The Alvastra diet from bone chemistry
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Man is an omnivorous creature. His ability to adapt diets from a wide range of ecological niches is one of the reasons why he inhabits almost the entire surface of the earth.

Man differs from animals in his complex way of food-sharing. Food is shared not only between close kin, but also within a social network which may differ from one society to another. However, food is not shared indiscriminately, because it is a scarce resource and linked to survival (van den Berghe 1984).

In all societies rituals are connected with food-sharing, and express how we transform nature into culture. Anthropological studies show us how culture influences our relationship to what we eat. Of all nutrients available only some will be recognized as food. Food is classified in a number of ways according to medical and religious beliefs, and variables such as status, sex and age (Foster et al. 1978).

The traditional methods which archaeologists use to study prehistoric diet are based on ecofacts and skeletal data. It is possible to assess with some certainty, which of the nutrients available to a society were actually exploited. Seasonal change in diet may also be studied. A main problem in the study of prehistoric diet and economy is the quantification of the proportions of meat and vegetarian food, and also how food was distributed to subgroups within a society.

The study of prehistoric diet was criticised by Dennell in 1979. In his opinion archaeological data pertain to the production of food rather than its consumption. He characterizes the developments in the study of prehistoric economy in the 70’s as “apparent rather than real” and states that (op.cit., p. 131) “… it seems unlikely that the size of prehistoric communities can be calculated from settlement data with sufficient precision to be used in evaluations of prehistoric food consumption”.

Although we realize that Dennell pointed out crucial problems concerning the study of prehistoric diet, we see reason to revise his pessimism.

A main topic of the doctoral thesis by Hans Browall in 1986 is an investigation of the economy of a Middle Neolithic settlement site at Alvastra, Sweden (Fig. 1). The source material comprises the remnants of a pile-dwelling, which was occupied for a short time c. 4500 B.P. For the suggested resource area of the settlement site, Browall presents three hypothetical models for consumption of meat versus vegetarian food: (A) 75 % meat—25 % vegetarian food, (B) 50 %—50 % and (C) 25 %—75 %.

Model A could immediately be rejected because the resource area would not provide sufficient grazing land for the animals required. Models B and C seem more likely.

Via new methods for the study of prehistoric diet we may be able to decide which of the two remaining models is the more likely. These
methods are based on chemical components in skeletal tissue and how they reflect the composition of meat and plant-food, marine and terrestrial food in diet.

We may also test whether archaeological data are reliable as indicators of prehistoric economy.

**Methods**

Cortical bone samples of three adult humans, undetermined as regards sex, and bones from red deer, wild boar and wolf found at the Alvastra pile-dwelling, were subjected to analysis via the Sr/Ca-method and the $^{13}$C-method to determine whether their diet consisted of meat or plants, and marine or terrestrial food. The former method is based on the relation between strontium (Sr) and calcium (Ca) in the inorganic part of the bone. The latter method is based on the proportion of $^{13}$C in bone collagen.

The study of diet from chemical elements in bone, involves three major problems. These are listed below with reference to relevant literature:

1) The overall distribution of the element to be studied, and the metabolic considerations in the uptake and deposition in skeletal tissue. (Sr/Ca: Comar et al. 1957; Kulp et al. 1957; Toots et al. 1965; Schoeninger 1979. $^{13}$C: DeNiro et al. 1983; Olsson 1985.)


**The Sr/Ca-method**

The Sr/Ca-ratio is decreasing through a food-chain, from plants to herbivores, to carnivores. A person living mainly on plants is thus likely to have a higher Sr/Ca-ratio in the skeletal tissue than one who eats a great deal of meat.

Brown 1974 was the first to apply this method to human subfossil bones. Research on the incorporation of strontium into skeletal tissue was prompted by the fallout of $^{90}$Sr from nuclear tests. A review of the method as used in paleodietary research is given by Sillen et al. 1982.

