New Evidence about Composite Bows and Their Arrows in Inner Asia

Michaela R. Reisinger
University of Vienna

During the summer of 2008 the Mongol-American Khovd Archaeology Project excavated a cluster of eight graves at the burial ground of Shombuuziin-belchir (Miller et. al. 2009). Burials SBR-12, SBR-13 and SBR-16 yielded bow and arrow artifacts including bone bow-stiffening plates, bow-wood and arrow remains. Bow reinforcements have been found quite frequently but rarely in their original position (Sosnovskii 1946; Rudenko 1969; Davydova 1985; Tseveendorj 1989; Khudiakov and Tseveendorzh 1990; Gorbunov et al. 2006). The fact that the original position was preserved in the Khovd burials is significant for determining approximate lengths of the respective parts of the bow and allowing reconstruction of its shape. Analysis of the new finds and comparison of them with previously found artifacts advances our understanding of Inner Asian archery equipment and the development of archery equipment in general.

Evidence to date suggests that bows of this type may vary considerably in length. Rausing (1967) proposes a prototype ranging from 125–160 cm. Bone plate findings from widely distributed sites in Inner Asia indicate a length of 140–155 cm [Fig. 1].[1] The length of preserved bows from Niya and Yingpan in Xinjiang is in a similar range (142–155 cm; Hall 2005). The prototype of this bow is an asymmetrical one, the upper and lower part of the bow — and their reinforcements — being of unequal length (15–40 cm for the above-mentioned bows, Hall 2005, 2006).

The reinforcements cover the tips of the bow as well as the handle. A bow type that features reinforcement of both is frequently referred to as a "Hun," "Hunnic" or "Hsiung-nu" composite bow (Waele 2005, Hall 2006), suggesting an association that, though definitely valid, is not exclusive. This bow type may have developed in Central Asia during the 3rd to 2nd century BCE (Gorbunov and Tishkin 2006; Hall 2006), with earliest finds from the area of Lake Baikal, but was distributed across Eurasia in a way that does not indicate its use by only one people (or confederation of peoples).

The strengthening plates distinguish it from another bow type, which is similarly associated with various peoples referred to by an umbrella term, the "Scythian" bow. This bow type, best known for portrayals of its pronounced "cupid bow" shape, is notably smaller, and usually associated with smaller, bronze trilobate arrowheads featuring a socketed hafting method. A variation of this type has been found in the Tarim Basin at Subexi (Wieczorek and Lind 2007).

Fig. 1. Map of bow findings in Inner Asia. Sites mentioned in the text are: 1 Shombuuziin-belchir (SBR), 2 Khirgist-khooloi (HGH), 3 Il'movaya pad' (ILM), 4 Buryat region: Cheremukhov Pad (CHR), Derestuy Kultuk (DRS), 5 Yaloman II (Y II), 6 Subexi, 7 Yingpan, 8 Lop Nor region: Qum Darya (L.N.), 9 Niya

A composite tool set

Bow and arrow function as a composite tool: being in fact one weapon, they should also be reviewed as such. A bow is a complex and powerful weapon with a broad range of potential applications. Precisely because of its broad application, it needs a counterpart which focuses on a narrower use. Thus, different arrows optimize a bow for use on dissimilar targets. Given the relative speed and relatively low cost of their manufacturing process and the quantity which a person may carry, it makes sense to specialize arrows for use on particular targets. Even if it is of poor quality, a bow can function effectively in shooting an arrow: "... arrow quality is normally more important [to accurate shooting] than [the] quality of the bow" (Lane 1968, p. 978).

The manufacturing of tools like bows and arrows will be influenced by a broad range of factors, not just the mechanics of the tools themselves. There are considerations involving the availability of materials and the manufacturing process, and there are contextual demands regarding the specialization for the use of the tools that are produced. Devising multi-purpose tools that have a broad application but also function effectively for specific purposes can be a challenge, and in general the various demands on the maker and by the user can conflict and thus require certain balancing or compromise.

The basic idea of a bow is a stave (acting like a two armed spring), spanned and held under tension by a string (McEwen et al. 1991). In the discussion which follows, I will refer to the bow handle, extending from which are the limbs, at the end of which the string is attached. The belly of the bow is the inside (facing the archer); the back is the outside. Drawing the bow applies different forces to different parts of the bow. With the bending of the limb, the belly is placed under compressive forces while the back is placed under tension. Drawing the bow increases the force continuously and, for a long, rather straight-limbed bow, results in a nearly linear *force-draw curve*. Changes in bow shape (e.g. reflex of the limbs, set-back at the handle, rigid end pieces) change this force-draw curve, leading to a steeper initial increase and a much more moderate one at the end of the draw. This is important, as aiming takes place at full draw where a maximum of energy must be employed to hold the draw and could, if excessive, damage accuracy. This force in fully drawn position is called the draw weight of the bow. (Klopsteg 1943, Kooi 1983, Kooi 1996). By loosing, the energy input accumulated in the limbs of the bow is (partly) transferred to the arrow, which, if constructed and cast (shot) correctly, will fly along the line of aim and transfer the remaining part of that energy to the target.

It is important to understand that the flight characteristics of the arrow are equally determined by the properties of the arrow and by the bow with which it is shot (Klopsteg 1943). The quality of the cast is a crucial factor that defines the functionality of both tools. To produce a powerful and accurate cast, the energy transfer, both from muscular effort to stored energy and from that to the arrow, must be optimized, and the act of discarding can not be detrimental to accuracy. Yet optimization means not only achieving a maximal cast by minimal energy input, but also achieving it by minimal material input – which is "a compromise between using as little material as one *dares* […] and using as much as one *must*, to avoid the hazard of breakage" (Klopsteg 1943, p.181).

Bow types

Bows can be described by their structural composition as well as by their shape (profile). While the first characterizes a bow by the used materials and their relative positions, the latter also reflects their exact arrangement. As similar shapes can be reached through different structural compositions and one kind of composition can result in different shapes, both approaches are used to describe unambiguously a bow. All types of bows deal with the same structural requirements and address the same mechanical problems to achieve a common goal — to propel an arrow with the necessary amount of force and speed for the intended purpose.

There are different ways to deal with the forces placed on the different parts of the bow. A bow may be made of different kinds of wood — or, for example, of harder heartwood for the belly and more elastic sapwood for the back. Other possible materials used to construct the bow or reinforce its stressed parts need to have a high capacity for withstanding the tensile and compressive forces without damage to the limb. A bow constructed of different pieces of the same material is called a *laminate* while a bow made up of different materials can be called a *reinforced*, *backed* or *composite bow* (Rausing, 1967).

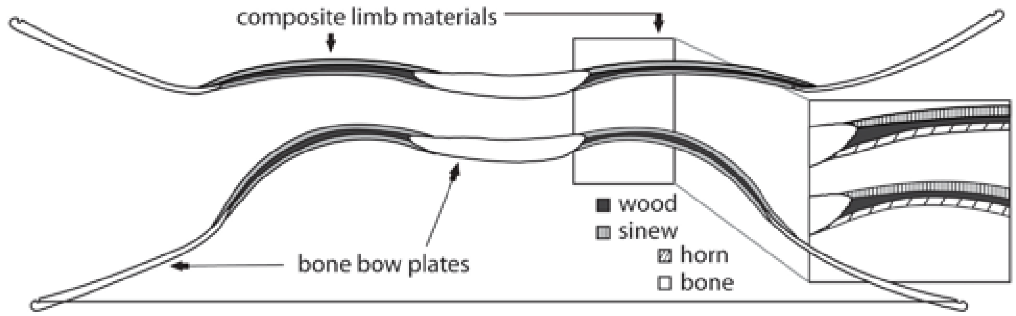


Fig. 2. Composite bow construction. Relative positions of horn, wood and sinew in a bow, with bone bow plates from SBR-16.

Backing is material applied to the back of the bow and can be of two types. While in a *reinforced bow* a string or (plaited) strands of sinews are lashed onto the back of the bow ("free" backing, used for example by the Inuit), a *backed bow* is reinforced by a whole layer of material that is firmly attached (glued) to the back ("close" backing; Balfour 1980, Kooi 1983). A composite bow features not only a close backing but several layers of different materials, held together using an adhesive (like hide- or skin-glue). This usually includes material applied to the belly of the core ("facing"; Kooi 1983).

In its full form the composite bow comprises the following materials [Fig. 2]:

- A wooden core, which gives the construction the necessary dimensional stability.
- A material bearing compressive loads; usually horn, with a maximal strength of 13 kg per mm^2 (which is twice to 3.5 times that of hardwood; Mc Ewen et al. 1991, Bergman and McEwen 1997). It also has a high coefficient of restitution (the ability to return to original shape after distortion). Most commonly water buffalo horn is used (Mc Ewen et al. 1991), though the use of horn of the fossil rhinoceros is not unheard of (*B. tichorhinas*; Balfour 1980). Another material with similar properties is baleen.
- A material handling tensile stress, usually sinew, which has a high tensile strength of 20 kg per mm^2 (four to five times that of wood; McEwen et al. 1991, Bergman and McEwen 1997). (Unspun) silk can also be used, replacing "a larger mass of wood than its own" and storing more energy per unit mass (Klopsteg 1943).
- Adhesives derived from hide, sinew, or fish-bladder (McEwen et al. 1991).
- A stiff material like bone or antler for reinforcement laths; other materials include hardwood and horn (Rudenko 1969). I would treat references to the latter with care as, especially in translated works, horn and antler are often confused.

