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ORIGINAL PAPER

The Secondary Products Revolution, Horse-Riding, and Mounted Warfare

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Abstract Andrew Sherratt included horseback riding and chariotry in his conception of the Secondary Products Revolution, but his emphasis on the role of horses in warfare and on a Near Eastern influence in the earliest episode of horse domestication is viewed here as as an important shortcoming in his understanding of the process of horse domestication. Current evidence indicates that horses were domesticated in the steppes of Kazakhstan and Russia, certainly by 3500 BC and possibly by 4500 BC. Tribal raiding on horseback could be almost that old, but organized cavalry appeared only after 1000 BC. Riding might initially have been more important for increasing the productivity and efficiency of sheep and cattle pastoralism in the western Eurasian steppes. The earliest (so far) direct evidence for riding consists of pathologies on the teeth and jaw associated with bitting, found at Botai and Kozhai 1. Recent developments and debates in the study of bit-related pathologies are reviewed and the reliability of bit wear as a diagnostic indicator of riding and driving is defended.

Keywords Horse domestication · Bit wear · Horses in warfare

Introduction: The Secondary Products Revolution and the Horse

Like V. Gordon Childe (1957), who had imposed a new coherence on European prehistory two generations earlier, Andrew Sherratt perceived a driving force that he thought might explain the wave of change that swept across Europe between about 3500 and 2500 BC (Sherratt 1983, 1997a). Childe had seen metallurgy as the prime mover. For Sherratt it was the Secondary Products Revolution (SPR). In the 1970s zoologists had realized that the earliest domesticated economic animals—sheep and goats, cattle, and pigs—were butchered young for two millennia or more after domestication, so were used almost solely for

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meat. Sherratt recognized that this conclusion carried an important implication: that secondary animal products—wool, dairy foods, traction power, and transport—were discovered later, and that this discovery should have had profound effects on human economies across the Old World. The SPR increased both the economic value and the political importance of livestock. The ensuing expansion of animal herding literally cleared the European landscape of its unbroken forests while establishing the economic foundation for growing disparities in wealth and social rank.

Thus the stage was set for his second revolution, in which emerging hierarchical Bronze Age political structures were reorganized around a set of imported elite drinking rituals (Sherratt 1985, 1987, 1991, 1997b, c). According to Sherratt, both the SPR and the drinking revolution (or 'driving and drinking', in a convenient shorthand he used in a 1985 lecture) emanated from the civilizations of the Near East but became distinctively European as they diffused across Europe (Sherratt 2003, p. 236). Elements of the SPR were criticized almost immediately (Chapman 1983), but modified versions of his economic model, pared down to the diffusion of wagons, wool sheep, and beer/mead-feasting, quickly replaced migrations by Indo-European horse-riders as a leading explanation for the far-reaching changes that appeared with the Yamnaya, late Baden, Globular Amphorae, Corded Ware, and Bell Beaker cultures across Europe between 3500 and 2500 BC (Piggott 1983, p. 61; Bökönyi 1987; Maran 2001; Cunliffe 2008, pp. 157–159, 169, 180).

Sherratt described how the domestication of the horse was articulated with the SPR in three publications (1983, 1997a, 2003). Although his views changed, he consistently saw the principal significance of horses in military activities, associated first (about 2000 BC) with chariots and later (after 800 BC) with cavalry. He accepted a date in the fourth millennium BC for the earliest domestication of the horse, but like many he felt that horses were not used in war that early (Sherratt 2003, p. 242). The earliest widespread evidence for the use of horses in warfare coincided with the invention of the metal bit and the chariot about 2000 BC (Littauer and Crouwel 2001), leading Sherratt to speculate that fourth-millennium horses might have been too small to ride comfortably, or that bits made of rope or leather might have been inadequate to control them in battle (Sherratt1997a, p. 217). Doubts about the size of steppe wild horses and the adequacy of organic bits were repeated by an influential group of archaeologists (Renfrew 2002, pp. 5–6; Kuzmina 2003, p. 213; Drews 2004, p. 20). They interpreted the spread of domesticated horses across Europe in the late fourth millennium BC as a trade in prestige symbols used as pack animals, and perhaps ridden with some difficulty, but whose potential as mounts in war remained unrealized (Sherratt 2003, p. 242).

Sherratt connected the domestication of the horse with the domestication of the camel and the ass, all of which, he suggested, were responses to the need for heavy-burden transport during the long-distance trade boom caused by the Uruk expansion, 3800–3100 BC (Rothman 2001). He placed the domestication of the horse in the arid valley of the lower Kura River in what is now eastern Georgia and Azerbaijan, where local wild horses could have been domesticated to serve as pack animals for Uruk metal-traders who, in this scenario, brought pack-trains of domesticated asses to the copper mines of the Caucasus (Sherratt 2003, p. 240). The Asian pack-ass could have been the model for the domesticated pack-horse, a concept Sherratt borrowed from Uerpmann (1990). Donkey-riding could have inspired the earliest horse-riding, and that could explain why, in Near Eastern art, many early horse-riders are shown sitting on the rear of the horse, a seat suitable for a donkey but uncomfortable and ineffective on a horse (Drews 2004, pp. 40–55; Littauer and Crouwel 1979). This early (ineffective) style of horse-riding could have been a product of the initial context of domestication on the northern frontier of the Uruk expansion.

We question most of this scenario, including its emphasis on warfare, its interpretation of horse sizes and capacities, and its location for horse domestication. On the subject of horse sizes, the Eneolithic (5200–3300 BC) horses of the Eurasian steppes were big enough to ride into battle. More than 70% of the Late Eneolithic horses at Dereivka, Ukraine (4200–3700 BC) and Botai, Kazakhstan (3600–3100 BC) stood 136–144 cm at the withers (shoulders), or about 13–14 hands high (Benecke and von den Dreisch 2003; Bibikova 1970). The horses ridden into battle by Roman cavalrymen commonly measured 120–150 cm at the withers (Hyland 1990, p. 68), and those of the American Plains Indians stood about 130–140 cm, or ‘a little under 14 hands’ (Ewers 1955, p. 33). Eneolithic steppe horses were about the same size as Roman and American Indian cavalry horses. On the question of rope bits, the authors conducted a riding experiment in which two expert riders rode never-bitted horses with rope and leather bits (Brown and Anthony 1998; Anthony et al. 2006). Our riders had ‘no problem’ controlling their horses. The American Plains Indians, regarded in the nineteenth century as among the finest light cavalry in the world, used a ‘war bridle’ that was just a rope looped around the lower jaw (Ewers 1955, p. 76). History and experiment both show that horses the same size as Eneolithic steppe horses can be ridden effectively at a gallop, even in warfare, with a rope bit.

The notion that the seat used in early horseback riding was ineffective (Drews 2004, pp. 40–55; Sherratt 1997a, p. 217) is derived from Near Eastern art. Horses were not native to the Near East and remained rare there until after about 1800 BC. The native Near Eastern equids were onagers (*Equus hemionus*), behaviorally resistant to domestication, distributed in the steppes of Central Asia, Iran, Syria and Iraq; and asses (*Equus asinus*), amenable to domestication, and distributed in the south, in Egypt and the southern Levant. Asses were domesticated as pack animals in Egypt perhaps around 4000 BC and were used for transport throughout the Near East by 3500 BC, long before horses appeared there (Rossel et al. 2008). Asses have low withers and a high, broad rump. If a rider sits forward on an ass and the animal lowers its head the rider can easily fall forward. Donkey-riders wishing to retain their dignity therefore usually sit back on the rump and hang on to a belly band. Horses are built differently: they have high withers, so horse-riders sit forward, just behind the withers, a seat that also permits the rider to grasp the mane. Bronze Age Near Eastern artistic images that show a rider on an animal that clearly is a horse, but sitting on the rump and grasping a belly band, probably indicate only that some Near Eastern artists before 1000 BC were more familiar with donkey-riding than horse-riding. Other images correctly placed horse-riders in a forward seat, even among the earliest depictions of horse-riding, Akkadian and Ur III images dated 2300–1900 BC (Owen 1991; Oates 2003). Steppe horse-riders would not have used a seat suited only to the body of a donkey, an animal most of them had never seen.

Near Eastern art is an odd lens through which to examine the domestication of an animal that did not live in the Near East. Questions about the domestication of the horse are answered best in the region where wild horses were most important in human economies prior to their domestication—where humans relied on wild horse hunting for the majority of their meat diet. That region was the western Eurasian steppes, from the Dnieper to the Ural Rivers. Many settlements here dated well before 3500 BC contain more than 40% horse bones (Fig. 1) (Anthony 2007, p. 198). The earlier settlements are interpreted as the camps of pedestrian wild horse hunters, but the later sites, after about 4500 BC, likely contain the bones of domesticated horses.

