slightly larger type Egolzwil (Fig. 2 b; ca. 3500 BC) and the narrower type Onstwedde (Fig. 3 b–c; ca. 2500 BC), respectively (Junkmanns 2013). The only known parallel to the protruding nock pegs of the Schnidejoch bow can be found in a bow recovered in Vrees, Germany, dated to approx. 3000–2000 BC (Fig. 3 d; Beckhoff 1964).

Bow dimensions and strength

It is common knowledge today that a simple wooden bow made from one piece, a so-called self-bow, is most efficient when the length of the bow corresponds to the size of the archer who uses it (Baker 1992). If it is too short, the bow is in danger of breaking by overdrawing. When the bow is too long, the limbs are heavy and slow down the arrow if the bow is not drawn far enough to store a sufficient amount of energy. Short arms normally go with a short body, which restrict the possible draw length of the archer. The Tisenjoch Iceman's bow should thus have been probably around 160 cm long when finished.

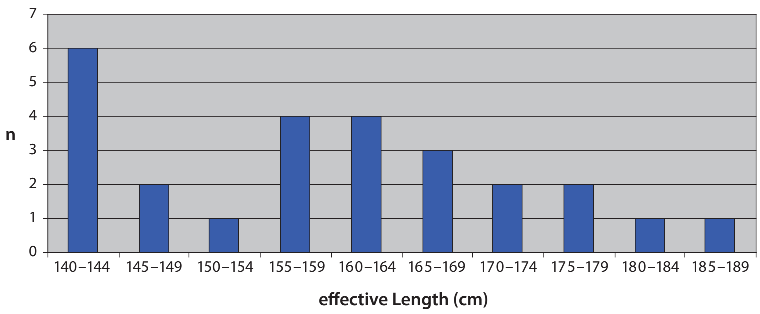

Fig. 11. Distribution of the reconstructed length of Neolithic adult bows (n = 26).

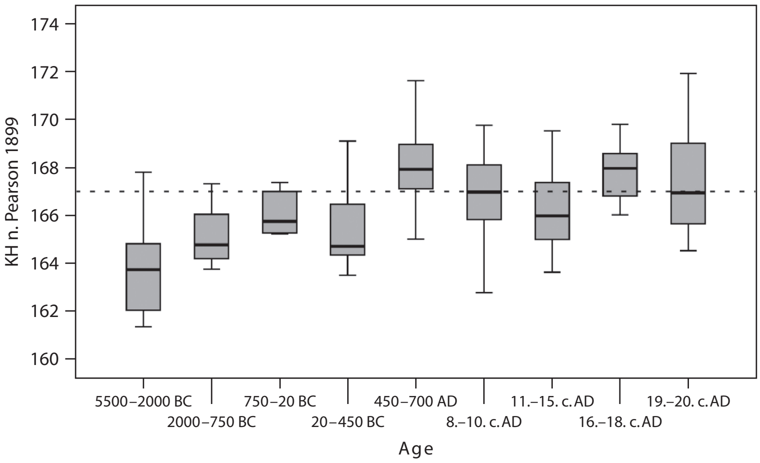

Fig. 12. Average body size of males in Middle Europe from the Neolithic until today. Neolithic females were about 12 cm shorter (after Siegmund 2010).

Table 4. Length of Neolithic bows.

Entire or length computable Neolithic adult bows (n = 26)	**effective length[1]**
La Draga Bow 2	ca. 140 cm
Seeberg/Burgäschisee-Süd	ca. 140 cm
Robenhausen Bow 4	ca. 140 cm
Robenhausen Bow 1	141 cm
Lac de Chalain Bow 3	ca. 143 cm
Feldmeilen-Vorderfeld	ca. 144 cm
Pfäffikon-Burg Bow 2	ca. 145 cm
Bodman	148 cm
Ashcott Heath	ca. 153 cm
La Draga Bow 1	ca. 155 cm
Pfäffikon-Burg Bow 1	ca. 155 cm
Lac de Chalain Bow 2	ca. 155 cm
Schnidejoch	156 cm
Robenhausen Bow 5	ca. 160 cm
La Croix St. Ouen	ca. 160 cm
Sutz-Rütte/Schloss	ca. 160 cm
Vrees	ca. 164 cm
Niederwil Bow 1	165 cm
Thayngen-Weier	168 cm
Onstwedde/Stadskanaal	ca. 168 cm
Egolzwil 4 Bow 1	ca. 170 cm
Lac de Chalain Bow 6	ca. 170 cm
Rotten Bottom	ca. 175 cm
Koldingen	ca. 176 cm
Similaun	ca. 180 cm
Meare Heath	ca. 188 cm
Average effective length:	**ca. 158 cm**

[1] Distance between string nocks

Neolithic adult bows vary in length between 140 and 188 cm, averaging around 158 cm, but most range from 150–178 cm (Table 4; Fig. 11). Bows shorter than 140 cm can be considered to be youth or kids bows. An extremely long example is the 188 cm long Meare Heath bow (Somerset, UK). According to its unusual and unique decoration, it was most probably made to impress (Junkmanns 2013).

An overview of Neolithic male skeletons from all over Europe shows variations in size between 161 and 168 cm (Fig. 12; Siegmund 2010). This corresponds quite well with the known bow sizes. A possible explanation for the Tisenjoch Iceman's oversized bow stave could be that he did not cut the wood himself, but rather got it by trade or exchange. That would also explain why he bothered to carry an unfinished bow over the Alps.

From dimensions of more or less complete bow limbs, the strength or draw weight of Neolithic adult bows can be estimated roughly between 40 and 90 lb at a draw length of approx. 28 inches (Junkmanns 2013).

Table 5. Dimensions of the Schnidejoch bow and calculation of its draw weight. The method used is described in Junkmanns (2013).

