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NEW INFORMATION ON THE STONE AGE GRAVES AT DRAGSHOLM, DENMARK

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BACKGROUND

Two graves (Fig. 1) were excavated near the castle at Dragsholm in northwest Zealand, Denmark (Fig. 2), in the early 1970s by the National Museum of Denmark (Brinch Petersen 1973, 1974). Grave I contained the skeletons of two women who at that time were suggested to be 18 years old (Burial A) and 40-50 years old (Burial B), respectively. These women had been interred with 144 animal tooth pendants, a decorated bone dagger (or spatula) and a bone point, and were covered with red ochre. The published radiocarbon date of 5160±100 bp on a human bone from burial A confirmed the Mesolithic age of the two women; stable carbon isotope ratios from the bones indicated a diet dominated by marine foods, also a Late Mesolithic hallmark.

Because of the significance of these graves and recent questions about their age and contents, we have assembled new archaeological, biological, and isotopic information on the burials and some of the grave goods. Our report is organized as follows. A description of the discovery and recovery of the graves by the original excavator, Erik Brinch Petersen, provides the find context for the materials. A subsequent section by T. Douglas Price and Peter Vang Petersen concerns some issues and questions that have arisen regarding the graves; the next section deals with questions about radiocarbon calibration and the archaeological finds in the graves and their context.

Discussion of the new investigations begins with an anthropological examination of the skeletons by Pia Bennike. The specific samples of human and animal bone and enamel that were used in this study are described in the following section, along with some information on the preservation of this material and conservation measures that were used. Next, new radiocarbon determinations are described by Price and Jan Heinemeier, along with the calibration of these dates in light of reservoir effects. The following section by Michael Richards focuses on the stable isotopes of carbon and nitrogen from the burials. A subsequent section by Price and Stanley Ambrose presents the results of carbon isotopes measured in apatite and a comparison with the collagen results. In the next section, the use of strontium isotope ratios as an indicator of residence change is discussed by Price and the results of this analysis at Dragsholm are discussed. Price and Noe-Nygaard discuss the recent archaeological and geological investigations at the site relevant to understanding the situation and date of the graves. Our conclusions provide a summary of what these new radiocarbon dates and stable isotope measurements tell us about the Dragsholm graves, as well as what the Dragsholm graves tell us about radiocarbon dating, stable isotopes, and the transition to the Neolithic in prehistory.

DISCOVERY AND EXCAVATION OF THE GRAVES (EBP)

Dragsholm is the name of the castle, formerly known as "Adelersborg", located less than one km east of the coast of northwest Zealand, in the innermost part of the Bay of Sejrø at the base of the distinctive peninsula known as Ordrup Næs. Situated on a prominent rise in the landscape, the castle overlooks a reclaimed area to the east. In conjunction with the drainage of the adjacent Lammefjord in the 19th century, a primary canal was dug at Drags Mølle (2 m asl), linking the former Lammefjord with the Dragsholm inlet, draining the Lammefjord region into the bay of Sejrø.

A small island (4.65 m asl) was originally situated on the leeward side of the mouth of this fossil inlet just to the north of the canal. In fact, fill from the excavation of the canal had been piled up along parts of the island. It was precisely here in the early spring of 1973 that a double burial was first discovered by an observant plowman, Erling Pedersen, from the seat of his tractor. Mr. Pedersen was also an amateur archaeologist and photographer. The big field to the southwest of Dragsholm Slot had provided a large portion of Mr. Pedersen's collection, more than 750 objects. In the field in the spring of 1973 he noticed several bones and a distinctive red color exposed on the surface of the ground atop a small rise at the south end of the field near the Dragsholm Canal (Fig. 3). Recognizing these bones as human, he notified the National Museum.

The National Museum initiated an investigation during the early days of March headed by Per Poulsen. After recognizing the importance of the discovery - a burial of Mesolithic age containing the well- preserved skeletons of two richly adorned females covered with red ochre, it was decided to attempt to remove the double grave en bloc Unfortunately, the attempt failed partly due to the size of the burial and partly due to the sandy and stony sedi-

1 Editorial note: The present contribution has the format of a technical report, even with sketchy illustrations. Nevertheless, it has been published in Acta Archaeologica due to the importance of the finds and the novel analyses, in particular C-14 dates and isotope analyses.

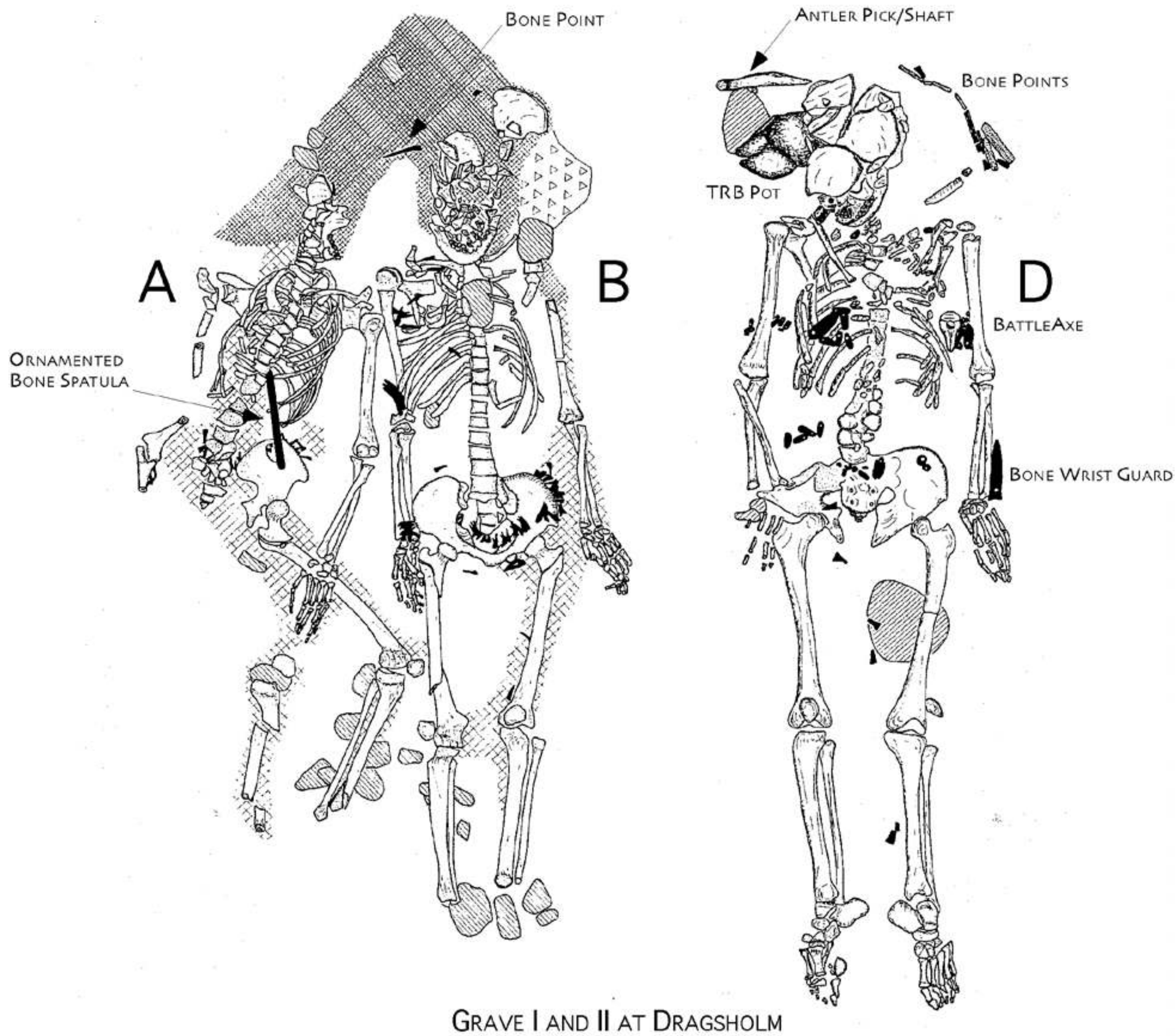


Fig. 1. Graves I and II at Dragsholm (Brinch Petersen 1974). The second grave, less than 2 meters from the first, held the bones of a skeleton which was determined to be of a twenty-year-old male (Grave II, Burial D). This grave contained a number of artifacts including at least 60 amber beads, a stone battle axe, flint blades and projectile points, an antler pick or shaft, a bone spoon and a wrist guard, and a small ceramic beaker from the early Neolithic Funnel Beaker culture. The contents of the grave indicated a Neolithic age for this individual, confirmed by a radiocarbon date of 4840±100 bp (approximately 300 years younger than the females) and a stable carbon isotope ratio that indicated a largely terrestrial diet. The close proximity of these two burials and the very different grave goods and diets represented are remarkable. No other graves were found at this location.