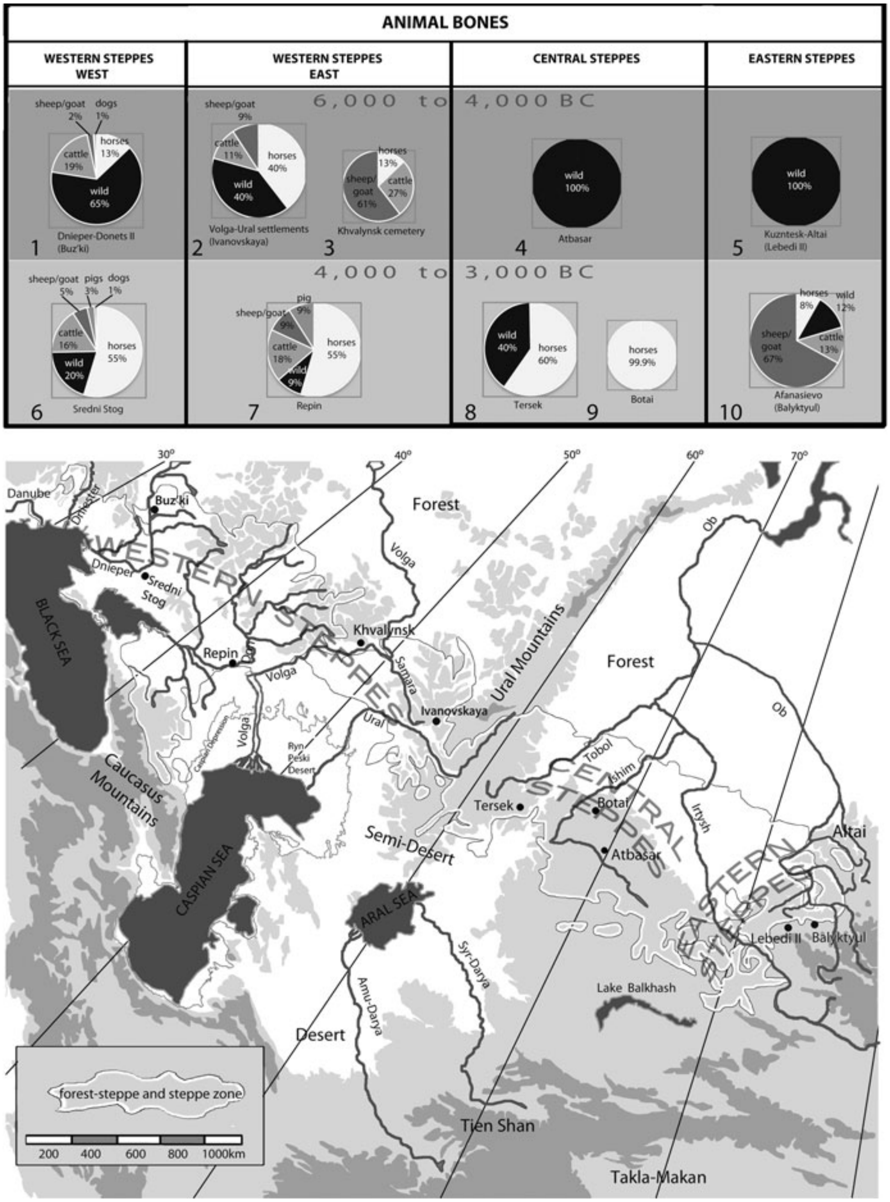

Fig. 1 Pie charts show the percentages of different types of animal remains found in archaeological sites across the western steppes (east and west) and the central and eastern steppes during the fifth and sixth millennia compared to the fourth millennium BC. Names under the pie charts indicate culture groups. Mapped sites are selected from the general region of the culture groups represented in the pie charts

What is a Domesticated Horse?

The standard zoological indicators of domestication have proven uncertain guides to the identification of the earliest domesticated horses. The preferred zoological indicator would be a change in the size or proportions of horse leg bones (Fig. 2). But the wild horses of the mid-Holocene varied in size, with the horses of the central Eurasian steppes in Kazakhstan (Fig. 2:7–9) larger than those of the western Eurasian steppes in Ukraine (Fig. 2:6), and all the horses of the steppes significantly larger than the pony-sized wild horses of central and western Europe (Fig. 2:1–3). Natural shifts in size linked to inter-regional movements might be confused with size changes linked to domestication. Different scholars who have studied the horse bone collections from sites of the Botai and Tersek cultures in northern Kazakhstan have come to different conclusions about their domesticated status (Benecke and von den Dreisch 2003, p. 76), but a recent metric study of leg-bone robusticity by Outram at Botai (Outram et al. 2009, p. 1333) has produced a clear metric separation of the Botai horses from wild populations, grouping them instead with domesticated horses. This is the earliest metric change in horse bone proportions indicating domestication.

Another zoological indicator is an increase in variation. The increase in variation that began about 2500 BC, indicated in Fig. 2:10 by the white bar for the horses of Csepel-Háros in eastern Hungary, continued thereafter (Fig. 2:11–13). This is often taken as an indicator that domestication began at about 2500 BC (Benecke and von den Dreisch 2003, pp. 77–78). But increased variation is sensitive to sample size, and in any case the increased variation in horse stature that began about 2500 BC might reflect the development of specific breeds for specific purposes, not the initial phase of domestication.

Recent studies of the genetics of horse coat colors (Ludwig et al. 2009) suggest a burst of genetic variation in coat color during the third millennium BC, more or less correlated

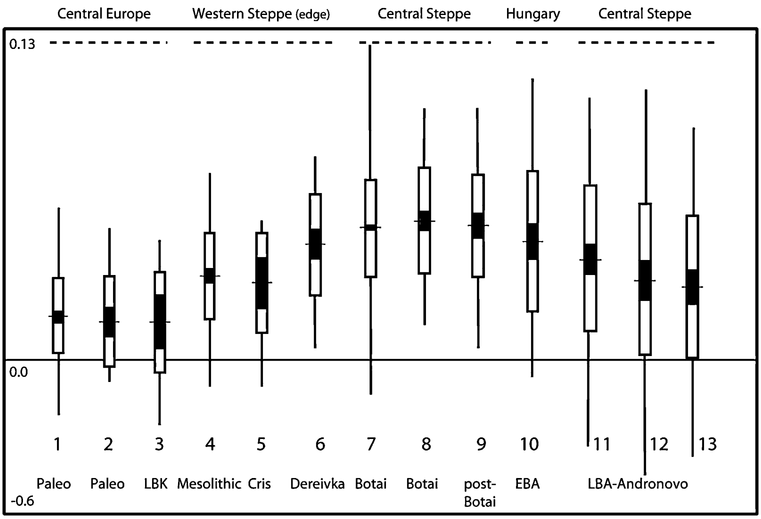

Fig. 2 Measurements indicating the robusticity of horse populations at archaeological sites across different environments and through time. Horses at sites 7–13 are accepted as domesticated. The maximum and minimum are indicated by the *thin line*, the standard deviation (the best comparison) by the *bar*, the mean by the *horizontal line*, and the double standard error of the mean by the *black bar*. *Sites 1* (Kniegrotte) and *2* (Bärenkeller) are Late Glacial sites in Germany; *3* represents Bandkeramik Neolithic sites in central Germany; *4* (Mirnoe) is a Mesolithic steppe site in Ukraine; *5* (Sakarovka) is a Criş Neolithic forest-steppe site in Moldova; *6* (Derievka) is an Eneolithic site in steppe Ukraine; *7* (Botai) and 8 (Krasni Yar) are Eneolithic Botai-culture sites in northern Kazakhstan; 9 (Sergeivka) is a post-Botai site in northern Kazakhstan; 10 (Csepel-Háros) is a Bell Beaker/EBA site in Hungary; *11* (Novonikolskoe I) and *12* (Petrovka II) are late MBA/LBA Petrovka culture sites in northern Kazakhstan; and *13* (Atasu) is an Andronovo LBA site in central Kazakhstan. After Benecke and von den Dreisch (2003, figures 6.7 and 6.8 combined). Slightly revised from Anthony (2007, figure 10.3)

with the increase in variation in stature. While these increases in variation in color and size certainly are significant, they are likely to identify an advanced stage in horse domestication rather than its beginning. The Ludwig et al. study did not include any horse bones from the western or central Eurasian steppes between the Dniester River in western Ukraine and the Irtysh in western Siberia. This is the critical region where Botai and Dereivka, sites central to the study of horse domestication, were located. Until we get DNA from horse bones in this region the range of horse color variation across the Eurasian steppe zone will remain unknown.

Another zoological indicator is a change in the ages of the animals chosen for slaughter, or mortality profiles, which should differ between hunted and domesticated populations. But mortality profiles are only indirect indicators of butchering patterns. They are affected by deposition and curation (particularly with decades-old collections like the Dereivka faunal assemblage), and are open to different interpretations. Levine (1990, 1999) documented quite different mortality profiles for the horses at Dereivka and Botai (Fig. 3a)—two Eneolithic steppe sites critical for the understanding of early horse domestication—but interpreted both as wild populations. The Dereivka profile (Fig. 3b) was almost identical to that of the Roman military fort of Kesteren on the Rhine, where the horses certainly were domesticated. Even the method for estimating age, the basic datum for constructing

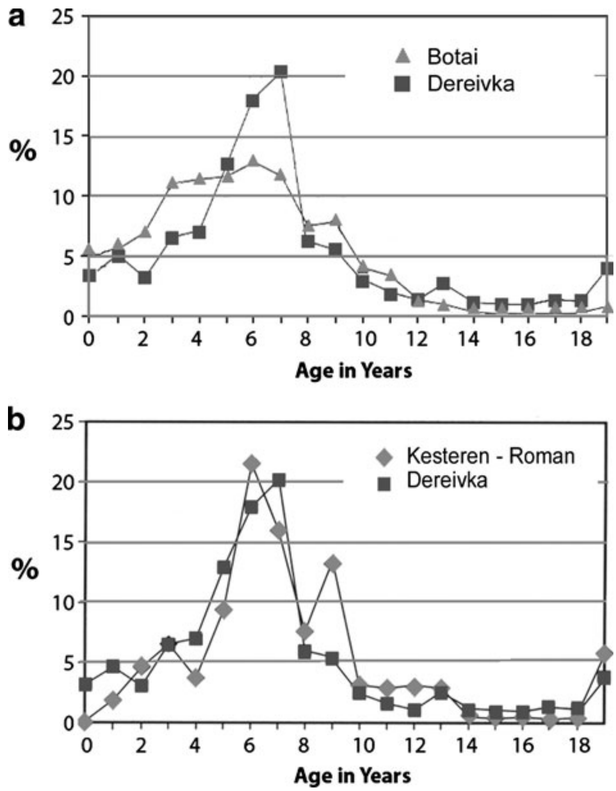

Fig. 3 Age at death mortality profiles for horses at three sites: Eneolithic Botai, Eneolithic Dereivka, and Roman Kesteren on the Rhine frontier. Levine interpreted the Botai and Dereivka patterns as indicating hunting, while the Kesteren profile resulted from deaths among domesticated military horses. After Levine (1999, figures 2.21 & 2.28)

mortality profiles, is itself cruder than is usually realized. Age at death is often derived from the crown height of horse molar teeth (Levine 1982), yet we found that the crown heights of the right and left P_2s of a single horse could vary by as much as 5 mm (Brown and Anthony 1998, p. 339), a figure that would usually be interpreted as indicating 2 or 3 years difference in age. Age categories derived from crown heights should be discussed as age ranges, not specific years, and this is not always clear.

Ultimately, the search for morphological changes is motivated by the assumption that humans should have controlled the breeding and feeding of the earliest domesticated horses, and this would have affected their stature and morphology. This assumption does not necessarily apply to the earliest stage of horse management.

The Earliest Domesticated Horses

Horses probably were domesticated as an inexpensive source of winter meat by people who already possessed herds of domesticated cattle and sheep. The bones of domesticated cattle and sheep first appeared in sites in the western steppes, between the Dnieper and Ural Rivers, north of the Black and Caspian Seas, about 5300–4800 BC (Fig. 1:1–3) (calibrated dates, see Anthony 2007, chapter 9). Radiocarbon dates from a few sites on the lower Don and middle Volga might suggest that cattle and sheep herding began even earlier than this, perhaps as early as 6000 BC, although this remains to be proven. Wild horses remained the most important source of meat in many sites in the western steppes, as they had been before cattle and sheep were accepted.