Schnidejoch Bow				effective length: 156.3 cm				Yew (*Taxus baccata*)			
cm		width	thickness	Qs	Br	cm		width	thickness	Qs	Br
80	tip	--	--	--	--	80	tip	--	--	--	--
78	nock	1.45	0.86	--	--	78	nock	1.62	1.14	--	--
70		1.89	1.30	3.19	2.50	70		2.11	1.38	4.02	1.99
60		2.25	1.51	5.13	3.51	60		2.55	1.67	7.11	2.53
50		2.55	1.77	7.99	3.50	50		2.73	1.77	8.55	3.27
40		2.64	1.88	9.33	4.07	40		2.78	2.02	11.34	3.35
30		2.90	2.11	12.91	3.72	30		2.83	2.30	14.97	3.21
20		2.86	2.11	12.73	4.56	20		2.95	2.27	15.20	3.82
10		2.90	2.36	16.15	4.21	10		2.88	2.28	14.97	4.54
0	centre	3.00	2.35	16.57	4.71	0	centre	3.00	2.35	16.57	4.71

Estimated draw weight calculated from bow dimensions	effective length	wood	bend resistance average (Br)	calculated strength	correlation factor yew wood (min.) – av – (max.)	estimated draw weight
(in lb at 71.3 cm)	156.3 cm	Yew	3.64	11.24	(3.7) – 5.6 – (7.6)	63 lb ± 35 %

The calculated strength of the Schnidejoch bow using the dimensions following the procedure described by Junkmanns (2013) gives a statistical value of 41–86 lb at a draw length of 28 inches (71.3 cm) with an average of 63 lb. Thus, the bow could have been from 41 to 86 lb strong. As the quality and hardness of the wood that was actually used is not known, no exact value can be determined. Reconstruction bows with approximated dimensions were 52–82 lb at 28 inches (Junkmanns et al. 2015). Judging by its dimensions (Table 5), the bow bent in a full arc and was not stiff in the handle. In comparison, the outer ends of the limbs must have been a bit stiff, which act like a lever and make a pretty fast bow. Using a light 20-gram arrow, the initial speed can be assumed to have been around 170–200 km/h, and the maximum possible distance that an arrow could have been shot was up to 200 m. This was confirmed by tests done by with a replica bow of 55 lb. It shot arrows with a speed of 187.4 km/h (20 grams), 168.5 km/h (30 grams) and 154.5 km/h (40 grams) with a kinetic energy of 27.2 to 37.0 joule. Heavy arrows store more energy than light ones. In modern bow hunting, heavy arrows are preferred over light ones because of better penetration. 40–50 g would have been a realistic weight of a Neolithic hunting arrow. Thus, the Schnidejoch bow was a very capable weapon adequate for every possible hunting or fighting activity.

Bow-making wood

The preferred and, as far as we know, exclusively used raw material for bows in the Western European Neolithic was yew (*Taxus baccata*). The preferred material used by Mesolithic bowmakers, elm (*Ulmus* sp.), was replaced by yew as soon as it became available due to postglacial climatic changes. The earliest evidence for the presence of yew north of the Alps is around 5000 BC (Knörzer 1998), while the oldest known yew bows in this area date to ca. 4300 BC. In northern Spain, yew bows are verified from 5200 BC (Palomo et al. 2005). Usually, thin trees were used in order to avoid unnecessary work. The bow stave of the Tisenjoch Iceman was prepared from an 8–10 cm stem. As the colour today has turned to a dark brown, no differentiation of the lighter sapwood and the darker heartwood is possible. The growth rings of the Tisenjoch bow stave vary from 0.18 to 0.6 mm, which translates into a ring count of 16 rings per cm on average (Oberhuber/Knapp 2000). Very fine-grained yew wood like this is considered to be best quality bow-making material by many modern bow makers. Nonetheless, personal experience of one of the authors (J.J.) after making several hundred yew bows does not confirm this. Sometimes, coarse-grained yew from a public park can result in efficient and fast bows, while super-fine-grained yew sometimes yields an average or even slow bow. On the other hand, fine-grained wood is much more pleasant to the eye and easier to work with than a coarse-grained, knotty piece of wood. One might think this would have influenced the prehistoric bow makers in mostly choosing fine-grained wood for their bows, although the grain is not visible on the outside of a tree. All the same, in the natural forests of these times, trees probably grew slower than in modern cultivated, more open forests, thus realizing more fine-grained wood.

Medieval bowyers always used the sapwood on the back of a yew bow (Hardy 1992). Tests prove that the sapwood of yew is at least three times more elastic than its heartwood (Pope 1923). On the back of a bow, which is subjected to enormous stretching strain, the sapwood prevents a yew bow from breaking. The heartwood, on the other hand, is much firmer and produces more power in a bow. In the first studies of Neolithic bows, the presence of sapwood, which is lighter coloured than heartwood, was recognised optically (Adler 1915). But since the 1960s, a hypothesis of sapwood free prehistoric bows became popular among archaeologists, originally formulated by Clark (Clark 1963). This was also postulated for the Tisenjoch bow stave (Egg 1992; Oberhuber/Knapp 2000; Spindler 2004). Clark misinterpreted the orientation of prehistoric bows and reversed back and front. Because he was looking for sapwood on the flat inside or "belly" of prehistoric yew bows, he was probably not able to detect it. On some of the bows that he investigated, sapwood on the opposite rounded side can easily be seen and was already published in earlier works (Adler 1915).

Recent studies reveal that sapwood was indeed regularly used (Junkmanns 2013). In all of the ca. 50 yew bows found in the site of Pfäffikon (Canton Zurich, Switzerland), the presence of sapwood is clearly visible by colour (Eberli et al. 2010), which is the most obvious proof for sapwood implementation. A total of 56 Neolithic yew bows have sapwood discernible by colour (Table 6). Unfortunately, yew sapwood cannot yet be detected by microscopical analysis when the colour has turned to brown due to soil contact, which is given for most bow finds. Nevertheless, sapwood can also be confirmed by the presence of the outermost growth ring (wane). Indicators are very characteristic structures (small cavities, channels, knots) on the surface, which would have been removed by working down

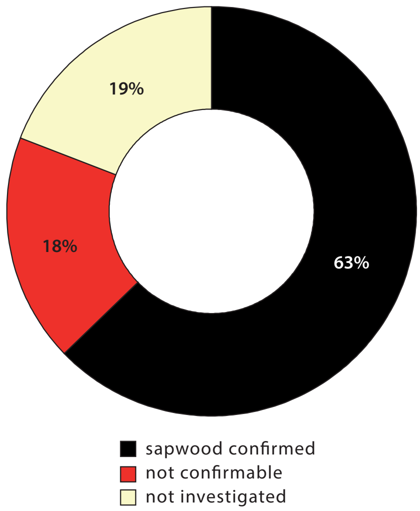

Fig. 13. Percentage of detectable sapwood presence in Mesolithic and Neolithic yew bows (n = 140).

