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# New insights into the subsistence economy of the Eneolithic Dereivka culture of the Ukrainian North-Pontic region through lipid residues analysis of pottery vessels

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## Abstract

The Dereivka site of the North-Pontic forest-steppe has been widely investigated because of its potential as a centre for horse domestication (Levine, 1990; Telegin, 1986). Despite the significant archaeological evidence available, Dereivka is considered a contradictory and complex site (Rassamakin, 1999: 143) due to a range of challenges connected with reconciling the various lines of available archaeological evidence. Consequently, a generally acceptable subsistence economic model has still to be developed, with contrasting theories remaining unresolved. This paper presents new results of organic residues analyses from the site. Forty potsherds were submitted to biomolecular and stable carbon and hydrogen isotope analyses and the results discussed in relation to previously published zooarchaeological evidence (Bibikova, 1986; Levine, 1999; Kaiser, 2010). The findings offer a further perspective on the overall subsistence economic strategies of the community, particularly in relation to the exploitation of the horse. Significantly, the biomolecular and stable carbon isotope results confirmed that Dereivka community consumed horse products predominantly, together with smaller proportions of ruminant and non-ruminant products. Interestingly, although ruminant adipose fats were recovered from some vessels, evidence of ruminant dairy product exploitation was insignificant, with only one residue displaying a possible ruminant dairy fat origin. Hydrogen isotope analysis of lipids was applied to investigate equine milk processing in pots (Outram et al., 2009) but these analyses did not offer significant new insights.

## 1. Introduction

35 Dereivka was discovered in 1959 (Telegin, 1986), and extensively excavated between 1960 and  
36 1967. The site, located on a promontory of the River Omelnik, a tributary of the Dnieper River  
37 (Figure 1), included a settlement from which ceramic sherds were recovered, together with two  
38 cemeteries. The finds recovered in the settlement points to Dereivka being influenced by the  
39 Tripolye culture (Rassamakin, 1999: 143-149; Telegin, 1986: 36). Although the chronology is  
40 still to be resolved, Dereivka has been attributed to the Middle Eneolithic period (3800/3700-  
41 3500/3400 BC; Rassamakin, 1999: 127-129), with seven new radiocarbon dates supporting this  
42 chronological attribution, placing Dereivka between 3700 and 3530 BC or 3950 and 3530 BC  
43 (Rassamakin & Kaiser, in press.).  
44



45  
46 Figure 1. Location of Dereivka site along the Dnieper River, in the North-Pontic forest-steppe. The location of Botai  
47 site in Kazakhstan is also indicated, as it will be mentioned in later discussions.  
48

49 Rassamakin (1999) describes Dereivka as a permanent settlement with a subsistence economy  
50 based on: (i) primitive hoe agriculture, as cereal imprints are seen in ceramic vessels  
51 (Pashkevych, 2012; the possibility of using cereal imprints as an indication for agriculture is  
52 discussed by Motuzaitė-Matuzevičiūtė, 2012, 2014); several agricultural tools (Telegin, 1986)  
53 have also been recovered, and (ii) hunting-fishing activities, indicated by the faunal evidence  
54 that displays a predominance of horses, wild animals and fish bones (Table 1; Bibikova, 1986;  
55 Rassamakin, 1999) and by isotope evidence obtained from human and animal bones recovered

56 from the Neolithic cemetery of Dereivka (Lillie et al. 2011) that suggests a diet mainly based on  
 57 C<sub>3</sub> terrestrial foodstuffs, supplemented with aquatic resources, such as freshwater fish.  
 58 Table 1 summarises the different classes of animals inferred from the faunal records from the  
 59 Dereivka excavations (Bibikova, 1986) and the relative percentages of the main animal groups.  
 60 It is notable that the number of identified specimen (NISP) and the minimum number of  
 61 individuals (MNI), the only evidence available at the site, are inconsistent, with the abundance of  
 62 equines being 59.7% based on NISP, whereas based on the MNI is only 24.2% of the total faunal  
 63 assemblage. This, together with the absence of additional evidence, has led to contrasting  
 64 interpretations, notably Anthony & Brown (2003: 58) discarded the possibility that Dereivka  
 65 people were hunters, believing instead that it was a community of animal breeders (including  
 66 horses) and arable agriculturalists. Further interpretations are not helped by the fact that animal  
 67 exploitation by the Tripolye culture, believed to be the major influence on Dereivka community,  
 68 has not been extensively investigated (Rassamakin, 1999) so does not offer a general  
 69 comparative model.

70  
 71 Besides the existing evidence, an accepted reconstruction of the Dereivka subsistence economic  
 72 strategy, a common theory about the extent of the animal exploitation and specifically the  
 73 importance of horse domestication has yet to be achieved and remains a subject of major interest  
 74 in Eurasian prehistoric studies.

75

76 Table 1  
 77 The different classes of animals inferred from faunal records in Dereivka site (Bibikova, 1986).  
 78 Both MNI and NISP are shown. Sheep and goats are combined; the wild animals includes red  
 79 deer, roe deer, boar, elk, badger, beaver, wolf, fox, hare, bear and otter.

	<i>Cattle</i>	<i>Sheep/Goats</i>	<i>Pigs</i>	<i>Horses</i>	<i>Wild animals</i>	<i>Fishes</i>
MNI	18	16	9	52	83	37
MNI%	8.4	7.4	4.2	24.2	38.6	17.2
NISP	618	88	114	2412	673	136
NISP%	15.3	2.2	2.8	59.7	16.7	3.4

80

### 81 1.1 Horse domestication

82 Several questions exist surrounding the matter of horse domestication (Levine, 1999) including:  
 83 (i) the reasons why horses were first domesticated, i.e. for either meat, riding and/or traction; (ii)  
 84 the period when this important knowledge was firstly attained, i.e. Neolithic, Eneolithic or  
 85 Bronze Age; and (iii) the location of the first centre(s) of horse domestication, considered by the

86 majority to be the Eurasian steppe (Levine, 1999; Olsen, 2006; Sherratt, 2003; Stear, 2008; Vilà,  
87 2001; Warmuth, 2012; Outram et al., 2009). This paper will not answer to all these questions but  
88 it will attempt to add new evidence to an archaeological question that for decades has intrigued a  
89 wide range of scholars (e.g. Anthony, 2010; Bibikova, 1969; Bunyatyan, 2003; Dietz, 2003;  
90 Levine, 2005; Sherratt, 2003; Telegin, 1986). After all, the domestication of horse was a major  
91 event that changed the way of life both socially and economically, revolutionizing transportation,  
92 communication and trade. Critically, wild horses were a common part of the fauna in the  
93 Eurasian steppe (Levine, 2006: 193), and prior to domestication, these animals were frequently  
94 hunted in the Eastern steppe (Benecke & Von den Driesch, 2003). Later, the horse became  
95 mainly important for secondary products and as a possible transport instrument (Olsen, 2006) for  
96 use in the herding of other animals or even a weapon during conflicts (Anthony, 2010).  
97 However, the domestication of horse represents a particularly controversial matter in  
98 zooarchaeology as: (i) there are no generally accepted osteological differences between wild and  
99 domesticated horses (Levine, 2005: 11) especially in the initial domestication stages (Bökönyi,  
100 1974; Clutton-Brock, 1999; Olsen, 2006), and (ii) mortality profiles are particularly challenging  
101 to interpret (Olsen, 2006: 248).

