**[Online supplementary material]**

**The origins of saddles and riding technology in East Asia: discoveries from the Mongolian Altai**

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**Figure S1. Detailed sketch of Urd Ulaan Uneet saddle, showing wooden nails joining halves of pommel and cantle.**

**Detailed methods**

*Radiocarbon dating*

Previously unpublished radiocarbon dating of a human tooth from the burial of Urd Ulaan Uneet at the Laboratory of the Institute of Accelerator Analysis in Japan suggested that the burial and its contents, including the saddle, date to *c*. 1737±20 BP, or between *c*. cal AD 247–402 (at 95.4% confidence). Quality control measures suggest good collagen preservation associated with this date (Table S1), but recent studies have raised concerns over reservoir effects on radiocarbon dates from human bones in the region (Svyatko *et al.* 2022). To date the saddle directly, we also sampled a portion of animal-hide strap material. Sample cleaning, carbon extraction and graphite preparation from this specimen were carried out at the Accelerator Mass Spectrometry Laboratory at the University of Arizona before analysing 14C values at the University of Georgia Center for Applied Isotope Studies. The strap was dated to 1646±22 BP, or cal AD 267–535 (at 95.4% confidence). Because this date derives from horse material, we retain high confidence in its accuracy in dating the saddle’s construction, implying a reservoir offset of just over a century from the human remains (Figure 10). All radiocarbon dates were calibrated using the INTCAL20 calibration curve (Reimer *et al.* 2020).

*ZooMS analysis of leather components*

On the same sample, we performed collagen peptide mass fingerprinting, also known as Zooarchaeology by Mass Spectrometry (ZooMS) (Buckley *et al.* 2009) to identify the taxonomic origin of the leather components of the saddle. We extracted collagen protein from approximately 10mg of leather following the acid insoluble protocol described in Brown *et al*. (2020). Samples were analysed using a Bruker Ultraflex MALDI-TOF/TOF mass spectrometer at the Harvard Center for Mass Spectrometry. Spectra were visually inspected using mMass (Strohalm *et al.* 2008). Markers were compared to published marker lists (Buckley *et al.* 2017). Eight collagen marker peptides were successfully identified, allowing a confident identification of the leather as *Equus* (Figure 9, Table S2).

*DNA analysis*

To assess the species and sex of the horse interred along with the Urd Ulaan Uneet saddle, DNA extractions were carried out at the ancient DNA research facilities of the Centre for Anthropobiology and Genomics of Toulouse, France (CAGT, Université Paul Sabatier). We extracted DNA from 190mg of bone powder following the methodology presented by Librado and colleagues (2021). DNA extracts were treated with the USER enzyme mix (NEB) to limit the impact of post-mortem DNA damage in sequence analyses. Triple-indexed DNA libraries were then constructed, amplified, bead purified and quantified on a TapeStation 4200 instrument (Agilent technologies) before shallow sequencing on the Illumina Miniseq instrument (Paired-End mode, 81x2). Sequencing reads were demultiplexed based on their internal adapter indexes using AdapterRemoval2 (-minadapteroverlap 3 –mm 5 –barcode-mm-r[12]; Schubert *et al.* 2016) and provided to PALEOMIX v1.2.13.2 (Schubert *et al.* 2014) for alignment against the EquCab2 nuclear reference genome (Wade *et al*. 2009) and the horse mitochondrial reference genome (Accession nb=NC\_001640; Xu & Arnason 1994). The resulting read alignment files were then processed with the Zonkey package (Schubert *et al.* 2017), disregarding PCR duplicates, low-quality alignments (mapping quality < 25) and reads shorter than 25 nucleotides.

We successfully extracted ancient DNA from the sample, recovering 301,925 nuclear and 347 mitochondrial sequences from a total of 2,683,260 demultiplexed reads (including 2,026,340 collapsed, 816 collapsed truncated and 328,052 uncollapsed read pairs). This provides sufficient data for identifying the sex and species and/or first-generation hybrid status of the specimen with maximal sensitivity and specificity (Schubert *et al.* 2017; Fages *et al.* 2020). Results indicate that the equid recovered in the Urd Ulaan Uneet cave burial is indeed the domestic *E. caballus* (Table S3), rather than a domestic donkey, wild equid, or a hybrid, and that this individual was male (OSM Appendix 1).

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**Table S1. Radiocarbon date information for new early saddles and stirrups presented in this paper.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **Equipment** | **Material** | **Laboratory number** | **%C** | **C:N ratio** | **Radiocarbon age** | **Calibrated range (1 sigma)** | **Calibrated range (2 sigma)** | **Median date** |
| Khukh Nuur | Single stirrup | Human bone | COL3892.1.1 | --- | --- | 1739 ± 37 | Cal AD 251–375  | Cal AD 243–405  | Cal AD 323 |
| Urd Ulaan Uneet | Saddle with likely stirrups | Human tooth | IAAA-170205 | 42.7 | 3.2 | 1737 ± 20 | Cal AD 245–363  | Cal AD 247–402  | Cal AD 326  |
| Urd Ulaan Uneet | Saddle with likely stirrups | Horse skin/leather | AA115726 (UGA57326) | 74.1 | 3.6 | 1646 ± 22 | Cal AD 384–529  | Cal AD 267–535  | Cal AD 420  |

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| **Table S2. Collagen marker m/z identified from leather components of the Urd Ulaan Uneet saddle**  |
| **ɑ-helix** | **COL1ɑ1** | **COL1ɑ2** | **COL1ɑ2** | **COL1ɑ2** | **COL1ɑ2** | **COL1ɑ2** | **COL1ɑ2** | **COL1ɑ1** | **COL1ɑ2** |
| Position | 508–519 | 978–990 | 484–498 | 502–519 | 292–309 | 793–816 | 454–483 | 586–618 | 757–789 |
| Marker | P1 | A | B | C | P2 | D | E | F | G |
| *Equus sp.* | 1105.6 | 1182.6/1198.6 | 1427.7 | 1550.8 | 1649.8 | 2145.1 | 2820.4 | 2883.4/2899.4 | 2983.4/2999.4 |
| Saddle | 1105.6 | 1182.6 | 1427.7 | 1550.8 | - | 2145.1 | 2820.4 | 2883.4 | 2983.5/2999.5\* |
| *\*mass shift due to oxidation* |

**Table S3. Genetic identification of species and sex of *Equus* specimen from Urd Ulaan Uneet cave.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Specimen** | **Endogenous DNA content** | **Mitochondrial fold-coverage** | **Total number of reads sequenced** | **Reads uniquely mapping to nuclear reference** | **Reads uniquely mapping to mitochondrial reference** | **Species** | **Sex** |
| Mon2017x150 | 11.26% | 1.41 | 2 683 260 | 301 925 | 347 | Horse (*Equus caballus*) | ♂ |

**See also OSM Appendix I for Zonkey pipeline DNA results for Urd Ulaan Uneet horse.**