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Stable Isotopes, Radiocarbon and the Mesolithic–Neolithic Transition in the Iron Gates

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ABSTRACT – *The results of stable carbon and nitrogen-isotope analyses of human bone collagen from the Iron Gates sites of Lepenski Vir, Vlasac and Schela Cladovei are reconsidered in the light of recent developments in stable isotope palaeodietary research and new information on chronology. The revised data have implications for the interpretation of Lepenski Vir and Vlasac, and the timing of the Mesolithic–Neolithic transition in the Iron Gates.*

IZVLEČEK – *V članku smo preučili rezultate analiz stabilnih izotopov ogljika in dušika iz kolagena človeških kosti, ki izvirajo iz najdišč Železnih vrat: Lepenski Vir, Vlasac in Schela Cladovei. Pri tem smo upoštevali najnovejše izsledke raziskovanja paleoprehrane s stabilnimi izotopi in nove kronološke podatke. Nanovo pregledani podatki vplivajo na interpretacijo Lepenskega Vira in Vlasca ter na časovno umestitev mezolitsko-neolitskega prehoda v Železnih vratih.*

KEY WORDS – *Iron Gates; stable isotopes; radiocarbon; palaeodiet; Mesolithic; Neolithic; Lepenski Vir; Schela Cladovei; Vlasac*

INTRODUCTION

The Iron Gates has an abundant and continuous record of human occupation in open-air settlements from the Late Mesolithic into the Early Neolithic, *c.* 8500-6500 BP (7500-5450 cal BC). While early farming settlements are well represented in other parts of the Balkan peninsula, Mesolithic sites are uncommon and there are few if any sites that were inhabited continuously from one period to the next. Therefore, the Iron Gates is arguably the only area of southeast Europe where the transition from Mesolithic to Neolithic can be studied in detail.

The evidence for changes in subsistence practices across the Mesolithic-Neolithic transition in the Iron Gates was reviewed by Bonsall *et al.* (*1997*). Their assessment was based largely on the results of stable carbon and nitrogen isotope analyses of human bone from Lepenski Vir, Vlasac and Schela Cladovei.

The purpose of the present paper is to re-examine the Iron Gates stable isotope data and their significance, in the light of better information on food sources and chronology.

DIETARY RECONSTRUCTION FROM STABLE ISOTOPES: SOME BASIC CONSIDERATIONS

Stable isotope analysis of carbon and nitrogen in bone collagen has become a standard technique for palaeodietary studies. The underlying principles may be summarized briefly as follows:

- stable isotope ratios in bone collagen reflect those in diet
- ratios of stable isotopes vary naturally between major food sources
- therefore the importance of different foods in human diets can be estimated from the isotopic composition of collagen.

Table 1 lists "typical" $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen for various major food sources. With each step along the food chain, there is fractionation of one isotope relative to another, resulting in a change in ratio. Most workers assume a slight enrichment in $\delta^{13}C$ (up to 1‰) and an enrichment in $\delta^{15}N$ of 3–4‰ between the bone collagen of the food source and that of the consumer. Because aquatic food webs are more complex than terrestrial food webs, this results in much higher $\delta^{15}N$ values at the top of the aquatic food chain. These factors lead to the "expected" values in bone collagen of humans shown in Table 2.

Food source	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
C_3 terrestrial herbivores	−21.0	+5.0
freshwater fish	−20.0	+11.0
marine fish	−13.0	+13.0

Tab. 1. "Typical" $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen of three major animal food sources available to humans.

The figures for stable isotope ratios in food sources and estimates of trophic level effects cited above should be regarded as "global" averages. There can be significant variation between ecosystems. Therefore, precise dietary reconstruction requires detailed knowledge of the isotopic compositions of local food resources.

Humans feeding on:	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
C_3 terrestrial herbivores	−20.0	+8.0
freshwater fish	−19.0	+14.0
marine fish	−12.0	+16.0

Tab. 2. "Expected" $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen of humans feeding exclusively on each of the food sources listed in Table 1.

Other factors need to be taken into account when interpreting stable isotope data. Bone collagen in adult humans is estimated to have a turnover (replacement) rate in a range of 10–30 years (*Mays 1998*). Therefore, stable isotope ratios are a reflection of average diet over decadal timescales. However, in children the turnover rate is probably more rapid (*Kleppinger 1984*). Furthermore, the nitrogen isotopic composition of bone collagen is thought to reflect mainly the protein component of the diet as virtually all nitrogen in food comes from protein. Carbon in collagen can be derived from protein, fats or carbohydrates. In high protein diets, the carbon in collagen is thought to come mainly from protein, but in low protein diets a significant proportion of the carbon is probably derived from carbohydrates (*Ambrose 1993*).

REVIEWING THE IRON GATES DATA

Since the original study of the Iron Gates stable isotope data (*Bonsall et al. 1997*), new information has become available that makes it possible to refine some aspects of the interpretation. This includes information on the isotopic composition of the major food sources, and more accurate age estimates for the human bone samples from Lepenski Vir, Vlasac and Schela Cladovei. There is also a larger data set for Lepenski Vir and Vlasac that can be considered.

Food sources

In the original study, because of a lack of detailed information on the isotopic composition of local food sources, the human bone stable isotope results from Lepenski Vir, Vlasac and Schela Cladovei were plotted against data for North American food sources published by Schwarcz (*1991*), with allowance for fractionation effects (Fig. 1). From this it was concluded that the diets of Mesolithic and Early Neolithic populations were a mixture of foods drawn from two major sources, freshwater fish and terrestrial herbivores/C_3 plants.

It is true that, when compared against the North American data, average $\delta^{15}N$ values for Mesolithic skeletons from the Iron Gates appear unusually high for a population that subsisted mainly on freshwater fish (cf. Fig. 1). This has led some other researchers (*Hedges et al. 1998; Schulting 1999*) to infer that the Iron Gates Mesolithic diet must have included a high proportion of Danube-caught anadromous fish from a marine environment, i.e. the Black Sea.

The possibility that anadromous fish were the source of the high $\delta^{15}N$ values was also considered by Bonsall *et al.* (*1997*) but was rejected because there was no corresponding enrichment in the $\delta^{13}C$ values, and because average $\delta^{15}N$ and $\delta^{13}C$ values for Mesolithic adults at Schela Cladovei (where there is abundant evidence for Mesolithic exploitation of

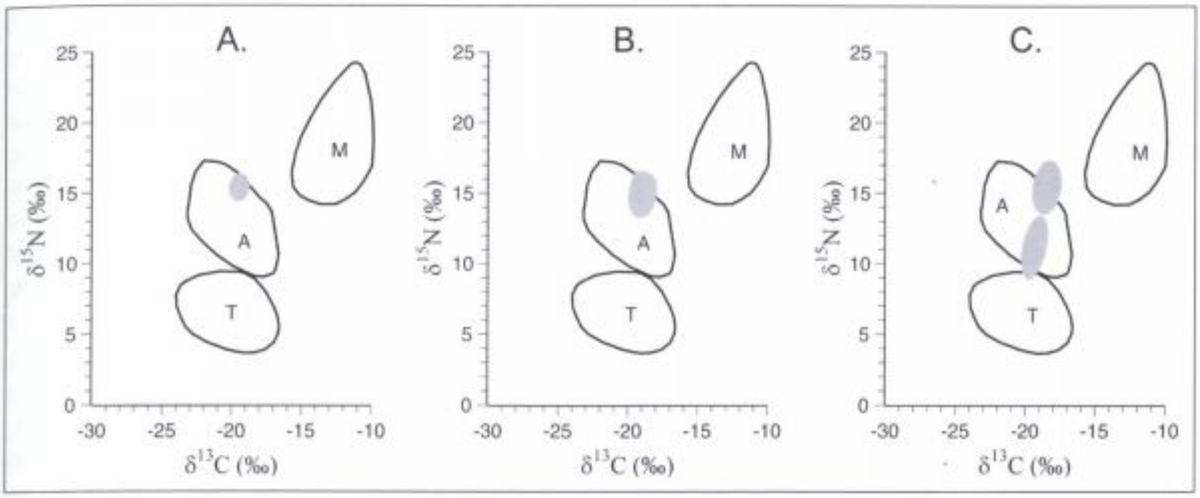

Fig. 1. $\delta^{13}C$ and $\delta^{15}N$ profiles of human populations from Schela Cladovei (A), Vlasac (B) and Lepenski Vir (C) plotted against the ranges of North American aquatic (A), marine (M) and terrestrial (T) food sources, derived from Schwarcz (*1991*). Redrawn from Bonsall et al. (*1997*).

