Pots and food: uses of pottery from Resnikov prekop

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ABSTRACT – *In this article, we discuss the role of pottery in food-related practices at the Resnikov prekop site on Ljubljansko barje (Ljubljana Marshes). We integrate chemical analyses of organic food residues with typological, technological and functional analyses of pottery. The vessels from Resnikov prekop reveal a broad range of sizes, forms and fabrics, as demonstrated by our analyses. The lipid residue analysis demonstrate that vessels from Resnikov prekop were mostly used for storing and serving different foods derived from terrestrial animals, mostly ruminants.*

IZVLEČEK – *V prispevku razpravljamo o vlogi lončenine pri praksah, povezanih s pripravo in uživanjem hrane na najdišču Resnikov prekop na Ljubljanskem barju. Integriramo kemične analize organskih ostankov v lončenini s tipološkimi, tehnološkimi in funkcionalnimi analizami lončenine. Posode iz Resnikovega prekopa kažejo veliko variabilnost glede na oblike, velikosti in tehnološke značilnosti, medtem ko analize lipidov kažejo, da so posode uporabljali za shranjevanje in serviranje različnih jedi, pripravljenih iz kopenskih živali, predvsem prežvekovalcev.*

KEY WORDS – *pottery; lipid analyses; pile-dwellings; Ljubljansko barje; Neolithic*

Introduction

Pottery is the most abundant type of material from Neolithic sites. Whereas pottery research used to be concerned primarily with questions focusing on typology and chronology, pottery constitutes an important source of information on various aspects of Neolithic daily life. Pots were made for use in diverse human activities, from transport and storage to the preparation, cooking and consumption of food. The *chaîne opératoire* of pottery manufacture intersects with other operational sequences, usually food preparation, storage and consumption. Relations between these operational sequences are not straightforward. The same pots can be used for different functions, even if they were made for a specific purpose. Thus in order to understand the role of pottery in daily food-related practices at the Resnikov prekop site on Ljubljansko barje (Ljubljana Marshes) we juxtapose chemical analyses of organic food residues in pottery with typological, technological and functional analyses.

Resnikov prekop

Resnikov prekop is located in the eastern part of the Ljubljansko barje area on a floodplain of the Iščica River (Fig. 1). Several test trenches have been excavated at Resnikov prekop since the 1950s (*Jesse 1954; Bregant 1964; Korošec 1964; Veluščček 2006*). The largest area of 160m^2 was excavated by Josip Korošec in 1962. He encountered the remains of vertical wooden piles, wooden objects, platy stones, pieces of daub, pottery and stone tools. Artefacts were deposited directly on the lake marl, in a layer of organic detritus and silt. The general density of piles is very low, only one pile per $2m^2$, concentrated in several parallel rows, suggesting the outlines of several rectangular buildings with dimensions of approx. 5 x 3m (*Bregant 1964*; see also *Budja 1994/1995*).

The Lidar image clearly shows that the test trenches at Resnikov prekop are located in the middle of an abandoned palaeochannel (Fig. 1). This explains the recent analyses at the site which demonstrated that the stratigraphic sequence of the site was destroyed by intensive river erosion (*Andrič 2006*). The channel cut into the lake marl dates to 6396–6230 calBC, and the artefacts were deposited on this surface. Two radiocarbon dates from the channel infill date the silting up of the palaeochannel to 392–203 calBC (*Andrič 2006*).

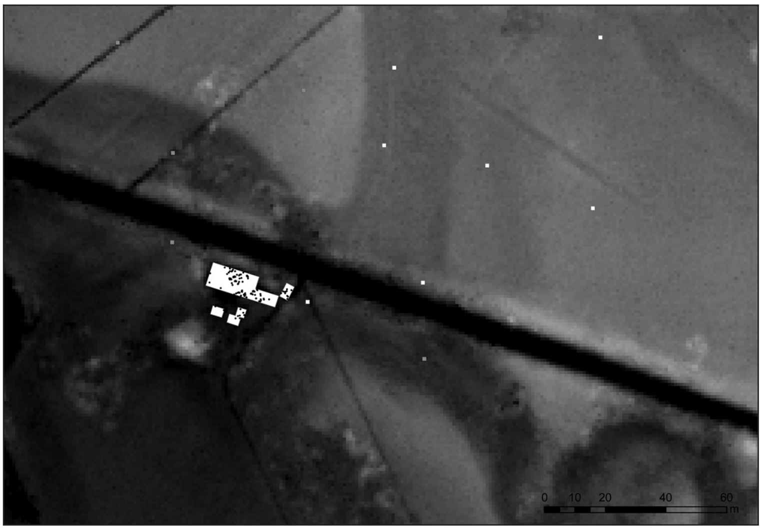

Fig. 1. Plan of Resnikov prekop test trenches.

Radiocarbon dates

Prior to this research, only two radiocarbon dates were available for Resnikov prekop, both being taken from wood piles recovered during Korošec's excavations in 1962 and Velušček's excavation in 2004. The wood piles were dated to 4605–4500 calBC and 4900–4535 calBC, making Resnikov prekop one of the oldest Slovenian Neolithic sites.

These two dates are now complemented by ten new AMS radiocarbon dates obtained from organic residue on the surface of the pottery (Tab. 1). The dates range over almost 1500 years in the period between 5726–4242 calBC. At least three new dates correspond well with the existing dates (*i.e.* Poz-55549, Poz-55548 and Poz-48529). However, several dates of food residue yielded much older dates than the dates of wood structures, dating the pots from Resnikov prekop to a period between 5726–4730 BC. If those dates are accurate, then they are the oldest dates of pottery in central Slovenia so far, preceding the earliest known dates by some 1000 years.

A similar pattern with some dates of pottery being much older than dates of wooden structures and bones was found at the nearby Maharski prekop site (*Mlekuž* et al. *2012*). The analyses of food residue on pottery from Maharski prekop and Resnikov prekop have not produced any markers of freshwater resources (which is surprising in itself, given that both Resnikov prekop and Maharski prekop are located on a marshy floodplain). Thus the freshwater reservoir effect, producing anomalous older dates, cannot be taken into account.

The new radiocarbon dates might indicate – as we have suggested already for Maharski prekop (*Mlekuž* et al. *2012*) – that activities at Resnikov prekop occurred much earlier than is indicated by the dates of wooden structures This might point to either several discrete periods of occupation or a long-term settlement. The idea of the long-term use of the site is further supported by the variability in the composition of the pottery assemblage and pottery technology (see below and *Žibrat Gašparič 2013.149–153*). These very old dates could have important implications for understanding and dating the process of neolithisation in continental Slovenia. The oldest date from Resnikov prekop is contemporaneous with the only radiocarbon date from the Breg near Škofljica site, located a few hundred metres to the east, on the edge of the Ljubljansko barje, where fragments of pottery were retrieved from a Late Mesolithic context (*Mlekuž 2002*).

However, another possible explanation for these older dates is the hard water effect (*Philippsen* et al. *2010*). The hard water effect arises when the dated material incorporated bicarbonate during its life that derived in part from old, inert sources, which causes ages to be over-assessed. Since the watershed of the Iščica floodplain lies in predominately carbonate geology, the hard water effect could be a source of apparently older dates. The hard water effect is still a poorly understood source of error in radiocarbon dates; it is usually reckoned that the maximum possible error is equivalent to the half-life of ^{14}C.