**The $^{13}$C-method**

This method derives from the $^{14}$C-dating method. As used in studies of prehistoric diet, it was originally applied to early maize-cultivating societies. Maize incorporates the carbon isotope $^{13}$C differently from most other plants (e.g. Vogel et al. 1977). Tauber first applied this method to distinguish between marine and terrestrial food in 1981, and it was later used in similar ways by other scientists (Hobson et al. 1984; Chisholm 1983).

Both marine food and terrestrial plants contain strontium in similar proportions. An individual with a high Sr/Ca-ratio, and an unknown proportion of marine food in his diet, is difficult to evaluate, because the high ratio may
Table 1. Skeletal chemistry data from the Middle Neolithic pile-dwelling Alvastra, Sweden. — Kemiska analyser av ben från Alvastra påbyggnad.

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<td>.70</td>
<td>.57—.87</td>
<td>.13</td>
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<td>.37—.55</td>
<td>.08</td>
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<tr>
<td>Wolf</td>
<td>1</td>
<td>.020</td>
<td>31.7</td>
<td>.63</td>
<td>.41—.42</td>
<td>.01</td>
<td>—21.13</td>
<td>.20</td>
</tr>
<tr>
<td>Humans</td>
<td>3</td>
<td>.013</td>
<td>31.6</td>
<td>.42</td>
<td>.57—.57</td>
<td>.37—.55</td>
<td>.41—.42</td>
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</tr>
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(1)= number of samples, (2)= mean content of Sr (%), (3)= mean content of Ca (%), (4)= mean ratio Sr/Ca (× 10^3), (5)= range of ratio Sr/Ca (×10^3), (6)= stand. dev. of (4), (7)= mean δ13C PDB (/‰), (8)= stand. dev. of (7).

be due to either plant or marine food. To exclude marine food as a source of error in our analyses, the 13C-content in the human bones was analysed.

The human bone samples (all of them from fibulae) were treated according to Method 2 as described by Chisholm et al. 1983. This method implies that the bone samples are steeped in caustic soda for 18—20 hours in one step of the preparation procedure. As compared with other methods this may cause a variation of 0.6—0.8 /‰, which should be borne in mind when the results are evaluated. The content of 13C in prepared solid bone collagen was measured by mass spectrometry.

Results and discussion
The Sr/Ca and 13C values are displayed in Table 1. The results obtained from the 13C analyses show values indicating a terrestrial diet for all three of the humans. Even with a variation of 0.6—0.8 /‰ due to preparation procedure, and one of 1 /‰ caused by metabolic differences in individuals having the same diet (DeNiro et al. 1983) the results still fall within the range of terrestrial food-choice.

However, sources of error were indicated by a study of the diet of occupants of (coastal) settlements on the Baltic (Welinder 1985). The freshwater content of the Baltic is higher than that of the North Atlantic, and this may cause differences in 13C-content. There are, however, no obvious errors in the 13C-content of existing measurements of individuals from coastal and inland settlements in the Baltic area, as differences actually exist between these two sets of data (cf. Olsson 1985). It is thus likely that we have interpreted the Alvastra values correctly, and can state that marine food was of insignificant importance for the inhabitants of Alvastra.

The values of the Sr/Ca analyses should now be reliable since marine food is excluded as a main source. The values obtained for the Sr/Ca ratio in the bone samples from the species analysed fall approximately within the range of 20 ‰ to the mean ratio for each species (Schoeninger 1979). Red deer have a diet completely based on plants, and have the highest Sr/Ca-ratio. The only carnivore present, a wolf, has a Sr/Ca-ratio of 0.63, which qualifies it as a herbivore. Overlap between carnivores and herbivores has previously been reported (Sillen 1981), and the unfortunate fact that we have had only one carnivore available for our analyses may have caused this result.