sturgeon) appeared very similar to those of their counterparts at Lepenski Vir and Vlasac, where no sturgeon remains were identified by Bökönyi (*1969; 1970; 1977*). Although he did not claim to have been a fish expert, masses of large sturgeon remains would not have escaped his attention. Moreover, he did identify Neolithic sturgeon at the site of Mihajlovac-Knjepište (*Bökönyi 1992*), downstream of Schela Cladovei and the gorge.

In this context it is worth noting that research by Ryan *et al.* (*1997*) strongly implies that the Black Sea was a freshwater lake until 6700 BP, when there was a rapid influx of salt water as the Mediterranean broke through the Bosporus "dam". If their hypothesis is correct, then all Danube fish exploited during the Mesolithic were freshwater fish, and Neolithic people could not have had access to marine fish until after 6700 BP. This in turn implies that freshwater fish are the source of the very high $\delta^{15}N$ values recorded in Mesolithic skeletons from the Iron Gates.

Existing stable isotope data for aquatic food sources from the Iron Gates are limited to analyses of collagen from three fish bones and an otter bone from Lepenski Vir. These show no consistent pattern, with $\delta^{13}C$ values varying between -26.3 and -15.7‰ and $\delta^{15}N$ values varying between +8.2 and +12.9‰ (*Bonsall et al. 1997*). With hindsight, these results may not be unusual. Recent research suggests that $\delta^{15}N$ and $\delta^{13}C$ values of freshwater fish can be highly variable (Fig. 2). Moreover, the values can vary quite considerably for different species from the same freshwater system, and for the same species from different freshwater systems. For example, Dufour *et al.* (*1999*) report inter-species differences from Lake Constance of ~7‰ for $\delta^{13}C$ and ~8‰ for $\delta^{15}N$. In the case of the $\delta^{13}C$ values for the Iron Gates, the spread is almost 11‰. While this spread appears very large, it could be due to a number of factors:

① The number of species in the River Danube could be greater. From the work of Dufour *et al.* (*1999*) it can be observed that for each lake under study, the inter-species differences were much greater than the intra-species differences.
② The age range of the fish from the study of Dufour *et al.* (*1999*) was limited (3–5 years) while those from the Iron Gates could be much greater, as is shown by the evidence of bones from large sturgeon as well as mature carp of extremely large sizes.
③ The study by Dufour *et al.* (*1999*) was effectively a snap-shot in time, while the samples analyzed from the Iron Gates sites could conceivably span several thousand years and there could have been changes in the freshwater ecosystem within this time-span.
④ Most importantly, there could have been a shift to anadromous fish when the Bosporus was breached and the Black Sea became a marine system. The fish specimen with a $\delta^{13}C$ value of -15.7‰ and a $\delta^{15}N$ value of +12.9‰ is certainly not inconsistent with this hypothesis.

If a +3.4‰ trophic level shift is employed between freshwater fish and human bone collagen (*Minagawa and Wada 1984*), then it would require average $\delta^{15}N$ values for Danube fish of approximately +10.5‰, or greater, to produce human bone collagen values of >+14‰, which are characteristic of Mesolithic people from the Iron Gates. While this type of data for fish from the Iron Gates is limited, such values are not uncommon. Iacumin *et al.* (*1998*) and Pate (*1998*) report δ^{15}N values of about +12‰ for Lake Nasser and South Australia fish, respectively. Dufour *et al.* (*1999*) report δ^{15}N values >+13‰ for fish from Lake Geneva and Lake Constance, while Hobson and Welch (*1995*) report δ^{15}N values for large char collected from a high Arctic lake in Canada of >+14‰.

The enrichment of any species will of course depend on the complexity of the food web and its trophic level within the web. Moreover, there is evidence for certain freshwater species that the δ^{15}N value increases with the age/size of the fish. This is related to the fact that as a fish grows, it tends to feed at higher trophic levels - in effect, it becomes increasingly carnivorous - and beyond a certain growth stage may start to feed on smaller members of the same species. This phenomenon has been reported for arctic char from Canada (*Hobson and Welch 1995*). It may also be characteristic of species such as carp, catfish and sturgeon, which dominate fish bone assemblages from the Iron Gates. Many Mesolithic specimens of these species from the Iron Gates sites were very large and, in comparison to their numbers, such fish may have made a disproportionately large contribution to the food supply.

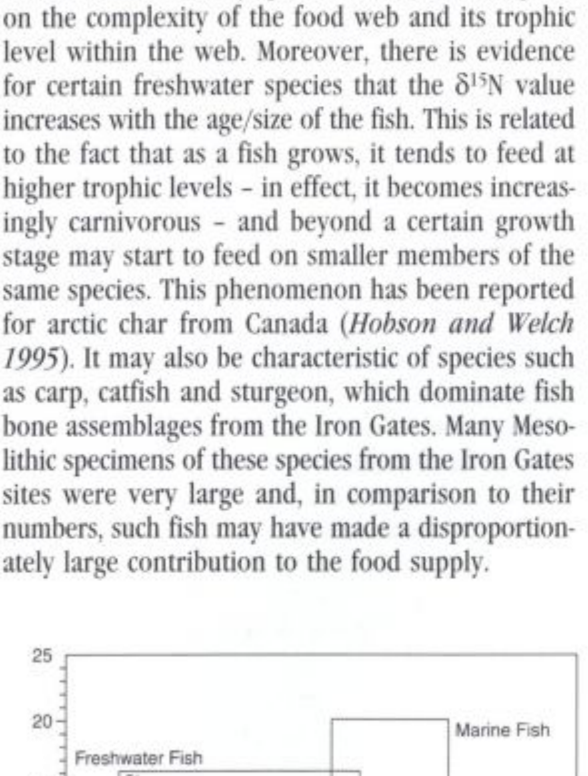

Fig. 2. δ^{13}C and δ^{15}N natural variations in freshwater fish (F1), terrestrial herbivores (T1) and marine fish from Eurasia (*after Dufour et al. 1999*) compared against North American freshwater fish (F2) and terrestrial herbivores (T2) (*after Schwarcz 1991*) and terrestrial herbivores (T3), river fish (●) and an otter (■) from the Iron Gates (*after Bonsall et al. 1997*).

