

## Durham Research Online

---

### Deposited in DRO:

24 May 2011

### Version of attached file:

Accepted Version

### Peer-review status of attached file:

Peer-reviewed

### Citation for published item:

Smits, E. and Millard, A. R. and Nowell, G. M. and Pearson, D.G. (2010) 'Isotopic investigation of diet and residential mobility in the Neolithic of the Lower Rhine Basin.', *European journal of archaeology.*, 13 (1). pp. 5-31.

### Further information on publisher's website:

<http://dx.doi.org/10.1177/1461957109355040>

### Publisher's copyright statement:

The final definitive version of this article has been published in the journal *European journal of archaeology* 13/1, 2010  
Copyright © 2010 SAGE Publications at the *European journal of archaeology* page: <http://eja.sagepub.com/> on SAGE  
Journals Online: <http://online.sagepub.com/>

### Additional information:

## Use policy

---

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in DRO
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full DRO policy](#) for further details.

# Isotopic investigation of diet and residential mobility in the Neolithic of the Lower Rhine Basin

Elisabeth Smits  
University of Amsterdam, Netherlands

Andrew R Millard,  
Durham University, United Kingdom

Geoff Nowell  
Durham University, United Kingdom

D Graham Pearson  
Durham University, United Kingdom

# Isotopic investigation of diet and residential mobility in the Neolithic of the Lower Rhine Basin

## Abstract

Multiple isotopic systems (C, N, O, S, Sr, Pb) are applied to investigate diet and mobility amongst the Middle Neolithic populations at Schipluiden and Swifterbant (Netherlands). A review of carbon and nitrogen isotope analyses of European Mesolithic and Neolithic populations shows a shift in diet from the Mesolithic to the Neolithic, but also great variety in Neolithic diets, several of which incorporate fish. At Swifterbant (c. 4300-4000 BC) the population had a diet largely based on terrestrial and freshwater resources, despite proximity to tidal waters. Only one individual (of ten) showed evidence for migration. In contrast at Schipluiden (c. 3600-3400 BC) there were migrants who had a diet lower in marine resources than those without evidence for migration. The faunal spectrum and isotopic similarities with sites in the Iron Gates Gorge suggest that sturgeon may have been important. There is some evidence that migrants at Schipluiden were not accorded the formal burial given to locally born people.

Keywords: Neolithic, diet, migration, Netherlands, Swifterbant carbon and nitrogen isotopes, strontium isotopes, oxygen isotopes

## Samenvatting

Meervoudige isotopen systemen (C, N, O, S, Sr, Pb) zijn toegepast voor het onderzoek naar dieet en mobiliteit van de midden neolithische bevolkingsgroepen te Schipluiden en Swifterbant (Nederland). Een recensie van koolstof en stikstof isotopen analyse bij Europese mesolithische en neolithische populaties toont een verschuiving in het dieet van het Mesolithicum naar het Neolithicum, maar ook grote variatie in neolithische diëten, waarvan enkele met een aanzienlijke viscomponent. De bevolking van Swifterbant (c. 4300-4000 BC) had een dieet dat vooral gebaseerd was op landelijke en zoetwater voedselbronnen, ondanks de nabijheid van een getijdengebied. Slechts voor één individu (van de tien) zijn er aanwijzingen voor migratie. Sommige migranten te Schipluiden (c. 3600-3400 BC) hadden een dieet met minder marine voedselbronnen dan individuen van lokale herkomst. De overeenkomsten wat betreft het faunaspectrum en de isotopenwaarden met vindplaatsen in het IJzeren Poort gebied suggereren dat de consumptie van steur van belang was. Er bestaan aanwijzingen dat de migranten te Schipluiden niet op dezelfde formele wijze werden begraven als de lokale bevolking.

Sleutelwoorden: Neolithicum, dieet, migratie, Nederland, Swifterbant, stikstof en koolstof isotopen, strontium isotopen, zuurstof isotopen.

## Introduction

The transition from a Mesolithic hunter-gatherer lifestyle to a Neolithic agriculturally-based lifestyle in Europe has been the focus of much research in recent years as archaeologists have attempted to understand the cultural, technological, dietary and biological correlates of this most significant change in human subsistence. The dietary aspects of this change have been investigated for many years using traditional zooarchaeological and archaeobotanical methods, but in the last decade stable isotope analysis has become an additional major tool in these investigations. Stable isotope results have been presented as strongly indicating a rapid shift from

wild to domesticated foodstuffs (Richards et al., 2003c) but this has been contested and the meaning of the isotope evidence in contrast to the zooarchaeological evidence has been hotly debated (Barberena and Borrero 2005; Hedges 2004; Milner et al. 2004, 2006; Richards and Schulting 2006). This debate has mostly been focussed on Scandinavian, British, Breton and Portuguese sites. In this study we contribute data on Middle Neolithic populations from Swifterbant (c. 4300-4000 BC) and Schipluiden (c. 3600-3400 BC) in the Lower Rhine Basin, in addition to the dietary isotope studies of the Late Mesolithic populations of Polderweg and De Bruin (Smits and Van der Plicht 2009). Here however we also aim to go beyond the simple use of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements to examine diet and apply the isotopes of S, Sr, O and Pb to gain more insight into the diet, homogeneity of group composition, and food procurement strategies of these populations.

## Background

The Mesolithic-Neolithic transition is generally characterised by an overall change in lifestyle, especially in respect to subsistence, it witnesses a change from food gathering to food production largely coinciding with a change from living in temporary camps to permanent settlements, including the use of pottery and implements associated with a more agricultural economy. On the whole it is expected that this process is associated with a decline in the consumption of fish through time concomitant with an increased intake of terrestrial food as has been observed for several regions of North-western Europe. Regional variation in the nature and pace of the Mesolithic-Neolithic transition is a topic raised time and again. Much discussion focuses on the dichotomy in subsistence, *i.e.* the Mesolithic versus Neolithic diet, especially on the fringes of the North-western Europe. Comparisons between sites and regions are beset by problems (not always recognised) such as dating, geographical setting, climate, continuity of habitation, the quality and quantity of archaeological remains and excavation procedures as well as formation processes and the small sample sizes available for isotope research.

Isotope analysis has nevertheless increasingly been used to highlight aspects of diet and thus has become a crucial tool in the understanding of the transition. The carbon and nitrogen isotope composition of bone collagen primarily reflects the protein part of the diet, broadly distinguishing plant, animal, marine and freshwater food sources (see, for example, Hedges 2004 and the references therein). This method has proved its value and during the last ten years has been applied to a series of populations from various regions and periods all over the world. Recent debate has focused on the transition from forager to farmer in North-western Europe, with some favouring a sharp and complete transition (among others Lubell et al. 1994; Richards et al. 2003b, 2003c; Schulting 1998) but others opting for a more gradual and variable change in lifestyle during a much longer time span (including Boric et al. 2004; Lidén et al. 2004; Milner et al. 2004). Here we briefly review these studies and studies from elsewhere in Europe. In particular, studies of populations in the Iron Gates Gorges region of the Danube provide a parallel to the Lower Rhine Basin in terms of the food resources available on a major river system.

It is no wonder that different views exist on the manner in which the transition took place. Clearly for Southern Scandinavia the geographical setting of the sites played an important role, from which it has been deduced that populations in coastal areas of Southern Sweden (c.8000-3000 BC) were less inclined to radically change their food procurement strategies (Lidén et al. 2004). This contrasts with Denmark where a radical change occurs between the Mesolithic and Neolithic at about 4000 BC (Fischer et al. 2007; Richards et al. 2003b) and with sites in Latvia (Eriksson et al. 2003) where fish remained an important dietary component from the Mesolithic into

the early Neolithic, but were not detected in the Late Neolithic at the Zvejnieki cemetery (8<sup>th</sup> to 4<sup>th</sup> millennium BC). For Great Britain there is apparently a rapid change at the Mesolithic-Neolithic transition (c. 4000 BC) for both coastal and inland sites (Hedges et al. 2008; Richards et al. 2003c), although sample sizes are small. In Portugal the same sharp shift in subsistence is attested between the Late Mesolithic (c.8100-7100 BC) and the Early Neolithic (c.6900-4500 BC) (Lubell et al. 1994). For Brittany the distinction is not as clear because dating problems obscure the overall picture (Schulting 1998; Schulting and Richards 2001). The Breton Mesolithic sites of Hoëdic (c.3400-5800 BC) and Tévéc (c.5600-4300 BC) are typified as having mainly a marine/aquatic subsistence, despite inter- and intra-site variation in isotope values, while further south and away from the coast at La Vergne (Charente-Maritime, France) the Mesolithic diet was strongly terrestrial (Schulting et al. 2008). Further east on the northern coast of Europe, the Late Mesolithic sites of Polderweg and De Bruin revealed a mixed diet with terrestrial and aquatic components consistent with the exploitation of various regions throughout the year (Smits and Van der Plicht 2009). A picture distinct from the coastal areas of North-western Europe emerges from the Meuse valley where human remains from strictly continental sites were investigated in absence of comparable coastal sites (Bocherens et al. 2007). There the Early Mesolithic diet (c.9300-8000 BC) was mixed, but mainly terrestrial, but in the Middle Neolithic (c.4300-3000 BC) there is a slightly higher aquatic component in the diet. The change in composition of the diet is attributed to changes in resource availability with landscape evolution, and dietary differences are attributed to the different geographical settings of the sites. An alternative view of diet is provided by charred surface residues on pottery, from which Craig et al. (2007) deduced that Danish coastal Mesolithic Ertebølle populations (c.4600-3900 BC) utilised marine and freshwater resources, whilst inland Neolithic Funnel Beaker pottery (c.3900-2700 BC) had evidence for processing of freshwater fish. Pottery from the Late Mesolithic Ertebølle, and Neolithic Swifterbant and Michelsberg periods (c.5000-4000 BC) in the Schelde Valley of Belgium yielded evidence for freshwater fish processing. Further south, at the early Neolithic (after 5400 BC) site of Nieder-Mörlen in the Rhineland, isotope ratios are indicative of a purely terrestrial diet (Nehlich et al. 2009). Still further south, Durrwachter et al. (2006) found evidence for small amounts of freshwater fish consumption at the Early Neolithic LBK (c.5000 BC) site of Herxheim in the middle Rhine Valley of Bavaria but not in a nearby Middle Neolithic site (c.4900-4600 BC) and similarly Bosl et al. (2006) found limited if any freshwater fish consumption in the Late Neolithic of Bavaria (c.3500-3400 BC).