Table 6. Sapwood presence in Meso-/Neolithic yew bow finds. A: Adult bow, K: Kids/Youth bow, B: Blank.

Meso-/Neolithic Yew bows (n = 140)	Model	Sapwood discernible
Ochsenmoor bow 1	A	yes (transverse cracks)
Ochsenmoor bow 2	A	yes (transverse cracks)
La Draga bow 1	A	yes (latest growth ring present)
La Draga bow 2	A	yes (latest growth ring present)
La Draga bow 3	K	no
Egolzwil 3	K	yes (latest growth ring present)
Hornstaad/Hörnle IA	A	no
Rotten Bottom	A	no
Egolzwil 4 bow 1	A	yes (colour)
Egolzwil 4 bow 2	A	no
Egolzwil 4 bow 3	A	yes (colour)
Seeberg/Burgäschisee-Süd bow 1	A	no
Seeberg/Burgäschisee-Süd bow 2	K	yes (colour)
Twann bow 1	R	no
Feldmeilen-Vorderfeld	B	yes (colour)
Thayngen-Weier bow 1	A	yes (transverse cracks, shrinking)
Thayngen-Weier bow 2	K	no
Twann bow 2	A	yes (latest growth ring present)
Niederwil bow 1	A	yes (colour and transverse cracks)
Niederwil bow 2	A	yes (transverse cracks)
Niederwil bow 3	A	no
Similaun	B	no
Robenhausen bow 1	A	yes (transverse cracks, shrinking)
Robenhausen bow 2	A	no
Robenhausen bow 3	A	no
Robenhausen bow 4	A	no
Bodman	A	yes (colour and transverse cracks)
Ashcott Heath	A	no
Meare Heath	A	no
Zürich Kanalisationssanierung bow 1	K	yes (latest growth ring present)
Zürich Kanalisationssanierung bow 2	K	yes (latest growth ring present)
Zürich Kanalisationssanierung bow 3	K	no
Zürich Kanalisationssanierung bow 4	K	? (not investigated)
Zürich Kanalisationssanierung bow 5	K	? (not investigated)
Zürich Mozartstrasse bow 1	B	yes (ca. latest growth ring present)
Zürich Mozartstrasse bow 2	K	yes (latest growth ring present)
Zürich Mozartstrasse bow 3	K	yes (latest growth ring present)
Zürich Mozartstrasse bow 4	K	no
Horgen-Scheller bow 1	K	yes (latest growth ring present)
Horgen-Scheller bow 2	K	no
Horgen-Scheller bow 3	A	no
La Neuveville-Schaffis bow 1	A	no
Nidau Schlossmatte Bogen 1	B	no
Nidau Schlossmatte bow 2	A	no
La Croix-Saint-Ouen	K	yes (latest growth ring present)
Pfäffikon-Burg (50 bows)	K/A/B	yes (colour and latest growth ring present)
Vrees	A	no
Sutz-Rütte/Schloss	A	yes (latest growth ring present)

Table 6, continued. Sapwood presence in Meso-/Neolithic yew bow finds. A: Adult bow, K: Kids- / Youth bow, B: Blank.

Meso-/Neolithic Yew bows (n = 140)	Model	Sapwood discernible
Bevaix	A	yes (latest growth ring present)
Robenhausen bow 5	A	yes (latest growth ring present)
Vinelz-Strandboden/Ländti	A	yes (latest growth ring present)
La Neuveville-Schaffis bow 2	A	yes (latest growth ring present)
Lüscherz bow 1	A	yes (latest growth ring present)
Lüscherz bow 2	A	yes (transverse cracks)
Zürich-Utoquai bow 1	A	? (not investigated)
Zürich-Utoquai bow 2	A	? (not investigated)
Zürich Kanalisationssanierung bows 6-11	A	yes (latest growth ring present)
Zürich Mythenschloss	B	yes (latest growth ring present)
Lac de Chalain bows 1-16	K/A	? (not investigated, drawing shows latest growth ring present)
Charavines	K	yes (latest growth ring present)
Lac de Clairvaux-Motte aux Magnins bows 1-5	K/A/B	? (not investigated, drawing shows latest growth ring present)
Lac de Clairvaux-Station III	A	? (not investigated, drawing shows latest growth ring present)
Lac de Clairvaux-Station II´	A ?	yes (latest growth ring present)
Foissac	A	no
Schnidejoch	A	no
Onstwedde/Stadskanaal	A	no
Koldingen	A	? (not investigated)
n= 140		yes: 88 no: 25 unknown: 27

the bow's back. A third possibility is the presence of characteristic transverse cracks on the back of the bow. As yew sapwood contains more water than heartwood, it shrinks more during drying after excavation, which causes it to crack in a very typical way. This applies only to older finds, which did not receive modern conservation treatment. An additional sign is the shrinking of a bow find into a reflexed position (bent to a curve as opposed to the bow being strung). Like the cracks, it is caused by the shrinking of the sapwood in non-treated older bow finds. By these indicators, the presence of sapwood can be identified in 88 out of a total of 140 Neolithic bows or 63 % of them (Fig. 13). 25 bows provided no indication of the presence of sapwood (18 %). For another 27 yew bows, it was not possible to obtain sufficient data (Junkmanns 2013).