By employing different materials for the parts most stressed, it is possible to maximize the benefits of having an easily handled short bow which nonetheless will be strong and very efficient in the transfer of energy. In the case of self-bows, made only of wood, shortening the bow-length results in a loss of draw-length, as the limbs can be bent only to a certain extent before damage occurs. A composite construction allows for a smaller bow-length while retaining the long draw without increasing the risk of breakage. The limbs in such a reinforced bow can be bent over a smaller radius, withstanding the stronger tension at the back and stronger compression of the belly. Additionally, shorter, lightweight limbs use less energy when moved forward with the release of the string and thus move over a shorter distance with greater speed. This results in higher arrow velocity (Bergman et al. 1988, McEwen et al. 1991, Alex and Menes 1995). Since the combination of the horn, sinew, glue and bone is roughly twice as heavy as an equivalent of hardwood, in the interest of building limbs and especially their ends as lightweight as possible, the amount of material used should be reduced to a minimum (Alex and Menes 1995). Another factor contributing to the recovery speed of the tips and thus to the velocity of the arrow is the backing of the bow — to connect the ends of a stave with a mass of elastic material running along its back makes the mass act like an elastic string. Drawing the bow will stretch this "ribbon"; release will lead to rapid contraction, which will "increase the speed with which the stave regains its state of rest, and thus the cast of the bow" (Rausing 1967, p.19).

The reinforcements used in a bow alter flexibility and stiffness, and their length affects efficiency. Stiffening the handle is crucial for

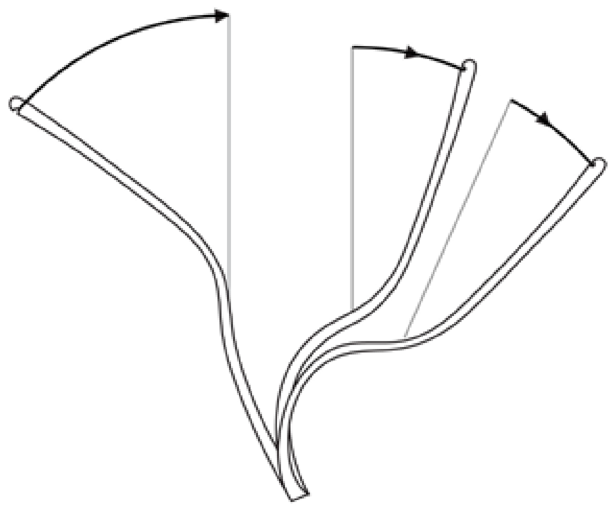


Fig. 3. Contribution of limb and rigid end pieces to movement of the tip. Bending of the limb moves the center point of the "large-diameter wheel" (shown in segments).

stability reasons. This is done using a (bone) rod for each side of the handle (*central side lamination*) and in some cases another item covering the belly side of the handle (*central belly lamination*). "Altering the relative zones of flexibility and stiffness" can alter considerably the strength of the bow (Khudiakov and Tseveendorzh 1990, p. 364). If the zones of stiffness are extended, when for example longer central side plates are applied on top of existing shorter ones, the radius over which the limb bends is smaller. Therefore the bow is heavier to draw. Stiffening the tips is not done so much for stability, but to make shooting more efficient. The stiffened ears, often set at a recurved angle, produce a lever at the end of each limb, acting like a "large-diameter wheel" (McEwen et al. 1991, p. 56), which "unrolls" when the bow is drawn [Fig. 3], thereby lengthening the string. Hence less effort is needed fully to draw the bow. As release shortens the string accordingly, the velocity of the arrow increases. The longer the stiffening plates the larger the diameter of the "wheel," which can result in unstable construction and loss of energy from moving the heavier weight of the limb ends.

The bow remains found at Shombuuziin-belchir

In situ position of the bows

In the largely undisturbed tombs SBR-12 and SBR-13, the bows were lying alongside the skeletal remains. It is notable that in SBR-12 the bow was placed to the left of the buried person and in SBR-13 to the right, which coincides with the muscular markings of the interred (Miller et. al. 2009). That is, the bow placement was at the side on which the bow would have been used.

The position of the stiffening rods in SBR-12 [Fig. 4] implies interment in an unstrung state (the belly facing upward with a tilt to the side;

Fig. 4. SBR-12. *Image copyright © 2009 Mongol-American Khovd Archaeology Project.*

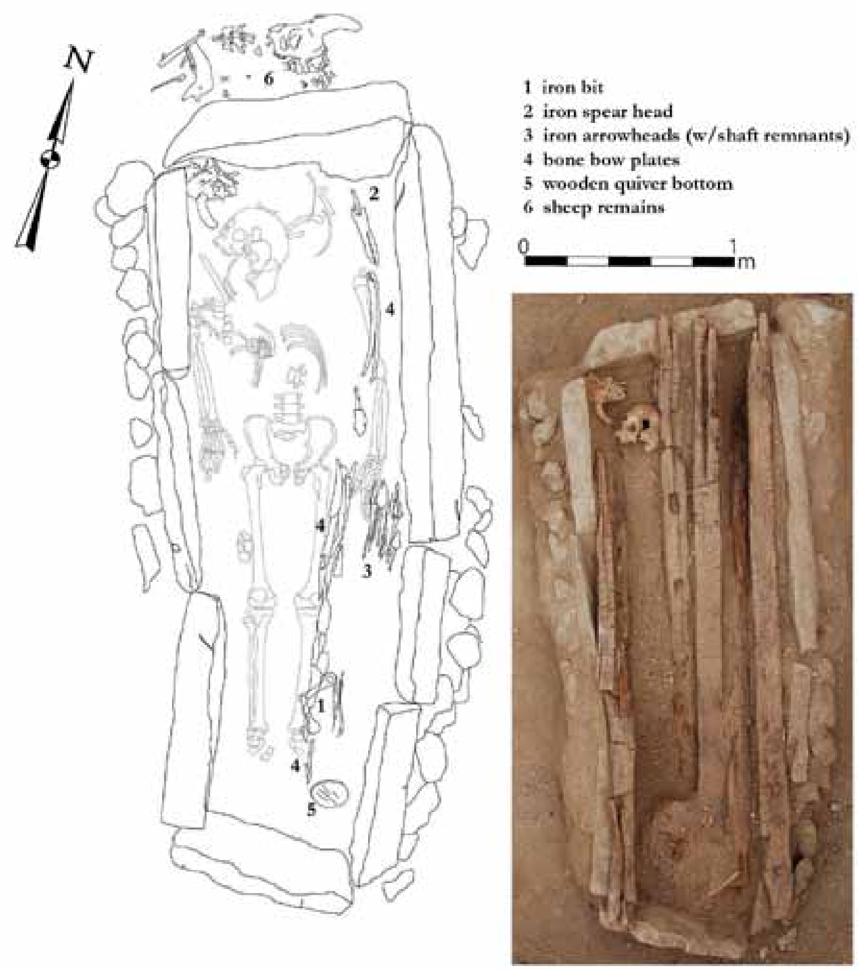


Fig. 5) and a length of 30–40 cm for the working part of each limb. The distance between the endplates was about 150 cm. The remains of the wooden core feature at least a small hole with a wooden insert [Fig. 6]. This could indicate that the core was of two pieces, joined at the handle by pins on its side. Such limb splicing can be seen in examples such as the Yingpan bow no. M30 and makes sense especially in regions where good bow wood was not abundant. The limbs were at least 4 cm wide, as

Fig. 5 (above). SBR-12 waist area with arrowheads and bow pieces in situ.

Fig. 6 (right). Wooden handle piece with wooden inset. Another, similar structure can be seen at 7 cm distance from the other inset.

Fig. 7. SBR-12: Preserved wood from the lower limb.

indicated by the preserved amount of wood of the lower limb [Fig. 7].[2]

The bow in SBR-13 [Fig. 8] was also interred unstrung and lying on its back. Since the lower section showed signs of disturbance (possibly by a rodent), the only indication for bow length was the upper half of the bow. Unless it was an asymmetrical bow it would have been at least 160 cm long, with a working limb of about 30 cm. The limb narrows towards the endplates to leave them only 0.1 cm apart [Fig. 9], showing that the bone rods probably reached beyond the wooden core.

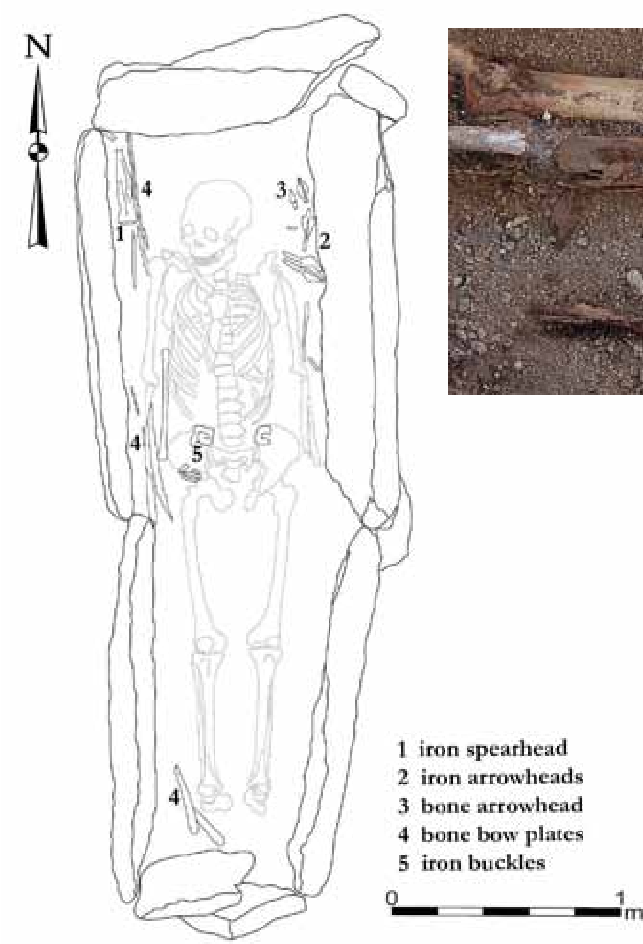


Fig. 8. SBR-13.