In Eastern Europe there is also a variable picture. Several isotope investigations have been undertaken of the populations of Lepenski Vir and Vlasac in the Iron Gates Gorge region of the Danube (c. 9000-5500 BC) (Bonsall et al. 1997, 2000; Boric et al. 2004). The initial findings by Bonsall et al. (1997, 2000) describing a sharp Mesolithic-Neolithic dichotomy in diet have since been contradicted by Boric et al. (2004), based on a renewed analysis of the faunal remains and a critical review of the dating procedures. The new conclusions emphasise continuity in exploitation of food resources during the transition phase, especially for the site of Lepenski Vir. Although some individuals from a slightly later phase show lower  $\delta^{15}\text{N}$  values, suggesting that diet became more mixed, there was no sharp chronological distinction. In particular, the study of fish remains has contributed to a better understanding of the nitrogen isotope ratios. In earlier studies a large portion of these remains were not identified, but the new data indicate the presence of sturgeon in the faunal remains. Considering the fact that these fish were very large in comparison to the other species, Boric et al. (2004) expected that they contributed considerably to the diet. Boric et al. (2004) explain the high  $\delta^{15}\text{N}$  values not only by the consumption of sturgeon but also of the fish roe or caviar as they believe this latter is one trophic level higher than the mother, by analogy with trophic level differences between

suckling mammals and their mothers. Although there is no direct evidence of the isotopic relationship of fish roe to its mother, a better analogy would be with tissues formed before birth in mammals, which suggests that roe would be isotopically indistinguishable from the mother (Balasse et al. 1997; Fogel et al. 1989; Millard 2000). Nevertheless, Boric et al. (2004) are correct to deduce that these fish were probably an easy catch as they swam upriver in springtime to spawn and often were close to the surface of the water, and they also provided a large amount of fish meat and fat which must have made them attractive prey. Adult specimens can weigh as much as one hundred kilograms with the female sturgeon carrying 10-15% of her weight in caviar (Holčík 1989).

Freshwater fish consumption is also evident from Mesolithic (c.7300-6200 BC) remains from sites in Dnieper Rapids region of the Ukraine, where the amount varies but is always detectable, and fish consumption continues at lower levels into the Early Neolithic (c.5500 BC), where it is interpreted as part of a broader resource exploitation strategy (Lillie and Jacobs 2006). On the Bulgarian coast of the Black Sea analyses of the early- to mid-fifth millennium BC Neolithic and Copper Age burials from Varna and Durankulak show that a minority of individuals had a small marine component to their diet and the majority had no detectable marine component (Honch et al. 2006). Similarly, in Greece Neolithic diets from both inland and coastal sites were found to be primarily terrestrial but with small amounts of marine resource utilisation detected at coastal sites (Papathanasiou 2003). In contrast there was no evidence for anything other than terrestrial resources being consumed at the Neolithic (4400 to 3300 BC) site of Ajdovska Jama in eastern Slovenia (Ogrinc and Budja 2005).

Questions have been raised on the discrepancies between, and the reliability of, the isotope analyses and the archaeological remains, as both sources of information have flaws (Hedges 2004; Lidén et al. 2004; Milner et al. 2004). The faunal remains are incomplete palimpsests spanning hundreds, or even thousands, of years that inhibit definite conclusions on the composition of the diet and the proportional division between the various food sources. On the other hand the stable isotope results represent the average diet of specific individuals, so that with the small numbers analysed, and the possibility that we are dealing with a certain subset of the whole population, it may not be reliable to extrapolate the findings to Mesolithic and Neolithic populations in general. In addition to this, the interpretation of isotope results is ambiguous due to (a) uncertainties in the trophic level offset between collagen and food, (b) the difficulty of detecting small proportions of marine foods (Hedges 2004), (c) the averaging of food sources and the difficulties in estimating the proportions of more than three isotopically distinct foods (Phillips et al. 2005), (d) the influence of non-protein components of food on bone  $\delta^{13}\text{C}$  in a low protein diet (Hedges 2004), and (e) the possibility of manuring increasing cultivated plant  $\delta^{15}\text{N}$  to otherwise higher than expected values (Bogaard et al. 2007).

The picture of dietary change in Europe at the Mesolithic-Neolithic transition is therefore quite varied, with sharp changes of aquatic resource consumption occurring in a few areas, but more generally a gradual change in aquatic resource consumption, which continues to decline throughout the Neolithic.

### *The present study*

In this study the results of stable isotope analyses of two Middle Neolithic populations from the Lower Rhine Basin are presented. These show that in this relatively small region the nature of the transition was not as straightforward and uniform as one might expect and probably varied depending on factors like landscape, food

resources, social organisation and cultural identity. Like previous studies, we present information on subsistence by way of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) analyses. Further, we have incorporated analyses of the stable isotopes of strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ), oxygen ( $\delta^{18}\text{O}$ ), sulphur ( $\delta^{34}\text{S}$ ) and lead ( $^{206}\text{Pb}/^{204}\text{Pb}$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$ ,  $^{208}\text{Pb}/^{204}\text{Pb}$ ) in this study, even though limited in scale, to gain insight in the use of the natural landscape and local food sources as well as the homogeneity terms of childhood residence of the two populations. This additional data offers an enhanced understanding of the intra- and inter-site variability in diet.

As described above,  $\delta^{13}\text{C}$ , and  $\delta^{15}\text{N}$  analyses allow the reconstruction of aspects of human diet within each group.  $^{87}\text{Sr}/^{86}\text{Sr}$  analyses of wild and domestic animal remains (tooth enamel) from archaeological contexts at both sites may allow commentary on the geography of food procurement by providing additional information on the use of the landscape for both hunting and early pastoralism. Combined Pb-, Sr- and O-isotope analyses of human tooth enamel allows the identification of immigrants amongst a population (Budd et al. 2004) and commentary on their possible place of origin.

Although the use of sulphur isotopes in archaeological studies is in its infancy,  $\delta^{34}\text{S}$  analysis offers an addition to the residential reconstruction by potentially discriminating between coastal and inland dwellers (Richards et al. 2001). Animals from marine food chains have  $\delta^{34}\text{S}$  values of +16 to +20‰, whilst terrestrial animal and freshwater  $\delta^{34}\text{S}$  ranges from -22 to +22‰ (Richards et al. 2003a), however in areas with significant freshwater input into a marine environment this can vary depending on location (Craig et al. 2006). In plants and terrestrial animals  $\delta^{34}\text{S}$  reflects that of local soils.

Although there is much less experience with the other isotopes compared to carbon and nitrogen analyses, we believe it is important to explore the possibilities for the reconstruction of the group composition and landscape use as a background for understanding different factors influencing the Neolithisation process.

## **Materials and methods**

### *Swifterbant*

The Swifterbant cluster of sites is located in the northeast of the Flevoland Polders of the Netherlands (Figure 1), and is the type site for the Swifterbant culture (Van der Waals 1977, Louwe Kooijmans 2005). At the time of occupation the site was close to tidal waters, but some 10 km from the sea. Swifterbant can be seen as the earliest Neolithic of indigenous origin, about 1000 years later than the introduction of agriculture c. 5300 BC by the LBK culture in the Meuse basin. The indigenous Mesolithic populations apparently retained a distinctive way of life for a long period, although there is ample evidence for contacts with the farming communities.

Excavations have revealed traces of habitation pointing to a semi-permanent settlement on several river dunes bordering a system of rivulets. Faunal and carbonized botanical remains and the presence of pottery point to the introduction of a Neolithic lifestyle (Van Zeist and Palfenier-Vegter 1981), including cereal cultivation (Cappers and Raemaekers 2008).

Various clusters of graves were present, with the locations Swifterbant 2 and 3 (S2 and S3) particularly containing a number of graves (Constandse-Westermann and Meiklejohn 1979; Meiklejohn and Constandse-Westermann 1978). Despite poor preservation of the skeletal remains, a physical anthropological study provided

insight into the demographic structure of the population indicating a group of c. 66 individuals representing complete households.

The dead were buried supine with hardly any grave goods, apart from limited personal ornaments in some cases. In addition to the burials, recovery of isolated and scattered human bones on these sites as well as in the settlement area indicates that burial was not the only mode of treatment of the dead. These traditions are reminiscent of the Late Mesolithic burial practices observed at the sites of Hardinxveld-Giessendam, Polderweg and De Bruin (Louwe Kooijmans and Smits 2001; Smits and Louwe Kooijmans 2001).

The samples analysed derive from S2 and S3, which are both radiocarbon dated to broadly the same period of 4300-4000 BC and located on river levees, with one sample from S21, c.6000BC. Tooth samples comprised six human teeth and one deer tooth from S2, four human and five animal teeth from S3, and one human tooth from S21. Soil samples deriving from different contexts at S2 were also analysed (Tables 1-3).

### *Schipluiden*

Schipluiden is a Middle Neolithic site dated to c. 3600–3400 BC (Louwe Kooijmans and Jongste 2006), located south of Delft (Figure 1). It was situated on a former beach deposit, some three kilometres from the sea at the time of occupation. During the course of occupation the intracoastal plain between the site and the sea was transformed from a salt marsh to a freshwater reed-swamp.

The settlement remains included many postholes, with at least one detectable house plan, a small burial ground, a fence at the perimeter of the dune and a refuse area. Faunal and botanical remains are indicative of a year-round permanent settlement site. The strategic location allowed the exploitation of various eco-zones not only for hunting, fishing and gathering but also for husbandry and crop cultivation. Louwe Kooijmans and Jongste (2006) define the subsistence system as an extended broad-spectrum economy.