Horses can feed themselves through the winter, while cattle and sheep often cannot. Cattle and sheep push snow aside with their noses, while horses use their hard hooves. If the snow becomes crusted with ice the noses of cattle and sheep will become raw and bloody, and they will stand and starve in a field where there is ample winter forage just beneath their hooves. Horses have the instinct to break through ice and paw frozen snow away with their hooves, so do not need water or fodder. In blizzards, range cattle have survived by following herds of mustangs to graze in the areas they opened (Ryden 1978, pp. 160–162).

Early Eneolithic herders had to supply cattle and sheep winter fodder and break the ice on their water—unless horses did it for them. A shift to colder climatic conditions or even a particularly cold series of winters could have made cattle and sheep herders who hunted wild horses think seriously about taming horses for use as an easy source of winter meat and pasture clearance for cattle and sheep (Anthony 2007, pp. 200–201, 227). Just such a cold period, the Piora Oscillation, occurred across Europe about 4200–3800 BC (Leuschner et al. 2002; Perry and Hsu 2000). But the benefit could be realized only if the tamed horses were free-ranging. Penning and foddering would defeat the purpose. Tame horses could have been kept near the settlement by restraining them with rope or leather hobbles (leg restraints) that permitted a walk but not a run. A long trailing rope would make them easy to catch. Horses kept this way might show very little morphological difference from their wild cousins.

Non-Metric Indicators of Domestication

Given the uncertainties attending the standard zoological methods, the identification of the earliest domesticated horses must rely on additional indicators. Four other kinds of indicators are frequently cited.

Horses as Symbols in Early Eneolithic Graves

The earliest indicator is in the domain of ritual symbolism. Parts of butchered horses, usually a lower leg but sometimes also the head, were placed in human graves in three Early Eneolithic sites in the steppes between the Volga and Ural Rivers dated by radiocarbon to about 5200–4700 BC. These calibrated dates are principally on human bone, and Early Eneolithic human bones in the Dnieper and Volga steppes typically contained high levels of ^{15}N, possibly a sign of a high-fish diet that could introduce a reservoir effect, making ^{14}C dates too old by 300–600 years. The true calendar date for these sites is probably around 4700–4200 BC, five centuries more recent than the standard calibrated dates that I use in this article. In a recent book for a general audience (Anthony 2007) I used a reservoir-corrected chronology because it was easier to understand and probably more correct, but here I return to a standard calibrated-date chronology because there is no accepted way to correct for reservoir effects, and peers might prefer a non-speculative chronology that they can adjust themselves as they prefer.

The three sites with horse ritual symbolism (Fig. 4) are the settlement and cemetery of Varfolomievka, east of the lower Volga River, the large cemetery of Khvalynsk, west of the middle Volga, and the smaller Syezzheye (S'yezzhe) cemetery on the middle Samara River east of the middle Volga. In the same region, the settlement middens at Ivanovskaya on the upper Samara and Varfolomievka provide good profiles of the role of horses in the daily diet (Anthony 2007, pp. 182–192). The people at these sites acquired a surprising quantity of copper ornaments, the first metals in the Volga–Ural region, through long-distance trade with the far-off Balkans about 5200–5000 BC (or probably 4700–4500 BC, reservoir corrected, which fits much better with the dates for copper in the Balkans). Like their forager ancestors, they still consumed more horse meat than beef or mutton in their daily diet (Figs. 1, 2). In funeral feasts, in contrast, domesticated cattle and sheep were far more important than horses (Fig. 1:3). Domesticated cattle and sheep might have first diffused across the steppes more as a new ritual currency than as daily food—but horses were included even in these newly-important funeral displays.

At Khvalynsk (Fig. 5) archaeologists led by Igor Vasiliev excavated 158 human graves dated by ten radiocarbon assays on human bone to about 5200–4700 BC (or 4700–4200 BC, reservoir corrected). Twenty-two of these graves (14%) contained the bones of animals, apparently representing funeral feasts. The bones amounted to 52 (or 70) sheep/goat, 23 cattle, and 11 horses, MNI (Petrenko 1984, p. 48; Agapov et al. 1990, tables 1 and 2; Anthony 2007, pp. 184–185; the published reports are inconsistent on the MNI for sheep/goat.) Leg and head parts were found on grave floors, in grave fill, at the edges of graves, and in 12 sacrificial deposits stained with red ochre above the graves. At least 17 sheep/goat and nine cattle were deposited at Khvalynsk in head-and-hoof rituals—the oldest example of this important custom. Head-and-hoof deposits consisted of a skull with associated lower leg bones, probably still attached to the animal's hide. In later steppe funerals the custom of placing a hide with the head and hooves still attached in or over the grave as a symbol of the god's portion was very common (Piggott 1962).

Horse phalanges occurred alone in six Khvalynsk graves (64, 131, 132, 143, 145, 157) and one sacrificial deposit (3). They were grouped with sheep/goat and cattle bones in one grave (127) and two sacrificial deposits (1 & 4). No obviously wild animals, unless the horses were wild, were included in the graves. Only four graves (100, 127, 139, and 55–57) contained multiple species (cattle and sheep, sheep and horse, cattle and horse) and two of these (100,139) also were covered by ochre-stained ritual deposits above the grave with additional sacrifices. One (55–57) also contained a polished stone mace-head, one of only

Fig. 4 Map of Early Eneolithic sites dated about 5000–4000 BC, calibrated, in the Pontic–Caspian steppes, including Khvalynsk, Varfolomievka, Ivanovskaya, and Syezzheye; and Tripolye A–B1, Cucuteni, Gumelniţa and Karanovo V–VI sites in the neighboring forest-steppe and forest zones

two mace graves. Animal sacrifices seem to have been associated with a newly created elite social role represented by funeral feasts of domesticated cattle and sheep, and perhaps domesticated horses; and by new kinds of funeral equipment displayed by elite people: stone mace heads, bird-bone flutes, unifacial flint blades, polished serpentine bracelets, multiple strands of shell beads worn as belts or girdles, boar-tusk chest pendants, and imported copper beads and rings made from Balkan ore. None of these items were worn in death during the preceding Mesolithic or ceramic (forager) Neolithic.

At the contemporary Early Eneolithic cemetery of Syezzheye (Fig. 6) two horses were sacrificed and their heads-and-hooves (two skulls, phalanges, an astragalus, and a radius) were offered in a similar ochre-stained deposit above a group of nine human graves. Carved bone images of horses and bulls were placed in the same ochre-stained deposit (Vasiliev and Matveeva 1979). Similar carved bone images of horses were found at the contemporary settlement-and-cemetery of Varfolomievka (level II), and a zoomorphic polished stone mace at Varfolomievka might portray a horse (Yudin 1998). Although the species of animal is open to interpretation, stone mace heads at Varfolomievka,

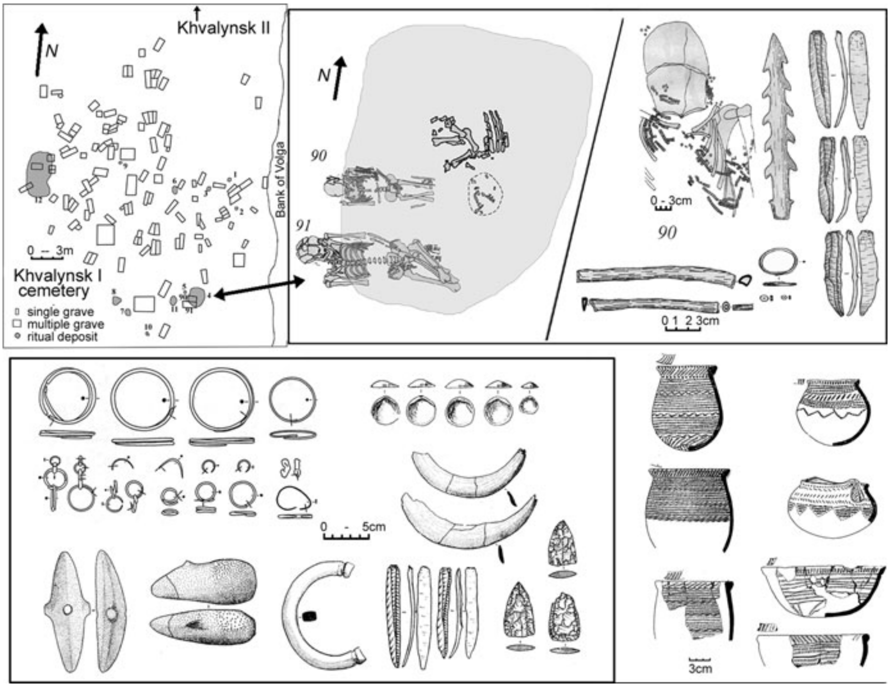

Fig. 5 The Khvalynsk I cemetery, with graves 91 (adult male) and 90 enlarged. Grave 90, an adolescent aged 10–14, had copper beads, a copper ring, a harpoon, bird-bone tubes, and flint blades. Sacrifice 4 above the grave contained bones of cattle, sheep, and horse. Pots from the graves are on the right, and on the left are selected copper ornaments, shell ornaments, boar's tusk ornaments, flint tools, a polished serpentine bracelet probably from the North Caucasus, and two polished stone mace heads. After Anthony (2007, figure 9.7)

Lebyazhinka, and other Early Eneolithic sites in the Volga–Ural steppes (Dergachev 2007) at least document the beginning of a tradition of making zoomorphic stone mace heads, contemporary with the beginning of herding economies (Fig. 7). Graves at the edge of the Varfolomievka settlement were accompanied by horse-incisor beads in ochre-stained deposits above the grave and by unspecified parts of horses.

Horses had been the principal game animal in the Late Neolithic (in the lower level III at Varfolomievka, the lower level at Ivanovskaya, and the equid-hunting site of Dzhangar) but were not given any materially denoted symbolic status in funerals or art. Horses acquired a new ritual and symbolic importance in Volga-region sites of the Early Eneolithic dated 5200–4700 BC (probably more like 4700–4200 BC), not long after the adoption of cattle and sheep herding. At Khvalynsk horses were buried in funerals with cattle, sheep, and humans. They remained the principal meat animal at the Early Eneolithic settlements of Ivanovskaya and Varfolomievka, although domesticated cattle and sheep/goat also were eaten. If they were domesticated, these were the first domesticated horses.