102  
103 Dereivka has been central to discussions of horse domestication since 1967 (e.g. Anthony &  
104 Brown, 1991; 2003; Bibikova, 1969; Bökönyi, 1974; Levine 1990; Rassamakin, 1999; Telegin,  
105 1986). The evidence of horse domestication from Dereivka is indirect, primarily inferred from  
106 bone and artefactual evidence (Levine, 2005), however, interpretations are compromised by the  
107 fact that a large number of bones were lost due to ineffective curation post-excavation. Hence,  
108 the main indirect evidence of horse exploitation at Dereivka is the recorded high relative  
109 abundances of equine bones (Levine, 2006: 193; Telegin, 1986: 84), however, the high  
110 proportion of equine bones might be interpreted as arising through increasing horse hunting  
111 rather than its domestication (Levine, 2006: 193). After Bibikova (1986) Levine carried out  
112 zooarchaeological metrical analyses of 900 bones and teeth in Dereivka (Levine, 1990; 2005)  
113 during which she was able to distinguish between equine bones of adult males and females  
114 discovering that the ratio between males and females was 9:1. The latter was interpreted as  
115 evidence of a selective hunting technique or 'stalking model', in which the prey is approached by  
116 stealth and killed (Levine, 1990: 736). In addition, Levine pointed out that the majority of the  
117 equine teeth from Dereivka belonged to individuals between 5 and 8 years old, which are the  
118 most productive years of a horse (Levine, 1990: 738). It was argued that if the horses from

119 Dereivka were domesticated for meat they would have been killed at 2 or 3 years old, when  
120 maximum size and hence maximum meat yield was reached. In contrast, if they were  
121 domesticated for secondary products, they would have been slaughtered after the age of 15 or 16  
122 years old in order to exploit the secondary products as long as possible (Levine, 1990: 738).  
123 Therefore, the latter analysis points to the Dereivka horses being a predominantly wild  
124 assemblage.

125  
126 Three conditions are considered to be required for the domestication of a species (Kuzmina,  
127 2003): (i) the presence of a wild ancestor, (ii) the requirement for food that could only be met  
128 through domestication, and (iii) the possession of sophisticated herding skills (Kuzmina, 2003:  
129 209). The first two conditions have been broadly discussed in the past (Rassamakin, 1999: 134)  
130 and appear to have existed in the North-Pontic region (Kuzmina, 2003: 209). Concerning the  
131 third prerequisite, it is generally believed that domesticated ruminants appeared in the North-  
132 Pontic region at around the 6<sup>th</sup> millennium BC (Bunyatyan, 2003; Kotova, 2003; Kuzmina,  
133 2003) and, given the 20% (NISP) of domesticated animal bones in the faunal record, it can be  
134 assumed that the Eneolithic Dereivka people were at an initial phase of animal domestication.  
135 Nevertheless, others strongly believe in a later introduction of domesticated animals in the  
136 North-Pontic region (e.g. Wechler, 2001), or at least in some areas, depending on the local-  
137 regional ecosystem (Rassamakin, 1999). Thus, providing direct evidence for the Dereivka  
138 community possessing advanced ‘herding skills’, such as dairying based on milk fat residues in  
139 pottery, would lend concrete support to this hypothesis.

140  
141 In an effort to test the latter hypothesis, herein, we explore a new source of information  
142 regarding the animal exploitation and management at Dereivka, namely animal fat residues  
143 preserved in cooking pots. This approach has been widely used to investigate the processing of  
144 animal product in pottery at both the new and old world sites (e.g. Craig et al., 2005; Evershed et  
145 al., 2008a, b; Spangenberg et al., 2006; Lantos et al., 2015). The identification of fats is achieved  
146 through gas chromatographic and mass spectrometric analyses, with further classification, i.e.  
147 ruminant *versus* non-ruminant, ruminant carcass *versus* dairy, terrestrial *versus* aquatic, attained  
148 through compound-specific stable isotope analysis (Evershed et al, 1997; 2002; Hansel &  
149 Evershed, 2009; Cramp & Evershed, 2014; Cramp et al., 2014). Of particular relevance to this  
150 investigation is the study of Outram et al. (2009) who combined zooarchaeological information  
151 with organic residue data from pottery to provide new evidence for horse domestication at the

152 Eneolithic site of Botai in Kazakhstan (Figure 1). The new zooarchaeological approaches cannot  
153 now be applied at Dereivka due to loss of the faunal collection. However, we can apply the  
154 organic residue approach, including a novel dual isotope carbon and hydrogen isotope-based  
155 protocol to look for evidence for horse milk and carcass product processing in pottery. Hence,  
156 lipid residue analyses have the potential to provide evidence for the management strategies used  
157 by the Dereivka people for ruminants *versus* horses (*cf.* Outram et al., 2012), and possibly the  
158 exploitation of aquatic resources (*cf.* Cramp et al. 2014).

159

## 160 **2. Material and methods**

### 161 2.1 Glassware, solvents and reagents

162 All solvents used were HPLC grade (Rathburn) and the reagents were analytical grade (>98%  
163 purity). Reusable glassware was washed with Deacon 90 (Deacon Laboratories), rinsed with  
164 acetone, oven dried and, when possible, furnace at 450°C for 4 h. Analytical blanks were  
165 prepared with each batch of samples to monitor for possible sources of contamination in solvents  
166 and reagents.

167

### 168 2.2 Archaeological pottery

169 A total of 40 potsherds from the Eneolithic Dereivka site were subjected to organic residue  
170 analysis. The sample selection was carried out at the archaeological Institute of Kiev and  
171 supervised by the archaeologist Yuri Rassamakin. Sherds likely to have been used in cooking  
172 processes were chosen, the great majority of the sherds were previously cleaned by  
173 archaeologists, and therefore no presence of burning area that could have indicated use in  
174 cooking were seen. However, rim and body of the sherds were mainly selected as these have  
175 been proven to contain higher concentrations of solvent extractable lipid (Charters et al., 1993).

176

### 177 2.3 Modern reference animal fats

178 The identification of the archaeological fats has been realized by comparing the archaeological  
179 stable isotope composition with those of a broad reference database of modern fats. The database  
180 comprises compound-specific  $\delta^{13}\text{C}$  values of the palmitic ( $\text{C}_{16:0}$ ) and stearic ( $\text{C}_{18:0}$ ) fatty acids of  
181 modern reference dairy fats, ruminant adipose fats and non-ruminant adipose fats from Europe  
182 (Copley et al. 2003; Salque et al., 2012; Spangenberg et al., 2006), Asia (Outram et al., 2009;  
183 Pitter, et al., 2012) and Africa (Dunne et al., 2012) In addition modern Kazakh equine and  
184 freshwater fish fats have been added to the database (Chivall, 2008; Outram et al., 2009; Stear,  
185 2008).