ment. Poulsen was then joined by Erik Brinch Petersen and Steen W. Andersen both of the Institute of Archaeology at the University of Copenhagen, and the two interred individuals and the grave goods were recorded in situ and then removed, bone by bone and pendant by pendant.

After the harvest, a second investigation took place during August and September. Erik Brinch Petersen and Per Poulsen were now assisted by Tom Christensen, Lotte Hedeager, Leif Chr. Nielsen, and Peter Vang Petersen, students at the Institute. Some 274 m of 1 m trenches were excavated by hand across the top of the island, resulting in the discovery of the second grave situated less than two meters from the first (Fig. 4). Again the burial was recorded in situ, followed by a lifting of the individual bones and the grave goods.

These two graves with the three buried individuals have haunted archaeologists ever since. Originally, there must have been both an Ertebølle, late Mesolithic, as well as an early Neolithic, TRB, occupation on the island, but changes in sea level and modern agriculture destroyed the cultural horizon on the top of the island. A few oyster shells were found in the fill of the second burial and a small shell midden must have been present, but whether it was of Mesolithic or Neolithic age has not been determined. The double

Fig. 2. The location of Dragsholm in southern Scandinavia.

burial was initially thought to be of Mesolithic age on the basis of the artifacts and the jewelry adorning the two individuals (Brinch Petersen 1973). The younger female (skeleton A) was buried with a bone dagger made from the metacarpus/metatarsus of a red deer. The dagger was ornamented on both sides with a drilled pattern in a geometrical design with a human person on one side. Behind her pelvis was a belt adorned with a string of tooth pendants, all of which, with one exception, had been made from the front teeth and the canines of red deer (Cervus elaphus), the exception being a single tooth from an Elk (Alces alces).

The older female (skeleton B) wore a similar pelvic girdle of red deer teeth. In this case, the individual teeth had been arranged in bundles, 22 in all (Brinch Petersen 1974; 1979). Placed among the red deer teeth was a single incisor from a bovid, considered to come from an auroch (Bos primigenius). Furthermore, three incisors of a wild boar (Sus scrofa ferus) were found on her right upper arm. On her chest was a pectoral consisting of seven front teeth of red deer, again all perforated. A bone pin was located next to the skull, presumably a hairpin, while a single transverse arrowhead was found above the skull. Both individuals were covered with red ochre, especially around the skulls, but also the extremities were discolored, while both torsos were largely unstained. The ornamented bone dagger and the presence of teeth from elk, aurochs, and red deer certainly suggested a Mesolithic date, although similar girdles of red deer teeth had been observed at the Neolithic cemetery of Ostorf in Mecklenburg (Bastian 1962, Schuldt 1961). Also the intensive use of red ochre pointed to a Mesolithic age for the burial.

While the first grave was oriented NW to SE with the heads towards the northwest, the second grave was laid out in a W to E direction, and with the head towards the west. Apparently, no red ochre was used, but an antler beam had been driven into the ground behind the head of the deceased. The buried individual was a male, originally identified as some twenty years of age. By the left side of his head was a ceramic pot of TRB A style (Brinch Petersen 1974, Koch 1998), while on his right side were three flint blades, four transverse arrowheads, a strike-a-light flint and a bone spatula (Fig. 1). Six additional transverse arrowheads were found between his legs. A wrist guard of bone was found along the lower part of the left arm, while a battleaxe of greenstone (Ebbesen 1998: type I) had been hammered into the ground between the upper left arm and the rib case. No less than sixty amber pendants, arranged in six different sets, completed his adornment. One set of these pendants was found across the abdomen, one on the upper right of the stomach area, another one on the chest, one each on the upper arms, and one in the neck region.

The excavation of the two graves actually raised more questions than it resolved (Brinch Petersen 1974). On one hand the graves could be contemporaneous, making both of them Neolithic; the Neolithic designation of the second burial is obvious. Given the fact that the Dragsholm male is the oldest known Neolithic burial, the graves might provide an example of gender differences at the very beginning of the Early Neolithic period. In that case, the tooth pendant could have come from a domestic cow, and so it was unfortunately stated (Brinch Petersen 1974).

Meanwhile, the first 14C datings of the Dragsholm skeletons became available, uncalibrated, and a date around 3210±100 bc (K-2224) was accepted for the double burial; the Neolithic male was slightly younger, around 2890±100 bc (K2291). Despite the standard deviations of the two dates, H. Tauber from the Radiocarbon Lab in Copenhagen has maintained that the two burials could not be contemporaneous (Tauber 1981). However, with a calibrated date for the double burial around 4000 cal BC, it became even more difficult to favor either a Mesolithic or a Neolithic association.

Only a few years later came the discovery of the eighteen Mesolithic graves with 22 individuals from the site of Henriksholm-Bøgebakken at Vedbæk (Albrethsen & Brinch Petersen 1977). The costume of the young female in grave 8 at Bøgebakken was very similar to the two females from Dragsholm. She too was wearing a pelvic girdle, consisting of 60 red deer tooth pendants, including seven canine teeth (“Grandeln”), and a single tooth from a brown bear (Ursus arcticus). The girdle was also adorned with rows of snail shells. Exactly the same arrangement of pendants - teeth of red deer including canines, perforated shells of snails, and some teeth from wild boar and one from an elk (Alces alces) - was found in a bundle next to her head. Furthermore, an interesting pectoral was found with one of the females (individual 19C) in the triple burial at the same site, and among the elements here was an incisor from an aurochs (Bos primigenius) (Brinch Petersen 1979).

The burials at Bøgebakken were indeed Mesolithic, as shown by the 14C dates from the first three burials: Grave 3 (K-2781): 4100±75 bc; Grave 5 (K-2782): 4340±75 bc; Grave no 14 (K-2784): 3860±105 bc (all uncalibrated). It was also in this case that Tauber measured the δ13C values of the bone collagen in these individuals. Because of their high values, between -13.4‰ and -15.3‰, he suggested, that they had consumed a heavily marine diet. He then returned to the Dragsholm individuals and discovered that the two females also exhibited very marine δ13C values, -11.4‰ and -12.1‰, while the male had a terrestrial value of -21.7‰. So at Dragsholm from the same locality, a dietary shift could be documented across the Mesolithic/Neolithic transition (Tauber 1981). With such high δ13C values for both the women in Grave I, they became the late Mesolithic stereotypes of coastal dwellers living from the sea, while the male epitomized an inland Neolithic life style.