In total six graves revealed seven individuals because of the presence of one double grave. The double grave contained the skeletons of two men, differing in burial posture from the other interments and possibly associated with an unnatural cause of death as attested by the physical anthropological study (Smits and Louwe Kooijmans 2006). Isolated human bones were present in the burial area and in the refuse zone. In total the human remains at this site represent 15 individuals, mostly men and children. The loose, scattered human remains are interpreted as the remnants of a treatment of the dead that is mainly invisible archaeologically.

Burial traditions differ from those at Swifterbant, in the fact that the dead were buried in a contracted, flexed position with folded (tied) limbs. Although variation was detected in posture, for instance on the back, sideways or face down, the extremely flexed position of the arms and legs is the most remarkable feature. This is comparable with the burials at Ypenburg, a contemporaneous site north of Schipluiden (Koot and Van der Have 2001; Koot et al. 2008). Grave goods were scarce and limited to some personal possessions. Exceptional is the presence of a strike-a-light in grave 2 from which the skeleton of an elderly man was recovered.

From Schipluiden human teeth and bone samples from six individuals from five graves were analysed together with three human teeth from other contexts. Soil samples derived from four graves and a feature (no. 4018) yielding a human tooth.



Six animal teeth from a variety of contexts, including two from no. 4018 were also available for analysis. All these samples are detailed in Table 1.

### *Sample preparation*

Initial sample preparation was conducted in the Department of Archaeology, Durham University. Each tooth was sectioned using a flexible diamond impregnated cutting disc, and enamel and dentine separated for independent chemical processing. Where there was sufficient material, only half of the tooth was used.

The crown and cut surfaces of the enamel were abraded from the surface to a depth of ~100  $\mu\text{m}$  using a tungsten carbide dental burr and the removed material discarded. Any adhering dentine was then removed using the burr and the resulting clean core enamel isolated for oxygen, strontium and lead isotope analysis.

Soil samples were leached overnight in 10 % v/v acetic acid (Romil UpA) to extract total exchangeable cations representative of labile, and therefore ancient bioavailable, Sr. Leachates were evaporated to dryness and then treated in the same way as cleaned enamel samples.

### *O-isotope analysis*

Analyses were conducted at the NERC Isotope Geoscience Laboratory, Keyworth, UK. Sub-samples of 15-30 mg of enamel were cleaned using  $\text{H}_2\text{O}_2$ . Biological phosphate dissolution and re-precipitation as  $\text{Ag}_3\text{PO}_4$  was carried out using standard methods (Chenery 2005; O'Neil et al. 1994). Measurement of  $\text{Ag}_3\text{PO}_4$   $\delta^{18}\text{O}$  was carried out by Continuous Flow Isotope Ratio Mass Spectrometry (CFIRMS). The instrumentation comprised a TC/EA (high temperature elemental analyser) coupled to a Delta Plus XL isotope ratio mass spectrometer via a ConFlo III interface (Thermo Finnigan). Mean reproducibility on batch controls was 0.09 ‰, and for the NBS120C phosphate standard was 0.17 ‰ ( $1\sigma$ ,  $n=15$ ). All samples were analysed in triplicate.

### *Sr- and Pb-isotope analysis*

Chemical purification and analysis were performed in the Northern Centre for Isotopic and Elemental Tracing, Department of Earth Sciences, Durham University. Tooth enamel samples of ~20-175 mg were cleaned in deionised water and dissolved in 16 M  $\text{HNO}_3$  (Romil UpA) for analysis. Sr and Pb were extracted as separate fractions eluted from a column of Sr-Spec (a crown-ether based exchange chromatography medium, Eichrom). Procedural Sr blanks were 0.15–0.57 ng. To ensure sufficient lead was present for measurement, lead extracts were screened for concentration using ICPMS. Procedural blanks for Pb extraction were 0.34–0.91 ng, and analysed samples contained 10–56 ng Pb.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios and the Pb isotope ratios were measured using a ThermoFinnigan Multi-collector ICP Mass Spectrometer (MC-ICP-MS). For Sr, reproducibility of the standard NBS987 during analysis was  $0.710258 \pm 21$  ppm ( $2\sigma$ ,  $n=14$ ). The NBS 981 standard was used for lead isotopes, the reproducibility is given in Table 2.

### *C-, N- and S-isotope analysis*

Samples of dentine between 150 and 500 mg were taken (depending on availability), and processed following a modified Longin method. Samples were demineralised in 0.5 M HCl for several days in a fridge, with a change of acid every day. The resulting insoluble collagen was solubilised by gelatinisation at pH 4 and 75 °C over night, and lyophilised. Iso-Analytical Limited conducted isotopic measurements of prepared

samples. All measurements were made in duplicate where there was sufficient material.

For C and N isotope analysis, freeze-dried gelatin was weighed into tin capsules, sealed, and then loaded into an automatic sampler on a sample preparation module. Carbon and nitrogen contents were measured using a Europa Scientific Roboprep, and the samples automatically passed to a Europa Scientific 20-20 IRMS. The reference material used during analysis of the samples was NBS-1577a, Bovine Liver, with certified isotopic values of  $\delta^{13}\text{C} = -21.68 \text{ ‰}$  and  $\delta^{15}\text{N} = 7.25 \text{ ‰}$ . Values measured during the analysis were  $\delta^{13}\text{C} = -21.65 \pm 0.13 \text{ ‰}$  and  $\delta^{15}\text{N} = 7.28 \pm 0.2 \text{ ‰}$  ( $1\sigma$ ,  $n=5$ ).

For sulphur isotope analysis, samples were weighed into tin capsules, and vanadium pentoxide catalyst added. The tin capsules were sealed, and loaded into an automatic sampler, combusted and isotope measurements made by IRMS. The reference materials used during analysis of the samples were IA-R036 (Iso-Analytical working standard barium sulphate, with  $\delta^{34}\text{S}=20.74 \text{ ‰}$ ) and NBS-1577A (which does not have a certified value, but for which Iso-Analytical report a long-term average of  $7.86 \text{ ‰}$ ). The values measured during the analysis were  $20.92 \pm 0.40 \text{ ‰}$  ( $1\sigma$ ,  $n=4$ ) for IA-R036 and  $8.27 \pm 0.49 \text{ ‰}$  ( $1\sigma$ ,  $n=4$ ) for NBS-1577A.

## Results

Isotope results for human teeth are tabulated in Tables 1 and 2, and strontium isotope values for animal teeth and soils in Table 3. Samples SCH6 and SWH4 failed to yield sufficient collagen for analysis, and yields from SWH2 and SWH3 were too low to permit  $\delta^{34}\text{S}$  analysis. Several other samples yielded collagen sufficient for only one measurement on  $\delta^{34}\text{S}$  (SWH1, SWH7, SWH8, SWH9).

### *Carbon and nitrogen isotopes*

Quality control on extracted collagen is given by examination of the C/N ratio, which should normally lie in the range 2.9 to 3.6 (DeNiro 1985). Four samples fall outside this range, and must therefore be considered less reliable.

A plot of  $\delta^{13}\text{C}$  versus  $\delta^{15}\text{N}$  is shown in Figure 2. Samples SWH3 and SWH8 come from deciduous molars whose dentine is forming during the last few months *in utero* and during the first year of life. They are therefore forming during the period of breastfeeding and may show elevated  $\delta^{15}\text{N}$  and slightly elevated  $\delta^{13}\text{C}$  compared to others in the population as a result (Fogel et al. 1989). This certainly seems to be the case for SWH3, which has an elevated  $\delta^{15}\text{N}$  compared to the other Swifterbant samples. Typical  $\delta^{13}\text{C}$  values for consumers of terrestrial foods are  $-21$  to  $-20 \text{ ‰}$ , but the Swifterbant population shows slightly lower values and relatively high  $\delta^{15}\text{N}$ , suggesting a possible input of protein from freshwater fish in the diet. In contrast, the Schipluiden people have higher  $\delta^{13}\text{C}$  values with a greater range, and  $\delta^{15}\text{N}$  that is even more elevated. SCH2, SCH7 and SCH8 appear to have diets of similar isotopic composition to the Swifterbant people, but the others from Schipluiden have higher  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  indicating a significant marine protein input to their diet. SCH1, with  $\delta^{13}\text{C}$  of  $-16.5 \text{ ‰}$  may have obtained as much as 50 % of his or her protein from marine sources. The highest nitrogen value was measured in SCH9, a child of about two years old, and is therefore probably influenced by breastfeeding that elevated the  $\delta^{15}\text{N}$  by up to 3 ‰ (Fogel et al. 1989). The pattern of results from the teeth are repeated in carbon and nitrogen isotope analyses of bone from six Schipluiden individuals at the Groningen radiocarbon laboratory (Table 1, Figure 2), with four of

them corresponding to individuals analysed in this project. They show a slight offset in both carbon and nitrogen isotopes, perhaps indicating a shift in diet between childhood and adulthood. The one exception is SCH8 who shows a more terrestrial signal, with a lower nitrogen isotope ratio. Altogether, these isotope results are entirely consistent with faunal evidence for the exploitation of domestic animals, wild animals, aquatic birds, marine and freshwater fish, and a few marine mammals. However, they suggest more emphasis on the marine component of diet than would be deduced from meat weights derived from the faunal remains, which is not surprising as fish bones are often underrepresented in excavated samples. They also suggest a significant amount of variability between individuals.

### *Sulphur isotopes*

Criteria for the reliability of  $\delta^{34}\text{S}$  measurements from collagen have only been established since we conducted our study. The C/S ratio of fresh collagen is expected to be about 780 according to Richards et al. (2001) but our calculations from the amino-acid composition of collagen suggest a value of about 500, as do Craig et al. (2006). All our samples yield values much lower than this, suggesting that sulphur has been added to the samples during diagenesis. Our C/S values are at the lower end of the range reported by Richards et al. (2001) and outside the 300-900 range for well preserved collagen established by Nehlich and Richards (2009), so the  $\delta^{34}\text{S}$  results must be interpreted very cautiously. However, the two sites are clearly distinguished in their  $\delta^{34}\text{S}$  values (Figure 3). At Schipluiden the values are lower than at Swifterbant, despite the  $\delta^{13}\text{C}$  evidence of a higher marine component to the diet in the Schipluiden population. The relative importance of different dietary sources in contributing to the  $\delta^{13}\text{C}$  and  $\delta^{34}\text{S}$  signals in collagen is unknown, as are the local  $\delta^{34}\text{S}$  values for the two sites, though being coastal one would expect values close to marine values. Sulphur isotopes alone do not identify any migrants, though SCH1 and SCH2 appear to differ from the other four Schipluiden individuals.