Lab No.	Material	^{14}C Conventional age BP	Stand. dev.	Calibrated age calBC (1σ)	Calibrated age calBC (2σ)	$\delta^{13}C_{bulk}$ ±0.2 (‰)	$\delta^{15}N_{bulk}$ ±0.3 (‰)	Reference
Poz–48527	food crust	6310	40	5322–5225	5369–5214	–34.6	5.5	
Poz–48528	food crust	6290	40	5309–5225	5368–5207	–34.3		
Poz–55545	food crust	6340	40	5371–5229	5465–5219	–35.4	5.2	
Poz–55547	food crust	6780	35	5711–5646	5726–5631	–29.3	7.3	
Poz–55548	food crust	5625	35	4498–4373	4528–4365	–25.0	1.4	
Poz–55542	food crust	6020	60	5000–4840	5195–4780			
Poz–55543	food crust	6220	40	5295–5075	5305–5060			
Poz–55793	food crust	5955	35	4900–4785	4935–4730			
Poz–55549	food crust	5445	35	4345–4260	4350–4250			
Poz–48529	food crust	5630	40	4515–4375	4535–4370			
Z–354	wood	5850	150	4900–4535	5055–4365			*Srdoć* et al. *1987.354*
Hd–24038	wood	5718	23	4605–4500	4610–4495			*Čufar, Korenčič 2006.124*

Tab. 1. Radiocarbon dates from Resnikov prekop.

Recently, it has become apparent that many radiocarbon dates of food residue from North Europe are up to several hundred years older than expected given their context (*Fischer 2002; Fischer, Heinemeier 2003*). The wide range of potentially anomalous old dates on pottery from Resnikov prekop could be a result of mixing plant freshwater and terrestrial foodstuffs during cooking. However, as we have no evidence of the use of freshwater foodstuffs, the path for the incorporation of older carbon in the food residue might be more complex, such as through the grazing of animals on wetland plants. It might be significant that stable isotope analyses of bulk samples of food crust that yielded dates older than expected display very negative $\delta^{13}C$ values (less than –30‰; Tab. 1). Therefore, without further research, we cannot exclude the possibility that dates older than expected are not the result of the hard water effect.

Pottery typology and functional categories

In its life cycle, every pot goes through three distinct stages: manufacture, use and discard. Manufacture consists of the fashioning of a pot for some intended function from raw materials obtained from the environment; this is followed by the utilisation of the pot for either food storage, preparation or consumption, in some instances followed by its use for some other purposes. When it is no longer useful – usually due to fragmentation – it is discarded and the fragments are then incorporated into archaeological deposits, becoming part of the archaeological record. If we are interested in the role of pottery in social life, its production and use in food processing and consumption operation sequences, then the main unit of analysis is the individual pot or vessel, not a sherd; vessels need to be reconstructed from sherds.

The potter makes technical choices related to performance in manufacture and use in accordance with the vessel's intended functions, controls the shape and size of vessels, paste characteristics, firing conditions and surface treatments to create vessels to perform their intended roles (*Skibo 1992.27–56; DeBoer 1984; Tite 2008; van As 1984*). Vessel shape, size and capacity are likely to relate very closely to the different potential functions of the pot (*Rice 1987.207*).

Technical choices made by potters are marked by equifinality: the same vessel shapes and fabrics can be chosen for different intended uses. Interpretation is made even more difficult by the fact that the same vessels may have been used for different purposes, or may have been reused when considered no longer appropriate for their intended function (*Rice 1987. 207–208*). And while the choice of shape and fabric could suggest their intended function, only an analysis of preserved lipids in pots can show what was actually boiled, cooked, boiled, stored or processed in them.

Prudence Rice (*1987.224–226*) identified four loosely defined performance characteristics related to vessel shape: capacity, stability, accessibility and transportability. These attributes are not defined mathematically, but are nevertheless useful in describing the properties of vessels in relation to their intended use. On the other hand, Marion Smith (*1988*) found three properties of vessels to be particularly informative when correlating form to function. The first is the relative openness of the vessels, which is the ratio of the circumference of the rim to the total external surface area; the second is the diameter of the vessel rim and the capacity of the vessel. These properties determine the possible uses of pots; for example, rim size is usually related to the frequency with which the contents of a vessel are changed. Long-term storage vessels usually have smaller openings, while vessels that require access to the contents during use will have an opening big enough for hand access. Vessels used for transporting liquids have a small opening, while serving vessels usually have rim forms that do not curve inward.

Other technological choices are also closely related to the intended use of the pot. Thus the choice of a particular temper, paste characteristics and firing conditions might have an impact on how the vessel performs during manufacture and use (*Braun 1983; DeBoer 1984; Skibo 1992.27–56*). Technological properties such as thermal shock resistance and heating effectiveness might thus be closely related to the intended function of vessels.

The pottery assemblage from Resnikov prekop was scattered over three trenches (*Korošec 1964; Harej 1975; Velušček 2006*); we were able to reconstruct the shape of 128 individual vessels from the pottery fragments.

Pottery technology

For the present study, 120 pottery samples from Resnikov prekop were analysed with a hand lens to identify inclusions, their size and frequency, and the presence of voids. The samples were chosen according to typological groups and could be attributed to three technological groups (description after *Horvat 1999*): the first group of vessels, made from non-calcareous clay and only quartz inclusions (25.8%); the second group with quartz and calcite/limestone inclusions is the most common (49.2%); and the third comprised mostly calcite/limestone inclusions (25%). The majority of vessels have inclusions in the size range of medium sand (0.25 to 0.50mm) and very fine sand (less than 0.25mm). Vessels with coarser sand inclusions (0.50 to 2.00mm) are much less common (less than 10%) and are mostly made with quartz and calcite/limestone inclusions belonging to the second technological group. The vessel surfaces of pottery from Resnikov prekop were smoothed or burnished; some vessels were decorated with a red and, rarely, black slip. The vessels were fired in an incomplete oxidising atmosphere and only rarely in an oxidising and reducing atmosphere.

For the petrographic analysis of pottery from Resnikov prekop, 25 samples were chosen and prepared as standard thin sections. These samples can be attributed to eight different fabric groups according to the characteristics of clays and inclusions, as well as temper added by the potters (for a description of the fabrics see *Žibrat Gašparič 2013.149–153*). The fabrics show the characteristics of at least four different natural non-calcareous clay pastes: very fine-grained with sponge spicules, very fine-grained with frequent opaque minerals, a fine to coarse paste with many natural limestone inclusions and only few mica grains, and a paste with naturally occurring concentrations of chert, sandstone and limestone grains in the silt fraction. The potters prepared these pastes into different recipes; for example, with no temper added or with chert, sandstone, limestone and calcite tempers added to mostly the same natural clay paste. Therefore, the potters made vessels with no temper, using different types of paste; on the other hand, they added various natural inclusions as temper to similar pastes. This shows the variety of technical solutions of these potters when preparing the clay body; nevertheless, the forming, decorating and firing techniques of Resnikov prekop pottery were quite similar for most of the vessels made at the site.

Pottery typology

The typological analysis of Resnikov prekop pottery excavated in the years 1957, 1962 and 2002 (*Korošec 1964; Harej 1975; Tomaž, Velušček 2005; Velušček 2006*) showed the use of a variety of types at the site. The vessels could be assigned to eight basic types according to their shapes and the proportions of different vessels' sections, *i.e.* pots, jugs, dishes, bowls, pedestal dishes, cups, beakers and lids.