The fact that not only the population from Bøgebakken, but also the two females from Dragsholm, were of Mesolithic age could now be further corroborated by the evidence that other females buried on Zealand were found with exotic tooth pendants among their sets of jewelry. Meanwhile K. Aaris-Sørensen had demonstrated (1980) that the faunal picture of Zealand during the Ertebølle period was one of depauperation with the disappearance of aurochs, elk and brown bear. We have always looked to Scania as the closest

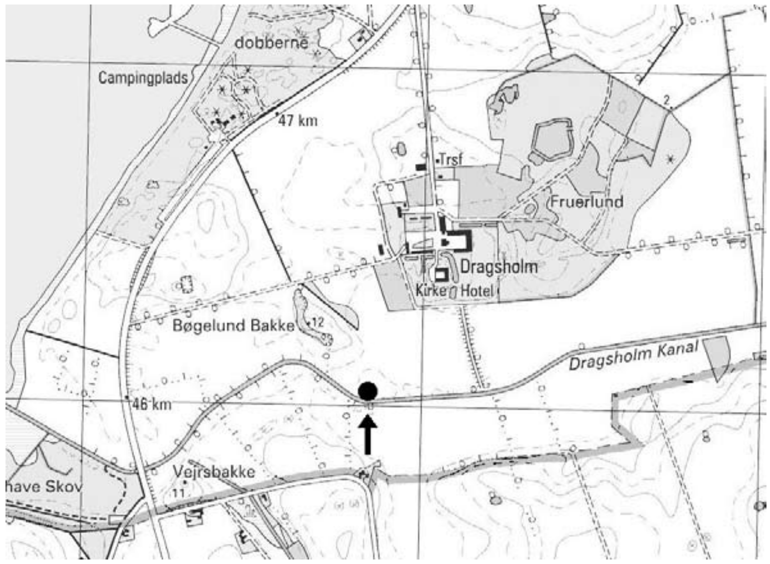


Fig. 3. The location of the Stone Age graves at Dragsholm.

place for origin for these pendants, but the same teeth could also have been procured from Jutland or even Northern Germany.

MISCELLANEOUS ISSUES (TDP AND PVP)

There are a number of minor issues relevant to the Dragsholm graves that can be addressed here in light of our study, including an unpublished radiocarbon date, a loose human bone, switched skulls, and the presence of exotic animal bones in the graves.

Two radiocarbon dates, listed above, were provided for the Dragsholm skeletons in the original publication (Brinch Petersen 1974). Tauber (1983) published these same two dates several years later with information on their calibration and carbon isotope values. This information is repeated here in Table 1. Tauber transformed the dates from radiocarbon years bp to radiocarbon years BC in the conventional way by subtracting 1,950 years. The calibration of the dates to calendar years BC was done using a table of values in Clark (1975), based on tree-ring corrections of radiocarbon dates at that time. Note also that a stable carbon isotope ratio on collagen in the bone of Burial B was measured, although a date was not reported.

There are, however, three original radiocarbon determinations listed in the records of the Radiocarbon Laboratory at the National Museum in Copenhagen and shown in Table 2. There are two important things to observe in this table. First, there is an unpublished radiocarbon date for Skeleton B of 5930±100 bp. This is 550 years older than the date for Skeleton A in the same grave and was apparently disregarded as anomalous because of the presence of conservation chemicals (Tauber 1981b: 123). Second, the date for Skeleton A of 5380±100 listed in the Museum document is 220 years older than the published date for this skeleton of 5160±100. This suggests that the original measurement was calibrated for marine reservoir effects by subtracting 220 years before the date was published. The date for the male Burial D remained unchanged. More on this later.

A Loose Human Bone. As noted above, the three burials at Dragsholm are designated as A (young female), B (older female), and D (male). Individual C is represented only by a single bone (a humerus) found on the surface near the graves at the time of the original discovery by Erling Pedersen. There was no grave associated with this find. No other parts of this skeleton were recovered and the prehistoric context of this bone is unknown.

Such loose human bones are not uncommon and are known from at least sixty different Mesolithic sites in Denmark. A number of different interpretations has been offered for this group of finds, ranging from cannibalism to burial ritual if not simply the result of disturbed or destroyed burials. Stable carbon isotopes and radiocarbon have now been measured on the humerus from Individual C. The determination (AAR-8724, 3097±44 BP, 1390-1050 B.C. at 95%) clearly indicates a Bronze Age date for this bone and means that it not relevant to the Mesolithic and Neolithic burials.

Switched Skulls. Some years ago, Christopher Meiklejohn noted that the skulls of the two Mesolithic females from Dragsholm were switched. Both skulls have the letters A and B on the inside of different segments of the cranium. Peter Vang Petersen recalls that part of one woman's skull was found after the graves had been uncovered, during the subsequent digging of exploratory trenches. Re-examination of tooth wear, bone thickness, and other characteristics of the skulls has provided a reliable assignation of skull to owner and this error has been corrected.

Exotic Animal Bones. A number of domestic animal bones were reported in the fill of the male's grave, including cow, dog, and sheep (Brinch Petersen 1974). Re-examination of the material has confirmed only the presence of domestic cow and dog. The bone pin (accession number DR 55), lying between the two women in the Mesolithic grave, has been examined by Kim Aaris-Sørensen and determined as roe deer, rather than sheep or goat.

A heavy bone chisel was found at the site during the excavation of the test pit in 1974. This bone was thought to be an elk, or perhaps aurochs, based on size and thickness. Both of these species