3.2 Bronze Age bow technology

The Early Bronze Age bows from Loetschenpass, despite being simple self-bows of man height like the Neolithic ones, display slightly different characteristics (Fig. 4). The moving limbs are slightly wider and flatter than those from the Neolithic, which possibly makes them a bit slower. The lens-shaped, sometimes keeled cross-section weakens the inside face (belly) of the bow, which makes it safer with respect to the danger of breaking. The estimated strength or draw weight of the best-preserved Loetschenpass bows is roughly around 45–55 pounds, which is a bit less than in Neolithic bows (Junkmanns 2013). In contrast, the extremely narrow handles permit the arrows to fly straighter as they have to bend less around the handle during launch. About half of the Loetschenpass bows were made from yew wood. The use of yew sapwood seems to have been common, as the use of sapwood on the back can be determined in some cases. What is really surprising is the fact that at least four bows were made from elm wood (*Ulmus* sp.), since it is inferior to yew (*Taxus baccata*) as bow wood, and, as a consequence, had been abandoned for Neolithic bow making since about 5000 BC (Junkmanns 2013). As an explanation, it can be assumed that is was difficult to obtain good quality yew wood during that time.

3.3 Neolithic arrow technology

Neolithic arrows of the 5th millennium from Schnidejoch are all made from shoots of hazel (Fig. 7 a–d). The V-shaped notches for the bowstring and also for the arrowhead are cut and not split into the shaft. As only fragments survived, not much can be said about the dimensions of these arrows. The younger Neolithic arrows of the 4th and 3rd millennia found at Tisenjoch and Schnidejoch are among the best sources for Neolithic arrow-making technology. The two finished arrows and one dozen raw arrow shafts found in the Tisenjoch quiver are the best-preserved examples of arrow finds of the European Neolithic.

Dimensions and shaft material

Guelder rose *(Viburnum* sp.) was the preferred wood for making arrows in the Neolithic (Fig. 6; Fig. 7.e–i, k and l). In shady areas, the shoots grow quite straight and without side branches. Other quality arrow woods, such as dogwood (*Cornus* sp.) or honeysuckle (Fig. 7 j; *Lonicera* sp.), were used less frequently. These dense and tough woods bend easily with heat. In comparison to the latter species, guelder rose is lighter because of the thicker inner pith channel. Furthermore, practical experience shows that it also stays straighter for a longer time. In use, it is very rare that an arrow made of a shoot of one of these species ever breaks. Due to a different climate, Mesolithic arrows were often made, among others, from hazel shoots, which are not nearly as good. During Final Palaeolithic and Early Mesolithic periods, split pine wood was used nearly exclusively because many other usable species were probably not available at that time (Junkmanns 2013).

The arrows of the Tisenjoch Iceman were made exclusively from shoots of mealy guelder rose (*Viburnum lantana*; Egg 1992). The Tisenjoch arrows measure between 84 and 90 cm in length. Both finished arrows are broken, the longer one at the beginning of the fletching zone, the shorter one ca. one-third behind the point and directly under the point. One of the unfinished shafts is broken as well.

One of the two finished arrows has a dogwood insert as a foreshaft, maybe a repair. The 12 unfinished arrows from Tisenjoch are between 84 and 87 cm long and made from max. 13 mm thick shoots (Fig. 6). The shoots were debarked and heat straightened. They are about 13 mm thick and have a split notch in the front end for the future arrowhead. The diameter at the butt end is 8 mm. Experience shows that this kind of shafting can only be successfully straightened by heat when already dried. The nodes were reduced a little, but the shafts are not smoothed.

Both finished arrows are ca. 9 mm thick at the end, while the front measures about 10 mm (11 mm for the repaired one). The characteristics of the clean, perpendicular fractures show that the wood must have been already decayed at the time of breaking. *Viburnum* wood in good condition would break in long parallel splinters. A study of the Oetzi find complex concludes that the find ensemble must have undergone several thawing periods, which must have degraded the cell structures of wooden finds (Pilø 2018). The two finished arrows differ considerably in length and some other attributes. While the shorter arrow was 85 cm from the tip of the arrowhead to the tail end and conforms to the length of the unfinished arrows and the quiver, the other one measures 90 cm in total.

Replicas of the smaller finished arrow show a total mass of 46–56 g. Measured on a modern Spine Testing device, the arrow shafts gave a value of 84–100 lb for 28-inch length. Because they are about 10 cm longer than that, it means their bending resistance (spine) would be best for a bow of 75–90 lb draw weight at 28 inches.

The Neolithic arrows of the 4th and 3rd millennia BC from Schnidejoch show more or less the same characteristics as the Tisenjoch arrows, but are slightly thinner. The complete arrow shafts vary in length from 79 to 91 cm. At the front end they measure between 8 and 10 mm in diameter, while the rear ends measure 6–8 mm. In one case, an arrow has a constant thickness of 10 mm, while in two the front ends are thinned for better penetration so that the maximal diameter is in the centre or at 3/4th of arrow length. The Schnidejoch arrows show a great variation in length, diameter and front shape. Their weight can be estimated to 40–55 g, and they would probably have been best suitable for bows from 60–80 pounds of draw weight. Only one is made from honeysuckle, while all others were fashioned from guelder rose.

Fletching

The Tisenjoch arrows are the only ones known from European prehistory which still retain their fletching. Other known examples of survived fletching outside of Europe were found in Egypt (Clark et al. 1974). In some cases, prehistoric arrow finds contain traces of the pitch used to glue the feather vanes, and in some of these traces the impressions of quills can still be observed. Older Mesolithic arrows sometimes show negatives of bindings, which very likely served to attach feathers without pitch (Junkmanns 2013). The finished arrows from the Tisenjoch Iceman have slightly thinned, 13–14 cm long fletching zones, which extend to the string nock (Fig. 6 left side). Three split feather vanes were glued onto a very thin layer of birch bark tar and then wound with fine thread. The nature of the feathers could not be determined, but they were from a big brownish bird. This type, known as triple radial fletching, is still the most popular way of arrow fletching today. A three-feather radial fletch is more effective in stabilizing arrow flight than two feather styles and creates a faster arrow than styles with more than 3 feathers or tangential fletching. From published photographs (Egg 1992), it appears that one feather was set “on top” of the arrow, parallel to the notch which takes the bowstring (12 o’clock position), while the other two feathers were positioned at 8 and 4 o’clock. In this respect, the fletching differs from the usual feather positions used in modern archery.