### *Strontium isotopes*

The remarkable thing about the Swifterbant Sr isotope values is the homogeneity of all but SWH10 (Figure 4). They show a smaller range of enamel isotope values than any other site we are aware of. Homogeneity of the Sr isotope ratios in *bone* samples is commonly caused by diagenesis. However, all samples show higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios than the soils, suggesting that diagenesis is not the cause. They are also distinct from, though close to, the seawater ratio of 0.70918. Whilst diagenesis is a possible explanation, it seems more likely that these values represent a “catchment” for diet at Swifterbant that is isotopically very homogeneous. The outlier, SWH10, must have migrated to the site after childhood and have come from an area with an underlying geology having more radiogenic strontium. It is interesting to note that the  $\delta^{15}\text{N}$  for this individual is significantly lower than for all the others, but the collagen quality was not within acceptable limits. If the  $\delta^{15}\text{N}$  is reliable then in childhood this person was partaking of different foods than the others, possibly eating less fish or less meat.

Three of the deer from Swifterbant show higher Sr isotope ratios than the humans, whilst the dog, beaver and one deer are indistinguishable from the majority of humans. The animals primarily come from site S3, whilst the humans were buried at site S2. It appears that the isotopic sources contributing to human diet at one site and to animal diet at the other were different. This may represent changing procurement strategies, or different catchments. The two sites are less than one kilometre apart,

but separated by a large river channel, which could cause their catchments to be geographically distinct.

At Schipluiden the humans show similar values to the majority at Swifterbant, but with slightly more variation. The animals show a similar range to the humans. The differences between the humans and soil samples from their grave fills imply that diagenesis is not a problem. The range of values from the soils indicates that neither humans nor animals were exploiting all these soil substrates for food resources. There are no clearly identified migrants there, and, given the similarity of values from Swifterbant, it may be that the Pleistocene and Holocene sediments of the Dutch coast are homogeneous in Sr isotopes and thus it may be impossible to identify migrants from anywhere along the 100 km of coast between the two sites.

### *Oxygen isotopes*

The oxygen isotope results from both sites (Figure 4) show a wider range of values than the approximately 1 ‰ that would be expected from humans drinking a single source of water (Longinelli 1984). The range at Schipluiden is particularly large (3.1 ‰), but that at Swifterbant is less remarkable (1.5 ‰).

Analysis of  $\delta^{18}\text{O}$  of precipitation from nearby stations of the ISOHIS database (IAEA/WMO, 2004) suggests that both sites have modern precipitation with an annual mean within the range  $-6.9$  to  $-7.0$  ‰. Calibration to human tooth enamel values using the equation of Daux et al. (2008) and allowing for the variability of human populations on a single drinking water source, suggests that local human tooth enamel values derived from this water should have enamel  $\delta^{18}\text{O}$  in the range approximately 16.9-17.9 ‰.

In evaluating the results from Swifterbant it is necessary to consider the possibility of climatic change over the long period of occupation of the site. During the occupation of S21, c.6000 BC, the temperature in North-west Europe was slightly warmer than in the recent past, and the time of S2 and S3 at about 4000 BC saw a cooling. This is reflected (with other factors) in the changing  $\delta^{18}\text{O}$  of stalagmite B7-7 from Cave B7 in the Sauerland (Niggemann et al. 2003), which is slightly lower in the later period. Although in Europe precipitation  $\delta^{18}\text{O}$  changes at 0.25 ‰ per °C (Darling 2004) the coastal location of these sites may be subject to stronger effects and other causes of change. In particular, the current distribution of  $\delta^{18}\text{O}$  of precipitation shows a 'tongue' of high values extending from the Atlantic along the English Channel, but not affecting the North Sea. It is quite conceivable that this marine effect could be extended eastwards along the Dutch coast under conditions of slightly warmer climate or with slightly changed weather patterns, leading to an increase of  $\delta^{18}\text{O}$  in precipitation that is larger than would otherwise be predicted.

Thus the  $\delta^{18}\text{O}$  values in the range 17.1 to 17.7 ‰ at S2 and S3 are all plausible local values. The other two apparently high values of 18.1 and 18.4 ‰ for SWH3 and SWH8 respectively come from deciduous molars which may include a signal from the suckling effect which can raise  $\delta^{18}\text{O}$  by anything up to 2 ‰ (White et al. 2004). Oxygen isotopes therefore provide no positive evidence for immigrants at Swifterbant.

At Schipluiden, with its much shorter occupation in a period of climate not dissimilar to today, it is easier to interpret the  $\delta^{18}\text{O}$  results. As at Swifterbant, the 'local' tooth enamel signal is expected to be approximately 16.8-17.8 ‰ and the majority of individuals fall in or close to this range at 16.6-17.4 ‰. SCH5 at 16.4 ‰ is a possible

migrant, but it is possible that analytical uncertainty (0.17 ‰) or a small shift in  $\delta^{18}\text{O}$  of precipitation could account for the difference. On the other hand, SCH6 at 15.8 ‰ and SCH7 at 18.9 ‰ cannot conceivably be local. Using the calibration of Daux et al. (2008) shows that SCH6 must have spent his childhood somewhere well to the east or south with a drinking water  $\delta^{18}\text{O}$  of  $-9.4 \pm 0.5$  ‰, which is consistent with modern precipitation in a broad band from central Scandinavia, though eastern and southern Germany to the western Alps. Conversely SCH7 came from the west with a childhood drinking water of  $-4.6 \pm 0.5$  ‰, corresponding to the western fringes of Britain, the west coast of France, or Spain. Whilst the other individuals have values compatible with a local origin, it is also quite possible that they have migrated shorter distances.

### *Lead isotopes*

Due to low lead levels and small sample sizes, after screening for sufficient Pb, only 7 of the 18 human tooth samples were found suitable for Pb isotope measurements. Even so the procedural blank for Pb was relatively high compared to the yields from the samples, and we cannot be entirely certain that the results are not biased by blank contamination. This illustrates the need for consistent low-lead blanks when analysing prehistoric humans.

Figure 5 shows  $^{207}\text{Pb}/^{206}\text{Pb}$  data plotted against  $^{87}\text{Sr}/^{86}\text{Sr}$ . For comparison of humans to local environmental values, soil values are plotted by combining our Sr isotope measurements with soil Pb isotope data for top- and sub-soils from four sites close to the archaeological sites (Walraven et al. in prep.), given in Table 2. Urk is located in Flevoland, 17 kilometres north across the River IJssel from Swifterbant. There is an analysis from Schipluiden itself and from the site of Rijswijk some 12 km further north. Giessendam is some 64 km east of Schipluiden. Both top-soil and sub-soil Pb are likely to be contaminated with lead from vehicle exhausts, but the sub-soil should be less contaminated, and these values are plotted.

Three of the four Swifterbant human analyses cluster close together, but SWH10 appears to be an outlier, falling the other side of the one local soil measurement, and much further away. At Schipluiden two of the individuals have lead isotope values consistent with local soils, but again there is one, SCH7, with a higher value. Clearly there is a need for further analyses of local geological formations to investigate environmental lead isotope variation more fully, but currently SWH10 and SCH7 are possible migrants on the basis of the Pb isotope data. However, we stress that this interpretation must be regarded as tentative given the possibility of a blank contribution to the measured ratio, and the lack of lead isotope measurements on soils from Swifterbant itself.

## **Discussion**

### *Diet*

Swifterbant and Schipluiden are both clearly Neolithic not only in date but also in view of the archaeological indicators for living in (semi-)permanent settlements, the toolkit and the knowledge of agriculture. The carbon and nitrogen isotope values for the Swifterbant people are in accordance with the general trend discussed above, having a diet which was mostly terrestrial but with a definite aquatic component, though this contrasts with the nearest northern European areas (British Isles, Denmark, Meuse Valley) where there is little or no aquatic component detectable from isotopes in human bones. Elsewhere, where there is sufficient data, there is evidence for declining use of aquatic resources through the Neolithic, but although

Swifterbant is 500 years earlier than Schipluiden the values from Schipluiden reveal a strong aquatic dependence in subsistence which compares with Mesolithic values elsewhere, and is even stronger than at the relatively close Late Mesolithic sites from the Dutch river area, Polderweg and De Bruin (Smits and Van der Plicht 2009). The nitrogen values are especially indicative of a high trophic level associated with the marine food chain. Thus Schipluiden does not comply with the general picture, even though agriculture had been practised in the loess zone of the Lower Rhine Basin for 1500 years.

The unusual isotope values for Schipluiden are paralleled by those from Lepenski Vir and Vlasac in the Danube Gorges (Bonsall et al. 1997, 2000; Boric et al. 2004) (Figure 6), and this parallel is strengthened by the well-attested presence of sturgeon in both faunal spectra (Brinckhuizen 2006). The practical absence of sturgeon remains at Swifterbant and the lower nitrogen isotope ratios accord with this (Zeiler 1997), although specific taphonomic processes may be responsible for the invisibility of sturgeon remains in the faunal spectrum of Swifterbant.

The type of sturgeon present in the Dutch rivers was the Atlantic sturgeon (*Acipenser sturio*). This anadromous fish migrated from the sea to the rivers around the end of April to spawn on the riverbeds in June and July. The fish could have been processed or dried for winter supplies and the caviar may not only have been consumed by itself but conceivably served for the salting and flavouring or even the preserving of other foodstuffs. In this respect the isotope analysis of food crusts in pottery may provide useful information.

Apart from sturgeon, Boric et al. (2004) take the consumption of dogs that were fed on fish remains into account, a feature that might have contributed to the high nitrogen isotope ratios as well. At Schipluiden the skeletal remains of a number of dogs were present, including three deliberately killed by a blow to the head, but it is unclear whether dogs were eaten there (Zeiler 2006). One observation resulting from the similarity between the Lepenski Vir and Schipluiden is inescapable and that is the importance of the local habitat and the presence of probably highly favoured food sources that could have served as an important factor in inhibiting radical changes in subsistence. This feature also helps explain the differences between Swifterbant and Schipluiden in a relatively small area like the Lower Rhine Basin.