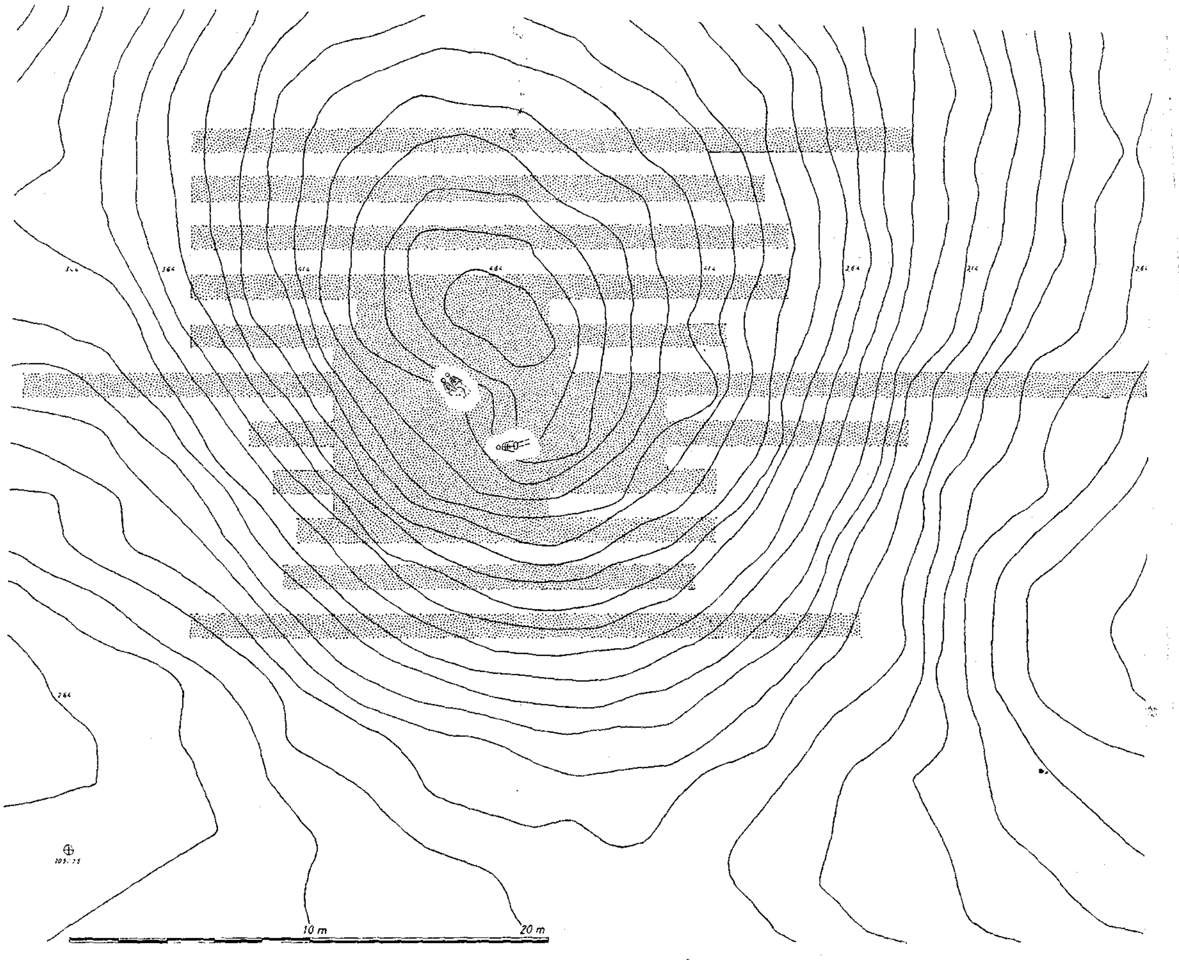


Fig. 4. The two graves and archaeological trenches at Dragsholm (Brinch Petersen 1974).

were absent from Zealand after about 6000 B.C. and their presence would be surprising. The bone is likely from a domestic cow. Stable carbon isotopes and radiocarbon have now been measured in this sample. The radiocarbon date of 4050-3770 B.C. cal (AAR-8774) confirms the Early Neolithic date for the cow and also helps to date Layer 6 at the site in which the bone artifact was found. The δ13C value for the cow is -21.5 ‰ in line with other early cows from Scandinavia (Noe-Nygaard et al. 2005).

There is an exotic species, an elk, among the animal tooth pendants in the females' grave. Another pendant was originally reported to be either a wild aurochs or domestic ox (Brinch Petersen 1973), while at the same time a third pendant, originally identified as red deer, is now classified as aurochs.

CALIBRATIONS AND QUESTIONS

Accurate dating of the Dragsholm graves is critical to resolution of a number of questions. To reiterate here, the first dates made on the Dragsholm burials were reported by Brinch Petersen in 1974 in radiocarbon years before present (bp). When initially described, both graves were attributed to the Early Neolithic and the women's grave was called the oldest Neolithic grave in Scandinavia (Brinch Petersen 1974). Subsequent authors (e.g., Persson 1998, Larsson 1991) have emphasized the possible contemporaniety of the burials. For example, in a recent publication, Fischer (2002: 377-378) states, "the two graves at Dragsholm were constructed after the introduction of farming in the region … The two graves may represent a man and his wives."

The original dates and calibrations are provided in Table 3, along with new calibrations. In our study, radiocarbon dates are given in calibrated years B.C. The new calibration of the original Dragsholm dates is based on recent revisions in the web-based calibration program (Calib 4.4 html version) of Stuiver et al. (1998), along with new information for marine corrections. Site-specific marine corrections are now recommended since marine waters vary substantially in the amount of incorporated old radiocarbon. The new calibrations for Dragsholm are based on recently measured marine corrections from the Kattegat just north of the site itself (Heier-Nielsen et al. 1998). The new calibration of the dates shifts the age of the female (Individual A) substantially, from ca.

4000 B.C. to ca. 3695 B.C., making the Mesolithic grave virtually identical in age to that of the male. Note that this calibration is made on the original published date. It is clear, however, from the three dates in the archives of the Radiocarbon Laboratory (Table 2) that the published date of 5380±100 had already been corrected for marine reservoir effect by approximately 220 years. How this value for the calibration was determined is unknown. This does mean, however, that any new calibration should be made on the original measurement rather than the corrected date. Calibration of the original date of 5380±100 gives a new date of approximately 4150 BC (mean of 4363 - 3980 at the highest probability of 0.991 for two sigma, Calib 4.4), approximately 500 years earlier than the male grave.

This calibration reaffirms the Mesolithic age of the female burials and casts substantial doubt on the contemporaniety of the two graves. Archaeological information also supports a different age for the graves. The original excavator, Brinch Petersen, noted that the graves had been covered by a cultural horizon, but that it had been plowed away. He also observed that the fill of the male grave contained settlement debris in the form of artifacts and oyster and blue mussel shell. No information was available on the fill of the females' grave. The male grave contained a Funnel Beaker pot, recently classified according to a new typology devised by Eva Koch (1998) as Type 1, belonging to the Early Neolithic. This type occurs in southern Scandinavia between approximately 3800 - 3500 B.C., which fits well with date for the grave.

NEW INVESTIGATIONS

Recent developments in physical anthropology, radiocarbon dating, and bone chemistry can help to resolve some of the questions that have arisen about the Dragsholm graves and to provide new information. The remainder of this report is divided into two major sections. First, a detailed re-examination of the skeletal material from Dragsholm by Pia Bennike provides new information on the characteristics, similarities and differences among the individuals. Second, isotopic studies of new samples from the graves provide a resolution of issues regarding the dating of the burials, new information on diet from carbon and nitrogen isotopes in collagen and carbon in apatite, and information on place of origin from strontium isotopes in tooth enamel. The results of our study are summarized in the conclusion.

BIOLOGICAL ANTHROPOLOGY (PB)

Renewed interest in the Dragsholm graves has given rise to several interesting anthropological questions: Is there any evidence of a familial relationship between the two Mesolithic women (A and B) in the double grave, and do they reflect a different lifestyle, including a different type of subsistence, from that of a Neolithic male skeleton (D) found in a single grave located only a few meters away? In the report below, discussion of these and other questions is organized by the topics of preservation and material, sex and age, dentition, bone mineral content, stature, asymmetry, and genetic relationships.

Preservation and Condition of Material. Although all three skeletons are incomplete, they seem to share the same degree of preservation. Several bones are more or less fragmented, while others are extremely well preserved including the jaws and most of the teeth (Fig. 5). The rather good preservation of the skeletons is reflected in the organic content of the bones which was 33 %, 28% and 34% in A, B and D respectively. It is generally known that post-mortem destruction of bone tissue mainly depends on the type of soil, its pH and humidity, and less on how long the bones have been lying in the soil. Our experience from routine measurements of organic/inorganic content in prehistoric bones (Bennike et al. 1993) shows that when the organic content is over 25%, which is the case for the Dragsholm bones, microscopic structures often remain undamaged and intact. Therefore, the bone tissue may be suitable for future microscopic studies on age-related changes or possible evidence of diseases.

In contrast to the two Mesolithic skeletons, the bones of the Neolithic male have a rather irregular surface due to taphonomic factors. This information is useful for distinguishing the stray find of the upper part of a humerus that did not belong to any of the three skeletons and must therefore belong to a fourth, designated as (C). This bone fragment has a smooth surface and its robusticity is more pronounced than that of the humeri of the two Mesolithic females, but less marked than the Neolithic male humerus. This bone has now been radiocarbon dated to the Bronze Age (see below). The caput of the fragment is fused to the shaft of the bone, which indicates that the person was more than 16-18 years old. An upper age limit cannot be determined, but there is no evidence of osteoarthritis that is sometimes seen in older people.

A single tooth and another fragment of a left mandible with the first and second molars in situ and half of an open alveolus for a third molar were found during the most recent excavations in 2003. The single tooth turned out to be a third right lower molar which may just have been erupting, as the occlusal area of the enamel shows no sign of wear, the apex of the root is not yet closed and there is no facet on the mesial area. The first and second molars in the mandible are only slightly worn, and there is no facet on the distal area of the second molar, proving that a third molar had not yet erupted. The partly visible alveolus of the third molar seems to fit well with an erupting tooth. It is therefore most probable that the separate find of a third, lower right molar belonged to the same mandible or to another young person with a similar dentition, stage of eruption and wear pattern.