In the classification of dishes and bowls, functional criteria (*e.g.*, open/closed, deep/shallow) and the criteria of the outline of the vessel were used. Dishes (Fig. 2) are classified into closed shallow dishes, with a biconical outline with a semi-ellipsoid shape and a simple mouth (S01, S02), and dishes with an ellipsoid shape, a rim and a prominent contact point with the wall (S03). The open dishes include shallow types with a simple semi-ellipsoid outline (S04) and deep dishes with a composed, slightly biconical outline, with a spherical-cylindrical shape (S05) with a simple mouth and fluid contact with the wall. Among the open deep dishes, a special group is represented by an obliquely shaped rim and typical contact be-

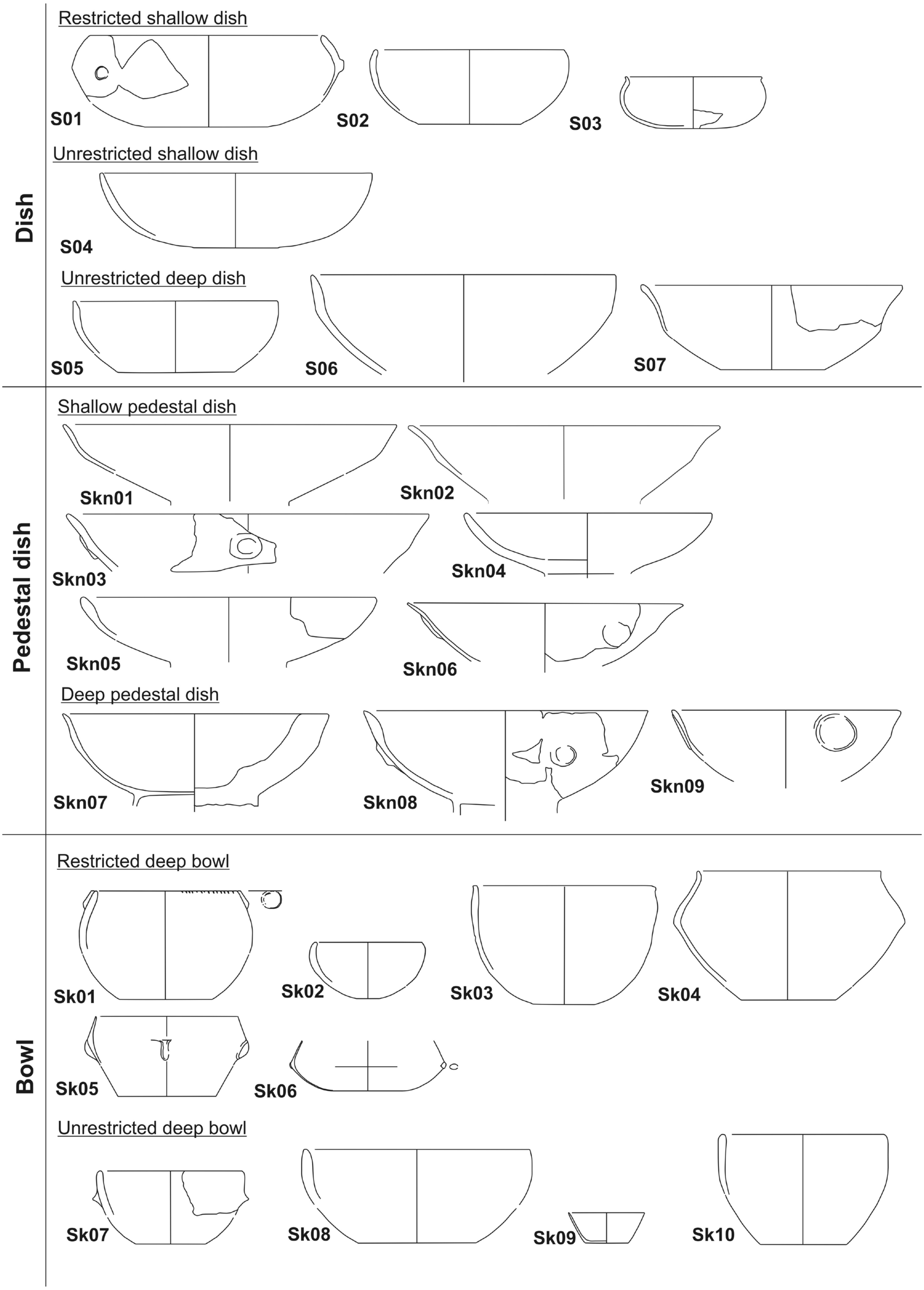

Fig. 2. Typological classification of vessels from Resnikov prekop: dishes, pedestal dishes and bowls. Scale 1:4.

tween the rim and the spherical (S06) or ellipsoid (S07) lower part of the vessel.

The typological classification of vessels with a foot or pedestal is more complicated in the Resnikov prekop pottery assemblage. It is difficult to determine if the vessels had a pedestal, especially when only the upper parts of vessel walls were preserved (see *Tomaž, Velušček 2005.91*). In our classification of pedestal vessels, we considered only fragments with a preserved lower part of the vessel body (Fig. 2). Regarding the proportion – between height and maximum rim circumference – we observed that open shallow types with a conical (Skn01, Skn02), semi-ellipsoid (Skn04, Skn05, Skn06) or cut hyperboloid cone (Skn03) shape in the lower part of the vessels predominate among pedestal dishes. Most of these vessels have a prominent contact point between the rim and the wall. The only exceptions are variants Skn04 and Skn05, with an inconspicuous contact between rim and wall. Deep open pedestal dishes represent the second and less common group, with a spherical lower part (Skn07, Skn08, Skn09) and with less prominent contact between the rim and the wall of the vessel. Only variant Skn04 has a simple rim, but the majority of pedestal dishes have diverse shapes of rims.

The typologically defined bowls (Fig. 2) all have deep shapes. The deep closed bowls have a simple outline with a spherical (Sk01, Sk03) or spherical ellipsoid shape (Sk02), but closed deep bowls with a biconical outline and a spherical half-ellipsoid (Sk04), double cone (Sk05) or half-ellipsoid spherical shape (Sk 06) are also present. The open deep bowls with a simple outline and spherical (Sk07) or conical shapes (Sk09) are less common. The biconical shape is less prominent in bowls with a complex outline, which have a spherical cylindrical (Sk08) or a semi-ellipsoid cylindrical shape (Sk10). Most of the bowls have a simple mouth and a fluid, almost inconspicuous contact with the wall. Only two type variants have a prominently shaped rim, *e.g.* bowl Sk03 with a stunted rim and bowl Sk04 with a vertical rim.

Pots (Fig. 3) are classified into two groups according to their outline and the shape of the contact between the upper and lower part of the vessel. The first group is comprised of pots without necks and with a simple cone (L01), ellipsoid (L02) or biconical shape (L03, L04). The mouth of the pot is either simple, with a fluid contact with the wall (L01, L02, L04a) or with a shaped rim with a prominent contact with the wall (L03, L04b). The second group is comprised of pots with different necks and a complex outline and sharp (L06–L12) or rounded contact with the wall (L13–L16); the pots have various mouth or rim shapes and the contact with the wall can be fluid or prominent. The necks of the pots can be slightly arched (L06), prominently arched (L07, L08, L13), cone shaped (L10, L11), cylinder cone shaped (L12) or hyperboloid cone shaped (L15, L16), but a hyperboloid collar (L09, L14) is also present in some vessels.

Jugs (Fig. 3) are rare among the Resnikov prekop pottery assemblage. Their shapes are very similar to pots, but they have different capacities and differently attached handles. The position of the upper part of the handle is just below the vessels' aperture, and the lower part is close to the maximum circumference of the vessel. The jugs have a complicated outline, with a sharp contact with the lower part of the vessel; they have slightly arched (V02) or prominently arched necks (V03) or a collar (V01). The mouth is simple, with fluid contact with the walls.

The rarest types of vessels at Resnikov prekop are cups and beakers (Fig. 3). Only two cups and beakers could be typologically reconstructed from the whole assemblage. They can be classified into shallow and deep dishes according to their function, capacity and shape. They have complicated outlines and sharp contact points between the upper part and lower spherical (Sd01) or semi-ellipsoid (Sd02) parts of the vessel. The neck is heavily arched (Sd01) or conical (Sd02); the shape of the mouth is simple. The ideal size of beakers is achieved if they can fit into a hand. Their height is usually higher than the circumference of the aperture. The beakers (Fig. 3) have simple mouths and the walls have simple outlines with an ellipsoid shape (K02) or biconical outline, with a conical hyperboloid shape (K01).