It will be evident from the foregoing discussion and Figure 2 that the North American data on freshwater fish published by Schwarcz (*1991*) are not necessarily an appropriate model for the Danube, and that locally derived data are to be preferred. While the locally derived data are limited to three fish bone collagen analyses, the isotopic signature for the otter (δ^{13}C, -19.8‰; δ^{15}N, +10.7‰) effectively provides an average signature for small fish from the Iron Gates, since these will be its primary food source, and arguably, this provides the most reliable model for the Mesolithic human population of the Iron Gates (Fig. 2). An otter's diet comprises primarily small fish, but includes other aquatic animals and small land mammals. Compared to an otter, the bone collagen of a human feeding mainly on much larger fish (and occasionally otters) from the same freshwater ecosystem could be expected to show a slight enrichment in δ^{13}C and an enrichment of 3-4‰ in δ^{15}N. The data for Mesolithic people from Lepenski Vir, Vlasac and Schela Cladovei are perfectly consistent with this model.

While further research is needed into the isotopic composition of aquatic food resources available to Mesolithic and Neolithic peoples in the Iron Gates, new information *is* available for terrestrial food sources. Collagen values for ungulate bone samples from Mesolithic and Neolithic contexts at Lepenski Vir and Schela Cladovei can be substituted for the North American herbivore data used in the original study (*Bonsall et al. 1997*). Figure 2 compares the two data sets (T2, T3). Although not all the Iron Gates ungulate samples could be identified to species, probably they derive mainly from deer and cattle. The spread of values on the δ^{13}C axis is significantly less for the Iron Gates data set and, while the spread on the δ^{15}N axis is similar to the North American sample, the median value (+5.3‰) is significantly higher.

Taking into account the various lines of information on the isotopic composition of aquatic and terrestrial food sources, it seems reasonable to continue to use the δ^{15}N value as a measure of freshwater *versus* terrestrial food intake in Iron Gates stone age populations (*cf. Cook et al., in press*). An end point of +17‰ for a 100% aquatic diet is assumed, which is the highest δ^{15}N value measured in an adult from the Iron Gates region (*Bonsall et al. 1997*). For a 100% terrestrial diet a value of +8‰ is assumed. This is based on studies by Ogrinc (*1999*) and Mays (*1998*) supported by local data for herbivores, as discussed above.

Chronology

In their original study, Bonsall *et al.* (*1997*) published new AMS ^{14}C age measurements on human bones from Lepenski Vir, Vlasac and Schela Cladovei. For all three sites, the human bone ages were older than expected on the basis of existing dates on charcoal - for detailed discussion, see Cook *et al.* (*in press, and forthcoming*).

From this, it was suggested that the bone collagen of humans who had ingested large quantities of freshwater fish may be depleted in ^{14}C as a consequence of the consumption of material from a reservoir that differed in ^{14}C specific activity from the contemporary atmosphere, thus resulting in ^{14}C ages that are "too old".

It was further suggested that this possibility could most easily be tested by comparing radiocarbon age measurements on human bones with those on artefacts of terrestrial animal bone found in the same graves. Schela Cladovei provided material ideal for investigating this problem in the form of bone projectile points, made from long bone splinters of artiodactyls, found in direct association with skeletons. These were either embedded in human bone or found immediately adjacent to bones of articulated skeletons (which may originally have been embedded in the soft tissue surrounding the bones). In all cases, the bone points may have been the actual cause of death.

Cook *et al.* (*in press*) obtained AMS ^{14}C dates on paired human and ungulate bone (projectile point) samples. Systematic differences were found between the two sets of ages, demonstrating the existence of a freshwater reservoir effect, and its magnitude was calculated as 540±70 radiocarbon years. From this, and using the $\delta^{15}N$ value as a measure of the proportion of the diet derived from aquatic foods, it is possible to apply a correction to the human bone ages from all the sites (*Cook et al. in press, and forthcoming*). The corrected ages are given in Table 3. The effect of the correction is to make the human bone ages significantly younger by approximately 200–500 years depending on the $\delta^{15}N$ value. However, the reservoir-corrected ages are less precise, i.e. have larger error terms.

The expanded data set

Bonsall *et al.* (*1997*) reported $\delta^{13}C$ and $\delta^{15}N$ measurements on 70 individual skeletons - 33 from Lepenski Vir, 29 from Vlasac, and 8 from Schela Cladovei. All the skeletons were those of adults of (supposedly) known chronological context. The Schela Cladovei skeletons were a burial group from below and adjacent to a Mesolithic "house", and seven of them were directly dated by AMS to the Late Mesolithic (Tab. 3). The skeletons from the other two sites had all been recorded as belonging to specific phases of Mesolithic or Early Neolithic occupation - Vlasac I–III ("Mesolithic"), Lepenski Vir I–II ("Mesolithic") and Lepenski Vir III ("Neolithic").

To the original data set can now be added the results from a further 46 skeletons, all from Lepenski and Vlasac. They comprise both adults (25 from Lepen-

Site	Laboratory ID	Burial	^{14}C Age BP	Corrected ^{14}C age BP	Calibrated Age Range (2σ) BC
Schela	OxA–4384	M52	8570±105	–	–
	OxA–4379	M43	8550±105	8070±122	7450–6645
	OxA–4385	M55	8510±105	8090±118	7465–6653
	OxA–4382	M49	8490±110	8046±124	7448–6615
	OxA–4380	M46	8460±110	8046±123	7448–6640
	OxA–4378	M42	8415±100	7971±116	7295–6512
	OxA–4381	M48	8400±115	7932±130	7289–6466
	OxA–4383	M50	8290±105	7834±120	7061–6439
Vlasac	OxA–5824	72	10240±120	9850±130	9949–8843
	OxA–5822	51a	8760±110	8380±120	7600–7080
	OxA–5827	83	8200±90	7810±105	7049–6441
	OxA–5823	54	8170±100	7750±115	7032–6401
	OxA–5826	24	8000±100	7600±115	6647–6625
Lepenski Vir	OxA–5827	31a	7770±90	7310±108	6404–5926
	OxA–5830	44	7590±90	7150±106	6225–5797
	OxA–5828	32	7270±90	7040±95	6156–5721
	OxA–5831	88	7130±90	6960±93	6011–5644
	OxA–5829	35	6910±90	6720±93	5772–5479

Tab. 3. Human bone radiocarbon ages from Lepenski Vir, Vlasac and Schela Cladovei, corrected for the freshwater reservoir effect using method 1 of Cook et al. (**forthcoming*****). All ^{14}C ages are expressed in conventional radiocarbon years BP (before 1950 AD). The errors are expressed at the one-sigma level of confidence. Calibrated age ranges were determined using CALIB 4.2 (*****Stuiver and Reimer 1993; Stuiver et al. 1998*****).***

ski Vir, and 2 from Vlasac) and children (12 from Lepenski Vir, and 7 from Vlasac). The adults are individuals whose chronological context is either unknown or not recorded, or which (in the case of five samples from Lepenski Vir) were assigned to post-Neolithic occupations. These new data are only presented here in graphic form (Figs. 4–7). Full details will be presented in a later publication.

All analyses were carried out by the sealed tube combustion method described in Bonsall *et al.* (*1997*). Briefly, this comprises the combustion of small collagen samples in evacuated quartz tubes containing copper oxide as the source of oxygen and a small quantity of silver wire to remove halide contaminants. The CO_2 and N_2 are then cryogenically separated and analyzed by stable isotope mass spectrometry. The authors consider this to be the most precise and accurate method to determine stable isotope ratios in human bone collagen, and would advise that these and continuous flow measurements should not be combined.

In the original study, identification of groups was done primarily by visual inspection of bivariate scatterplots. In this paper, a variety of exploratory and formal statistical methods, including exploratory cluster analysis, linear discrimination techniques and hypothesis tests have been used to explore groupings and to assess evidence for pre-defined archaeological groups. Statistical analysis was carried out in MINITAB v. 13.