Horses as Symbols on Late Eneolithic Weapons of War

The next-oldest possible indicators of domestication should traditionally include 'cheek-pieces' or *psalia*. These perforated bone and antler objects from Eneolithic steppe sites

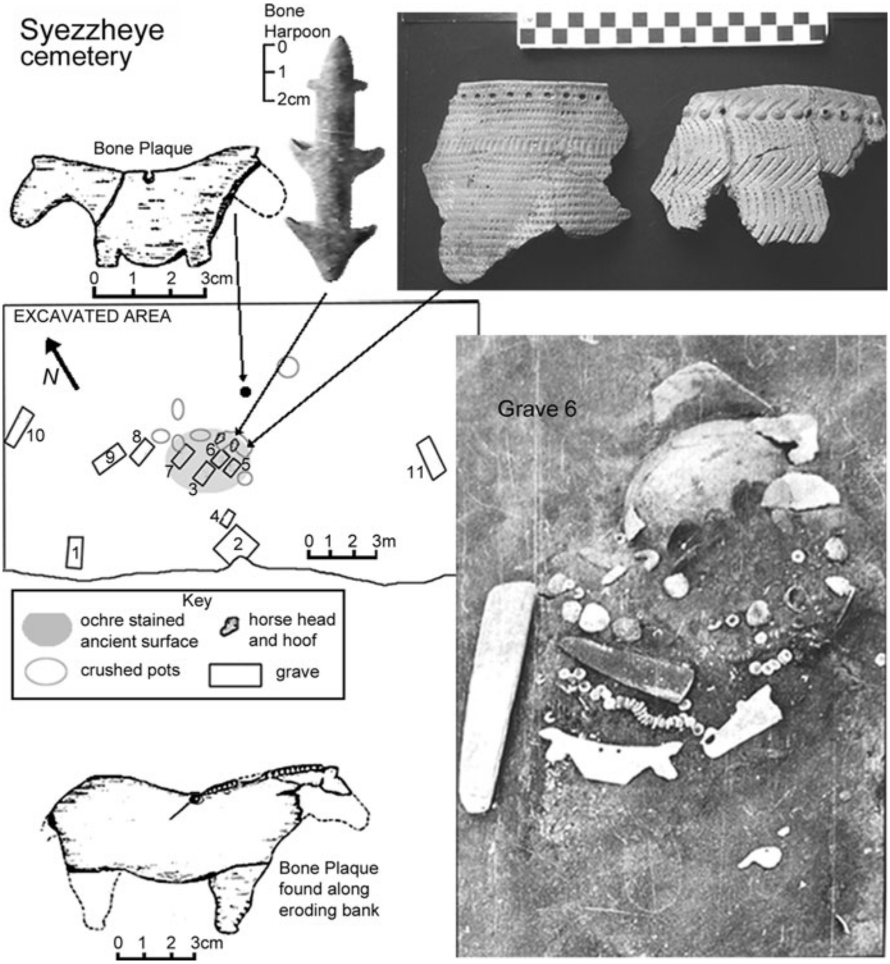

Fig. 6 The Syezzheye cemetery, with carved bone horse plaques, two horse head-and-hoof sacrifices placed in red ochre in graves, and an excavation photograph of Grave 6, a child, with a double-headed bull plaque and a duck plaque visible near a polished stone adze and axe, and shell and bone beads. After Anthony (2007, figure 9.8)

have been identified as cheekpieces for bits (Telegin 1986, pp. 82–83), but a close look reveals that none of these objects has a known function, and the find contexts do not indicate an association with horses (Dietz 1992). I will not discuss them further.

Instead the next indicator is the appearance of polished stone mace-heads, some shaped as horse heads (Fig. 7) in Late Eneolithic graves in the Dnieper-to-Ural steppes and in the lower Danube valley about 4200–3800 BC (Kotova 2008; Dergachev 2003, 2007; Anthony 2007, pp. 256–258). One of these came from the grave at Suvorovo (Alekseeva 1976), the type site for a cluster of steppe-type graves that appeared in the grasslands north of the Danube delta about 4300–4100 BC, just before 600 tell settlements of the Karanovo VI–Gumelniţa–Varna cultures were abandoned in the lower Danube valley and the Balkans. The Suvorovo-type graves represent an immigration into the lower Danube valley of people who probably came from the steppes around the lower Dnieper in Ukraine, where

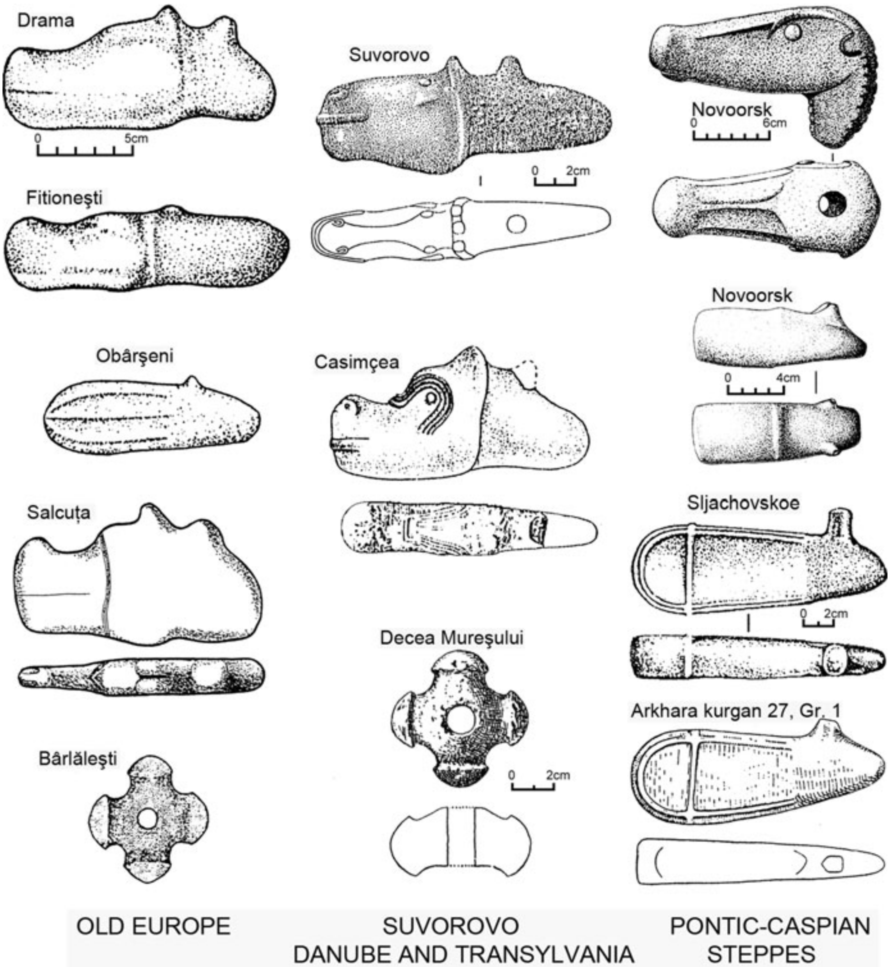

Fig. 7 Polished stone mace-heads of the 'eared' and zoomorphic types in three kinds of contexts: Old European (Tripolye B1, Salcuţa, late Gumelniţa) settlements on the left; the intrusive steppe graves of Suvorovo type in the lower Danube valley and Transylvania in the middle; and Pontic–Caspian steppe graves on the right. Compare the maces in Fig. 5. After Anthony (2007, figure 11.5)

there are similar graves containing similar artifacts and imported Balkan copper ornaments. At Giurgiuleşti, an intrusive Suvorovo-type cemetery overlooking the Danube at its confluence with the Prut in southern Moldova, one very rich steppe-type grave was covered by five sacrificed animal skulls including at least one horse (Bicbaev 2010). Polished stone zoomorphic mace-heads, ornaments made of Balkan copper, and bifacial projectile points were deposited as gifts in the Suvorovo-type graves. Polished stone mace-heads were typical prestige objects in the steppes going back to Khvalynsk and Varfolomievka, but were absent from Karanovo or Gumelniţa [also known as Gumelnitsa] societies (Chapman 1999) prior to the Suvorovo intrusion.

Maces shaped into horse-heads were made by people for whom the horse was a powerful symbol. Horses contributed an average of less than 6% of animal bones in Tripolye [also known as Trypillian] B1 sites, and were almost absent from the Gumelniţa and late Karanovo VI cultures. Horse-head maces signaled an iconic status for horses in the lower Danube valley at about 4200–3800 BC; just when horses were introduced, the intrusive Suvorovo graves appeared, and hundreds of long-established tell settlements were abandoned. Mounted raiding could have contributed to the Karanovo VI–Gumelniţa collapse (Anthony 2007, chapter 11, 2010).

The Expansion of Horse Exploitation into New Regions

The next-oldest non-metric indicator of domestication is the spread of horse exploitation into regions outside the western Eurasian steppes and lower Danube valley during the late fourth millennium BC. Sherratt and others (Bökönyi 1979; Benecke 1994, pp. 73–75; Benecke and von den Dreisch 2003) accepted this geographic expansion as evidence for the domestication of the horse even in the absence of clear metric indicators. Between 3500 and 3000 BC horses began to appear in settlements of the Maikop and Early Transcaucasian Culture (ETC) in the Caucasus (Anthony 2007, p. 291). They appeared regularly for the first time in the middle Danube valley in settlements of the Cernavodă III and Baden–Boleráz cultures, as at Kétegyháza (Bökönyi 1979); and in sites in Poland (Milisauskas et al. 2006). Around 3000 BC they rose to 10–20% of the bones in Bernberg sites in central Germany, and to above 20% of the bones at the Cham site of Galgenberg in Bavaria. The Galgenburg horses included a native small type and a larger type probably imported from the steppes (Benecke 1994, pp. 73–75). This general increase in the importance of horses from the Caucasus to the Danube valley, Poland and Germany about 3500–3000 BC suggests that something significant had changed in the relationship between humans and horses. Exactly what had changed is indicated most clearly at sites of the Botai–Tersek type in the steppes of northern Kazakhstan, where additional evidence, including some metric data, suggests that horses were being ridden by 3600–3100 BC.

Horse Exploitation in the Botai–Tersek Culture

The Botai–Tersek culture was a society of specialized horse-herders and hunters who rode domesticated horses and hunted wild horses, a peculiar kind of economy that existed only between 3600 and 3100 BC (calibrated dates on animal bone, requiring no correction), and only in the steppes of northern Kazakhstan (Zaibert 1993; Kalieva and Logvin 1997; Levine 1999; Anthony and Brown 2000; Olsen 2003, 2006a, b; Olsen et al. 2006; Benecke and von den Dreisch 2003). The initial impulse to keep horses as domesticated animals probably came to the northern Kazakh steppes from the west, from the Volga–Ural steppes, where at sites such as Khvalynsk and Ivanovskaya cattle and sheep (and perhaps horses) had been kept as domesticated stock before 4500 BC. Around 3700–3500 BC, probably beginning just before the Botai people adopted domesticated horses, a long-distance migration stream seems to have crossed the northern Kazakh steppes from the Volga–Ural steppes on the west to the Altai Mountains on the east (Fig. 8). The migrants introduced the Afanasievo culture to the Altai mountain steppes, with the first domesticated cattle, sheep, and horses, the first kurgan graves, and the first copper metallurgy, in styles and grave types similar to Repin and Yamnaya styles and grave types from the western steppes. This stream of back-and-forth movement persisted for at least 600 years, 3700–3100 BC, and perhaps longer (long enough to introduce Late Yamnaya bronze axe types, dated after 3000 BC, to the western Altai). The cattle- and sheep-keeping cultures involved in the initial

Fig. 8 The initial migration across northern Kazakhstan about 3700–3500 BC that brought the Afanasievo culture to the Altai Mountains, with the Botai–Tersek region shown. The kurgan cemeteries of Verkhnaya Abuga and Karagash date later, perhaps 3300–3100 BC, and exhibit Yamnaya traits. After Anthony (2007, figure 13.2)

west–to–east Afanasievo migration could have introduced horseback riding to the foragers of the northern Kazakh steppes, who lived on the migration route.