The fletching zone of the Schnidejoch Neolithic arrows (Table 3) was 8 cm long in one case (Fig. 7 j), in another 12 cm long (Fig. 7 l), both additionally wound to secure the feathers. Traces of birch bark tar with impressions of bindings extend to the nock where they are meant to prevent splitting by the force of the bowstring.

String notches (nocks)

In the Tisenjoch unfinished arrow shafts, a notch about 2 cm long and 2–3 mm wide was split into the thicker end of each shaft for the insertion of the arrowhead's tang. The nock for the string, which is only present in the two finished arrows from the site, was placed at the thinner end of the arrow (Fig. 6 left). Arrows fly much better if the front is heavier than the tail. The way the notches were fashioned could be reconstructed experimentally (Junkmanns 2013). The inner edges are very clean and parallel, so it would have been impossible that they were made by sawing or grinding with a flint implement. Flint can have very sharp cutting edges, but it is far too brittle for clean cuts into hardwood. On the other hand, when cutting parallel to the grain, the wood will always split easily. By controlled lengthwise splitting, while stopping the fissures with a tight binding, two parallel fissures 2 cm long can be produced. Then, after cutting a small groove perpendicular to the base, the wood in the centre can be split outwards from the soft hollow pith in the centre of the shoot (Fig. 14).

String notches are present in 9 Neolithic Schnidejoch arrows (Fig. 7 a and b, d–k). Four are V-shaped and cut or ground into the end (Fig. 7 a and b, d–i). The other five were split and are 7–15 mm deep and 2–3 mm wide (Fig. 7 e–g, i and j).

Fig. 14. Experimental splitting technique for string notches.

Arrowheads and their attachment

For the two finished arrows found on the Tisenjoch, the arrowheads and their attachment with birch bark tar are preserved (Fig. 6). Both completely retouched arrowheads, made of Trentino flint (Wierer et al. 2018), have the usual triangular blade and different shaped stems. The blades are about 3 cm long and 1.6–1.8 cm wide. While the stem is in one case about 1 cm long and 0.7 cm wide, the other one is fitted with a 3 cm long and 1 cm wide tongue. The points, today broken off the shaft, were fastened to the arrow by a coating of birch bark pitch. The coating has partly come off, but tiny remains of tar prove that they were once encased fully, leaving only the cutting edges free. A wrapping of vegetal fibres underneath the points prevented the splitting of the arrow on impact. This method of hafting has been proven for all younger Neolithic triangular arrowheads by numerous finds from the alpine lake dwellings. One of the finished arrows, the longest one, is composed of two pieces. A 10 cm long foreshaft made from dogwood (*Cornus* sp.) was inserted with a conical point into the drilled-out front of the *Viburnum lantana* shaft and wrapped. The binding was covered with birch bark pitch and therefore might very probably indicate a repair. The shorter finished arrow is slightly thicker than average measuring to about 10 cm in the front. This way, the centre of gravity was shifted a bit towards the tip, which improves its ballistic quality. On the other hand, the somewhat abrupt reduction of the diameter is a possible weak point. The other arrow was probably repaired at roughly the same spot.

Most of the Schnidejoch arrowheads have been lost. Only two triangular pedunculated points made from Olten, Chalchofen flint were found inside the bow case (Hafner/Affolter 2015). They are geometrically shaped with 2 cm long, 1.8 and 2.3 cm wide blades and 1 cm long pointed stems (Fig. 15).

Fig. 15. Two silex arrowheads found inside the Schnidejoch bow case (© Archaeological Service Canton of Bern).

The maximum width of the stems is 1.3 and 0.9 cm, respectively, the thickness is 2–3 mm. Numerous traces of birchbark tar from the hafting of the arrowheads are preserved. Three of the Schnidejoch arrows have split notches on the front end (Fig. 7 e and f, h) to hold this kind of arrowhead, while two others are hollowed out (Fig. 7 j and k). The slots are 2 to 4 mm wide and 6 to 10 mm deep. The cavities of the hollowed arrows are 10 and 12 mm deep and partly filled with tar. Traces of bindings in tar can be seen on the outside. Arrowheads for these should have narrower stems to fit inside. On one of these, a binding of thin sinew fibres could be identified (Fig. 7 e). Another one shows impressions of a binding in birch bark tar (Fig. 7 i). Front bindings prevent the arrow from being split by the arrowhead on impact. Two front ends are not preserved, while one arrow has a dull wooden point (Fig. 7 g) and has obviously never had any other point attached.

3.4 Prehistoric bowstring technology

Prehistoric bowstrings are very rare in the archaeological record. Several animal gut bowstrings are known from Egyptian graves, the oldest ones from the 11th dynasty (ca. 2200–1900 BC). In the tomb of Tut Ankh Amun, several fragments of bowstrings made from gut adhering to self-bow tips and one bigger cord with a knot made from linen were present (Fig. 16; Mcleod 1982). The linen string (Fig. 16 b), of which 3 fragments with a total length of 1.31 m and a thickness of ca. 3 mm survive, was also attached to the tip of a self-bow. It is described as being composed of two strands of flax fibres joined tightly by a Z-twist. The photograph in Mcleod (1982), however, shows definitely a string of S-twist of probable 3-ply twine. The knot looks like a clove hitch. Four other bowstring fragments are reported to have clung to composite bows from the same tomb. They are made from gut, 2–4.5 mm thick of up to 4-ply twisted twine (Fig. 16 a). One of them has a loop or a knot, whereby the type is not clear (Mcleod 1970).

Excavations at the 6th millennium Neolithic site of La Draga (Banyoles, Catalonia, Spain) yielded three fragments of bows, several arrows and one or more possible fragments of bowstrings thus far (Bosch et al. 2000; 2006; 2011). Several fragments of tightly twisted cords made from nettle fibres (*Urtica* sp.) have been found. Although there was no connection to the bows found, it is conceivable that they represent bow strings. Nettle fibre is exceptionally strong and well-suited for the strains appearing in a bowstring. Diameters of 3–4 mm support the interpretation. In particular, a roll of an estimated 190 cm long and about 4 mm thick twisted cord is interpreted as possible bowstring (Fig. 17; Piqué et al. 2018).