DISCUSSION

Adults

Lepenski Vir

The original data set from Lepenski Vir comprised measurements on 33 adults from the various Stone Age occupation phases that were recognized by Srejović (*1969; 1972; Zoffmann 1983*) – Proto-Lepenski Vir, Lepenski Vir I, II and III. A bivariate scatterplot of the data (*Bonsall et al. 1997; cf. Fig. 1c*) suggested that there were two groups. One group exhibited $\delta^{13}C$ and $\delta^{15}N$ values that were similar to Mesolithic individuals from Schela Cladovei and Vlasac (cf. Figs. 1a and 1b), indicative of diets with a high input of protein from aquatic sources, and the other showed much lower $\delta^{15}N$ values suggesting diets with increased levels of protein from terrestrial food sources. Cluster analysis of the original data set (Fig. 3) broadly supports these two groupings.

The enlarged data set of 58 adults comprises the 33 individuals that had been attributed to Mesolithic and Neolithic contexts, plus 5 individuals "dated" to the Chalcolithic and Medieval periods, and 20 individuals that were not assigned to any occupation "phase". Dietary end points of +8‰ and +17.0‰ were adopted as representing 100% terrestrial and 100% aquatic diets respectively (*Cook et al. in press*). Cluster analysis of this revised data set suggests that there are at least three groups, distinguished primarily on the basis of the $\delta^{15}N$ value (Fig. 4A). The individuals in group 1 have $\delta^{15}N$ values ranging between +14.4 and +17.0‰, which implies that this group had diets in which 71–100% of the protein was derived from aquatic sources. Group 3 individuals have $\delta^{15}N$ values between +9.3 and +11.2‰, which implies that the bulk (64–86%) of the protein came from terrestrial sources. Group 2 skeletons have $\delta^{15}N$ values ranging from +11.8 to +14.0‰, intermediate between groups 1 and 3, indicating diets in which protein was derived from aquatic and terrestrial sources in similar proportions (42– 67%).

The provisionally identified groups (clusters) do not correspond to archaeological (Srejović) phases and groups contain individuals of diverse age at death and both sexes. However, there appears to be a link between groups and radiocarbon age. Of the five radiocarbon ages currently available (Tab. 3), two lie in group 1 (7310±108 BP, 7150±106 BP), one falls in group 2 (7040±95 BP), and two lie in group 3 (6960±93 BP, 6720±93 BP). The reservoir-corrected ages form a more or less continuous series, and suggest that the three groups relate to different phases in the use of the site.

The dendrogram (Fig. 4A) and scatterplot (Fig. 4B) show that sub-groups may exist within the main groups 1 and 3, but their identification is based on only small numbers of individuals and so remains unconfirmed.

For example, in group 1 there are seven individuals with very low $\delta^{13}C$ values relative to $\delta^{15}N$, and with virtually identical $\delta^{15}N$ values (Fig. 4B, "sub-group 1b"). Of these, five are male/probably male, one is probably female, and one is of indeterminate sex (*Roksandić 1999*). The female is an elderly individual (>40). Given the age/sex composition of this "sub-group" and the fact that there is at least one child with a similar $\delta^{13}C$ isotopic signature (see below), it would be difficult to see these as "outsiders" who had married into the Lepenski Vir community (*cf. Bonsall et al. 1997*). A more likely expla-

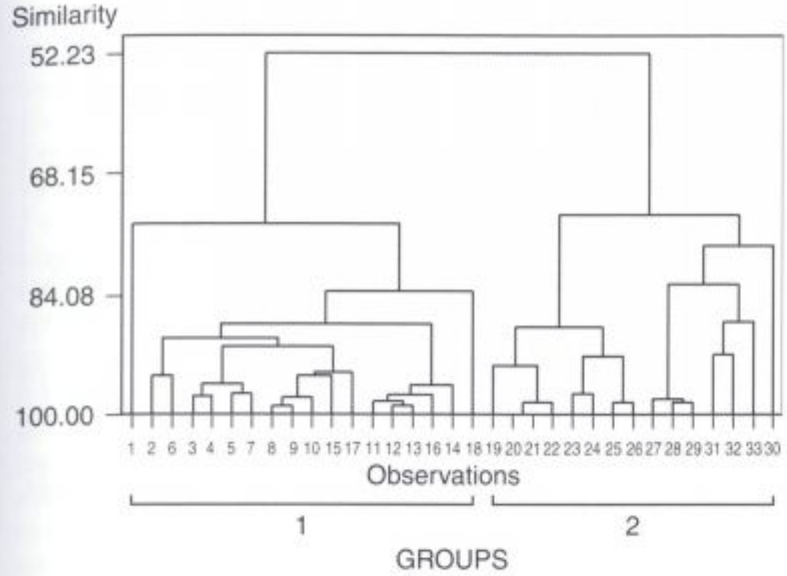

Fig. 3. Dendrogram grouping 33 skeletons from Lepenski Vir (**cf.* **Bonsall et al. 1997*****) according to $\delta^{13}C$ and $\delta^{15}N$ values.***

nation is that they represent a specific phase in the occupation of the site when people had access to aquatic food sources that were relatively depleted in ^{13}C (compared to other group 1 individuals). Variations in the isotopic composition of Danube fish may have occurred through time as a result of natural changes in the freshwater ecosystem.

A similar explanation may be proposed for four individuals in group 3 who have unusually enriched $\delta^{13}C$ relative to $\delta^{15}N$ values (Fig. 4B, "sub-group 3b"). They evidently consumed larger amounts of $\delta^{13}C$-enriched terrestrial (and possibly aquatic) foods compared to other group 3 individuals, which may indicate that they belong to a different phase in the occupation of the site. Theoretically, changes in the natural environment and/or economic practices could have raised average $\delta^{13}C$ levels of some important food sources. Such changes include (i) an increase in grazing herbivores (including domesticated cattle) at the expense of browsers (deer), as agriculture expanded and woodland cover was reduced; (ii) the introduction of C_4 millet (*Panicum miliaceum*) into the food chain during the Neolithic (or a subsequent increase in its use) either directly as human food or indirectly as grown forage for livestock, and (iii) the appearance of true marine fish (anadromous) in the Danube after 6700 BP when the Black Lake was converted into the Black Sea.

The suggestion that within their respective groups, "sub-groups" 1B and 3B are chronologically distinct is a working hypothesis that requires confirmation from radiocarbon dating.

Vlasac

Cluster analysis of the enlarged data set of 35 individuals from Vlasac suggests a division into four groups (Fig. 5A). Groups 1 and 4 are separated on the basis of $\delta^{15}N$. Groups 2 and 3 are distinguished on the basis of both $\delta^{13}C$ and $\delta^{15}N$ (Fig. 5B).

Again, the provisional groups (clusters) do not correspond to archaeological phase (*cf. Srejović and Letica 1978*) and groups contain individuals of diverse age at death and both sexes. Of the five radiocarbon ages currently available, four lie in group 1 (9800±108 - 7768±113 BP) and one lies in group 2 (7598±113 BP). The single group 2 age measurement is in trend the youngest and raises the possibility that the two clusters represent different periods in the use of the site. However, to confirm any time relationship between the two groups would require further ^{14}C measurements with improved precision.

No ^{14}C age measurements are currently available for groups 3 or 4. Groups 1-3 at Vlasac have $\delta^{13}C$ and $\delta^{15}N$ values similar to group 1 at Lepenski Vir, while Vlasac group 4 has $\delta^{15}N$ values in the range of Lepenski Vir group 2. Vlasac and Lepenski Vir occupy almost identical riverside locations just a few kilometres apart that, presumably, gave access to essentially the same food resources. Therefore, it may be suggested that Vlasac group 4 belongs to the same time-range as Lepenski Vir group 2, and is later than Vlasac groups 1-3 and Lepenski Vir group 1.