Botai and Tersek were two contemporary archaeological cultures that occupied the northern Kazakh steppes between 3600 and 3000 BC, very similar to each other in their stone and bone tools and house types and somewhat less similar in their ceramics. Both probably derived from the earlier forager cultures (with ceramics) of the Boborykino I type (Kovaleva and Chairkina 1991) that had occupied the forest-steppe zone southeast of the Ural Mountains before 4000 BC. About 3600 BC, these forest-steppe foragers expanded into the northern Kazakh steppe zone, an expansion possibly enabled by horseback riding. After riding appeared among steppe foragers it would have spread very quickly because riders would have made hunting impossible for their pedestrian forager neighbors. Riders can regularly cover 50 miles in a day, twice as far as hunters on foot (Ewers 1955, p. 185). Nathaniel Wyeth, a fur trader in the northern American Plains, observed in 1851 (Ewers 1955, p. 305): 'Men on foot cannot live, even in the best game countries, in the same camp with those who have horses. The latter reach the game, secure what they want, and drive it beyond the reach of the former.'

The Botai and Tersek cultures seem to have replaced the earlier steppe forager cultures in their respective regions, introducing a new and different flake-and-biface lithic industry, replacing the microlithic toolkits of the earlier foragers; Botai and Tersek ceramics also showed stronger links to the Ural forest-steppe than to the local Neolithic forager ceramics of the Atbasar and Makhandzhar types (Kovaleva and Chairkina 1991; Kislenko and Tatarintseva 1999). Botai and Tersek probably maintained long-lasting social interactions with the forest-zone foragers of the southeastern Urals, known after 3600 BC as the

Surtanda, Lipchin and Ayatskii cultures (Kalieva and Logvin 1997, p. 130), and could be interpreted as subgroups of these forest-zone cultures adapted to the steppe environment. Sites of the Botai type were clustered in the northern Kazakh steppe uplands east of the Ishim River, and contained more than 90% horse bones. Sites of the related Tersek type, located west of the Ishim in the Turgai Depression, were less specialized, making the Botai sites' extreme degree of specialization in horses a regional phenomenon. Tersek sites exhibit 43–66% horse bones, with aurochs and saiga antelope playing significant roles as secondary game animals. Botai settlements seem to have been bigger (more than 150 house-pits were mapped at Botai; 50 at the Tersek settlement of Kozhai 1) and less numerous (more than 30 Tersek sites are known, and fewer than 10 Botai sites). It is possible that Botai's almost exclusive specialization in horse-hunting and horse-raising fed an external demand for the larger-statured horses of the Ishim steppes during the geographic expansion in the use of domesticated horses between 3500 and 3000 BC, described above.

Botai had more than 150 house-pits (Fig. 9) distributed over 9 ha., and 300,000 animal bones, 99.9% of them horse (Fig. 1:8–9). The other animals available around Botai (represented primarily by isolated teeth and phalanges) included a very large bovid, probably bison, perhaps aurochs; elk; red deer; roe deer; boar; bear; beaver; saiga antelope; and gazelle. No domesticated sheep or cattle bones were found. Some of the wild animals (deer, beaver) probably were confined to gallery forests in the river valleys. Others (bison, antelope, gazelle) shared the grasslands with large herds of wild horses. Horses, not the easiest prey for people on foot, were overwhelmingly preferred to all other animals.

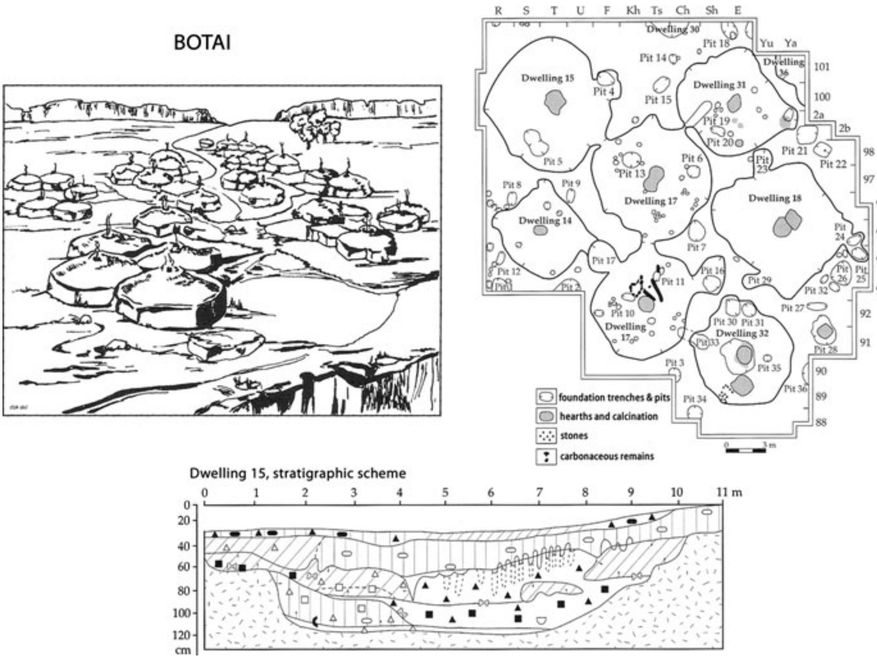

Fig. 9 The Botai settlement reconstructed; the excavation plan for one group of houses; and a typical cross-section of a house pit. A layer of discarded horse manure was found in a similar house pit, Olsen's excavation 32 at Botai. After Kislenko and Tatarintseva (1999, figures 4.17 and 4.19)

Before 3600 BC, foragers in the northern Kazkah steppes lived in small groups at temporary lakeside camps such as Vinogradovka XIV in Kokchetav district and Tel'manskie in Tselinograd district, assigned to the Atbasar Neolithic (Kislenko and Tatarintseva 1999; Benecke and von den Dreisch 2003; Akhinzhalov et al. 1992). They hunted horses, but also a variety of other game: short-horned bison, saiga antelope, aurochs, and red deer. Their foraging economy is poorly known because their sites were small and ephemeral and typically yield fewer than 100 animal bones.

Around 3600 BC their temporary camps were replaced by large settlements—a new settlement pattern introduced with the Botai and Tersek tool and ceramic types. The number of animal bones deposited in settlements rose to tens of thousands in Tersek and hundreds of thousands in Botai settlements. At Botai, whole herds of horses were killed, including mares with gestating fetuses, probably in large-scale drives (Benecke and von den Dreisch 2003, p. 76), implying hunting. On the other hand, many indicators at Botai suggest the presence of domesticated horses. One of these is the occurrence of whole horse carcasses butchered within the settlement (Olsen 2003; Olsen et al. 2006). In-settlement butchering implies either that carcasses were regularly transported into settlements—difficult without draft animals—or that herds of living horses were kept near settlements. Another indicator was the presence in a house pit at Botai (Olsen's excavation 32) of a layer of soil filled with horse dung, identified as re-deposited horse waste from stable floors (French and Kousoulakou 2002, p. 113; Olsen 2006a, p. 264). The handling and movement of horse manure in the settlement strongly suggests domestication.

The discovery by Natalie Stear, Richard Evershed, Alan Outram and others (Travis 2008; Outram et al. 2009) of apparent horse milk residues in five ceramic sherds at Botai indicates that at least some Botai horses were milked. Organic residues in 84 additional Botai potsherds showed an overwhelming signature of adipose horse fats, indicating cooking and consumption of horse meat, confirming the horse-centered diet suggested by 99.9% horse bones at Botai. Finally, Outram's measurements of robusticity in horse metapodials showed that the Botai horse metapodials grouped with Late Bronze Age and modern domesticated horses, while those from Tersek sites were intermediate, and Paleolithic horses were the outlier. These recent discoveries indicate that Botai horses were milked, their dung was collected and discarded in the settlement, they were butchered in the settlement, their meat and milk constituted most of the Botai diet and their breeding possibly was manipulated. All of these indicators point to domestication.

Bit Wear and Horseback Riding

Were the Botai horses ridden? Direct archaeological evidence for riding has been elusive. The best evidence would be a pathology in horse bones or teeth associated strongly with riding. The most promising riding-related pathology is wear on the premolar teeth and mandible caused by a bit. A bit is a mouthpiece that delivers pressure on the tongue and gums when the rider pulls on the reins attached to the ends of the bit. Bits can cause numerous pathologies in horses, as horse veterinarians have shown (Cook and Strasser (2003). Of Cook and Strasser's eight 'harmful effects of the bit', three have been shown to leave pathological marks on the mandible and teeth that might be archaeologically attested. Type 1 is a wear facet or bevel (Fig. 10) created by the horse grasping the bit between the tips of its premolar teeth, causing the bit to slip back and forth over the front or mesial corner of the occlusal surface of the P_2 or lower second premolar, manifested in a bevel of