In general, the Resnikov prekop pottery was richly decorated. Different basic techniques were used for the decorations. The most common techniques are incisions (incised, grooved and fluted decoration) and impressions made with a fingernail (*Korošec 1964.T. 6.3, T. 10.9, T. 18.1*), with a fingernail or finger (*Korošec 1964.T. 12.2, T. 10.5–7; Harej 1975.T. 6.7*) or with an awl or similar tool with a modified point. Appliqués are also present, mostly in the form of shallow plastic button-shaped bulges. In two vessels, the decoration is made with a modelling technique, *i.e.* with a cordon (*Korošec 1964.T. 14.1, T. 10.1–4*). Usually, a combination of these techniques was used to decorate the vessels from Resnikov pre-

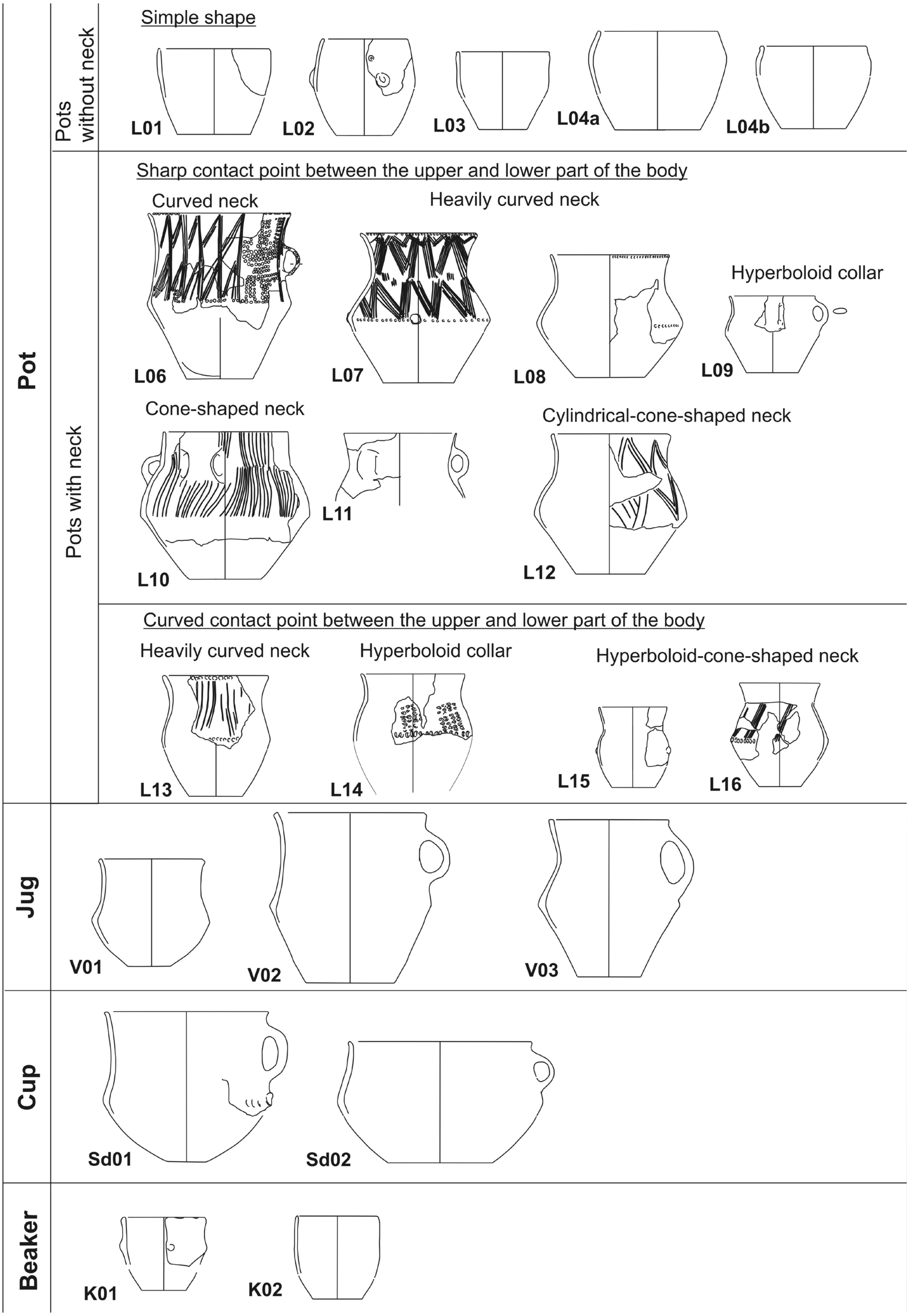

Fig. 3. Typological classification of vessels from Resnikov prekop: pots, jugs, cups and beakers. Pots are in scale 1:8; jugs, cups and beakers are in scale 1:4.

kop, such as a combination of impressions and appliqués, or of incisions, impressions and appliqués.

The ornamentation can be simple or complex, with straight motifs, short incisions, plastic appliqués or simple impressions. Some vessels have more complex motifs, such as a band with a number of parallel lines that form zigzags (see Fig. 3.L06, L12; *Korošec 1964.T. 16.4; Harej 1975.T. 1.3, T. 1.6, T.2.3*). Some bands with parallel lines are formed into vertical or inclined motifs (see Fig. 3.L16; *Harej 1975.T. 1.7, T. 6.7*) or a combination of the two bands (see Fig. 3.L10; *Harej 1975.T. 1.1, T. 7.12*). One pot (Fig. 4) from Resnikov prekop stands out from the assemblage with its rich decoration of complex zigzag bands and two seated anthropomorphic figures on each side of the handle. During our revised analysis of Resnikov prekop pottery from the 2002 excavation, we were able to reconstruct a vessel that was previously published as single fragments (*Velušček 2006.T. 8.5, T. 10.1–14, T. 13.6, T. 16.9, T. 17.9*) or with an incorrect reconstruction (*Tomaž, Velušček 2005.96, Fig. 33*).

Functional categories of vessels

The reconstruction of 56 vessels was sufficiently complete for the capacity, openness and rim diameter to be estimated. Openness was defined as the ratio between the orifice area and the exterior surface area. The vessels were then arranged along three axes: capacity, openness and rim diameter. The most informative proved to be the relation between the vessel's openness and its capacity (Fig. 5).

Vessel capacities range from 0.05 litres to 9 litres, with a median of 1.7 litres. Thus vessel volume is generally low: the first quartile is at 1 litre, while the third quartile is at 3.5 litres, meaning that three quarters of the vessels have a capacity of less than 3.5 litres, and half of the vessels have a volume between 1–3.5 litres.

Openness – defined as the ratio between the orifice area and the exterior surface of the pot – varies between 0.1 (very closed) to 0.7 (very open). The median is around 0.27, while the first and third quartiles are at 1.9 and 0.4. When plotted on a graph (Fig. 5), the relation between openness and volume is L-shaped, *i.e.* vessels with low volumes (less than 3 litres) display high variability in their openness, and vessels with a more restricted opening have volumes over 3 litres.

High variability in openness among low-capacity vessels indicates different intended uses for smaller pots. Very open vessels can be interpreted as vessels for serving or even displaying food, while closed vessels could have been used for the consumption and storage of liquids and cooking. Vessels with a high volume and closed rim shape were probably intended for cooking or storing (liquid) foodstuffs.

Based on these criteria, we divided the corpus of vessels into five functional groups (Figs. 2, 3, 5).

❶ The first group consists of small vessels with volumes below 0.5 litres and moderate openness, between 0.3 in 0.5. Their moderate accessibility and very small rim diameter suggest that they were used for the individual consumption of liquids, possibly fitting in one hand. Typologically, they are defined as bowls (Sk) or cups (Sd).