Children

Isotopic analyses are available for 10 children (under 15 years old) from Lepenski Vir. These are compared against the adult ranges in Figure 6. The overall distribution is similar to that of the adults. Six children have $\delta^{15}N$ values in the range of the group 1 adults, including one with a $\delta^{13}C$ relative to $\delta^{15}N$ value reminiscent of the adult "1b sub-group". One child has a $\delta^{15}N$ value in the range of the group 2 adults, and there are three children whose $\delta^{15}N$ values are similar to group 3 adults.

It is interesting that the first group of children have $\delta^{15}N$ values that are, on average, 1.1‰ higher than the corresponding group of adults (+16.5‰ *versus*

+15.4‰). A tendency toward more positive δ^{15}N values in children compared to adults has been observed in some previous studies (e.g. *Pate 1997; Ogrinc 1999*). This is usually attributed to the fact that, during infancy, children ingest their mothers' milk and thus, in effect, feed at a higher trophic level. After weaning, it is supposed that bone collagen turnover would result in the progressive loss of this "nursing signal" (*cf. Pate 1997*).

A "nursing effect" is not apparent for the other Lepenski Vir children, perhaps because of the very small number of individuals involved. Nor is it evident among the children from Vlasac (Fig. 7), although the possibility cannot be excluded. Of the seven Vlasac children analysed, five have δ^{13}C and δ^{15}N values similar to group 1 adults, while another has a δ^{15}N value that falls at the bottom of the range for group 2 adults. Assuming a 1.1‰ difference between the average δ^{15}N values of adults and children, it is possible that some of the Vlasac children are the offspring of group 4 females, and others are the offspring of group 1 and 2 females.

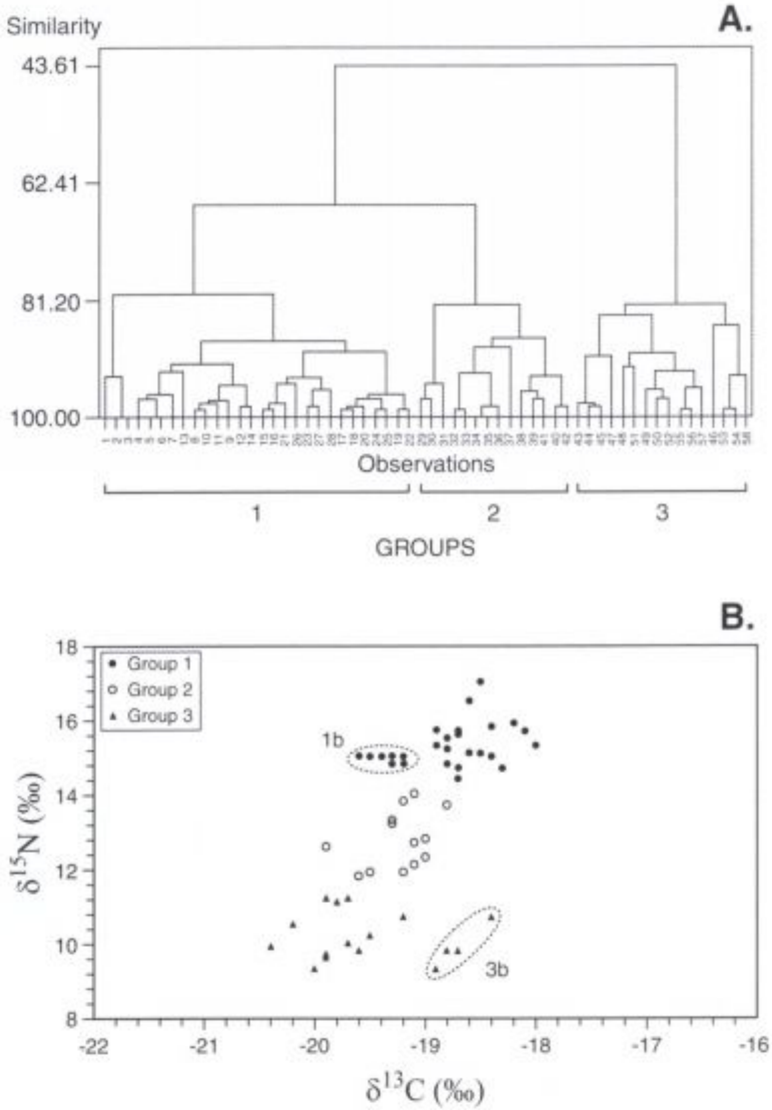

Fig. 4. A. Dendrogram grouping 58 skeletons from Lepenski Vir according to δ^{13}C and δ^{15}N values. B. Scatterplot of δ^{13}C versus δ^{15}N for 58 adults from Lepenski Vir, and groupings suggested by cluster analysis. Note the exaggerated scale on the δ^{13}C axis.

The remaining child from Vlasac has δ^{15}N and δ^{13}C values of +12.7‰ and −19.8‰, respectively. These are the lowest values recorded for any individual (child or adult) from Vlasac, and fall within the range of the group 2 individuals from Lepenski Vir. This evidence appears to confirm the presence at Vlasac of individuals with "intermediate" diets, and it is not inconceivable that this child was that of a female who had a predominantly terrestrial diet (cf. Lepenski Vir group 3).

Because of the possibility of systematic differences between the isotopic signatures of adults and children, it was decided that separate statistical analyses be carried out.

Dietary change and the timing of the Mesolithic-Neolithic transition in the Iron Gates

The direct AMS ^{14}C age measurements on human bones from Lepenski Vir and Vlasac (Tab. 3) are evidence of human occupation of that part of the Iron Gates gorge from *c.* 9800–6700 BP. Bone collagen stable isotope analyses indicate fundamental changes in diet during that time range.

Humans dated before 7150±106 to 7040±95 BP on the reservoir-corrected time-scale have δ^{15}N values of ≥+14.4‰, indicating diets in which the bulk (>67%) of the protein was derived from Danube fish. This phase is represented by the group 1 individuals at Lepenski Vir and by Vlasac groups 1, 2 and 3. Since there is no evidence for the keeping of domesticated animals (other than dog) prior to that time, it seems reasonable, using this criterion, to describe the pre-7150–7040 BP inhabitants of Lepenski Vir and Vlasac as "Mesolithic".

If so, when did the people of the Lepenski Vir–Vlasac section of the Iron Gates become "Neolithic" farmers?

A change in diet is evident at Lepenski Vir between 7150–7040 BP. The group 2 individuals from Lepenski Vir show a significant reduction in average $\delta^{15}N$ values, consistent with an increase in the amount of protein derived from terrestrial food sources and a corresponding decrease in protein from aquatic sources. The same change may be represented at Vlasac by the group 4 adults. At Lepenski Vir this can be seen as the beginning of a trend that culminated in the adoption of a predominantly terrestrial diet by *c.* 6960 BP, represented by the group 3 individuals. The timing of this dietary change corresponds quite closely with the appearance of Neolithic farmers in the regions surrounding the Iron Gates, represented by the earliest Starčevo-Criş-Körös settlements, and it is reasonable to infer that the two events are connected.

There are two hypotheses that can plausibly account for the changes observed at Lepenski Vir (and possibly Vlasac) after 7150±106 BP. The first is that Mesolithic people of the Lepenski Vir–Vlasac area adopted farming more or less as soon as it became available to them, and gradually increased the amount of agricultural products in their diets at the expense of traditional aquatic resources. The second is that the local population did not become farmers immediately, but traded with neighbouring farmers for agricultural products for a period of decades to centuries before eventually taking up livestock raising and cultivation.