The Sr/Ca-ratio for the wolf must also be considered from another point of view. Wolves are reported to migrate (Bjärvall et al. 1986, Pulliainen 1979). Male wolves of about 2—3 years of age may leave the group to roam often for long distances. Thus, it is possible that the wolf came from far away. Individuals raised on diets from different areas with different strontium levels in the soil should not be directly compared (Sillen et al. 1982).

The humans in our study have values within the range of those of the wild boars. An analysis of the stomach-contents of several hundred wild boars in DDR shows that they eat mainly plant-food and prefer acorns when available (Briedermann 1976). The Sr/Ca-ratio of the
Alvastra wild boars compared with that of the red deer shows that they were not entirely dependent on plantfood. This may conform to Lepiksaar’s (1974) theory concerning the wild boars at the Middle Neolithic site Ås, i.e. groups of wild boar lived close to the settlement in the winter-season where they had easy access to scraps and refuse from human food-preparation and consumption. Thus, the wild boars would have eaten more meat than their present relatives in DDR, which rarely eat more than 5 % meat annually. It has also been suggested that the Alvastra specimens in fact represent domestic pigs (Jonsson 1986).

According to the Sr/Ca analyses of the human bone samples from Alvastra and the comparison with those animals with a known diet from the same site, we have come to the conclusion that Model C is the most probable for the consumption of meat and plant-food, viz. the consumption of meat was approximately 25 % and the remaining 75 % plants.

Our results agree closely with Browall’s hypothesis, which may prove, or at least indicate, that ecofact and site catchment data could be used for reconstruction of prehistoric food consumption and paleoeconomy.

By using bone strontium as an indicator of access to meat, skeletal samples from Huitzo, Mexico, were analysed by Brown 1974. His results show that in unstratified societies males ate more meat than females. The same analysis showed that as the society became stratified, the high-ranking individuals ate more meat than those of low status. Skeletons from Chalcatzingo, Mexico, indicate the same tendency (Schoeninger 1979). The difference between those buried with jade artefacts and those without grave-goods was significant with respect to access to meat. Further, Sillen 1981 has found a slight difference between males and females from the Natufian levels in the Hayonim Cave, Israel. The males had the lowest Sr/Ca-ratio, which means that they ate more meat than the females.

The three humans from Alvastra are undetermined as regards sex and no information on status is available. Still we are able to suggest that there was no significant difference in diet between them, with respect either to the consumption of plants and meat, or to marine and terrestrial food.

With these comparatively new methods in the study of prehistoric diet, it is possible to exceed the framework within which archaeologists have worked to separate production from consumption and penetrate the complex systems of subdivision of food in prehistoric societies. The methods developed are in fact a consequence of research on nuclear weapons and fallout of strontium from nuclear tests. Paleodiets research may perhaps, for sad reasons, be intensified in years to come, as scientists study the fallout of 137Cs from Chernobyl, and its deposition in living organisms.

References
Kemiska undersökningar av ben kan indikera de levande individernas kosthåll. $^{13}C$-innehållet i benen är ett mått på andelen marin föda i det totala kosthållet, kvoten strontium/calcium ett mått på relationen mellan animalisk föda och växtföda.

För tre individer från Alvastra påbyggnad gäller att deras kosthåll har varit lika med avseende på de ovan refererade parametrarna. Detta kosthåll har inte innehållit marin föda eller endast försumbart lite marin föda utan har dominerats av växtföda. En kalibrering mot de på boplatsen förekommande djurarterna visar att de ätit animalisk föda i ungefär lika stor mängd som vildsvinen. Moderna östtyska vildsvin äter högst 5—10% animalier. Melanneolitiska vildsvin, som har haft tillgång till avfallshögarna runt en boplats, kan förväntas ha ätit mera animalisk föda.

Vår bedömning är, att av de av Browall 1986 för Alvastra föreslagna ekonomiska modellerna är modell C den sannolikaste. Denna innebär ett kosthåll med 25% animalisk föda och 75% växtföda.