The color difference between the Mesolithic and the Neolithic skeletons is striking. Following the usual pattern, the two Mesolithic skeletons (A and B) are clearly stained with red ochre, while the Neolithic skeleton (D) is not. Skeleton D is light grey in color that may partly be attributed to the remains of shells found in the grave soil. Neither of the two stray finds, the upper arm and the mandible fragment respectively, are stained with ochre. On the contrary, both appear rather gray. An attempt to find patterning in the distribution of the ochre staining on the Mesolithic bones almost failed. It seemed to be very diffuse, and both the ventral and dorsal parts of the bones of both skeletons were stained. However, the highest concentrations of ochre were found in the bones of the pelvic area and the craniums of the female skeletons. Skeleton (A) exhibits more heavily ochre-stained upper and lower vertebrae on the almost intact spine compared to those from the middle section.

The upper part of each of the three skeletons was placed in a supine position with the arms parallel to the body. One Mesolithic skeleton (B) and the Neolithic skeleton (D) lay with their legs stretched, while Mesolithic skeleton (A) lay with its legs bent at the hip with the knee joints pointing towards skeleton (B) to the left. The right side of the skeleton (A) was probably disturbed by plow-

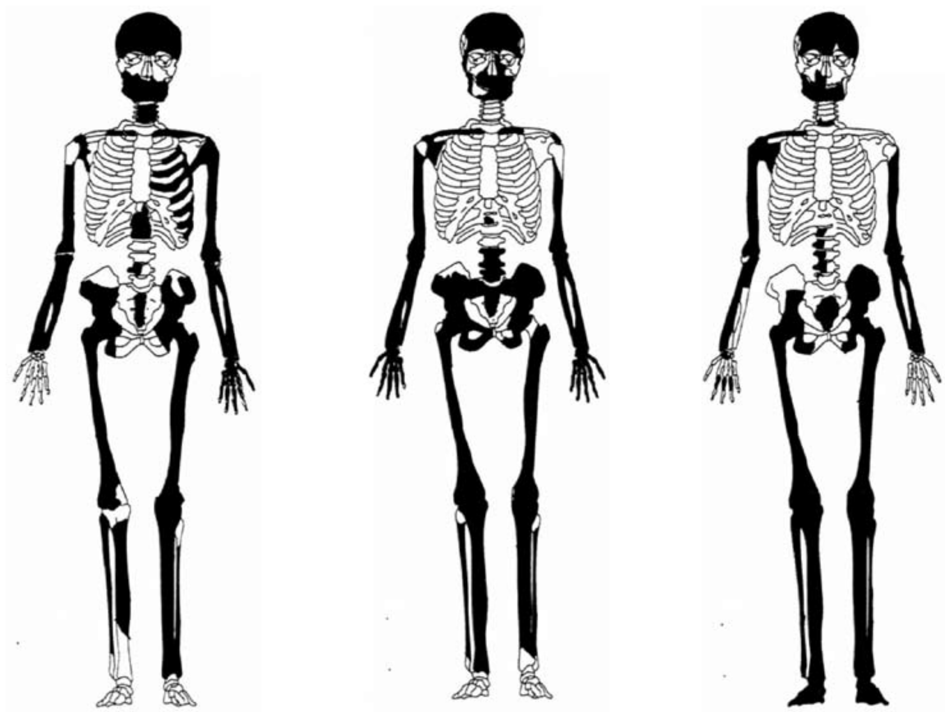


Fig. 5. The preserved bones (black) of the skeleton from individuals A, B, and D at Dragsholm.

ing, but judging from the position of the left femur, the right leg must have been lying parallel to the left.

Sex Determination. The shape and size of the bones was used for the sex determination of the skeletons, which was rather certain and concurs with the gender-related equipment found in the individual graves. The skeletons' sex was clearly reflected in the skulls and the pelvic bones as well as in several bone measurements; the femoral head measured 4.1 cm in both Mesolithic females and 4.8 cm in the Neolithic man. While we have no average values for male and female Mesolithic skeletons, the average values for Neolithic skeletons are 4.2 cm for women and 4.8 cm for men. With regard to this single measurement, the diameters of the femoral head of the two Mesolithic women were almost similar to Neolithic women. A similar pattern of sexual dimorphism as illustrated by the size of the individual femoral heads was seen in the measurements of Bone Mineral Content (BMC) (see below). Most of the variation in the size of the postcranial bones was related to such female/male differences. Unfortunately, the skulls, particularly of skeleton D, were too fragmentary for the comparison of measurements.

Age Determination. Age estimates were based on a combination of methods (excluding dental attrition) used to establish skeletal maturation (fusion of the epiphyses and dental development), structures of facies auricularis, symphysis pubica, the sternal rib-ends and the appearance of the joints with regard to any possible osteoarthritis. The study showed that individual A in the Mesolithic grave was approximately 18-20 years old when she died, while female B was over 40 years old. The considerable age difference was confirmed by almost all employed methods. The skeleton in the Neolithic grave (D) died at the age of about 30.

It is worth noting that, although dental attrition was not included in the age determination methods, the young Mesolithic woman (A) and the Neolithic man (D) exhibited very similar patterns of dental wear. However, while some of the epiphyses of the Mesolithic woman (A) had not yet fused and the third molars still had open roots, all bones of the Neolithic male skeleton had fused. In addition, some of the male's joints showed slight traces of osteoarthritis, which indicates that he must have been older than 18-20 years. This evidence was also corroborated by the results of methods based on the structures of the pelvic bones and the rib-ends. Despite the similar dental wear, it was concluded that the Neolithic man (D) was at least 10 years older than the young Mesolithic woman (A) in the double grave.

Dentition. Judging from the dental wear of skeleton A, the time of function of the third molars seems to have been 1-2 years, and their roots were not yet fully developed. These facts are in accordance with the transparency of the root (V. Alexandersen, n.d.) and the non-fusion of several epiphyses in a ca. 18-20-year-old individual.

The facial and lingual regions of the upper teeth of skeleton A exhibit polished areas. The lower frontal teeth only have polished areas on the facial sides, while calculus is seen on the lingual sides. The lower premolars and molars also have polished areas lingually. The presence of small fractures of the enamel on two teeth, frontal tooth resorption and hypercementosis in several teeth seem to confirm a pattern of severe attrition. Such severe attrition and heavy load on the teeth will also result in a reduction of the length of the roots. In such cases the apex of the root will appear rounded due to a thickening of the cement layer. This is mainly seen on the upper- and lower frontal teeth. A similar pattern has previously been noted in Eskimo dentition (Pedersen 1949). However, it cannot be determined to what degree the dentition was used as a tool, for example the chewing of hide, and whether this may have caused the polishing.

The dentition of skeleton B has some calculus and marked wear of the teeth - a flat horizontal wear of the front teeth and a helicoid wear of the molars. Together with the transparency of the roots, the age of this individual was evaluated to be ca. 40-44 years (V. Alexandersen, n.d.). Several teeth are marked with repeated linear hypoplasia of the enamel, which developed at the ages of 3, 4, 5 and 6 years. In modern children such hypoplasias usually develop during the first years of life and may be related to weaning, but prehistoric children often developed hypoplasia several years later. The causes could be attributed to seasonal crises of diet or diseases with high fevers and diarrhea or late weaning.