186  
187 2.4 Solvent extraction of lipid residues from archaeological pottery  
188 About 2 g of potsherd surface was cleaned using a modelling drill to remove exogenous residues.  
189 The cleaned sample was grounded in a glass pestle and mortar; the fine powder was weighed and  
190 placed in a glass vial. An internal standard (20 µg of n-tetratriacontane) was added to the  
191 powdered sherd to enable the quantification of lipid extract. Lipids were extracted using CHCl<sub>3</sub>-  
192 MeOH (10 ml; 2:1 v/v) by ultra-sonication (2 x 20 min). After centrifugation in a test tube  
193 (2,500 rpm, 10 min), the total lipid extract (TLE) was evaporated under a gentle stream of  
194 nitrogen to 3 mL. Aliquots were derivatised with BSTFA (70°C, 1 h) for high temperature GC  
195 analysis (Evershed et al., 1990; Charters et al., 1993a). Further TLE aliquots were hydrolysed  
196 with 0.5 M NaOH in MeOH-H<sub>2</sub>O solution (5 ml; 9:1 v/v, 70°C). The neutral fraction was  
197 extracted with hexane (3 x 3 mL) in a clean glass vial and store in the refrigerator until required  
198 for analysis. Finally, the methanol fraction was acidified to pH 3 with 1 M HCl and the fatty  
199 acids extracted with chloroform (3 x 3 mL) for the archaeological fats. The extracted fatty acids  
200 in solvent were evaporated under gentle stream of nitrogen and treated with 100uL of  
201 BF<sub>3</sub>/MeOH (Sigma Aldrich; 14% w/v, 70°C, 1 h). After allowing to cool, dichloromethane  
202 (DCM) extracted double-distilled water was added (1 mL) and FAMES extracted (3 x 2 mL)  
203 with chloroform. The solvent was evaporated to dryness under a gentle stream of nitrogen and  
204 the FAMES stored in freezer until required for analysis. The FAMES were dissolved in hexane  
205 for analyses by GC, GC/MS and GC/C/IRMS.

206  
207 2.5 Direct methanolic acid extraction  
208 Lipids were extracted from the powdered sherd in a culture tube (I) by adding 5 mL of a H<sub>2</sub>SO<sub>4</sub>-  
209 MeOH and heating (2% v/v, 70°C, 1 h, vortex mixing every 5 min). Then the H<sub>2</sub>SO<sub>4</sub>-MeOH  
210 solution containing the extract was transferred to a test tube and centrifuged (2500 r.p.m., 10  
211 min). The clear supernatant was transferred to clean culture tube (II) and 2 mL of (DCM)  
212 extracted double-distilled water added. For a total organic residues extraction, 3 mL of hexane  
213 were added to the extracted potsherd in the culture tube (I) to recover any lipids not fully  
214 solubilised by the methanol solution. The hexane supernatant was then transferred to the H<sub>2</sub>SO<sub>4</sub>-  
215 MeOH solution in culture tube (II) and vortex mixed to extract the lipids - the washing of the  
216 sherd with hexane and vortex mixed in culture tube (II) was repeated twice with the hexane  
217 being transferred to a clean vial for blowing down. Following this, 2 mL hexane were added  
218 directly to the H<sub>2</sub>SO<sub>4</sub>-MeOH solution in culture tube (II) and vortex mixed to extract remaining



219 lipid residues (x2). The hexane extracts were combined and evaporated to dryness under a gentle  
220 nitrogen stream and re-dissolved in 1 mL of hexane to give the hydrolysed/transmethylated total  
221 lipid extract (TLE). In case *n*-alkanols are present in the lipid extract, an aliquot is treated with  
222 BSTFA (70°C, 1 h) for GC, GC/MS and GC/IRMS analyses.

223

## 224 2.6 Instrumental analysis

### 225 2.6.1 High Temperature-Gas Chromatography (HT/GC)

226 HT/GC analyses were performed on an Agilent Technologies 7890A GC System.  
227 Trimethylsilylated (TMS) total lipid extracts (1 µL) were injected through an on-column injector,  
228 in track-oven mode onto a 15 m x 0.32 mm i.d. fused silica capillary column coated with a  
229 dimethyl polysiloxane stationary phase (non-polar column, 100% DB1-HT, 0.1 µm film  
230 thickness; Agilent Technologies). The carrier gas was helium and the GC oven temperature  
231 program was 50°C (2 min) to 350°C (10 min) at a rate of 10°C min<sup>-1</sup>, followed by an isothermal  
232 hold at 50°C for 1 min (Charters et al., 1993a; Evershed et al., 1990). A flame ionisation detector  
233 (FID) was used to monitor the column effluent. Peaks were identified by comparison of retention  
234 times with those of derivatised external standards. Finally, quantification was achieved by the  
235 internal standard method.

236

### 237 2.6.2 Gas Chromatography-Mass spectrometry (GC/MS)

238 The GC/MS analyses for the detection of the TMS were performed on a ThermoFinnigan Trace  
239 MS operating with an ionizing energy (IE) of 70eV with a GC interface temperature was 300°C  
240 and a source temperature of 200°C. The scanning range was *m/z* 50-650. Samples were  
241 introduced by on-column injection. The analytical column was a 60 m x 0.32 mm coated with  
242 polymethylsiloxane (non-polar column, ZB-1, 0.12 µm film thickness, Phenomenex). The carrier  
243 gas was helium and the temperature program was 50°C (2 min) to 300°C (10 min) at a rate of  
244 10°C.min<sup>-1</sup>, followed by an isothermal hold at 50°C (1 min). Data acquisition and processing  
245 were carried out using XCalibur software. GC/MS analyses of FAME derivatives were  
246 performed using a Finnigan Trace quadrupole MS, operated in electron source (EI) mode  
247 operating at 70eV with a GC interface temperature of 250°C and a source of temperature of  
248 200°C. The scanning rate was between *m/z* 50-650. Diluted samples were introduced using a  
249 PTV injector onto a 60 m x 0.32 mm i.d. fused silica capillary column coated with cyanopropyl-  
250 methylpolysiloxane stationary phase (polar column, 50%, VF-23 ms, 0.15 µm film thickness;  
251 Varian, Factor Four). The carrier gas was helium and the temperature program was 50°C (2 min)

252 to 250°C at the rate of 10°C min<sup>-1</sup>, followed by an isothermal hold at 50°C (1 min). For the  
253 detection of ω-(*o*-alkylphenyl)alkanoic acids (APAAs), the MS was operated in total ion current  
254 (TIC) and selected ion monitoring (SIM) mode acquiring at *m/z* 105, 262, 290, 312 (Cramp &  
255 Evershed, 2014). Data acquisition and processing were carried out using XCalibur software).

256

#### 257 *2.6.3 Gas Chromatography/Combustion/Isotope Ratio Mass spectrometry (GC/C/IRMS)*

258 Compound/specific stable Carbon isotope ratios were performed using a GC Agilent  
259 Technologies 7890A coupled to an IsoPrime 100 (EI, 70eV, three faraday cup collectors *m/z* 44,  
260 45 and 46) via an IsoPrime GC5 combustion interface with a CuO and silver wool reactor  
261 maintained at 850°C. Lipid extracts were analysed using a cyanopropyl/methylpolysiloxane  
262 stationary phase (Polar column, 50% VF/23ms, 60 m x 0.32 mm i.d., 0.15 mm film thickness).  
263 Helium was used as carrier gas and the temperature programme was the same as for the GC/MS  
264 analyses.

265

#### 266 *2.6.4 Gas Chromatography/Thermal Conversion /Isotope Ratio Mass spectrometry* 267 *(GC/TC/IRMS)*

268 Compound-specific stable hydrogen isotope ratios were performed using a ThermoFisher  
269 Scientific Delta<sup>Plus</sup> V GC/TC/IRMS (TC reactor, 300 x 0.5 mm i.d.; Al<sub>2</sub>O<sub>3</sub>; 1450°C). FAMES  
270 were introduced to the GC via Agilent PTV injector (splitless mode; 50-300°C; purge time=1  
271 min) and later an Agilent Split/Splitless injector (splitless mode; 300°C purge time=2 min).  
272 Lipid extracts were analysed using a fused silica capillary column (30 m × 0.25 mm i.d.) with a  
273 methylpolysiloxane stationary phase (Zebron ZB-1; 0.25 μm film thickness). Faraday cups were  
274 used for the detection of ions of *m/z* = 2 (H<sub>2</sub><sup>+</sup>) and *m/z* = 3 (HD<sup>+</sup>) with cup centring performed  
275 using the HD<sup>+</sup> ion beam. A retardation lens removed <sup>4</sup>He<sup>+</sup> ions and in order to correct for H<sup>3+</sup>  
276 ions a calibration was performed every day using Thermo Finnigan ISODAT 2.0 software; the  
277 H<sup>3+</sup> factor was typically below 5 and had a rate of change of less than 0.1 day<sup>-1</sup>.