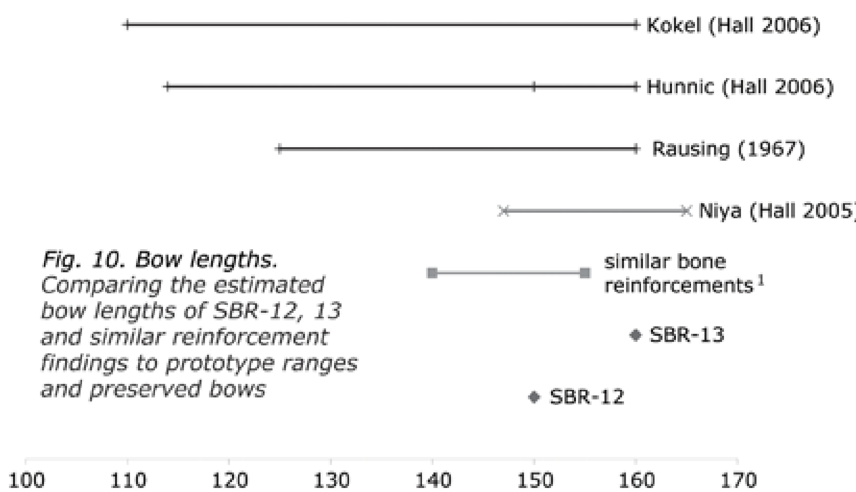


Fig. 10. Bow lengths. Comparing the estimated bow lengths of SBR-12, 13 and similar reinforcement findings to prototype ranges and preserved bows

Fig. 9. SBR-13: In situ positions of the upper end-plates.

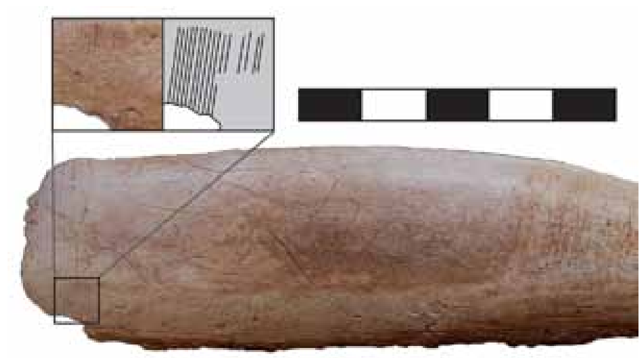


Fig. 11 (right). SBR-12 central side piece with polished outside and hatching on the side and at one end. Tool impressions can be seen at the thinning end (detail).

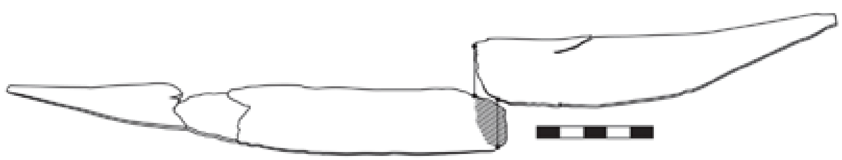


Fig. 12 (above right). Composite construction of a SBR-12 side plate.

Fig. 13. SBR-12 endplate tip with U-shaped string incision.

Both bows, though not unusually long for their type, are the upper length range compared to similar findings [Fig. 10].

A description of the bow plates

Common features. The inside of the plates is completely hatched and roughened to facilitate gluing to the wooden core; the outsides are partly hatched, and otherwise highly polished [Fig. 11]. In the case of double central side plates the outer surface of the inner plate pair was roughened accordingly as well. In addition to the strongly incised hatching marks, much finer imprints could be discerned on the surface of some of the plates. The very thin, parallel lines resemble imprints made by pliers or a file [Fig. 11 above; Fig. 14 below].

Some of the plates were not made of a single bone piece but of two to three overlapping pieces, thinning out to match (composite plate construction; Fig. 12).

Fig. 14 (below). SBR-16 endplate with string furrow and tool markings.

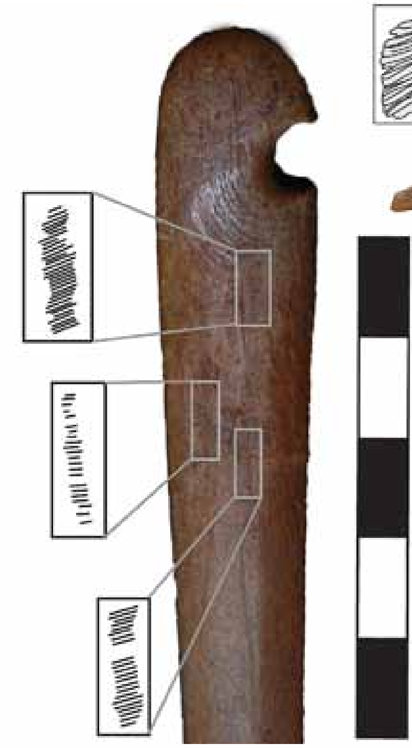
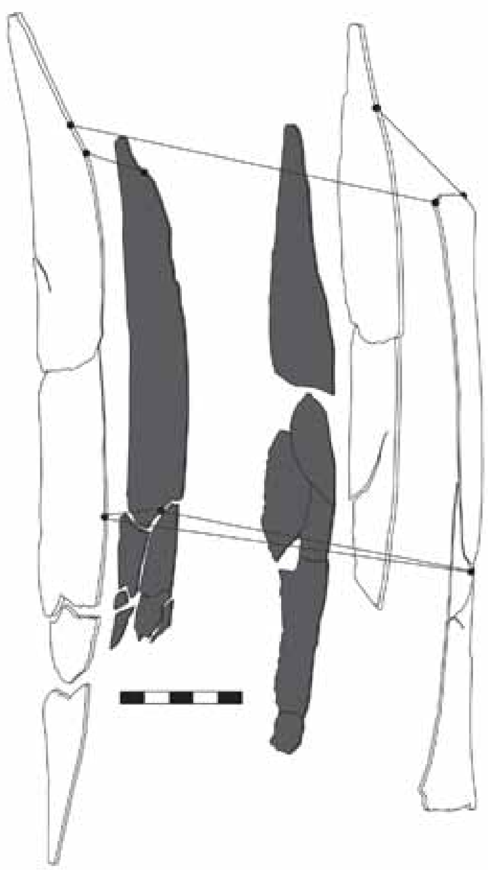


Fig. 15 (above). SBR-13 handle laminations featuring parallel incised lines on the edge and vertical hatching on the central belly piece.

Fig. 16 (below). SBR-12. Handle construction of five plates.



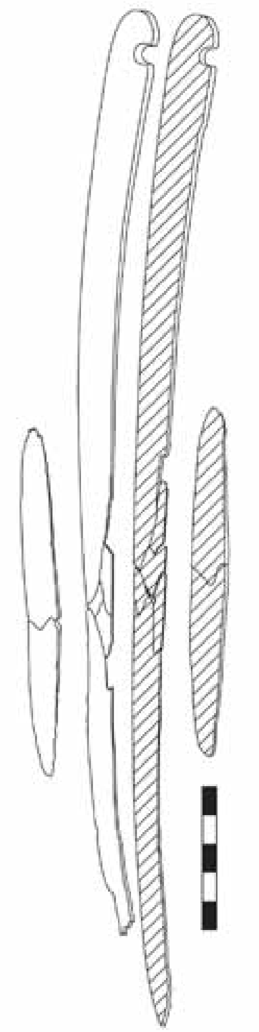
• The endplates are narrow, slightly to markedly curving laths, featuring rounded notch ends with U-shaped incisions for the string 0.8–1.2 cm from the end [Fig. 13, previous page]. They taper towards the lower part and have a plano-convex section. The backside was diagonally hatched and roughened. Some specimens exhibit a furrow near the notch, probably worn by the bow string [Fig. 14; Fig. 18 below].

• The handle consists of segment-shaped central side laminations and a slightly hourglass-shaped central belly lamination [Fig. 15]. The cross-section of the central laminations is convex with slight flattening at the ends (more marked in the belly application). There are shaping marks on the edges of the central side laminations (parallel incised lines, probably for gluing as well), and visible roughening (horizontal hatching) of the surface for lashing of both ends. The central belly lamination shows outside hatching only on the ends where they start flaring out from the body.

SBR-12. This bow featured at least nine bone plates: two pairs of endplates, two pairs of central sides and one central belly lamination.

• Endplates. The lower end lamination pair was highly fragmented, but one of them could be reconstructed, giving a total length of 31.5 cm. One fragment of the other lamination shows thinning, indicating a composite plate construction. The upper endplate pair was about as long as the lower pair and exhibits a string furrow.

• The handle consisted of two plates on each side, placed on top of each other and the belly piece [Fig. 16]. The central belly plate and outer central sides were made of two pieces each; the most complete central side had a length of 38.0 cm. The inner central side plates were in a more fragmented state, with considerable loss at the ends. They too exhibited shaped edges and lashing marks.



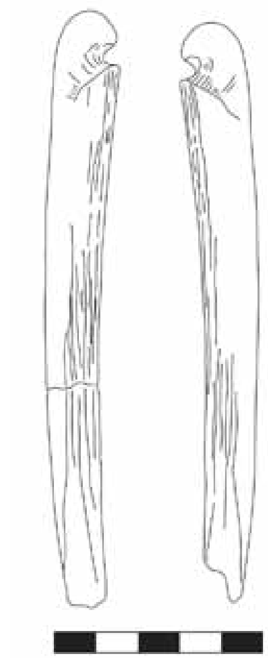


Fig. 17 (left). SBR-13 upper bone laths. Composite endplate construction with a main and a strengthening piece.