The dentition of skeleton B is marked by fractures of the enamel and by considerable marginal alveolar loss at the upper and lower molars. In addition hypercementoses is seen in the upper premolars, and the height of the roots is lower than average due to severe attrition. A reduced form of several teeth is related to the reduced length of the roots. Both skeleton A and B have (according to Verner Alexandersen, pers. comm.) teeth that are smaller than the average size of medieval teeth (Lunt 1969). In addition, several teeth have a reduced form and fused molar roots, but they do not have caries. The pattern of reduced roots of all second and third molars from the two dentitions is so similar that it may indicate a close genetic relationship.

The dental attrition of skeleton D is similar to the wear seen on skeleton A, which would normally suggest that the individual was about 20 years old. However, contrary to skeleton A, all skeletal epiphyses are fused, slight osteoarthritis is seen in a few joints and the auricular surfaces indicating that skeleton D was about 30 years of age. If skeleton D is about 10 years older than skeleton A, the similar dental wear may then indicate different diets. Skeleton D also has rather short frontal roots, however not to the same degree as seen in skeleton A and B, and the dentition shows no reduction in the number of roots.

Overall, the dentition of skeleton D is very different from that of both A and B. This includes both the form and size of the teeth. While the differences in size could be explained by sexual dimorphism or different environmental factors during the two periods, the various morphological differences, including the form of the crown and the fusion of the roots, may stem from a certain genetic distance between the Neolithic man on the one hand and the two Mesolithic women on the other. The two women's rather similar pattern of dentition may, as already mentioned, alternatively indicate some degree of close genetic relationship. Although Neolithic teeth often present less attrition than Mesolithic ones, the incidence of dental decay, periodontal diseases and tooth loss was higher in the former which may well be due to a new terrestrial diet (Alexandersen 1989). No caries were, however, found in the three dentitions. While one would not expect to find caries in the Mesolithic skeletons, caries has been reported in 15% of Neolithic skeletons (Bennike 1985)

Bone Mineral Content. Both the organic and the mineral content of the bones were measured with a dual photon-absorptiometry scanner. The organic bone content has already been mentioned in relation to the preservation of bone tissue. The mineral content (BMC/BMD) of the bones indicates the so-called bone mass of the two women and the man. Previous tests on archaeological bones from various periods have shown that the measured amount of mineral in a bone (mid-diaphysis of femur) is well correlated to the area of a tranversal section of the same part of bone, with the exception of the endosteal area. This means that only few changes occur during burial when the surface of the bone is intact, even over long periods of time, in this case a period of almost 7,000 years (Bennike and Bohr 1990).

The bone mineral content (BMC) values were 4.7 g/cm for the femur of the young Mesolithic female skeleton (A), 4.3 g/cm for the older Mesolithic female skeleton (B) and 5.5 g/cm for the Neolithic male skeleton (D). In comparison, the average BMC in the same bone (femur) and site (mid-diaphysis) in Neolithic female skeletons was 4.4 g/cm (s.d. 0.55) and 5.7 g/cm (s.d. 0.49) in Neolithic male skeletons. The values obtained from the three Dragsholm skeletons fit neatly with the averages for the Neolithic, also with regard to sexual dimorphism. Unfortunately similar values for Mesolithic skeletal material are not yet available. The lower mineral content values for the two Mesolithic women as compared to the Neolithic man are probably due to sexual dimorphism. The question arises whether the Mesolithic women should not be expected to have a higher bone mineral content than the Neolithic females because of generally higher robusticity values during the Mesolithic. The femur circumferences of A and B are 79 and 84 respectively, and 88 mm in the Neolithic male; the robusticity indices (circumference middle (M8) x 100/length (M2) are 20, 21 and 21.5 respectively. However, our findings are difficult to evaluate as we have only the two Mesolithic cases. The slight difference in bone mineral content between the two Mesolithic women may also be random.

The two skeletons are those of a young woman in her late teens, and a rather older woman over the age of 40. Even though the young woman may not have reached her so-called bone peak mass, which occurs around the age of 30 in the contemporary population, her BMC is higher (4.7 g/cm) than the elder woman's BMC. The elder woman may have reached menopause, which usually occurs today in almost all populations around the age of 50-51 and initiates an age-related bone-loss (Pavelka and Fedigan 1991). However, as we have no knowledge of when menarche (onset of menses) occurred (in the modern Danish population it occurs around 12 years; during the 19th century it occurred around 16 years), nor is it known when bone peak mass was reached or the age at which menopause began during the Mesolithic, we cannot completely exclude the fact that the differences in BMC are normal variation. In our modern society we observe a decrease in bone mass from the onset of menopause, but we do not known whether this also was the case during the Mesolithic when the level of physical activity was much higher.

Stature. The stature of the skeletons was calculated from the femoral bones (Trotter and Gleser 1958). However, the method used often results in a stature estimate somewhat higher than the measured length of the skeleton in situ prior to excavation. A study of anatomical measurements of all the bones involved in the height correlated well with the length measured in situ, indicating that the calculated stature may not be reliable (Bennike, n.d.). Skeleton A in the Mesolithic grave is 153.0 cm (femur 400 mm) and skeleton B is 154.2 cm (femur 405 mm). This corresponds to the average stature of female skeletons in the Mesolithic, which is 154.0 cm. The average stature during the early Neolithic period seems to be rather similar to the Mesolithic period: 153 cm for females and 165 for males. The male skeleton (D) in the Neolithic grave was calculated to 160 cm. This is 5 cm less than the average for that period. During

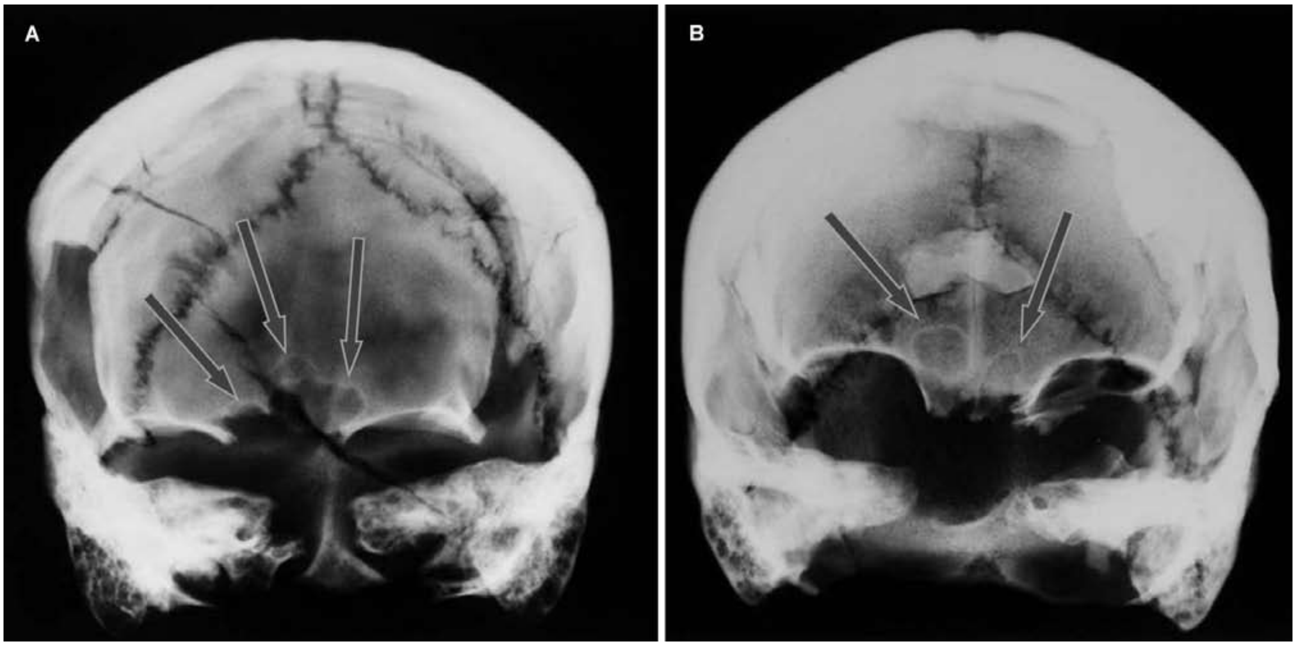


Fig. 6. X-rays of the crania of individuals A and B at Dragsholm. Arrows indicate frontal sinuses of the frontal bone.

the Neolithic the average stature increased considerably and in the late Neolithic period it had on average increased to 171 cm for men (Bennike and Alexandersen 2002).