#### *Group composition*

The isotope analysis has revealed several immigrants, some of them with a diet lower in fish consumption than the locals. For Swifterbant the oxygen, sulphur, strontium and lead isotopes are consistent with a local origin for all individuals except SWH10, whose nitrogen isotope value is also suggestive of a diet lower in fish than for the others. The  $\delta^{18}\text{O}$  values at Schipluiden show that the immigrants may well have travelled hundreds of kilometres.

At Schipluiden the strontium, oxygen and lead isotopes combined identify SCH6 and SCH7 as immigrants, with the possibility that SCH5 was also an immigrant. Carbon and nitrogen isotope results suggest that SCH2, SCH7 and SCH8 had less marine foods in their diet than the others.

It is notable that three of the identified immigrants (SWH10, SCH6 and SCH7) are represented only by isolated molars, and two of these individuals had a diet lower in fish than others at these sites. The sample size is very small, but, as these individuals were not of local origin, this does raise the possibility that differences in both diet and attitude towards burial were associated with cultural identity. An

association between burial characteristics and migration was also found at the Rhineland early Neolithic site of Nieder-Mörlen (Nehlich et al 2009) An additional factor might be social status, for example SCH5 was set apart by an exceptional grave gift – a strike-a-light – perhaps indicating a special position in society. Our combined isotope approach thus allows us to start to identify factors like immigration and social status as part of the reasons for intra-site variability in diet and treatment of the dead.

#### *Landscape use / food procurement strategies*

Although only a small number of animal and soil samples were analyzed some indications for landscape use are revealed. At Swifterbant animal strontium isotopes suggest that sites S2 and S3 may have had isotopically and therefore geographically separate catchments. However, from archaeological point of view this is unlikely for two contemporaneous sites as they are very close together, and mobility over water would not have been a problem. The different catchments may, therefore, arise from a slight chronological difference. At Schipluiden the range of soil strontium values indicates that humans and the animals they exploited were not using all the areas of landscape represented by our soil samples. This is compatible with the idea that still a significant part of the food was derived from the surrounding aquatic part of the landscape.

So the location of the sites and the natural surroundings show a variety of catchments for both sites, which sheds light on the use of the landscape. This coincides with the idea of a mixed diet in Swifterbant and the suspected semi-permanent settlement there. For Schipluiden the heterogeneous isotope results comply with the notion of an extended broad-spectrum economy, which is in accordance with, but also an addition to, the archaeological findings.

#### **Conclusions**

The population from Swifterbant had a remarkably uniform set of isotope results. Carbon and nitrogen isotopes suggest terrestrial and freshwater fish dependence. All individuals grew up locally except for SWH 10. Different catchments are suggested by the animal strontium values. At Schipluiden there is more variation. The combined isotope results identify not only immigrants but also reveal that some of them had a diet lower in fish than the local people. The lack of a formal burial ritual shows that these people were treated after death according to a tradition resulting in an above ground distribution of disarticulated bones. The isotope results corroborate the suggestion of Louwe Kooijmans and Jongste (2006) that various food resources were exploited throughout the year indicating an extended broad-spectrum economy.

Whilst it is dangerous to extrapolate from just two sites, even within the Middle Neolithic there is a clear variability in the isotope results, with the earlier Swifterbant showing very little evidence for migration, and a mostly terrestrial diet, whilst 500 years later Schipluiden has a higher proportion of migrants and strong evidence for the exploitation of marine resources.

This study has shown that apart from the reconstruction of the protein part of the diet by way of carbon and nitrogen analysis a more general background can be sketched including the use of the landscape and the provenance of the population by applying additional stable isotope research. Together with the archaeological data like the faunal remains and the burial ritual a better understanding of the intra- and inter-site variability in diet can be achieved. The results have provided the insight that even in a small area like the Lower Rhine Basin the nature and expansion of the Neolithic

lifestyle is very heterogeneous and even supply us with possible reasons why people responded as they did to new challenges, whether they adopted new habits or not and why they held on to their own traditional routines a while longer.

### Acknowledgements

We thank Susan Hughes for originally bringing the authors together. Paul Budd conducted much of the laboratory work. We thank Carolyn Chenery of NIGL and Steve Brooks of Iso-Analytical for isotope measurements. This work was performed as part of the project "From Hardinxveld to Noordhoorn – from forager to farmer", led by Prof. L. P. Louwe Kooijmans, within the framework of the 'Malta Harvest Programme' funded by the Netherlands Organisation for Scientific Research.

### References

- BALASSE M, BOCHERENS H, TRESSET A, MARIOTTI A, and VIGNE JD (1997) Émergence de la production laitière au Néolithique? Contribution de l'analyse isotopique d'ossements de bovins archéologique. *Comptes Rendus de l'Académie des Sciences, Paris, Sciences de la terre et des planètes* 325:1005-1010.
- BARBERENA R, and BORRERO LA (2005) Stable isotopes and faunal bones. Comments on Milner et al. (2004). *Antiquity* 79:191-195.
- BOCHERENS H, POLET C, and TOUSSAINT M (2007) Palaeodiet of Mesolithic and Neolithic populations of Meuse Basin (Belgium): evidence from stable isotopes. *Journal of Archaeological Science* 34:10-27.
- BOGAARD A, HEATON THE, POULTON P, and MERBACH I (2007) The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34:335-343.
- BONSALL C, COOK G, LENNON R, HARKNESS D, SCOTT M, BARTOSIEWICZ L, and MCSWEENEY K (2000) Stable isotopes, radiocarbon and the Mesolithic-Neolithic transition in the Iron Gates. *Documenta Praehistorica* 27:119-132.
- BONSALL C, LENNON R, MCSWEENEY K, STEWART C, HARKNESS D, BORONEANT V, BARTOSIEWICZ L, PAYTON R, and CHAPMAN J (1997) Mesolithic and early Neolithic in the Iron Gates: a palaeodietary perspective. *Journal of European Archaeology* 5:50-92.
- BORIC D, GRUPE G, PETERS J, and MIKIC Z (2004) Is the Mesolithic-Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges. *European Journal of Archaeology* 7:221-248.
- BOSL C, GRUPE G, and PETERS J (2006) A Late Neolithic vertebrate food web based on stable isotope analyses. *International Journal of Osteoarchaeology* 16:296-315.
- BRINCKHUIZEN DC (2006) Fish. In LP Louwe Kooijmans and P Jongste (eds.): *Schipluiden: A Neolithic settlement on the Dutch North sea coast c. 3500 cal BC*. *Analecta Praehistorica Leidensia*, 37/38. Leiden: Faculty of Archaeology Leiden University, pp. 449-470.
- BUDD P, MILLARD A, CHENERY C, LUCY S, and ROBERTS C (2004) Investigating population movement by stable isotopes: a report from Britain. *Antiquity* 78:127-140.
- CAPPERS RTJ and RAEMAEKERS DCM (2008) Cereal cultivation at Swifterbant. *Current Anthropology* 49:385-402
- CHENERY CA (2005) *The analysis of  $^{18}\text{O}/^{16}\text{O}$  ratios of biogenic phosphates*. Keyworth: NERC Isotope Geoscience Laboratory Report 195.



- CONSTANDSE-WESTERMANN TS, and MEIKLEJOHN C (1979) The human remains from Swifterbant (Swifterbant contributions, 12). *Helinium* 19:235-260.
- CRAIG OE, FORSTER M, ANDERSEN SH, KOCH E, CROMBE P, MILNER NJ, STERN B, BAILEY GN, and HERON CP (2007) Molecular and isotopic demonstration of the processing of aquatic products in northern European prehistoric pottery. *Archaeometry* 49:135-152.
- CRAIG OE, ROSS R, ANDERSEN SH, MILNER N, and BAILEY GN (2006) Focus: sulphur isotope variation in archaeological marine fauna from northern Europe. *Journal of Archaeological Science* 33:1642-1646.
- DARLING WG (2004) Hydrological factors in the interpretation of stable isotopic proxy data present and past: a European perspective. *Quaternary Science Reviews* 23:743-770.
- DAUX V, LÉCUYER C, HÉRAN M-A, AMIOT R, SIMON L, FOUREL F, MARTINEAU F, LYNNERUP N, REYCHLER H, and ESCARGUEL G (2008) Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution* 55:1138-1147.
- DENIRO MJ (1985) Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317:806-809.
- DURRWACHTER C, CRAIG OE, COLLINS MJ, BURGER J, and ALT KW (2006) Beyond the grave: variability in Neolithic diets in Southern Germany? *Journal of Archaeological Science* 33:39-48.
- ERIKSSON G, LOUGAS L, and ZAGORSKA I (2003) Stone Age hunter-fisher-gatherers at Zvejnieki, northern Latvia: radiocarbon, stable isotope and archaeozoology data. *Before Farming* 2003/1:1-25.
- FISCHER A., OLSEN J, RICHARDS M, HEINEMEIER J, SVEINBJÖRNSDÓTTIR ÁE and BENNIKE P (2007) Coast-inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *Journal of Archaeological Science* 34:2125-2150.
- FOGEL ML, TUROSS N, and OWSLEY DW (1989) Nitrogen isotope tracers. *Carnegie Institute of Washington Yearbook* 88:133-134.
- HEDGES REM (2004) Isotopes and red herrings: comments on Milner et al. and Liden et al. *Antiquity* 78:34-37.
- HEDGES R, SAVILLE A. and O'CONNELL T. (2008) Characterizing the diet of individuals at the Neolithic chambered tomb of Hazleton North, Gloucestershire, England, using stable isotopic analysis. *Archaeometry* 50:114-128.
- HOLČIK J (1989) *The freshwater fishes of Europe: general introduction to fishes / Acipenseriformes*. Wiesbaden.
- HONCH NV, HIGHAM TFG, CHAPMAN J, GAYDARSKA B, and HEDGES REM (2006) A palaeodietary investigation of carbon (C-13/C-12) and nitrogen (N-15/N-14) in human and faunal bones from the Copper Age cemeteries of Varna I and Durankulak, Bulgaria. *Journal of Archaeological Science* 33:1493-1504.
- IAEA/WMO (2004) *Global Network of Isotopes in Precipitation. The GNIP Database*. Accessible at: <http://isohis.iaea.org>.
- KOOT H, and VAN DER HAVE B (2001) *Graven in Rijswijk, de steentijdmensen van Ypenburg*. Rijswijk.
- KOOT JM, BRUNING L, and HOUKES RA (2008) *Ypenburg-locatie 4, Een nederzetting met grafveld uit het Midden-Neolithicum in het West-Nederlandse Kustgebied*. Den Haag: Haagse Oudheidkundige Publicaties.
- LIDÉN K, ERIKSSON G, NORDQVIST B, GOTHERSTROM A, and BENDIXEN E (2004) "The wet and the wild followed by the dry and the tame" - or did they occur at the same time? Diet in Mesolithic Neolithic southern Sweden. *Antiquity* 78:23-33.