Fig. 18 (above). String marks on lower endplates of SBR-13.

Fig. 19. In situ position of SBR-13 handle plates. The central belly piece has fallen off and lies in front of the cluster. *Photo copyright © 2009 Mongol-American Khovd Archaeology Project.*

SBR-13.

- Endplates. The upper endplates of SBR-13 are each made of a main piece, thinning out in the middle (from 0.41 and 0.49 down to 0.11 and 0.19 cm respectively), to be strengthened by a second smaller, oval plate [Fig. 17]. The lower endplate pair was found in fragments, with parts missing from the mid-section. Presumably due to the loss, it is shorter than the upper pair (38 cm). The two main pieces both show string furrows [Fig. 18]. Some fragments show marks of thinning; both plates seem to have been strengthened with additional plates.
- The handle [Fig. 19] consisted of a central belly piece and several central side fragments constituting two central side plates. Reconstruction of the central side pieces indicates a handle length of slightly more than 35 cm. The surface is very aged; marks of use or crafting can only be seen at the edges. In addition to those central side plate fragments, three (fragmented) bone pieces, which by their shape can belong to neither of the mentioned plates, were found within the handle cluster, suggesting there had been additional reinforcement to the handle.

SBR-16. Due to looting, its plates were found in a random position.

- The endplate pair found north of the coffin had a length of 38 cm, the other pair being shorter (34 cm). Three of the four plates were without significant losses and exhibited a string furrow, the longer pair showing parallel cutting marks and dark staining.
- The handle remains consist of one central belly lamination and at least two central side laminations, one of which was thinning at both ends. This piece could match two other plate pieces (also showing thinning at their ends) for a segmented plate construction [Fig. 20]. There is another central side fragment present, as well as one similar to the end of a central belly lamination. A third fragment features a roughly circular perforation and horizontal cutting marks. Those pieces and especially the last cannot definitely be attributed to this bow, or any bow at all.

Fig. 20. SBR-16. Composite side plate construction of three pieces.

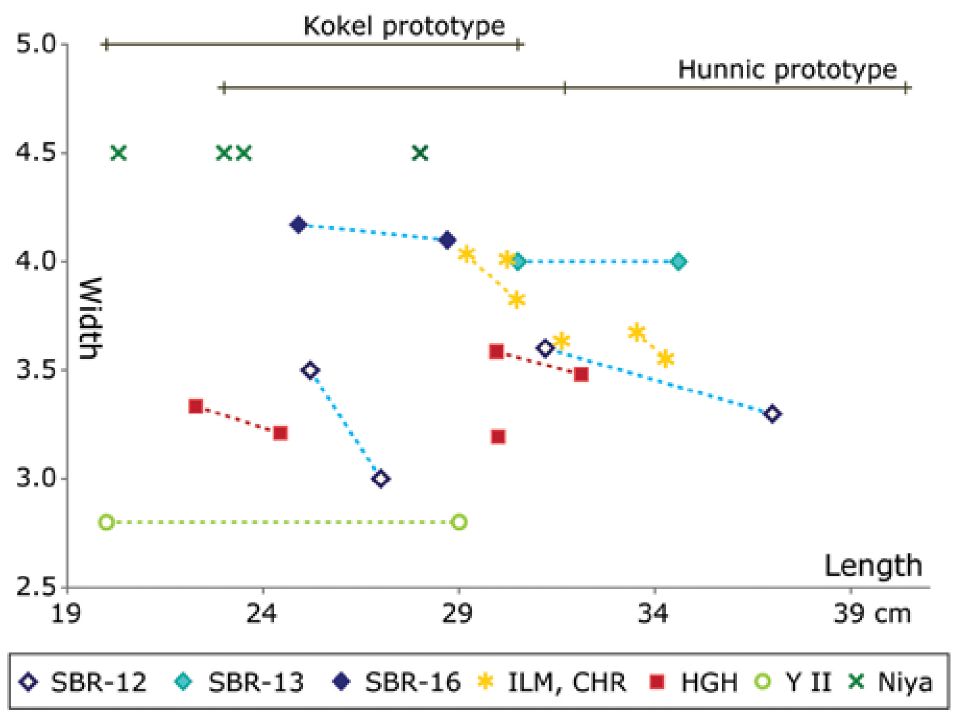


Fig. 21. Central side width-length ratios.

Connected dots indicate plates belonging to one set. Comparing the SBR-side plates shows handle length to be comparable to the "Hunnic" prototype while being longer than in the Kokel prototype (plates lie in range due to loss) and the findings of Y II and Niya.

For more information on the samples see Konovalov 1976 (ILM and CHR), Khudyakov and Tseveendorj 1990 (HGH), Gorbunov and Tishkin 2006 (Y II), and Hall 2005 (Niya). The Niya sample only recorded length measurements, like the prototypes (Hall 2006), they can not be compared to the other data points in width.

Comparisons. Compared to the range of lengths for bow-plates of this type (Hall 2006) the central side pieces of SBR-12 and 13 cluster around the average, while SBR-16 belongs to the lower range [Fig. 21]. The endplates of SBR-12 lie in the center of their range while SBR-13 and 16 are situated in the upper range [Fig. 22]. Interestingly, though of a greater overall length and with longer endplates, bow SBR-13 has a shorter handle than that in SBR-12 [Figs. 21, 23]. Another difference between the SBR bows and the prototype drawn up by Hall is the nearly symmetric design of the formers' endplates. A variation of his prototype is the Kokel design (Hall 2006), which though symmetric, differs from the SBR bows in having rather short side plates (only SBR-16 and the inner central sides

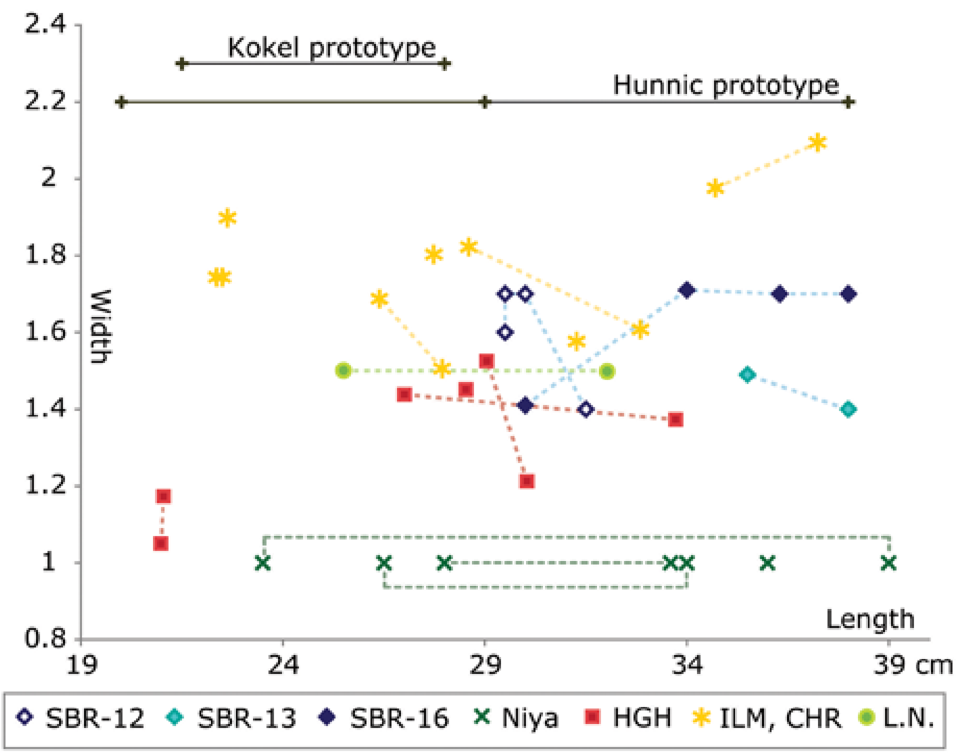
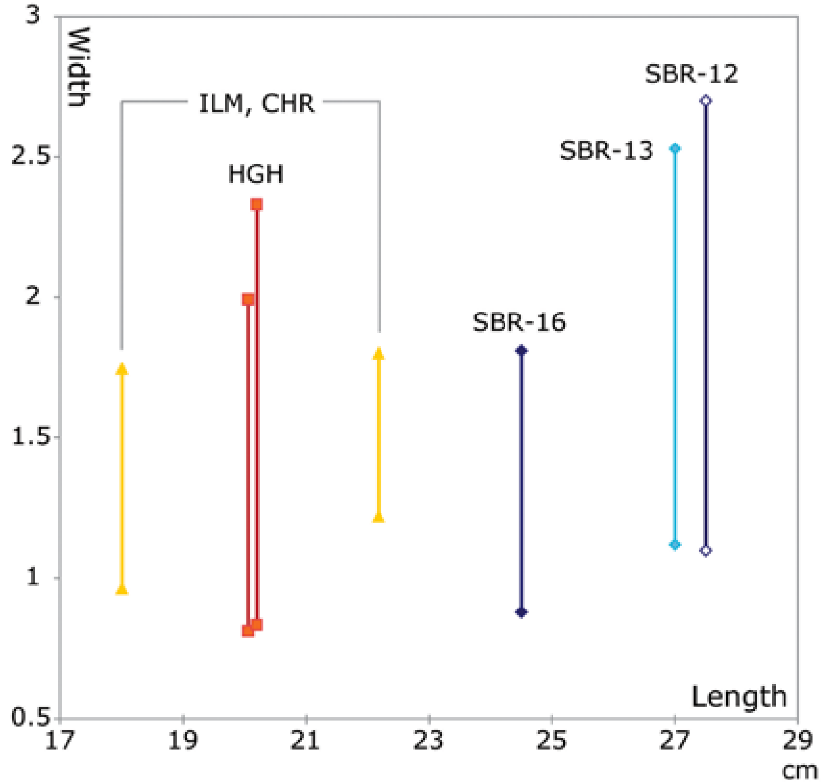


Fig. 22. Endplate width-length ratios.