Asymmetry. All three skeletons exhibit significant differences between the left and right humerus with regard to robusticity as seen on the traces of muscular modelling and size. The length of the preserved arm bones of the two women differed by 4-5 cm while neither the right and left arm bones were not intact on skeleton D for comparison. The difference in size between right and left side of the two Mesolithic women resemble the left/right side differences observed during the Iron Age, but the differences in the bone circumferences are larger.

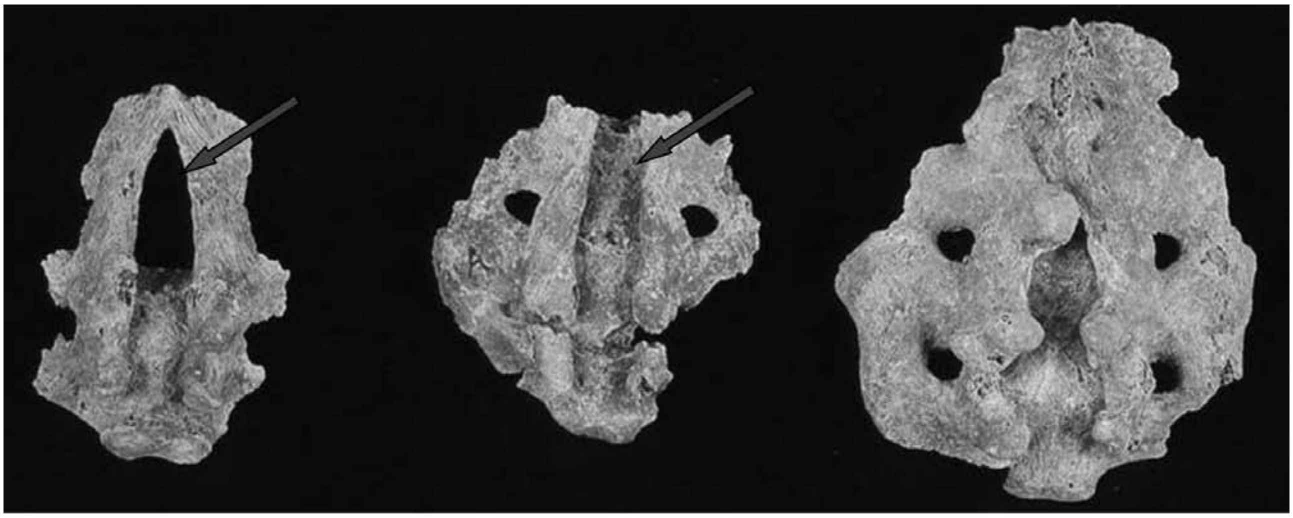
Genetic Relationships. While some characteristics seem to indicate a degree of familial relationship between the two Mesolithic skeletons in the double grave, others do not. Only a DNA analysis will be able to establish whether the two women were closely related genetically. Given the quality of the skeletal material, such an analysis is unlikely to be successful.

The two female skeletons share similar form of skull and mandible, short dental roots, and characteristics of the spinal area around the sacrum, all of which seem to indicate some relationship. Skeleton A has, however, a somewhat larger skull as the circumference is c. 5% greater. In some studies the size and form of the frontal sinuses have indicated genetic relationship (Szilvássy 1986), but rather disappointingly no clear and convincing similarities were found in the pattern of the two Dragsholm skeletons, even though they were not that different. Some damage of the frontal bone of skeleton B may influence the dissimilarity (Fig. 6). However, such a difference does not mean that a genetic relationship can be excluded. This is the same situation with the presence or absence of a cranial suture of the frontal bone. Skeleton A has a frontal suture, but skeleton B does not. However, this dissimilarity in a single trait can neither exclude nor confirm genetic relationship.

Both women have an incomplete closure of the sacral spine, the so-called spina bifida occulta (Fig. 7). At least three of the lower segments were open, while the rest of the bones were too damaged to study. A survey of the pattern of sacral closure in Danish prehistoric skeletons from various periods has not yet been carried out. One is planned, so that we will have comparative parameters. It is interesting to note, however, that Ferembach (1963) found a high variation in sacral segment closure in Mesolithic skeletons from Taforalt, Marocco. She concluded that the pattern might reflect a high degree of endogamy in the population. Similarly, due to the frequent occurrence of supraacetabular grooves on the pelvic bones in the Mesolithic skeletons from Bøgebakken and Skateholm, some degree of genetic relationship between the populations has been suggested (Frayer 1988). Even though we have no material for comparison as yet, it is no less interesting that the skeleton of the Neolithic man (D) also exhibits a lack of closure in at least 2 lower sacral segments (Fig. 7). If the two women were truly genetically related, it is hard to believe that they could have been sisters because of the ca. 20-year age difference. They would more likely have been mother and daughter or mother-in-law/daughter-in-law. Only a mother/daughter relationship, however, would produce in a positive DNA analysis.

ISOTOPIC ANALYSES (TDP)

New isotopic analyses involving carbon, nitrogen, and strontium were undertaken with the materials from Dragsholm. New radiocarbon dates may either demonstrate a similar age for the burials, documenting conventionally Mesolithic and Neolithic individuals as contemporaries, or document a difference in the dates of the graves.



B A D

Fig. 7. Sacral spine of individuals A, B, and D, showing lack of closure.

There are two possible solutions to the question of contemporaneity; either the two graves were used for burial at the same time by people with very different cultural and economic backgrounds, or the two graves are of the same date, but this place continued in use as a burial ground after the beginning of the Neolithic.

Stable carbon and nitrogen isotope analysis of bone collagen and apatite can provide additional information on the diet of these individuals and help to provide a better calibration for radiocarbon dating. Dietary differences between either contemporary individuals or between the foragers of the Mesolithic and the farmers of the Neolithic will be of substantial interest. Strontium isotope analysis of tooth enamel may reveal the place of origin, indicating if any of the individuals came from another region. These analyses can provide new information on the relationship between foragers and farmers and on the nature of culture change during the transition to agriculture, one of the most momentous events in the history of our species.

This section of our study begins with a discussion of the use of preservatives in the conservation of the materials and the sampling procedures used for our analyses. Description of the collagen and apatite preparation and analysis includes the results of replicative studies in several laboratories and discussion of the differences in collagen and apatite carbon isotopes. Next, the radiocarbon dating of these samples also involved multiple analyses in two different laboratories and these results and their calibration are presented and discussed. Stable isotopes of carbon and nitrogen are considered next along with comparison of the results of carbon isotopes from both collagen and apatite.

Specimen Conservation and Sampling Protocols. Samples for the new analyses are described below. The bone and teeth were sampled largely by drilling after abrading the outer surface to remove contaminants. Specific procedures are described for the individual samples below. Human bone was sampled at the Anthropological Laboratory; human teeth were sampled at the National Museum and the Laboratory for Archaeological Chemistry; artifacts from the graves were sampled at the National Museum.