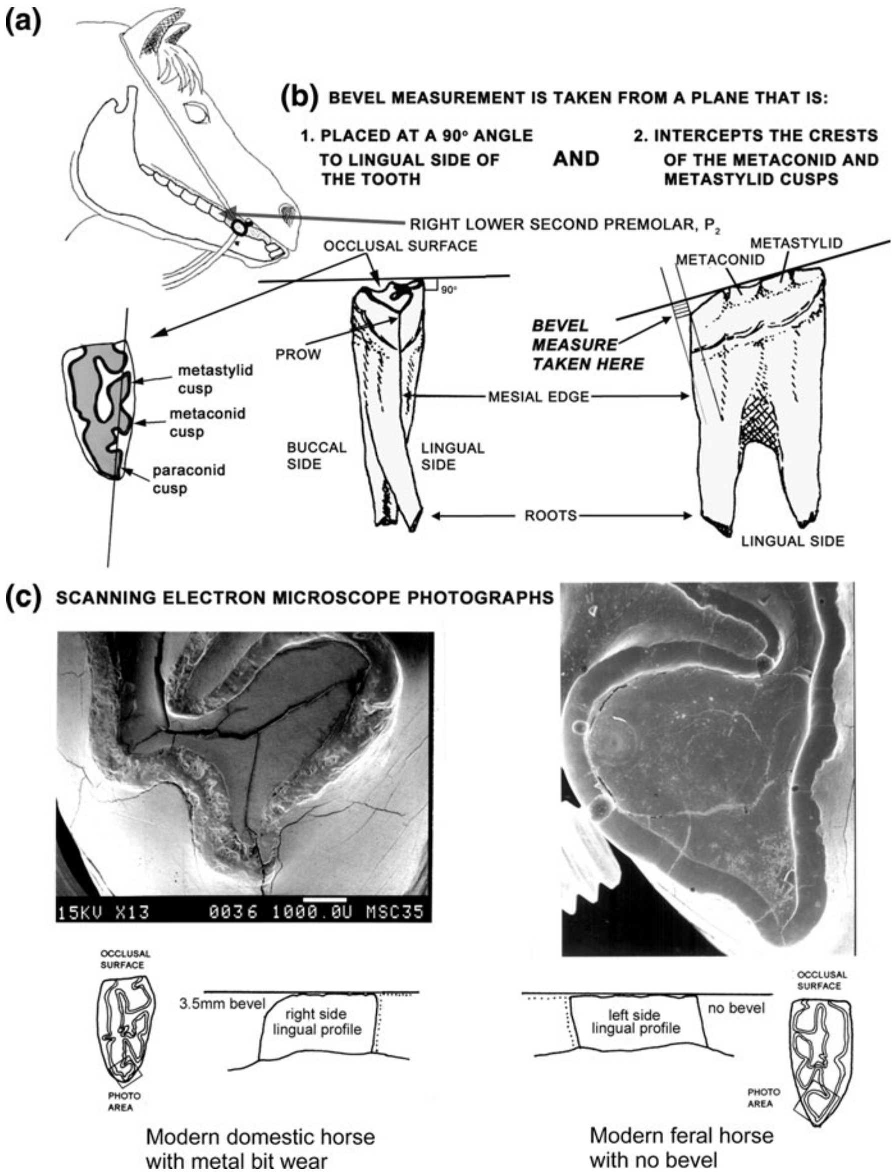

Fig. 10 **a** Normal position of the bit in relation to the horse mandible; **b** how to measure Type 1 bit wear 'bevel'; and SEM photos of a bit-worn P_2 with occlusal scars and a bevel measurement $\geq$3 mm compared to a never-bitted P_2 with neither scars nor a wear facet

3 mm or more on the occlusal surface of the mesial corner of the P_2 of an adult horse. Type 2 is abrasion on the leading or mesial vertical edge of the P_2, created by the rider pulling the bit back against the P_2, manifested in a narrow vertical patch of abraded enamel on the vertical prow of the tooth. Type 3 is bone spurs on the diastema of the mandible caused by inflammation of the gums in locations wounded by the bit.

Type 1 Bit Wear Defined

Type 1 bit wear was the first type recognized as a potential bit-related pathology (Clutton-Brock 1974; Azzaroli 1980). It was studied by us (Anthony and Brown 1991; Brown and Anthony 1998) and it continues to be used as a pathological indicator of bitting (Nicodemus 2010; Kanne 2010). When a rider or driver pulls the reins the horse feels the pull through the medium of the bit. The bit sits on the tongue and gums in the diastema between the incisor teeth and the premolars, designated the 'bars' of the mouth (Fig. 10a). When the bit presses into this soft tissue the horse is forced to respond by turning its head toward a one-sided pull (a turn) or tucking its chin into a two-handed pull (a stop). Horses frequently will lift the bit off of their tongue and gums by elevating and retracting their tongue, pushing the bit back between the tips of their premolar teeth. Because the soft corners of the mouth are anterior to the premolars, the bit must be pushed back into the corner of the cheek, which acts as a spring that makes the horse bite down very firmly with the tips of its teeth to hold the bit. This high-pressure gripping and the slipping of the bit across the tip of the tooth creates a wear facet or bevel on the occlusal surface of the first or paraconid cusp (Fig. 10b), extending sometimes as far back as the second cusp, on the anterior or mesial corner of the lower second premolar or P_2. Metal and bone bits (hard bits) make distinctive scars on the occlusal surface of the enamel, visible with a microscope within the bit-worn facet (Fig. 10c). Rope and leather bits (soft bits) polish the enamel rather than abrading it, so do not create as much abraded or scarred enamel within the wear facet. Type 1 bit wear is defined by a wear facet or bevel which can be seen and measured with the naked eye, a feature created by both soft and hard bits; and if a hard bit was used, the facet can be accompanied by scars on the occlusal enamel, which are visible at 10–15$\times$ magnification.

We defined metal bit wear after examining the P_2s of 52 adult ($\geq$3 years) domesticated horses autopsied in veterinary labs. We found that the P_2s must be from horses 3 years old or older, because permanent horse P_2s erupt at age two and a half years and are naturally uneven until they come into full occlusion with upper P^2s by about age three. Among 52 domesticated bitted horses 3 years and older, the mean wear facet or bevel measurement was 3.11 mm, and the maximum 10 mm (Fig. 11, top). We compared these bitted teeth with 31 P_2s of 16 modern adult horses that had never been bitted, including Nevada mustangs, Assateague ponies, and domesticated but never-trained horses (Fig. 11, bottom). The never-bitted P_2s did not have wear facets or microscopic scars like those found in horses bitted with metal bits. Their mean bevel measurement was 0.79 mm; their maximum was 2.0 mm (Brown and Anthony 1998). We set a bevel measurement of 3 mm as the threshold that separated bitted from never-bitted horses. The reliability of this measurement is the real problem fueling doubts about bit wear as a cultural indicator.

Bit Wear Made by Organic Bits

The earliest bits would have been rope or leather, unlike modern metal bits. Levine (1999, 2004) doubted whether organic bits could cause wear facets. We tested the effects of organic bits in 1992–1993 by riding four previously never-bitted horses with bits made of hemp rope, horsehair rope, sheep bone, and leather (Brown and Anthony 1998, pp. 340–343). Each horse was ridden with its unique bit for 150 h. We anaesthetized each horse and made casts of its P_2s at four intervals.

All four organic bits created a beveled facet on the front corner of the P_2, but the surface of the facet was smooth and polished, not scarred. The mean bevel measurement increased

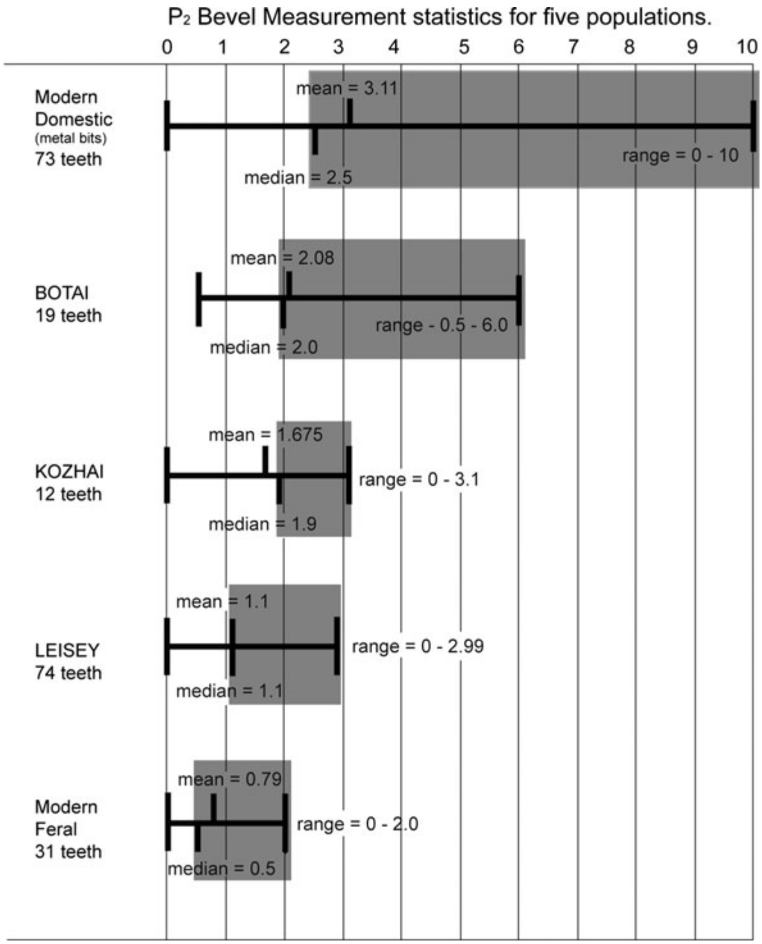

Fig. 11 Bevel measurements on horse P_2s from five populations. Area above the median is shaded for each population

steadily over 150 h by an average of more than two standard deviations above the beginning mean (Brown and Anthony 1998, p. 342; Anthony et al. 2006, p. 142). Rope and leather bits wore away 1–1.5 mm of enamel in 150 h. The facet was in the same location as that caused by a metal bit, and chewing wear was visible on all the organic bits. Microscopic grit and dirt trapped under the bit probably was the agent of wear. Apparently grit, not silica in dietary plants, causes most occlusal wear in herbivores (Sanson et al. 2007). No facet was as much as 3 mm deep at the end of the experiment, and this bothered Levine (1999, 2004). But each horse experienced only 150 h of riding, equivalent to 3 or 4 weeks of steady use. At the rate we measured, the 3 mm threshold would have been reached on all four horses in another 150 h of riding. Organic bits do create bevels.

Type 1 Bit Wear Confused with Natural Malocclusion

Critics of Type 1 bit wear suggested that wild horses might have *natural* facets on the mesial cusps of their lower P_2 teeth caused by an overbite of the upper P^2 rubbing against the lower P_2—a malocclusion called ‘parrot-mouth’ (Hyland 1990, p. 83). This non-cultural origin for beveled premolars was suggested by Levine (1999, 2004) and Olsen (2006a, p. 261, b, p. 101), who claimed that Type 1 facets occured on Pleistocene horse P_2s known to have been wild. Olsen rejected the validity of Type 1 bevels as a cultural indicator (2006a, pp. 260–261) because she said she had seen horse P_2s from four North American Pleistocene localities that revealed ‘several examples of Brown and Anthony’s “soft bit wear”’. She supplied bevel measurements for only two teeth from two horses from two sites. Both of these horses are in the Smithsonian collections and are classified as *Equus lambei*, described by Oliver P. Hay in 1917.