278

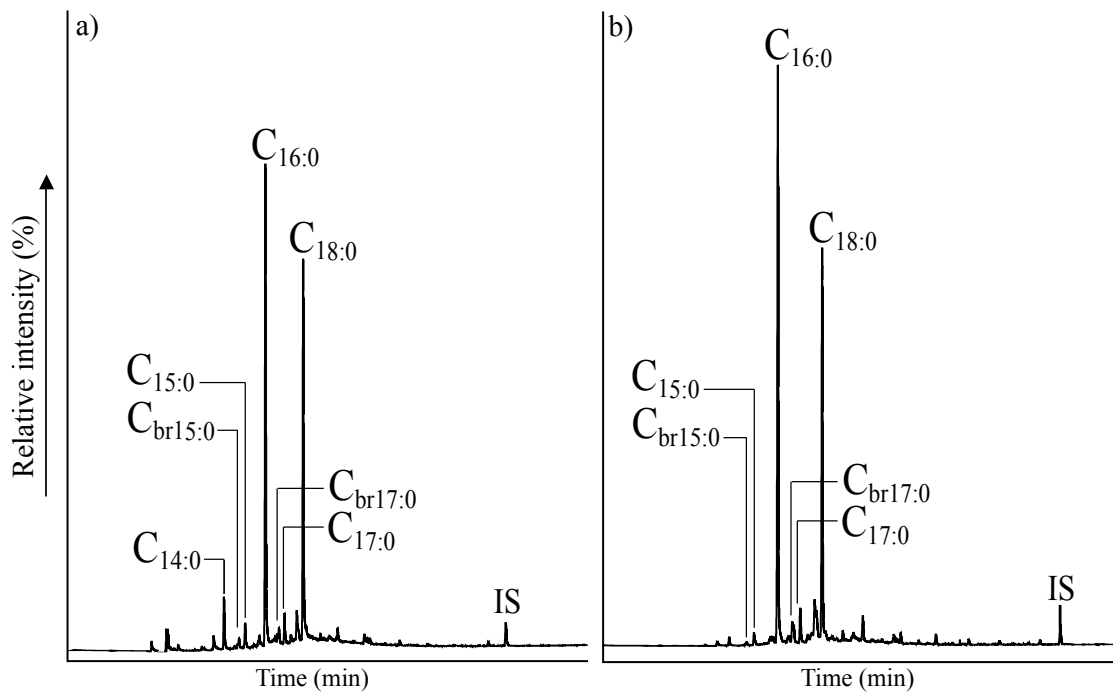
### 279 **3. Results**

#### 280 3.1 Lipid quantification and composition

281

282 Lipid preservation was good with a total of 75.5 % of potsherds (n=31) yielding appreciable lipid  
283 concentrations (>5 μg g<sup>-1</sup>); however, due to post-excavation contamination of 4 of the extracts,  
284 only 27 extracts were submitted to GC/C/IRMS. Figure 2 displays two typical chromatograms  
285 occurring in Dereivka potsherd extracts. The most common distribution was dominated by fatty

286 acids that generally range from C<sub>12:0</sub> to C<sub>24:0</sub> acyl carbon atoms with high abundances of the C<sub>16:0</sub>  
 287 and C<sub>18:0</sub> fatty acids, which are indicative of the presence of degraded animal products (e.g.  
 288 Evershed et al., 1997). The general abundance of branched-chain fatty acids suggested bacterial  
 289 origin diagnostic of ruminant animal fat (Christie, 2012). However, branched-chain fatty acids  
 290 (especially iso- and anteiso-C<sub>17:0</sub>) are also detected in equine adipose fats and likely derive from  
 291 similar groups of microorganism located in the hindgut of the horse (Hintz & Cymbaluk, 1994;  
 292 Pond et al., 1995). Finally, a number of residues displaying short chain fatty acids (mainly C<sub>14:0</sub>)  
 293 that may suggest dairy fats (Christie, 1983; Kuksis et al., 1973) were also detected. However,  
 294 short-chain saturated fatty acids are detected very rarely in archaeological pottery, due to their  
 295 compositional alteration during burial to a distribution more resembling adipose fats (Dudd &  
 296 Evershed, 1998), and thus cannot be used as reliable diagnostic criteria for milk processing.  
 297



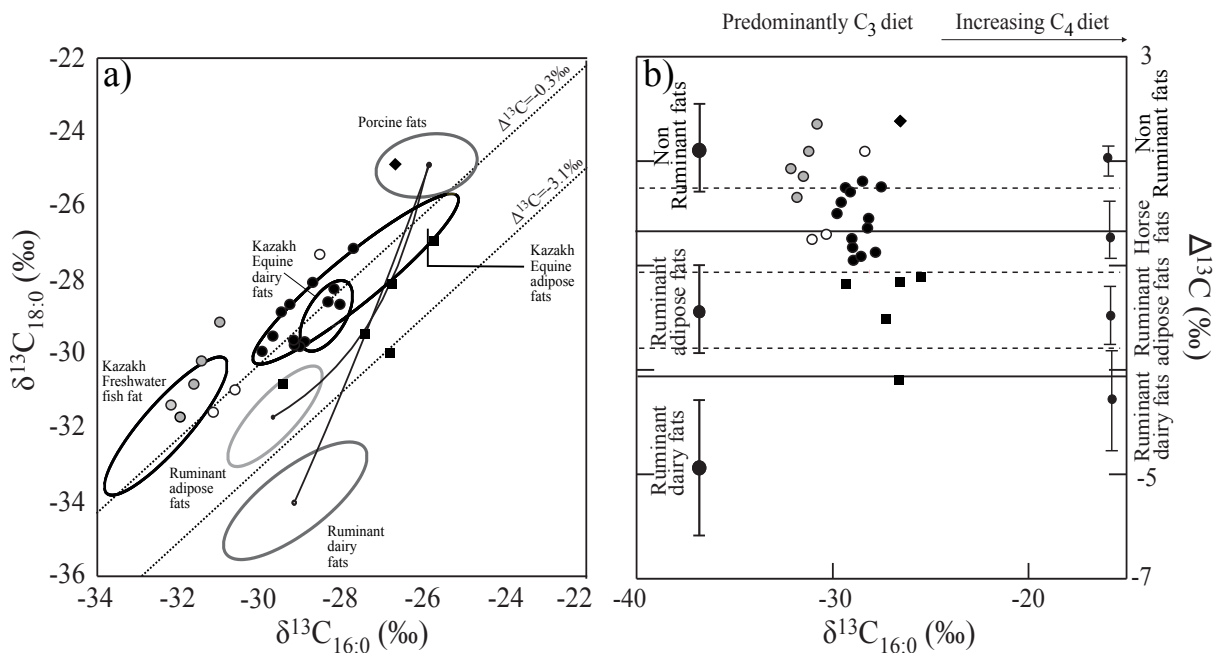
298  
 299 Figure 2. Partial gas chromatogram of TLEs from sherd (a) DER16 and (b) DER25 showing C<sub>15:0</sub>, C<sub>16:0</sub>, C<sub>17:0</sub> and  
 300 C<sub>18:0</sub> fatty acids (F); C<sub>br15</sub>, C<sub>br17</sub> are branched-chain F. The internal standard (IS) is C<sub>34</sub> *n*-tetratriacontane.  
 301