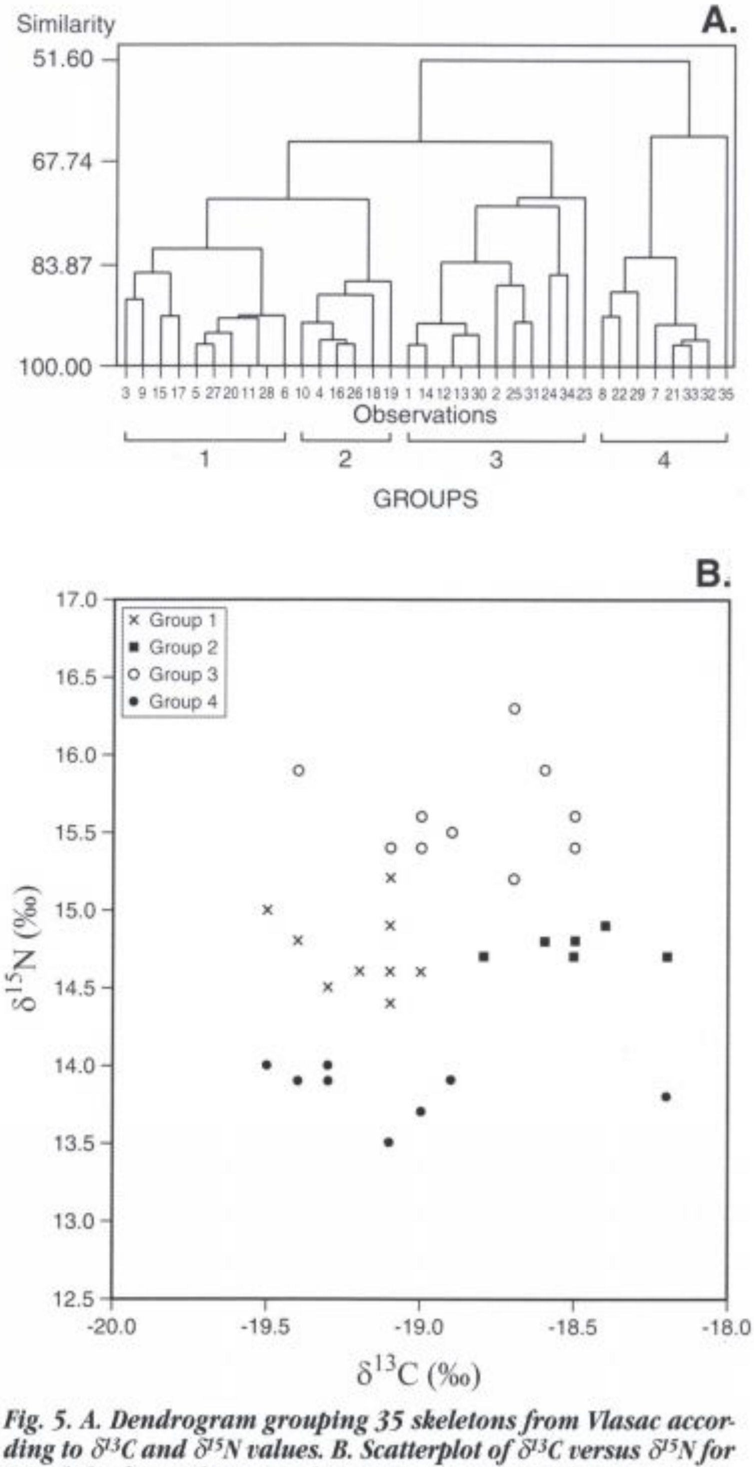

Fig. 5. A. Dendrogram grouping 35 skeletons from Vlasac according to $\delta^{13}C$ and $\delta^{15}N$ values. B. Scatterplot of $\delta^{13}C$ versus $\delta^{15}N$ for 35 adults from Vlasac, and groupings suggested by cluster analysis.

This latter possibility has been suggested by several authors, most notably Voytek and Tringham (*1989*). On the existing radiocarbon evidence, an "availability phase" (*cf. Zvelebil and Rowley-Conwy 1984; 1986*) during which Mesolithic people in the Iron Gates increased their intake of terrestrial protein through trade or exchange with farmers, could have lasted between a few decades and approximately 600 years. The same radiocarbon evidence suggests that it would have ended by *c.* 6800 BP at the latest. Two individuals from Lepenski Vir group 3 with reservoir-corrected radiocarbon ages of 6960±93 BP and 6720±93 BP have $\delta^{15}N$ values of +10.9‰ and +11.2‰, respectively, indicating predominantly (64–68%) terrestrial diets. In the context of the Iron Gates, it is difficult to see how such high levels of terrestrial protein intake could have been sustained without a direct investment in agriculture.

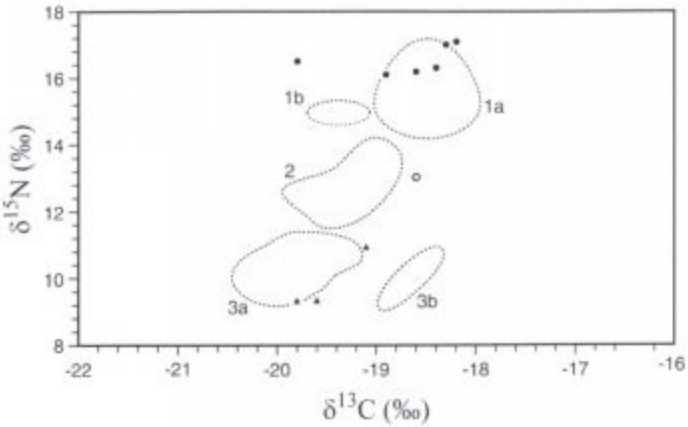

Fig. 6. $\delta^{13}C$ versus $\delta^{15}N$ for 10 children from Lepenski Vir, plotted against ranges of adult groupings suggested by cluster analysis.

Other explanations could be proposed for the *initial* reduction in average $\delta^{15}N$ values at 7150–7040 BP (cf. Lepenski Vir group 2, Vlasac group 4). They include a long-term increase in the consumption of wild animal and/or plant resources, a reduction in the average size of freshwater fish caught, or even a change in the type of fish caught. However, there is no convincing supporting evidence from either Lepenski Vir or Vlasac. Even if there were, such changes are most unlikely to account for the strongly "terrestrial" isotopic profile of the group 3 individuals from Lepenski Vir.

Stable isotopes and the dating of houses at Lepenski Vir

Since the publication of the account of the Lepenski Vir excavations (*Srejović 1969; 1972*) there has been considerable controversy over the age and cultural context of the trapezoidal-plan houses of Lepenski Vir I and II. While most authors now accept the radiocarbon ages on charcoal from the houses as valid, there is still disagreement on whether the houses should be interpreted as Mesolithic (*cf. Radovanović 1996*) or Neolithic (*cf. Ehrich 1974; Milisauskas 1978*). The radiocarbon and stable isotope measurements on human bones from Lepenski Vir, discussed in this paper, have a critical bearing on the issue.