Connected dots indicate plates belonging to one set. SBR-endplates are in the same range as those of ILM, CHR, Niya and the "Hunnic" prototype and far longer than in Kokel bows. Increase of endplate length amplifies their leverage-effect. Reference samples see Fig.21 and Bergmann 1939 (L.N.). Niya plates and prototypes are only valid for length comparisons.

Fig. 23. Central belly width-length ratios. Connected dots represent the amount of tapering in one specimen. Wider tapering indicates a wider limb compared to the handle (smaller value represents handle width at its center, while the greater value reflects the width of the handle limb transition). SBR central belly pieces are longer than compared pieces of HGH, ILM and CHR (references see Fig. 21). They also taper more strongly than ILM and CHR specimens.*



of SBR-12, which lack a fair amount of material, lie in the range). Bows found at Niya (Hall 2005) likewise have rather short side plates compared to those of SBR. However, the endplates of the SBR bows, while in the same range as those of Niya, are far longer than in Kokel bows.

Analysis of the SBR bows

Construction and materials

The construction technology employed in building the SBR composite bows was widespread throughout Eurasia. Evidence for its use is provided also by its appearance in a passage in the *Zhou li* which gives detailed instructions about which materials to use (what kind of wood, horn, glue, sinew), how to discern their quality, when to obtain them, how to work them and what effect they will have on the bow. "The bow stave is to give the bow distance. The horn is to give it speed. The sinew is to give it penetration. The glue is to bind it." (*Zhou li*, 6A1, Selby 2000, p. 91). This shows the internal construction to be uniform, though it also denotes a difference in finishing: "The silk is to give it strength. The lacquer is to proof it against moisture." Silk and lacquer could be substituted by available materials like sinew, leather or birch bark in other areas. The remains of some form of binding are preserved on the outer central side pieces of SBR-12, as can be seen in Fig. 24, which also indicates no full covering was used.

The SBR bows used bone and wood and some form of adhesive substance, even though the latter's presence cannot be proven. Even though horn is not often preserved, it has been documented for roughly contemporary bow findings of the Tarim basin (Miran — Hall and Farrell 2008; Niya — Hall 2005; Qum-Darya — Bergmann 1939; Subexi — Wieczorek and Lind 2007; Yingpan - Ma and Yue 1998; Hall 2005). Being readily available in a society of pastoralists it was probably used here too.

Fig. 24. SBR-12 central side plate with lashing remains. This residual band was matching the one on the other outer central side piece, indicating that it indeed was a form of wrapping around the handle.

The variation in the use of handle laminations (a possible absence of the central belly plate, and in our case the varying number of central sides) reflects general modification of bow design, the adoption of specific techniques to correct material weaknesses and the availability of materials (Khudiakov and Tseveendorzh 1990). Such considerations would explain the composite plate constructions we found and the different construction of Yingpan bow no. M30, which seems to feature short, slightly curved intermediate plates attached to the limbs in between handle and endplates (Ma and Yue 1998, Hall 2005). Similar intermediate plates are also mentioned by Tseveendorj (1989), but without detail on material or position. In the case of disturbed graves, we cannot always be certain whether there were stiffening rods, and it is important to recognize that laminations may be manufactured of horn or hardwood (an example is the Yrzi bow; Brown 1937), which survive rarely.

It is not possible to deduce whether the central side plates in SBR-12 were doubled to alter the strength of the bow or to smooth out material problems occurring with the inner central side plates. Nor can we be certain whether this construction of four central sides was planned initially or the result of later alteration. In either event, when the outer central sides were attached, the inner plates were manipulated (thinned and roughened) accordingly.

Shape

Bows having the same composition may vary considerably in shape and thus be difficult to reconstruct only on the basis of their remains (Brown 1937). For an approximation of true shape, it is critically important to know the positions of the stiffening rods. The shape of those reinforcements by themselves does allow some limited inference: In SBR-12 and 13 the endplates are gently curving over their whole length (moderate recurve), while in SBR-16 the upper parts of the laths are near to straight. The bases of the latter show a more marked curvature [Fig. 25], suggesting that the recurve must have been somewhat more pronounced than in the case of the other two bows.

The compressed semicircular shape of the central plates and the positions of the bows in graves SBR-12 and 13 — lying on the back, endplates and handle pieces about level — suggests that there was neither a strong reflex of the limbs, nor a definite set-back of the handle. In their unstrung state the bows resumed a gently curved, near-to-straight shape similar to the "Qum Darya bow" (Rausing 1967). This too would differentiate them from the bow type mentioned in the *Zhou li*, which when drawn back "[…] comes round in a circle, and when unstrung, […] does not lose this basic form [but] settles back into a circle" (6A15, Selby 2000, p.96). Were this the case with the bows found in SBR, the positioning of the plates would have to have been different.

Getting to the point — Choosing an arrow for that bow

The special mechanical requirements which must be addressed in constructing an arrow relate to the three stages of its flight: internal ballistics (acceleration by the bowstring), external ballistics (flight) and ballistics of impact (Kooi 1983, Sudhues 2004). For the arrow to be effective requires careful synchronization between its characteristics and that of the bow for the first stage of arrow flight.

To understand this, consider briefly what happens when the archer releases his shot. The bowstring moves forward in the median plane of the bow, yet the arrow is given a lateral impulse by the side of the bow, which makes the arrow curve around the handle.[3] It then continues to oscillate from side to side in flight. Where the characteristics of the bow and arrow have been properly matched, the tail of the arrow when released bends away from the bow

Fig. 25. SBR-16 endplate pair. The plates are near to straight with only the base curving. It exhibits diagonal backside hatching.

and never touches it, thus not deflecting the flight or damaging the arrow (Klopsteg 1943).

The rigidity and mass of the arrow are important characteristics which affect its flight and effectiveness. The stiffness, or *spine,* of the shaft depends on the properties of the wood and its overall dimensions — the shorter the shaft, the stiffer the arrow. If the arrow is too stiff (too much spine), it cannot bend correctly and deviates from the line of aim; if it is too soft the rear end might strike the handle (again causing deflection) and the flexing will continue too long, which takes energy out of the flight or even damages the shaft. As a more powerful bow induces greater flexion as well as more stress, the shaft of its arrow must be stiffer and thicker (Kooi and Sparenberg 1997); otherwise it is liable not to fly true or to break either on impact or even directly after releasing (Klopsteg 1943, Kooi 1983, Sudhues 2004).

Arrow mass is an important factor in matching bow and arrow: Energy transfer from the bow to the arrow is more effective using a heavy arrow than using a light one. A lighter arrow has the advantage of increased velocity with consequent flat trajectory, which is advantageous for precise aiming and enhances flight distance. However, due to the smaller energy input, the energy available both for overcoming air resistance and penetration on impact is reduced (Klopsteg 1943). To offset this, an archer may use a stronger bow, which consequently requires the use of a more massive shaft. Using a stronger bow to increase arrow velocity is limited by the fact that the exertion required to hold at full draw may be incompatible with accuracy. Arrow mass as well as mass distribution are affected most of all by the weight of the head. Increased mass at the tip introduces greater stress and effectively lowers the spine (Sudhues 2004). A heavier head therefore requires a more massive shaft.

Flight properties are affected by many other factors: Arrow length and diameter determine surface area and resistance (Rheingans 2001). Tapering/barreling the shaft may improve range. Fletching too has a significant impact: Longer vanes stabilize the arrow more quickly, yet they decrease its range by increasing air drag and lead to cross-wind susceptibility. Offset positioning of the vanes (rifling) and the natural properties of a feather (natural warp and rougher underside) make the arrow rotate in flight, thus smoothing out unbalances and compensating for some lack of straightness or symmetry (angular momentum stabilization) (Klopsteg 1943, Bergman et al. 1988, Sudhues 2004, Haywood 2006).

On impact the remaining energy is transferred to the target and the arrow is stopped. While the arrowhead is slowed down immediately, the shaft is moving forward a bit longer. Thus, it is compressed and bends (if excessively, damaging the shaft) with a shaking, jouncing motion. This induces a sideways, cutting movement if the arrow is equipped with a sharp blade. The spin of the arrow is greatly dampened on impact but can be partly retained depending on the target, leading to a spiral arrow channel. (Sudhues 2004). Certain arrowhead designs use this rotation to maximize tissue damage.

The arrow finds at Shombuuziin-belchir

Complete arrows are rarely found, since the wood may be preserved only in a special environment. Thus the heads are frequently the only surviving pieces. While this was largely true in the case in our findings, in SBR-12 considerable shaft remains were conserved by their proximity to the iron. The original arrow length can be deduced from our finding the bottom of a quiver (an oval wooden disk) about 75 cm from the cluster of arrowheads [Fig. 26]. Thus the arrows were placed in the quiver tips up. Arrow length is in most cases matched to the drawing length of the bow, so that the arrow can be drawn to the point, though exceptions exist (see Paterson 1984). As the drawing length is related to arm length this conveys some information on the archer.

All but one arrowhead had been manufactured of iron. Like the bone bow pieces they constitute such a small sample they can not be taken

Fig. 26. In situ position of the oval wooden disk.