Originally found by gold miners in the Canadian Yukon and Alaska in the early 1900s, both horse skulls are considered Pleistocene because of the depth and geological strata in which they were reportedly found. We are particularly interested in the provenance of these two fossils because Scott et al. (2010) have discovered by radiocarbon dating that another horse described by Hay as ‘Pleistocene’ is in fact less than 400 years old. This specimen, the holotype for *Equus laurentius*, was also obtained by Hay from amateur enthusiasts who had collected it years earlier. It exhibits both Type 1 and Type 2 bit wear as one might expect on a modern bitted horse.

Of the two Pleistocene horses with beveled P_2s brought to our attention by Olsen, one specimen is the holotype of *Equus lambei* (USNM 8426). It was found in 1903 by a gold miner in the Canadian Yukon, who also claimed to have panned ‘pay dirt’ from its eye sockets. After decorating the miner’s home for some years, it was obtained and described 14 years later by Oliver P. Hay as a new species, *Equus lambei*. Hay noted that it was unusual because both skull and mandible were together and the bone was cream-colored, unlike other Pleistocene finds from the region, which he said were ‘almost without other exception’ stained brown (Hay 1917, p. 435). The specimen is not radiocarbon dated. Olsen reported a bevel of 8.5 mm on the left P_2, but the upper P^2 shows no matching overbite and both P_2s are oddly worn. The horse might be modern.

Similar information about the other specimen (USNM 11705) was provided to us by staff of the Smithsonian National Museum of Natural History. This horse was found by a gold miner in Alaska around 1920. The gold miner’s letter that accompanied the mandible noted that it was in very poor condition because it had been left on top of the boiler house for 5 or 6 years. Like USNM 8426, it is not stained brown as the other Alaskan Pleistocene mammal bones in the collection are. Olsen measured one bevel of 4.5 mm. We found the cusps too damaged to measure but observed a Type 2 abrasion on the prow. Against these two teeth of uncertain origin we can cite a much larger study of bevel measurements on Pleistocene horse premolars.

In 2002 Christian George, then at the University of Florida, studied bevel measurements on a large collection of Pleistocene equid lower P_2s excavated under controlled conditions at the Leisey site in Florida (Hulbert et al. 1995). The equids were *Equus ‘leidyi’*, possibly an eastern subspecies of *E. scotti*, similar to modern horses in dentition, diet and stature. They had never seen a human, much less a bit. George used our methods to screen out teeth from equids < 3 years, leaving 74 Pleistocene lower P_2s from 44 mature animals (Fig. 11). George found no facets of 3 mm or more and just one greater than 2.5 mm (Anthony et al. 2006, pp. 140–141). George’s sample showed greater variation and a higher mean bevel measurement (1.1 mm) than we found in our sample of 31 P_2s of modern never-bitted horses (0.79 mm). An increase in variation is not surprising with a larger sample. The higher mean might also be a more accurate indication of the average expected among prehistoric horses. Combining the Leisey P_2s with our modern sample, only three of the

105 never-bitted P_2s in the pooled sample had a bevel measurement greater than 2 mm, only one was greater than 2.5 mm, and none were 3 mm or more.

George's study indicated that a facet measuring 3 mm or more should occur on the first cusp of the P_2 in less than 1% of P_2s among mature ($\geq$3 years), never-bitted, free-range horses. George was supported by Robert Cook's additional measurements of 24 never-bitted P_2s, none of which exhibited bevels of 3 mm (Cook 2011). Both studies supported a 3 mm facet as a cultural indicator.

We do not dispute that a bevel or facet on the lower P_2 can be caused by overbite. The question is not whether overbite exists, but how frequently it is manifested in a facet 3 mm deep on the P_2s of adult ($\geq$3 years) wild horses. In natural conditions overbite is not a neutral selective trait. Parrot-mouth makes it difficult for a horse to eat (Hyland 1990, p. 83), so natural selection operates against it, making it unusual in the wild.

Bendrey (2007) published bevel measurements and ages for a new sample of never-bitted equids, and he was able to study the upper P^2s to see if malocclusion might have caused beveled lower P_2s. Bendrey compared the P2s of 32 'worked' and bitted domesticated horses and mules/hinnies with 28 'non-worked' and never-bitted zoo-kept Przewalski horses. Unfortunately all but seven equids in his 'worked' category were either very old (>20 years) or were inter-species hybrids (mules and hinnies). Age-induced or breeding-induced malocclusion was quite common in both groups, so their teeth are not comparable to those of normal-aged adult horses. Four of the seven remaining 'worked' animals had P2s that could not be measured, so the 'worked' equids were not informative.

More interesting were the P2s of never-bitted zoo Przewalskis. All surviving Przewalski horses are descended from 13 horses taken into captivity in western Mongolia before WWI, but the bloodline unfortunately also includes a single domesticated non-Przewalski mare with malocclusion of its P2s (see Mohr 1971, p. 43, Fig. 30). The Przewalskis in Bendrey's sample included 10 very aged (>20 years) zoo animals whose teeth and occlusion exhibited many irregularities, and four others that were too young or whose teeth could not be measured. The other 14 individuals, aged 5–16, had 27 measurable P_2s with a mean bevel measurement of 1.61 mm. This was higher than our mean (0.79 mm) for never-bitted horses, partly because two P_2s measured 3 mm—possibly as a result of overbite malocclusion. An earlier study had found that zoo-raised Przewalskis exhibited shorter tooth-rows and a shorter ascending ramus of the jaw compared with wild-born Przewalskis, perhaps caused by '…inappropriate feeding with its consequences for jaw mechanics' (Volk 1970, cited in Groves 1994, p. 46). Malocclusion might be regarded as a zoological indicator of domestication in horses. Three factors besides bit wear seem important in promoting more frequent malocclusion among domesticates: a soft grain diet, raised trough feeding and the breeding of genetically larger with genetically smaller animals. A soft grain diet would promote malocclusion if exogenous particles of dirt in food are the principal agent of occlusal wear in herbivores, as recent research suggests (Sanson et al. 2007). Free-range grazing introduces more dirt into the mouth than browsing (Sanson et al. 2007, p. 529), and grain-fed zoo animals presumably have very little dirt in their food. This might explain the shortening of the jaw and tooth-row crowding found in zoo-born Przewalskis but not in wild-born Przewalskis by Volk, cited above. The second factor, trough feeding, also eliminates much dirt grit from feed by raising it off the ground, but additionally the elevation of the feeding surface changes the angle of the horse's mouth and interferes with normal tooth occlusion (Cook and Strasser 2003, p. 54). Horses evolved eating grasses and their jaws and teeth are conformed to chew with their heads extended down to the ground. When they eat from a raised surface their teeth do not line up properly. As a result the unopposed teeth overgrow and develop hooks. The third factor promoting malocclusion among domesticates is the breeding of genetically larger with smaller stock (mules, hinnies, horse-onager, horse-pony). But among free-range horses whose breeding was primarily with their local breeding pool, like those of the Eneolithic steppes, facet measurements of 3 mm or more on multiple adult P_2s indicates that the sample includes bitted individuals.

Olsen (2006a, p. 260) has suggested adding one more criterion to distinguish between natural facets caused by malocclusion and cultural facets created by a bit: the presence or absence of a 'Greaves effect'. A Greaves effect is a natural difference in height between the occlusal enamel ridges of a horse tooth and the softer occlusal dentine that surrounds the enamel ridges (Greaves 1973). The enamel ridges normally are elevated above the dentine, so that the enamel can cut the horse's food while the depressed dentine pockets provide room for the grass stems to lie on either side of the raised enamel crushing and cutting surfaces. Olsen suggested that bits should wear the enamel down to the level of the dentine, making a planed occlusal surface, without a Greaves effect, within the bit-worn facet. The presence of a Greaves effect was regarded by Olsen (2006a, p. 260) as proof that the facet was natural, not cultural. But in our sample of premolars from 52 domesticated horses known to have been bitted with modern steel bits, we found many P_2s with $\geq$3 mm bevels that retained the Greaves effect within the wear facet created by the metal bit, and others in which the enamel was worn down to the dentine as Olsen hypothesized should have happened in all cases of bitting. The absence of a Greaves effect is not strongly associated with known cases of bit wear in modern horses, so is not a diagnostic criterion of bitting.

Bit Wear in Archaeological Contexts

In Table 1 we present bevel measurements for all of the archaeological horse P_2s we measured from the steppes and neighboring parts of Eastern Europe. The earliest P_2s with facet measurements of 3 mm or more were found at Botai and Kozhai 1, two Botai–Tersek sites (Figs. 11, 12). At Botai we examined 42 horse P_2s with the permission of Victor Zaibert. Of these, 19 were reasonably undamaged and from adult horses, making them 'measurable'. Five of the 19 measurable P_2s (26%), from at least three different horses, had facet measurements of 3–6 mm (Anthony et al. 2006; Brown and Anthony 1998). Three of these retained a normal Greaves effect (Fig. 12: numbers 37 and 21), and on the other two teeth the enamel was worn down almost to the dentine, creating a much reduced Greaves effect (Fig. 12: specimen 2). A Tersek site, Kozhai 1, dated to the same period, yielded 46,000 bones. We examined 12 lower P_2s with the permission of Victor Logvin, two of which (16%) showed wear facets of 3 and 3.1 mm. Both exhibited a reduced Greaves effect, meaning that the enamel was worn down almost to the dentine. Organic bits can create wear facets like those seen at Botai and Kozhai 1, and facets like these are quite unexpected among wild free-ranging horses.

We are confident that these seven teeth from two Botai–Tersek sites came from the mouths of bitted horses. Bendrey identified a single P_2 with 'unambiguous' Type 2 (prow damage) bit wear and two more with 'possible' Type 2 wear from Botai (Outram et al. 2009, p. 1333). He also found four mandibles with Type 3 (diastema) wear but he did not discuss Type 1 (bevel) wear. Currently these pathologies represent the oldest direct evidence for horseback riding. But horseback riding might have started up to a thousand years earlier in the Dnieper–Ural steppes at places like Khvalynsk.