Charcoal samples from the LV I–II houses produced ^{14}C ages between 6560 and 7430 BP (*Quitta 1972; Borić 1999*). These are similar to the reservoir-corrected ^{14}C ages on human bone (Tab. 3). If the ^{14}C ages of the charcoal and human bone samples are accepted as being correct, then the houses and the human bones can be considered as belonging to approximately the same time-range. Since the human bones appear to span the transition from a Mesolithic to a Neolithic economy, it would be reasonable to conclude that the same applies to the houses. However, as Cook *et al.* (*in press and forthcoming*) have pointed out, the charcoal samples were from long-lived tree species (oak and elm). Such samples can yield ^{14}C ages that are several hundred years older than the archaeological events they purport to date - often referred to as the "old wood" problem. Therefore, it is conceivable that the houses are significantly younger than the radiocarbon ages of the charcoal samples, and all the houses post-date the change in diet between 7150 and 7040 BP, i.e. they belong to the time-range of the group 2 and 3 humans. This would be consistent with the presence of Starčevo pottery in several of the houses that were dated (*Budja 1999.Fig. 7*). These are house 54 (7161±56 BP - weighted mean of five ^{14}C measurements), house 1 (6860±100 BP) and house 16 (6820±100 BP).

Given the uncertainties over the interpretation of the charcoal-based radiocarbon ages, the question may be asked: can it be shown that *any* of the houses at Lepenski Vir belongs to the period of the group 1 ("Mesolithic") humans?

It was suggested above that the division of the human remains from Lepenski Vir into three groups, according to the $\delta^{13}C$ and $\delta^{15}N$ values, represents a time-series. For convenience, this may be characterised as: Period 1 ("Mesolithic") dating before 7040±95 BP and comprising individuals with $\delta^{15}N$ values of $\geq$+14.4‰. Period 2 ("transitional Mesolithic-Neolithic") dating *c.* 7040±95 BP and represented by individuals with $\delta^{15}N$ values ranging between +11.8 to +14.0‰. Period 3 ("Neolithic") dating after 7040±95 BP and comprising individuals with $\delta^{15}N$ values of $\leq$+11.2‰.

If the "phasing" of the human remains based on $\delta^{15}N$ is reliable, where there is a clear stratigraphic relationship between a human skeleton and a house, it follows that the bone collagen $\delta^{15}N$ value can be used to infer the age of the house. However, this would only apply in the case of articulated skeletons. Many of the "skeletons" uncovered in the Lepenski Vir excavations appear to be groups of disarticulated bones. These could represent delayed or secondary burials of individuals who had died some time previously, and hence there could be a significant "age offset" between the time of death of the individual and the time of final burial.

Few details of the stratigraphic relationships of burials and houses are provided in published accounts of the Lepenski Vir, but there is a limited amount of photographic evidence that can be considered.

Published photographs of house 21 (*Srejović 1969. Pl. 69; Radovanović 1996.Fig. 4.3*) show the articulated skeleton of an adult female lying below the floor of the house. It is clear from other photographs published by Radovanović (*1996.Figs 3.14, 3.31, 3.32*) that the burial was inserted through the plaster floor. This relationship indicates that the burial must have been emplaced after the plaster floor was laid, and therefore (presumably) post-dates construction of the house. The skeleton (7b or 7/I) has a $\delta^{15}N$ value of +15.8‰, placing it firmly within Period 1 ("Mesolithic"). Unless this is a case of delayed burial following excarnation, which seems highly improbable, the evidence implies that house 21 is also Mesolithic.

According to Srejović (*1969; 1972; Srejović and Babović 1983*) and Radovanović (*1996*) house 21 is superimposed upon houses 22, 29 and 30 (Fig. 8), which therefore places them also in period 1. Thus, there are at least four houses at Lepenski Vir that, on the combined evidence of stratigraphy and bone collagen isotopic data, can be argued to pre-date the change in diet between 7150 and 7040 BP.

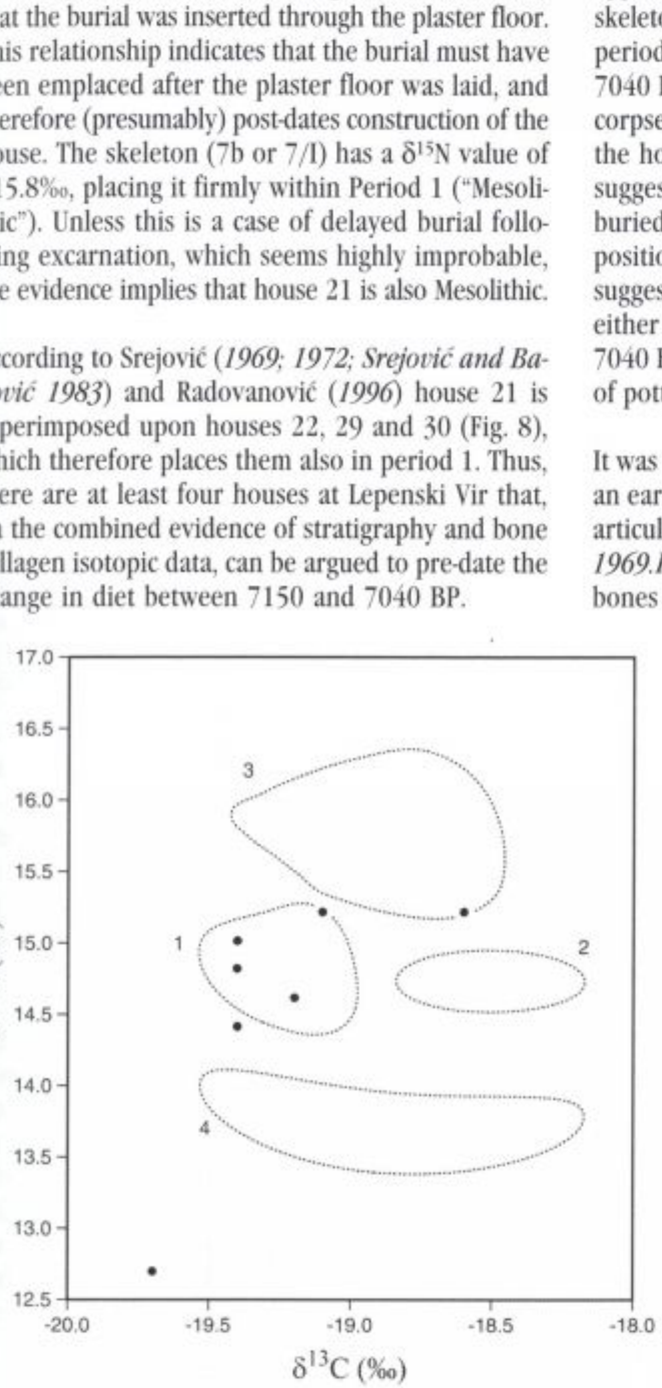

Fig. 7. $\delta^{13}C$ versus $\delta^{15}N$ for 7 children from Vlasac, plotted against ranges of adult groupings suggested by cluster analysis.

It is significant that none of the four probable period 1 houses discussed appears to have been associated with Starčevo pottery (*cf. Budja 1999.Fig. 7*). This would be consistent with a Mesolithic context and an age prior to 7040 BP.

The photograph in Srejović (*1969.Pl. 67; Srejović 1972.Pl. 58*) shows the articulated skeleton of an adult female (54e) lying directly above stone slabs apparently set into the floor of house 65 (Fig. 8). This skeleton has a $\delta^{15}N$ value of +13.2‰ and belongs to period 2, post-dating the dietary change at 7150–7040 BP. Leaving aside the question of whether the corpse was deliberately left exposed on the floor of the house, or placed beneath a cairn (a possibility suggested by other photographic evidence), or buried in a grave pit dug from a higher level, the position of the skeleton with respect to the floor suggests that the house is older and could belong to either period 1 or period 2. A period 2 (post-7150–7040 BP) age would be consistent with the presence of pottery inside the house (*cf. Budja 1999.Fig. 7*).