### 302 3.2 Carbon isotope composition

303 Figure 3 displays the results of absorbed lipid residue analysis on potsherds from 27 extracts.  
 304 The  $\delta^{13}\text{C}$  values of C<sub>16:0</sub> fatty acid plotted against C<sub>18:0</sub> fatty acid are shown in Figure 3a.  $\delta^{13}\text{C}_{16:0}$   
 305 range from -32.2‰ to -25.7‰, whereas  $\delta^{13}\text{C}_{18:0}$  values range between -31.7‰ and -24.9‰ with  
 306 mean values, respectively, of -29.1‰ and -29.3‰. Figure 3b shows the  $\Delta^{13}\text{C}$  plot ( $\delta^{13}\text{C}_{18:0}$ -  
 307  $\delta^{13}\text{C}_{16:0}$ ), which allows separation of animal fats, by removing environmental effects (Copley et

308 al., 2003; Evershed, 2008). An appreciable number of Dereivka residues (n=13) exhibit  $\delta^{13}\text{C}$   
 309 values of  $\text{C}_{16:0}$  and  $\text{C}_{18:0}$  fatty acids characteristic of equine products (displaying mean  $\delta^{13}\text{C}_{16:0}$   
 310 value of  $-28.9\text{‰}$ , mean  $\delta^{13}\text{C}_{18:0}$  value of  $-29.0\text{‰}$  and mean  $\Delta^{13}\text{C}$  value of  $-0.1\text{‰}$ ). Five residues  
 311 plot in the range of ruminant adipose, of which only one residue overlaps between adipose and  
 312 dairy fats. Examination of the raw data plot in Figure 3a further reveals that only one residue has  
 313 characteristic isotopic composition of porcine products (Mukherjee et al., 2007) with  $\delta^{13}\text{C}_{16:0} =$   
 314  $-26.7\text{‰}$ ,  $\delta^{13}\text{C}_{18:0} = -24.9\text{‰}$  and  $\Delta^{13}\text{C} = 1.8\text{‰}$ , and that five residues have possible freshwater fish  
 315 origin, showing more depleted isotopic composition (Cramp & Evershed, 2014) with mean  
 316  $\delta^{13}\text{C}_{16:0}$  value of  $-31.6\text{‰}$ , mean  $\delta^{13}\text{C}_{18:0}$  value of  $-30.7\text{‰}$  and mean  $\Delta^{13}\text{C}$  of  $1.0\text{‰}$ . Three  
 317 extracts have possible mixed origin (white dots). Finally, the distribution of  $\delta^{13}\text{C}_{16:0}$  values  
 318 (Figure 3b) of the majority of the extracts range between  $-32.2\text{‰}$  to  $-25.7\text{‰}$ , which is  
 319 comparable to the  $\delta^{13}\text{C}_{16:0}$  values for modern ruminant fats from British animals, raised on a  
 320 strict  $\text{C}_3$  diet ( $\delta^{13}\text{C}_{16:0}$  values ranging from  $-30.9\text{‰}$  and  $-28.6\text{‰}$  and  $-32.9\text{‰}$  and  $-30.4\text{‰}$  for the  
 321  $\delta^{13}\text{C}_{18:0}$ ; Copley et al., 2003). The latter data suggest that the animals producing these fats were  
 322 consuming  $\text{C}_3$  diets.

323



324

325 Figure 3. Scatterplots of (a)  $\delta^{13}\text{C}$  values of  $\text{C}_{16:0}$  fatty acid against the  $\text{C}_{18:0}$  fatty acid extracted from 40 pottery  
 326 vessels from Dereivka. In the plots, equine fats (black dots); porcine fat (black rhombus); freshwater fish fats (grey  
 327 dots); ruminants fats (black squares); mixed fat residues (white dots). Archaeological values overlay confidence  
 328 ellipses corresponding to the values obtained from modern reference fats, which enables the species classification of  
 329 the ancient animal products; and (b)  $\delta^{13}\text{C}$  values of  $\text{C}_{16:0}$  against the  $\Delta^{13}\text{C}$  values ( $\delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$ ).  
 330

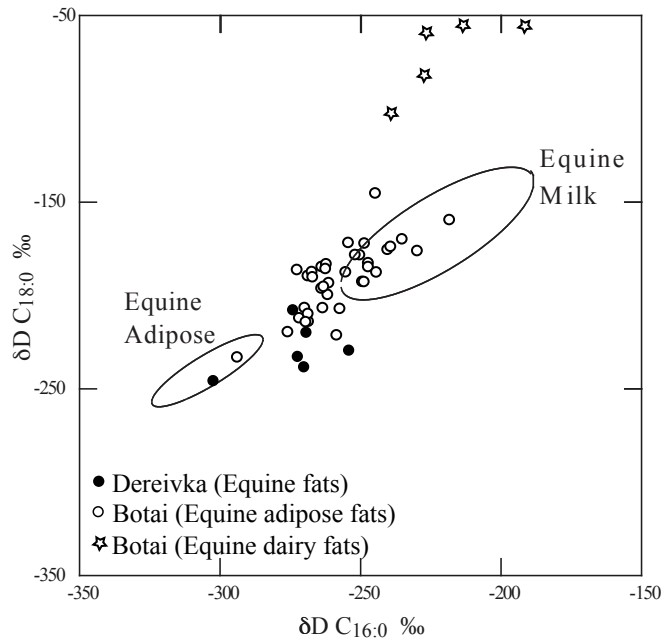
331

### 3.3 Hydrogen isotope composition

332 The research carried out by Outram et al. (2009) was based on the hypothesis that the hydrogen  
333 used to biosynthesise equine fats derives ultimately from environmental water, such that carcass  
334 fat will represent an integration of hydrogen for the entire period of accumulation, probably  
335 many months, while milk fat hydrogen derive from late spring or summer precipitation. These  
336 two different fats will exhibit different averaged  $\delta D$  values reflecting the period of biosynthesis  
337 (Dansgaard, 1964; Rozanski, 1993). Significantly, Kazakhstan precipitation shows a substantial  
338 modern seasonal variation in precipitation  $\delta D$ , of ca. 80‰ in the area of Raïsovka (where Botai  
339 was located), with values of -155‰ and -80‰, being recorded in January and July, respectively  
340 (Bowen et al., 2009). Interestingly, the seasonal deuterium effect in Kazakhstan appear to have  
341 persisted in precipitation over the millennia, allowing the identification of equine dairy residues,  
342 enriched by roughly 100‰ (indicated by stars in Figure 4) compared to the main cluster of  
343 carcass fat residues. Following this idea the lipid residues from Dereivka attributed to equine fats  
344 by compound-specific stable carbon isotope analysis, were submitted to compound-specific  
345 stable hydrogen isotope analysis in order to determine if the processing of equine milk products  
346 could be detected.

347  
348 Figure 4 displays the hydrogen isotope results of equine fat residues in potsherds from Dereivka  
349 (n=6; indicated by black dots) and Botai (n=42; indicated by white dots and stars; the data for  
350 Botai are taken from Outram et al., 2009). Examination of Figure 4 reveals that the 6 Dereivka  
351 residues display  $\delta D$  values (mean  $\delta D$   $C_{16:0}$  of -273.6‰ and  $C_{18:0}$  of -229.0‰) plotting closer to  
352 both the modern reference and Botai horse carcass fats than to horse milk fats.