When a little bundle of a fragmented thin rope was found on Schnidejoch (Fig. 5 b) just beneath the remains of the birch bark bow

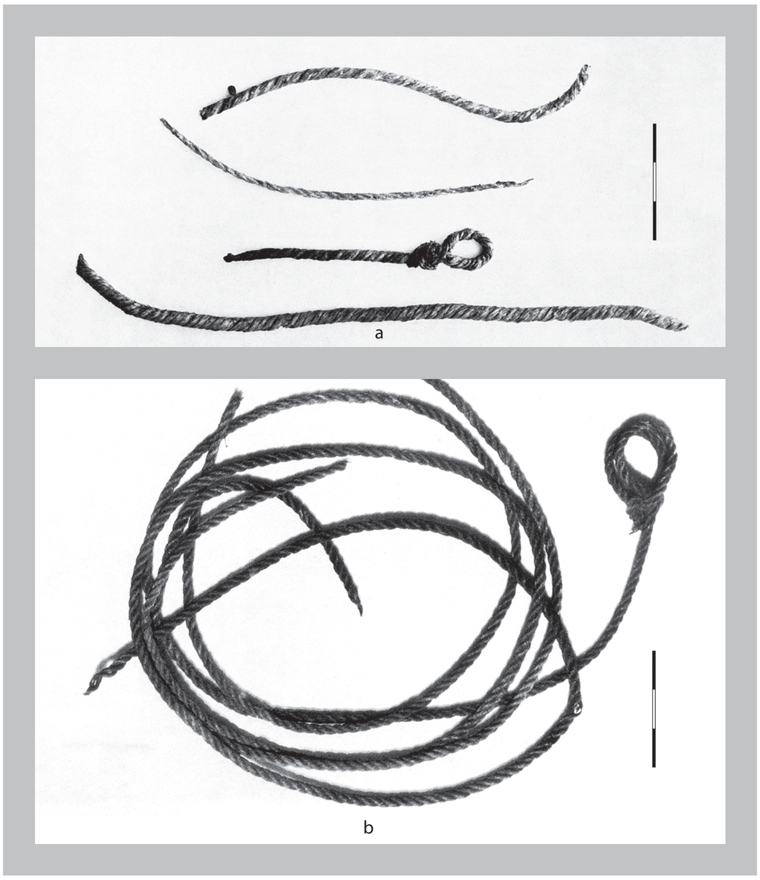

Fig. 16. Egyptian bow strings from the tomb of Tut-Ankh-Amun (after Mcleod 1982).

Fig. 17. Probable bow string from La Draga (Catalonia, Spain) (after Piquet et al. 2018).

case, it appeared to most likely represent a fragment of the bowstring, which belonged to the bow found close by. A length of 97 cm was measured for this small cord, with both ends missing. It was made from 3 strands of translucent fibres, which could be identified as animal sinew. The animal species could not be determined, but any bigger animals can provide the quality needed for a bowstring. Sinew fibres are a good material to make bowstrings, but it nevertheless has two disadvantages. It stretches more than strong plant fibres (linen, hemp or nettle), and it is sensible to moisture. However, it is very easy to obtain in herding or hunting societies and was widely used, for example, by North American Indians and Inuit as bowstring material. The fibres, which can be acquired, are never as long as the finished bowstring, so fibres have to be added constantly in the twisting of the string, but this applies to plant material as well. The 3.6 mm thick string on Schnidejoch was twisted in a tightly wound S-twine. Interestingly, A. Rast-Eicher could microscopically detect a coating on the outside, which is probably some sort of wax (Report Rast-Eicher 2009). Modern bowstrings are also waxed for protection against humidity.

A third candidate for a prehistoric bowstring was found inside the Tisenjoch quiver (Fig. 5 a). The clew of 1.75–2.00 m long and 4 mm strong, S-twined cord begged for recognition as a bowstring. But after preliminary inspection, the material was identified as "some sort of tree bast" (Egg 1992; Egg/Spindler 1993), which is unsuitable for bowstrings because it is too weak. As it was clear according to personal experience that tree bast could not be used as a bowstring, the authors asked the South Tyrol Museum of Archaeology for permission to have some fibres analysed. The first examination by the naked eye already revealed that plant fibres could be excluded as a raw material. Although of brownish colour, as could be expected for lime