❷ The second group consists of vessels with very high to extreme openness. The vessel capacities range between 0.5 and 2.5 litres. Rim diameters are very high and the vessels are mostly shallow, indicating very high accessibility and stability. These vessels

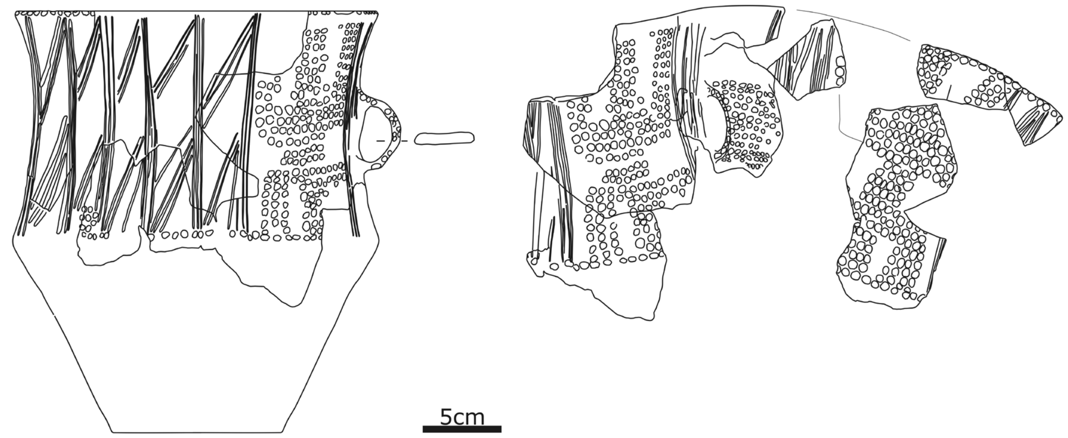

Fig. 4. Large decorated pot (sample No. RP82) of type L06 from Resnikov prekop.

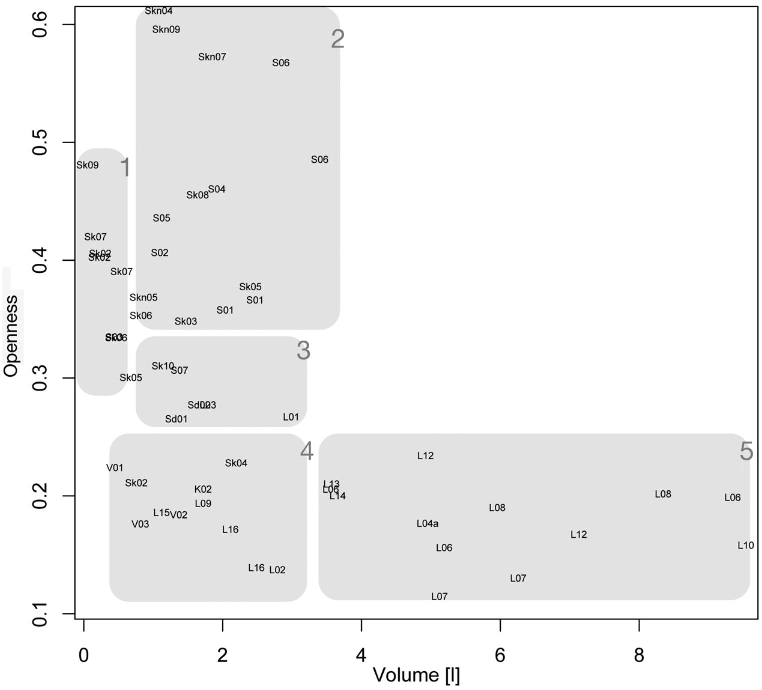

Fig. 5. Vessels from Resnikov prekop arranged according to capacity, openness and typological classification. Vessel use groups are indicated.

might have been used for individual (in the case of low-capacity vessels), communal consumption or even the display of food (in the case of pedestal vessels). Typologically, these vessels are described as dishes (S) and pedestal dishes (Skn).

❸ The third group consists of vessels with moderate openness and capacities in the range between 0.5 and 2.5 litres. These vessels are usually described as bowls (Sk), cups and beakers (Sd). Their intermediate accessibility suggests that they could have had a variety of possible functions.

❹ The fourth vessel group consists of smaller vessels, with volumes less than 2.5 litres. These vessels are generally closed, with openness less than 0.27. The vessels in this group are described as pots (L), jugs (V), and bowls (K). Their smaller volumes, small rim diameter and closed and inaccessible forms indicate that they might have been used to store liquid foodstuffs intended for a small group of people.

❺ The fifth group consists of vessels with volumes over 2.5 litres. The vessels in this group are closed, deep and inaccessible. Their large capacity and accessibility suggest that they can be used either for cooking larger meals and/or temporary storage. Typologically, all these vessels are classified as pots (L).

Food residues

Material and methods

For the organic residue analyses, we sampled 38 pottery samples from Resnikov prekop (Tab. 2); 12 samples were chosen from the 1957 assemblage (*Harej 1975*), 16 samples from the 1962 pottery assemblage (*Korošec 1964*) and 10 from the 2002 excavation (*Velušček 2006*). The samples included diverse vessel forms, such as 14 pots (types L02, L04b, L06, L07, L08, L12, L14, L15), 6 pedestal dishes (types Skn03, Skn 04, Skn06, Skn08, Skn09), 5 dishes (types S01, S05), 5 bowls (Sk02, Sk 05, Sk06), 3 beakers (types K01, K02), 2 jugs (types V01, V03), one cup of type Sd01 and one ladle or spoon (Figs. 2, 3). The pots, dishes and pedestal dishes share many technological characteristics and are typically made with inclusions of quartz and calcite/limestone, which are in the medium sand fraction. Bowls are similarly made, but nevertheless exhibit a greater presence of vessels made only with quartz inclusions and much more fine-grained fabrics with fine sand inclusions.

In the chemical study, we analysed the distribution of lipid biomarkers and stable isotope composition (bulk $\delta^{13}C$ and $\delta^{15}N$ values, and $\delta^{13}C$ of individual fatty acids) of organic residues from pottery. Firstly, we cleaned the surfaces of the samples to remove any exogenous lipids and then ground the sub-samples to a fine powder.

The bulk isotope composition of carbon and nitrogen was determined by elemental analysis isotope ratio mass spectrometry (IRMS) using Europa Scientific IRMS with an ANCA-SL preparation module for solid and liquid samples (PDZ Europa Ltd, Crewe, UK). Each sample was acidified using 1 N HCl to remove carbonate minerals, and dried. Stable isotope results are expressed as $\delta^{13}C$ or $\delta^{15}N$ values in per mil (‰) relative to the VPDB and AIR international standard, respectively. The precision of measurements was ±0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$.