353



354  
 355 Figure 4. Scatterplot of  $\delta D$  values of  $C_{16:0}$  against  $C_{18:0}$  fatty acids extracted from (i) six Middle Eneolithic potsherd  
 356 from Dereivka site (black dots) and (ii) 40 Middle Eneolithic potsherd from Botai site (white dots and stars). The  
 357 residues were previously attributed to equine products by compound-specific stable carbon isotope analysis.  
 358 Archaeological values overlay confidence ellipses corresponding to the values obtained from modern Kazakh  
 359 reference fats.  
 360

361 **4. Discussions**

362 The information obtained from existing archaeozoological evidence and from molecular and  
 363 stable carbon isotope analysis are consistent and revealed that the subsistence economy of  
 364 Dereivka community was predominantly based on horse exploitation (either wild or  
 365 domesticated). The organic residue analyses confirm that horses played a significant role in the  
 366 lives of prehistoric people in the Eneolithic of the North-Pontic forest-steppe (Levine, 1999;  
 367 2006). Significantly, only one residue is attributed to non-ruminant, likely porcine products,  
 368 which is surprising, as the faunal assemblage comprised 5 to 10% pigs and 14% wild animals,  
 369 including wild boar. It is likely that porcine products are simply not detectable against the  
 370 background of other animal products processed in the vessels or, much less likely, that they were  
 371 processed and consumed in an alternative manner, not involving the use of pottery vessels, e.g.  
 372 using a spit over an open fire. The consumption of freshwater fish is supported by depleted  $\delta^{13}C$   
 373 values for the  $C_{16:0}$  and  $C_{18:0}$  fatty acids which reflects the faunal record (Bibikova, 1986) that  
 374 includes 4 to 15% fish bones. However, no biomarkers for fish (APAA's) were detected,  
 375 probably suggesting that the cooking temperatures were typically low, as the diagnostic APAA's  
 376 are produced at temperatures higher than 260-270°C (Evershed, 2008; Hansel & Evershed,  
 377 2009). As mentioned in the Introduction, stable isotope analysis of human bones, recovered from

378 the Neolithic Dereivka cemetery, suggested a diet based on C<sub>3</sub> terrestrial resources supplemented  
379 with aquatic resources, such as freshwater fish (Lillie et al. 2011).

380  
381 Significantly, from the compound-specific stable carbon isotope analyses of the animal fat  
382 residues in the pottery, it appears that only 22% of the vessels analysed were used for the  
383 processing of ruminant products, which concurs with the *ca.* 20% ruminants represented in the  
384 faunal assemblage, which included cattle, sheep and goats (see Table 1). An interesting feature  
385 of the organic residue findings is the near absence of pottery vessels showing ruminant dairy  
386 products (only one extract out of 27 has a possible ruminant dairy origin,  $\Delta^{13}\text{C}$  value -3.2‰).  
387 The latter suggests that the Dereivka people did not regularly process milk, which is consistent  
388 with the low percentage of domestic ruminants observed in the Dereivka faunal records  
389 (Bibikova, 1986). This latter finding lends further weight to interpretations that animal  
390 domestication was at an initial stage of development, since the exploitation of secondary  
391 products, e.g. dairy, is strongly indicative of the existence of a full pastoral economy. The latter  
392 is consistent with the theory that Dereivka was a community mainly based on hunting-fishing  
393 activities (Rassamakin, 1999). The precise reasons why the Dereivka people had yet to adopt  
394 dairying by the 4<sup>th</sup> millennium BC remains unclear and are likely connected to lactose-  
395 intolerance (Salque et al., 2013), environmental constraints and/or cultural belief(s).

396  
397 While the exploitation of horses is clear from both faunal (Bibikova, 1986; Kaiser, 2010) and  
398 pottery lipid record, it is not possible to infer from the animal fat residues in the pottery whether  
399 the horses were wild or domesticated due to overlap of the  $\delta^{13}\text{C}$  values of equine adipose and  
400 milk reference fats (Outram et al., 2009; Stear, 2008). For the reasons described above, Botai  
401 horse milk and carcass fats were readily separable based on the  $\delta\text{D}$  values of their fatty acids.  $\delta\text{D}$   
402 values were recorded for a limited number (n=6) of the Dereivka residues, however, the values  
403 obtained (Figure 4) point to these residues deriving mainly from equine carcass fats. While this  
404 might seem to contrast with the successful detection of horse milking at Botai in Eneolithic  
405 Kazakhstan, there are differences between Botai investigation and the present study of Dereivka  
406 that are worth emphasising: (i) most importantly a larger difference exists between the  $\delta\text{D}$  value  
407 of summer and winter precipitation at Botai (80 ‰) than at Dereivka (50 ‰) that, given the  
408 precision of the compound-specific  $\delta\text{D}$  determinations ( $\pm 5$  ‰), fundamentally limits the capacity  
409 to resolve milk and carcass residues, (ii) the sample size studied at Botai was nearly an order of  
410 magnitude larger than for Dereivka, which necessarily increased the likelihood of detecting a

411 low level of horse milking on statistical grounds, and (iii) the interpretation of the deuterium  
412 isotope data from Dereivka is complicated by the limited understanding of the factors governing  
413 the fractionation of the hydrogen isotopes from the meteoric water to animal tissue (Chivall,  
414 2008; Cormie et al., 1994) exacerbated by the lack of modern reference fats from the region  
415 (Mileto, 2016, in prep).

416  
417 Nevertheless, the lipid residue results provide new insights into the subsistence economic  
418 strategies of Dereivka community. As discussed above the absence of ruminant dairy product  
419 residues from the Dereivka pottery, suggests a relatively unsophisticated knowledge of ruminant  
420 domestication existed in the region, which could imply that the Dereivka horses were wild rather  
421 than domesticated (e.g. Kuzmina 2003; Rassamakin 1999; Levine 2005; Anthony 2010).  
422 However, this interpretation is countered by the finding of equine dairy fats in Botai pots  
423 (Outram et al., 2009), a site essentially devoid of domestic ruminants (Olsen et al., 2006). The  
424 implication being that knowledge of horse domestication could have been acquired by  
425 communities with no obvious knowledge of ruminant milking (Kuzmina, 2003).

426 In summary, the lipid analyses of the Dereivka pottery are dominated by degraded animal fats  
427 yielding compound-specific stable carbon values of the fatty acids which correspond well with  
428 the faunal records. Overall, exploitation of equine products was substantial. However, although  
429 the number of organic residues deriving from equine fats was appreciable (48%), it is not  
430 possible to infer whether these derived from wild or domesticated horses (Outram et al., 2009).  
431 Finally, the lack of ruminant dairy products in Dereivka pots might point to a relatively  
432 unsophisticated knowledge of animal domestication which when viewed with zooarchaeological  
433 evidence potentially indicates the horses were wild (Levine, 1990). Thus, in the absence of other  
434 reliable evidence supporting domestication, we must assume that Dereivka horses were primarily  
435 hunted. Resolution of this matter in a way that was achieved at Botai site has been thwarted by  
436 the small number of horse fat residues available for deuterium isotope analysis from Dereivka,  
437 exacerbated by the differences in the seasonal water cycle between Botai and Dereivka, and the  
438 lack of an appropriately curated faunal assemblage for further metrical analysis (Outram et al.,  
439 2009).