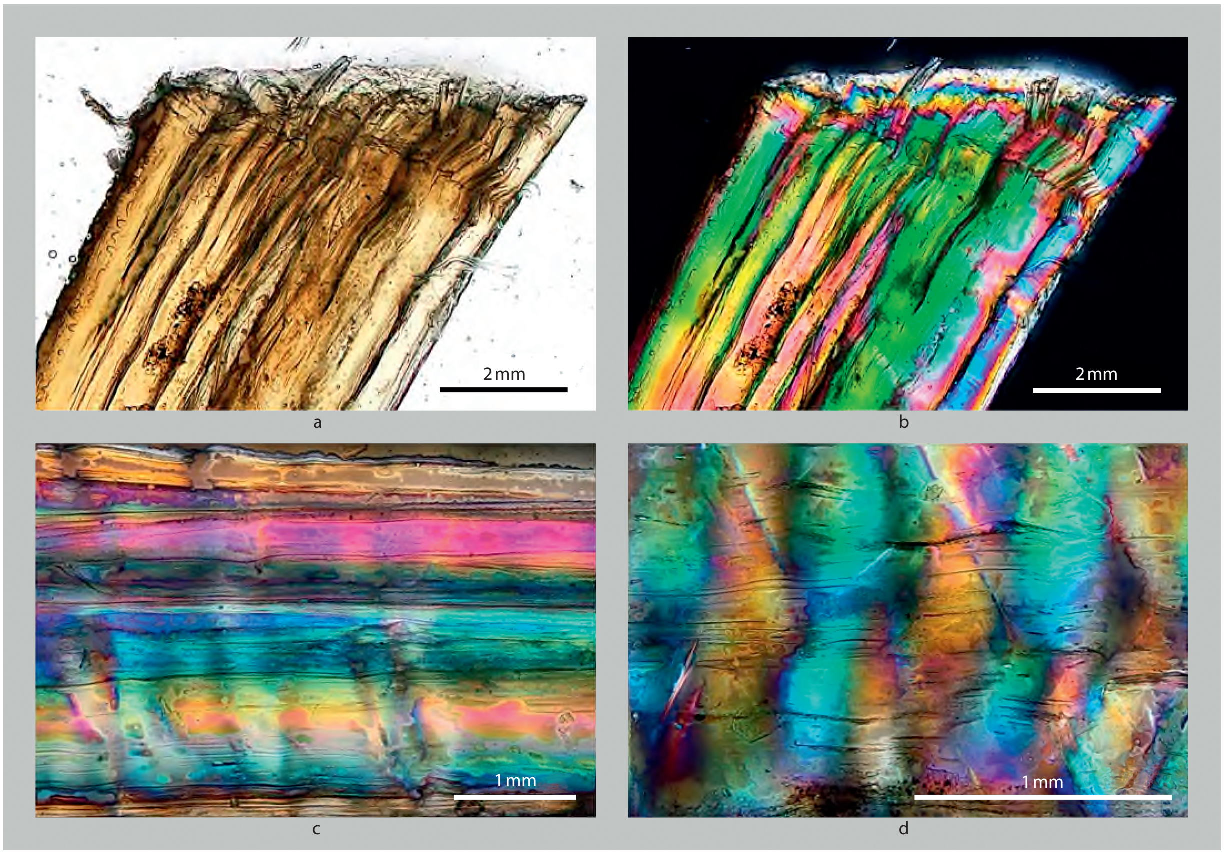

Fig. 18. Microscopic photographs of the Tisenjoch bow string fibres (Schoch in prep.). (a–b) fibres from the Tisenjoch string in transmitted and polarized light; (c–d) comparison of fibres from recent red deer (*Cervus elaphus*) sinew and from the Tisenjoch string in polarized light (© W. Schoch/ Archaeological Service Canton of Bern).

bast, the material showed a certain shine which is not common for vegetal material. Additionally, it appeared to be slightly translucent. Moreover, no characteristic traits of vegetal fibres could be detected with the microscope. In contrast, W. Schoch could prove that the microscopic structures are strongly similar to animal sinew (Fig. 18). Its brownish colour, which supposedly led to the earlier classification as tree bast, could possibly have derived from its having been inside the leather quiver for a long time or from some other substance it had been treated with. Both ends are knotted (Egg/Spindler 2009) – one side with a simple overhand hitch to protect the end from fraying, and the other one with a so-called anchor hitch. This knot proved to be capable to secure the string of a heavy 80-pound bow, allowing to shoot it without any sign of slipping (Fig. 19).

3.5 Quivers/bow containers

Containers for carrying bows or arrows are known world-wide from ethnographic and historical sources. They serve mainly two purposes: the protection of bows and arrows against bad weather and to enable the archer to carry them leaving both hands free for other tasks. Known examples are nearly exclusively made from animal hides, but sometimes tree bark, notably birch bark, was used in combination with wood and hide.

The bow case from Schnidejoch (Fig. 9) is at present the only existing Neolithic artefact of this kind. We can only speculate why no comparable bow containers have been found in the many known lake dwelling sites from the Alpine region. A good explanation could be that the choice of material (tree bark) was not the ordinarily chosen raw material for this kind of container. If other bow cases or containers, whose existence we do not doubt, were made from

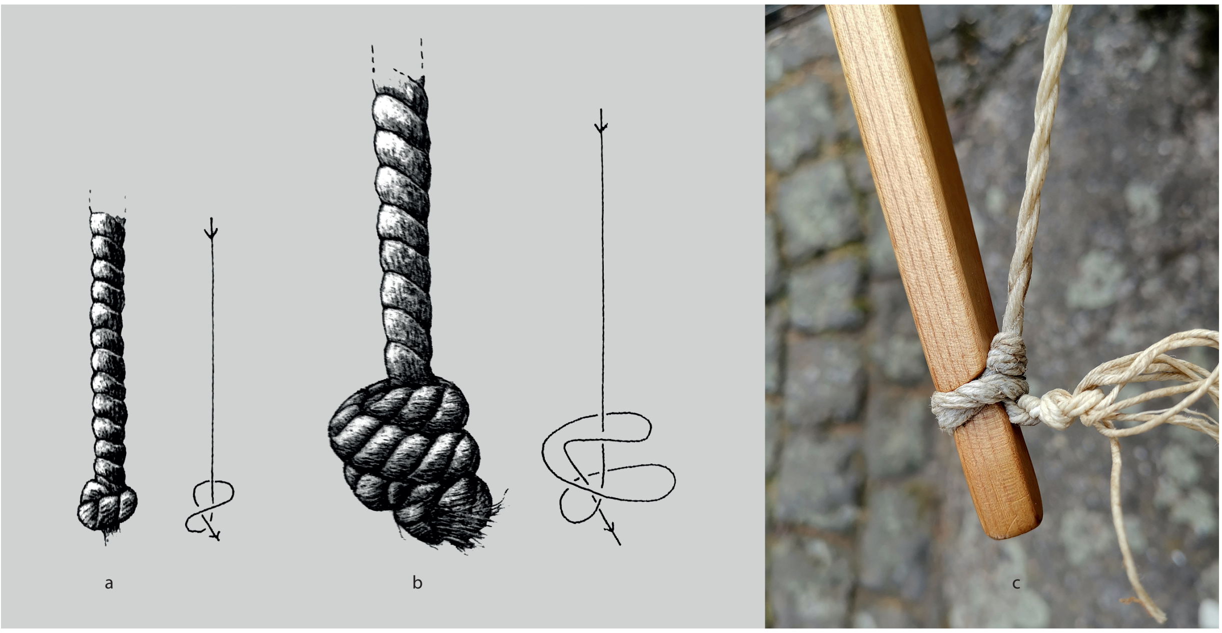

Fig. 19. The knotted ends of the Tisenjoch bow string. (a) simple overhand hitch; (b) anchor hitch (after Egg/Spindler 2009); (c) experimental use of the anchor hitch in an 80-pound bow.

perishable animal hide, they could simply not have been preserved in Alpine lakeshore sites. Nevertheless, the need for this kind of object in an archery-using group cannot seriously be denied. If we have a look at the arrow quiver situation, things are quite similar. The only existing Neolithic quiver today is the one found with the Tisenjoch Iceman (Fig. 8). It is made from leather, which can only survive longer periods of time in ice or in extremely arid climates, such as deserts, but this applies only to regions outside Europe (Egypt, China, and Peru, for example). Leather quivers of comparable age are known from Early Dynastic Egypt (Clark et al. 1974). If the preferred material for Neolithic quiver making would have been birch bark, hundreds of quivers and their fragments would probably exist from the lakeshore dwellings. The Schnidejoch bow case was made from birch bark and it seems that it was a rare choice of raw material for this kind of item.