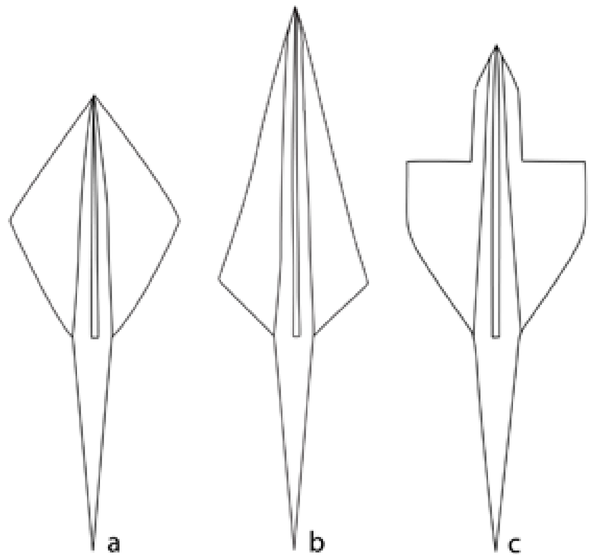


Fig. 27. Iron arrowhead types present at SBR. a) triangular blade shape with the widest point at the center, b) triangular blade shape with widest point near the base, c) tapering blade shape.

as representative. Yet they do give an idea of the variation in arrowheads. Most of them were strongly corroded, some additionally fragmented, which makes it difficult and in some instances impossible to determine their original shape. Thus, all measurements but especially those of thickness, have to be treated with care.

All the iron arrowheads which were in a state to be judged are tanged, trilobate arrowheads.[4] Other than the number of cutting edges and hafting method, several characteristics can be employed to differentiate arrowheads: the shape of the blade, including the curvature of the cutting edge and the presence or absence of barbs, the way the wings join with the tang/socket and the position of the widest point (or *point mésial*) of the blade (Mouton 1990, Delrue 2007).

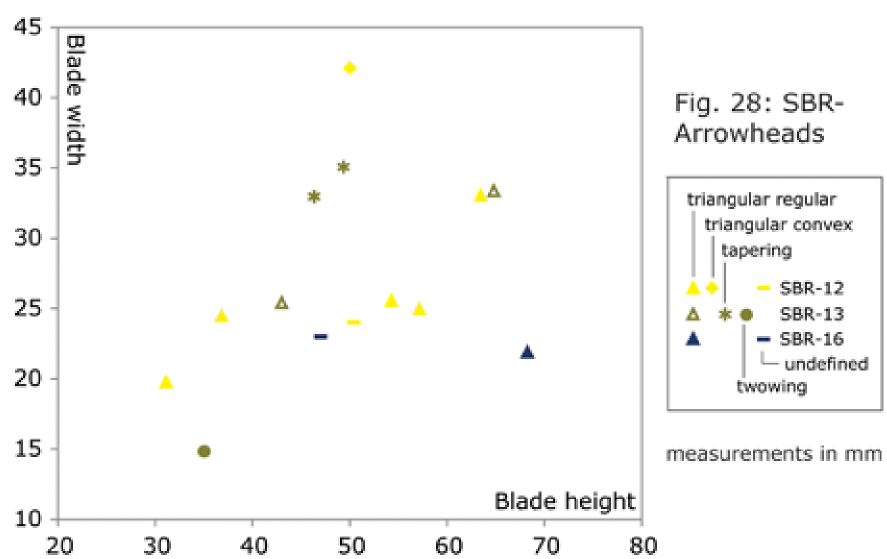


Fig. 28. Width-length ratios in SBR-arrowheads. Varieties in size can be seen in each set. Blade width is mostly proportional to blade length, only one triangular concave piece being exceptionally wide (12a) and one triangular specimen (16) being relatively long.

In the present sample the wings broaden from the tip either to a point after which they recede to form the base (Type A, triangular, Fig. 27a, b) or broaden slightly to a certain width only, subsequently running roughly parallel to the longitudinal axis to jut out sharply and reach the maximal width after which they recede into the base (Type B, tapering, Fig. 27c). The blades range from 3.1 to 6.8 cm in length and 1.4 to 4.2 cm in width [Fig. 28].

Most of the present arrowheads are of a triangular blade shape with a rather straight cutting edge and the widest part of the blade at its base or close to it (distance to the base is less than 1/3 of the arrowhead length). One other specimen (12a, Fig. 29), being more leaf-shaped, features a triangular blade shape with convex cutting edges and the widest part of the blade closer to its center (slightly more than 1/3). It also exhibits the widest blade compared to its length (5/6 as wide as it is long). The only distinct piece of SBR-16 meanwhile featured the longest blade [Fig. 30]. Most pieces of triangular shape were 3/5 to 4/5 as wide as they were long.

Only one definite example of a tapering blade shape was found, where the widest part of the blade is at its center (13c, Fig. 31). This often (though not always) seems to be the case with arrowheads of this shape (for comparison, see Fig. 34 below; Konovalov 1976). This specimen as well as one of either tapering or triangular-concave blade shape (13b) are nearly 3/4 as wide as they are long.

Aside from the iron pieces, a single bone arrowhead was found in SBR-13 [Fig. 32]. It is an exceptional piece not only because of its material but also because of the hafting method used (equipped with a socket) and its shape (oval section, slim body with relatively parallel sides, the

Fig. 29 (right). SBR-12 arrowheads. Lashing marks can be seen on c, d and e. Corrosion can be seen through cracks in the shafts.

Fig. 30 (below). SBR-16 arrowhead. While being the longest arrowhead from the SBR-sample it is rather slim.

Fig. 31 (lower right). SBR-13 arrowheads. Lashing marks can be seen on a and d.

Fig. 32. SBR-13 bone arrowhead. The outer socket diameter is oval while the inner is slightly squared.

Fig. 33. SBR-12 shaft remains with preserved lashing.

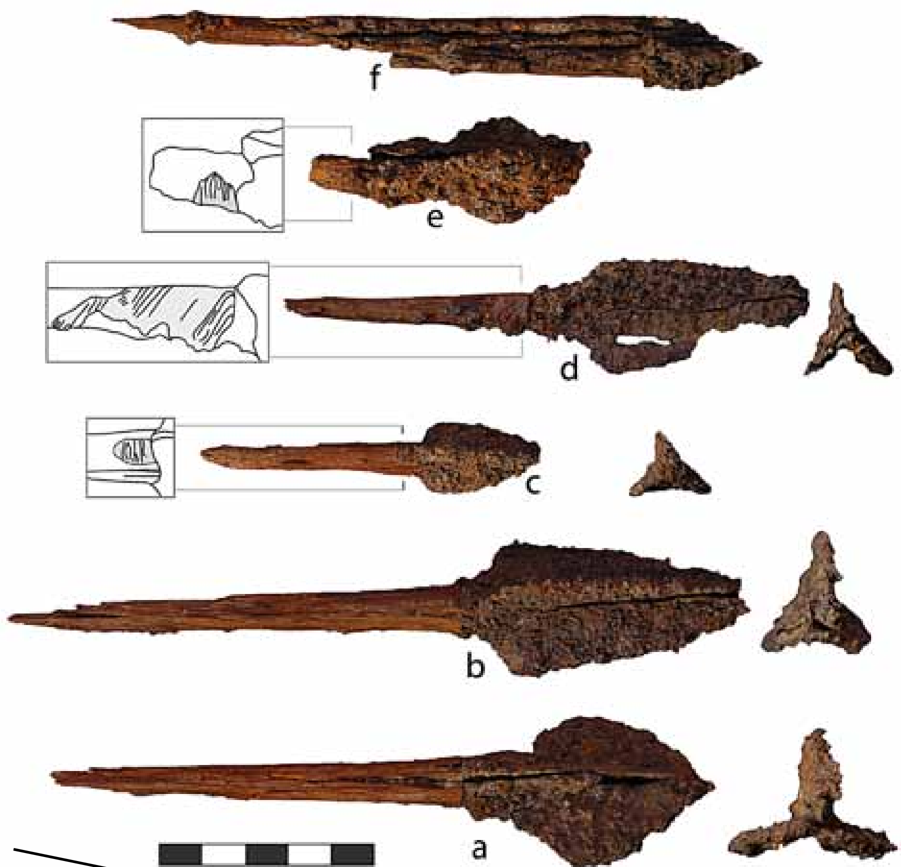
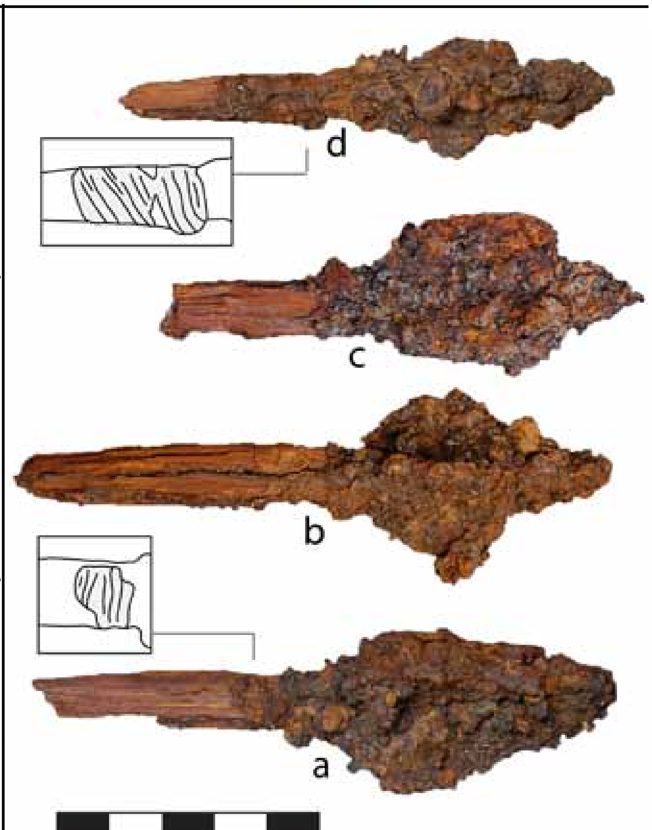


Fig. 32 (above) and Fig. 33 (below).



blades smoothly joining the socket). It is the slimmest arrowhead from this sample.