- LILLIE M, and JACOBS K (2006) Stable isotope analysis of 14 individuals from the Mesolithic cemetery of Vasilyevka II, Dnieper Rapids region, Ukraine. *Journal of Archaeological Science* 33:880-886.
- LONGINELLI A (1984) Oxygen isotopes in mammal bone phosphate : a new tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta* 48:385-390.
- LOUWE KOOIJMANS LP, and JONGSTE PFB, eds. (2006) *Schipluiden. A Neolithic settlement on the Dutch North sea coast c. 3500 cal BC*. Leiden.
- LOUWE KOOIJMANS LP, and SMITS E (2001) Menselijke skeletresten. In LP Louwe Kooijmans (ed.): *Hardinxveld-Giessendam, De Bruin. Een jachtkamp uit het Laat-Mesolithicum en het begin van de Swifterbant-cultuur, 5500-4450 v. Chr.* Rapportage Archeologische Monumentenzorg 83. Amersfoort: ROB, pp. 479-498.
- LOUWE KOOIJMANS LP (2005) Hunters become farmers: Early Neolithic B and Middle Neolithic A In Louwe Kooijmans LP, van den Broeke PW, Fokkens H, and van Gijn AL, eds.(2005). *The Prehistory of The Netherlands, Volume I*. Amsterdam. Amsterdam University Press, pp. 249-271.
- LUBELL D, JACKES M, SCHWARCZ H, KNYF M, and MEIKLEJOHN C (1994) The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science* 21:201-216.
- MEIKLEJOHN C, and CONSTANDSE-WESTERMANN TS (1978) The human skeletal material from Swifterbant, earlier Neolithic of the Northern Netherlands. *Palaeohistoria* 20:39-89.
- MILLARD AR (2000) A model for the effect of weaning on nitrogen isotope ratios in humans. In G Goodfriend, M Collins, M Fogel, S Macko and J Wehmler (eds.): *Perspectives in Amino Acid and Protein Geochemistry*. New York: Oxford University Press, pp. 51-59.
- MILNER N, CRAIG OE, BAILEY GN, and ANDERSEN SH (2006) Touch not the fish: the Mesolithic-Neolithic change of diet and its significance - A response to Richards and Schulting. *Antiquity* 80:456-458.
- MILNER N, CRAIG OE, BAILEY GN, PEDERSEN K, and ANDERSEN SH (2004) Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations. *Antiquity* 78:9-22.
- NEHLICH O, and RICHARDS MP (2009) Establishing collagen quality criteria for sulphur isotope analysis of archaeological bone collagen. *Archaeological and Anthropological Sciences* 1:59-75.
- NEHLICH O, MONTGOMERY J, EVANS J, SCHADE-LINDIG S, PICHLER SL, RICHARDS MP, and ALT KW (2009) Mobility or migration: a case study from the Neolithic settlement of Nieder-Mörlen (Hessen, Germany). *Journal of Archaeological Science* 36:1791-1799
- NIGGEMANN S, MANGINI A, RICHTER DK, and WURTH G (2003) A paleoclimate record of the last 17,600 years in stalagmites from the B7 cave, Sauerland, Germany. *Quaternary Science Reviews* 22:555-567.
- OGRINC N, and BUDJA M (2005) Paleodietary reconstruction of a Neolithic population in Slovenia: A stable isotope approach. *Chemical Geology* 218:103-116.
- O'NEIL JR, ROE LJ, REINHARD E, and BLAKE RE (1994) A Rapid and Precise method of Oxygen Isotope Analysis of Biogenic Phosphate. *Israel Journal of Earth Sciences* 43:203-212.
- PAPATHANASIOU A (2003) Stable isotope analysis in Neolithic Greece and possible implications on human health. *International Journal of Osteoarchaeology* 13:314-324.
- PHILLIPS DL, NEWSOME SD, and GREGG JW (2005) Combining sources in stable isotope mixing models: alternative methods. *Oecologia* 144:520-527.

- RICHARDS MP, and SCHULTING RJ (2006) Touch not the fish: the Mesolithic-Neolithic change of diet and its significance. *Antiquity* 80:444-456.
- RICHARDS MP, FULLER BT, and HEDGES REM (2001) Sulphur isotopic variation in ancient bone collagen from Europe: implications for human palaeodiet, residence mobility and modern pollutant studies. *Earth and Planetary Science Letters* 191:185-190.
- RICHARDS MP, FULLER BT, SPONHEIMER M, ROBINSON T, and AYLIFFE L (2003a) Sulphur isotopes in palaeodietary studies: a review and results from a controlled feeding experiment. *International Journal of Osteoarchaeology* 13:37-45.
- RICHARDS MP, PRICE TD, and KOCH E (2003b) Mesolithic and Neolithic subsistence in Denmark: new stable isotope data. *Current Anthropology* 44:288-295.
- RICHARDS MP, SCHULTING RJ, and HEDGES REM (2003c) Sharp shift in diet at onset of Neolithic. *Nature* 425:366-366.
- SCHULTING RJ (1998) Slighting the sea: stable isotope evidence for the transition to farming in northwestern Europe. *Documenta Praehistorica* 25:203-218.
- SCHULTING RJ, and RICHARDS MP (2001) Dating women and becoming famers: new palaeodietary and AMS dating evidence from the Breton Mesolithic Cemeteries of Tévéc and Hoëdic. *Journal of Anthropological Archaeology* 20:314-344.
- SCHULTING RJ, BLOCKLEY SM, BOCHERENS H, DRUCKER D, and RICHARDS M (2008) Stable carbon and nitrogen isotope analysis on human remains from the Early Mesolithic site of La Vergne (Charente-Maritime, France). *Journal of Archaeological Science* 35:763-772
- SMITS E, and LOUWE KOOIJMANS LP (2006) Graves and human remains. In LP Louwe Kooijmans and P Jongste (eds.): *Schipluiden - A Neolithic settlement on the Dutch North sea coast c. 3500 cal BC*. Leiden, pp. 91-112.
- SMITS E, and LOUWE KOOIJMANS LP (2001) De menselijke skeletresten. In LP Louwe Kooijmans (ed.): *Hardinxveld-Giessendam, Polderweg. Een jachtkamp uit het Laat-Mesolithicum, 5500-5000 v. Chr.* Rapportage Archeologische Monumentenzorg 83. Amersfoort: ROB, pp. 419-440.
- SMITS E and VAN DER PLICHT J (2009) Mesolithic and Neolithic human remains in the Netherlands: physical anthropological and stable isotope investigations. *Journal of Archaeology of the Low Countries*, 1-1: 55-85.
- VAN DER PLICHT J, WIJMA S, AERTS AT, PERTUISOT MH and MEIJER HAJ (2000) The Groningen AMS facility: status report. *Nuclear Instruments and Methods* B172, 58-65.
- VAN DER WAALS JD (1977) Excavations at the natural levee sites S2 and S3/5 and S4. *Helinium* 17:3-2.
- VAN ZEIST W and PALFENIER-VEGTER RM (1981) Seeds and fruits from the Swifterbant S3 site. Final reports on Swifterbant IV, *Palaeohistoria* 23:105-168.
- WALRAVEN N, VAN DER VEER G, VAN OS BJH, KLAVER GT, BAKER JH, VRIEND SP, and VAN CAPELLEN P (in preparation) Stable lead isotopic mapping of top- and subsoils in the Netherlands.
- WHITE C, LONGSTAFFE FJ, and LAW KR (2004) Exploring the effects of environment, physiology and diet on oxygen isotope ratios in ancient Nubian bones and teeth. *Journal of Archaeological Science* 31:233-250.
- ZEILER JT (1997) *Hunting, fowling and stock-breeding at Neolithic sites in the western and central Netherlands*. Ph.D. thesis, Groningen.
- ZEILER JT (2006) Mammals. In LP Louwe Kooijmans and P Jongste (eds.): *Schipluiden: A Neolithic settlement on the Dutch North sea coast c. 3500 cal BC*. *Analecta Praehistorica Leidensia*, 37/38. Leiden: Faculty of Archaeology Leiden University, 375-420.

## **Biographical notes**

Elisabeth Smits is an archaeologist and physical anthropologist specialising in burial archaeology. She is lecturer in physical anthropology in the Departments of Archaeology and Science at the University of Amsterdam.

*Address:* Amsterdam Archaeological Centre, University of Amsterdam, Turfdraagsterpad 9, 1012 XT Amsterdam, Netherlands. [email: e.smits@uva.nl]

Andrew R Millard is Senior Lecturer in Archaeology at Durham University. He specialises in the study of the chemistry of bones and teeth and the application of Bayesian statistics in Archaeology.

*Address:* Department of Archaeology, Durham University, South Road, Durham DH1 3LE, UK. [email: a.r.millard@durham.ac.uk]

Geoff Nowell is Senior Research Officer in the Department of Earth Sciences at Durham University and is a specialist in multi-collector plasma ionisation and thermal ionisation mass spectrometry.

*Address:* Northern Centre for Isotopic and Elemental Tracing, Department of Earth Sciences, Durham University, South Road, Durham DH1 3LE, UK. [email: ]

D Graham Pearson is Professor of Geochemistry in the Department of Earth Sciences at Durham University, and established the isotope geochemistry facilities at Durham.