To obtain the total lipid extract (TLE), 2g of the samples were extracted by ultrasonication with an organic solvent (*e.g.*, chloroform/methanol, 2:1 v/v) and then evaporated to dryness under a gentle stream of nitrogen. One portion of the extract was trimethyl-

Lab. sample no.	Vessel type (see Figs. 2–3)	Description	Lab.No.	^{14}C Conventional age BP	Stand. dev.	$\delta^{13}C_{bulk}$ ±0.2 (‰)	$\delta^{15}N_{bulk}$ ±0.3 (‰)	Lipid concentration ($\mu g\ g^{-1}$)	$\delta^{13}C_{16:0}$ ±0.3 (‰)	$\delta^{13}C_{18:0}$ ±0.3 (‰)	$\Delta^{13}C$ (‰)	$C_{16:0}/C_{18:0}$
RP1	V03	jug				–28.9	–1.6	36.5	–26.4	–28.4	–2.0	0.7
RP2	L07	pot				n/d	n/d	9.7	n/d	n/d	n/d	n/d
RP3	L02	pot	Poz–48527	6310	40	–34.6	5.5	113	–31.7	–31.6	0.1	1.6
RP4	K01	beaker				–32.2	–3.4	25.8	–27.6	–28.3	–0.7	1.8
RP6	Sk02	bowl				–28.7	1.9	46.1	–29.6	–30.9	–1.3	1.0
RP7	Sk06	bowl				–29,6	0,1	97,2	–28.3	–31.3	–3.0	1.2
RP10	Sk02	bowl				–31.0	–0.3	29.1	–32.9	–31.4	1.5	4.0
RP14	L14	pot				–25.8	–1.0	42.7	–25.8	–27.5	–1.7	1.9
RP15	L15	pot				n/d	n/d	3.2	n/d	n/d	n/d	n/d
RP16	Sk05	bowl				n/d	n/d	7.8	n/d	n/d	n/d	n/d
RP22		beaker				–26.7	–6.0	34.2	–29.2	–28.6	0.6	0.2
RP23		pot				n/d	n/d	3.1	n/d	n/d	n/d	n/d
RP27	Skn08	pedestal dish				n/d	n/d	7.3	n/d	n/d	n/d	n/d
RP28	K02	beaker				–27.9	3.7	31.0	–28.9	–31.2	–2.3	0.7
RP29	S01	dish				–27.0	5.7	27.5	–27.7	–29.8	–2.1	0.4
RP30	L08	pot				–29.7	0.8	27.3	–26.0	–28.2	–2.2	1.0
RP31	Skn06	pedestal dish				–29.8	1.1	44.0	–29.0	–29.2	–0.2	1.8
RP36	Sd01	cup				–26.1	–1.1	26.0	–28.2	–28.0	0.2	1.8
RP38	L12	pot				–27.5	3.4	17.2	–27.2	–28.4	–1.2	1.4
RP39	Skn09	pedestal dish				–30.0	2.9	21.2	–27.8	–27.4	0.4	0.1
RP42	S01	dish				n/d	n/d	4.6	n/d	n/d	n/d	n/d
RP43	L08	pot				–27.0	–0.9	42.9	–32.1	–31.9	0.2	1.2
RP44		dish				n/d	n/d	7.6	n/d	n/d	n/d	n/d
RP46		pot	Poz–48528	6290	40	–34.3	n/d	225	n/d	n/d	n/d	n/d
RP47	V01	jug	Poz–55545	6340	40	–35.4	5.2	146	–29.4	–31.5	–2.1	1.4
RP48		pot	Poz–55547	6780	35	n/d	n/d	60.8	–30.4	–30.4	0.0	1.9
RP50	Skn06	pedestal dish				n/d	n/d	6.2	n/d	n/d	n/d	n/d
RP71		ladle/spoon	Poz–55548	5625	35	–25.0	1.4	15.9	–30.1	–27.3	2.8	0.8
RP75		vessel	Poz–48529	5630	40	n/d	n/d	28.2	n/d	n/d	n/d	n/d
RP80		bowl				n/d	2.1	21.4	–27.8	–28.6	–0.8	1.5
RP82	L06	pot				–28.9	2.8	33.6	–28.5	–30.5	–2.0	0.9
RP93		pot				–26.6	3.6	13.7	–26.7	–27.6	–0.9	1.6
RP96	L04b	pot				n/d	n/d	3.4	n/d	n/d	n/d	n/d
RP98	Skn03	pedestal dish				–26.2	4.7	36.2	–27.1	–29.1	–2.0	0.5
RP104		pot				–29.2	3.8	47.4	–29.3	–31.8	–2.5	1.3
RP111		dish				–27.3	3.2	22.7	–29.5	–30.4	–0.9	0.6
RP112	Skn04	pedestal dish				n/d	n/d	6.1	n/d	n/d	n/d	n/d
RP118	S05	dish				n/d	n/d	??	n/d	n/d	n/d	n/d

Tab 2. A summary of lipid residues detected in pottery vessels from Resnikov prekop. Key: MAG – moniacylglycerols; DAG – diacylglycerols; TAG – triacylglycerols; ALK –* n*-alkanes; OH –* n*-alcohols; CH – cholesterol; n/d – not detected.

silylated directly and analysed by high temperature-gas chromatography (HT GC), and combined GC-mass spectrometry (GC-MS) analyses were performed to identify the structure of components where necessary (*Evershed* et al. *1990*).

Further aliquots of the TLE were then methylated using BF3/methanol to obtain fatty acid methyl esters (FAME) (14%, w/v; 100µl; Sigma Aldrich, Gillingham, UK; at 70°C for 1h). The methyl ester derivatives were extracted with hexane, and the solvent removed under nitrogen. FAMEs were re-dissolved in hexane for analysis by GC and GC-C-IRMS, using standard protocols (*Evershed* et al. *1994; Mottram* et al. *1999; Gregg, Slater 2010; Ogrinc* et al. *2012*). The GC-C-IRMS analyses were performed using an Iso-

Mono-, di- and tria-cylglycerols	Fatty acids (FA)	Other lipids	Predominant commodity type	Reference
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{14:1}$, $C_{15:0}$, $C_{15:1}$, $C_{16:0}$, $C_{16:1}$, $C_{18:0}$, $C_{18:1}$, $C_{19:0}$, $C_{20:0}$, $C_{21:0}$, $C_{24:0}$	ALK, OH	ruminant adipose fat	*Harej 1975.T. 1.5*
n/d	n/d	n/d	n/d	*Harej 1975.T. 2.1*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{14:1}$, $C_{15:0}$, cis-$C_{15:1}$, $C_{16:0}$, $C_{17:0}$, cis-$C_{17:0}$, $C_{18:0}$, $C_{18:1}$, $C_{20:0}$, $C_{22:0}$	CH	mixed	*Harej 1975.T. 2.6*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK, OH	mixed, plant	*Harej 1975.T. 2.7*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	n/d	ruminant adipose fat	*Harej 1975.T. 3.4*
DAG	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{19:0}$, $C_{20:0}$, $C_{21:0}$, $C_{22:0}$, $C_{23:0}$, $C_{24:0}$, C25:0, $C_{26:0}$	ALK, OH	dairy?	*Harej 1975.T. 3.7*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	n/d	non-ruminant	*Harej 1975.T. 4.5*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	n/d	ruminant adipose fat	*Harej 1975.T. 6.7*
n/d	n/d	n/d	n/d	*Harej 1975.T. 6.8*
n/d	n/d	n/d	n/d	*Harej 1975.T. 7.1*
DAG, TAG	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	mixed, plant	excavated in 1957; not published
n/d	n/d	n/d	n/d	excavated in 1957; not published
n/d	n/d	n/d	n/d	*Korošec 1964.T. 17.1*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	ruminant adipose fat	*Korošec 1964.T. 17.3*
MAG, DAG	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	ruminant adipose fat	*Korošec 1964.T. 17.7*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	ruminant adipose fat	*Korošec 1964.T. 18.1*
MAG, DAG	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK, OH	mixed, plant	*Korošec 1964.T. 18.3*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C1_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK, OH	mixed, plant	*Korošec 1964.T. 4.3*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK, OH	ruminant adipose fat	*Korošec 1964.T. 6.1*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	mixed, plant	*Korošec 1964.T. 7.1*
n/d	n/d	n/d	n/d	*Korošec 1964.T. 9.8*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	mixed	*Korošec 1964.T. 10.2*
n/d	n/d	n/d	n/d	*Korošec 1964.T. 10.7*
n/d	$C_{16:0}$, cis-$C_{17:0}$, $C_{18:0}$, $C_{18:1}$, $C_{19:0}$, $C_{22:0}$	n/d	n/d	*Korošec 1964.T. 12.2*
n/d	$C_{14:0}$, $C_{14:1}$, $C_{16:0}$, $C_{17:0}$, cis-$C_{17:0}$, $C_{18:0}$, $C_{18:1}$, $C2_{22:0}$	CH	ruminant adipose fat	*Korošec 1964.T. 13.4*
n/d	$C_{16:0}$, $C_{18:0}$, $C_{18:1}$, $C_{22:0}$	n/d	mixed	*Korošec 1964.T. 14.4*
n/d	n/d	n/d	n/d	*Korošec 1964.T. 15.4*
DAG, TAG	$C_{12:0}$, $C_{16:0}$, $C_{18:0}$, $C_{18:1}$, $C_{20:0}$	ALK, OH, CH	non-ruminant	excavated in 1957; not published
n/d	n/d	n/d	n/d	excavated in 1957; not published
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK, OH	mixed, plant	*Velušček 2006.T. 1.1*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	nd	ruminant adipose fat	*Tomaž, Velušček 2005.Fig. 33*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	mixed, plant	*Velušček 2006.T. 1.4*
n/d	n/d	n/d	n/d	*Velušček 2006.T. 16.5*
DAG	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	ruminant adipose fat	*Velušček 2006.T. 19.4*
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	ALK	ruminant adipose fat	excavated in 1957; not published
n/d	$C_{11:0}$, $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, $C_{20:0}$, $C_{21:0}$	n/d	mixed	*Velušček 2006.T. 14.18*
n/d	n/d	n/d	n/d	*Velušček 2006.T. 14.17*
n/d	n/d	n/d	n/d	*Velušček 2006.T. 15.4*