440  
441 **Conclusions**  
442 This research provided an interdisciplinary investigation of diet and subsistence strategies of the  
443 human groups that lived in the Middle Eneolithic site of Dereivka, in the forest-steppe of the



444 North-Pontic region, along the Dnieper River. The combination of existing zooarchaeological  
445 evidence and new molecular and stable isotope results provided a number of significant new  
446 findings:

- 447
- 448 (i) The carbon isotope results from the Dereivka pottery organic residues strongly reflect the  
449 faunal records, which increases the reliability of both lines of evidence.
  - 450 (ii) The subsistence economy of Dereivka site was predominantly based on horse exploitation,  
451 suggesting that horses played a significant role in the life of this community (Levine, 1999;  
452 2006; Anthony & Brown, 2003; Anthony, 2010);
  - 453 (iii) Apart from the exploitation of equine products, other animal products were identified in  
454 pots, including ruminant adipose products (n=5) and freshwater fish fats (n=5) supporting  
455 the findings of Lillie (2011) based on stable isotope analyses of human bones recovered  
456 from the Neolithic cemetery of Dereivka. This confirms a diverse subsistence economy of  
457 the Dereivka community;
  - 458 (iv) The compound-specific stable carbon analysis of animal fat residues revealed that  
459 ruminant dairy products were not processed in pottery vessels, suggesting that the  
460 Dereivka people did not commonly exploit secondary products, supporting the theory that  
461 Dereivka people were mainly hunters (Rassamakin, 1999);
  - 462 (v) The absence of ruminant dairy fats could be considered as further indirect evidence for the  
463 absence of horse domestication at Dereivka site as the 'herding skill' is considered a  
464 fundamental prerequisite to domesticate wild horses (Kuzmina, 2003);
  - 465 (vi) Dereivka people extensively used pots to process equine products; however, it was not  
466 possible to infer from the carbon of hydrogen isotope data if horses at Dereivka were wild  
467 or domesticated;
  - 468 (vii) It should, however, be emphasised that possibilities remain for the application of the dual  
469 carbon of hydrogen isotope approach to investigate horse milking at Dereivka through  
470 analyses of a substantially larger pottery assemblage and further assessments of the  
471 paleohydrological cycle in the region in order to establish the seasonal range of  $\delta D$  values  
472 of precipitation in the region.

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479

## 480 **Bibliography**

481 Anthony D. W. & Brown D. R., 1991. The origins of horseback riding. *Antiquity*, 65(246), 22-  
482 38.

483 Anthony D. W. & Brown D.R., 2003. Eneolithic horse rituals and riding in the steppes: new  
484 evidence. *Prehistoric Steppe adaptation and the horse*, 55–68.

485 Anthony D. W., 2010. The horse, the wheel, and language: how Bronze-Age riders from the  
486 Eurasian steppes shaped the modern world. *Princeton University Press*.

487 Benecke N. & A. Von den Driesch, 2003. Horse exploitation in the Kazakh steppes during the  
488 Eneolithic and Bronze Age. *Prehistoric steppe adaptation and the horse*, 69–82.

489 Bibikova V. I., 1969. History of Horse Domestication in South-Eastern Europe. *Arkheologiya*,  
490 22, 55-67. In Ukrainian: Do istorii domestikatsii konya na pivdennomu skhodi Evropy.

491 Bibikova V. I., 1986. A study of the earliest domestic horses of Eastern Europe. *Dereivka a*  
492 *settlement and cemetery of Copper Age horse keepers on the middle Dnieper*, BAR Int. Series,  
493 Oxford 287, 135–162.

494 Bökönyi S., 1974. History of domestic mammals in Central and Eastern Europe. *Technology and*  
495 *Culture*, 17, 108-110.

496 Bowen G. J., 2009. The Online Isotopes in Precipitation Calculator, version 2.2.  
497 <http://www.waterisotopes.org>; Bowen G. J.

498 Bunyatyan K. P., 2003. Correlations between Agriculture and Pastoralism in the Northern Pontic  
499 Steppe Area during the Bronze Age. *Prehistoric Steppe Adaptation and the Horse*, 269–286.

500 Charters S. et al., 1993. Quantification and distribution of lipid in archaeological ceramics:  
501 implications for sampling potsherds for organic residue analysis and the classification of vessel  
502 use. *Archaeometry*, 35 (2), 211-223.

503 Chivall D., 2008. Compound-specific hydrogen isotope analysis of animal fatty acids for  
504 palaeodietary reconstruction (*Doctoral dissertation, University of Bristol*).

505 Christie W. W., 1983. The composition and structure of milk lipids. *Developments in Dairy*  
506 *Chemistry*, 2, 1-35. Springer Netherlands.

507 Christie W. W., 2012. Fatty acids: Branched-chain structures, occurrence and biosynthesis. *The*  
508 *Lipid Library*.

509 Clutton-Brock J., 1999. A natural history of domesticated mammals. *Cambridge University*  
510 *Press*.

511 Copley M. S. et al., 2003. Direct chemical evidence for widespread dairying in prehistoric  
512 Britain. *Proceedings of the National Academy of Sciences*, 100(4), 1524-1529.

513 Cormie A. B. et al., 1994. Relationship between the hydrogen and oxygen isotopes of deer bone  
514 and their use in the estimation of relative humidity. *Geochimica et Cosmochimica Acta*, 58(16),  
515 3439-3449.

516 Craig O. E. et al., 2005. Did the first farmers of central and eastern Europe produce dairy foods?  
517 *Antiquity-Oxford*, 79(306), 882.

518 Cramp L. J. E. et al., 2011. What was a mortarium used for? Organic residues and cultural  
519 change in Iron Age and Roman Britain. *Antiquity*, 85:1339–1352.

520 Cramp L. J. E. & Evershed R. P., 2014. Reconstructing aquatic resource exploitation in human  
521 prehistory using lipid biomarkers and stable isotopes. *Treatise on Geochemistry*, 14, 319-339.

522 Cramp L. J. E. et al., 2014. Immediate replacement of fishing with dairying by the earliest  
523 farmers of the northeast Atlantic archipelagos. *Proceedings of the Royal Society of London B:  
524 Biological Sciences*, 281(1780), 20132372.

525 Dansgaard W., 1964. Stable isotopes in precipitation. *Tellus* 16, *Wiley Online Library*: 436–68.

526 Dietz U. L., 1992. Zur Frage vorbronzezeitlicher Trensbelege in Europa. *Germania*, 70, 17-36

527 Dietz, U. L., 2003. Horseback riding: man's access to speed. *Prehistoric steppe adaptation and  
528 the horse*, Cambridge: McDonald Institute of Archaeology, 189–199.

529 Dudd S. N. & Evershed R. P., 1998. Direct demonstration of milk as an element of  
530 archaeological economies, *Science*, 282(5393), 1478-1481.

531 Dunne J. et al., 2012. First dairying in green Saharan Africa in the fifth millennium BC. *Nature*,  
532 486 (7403), 390-394.

533 Evershed R. P. et al., 1990. Analysis of organic residues of archaeological origin by high-  
534 temperature gas chromatography and gas chromatography-mass spectrometry. *Analyst*, 115  
535 (10), 1339-1342.

536 Evershed R. P. et al., 1997. New criteria for the identification of animal fats preserved in  
537 archaeological pottery. *Naturwissenschaften*, 84 (9), 402-406.

538 Evershed R. P., 2008. Organic Residue Analysis. *Archaeology: The Archaeological Biomarker  
539 Revolution. Archaeometry*, 50 (6), 895-924.