*Address:* Northern Centre for Isotopic and Elemental Tracing, Department of Earth Sciences, Durham University, South Road, Durham DH1 3LE, UK. [email: ]

## Tables

Table 1: Human samples and isotopic results for carbon nitrogen, strontium and oxygen.

Sample reference	Sex	Age	Tooth	Durham lab number	$\delta^{18}\text{O}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\text{SE}^*$	Collagen yield	C/N	C/S	$\delta^{13}\text{C}$ dentine	$\delta^{15}\text{N}$ dentine	$\delta^{34}\text{S}$	$\delta^{13}\text{C}$ bone†	$\delta^{15}\text{N}$ bone †
<b>Schipluiden</b>															
Put 1 Sp 4018 V09267			M <sup>3</sup>	SCH1	16.6	0.709136	10	11.1%	3.23	53	-16.54	16.51	2.18		
Graf 3	M	41-50	M <sup>3</sup>	SCH2	16.7	0.708753	13	16.7%	3.08	100	-21.05	14.31	2.93	-21.52	12.79
Graf 1 IND.1	M	38-45	PM <sup>2</sup>	SCH3	17.0	0.709043	10	6.0%	3.28	59	-17.97	16.28	6.79	-18.67	15.77
Graf 1 IND.2	M	59-65	M <sup>3</sup>	SCH4	17.4	0.709016	09	12.9%	3.10	102	-18.24	16.37	6.62	-19.02	15.95
Graf 2	M	46-49	M <sup>3</sup>	SCH5	16.4	0.708957	12	10.2%	3.72	82	-18.57	15.71	6.84	-18.81	15.55
Put 26 Spoor 8010 V05001	M	adult	M <sup>3</sup>	SCH6	15.8	0.708921	12	2.7%							
Put 29 Spoor 8018 V08057			PM	SCH7	18.9	0.708924	12	11.6%	3.35	84	-20.39	13.56	7.09		
Graf 4	M	25-40		SCH8										-20.50	10.07
Graf 6		2		SCH9										-21,05	16.36
<b>Swifterbant</b>															
S2-38A-2543-XXXIX			M <sup>3</sup>	SWH1	17.1	0.709050	14	5.8%	3.10	142	-21.45	13.85	10.30		
S2-37A-XXXVII			M <sup>3</sup>	SWH2	17.5	0.709022	12	5.1%	3.00		-21.09	13.81			
S3-17576			m <sup>1</sup>	SWH3	18.1	0.709007	12	4.4%	3.24		-21.63	16.01			
S21-H46-485			M <sup>3</sup>	SWH4	18.6	0.709057	13	0.9%	-	-	-	-	-		
S3-G43-loose			P <sub>2</sub>	SWH5	17.2	0.708949	16	14.4%	2.48	162	-21.51	12.67	12.66		
S3-643-(loose find)			PM <sup>2</sup> + M <sup>2</sup>	SWH6	17.3	0.708949	13	15.1%	2.81	165	-22.39	12.65	13.12		
S2-1952			M <sup>3</sup>	SWH7	17.3	0.709009	12	5.1%	3.17	144	-21.22	13.78	10.29		
S3-30648			M <sup>3</sup> ?	SWH8	18.4	0.709003	12	4.1%	3.56	33	-22.74	12.46	7.75		
S2-642-III			PM <sup>2</sup>	SWH9	17.3	0.709023	13	10.1%	2.40	145	-21.86	13.14	11.10		
S2 900016			M <sup>2</sup>	SWH10	17.7	0.710649	12	8.1%	2.51	106	-21.81	9.96	10.37		
S2-1483			M <sup>1</sup>	SWH11	17.6	0.708997	14	8.8%	2.99	115	-21.52	13.74	9.51		

† Schipluiden bone samples were measured at Groningen Radiocarbon Laboratory by the methods described in Van der Plicht et al. (2000)

\*uncertainties on strontium isotope ratios are 2SE within-run precision

Table 2: Lead isotope results

Sample	Durham lab number	$^{206}\text{Pb}/^{204}\text{Pb}$		$^{207}\text{Pb}/^{204}\text{Pb}$		$^{208}\text{Pb}/^{204}\text{Pb}$		$^{207}\text{Pb}/^{206}\text{Pb}$		$^{208}\text{Pb}/^{206}\text{Pb}$	
<b>Schipluiden</b>											
Put 1 Sp 4018 V09267	SCH1	18.710	0.020	15.646	0.018	38.602	0.0440	0.836207	0.000069	2.06312	0.00018
Put 26 Spoor 8010 V05001	SCH6	18.786	0.006	15.668	0.005	38.707	0.013	0.834064	0.000022	2.06046	0.00005
Put 29 Spoor 8018 V08057	SCH7	18.730	0.011	15.705	0.010	38.700	0.023	0.838518	0.000047	2.06626	0.00010
<b>Swifterbant</b>											
S2-38A-2543-XXXIX	SWH1	18.783	0.006	15.659	0.005	38.676	0.012	0.833669	0.000035	2.05907	0.00006
S2-37A-XXXVII	SWH2	18.786	0.004	15.656	0.003	38.677	0.008	0.833391	0.000016	2.05879	0.00005
S2-1952	SWH7	18.804	0.003	15.656	0.003	38.692	0.006	0.832529	0.000022	2.05750	0.00006
S2 900016	SWH10	18.667	0.006	15.656	0.005	38.576	0.013	0.838674	0.000034	2.06648	0.00008
Standard NBS 981		16.9407	0.0020	15.4969	0.0014	36.7144	0.0034	0.91478	0.00003	2.16725	0.00010
Reference value NBS 981		16.9405		15.4963		36.7219		0.91475		2.16771	
<b>Soils (after Walraven and Van der Veer, 2005)</b>											
Urk topsoil								0.8489		2.086	
Urk subsoil								0.8345		2.063	
Schipluiden topsoil								0.8424		2.072	
Schipluiden subsoil								0.8332		2.063	
Rijswijk subsoil								0.8370		2.068	
Giessendam topsoil								0.8614		2.097	
Giessendam subsoil								0.8469		2.080	

\*uncertainties on isotope ratios are 2SE within-run precision

Table 3: Samples and strontium isotope results for animals and soils

Sample reference	description	Durham lab number	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\text{SE}^*$
<b>Schipluiden</b>				
Feature 2016, trench 14, find no. 01312	cow	SCA1	0.708865	12
Feature 4018, trench 18, find no. 03102	deer	SCA2	0.708753	13
Feature 4018, trench 11, find no. 08632	pig	SCA3	0.708909	10
Feature 2015, trench 11 find no. 08385	cow	SCA4	0.708963	13
Feature 2015, trench 11 fin no. 08386	deer	SCA5	0.709076	10
Feature 8015 trench 25 find no.09631	pig	SCA6	0.708965	11
Feature 4018	soil	SCS1	0.709250	11
Grave 1: filling of grave pit	soil	SCS2	0.709002	11
Grave 2: filling of grave pit	soil	SCS3	0.709771	18
Grave 3: filling of grave pit	soil	SCS4	0.708985	10
Grave 4: filling of grave pit	soil	SCS5	0.709027	13
<b>Swifterbant</b>				
S3:910077	red deer	SWA1	0.709691	19
S3:910231	red deer	SWA2	0.709539	14
S2-7294	deer	SWA3	0.710148	13
S3:910176	dog	SWA4	0.709007	15
S3:52130	beaver(?)	SWA5	0.708947	11
S3:26371	red deer	SWA6	0.708985	11
Flood basin I, -7.23m NAP	soil	SWS1	0.708449	14
Flood basin II, -4.57m NAP	soil	SWS5	0.708709	14
Flood basin III, -5.00m NAP	soil	SWS7	0.709015	04
Gully I, -6.18m NAP	soil	SWS2	0.708247	14
Gully II, -6.70m NAP	soil	SWS3	0.708391	13
S2 natural levee I (just above habitation area)	soil	SWS8	0.708925	06
S2 natural levee II (habitation area)	soil	SWS6	0.708933	12
S2 natural levee III (just below habitation area)	soil	SWS4	0.708923	06

\*uncertainties on strontium isotope ratios are 2SE within-run precision

## Figures

Figure 1: Locations of the sites. 1. Swifterbant, 2. Schipluiden.

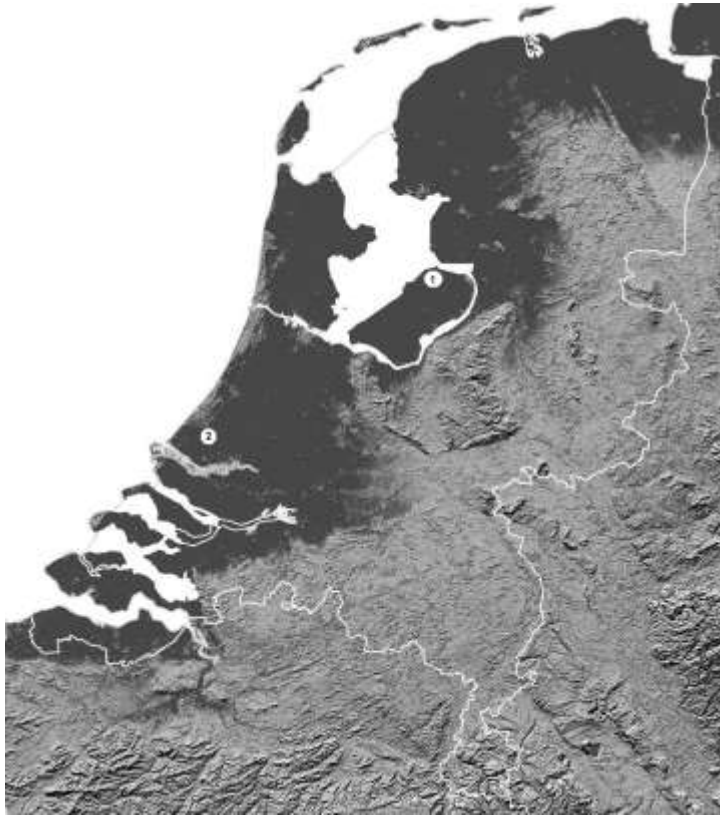


Figure 2: Nitrogen and carbon isotope results for human remains from Schipluiden and Swifterbant. Dotted lines connect bone and dentine samples from the same individual.