prime GV system (Micromass, Manchester, UK); the precision of repeated measurements was 0.3‰.

Results and discussion

General overviews (Tab. 2) of the lipids preserved in the vessels could be obtained from bulk $\delta^{13}C$ and $\delta^{15}N$ values. The $\delta^{13}C$ values are < –25.0‰, and the $\delta^{15}N$ values range from –6.0 to +7.3‰. These data indicates that these vessels were used to process terrestrial herbivore products and/or plant material. Terrestrial C3 plants have $\delta^{13}C$ values between –30 and –23‰, while $\delta^{15}N$ values range from –7 to +6‰ (*Ostrom, Fry 1993*).

It was found that 68% of the pottery samples contained extractable lipid residues. The lipid distribution is dominated by fatty acids, specifically $C_{16:0}$ and $C_{18:0}$. Other components include *n*-alkanes (principally C_{27}–C_{33}), *n*-alcohols (C_{24}–C_{34}) and mono-, di- and tri-acylglycerols (MAGs, DAGs, TAGs) (Tab. 2). Unfortunately, MAGs, DAGs and TAGs were present only as traces, making further identification impossible (in samples RP7, RP22, RP29, RP31, RP71, RP98). Therefore, in order to elucidate the origin of residues in pottery vessels, the $\delta^{13}C$ values of the principal fatty acids $C_{16:0}$ and $C_{18:0}$ were determined.

First, fat extracts from the samples were classified into principal commodity groups by plotting $\delta^{13}C_{16:0}$ versus $\delta^{13}C_{18:0}$ (Fig. 6). The three principal sources of animal fats were generated from the $\delta^{13}C$ values of modern domestic animal fats. Theoretical mixing curves were calculated to show the effect of vessel re-use and the processing of mixtures of commodities (*Copley* et al. *2005*). It should be mentioned that these modern animals (cow, sheep and goat) were from the same geographical area as Resnikov prekop and fed exclusively on C3 forage grasses (see *Budja* et al. *2013.Tab. 3*).

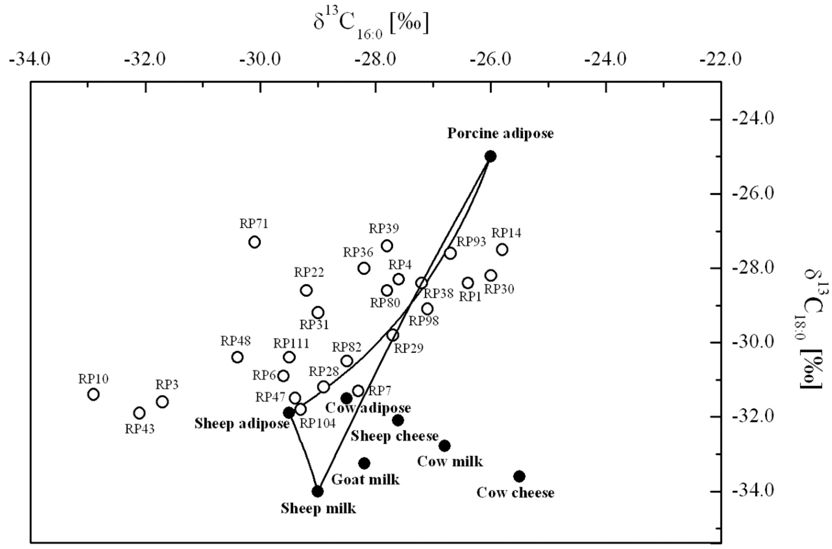

Fig. 6. Plot of the $\delta^{13}C$ of $C_{18:0}$ and $C_{16:0}$ fatty acids of modern reference fats and the lipid extracts of pottery samples from Resnikov prekop. Open circles represent the archaeological fats. The theoretical mixing curve is plotted to illustrate $\delta^{13}C$ values resulting from the mixing of modern fats (see **Budja** *et al. 2013.***Tab. 3***).*

The lipid extracts that plot between the reference animal fat field indicate the presence of a mixture of these specific fats as a consequence of vessel re-use (Fig. 6). As can be seen, there is evidence of the processing of ruminant animal products derived mainly from adipose fat (RP6, RP7, RP28, RP47, RP104), while none of the extracts plot within or in the vicinity of the reference porcine adipose fat or in the area of dairy fat. However, some samples plot in the area between porcine and ruminant adipose fat (RP1, RP4, RP14, RP29, RP30, RP38, RP80, RP82, RP93, RP98), suggesting that these vessels were used to process mixed ruminant and non-ruminant adipose fats. The data that do not plot along any of the theoretical mixing curves (RP3, RP10, RP22, RP31, RP36, RP39, RP43, RP48, RP71, RP111) indicate an admixture of fats of different origin and different degrees of degradation.

Furthermore, the plot where $\Delta^{13}C$ values ($\delta^{13}C_{18:0}$–$\delta^{13}C_{16:0}$) are plotted against the $\delta^{13}C_{16:0}$ values define the origin of the fats more explicitly (Fig. 7) by eliminating variability in diet and sources of local environmental variations (*Copley* et al. *2005*). Up to 15 samples (60%) contained predominantly ruminant adipose fat, indicating that ruminant meat produce was an important commodity at Resnikov pre-