540 Hansel F. A. & Evershed R. P., 2009. Formation of dihydroxy acids from Z-monounsaturated  
541 alkanolic acids and their use as biomarkers for the processing of marine commodities in  
542 archaeological pottery vessels. *Tetrahedron Letters*, 50 (40), 5562-5564.

543 Hintz H. F. & Cymbaluk N. F., 1994. Nutrition of the horse. *Annual review of nutrition*, 14.1,  
544 243-267.

545 Kaiser E., 2003. *Studien zur Katakombengrabkultur zwischen Dnepr und Prut*. Archäologie in  
546 Eurasien 14. von Zabern, Mainz.

547 Kaiser E., 2010. Der Übergang zur Rinderzucht im nördlichen Schwarzmeerraum. *Godišnjak*  
548 *Centar za balkanološka ispitivanja* 39, 23–34.

549 Kotova N. S., 2003. *Neolithization in Ukraine*. Vol. 1109. British Archaeological Reports Ltd.

550 Kuksis A. et al., 1973. Triglyceride structure of milk fats. *Journal of the American Oil Chemists*  
551 *Society*, 50 (6), 193-201.

552 Kuzmina, E. E., 2003. Origins of pastoralism in the Eurasian steppes. *Prehistoric steppe*  
553 *adaptation and the horse*, 203.

554 Lantos I. et al., 2015. Maize consumption in pre-Hispanic south-central Andes: chemical and  
555 microscopic evidence from organic residues in archaeological pottery from western Tinogasta  
556 (Catamarca, Argentina). *Journal of Archaeological Science*, 55, 83-99.

557 Levine M., 1990. Dereivka and the problem of horse domestication. *Antiquity*, 64 (245), 727.

558 Levine M., 1999. The origins of horse husbandry on the Eurasian steppe. *Late prehistoric*  
559 *exploitation of the Eurasian steppe*, 5–58.

560 Levine M., 2005. Domestication and early history of the horse. *The domestic horse: the*  
561 *evolution, development, and management of its behaviour*, 5–22.

562 Levine M., 2006. mtDNA and horse domestication: the archaeologist's cut. *Equids in Time and*  
563 *Space*. Proceedings of the 9th Conference of the International Council of Archaeozoology,  
564 Durham, August 2002, 192–201.

565 Lillie M., C. Budd & I. Potekhina, 2011. Stable isotope analysis of prehistoric populations from  
566 the cemeteries of the Middle and Lower Dnieper Basin, Ukraine. *Journal of Archaeological*  
567 *Science* 38, Elsevier, 57–68.

568 Motuzaite-Matuzeviciute G. M., 2012. The earliest appearance of domesticated plant species and  
569 their origins on the Western fringes of the Eurasian steppe. *Documenta Praehistorica* 39: 1–21.

570 Motuzaite-Matuzeviciute G. M., 2014. Neolithic Ukraine: a review of theoretical and  
571 chronological interpretations. *Archaeologia Baltica*, 20: 136–49.

572 Mileto S., 2016 (in prep). Diet and subsistence practices in the Dnieper area of the North-Pontic  
573 region (4<sup>th</sup> - 3<sup>rd</sup> millennium BC): An integrated archaeological, molecular and isotopic  
574 approach. (Doctoral dissertation, Freie Universität, Berlin).

575 Mukherjee A. J. et al., 2007. Compound-specific stable carbon isotopic detection of pig product  
576 processing in British Late Neolithic pottery. *Antiquity*, 81 (313), 743-754.

577 Olsen S. L., 2006. Early horse domestication on the Eurasian steppe. Documenting  
578 domestication: New genetic and archaeological paradigms 245–269.

579 Outram A. K. et al., 2009. The earliest horse harnessing and milking. *Science*, 323(5919), 1332-  
580 1335.

581 Outram A. K. et al., 2012. Patterns of pastoralism in later Bronze Age Kazakhstan: new evidence  
582 from faunal and lipid residue analyses. *Journal of Archaeological Science*, 39(7), 2424-2435.

583 Pashkevych G., 2012. Environment and economic activities of Neolithic and Bronze age  
584 populations of the Northern Pontic area. *Quaternary International*, 261, 176-182.

585 Pitter S. et al., 2012. Food residue fatty acid  $\delta^{13}\text{C}$  and  $\delta\text{D}$  values as proxies for evaluating  
586 cultural and climatic change at Çatalhöyük, Turkey. *AGU Fall Meeting Abstracts*, 1, p. 0464).

587 Pond W. G. et al., 1995. Basic animal nutrition and feeding (Ed. 4). John Wiley and Sons.

588 Rassamakin Y., 1999. The Eneolithic of the Black Sea steppe: Dynamics of cultural and  
589 economic development 4500–2300 BC. *Late prehistoric exploitation of the Eurasian steppe*,  
590 59–182.

591 Rassamakin Y. & E. Kaiser. Dereivka i eneoliticheskie poseleniya s keramikoi dereivskogo tipa:  
592 problem absolyutnoi khronologii (in Russian). Dereivka und äneolithische Siedlungen mit  
593 Keramik des Dereivka-Typs: Probleme der absoluten Chronologie (in German). *Der Kaukasus*  
594 *im Spannungsfeld zwischen Osteuropa und Vorderem Orient: Dialog der Kulturen, Kultur des*  
595 *Dialoges*, St. Petersburg, in press.

596 Rozanski, K., L. Araguás-Araguás & R. Gonfiantini, 1993. Isotopic patterns in modern global  
597 precipitation climate change in continental isotopic records. *Wiley Online Library*, 1-36.

598 Salque M., 2012. Regional and chronological trends in milk use in prehistoric Europe traced  
599 through molecular and stable isotope signatures of fatty acyl lipids preserved in pottery vessels.  
600 (Doctoral dissertation, University of Bristol).

601 Salque M. et al., 2013. Earliest evidence for cheese making in the sixth millennium BC in  
602 northern Europe. *Nature*, 493 (7433), 522-525.

603 Sherratt A., 2003. The horse and the wheel: The dialectics of change in the circum-Pontic region  
604 and adjacent areas, 4500-1500 BC. *Prehistoric Steppe Adaptation and the Horse*, Cambridge,  
605 233–252.

- 606 Spangenberg J. E. et al., 2006. Chemical analyses of organic residues in archaeological pottery  
607 from Arbon Bleiche 3, Switzerland—evidence for dairying in the late Neolithic. *Journal of*  
608 *Archaeological Science*, 33 (1), 1-13.
- 609 Stear N. A., 2008. Changing patterns of animal exploitation in the Prehistoric Eurasian steppe:  
610 an integrated molecular, stable isotopic and archaeological approach. (Doctoral dissertation,  
611 University of Bristol).
- 612 Telegin D. Y., 1986. Dereivka. A Settlement and Cemetery of Copper Age Horse Keepers on the  
613 Middle Dnieper. *BAR. International Series*.
- 614 Vilà C. et al., 2001. Widespread origins of domestic horse lineages. *Science*, 291(5503), 474-  
615 477.
- 616 Warmuth V. et al., 2012. Reconstructing the origin and spread of horse domestication in the  
617 Eurasian steppe. *Proceedings of the National Academy of Sciences*, 109 (21), 8202-8206.
- 618 Wechler K. P., 2001. Studien zum Neolithikum der osteuropäischen Steppe. von Zabern.
- 619 Zaibert V., 1993. Eneolit uralo-irtyshskogo mezhdurech'ya. *Petropavlovsk: Nauka*.