In four instances in SBR-13, and three instances in SBR-12 lashing marks have been preserved on the shaft fragments [Figs. 33, 29, 31, previous page]; the minimal extent of the lashing ranged from 2.3 to 4.0 cm measured from the base of the arrowhead. The minimum length of the tang varied from 3.8 to 9.3 cm.

Comparisons. Most of the pieces in the sample published by Konovalov (1976) have different width-length ratios, similar to the ones encountered within this sample. Yet the widest part of the blade is more uniformly positioned: There is a distinct cluster of arrowheads where the widest part of the blade was situated at a 3/5 position (with reference to total length) [Fig. 34]. Most of the SBR-specimens lay in range with arrowheads found at DRS, CHR and ILM (Konovalov 1976) though the latter also features arrowheads of greater size [Fig. 35]. 12a and 16 deviate from the more common width-length ratio and lie well outside the reference ranges efficient for hunting, which suggests use on larger and/or less vulnerable targets. Those reference numbers (Browne 1940; Paterson 1984) regarding the effectiveness of arrowhead sizes for hunting can be used as approximations only, since detailed information on the size, distance and nature of the game is lacking. It is evident that the arrows of the SBR-sample exceed the bronze findings of the Lop Nor region (Bergmann 1939) in size. The same holds true for the socketed trilobate arrowheads found at DRS. It is notable that the tapering design is produced with greater dimensions than the triangular design in the observed samples.[5]

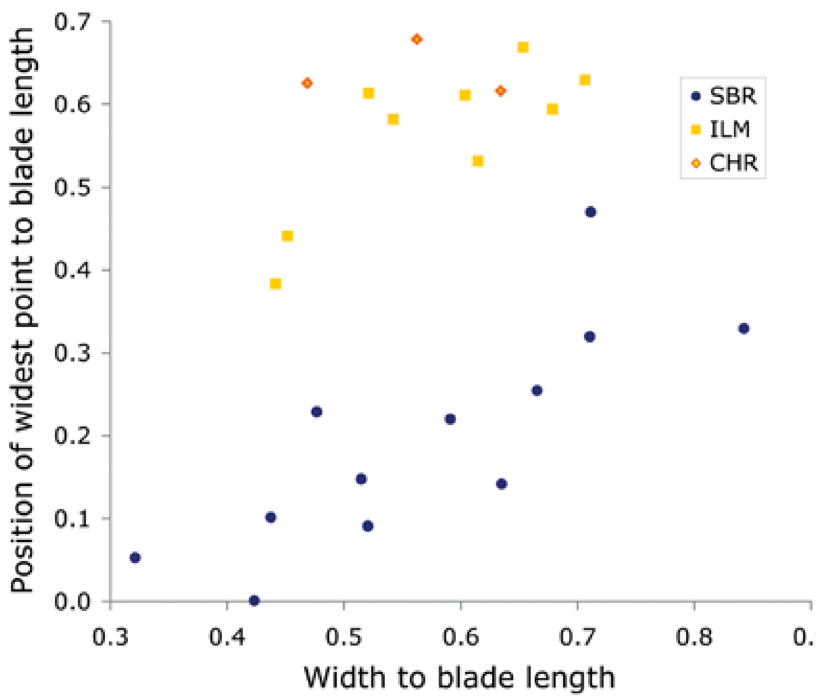


Fig. 34. Comparing the relative position of the widest point to width-length ratios.

This shows the ratios to be proportional in the SBR sample (featuring mostly triangular blade shapes). The tapered ILM and CHR arrowheads (Konovalov 1976) vary in their width-length ratio but are much more consistent in their position of the widest point. This position is much nearer at tip than in SBR arrowheads.

Arrow Material

There are undoubtedly several kinds of wood suitable for arrow-shaft manufacture; the actual use largely depends on availability, i.e. the local environment of the toolmaker. It is crucial for flight accuracy that the arrow be straight throughout its length. If whole branches or saplings are used, as opposed to shafts split from larger pieces of wood, they can be straightened by heating and bending but retain a tendency to warp. Reeds have the advantage being light and rigid, and though they naturally grow rather straight they sometimes have to be heat-treated as well. Being coreless they are suitable to take arrowheads with a long tang or a foreshaft. Strength, toughness and a high stiffness-density ratio are qualities valued in materials from which to manufacture shafts. The durability of shafts can be increased by nock reinforcement and splicing (Klopsteg 1943, Bergman et. al. 1988).

For fletching, feathers of both tail and wing can be used, and again there is a large variety of birds whose feathers would be suitable (Bergman et. al. 1988). Feathers of birds of prey are documented by Rudenko (1969), who also mentions the use birch (*Betula* sp.) for the shaft, which is in use for bow construction in today's Mongolia (Bergman and McEwen 1997). A footnote of the *Han shu* (94B: 3810) which also indicates the use of locally growing wood for making bows observes the use of falcon feathers for fletching in this area.

Various materials have been used for arrowheads; it is not uncommon to find both bone and iron ones coexisting (Rudenko 1969). For use on unarmored targets, bone arrowheads have proven to be as effective as their counterparts of stone or metal (Ikäheimo et al. 2004, Luik 2006). Loosening from the shaft and being smashed or stuck in bones occurs less often with bone arrowheads due to their elasticity. That makes them suitable for recovery and reuse. Using a socket with a bone arrowhead is less common; usually the natural properties of a bone suggest the use of a clamp. Firmly encasing the shaft in a socket provides more constructional stability.

Fig. 35. The widest efficiency point stated is meant for use on "heavy game". The smaller socketed DRS type is a trilobate arrowhead equipped with a socket and cutouts above the blade-socket transition. Most of the SBR pieces lie well in range with the other samples. The bronze specimens of the Lop Nor region are overall smaller than iron specimens; one L.N. specimen matches the bone two-wing of SBR in size and shape. Twowings feature only two wings, the materials in these samples include iron and bone. Sample references see Gorbunov and Tishkin 2006 (Y II), Konovalov 1976 (ILM, CHR, DRS) and Bergmann 1939 (L.N.). Reference ranges efficient for hunting see Browne 1940, Paterson 1984, p.32).

Arrowhead design

Compared to two-winged arrowheads, the trilobate types such as the iron specimens we found are usually more accurate, the blades acting as aerodynamic surfaces stabilizing arrow flight. Instead of two cutting edges the trilobate arrowhead features three, and having the same mass it is more robust, smaller and thus less easily affected by crosswind. Yet due to its more complicated shape the manufacture requires a large toolset and a greater extent of technical expertise and precision (Delrue 2007).

The design of an arrowhead must consider characteristics such as accuracy, range, penetration force and durability. Optimization of one characteristic can diminish the performance of another; so generally some balance and compromise is sought (Klopsteg 1943, Cheshier 2006). An important consideration is the target and the toughness of its surface.

The penetration force of an arrow (i.e. kinetic energy stored in the arrow at moment of impact) is governed by the speed and weight of the arrow (Browne 1940, Cheshier and Kelly 2006). Of those, speed is dependent on the velocity of the cast, the head-on resistance and the weight of the arrow. Increased weight