It was suggested by Srejović that house 65 contained an earlier burial (54d), which is represented by disarticulated bones around skeleton 54e (*Srejović 1969.Pl. 67; Srejović 1972.Pl. 58*). One of these bones gave a $\delta^{15}N$ value of +15.3‰ suggesting an age prior to 7150–7040 BP. It was claimed that the bones of 54d had been disturbed by burial 54e. However, given the disarticulated nature of 54d and the fact that the bones may be from more than one individual, they are more plausibly interpreted as a secondary burial and cannot therefore be used to "date" house 65.

The stable isotope data also have implications for Radovanović's architectural phasing of the Lepenski Vir houses (*Radovanović 1996*). As noted above, there is good evidence that houses 21, 22, 29 and 30 are Mesolithic and predate 7150–7040 BP. In Radovanović's scheme, houses 21 and 22 are assigned to phase I.2, and houses 29 and 30 to phase I.1 (Fig. 8). If her phasing of the houses were correct, one would have to conclude that the shift away from a traditional Mesolithic diet began either during or after phase I.2, and that all houses assigned to phase I.1 are Mesolithic. However, this interpretation is inconsistent with radiocarbon evidence from three other houses attributed to phase I.1 (houses 1, 9 and 37) suggesting

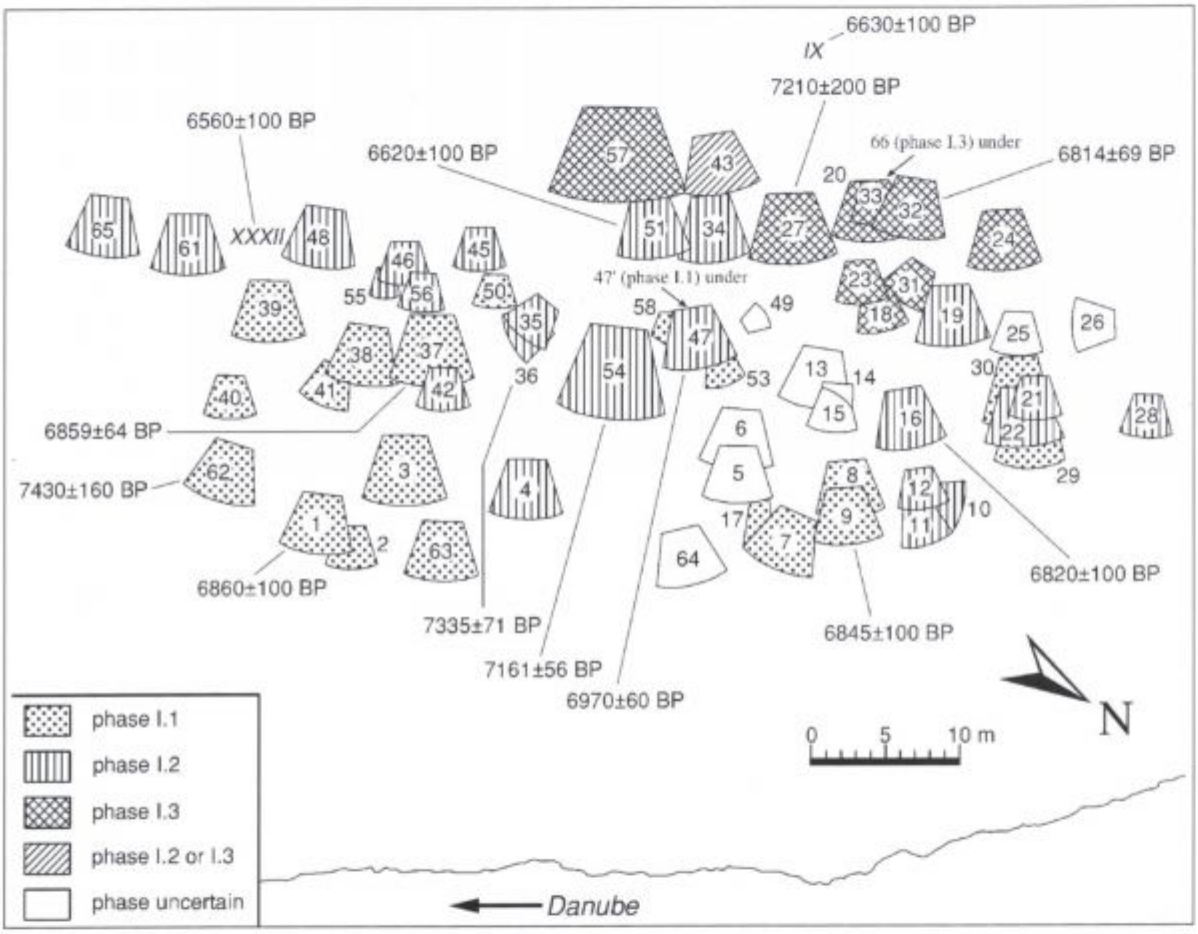

Fig. 8. Lepenski Vir I site plan showing architectural phases and radiocarbon ages of houses based on charcoal samples (*after Radovanović 1996, with acknowledgement to Borić 1999 and Bailey 2000*). The ^{14}C ages of houses 36, 37 and 54 are weighted means of several measurements. The locations of two Lepenski Vir II houses (IX and XXXII) and corresponding ^{14}C ages are also shown.

that they post-date the dietary change at 7150–7040 BP (Fig. 8).

The use of stable isotope data as a proxy dating tool may also contribute to a better understanding of the evidence from Vlasac. Five charcoal samples from Srejović and Letica's (*1978*) phase 1b gave ^{14}C ages of 6805–7000 BP. These ages were rejected because they were out of sequence with radiocarbon determinations for the succeeding phases II and III, and because they were not in accord with the excavators' belief that the contexts dated were Mesolithic. However, in European archaeology radiocarbon ages have often proved more reliable than chronologies derived from archaeological observations. The ages for "Vlasac 1b" are consistent with the presence of Early Neolithic (Starčevo) remains on the site. These have always been considered a very minor component of the archaeological record. However, as noted above, stable isotope evidence indicates that a significant proportion of the humans buried at Vlasac – the group 4 adults, representing 23% of the samples analyzed – had diets similar to the group 2 adults from Lepenski Vir, and may therefore belong to the same time-range of *c.* 7040±95 BP.

CONCLUSIONS

Reappraisal of a larger stable isotope data set for Lepenski Vir and Vlasac demonstrates a shift from a Mesolithic-type dietary regime, based largely on aquatic resources, through an intermediate phase, to one based largely on terrestrial resources that probably included a major agricultural component. Radiocarbon evidence suggests that the transition centred around 7040±95 BP (6156–5721 cal BC), and that agriculture was being practised in the Lepenski Vir–Vlasac area by 6800 BP (*c.* 5700 cal BC).

The stable isotope and radiocarbon data coupled with evidence of the stratigraphic relationships between burials and houses suggest that the trapezoidal plan houses of "LV I-II" span the time-range of the dietary change. This is contrary to previous interpretations of the houses as either exclusively Mesolithic or exclusively Neolithic. Moreover, the stable isotope evidence suggests that Lepenski Vir (and possibly Vlasac) was occupied continuously from the Mesolithic into the Early Neolithic.

For both Lepenski Vir and Vlasac, this paper has also highlighted apparent conflicts between archaeological sequences and radiocarbon based chronologies supported by stable isotope analyses. Future research must be directed toward resolving the issues that have been raised here.

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