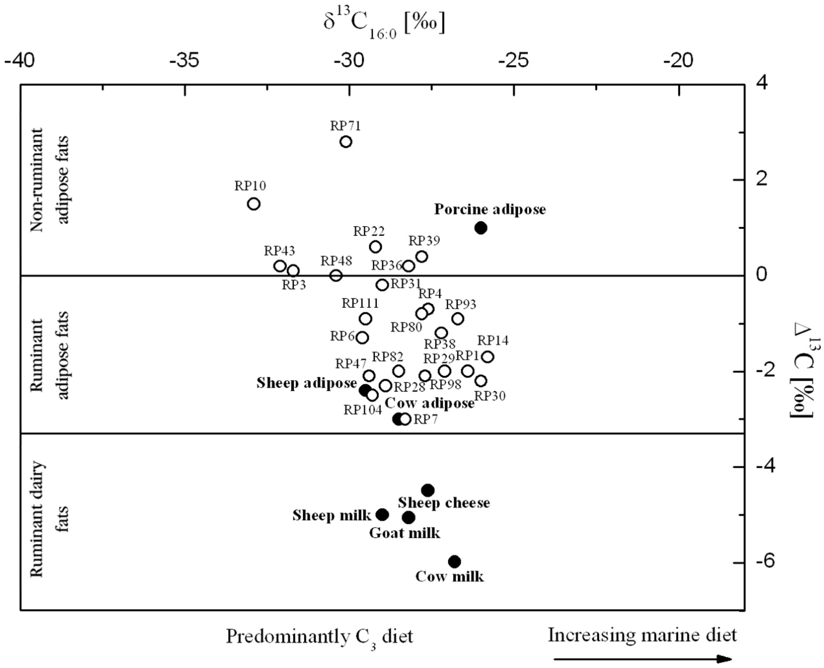

Fig. 7. Plot showing the difference in the $\delta^{13}C$ values of $C_{18:0}$ and $C_{16:0}$ fatty acids ($\Delta^{13}C$) versus $\delta^{13}C_{16:0}$ recovered from pottery extracts from Resnikov prekop and modern reference fats (see **Budja** *et al.* **2013.Tab. 3***).*

kop. One of the samples (RP7) plotted on the border of two ranges of ruminant and dairy fats suggests the possible mixing of these two types of fat during pottery use. However, none of the pottery samples plot below the $\Delta^{13}C = -3.3‰$ line, which was used as a criterion to determine dairy foods (*Evershed* et al. *2002; 2008; Copley* et al. *2003; 2005*).

A further 7 samples or 28% (RP3, RP22, RP31, RP36, RP39, RP43 and RP 47) fall close to the $\Delta^{13}C = 0‰$ line and are therefore indicative of the processing of mixed ruminant and non-ruminant animal products and/or processing of mixed plant and animal fats. Two of the samples plot in the area of non-ruminant adipose fat (RP10, RP 71). Low $\delta^{15}N$ values of –0.3 and +1.4, respectively, suggest the presence of plant fats in these two samples, and the high $C_{16:0}/C_{18:0}$ ratio of 4.0 (Tab. 2) determined in sample RP10 indicates the presence of degraded vegetable oil (*Copley* et al. *2005*). Fish fat was not detected in any of the pottery samples from Resnikov prekop.

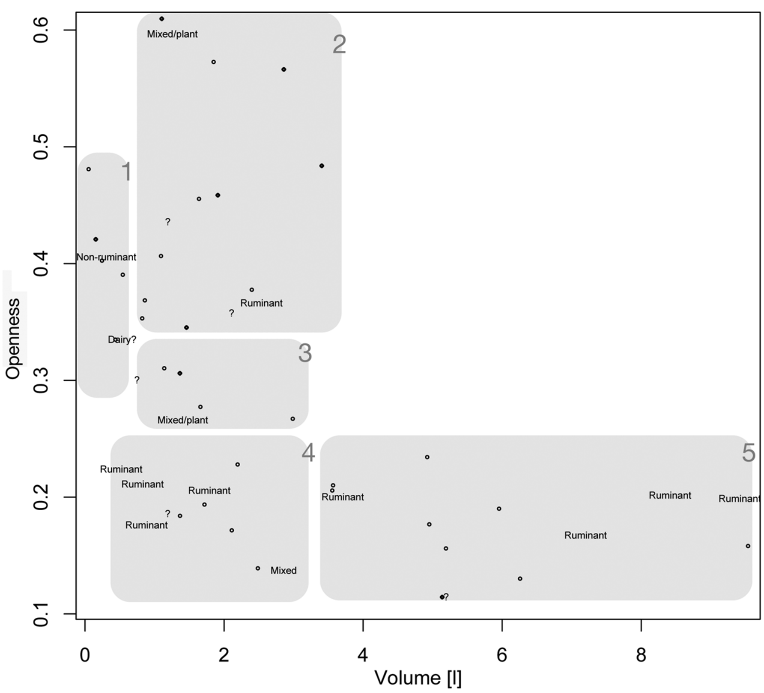

Fig. 8. Vessels from Resnikov prekop arranged according to capacity, openness and predominant organic residue identified using lipid analysis. Vessel use groups are indicated.

The processing of plant products was also detected by a homologous series of long chain *n*-alkanes and *n*-alcohols in almost 68% of the pottery samples. These compounds were associated with adipose fats (RP1, RP7, RP27, RP28, RP29, RP30, RP38, RP104, RP111), a mixture of ruminant and non-ruminant fats (RP4, RP22, RP31, RP36, RP39, RP43, RP80) and one with non-ruminant fat (RP71). The appearance of both animal and plant biomarkers suggests that these vessels were associated with the cooking/processing of a variety of different foods.

Pottery use at Resnikov prekop

The vessels from Resnikov prekop reveal a broad range of sizes, forms and fabrics, as demonstrated by our analyses. We could detect no correlation between functional types and fabric groups, suggesting that variability could not be explained by technical choices, but different traditions or individual idiosyncrasies. The vessels are generally very small, with a maximum volume of 9 litres, and capacities peak between 0.5 and 3.5 litres. This suggests that most of the assemblage consists of vessels for preparation and storage for small groups of people and individual consumption. The lipid residue analysis demonstrates that the vessels from Resnikov prekop were mostly used to process and serve different foods derived from terrestrial animals, mostly ruminants such as sheep, cattle or goat (Fig. 8).

Vessels that can be interpreted as cooking pots are generally lacking. Pots with very low accessibility (groups 4 and 5) are generally well made and richly decorated, have very thin walls and are made from a large variety of different fabrics. Only terrestrial animal (mostly ruminant) fats were detected in these two groups. Ruminant fat was also detected in jugs with very low capacities (Fig. 8). Rather than cooking pots, they can probably be interpreted as being for the long-term storage of foods containing ruminant fats. Richly decorated pots in this group might point to the social importance of such foodstuffs (*e.g.*, sample RP82; Fig. 4).

Plant fats were very rarely detected in pots, where terrestrial animal fats predominate in the samples. Traces of terrestrial plant foods, mostly mixed with animal fats, were found mostly in more open vessels (groups 3, 2 and 1) described as pedestal dishes, bowls, cups and beakers (Fig. 8). The only evidence of possibly dairy fats was found in group 1, with small volumes and moderate openness, intended for individual uses.

The exclusively terrestrial diet suggested by the lipid analysis is in stark contrast with the environment of Resnikov prekop. Since the site is located in a marshy floodplain and was interpreted as a pile-dwelling, we would expect many more freshwater resources to be used in food preparation and storage. Fish remains are present on some pile-dwellings (*Govedič 2004*) as well as elements of fishing toolkits (harpoons, hooks, net weights; *Greif 1997*); however, the scale and importance of fishing and the role of freshwater foodstuffs in the diet of people who lived at these sites remains unknown.

The pottery assemblage from Resnikov prekop is unusual, especially compared to the nearby site of Maharski prekop (see *Mlekuž* et al. *2012*). The Resnikov prekop assemblage clearly lacks vessels that can be interpreted as food processing vessels; instead, it seems that most of the larger pots were used for storage and consumption, perhaps even for displaying food.

Food articulates identity in many ways. Food can be described as "*a highly condensed social fact*" (*Appadurai 1986.494*). Food storage and consumption at Resnikov prekop seem to have played an important role in the expression of collective identity. The use of relatively large, richly decorated pots in the daily routine of food consumption expressed and created relations of equality or solidarity within group(s). On the other hand, the importance of individual consumption reflected in the wide variety of small serving vessels suggests that food consumption played a role in the creation of individual identity, indicating rank, distance or segmentation (*Appadurai 1986*).

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