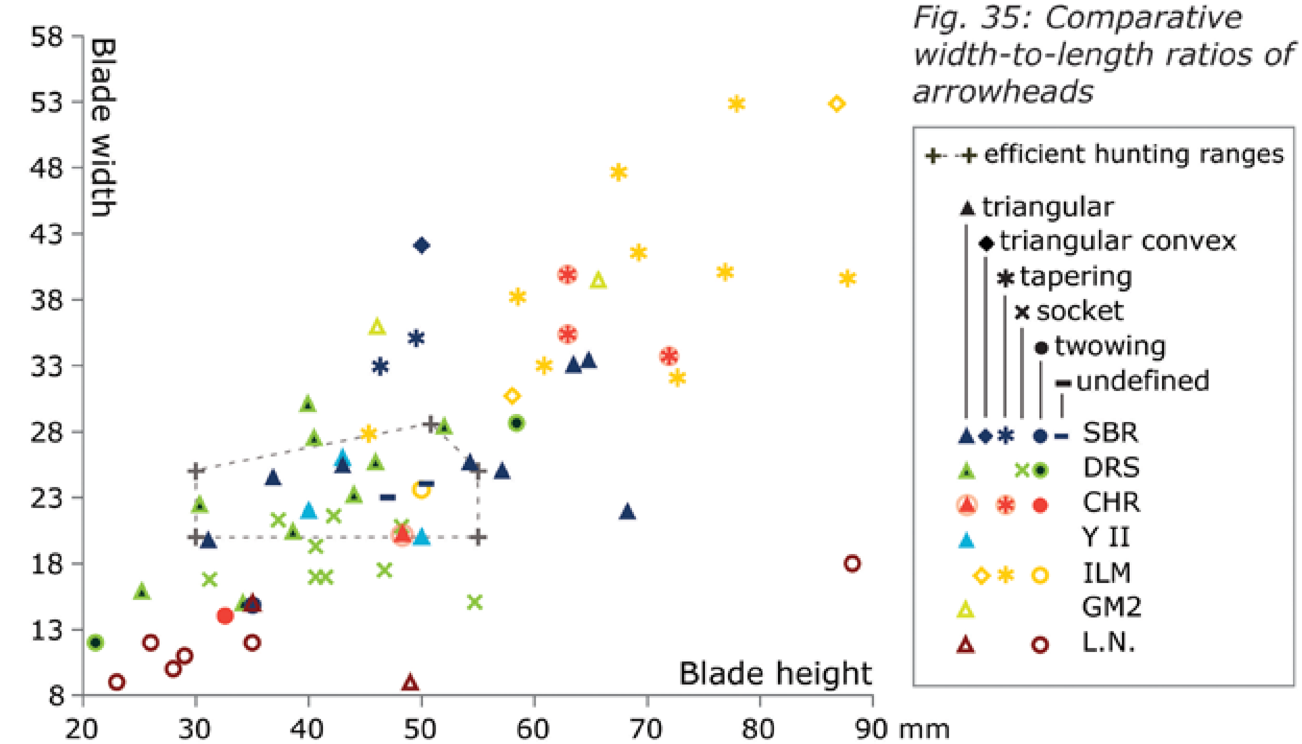


Fig. 35: Comparative width-to-length ratios of arrowheads

reduces the velocity of the arrow, leading to a shorter range but increased impact force. Both impact force and width of the point must be adjusted to the target (size, distance, vulnerability), so that a minimal penetration depth is reached and a hemorrhage sufficient to incapacitate or kill is produced. Penetration of the projectile into the target thus depends on the impact force, the vulnerability of the target and the shape of the head. If this head-on area is narrow, the projectile enters with greater ease, having greater penetrating power. If it is wide it creates a wider wound that bleeds more easily (Cheshier and Kelly 2006).

Application and usage of the tool set

In retrospect the role of this tool set of bows and arrows can be defined only by the possible range of usage, its construction purpose remaining open to speculation. With regard to the bows, the use for warfare *and* hunting is without doubt possible and suggested by the variety of arrowheads interred with them.[6] The overall heaviness of the found arrowheads suggests a heavy impact force. This matches the shaft remains, which consequently have to be rather thick (ranges 0.8–1.5 cm). A strong bow equipped with a heavy arrow has a relatively strong penetration force at a moderate distance.

In both hunting and warfare the best case scenario is to kill the target immediately. In hunting this might be effected by creating a large, severely bleeding wound (i.e. using an arrowhead with a wide cutting edge) that incapacitates the animal quickly (Holmberg 1994). A hunting arrow should also be durable to remain undamaged and to be reused. In warfare where the target is armored, the need of a greater penetration force restricts the use of wide blades. A shot might not be lethal by itself. If extraction was difficult however, it would extend the wound and lead to infection and sepsis (which in time will kill). Equipping an arrowhead with barbs is one way to achieve this.[7] Blades that jut out like the ones of 12a enlarge the wound; yet the penetration will probably not be as deep at the same distance as with slimmer specimens like 12b.

Even though those differences exist, they are insignificant as long as the development of body armor does not require an impact force greater than that needed for the largest, toughest skinned game that is hunted. As long as an arrowhead will suffice for use on both, there is no way to determine whether its use involved military conflict — it remains a multi-purpose tool. Even in the context of hunting, the variation is great, different sizes and shapes being used according to the game. Large game also requires deeper penetration and thus increased penetration force than does small game (Luik 2006).

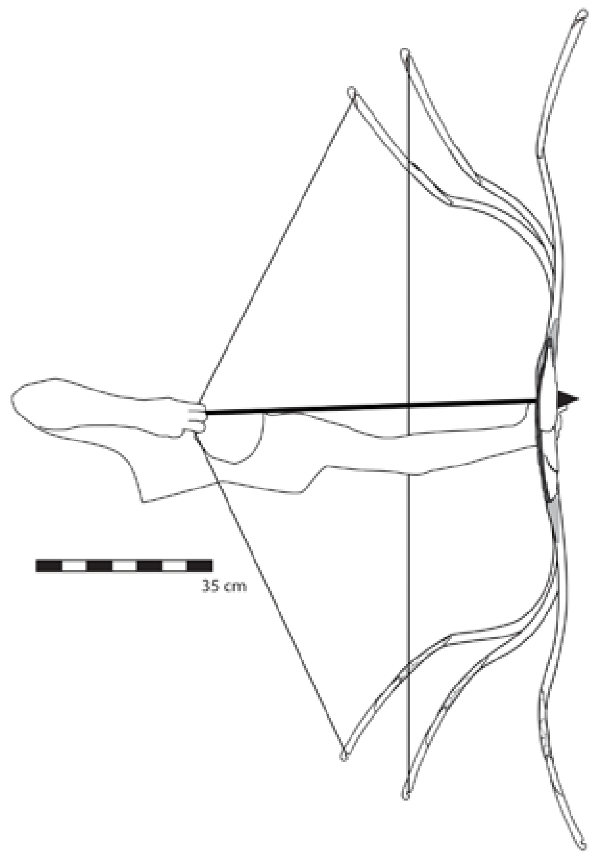


Fig. 36. Reconstruction of the approximate shape of the SBR-12 bow in unstrung, braced and drawn condition. The arrow is about 75 cm long.

Significance of the findings

The bow findings at Shombuuziin-belchir contribute to an improved understanding of the construction and development of this bow type and its variations in Inner Asia [Fig. 36]. Finding a complete set of arrowheads interred with one individual confirms the fact that different sizes and shapes, as well as different materials, might be used contemporaneously. The requirements for manufacturing the equipment and the marks on the bow plates provide some insights into the available technology in the Xiongnu period. This includes competence in obtaining and processing very different materials, all of which have several preconditions which must have been fulfilled to manufacture this tool set (e.g. the boiling of glue). The findings also reflect manufacturing equipment by different marks left by it on the bone rods and identify the tool set as one specialized in construction to contextual demands while retaining the function of a multi-purpose tool.

About the Author

Michaela R. Reisinger received her degree in General Biology in 2007. Currently she is a Mag. student in the Physical Anthropology Department at the University of Vienna. Her masters project focuses on archaeological approaches to human behaviour. She is concurrently working on her B.A. in Sinology at the Department of East Asian studies. She may be contacted at <michaelareisinger@gmx.at>.

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Notes

1. Among the sites are Il'movaya pad' in Transbaikalia (Mongait 1961), Qum-Darya in the Tarim Basin (Bergmann 1939) and Yaloman II in the Altai Mountains (Gorbunov et al. 2006). For additional evidence see Rudenko 1969, Sosnovskii 1946 and Davydova 1985.

2. The terms *upper* and *lower* relate to the positions of the bows relative to the interred person, which may or may not also correspond to the upper and lower bow limb as defined by function.

3. An exception, of course, is center-shot bows, not under consideration here, which have cut out handles to allow the arrow to pass in the vertical median plane of the bow.

For additional explanations, see especially Klopsteg 1943, Kooi 1983, Paterson 1984, Kooi and Sparenberg 1997, and Sudhues 2004. Among the technical details, note the following: Important contributions to lateral deflection come from the release of the string over finger/thumb causing the nock of the arrow to be moved sideways (Kooi and Sparenberg 1997), movement of the bow hand, motion of the string not being exactly in the median plane and by angular acceleration of the arrow out of the median plane (increase of the angle between median plane and arrow during release, related to handle width). Thus "the arrow has to be treated like a flexible beam, pushed at the rear end and hampered with respect to its sideways movement at the grip" (Kooi 1983, p. 15).

The angle between arrow and median plane of the bow is 1.5° for the fully drawn bow (6° for one braced but not drawn); if the arrow could not flex it would deviate about 4.5° from the line of aim the moment it leaves the string (Kooi 1983). That this does not occur (the so-called "archer's paradox") is due to the fact that the oscillation started by the arrow takes place about the line of aim.

4. This shape is defined by Delrue (2007, p. 239) as "an arrowhead that has three wings or blades that are usually placed at equal angles (i.e., *c*a. 120°) around the imaginary longitudinal axis extending from the centre of the socket or tang."

5. After writing the present article, I learned of an arrowhead typology proposed by Khudiakov (1985) (my thanks to Prof. Daniel Waugh). His typology differentiates arrowheads on the basis of the used material, hafting method, cross section and blade shape. Of the trilobate group three types are comparable to the samples analyzed in this article: Type 1 — a triangular blade shape with widest point at the center or above, type 5 — triangular blade shape with the widest point near the base, and type 2 — a different variation of a tapering blade shape that widens from the tip to a point after which it recedes towards the longitudinal axis before jutting out perpendicular to reach the maximal width. According to Khudiakov, all three types had made their appearance by the 2nd century BCE, and while Type 1 and 5 remained in use until the 8th and 10th century CE, the tapering form disappeared in the 1st century CE. Newer findings of triangular forms with the widest point at the base extend the proposed size range for this type both in length and width. This is also the case with tapering blade shapes, which seem to retain a similar width to length ratio even though produced with a greater variation in size. Comparable instances of triangular blade shapes with the widest point at the center or above are considerably wider.

6. Of course it is possible that a person used more than one bow, and even more than one type, depending on the application (distance, target, training purposes). Yet even if more than one bow was in use but only one was interred with the archer, the arrows would probably be such as could be and were used with that bow. Evidence for the contemporary use of both the simple and the composite bow in Inner Asia has been collected by Rausing (1967).

7. While an arrowhead that detaches from the shaft easily or a shaft splintering on impact could complicate the extraction and inhibit reuse, it is also true that an arrow that is designed to fail is prone to fail before it creates enough damage or any damage at all. Thus, constructions that concentrate on failure are probably rare (personal communication with Bede Dwyer).