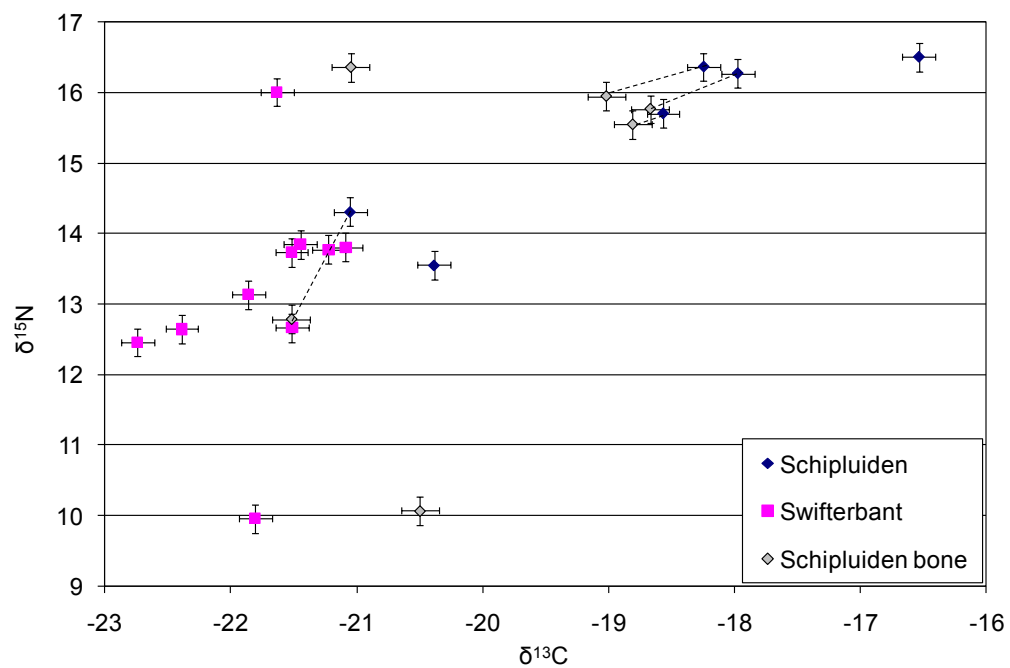




Figure 3: Sulphur and carbon isotope results for human remains from Schipluiden and Swifterbant.

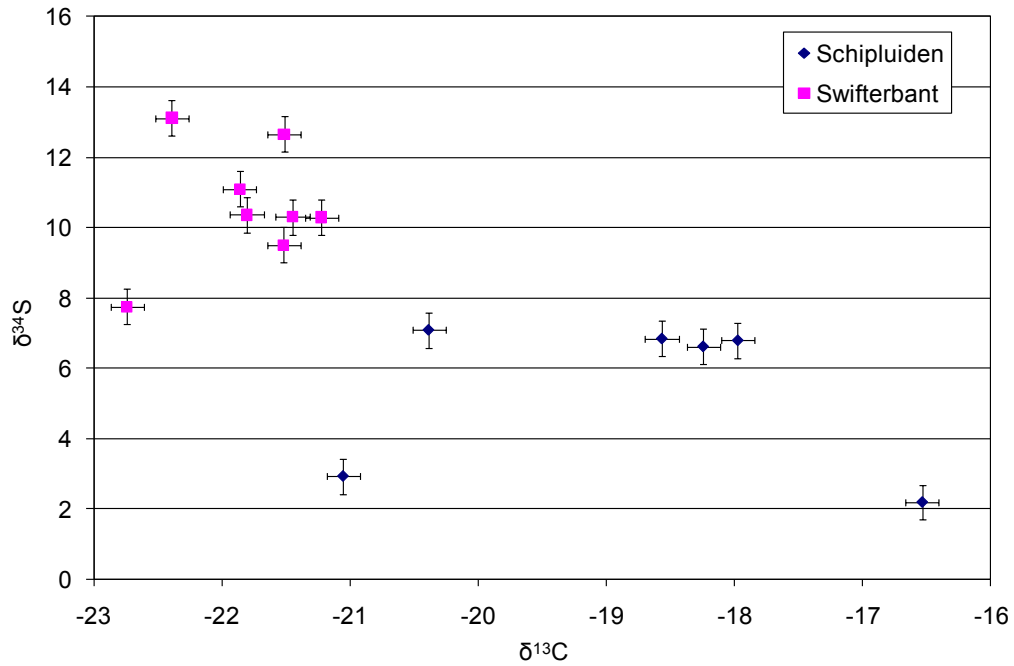


Figure 4: Strontium and oxygen isotope results for human remains from Schipluiden and Swifterbant. Error bars for Sr are smaller than the symbols.

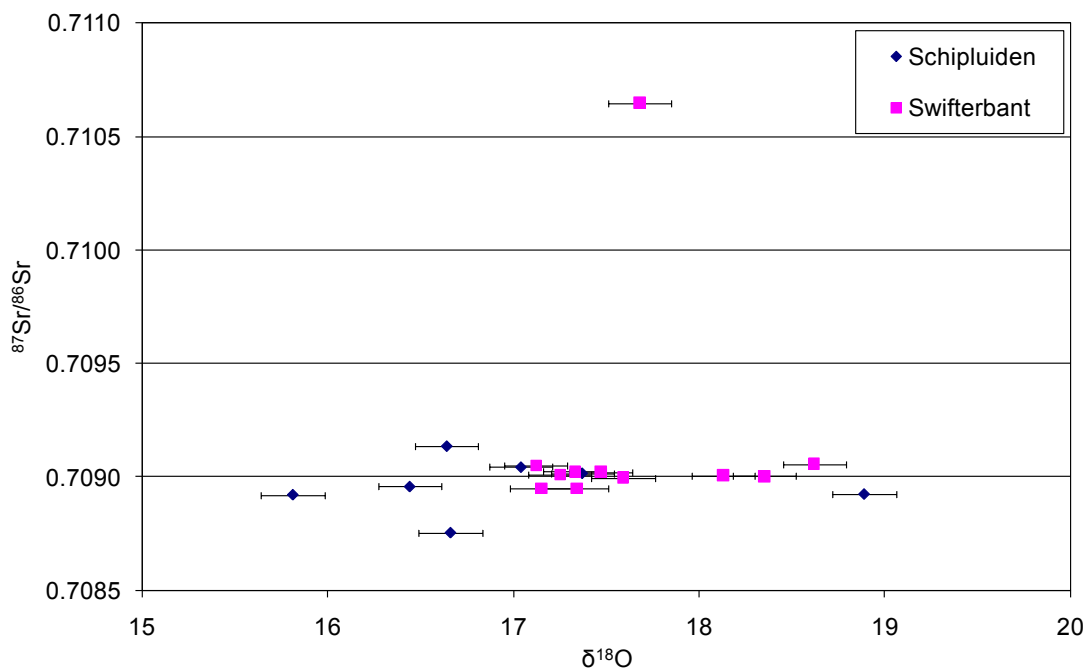


Figure 5: Lead and strontium isotope results for human remains and soils from Schipluiden and Swifterbant. Giessendam values are not shown as they are far off this scale. Error bars are smaller than the symbols.

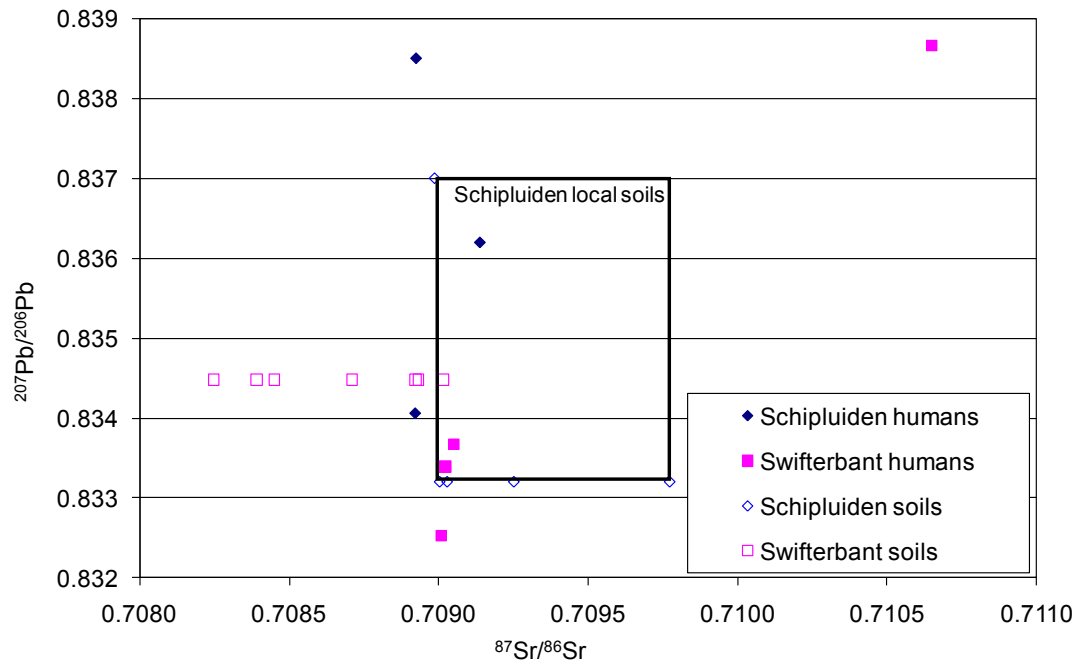


Figure 6. Carbon and nitrogen levels for Swifterbant, Schipluiden, Lepenski Vir and Vlasac (values of Lepenski Vir and Vlasac from Borić et al. 2004). For clarity analytical uncertainties are not shown. The data of Boric et al. (2004) have uncertainties of  $\pm 0.15$  ‰ on both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Dotted lines connect bone and dentine samples from the same individual.