The closest ethnographic parallels to the Schnidejoch bow case are the combined bow cases/quivers of North American Plains Indians (Fig. 20). Like the Schnidejoch bow case, they are stiffened by wooden rods and equipped with leather carrying straps. They were worn hung on the back over the shoulder and contained a bow and arrows, which were carried in separate sleeves. Unlike the Schnidejoch example, they were made from leather. Although they offered only limited protection against rain, which was not so important due to the much drier climate, they enabled archers to carry their weapon while keeping their hands free. This must have been even more important on horseback, but we can assume that this benefit was also nice to have on foot for a Late Neolithic archer, especially when hiking in mountainous areas. The Schnidejoch object was not as convenient as the Native American combined quiver/bow case. Keeping the arrows in the same tube as the bow must have made it quite difficult to retrieve them quickly.

4. Conclusion

The alpine ice-patch sites of Schnidejoch, Loetschenpass and Tisenjoch delivered exceptional finds of Neolithic and Bronze Age archery equipment. One unfinished bow blank (Tisenjoch) and one finished Late Neolithic bow (Schnidejoch), as well as the finished

Fig. 20. Bow case/quiver combination of North American Plains Indians. Omaha Nation (Collected 1824 by P. v. Württemberg. Linden Museum, Stuttgart, Germany).

Early Bronze Age bows from Loetschenpass can convey a lot about the construction and the typology of prehistoric bows as well as bow-making materials. While Neolithic bows were made exclusively from yew wood (*Taxus baccata*), in the Bronze Age elm wood was surprisingly used in some bows. All prehistoric bows are simple self-bows made from one piece of wood and of approximate man height. Despite their different shapes, there are only minor differences between the straight staved bows from Tisenjoch and Schnidejoch and the flatter and wider bows from Loetschenpass. The Bronze Age bows seem to emphasize accuracy more than pure shooting power.

Arrows found in the three ice-patch sites were exclusively made from heat-straightened shoots of bushes or small trees, and were not manufactured from split wood as in older periods and also during Antiquity and the Middle Ages. While the wood species of the older Middle Neolithic arrows from Schnidejoch is hazel (*Corylus* sp.), all other arrows were, with one exception, crafted from guelder rose (*Viburnum sp.*) – one of the best choices for a hunting arrow. Its extreme durability reduces the need for a replacement of arrows considerably, which saves a lot of time and effort. Neolithic arrows are quite long compared to the majority of historical arrows and also modern arrows for target use. The extra length provides additional weight, improving penetrating power, but reducing the range, which was not that important in hunting. Experimental data of replicated Tisenjoch and Schnidejoch arrows show that they would fly best with quite heavy bows. The Schnidejoch arrows show great variations in length, shape and diameter, which could mean that they were owned by different people.

A fletching consisting of three split feather vanes arranged around the shaft assured that the arrows flew as straight as possible. This type of arrow fletching already in use in the time of the Iceman from Tisenjoch could obviously not be improved further and is still in use today.

The most critical point in penetrating capabilities was the arrowhead, which must possess very sharp cutting edges to ensure the penetration of thicker animal hides. If the flint arrowhead was not shattered by bone impact, it could be used a second or maybe even third time, but would have to be resharpened to retain optimal cutting quality (Kelterborn 2000). The hafting method by inserting the point into a lump of birch bark tar made the exchange of arrowheads a quick and easy task.

Surviving prehistoric bowstrings are one of the rarest things to find in excavations, although there must have been millions of them around. A 100 % certified bowstring would have to be found still clung to the tips of a bow, which is only true for a handful of

Egyptian finds. In Europe, we have to deal with a varying degree of uncertainty in this respect. A string made of suitable material and having proper bowstring length and dimensions can be designated as a possible bowstring, for example, for some nettle fibre cords from the Early Neolithic site of La Draga. Most of surviving prehistoric cordage is made from tree bast, which is not in the slightest strong enough for this task. Flax would have been an ideal material because of its strength and its tolerance against dampness, but it has not yet been identified as possible prehistoric bowstring. If bowstrings were generally made from animal fibre, it becomes obvious why they cannot be found in great numbers in excavations. Their preservation is only possible in an arid climate and at frozen sites. In the case of the Tisenjoch cord made from animal sinew, which was carried inside an arrow quiver, we can be nearly sure that our interpretation as a bowstring is correct. The same goes for the Schnidejoch sinew string, which was found near a bow, arrows and a bow case. The bowstrings mentioned here are 3–4 mm in diameter, which fits nicely to the 2–3 mm wide rear notches in the arrows, considering that a bowstring becomes thinner from the tension of being strung on a bow. Technically, they consist of three separate strands of twisted fibres twisted into one cord.

Containers for protection and carrying archery equipment are a must-have in most archery cultures around the world. They are very useful in the protection of the equipment and in leaving your hands free for other tasks while carrying bow and arrows. Again, we are surprised by the very small number of prehistoric respective pre-metal age examples. At present, only the Tisenjoch quiver and the Schnidejoch combined bow/arrow bag are known. There can be no doubt that there were many more in existence during these times. So why are they so rarely found? The material used might provide an answer. If the majority of them were made from animal hide, like the Tisenjoch quiver, no trace of them could be left in the numerous alpine lakeshore sites. Hide can only be preserved in some bog sites and if kept frozen in ice-patches. The Schnidejoch bow bag appears, therefore, to have been exceptionally made from an unusual material. If many other bow bags had been made from birch bark, we surely would have been able to recover them from the lakeshore sites in great numbers.

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