Table 1 All examined archaeological P_2s, arranged chronologically, with the most recent at the top and bevel measurements on the right

Site name	Culture	Dates	# Measureable	# w/3 mm + BEVEL	Bevels
Feketekapu	Avar	600 AD	5	1	0.5, 0.5, 1.0, 1.5, 7.5
Khodosovka	Early Slavic	600 AD	2	0	1.0, 2.0
Olbia	Roman	100–300 AD	1	1	4
Zarubinnyetskaya		100–200 AD	2	0	0.5, 1.5
Skelka	Roman	100–200 AD	1	1	3
Kherson region	Scythian	500–200 BC	2	2	3.0, 3.5
Kutzurub nr. lbia	Classic Greek	500 BC	1	0	0.5
Chertomlyk	Scythian	500–400 BC	2	0	2@1.0
Olbia	Greek	500–400 BC	2	2	4.0, 5.0
Gaimonova Mogila	Scythian	600–500 BC	3	0	1.0, 2@2.5
Dereivka	Iron Age	600–200 BC?	2	2	3.5, 4.0
Bekes-Varoserdo	Gyulavarsand—MBA	1500 BC	1	0	1.5
Feudvar	Serbia—Bronze Age	2000–1500 BC	10	1	3@0, 2@0.5, 3@1.0, 2.5, 3.0
Kulevchi Settlement	Petrovka and Alakul	2000–1500 BC	8	1	0, 0.5, 2@1.0, 2@1.5, 2.0, 4.0
Potapovka	Potapovka—LBA	2000–1800 BC	4	0	2@1.5, 2@1.0
Utyevka	Potapovka	2000–1800 BC	10	2	0.5, 2@1.0, 1.5, 4@2.0, 2@5.0
Aleksandrovka	Late Catacomb—MBA	2000 BC	2	0	2.5, 1.5
Malyan	Kaftari phase	2000 BC	3	3	5.0, 6.0, 7.0
Toszeg-Laposhalom	End MBA	2100 BC	1	0	0.5
Krivoe Ozero Cemetery	Sintashta	2100 BC	4	0	2 @1.0, 1.5, 2.5
Kastanas	N. Greece EBA-LBA	2400–200 BC	4	0	0, 0.5, 1.0, 1.5
Toszeg-Laposhalom	Nagyrev—late EBA	2600 BC	2	0	0.5, 2.0
Csepel—Holland Ut.	Bell Beaker—EBA	2800–2600 BC	3	0	0, 0.5, 1.5
Sergeivka	Sergeivka	2900–2700 BC	10	3	0.5, 2@1.0, 1.5, 2@2.0, 2.5, 2@3.0, 3.5
Szigetcsep-Tangazdasag	Baden-Pecel OR Bell Beaker	3500–3000 BC OR 2800–2600 BC	1	0	0

Table 1 continued

Site name	Culture	Dates	# Measureable	# w/3 mm + BEVEL	Bevels
Kozhai 1	Tersek	3600–3100 BC	12	2	0, 0.5, 0.8, 1.2, 1.4, 1.8, 2@1.9, 2.0, 2.5, 3.0, 3.1
Kumkishu I	Eneolithic	3300–3100 BC	1	0	0
Krasni Yar	Botai	3600–3100 BC	0	0	Damaged
Botai	Botai	3600–3100 BC	19	5	6.0, 4.0, 3.5, 3.0, 3.0
Tiszaluc-Sarkad	Hunyadiholom (Trans. Bodrogk.)	3800–3700 BC	0	0	Damaged
Dereivka	Sredni Stog	4000 BC	4	0	0.5, 1.0, 1.5, 2.0
Varfolomyevka	Seroglazivka Neolithic	4500 BC	1	0	0
Luka Vrublavetskaya	Cucuteni-Tripolye A	4500 BC	1	0	2
Mirnoe	Mesolithic	6000 BC	1	0	0
Mezin	Paleolithic	23000 BC	4	0	0, 0.5, 1.0, 2.5

Horseback Riding and Warfare

The increased travel range of riders meant that resources that had previously been beyond ordinary reach became reachable. One of those resources was the steppe itself. Cattle and sheep could convert grass into food, clothing, housing, and wealth, but their numbers were limited by foot transport. In the Mongolian steppes a pedestrian herder with a dog can control about 200 sheep. A herder on horseback with a dog can control about 500 (Khazanov 1994, p. 32). Riding increased the efficiency of each herder, so made larger herds possible. Larger herds required more frequent changes of pasture, so encouraged higher human mobility, and this also was aided by horses. Larger herds could yield more surplus animals, which made it possible for the herding aspect of the economy to yield more disposable wealth. Early riding probably had its first impact on mobility and herding economics, and through social competition between herders, on political power.

The mounted archer became a widespread symbol in Iron Age Eurasian art after about 800 BC, and there can be little doubt that this reflected a newly elevated effectiveness for mounted archery. But we should differentiate between *tribal raiding* on horseback, which probably began before 4000 BC, and *cavalry*, which appeared only after 1000 BC, initially as a specialized force of mounted archers. Bow parts preserved in Bronze Age steppe kurgans suggest that bows were well over a meter long between 2500 and 1500 BC (Shishlina 1990; Malov 2002; Bratchenko 2003, p. 199; see also Grigoriev 2002, pp. 59–60; Gorelik 1993, pp. 66–70; and Zutterman 2003). The length of the bow is directly related to its penetrating power, so until recurved bows were invented, there was a good reason to retain a long bow even if it made mounted archery difficult. Eneolithic and Bronze Age arrowheads were made in many sizes and weights. Long bows and non-standardized arrows,

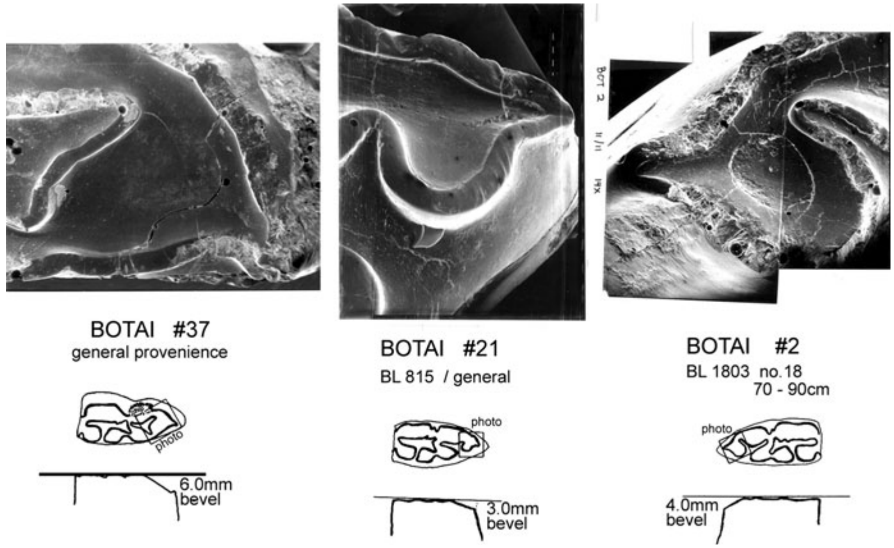

Fig. 12 Selected P_2s from Botai with bevel measurements ≥3 mm. Specimen no. 2 has post-mortem damage, but even before the damage, the enamel ridges were worn down to the dentine in the bevel facet, removing the Greaves effect in spots. Specimens 37 and 21 show polished smooth surfaces on the occlusal enamel within the facet. A similar smooth-surfaced wear facet was created by rope and leather bits, or soft bits, during our riding experiment. Specimens 37 and 21 also show a Greaves effect surviving within the beveled facet, similar to many modern known-bitted horses in our study. Bitted horse teeth can have the Greaves effect worn away within a bit-wear facet, but often retain it, so its presence does not rule out bitting

not rope bits or an ineffective riding seat, made Eneolithic mounted archery clumsy. Riding might have had a greater tactical role in the escape—often the most dangerous part of a pedestrian raid—than in the attack, which might still have been on foot. This was a frequent tactic in inter-tribal raiding in the North American Plains (Ewers 1955, pp. 186–87, 200).

Drews (2004, pp. 22–23) wondered why, if mounted raiding began so early in the steppes, it did not diffuse immediately to the Near East. One reason surely is that the native Near Eastern equids were unsuitable for riding in battle. Beside that, the failure of steppe tribal raiding tactics to impress Near Eastern urban siege armies is not surprising if we accept Turney-High's (1981, p. 34; Keeley 1996, p. 47) assertion that warfare *is* social organization. It was only after Eurasian steppe chiefs developed the chariot during a period of intensified internal conflict and increased social stratification in the steppes that steppe tactics began to influence warfare in the Near East.

The oldest horse-drawn chariots appeared in the southeastern Ural steppes in graves of the Sintashta culture, dated 2100–1700 BC (Anthony 2007, pp. 393–405, 2009; Kohl 2007, p. 151; Koryakova and Epimakhov 2007, pp. 66–98). At least 16 excavated Sintashta graves contained a spoke-wheeled chariot buried with a driver, a pair of head-and-hoof offerings representing the two-horse team, head-and-hoof offerings of cattle and sheep, and up to six other horses, including whole horse carcasses. A new kind of long stemmed point, perhaps designed for javelins, appeared in sets of up to 20 in Sintashta chariot graves. Charioteers could stand in a car and hurl a javelin with their entire body, while riders could use only their arm, so javelins were more effective from a chariot than from horseback. Bows might also have been fired from chariots, while Bronze Age bows might have been too long for effective mounted archery. Later Near Eastern (Mitanni) and Chinese (Chou) chariots, 1500–500 BC, operated in squads of five or six, with each chariot supported in battle by its own dedicated force of foot warriors. This small-unit organization, appropriate for tribal warfare, could be multiplied by combining ten or twenty squads into an army appropriate for urban warfare. Organized this way, Bronze Age chariots were more effective than individual warriors on horseback.

Around 1200 BC the recurve 'cupid' bow was developed, perhaps in Shang China (Gorelik 1993, p. 69), and over the following few centuries it diffused through the Karasuk culture in the Altai Mountains and across the steppes. It was a bow short enough to swing over a horse's neck or rump and yet powerful enough to deliver penetrating power. Cast socketed bronze arrowheads, which had been made episodically throughout the Late Bronze Age in the Kazakh steppes, settled into a standardized set of shapes, sizes, and weights after 900–700 BC, and the number deposited in graves exploded (Derin and Muscarella 2001). The short but powerful recurve bow and the standard-weight socketed arrowhead seem to have made mounted archery truly deadly.

Still, technical advances in bows and arrows were meaningless without a matching change in mentality, in the identity of the fighter, from a heroic single warrior to a nameless soldier. The ideal Bronze Age warrior as described in the *Iliad* and the *Rig Veda* was a hero like Achilles, whose motivation was personal glory, a self-centered ideal typical of tribal warfare (Mallory and Adams 2006, pp. 356–358; Keeley 1996, p. 43). In contrast, the defining feature of Iron Age cavalry was that it attacked and retreated as a body, in which individual riders became anonymous. An ideological model of fighting that was appropriate for a state, under the leadership of a general, was grafted onto tribal horseback riders armed with a new bow-and-arrow technology. That shift in the identity of the warrior, combined with the new recurve bows and standardized arrows, changed the effectiveness of mounted fighters somewhere in the steppes between about 900 and 700 BC. After this happened cavalry swept chariots from the battlefield and a new era in warfare began. We would disagree with Andrew Sherratt on where and how this sequence of events began, but he perceived and made clear its enormous geographic scale and cultural importance, and we will continue to read him on those topics for many years to come.

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