Conservation treatment of these finds is an important consideration for isotopic analyses. The finds from Dragsholm were prepared at the National Museum in the early 1970s, a period when a number of new treatments were being employed rather liberally. Primary preservatives in use included Bedacryl and Diacon. Many of the objects were treated with bedacryl during the excavation in the field. In addition some of the artifacts were dried with tertiary butyl alcohol and dipped in beeswax at 40° C (8 tooth pendants) or boiled in carnuba wax at 120° C (bone point and remaining tooth pendants). The ornamented spatula from the females' grave was repaired with Lyma-C (a nitrocellulose glue); in some of the bone artifacts from the male grave were boiled in carnuba wax and were fractures glued with Lyma-C. Specific treatments are described below along with the individual samples that were taken.

Human Femur and First Molar (DR Skeleton A NM 529/73). Grave I, younger female burial. Only known treatment was bedacryl in the field plus some glue used on cracks. Femur surface mechanically cleaned and bone powder drilled out of a series of small borings. The first molar was mechanically cleaned at the surface and powdered enamel removed by burring. Bone sample for 14C dating and light isotopes (C, N) on collagen and apatite. Enamel sample for strontium isotopes.

Human Femur (Skeleton B NM 529/73). Grave I, older female burial. Only known treatment was bedacryl in the field plus some glue used on cracks. Femur surface mechanically cleaned and bone powder drilled out. This sample released a distinct odor during drilling and the resulting powder was much finer than burials A and D. This skeleton may have been treated with an unknown substance. Bone sample for 14C dating and light isotopes (C, N) on collagen and apatite.

Human Humerus (Skeleton C NM 529/73). Isolated bone found on the surface at the time of the original discovery of the females' grave. Surface mechanically cleaned and bone powder drilled out. Bone sample for 14C dating and light isotopes (C, N) on collagen and apatite.

Human Femur and First Molar (Skeleton D NM 529/73). Grave II, male burial. Only known treatment was bedacryl in the field plus some glue used on cracks. Femur surface mechanically cleaned and bone powder drilled out. First molar was mechanically cleaned at the surface and powdered enamel removed by burring. Bone sample for 14C dating and light isotopes (C, N) on collagen and apatite. Enamel sample for strontium isotopes.

Tooth Pendant (DR 256). Animal tooth pendant mechanically abraded to remove outer surface of enamel and then enamel burred to obtain powder. Bone powder drilled from interior of root dentin. Tooth boiled in carnuba wax at 120 °C. Bone powder used for 14C dating and light isotopes (C, N) on collagen and apatite.

Ornamented Spatula (DR 147). Bone powder drilled from old crack. Spatula had been glued with Lyma C but other wise not treated. Glue was dissolved with acetone prior to drilling. Bone powder used for 14C dating and light isotopes (C, N) on collagen and apatite.

Antler Pick (DR 323). Bone powder drilled from interior of artifact. Artifact was boiled in carnuba wax at 120° C. Treated with Bedacryl in the field. Bone powder used for light isotopes (C, N) on collagen and apatite. Original sample vial exploded during transport; a second sample with more aggressive decontamination procedures was taken.

Heavy Bone Chisel (Test ditch 2, Layer 6). No known preservative. Bone powder drilled from interior of artifact. Bone powder used for 14C dating. Results from AMS determination yielded 5150 ± 65 b.p. (AAR-8774) or a range between 4050 BC – 3770 BC with a probability of 90.5%. The stable carbon isotope ratio of the sample was -21.5‰, clearly terrestrial.

Collagen and Apatite Purification and Isotopic Analysis (SHA, TDP). Several bones, teeth, and artifacts from the Dragsholm graves were selected and sampled for this project. These objects were generally well preserved, an important consideration for isotopic analysis. Table 4 shows the elemental and isotopic composition of collagen and apatite of the bones of Burials A, B and D, as determined in the Environmental Isotope Paleobiogeochemistry Laboratory at the University of Illinois. Preservation of the human bone is extremely good. Several characteristics that reflect their good condition will be discussed, after a description of the analytical methods.

Collagen purification methods are described in detail elsewhere (Ambrose 1990, 1993). Bone powder was demineralized with 0.2 M HCl (2 days), treated with 0.125 M NaOH (20 hours) to remove humic acids, solubulized at 95°C in acidified distilled water (pH3, 10 hours), filtered to remove particulate contaminants, and freeze-dried. Apatite was purified by treatment with 2% sodium hypochlorite (50% Clorox, 2 days) to remove organic matter, and 0.1 M acetic acid (0.1 ml/mg, 4 hours) to remove adsorbed carbonates (Balasse et al. 2002). Isotopic analysis of collagen (sample weight: ~400 μg) was performed by combustion and purification of CO2 and N2 in a Carlo-Erba elemental analyzer coupled to a Finnegan MAT 252 isotope ratio mass spectrometer. Replicate analyses of carbon and nitrogen isotopes of collagen of burials B and D are within analytical error (±0.1‰ for δ13C, and 0.2‰ for δ 15N). Apatite carbonate isotopic analysis (sample weight ~700 μg) was performed by reaction with 100% phosphoric acid at 70°C in a Kiel III automated carbonate reaction device coupled to the MAT 252. Carbon and oxygen isotope ratios are simultaneously determined on the CO2 generated by this reaction. Replicate analyses of apatite were not performed. Analytical error on this instrument is ±0.05‰ for δ13C and ±1.0‰ for δ18O (Balasse et al. 2002).

Criteria for good bone collagen preservation (Ambrose 1990, 1993; DeNiro 1985) include a yield of collagen greater than 1.8% by weight. Modern bone has ~19% to 21% collagen. Collagen was well preserved in all samples. Another criterion is the percent-by-weight of carbon and nitrogen in the extracted collagen. Modern bone collagen averages 42.7% carbon and 15.5% nitrogen. The percent of carbon in the Dragsholm bones ranges from 34.0% to 40.4%. The percent of nitrogen in the Dragsholm bones is also close to the modern average. Individual D had the lowest collagen yield, but the organic component is still relatively pure protein, as measured by its high carbon and nitrogen concentrations. An atomic carbon:nitrogen ratio (C:N) between 2.9 and 3.6 is another important criteria (Ambrose 1990; DeNiro 1985; Bocherens et al. 1996). The C:N ratio of pure collagen is 3.21 (Ambrose 1993:76). The C:N ratio in the collagen in the three human bones from Dragsholm varies from 3.18 to 3.29, which is well within this range.

The collagen carbon concentrations and C:N ratios are slightly lower, and δ13C values slightly less negative in the samples prepared in Illinois compared to those prepared in Bradford (see below). These small differences in elemental and isotopic composition are consistent with differences in purification protocols. Lipids and humic acids have low δ13C values and high C:N ratios (Ambrose 1993). They were removed by treatment with NaOH in the Illinois protocol, but not in the Bradford protocol.

The yield of carbon from apatite carbonate by percent weight provides another check for diagenetic alteration. After apatite purification, the average weight percent carbon in apatite of modern bone is ~0.9%, with a range from 0.65% to 1.3% (Ambrose 1993:80). Values of the Dragsholm burials range from 0.91 % to 1.06 %, well within the in-vivo range for bone apatite. However, as will be discussed in a later section, the isotopic composition of the apatite of burial D suggests apatite has been affected by diagenesis.

RADIOCARBON DATING AND CALIBRATION (TDP, JH)

A series of radiocarbon dates were made on materials from the Dragsholm graves. In addition to the three original skeletons, new dates were obtained from Dragsholm C, the single isolated tibia, from the mandible fragment found in 2003, and the decorated bone spatula in the grave of the females. The results of the analyses are listed in Table 5 including the lab number, sample designation, material dated, the measured age in radiocarbon years, the reservoir corrected age in radiocarbon years, the calibrated date in calendar years with probability, and the stable carbon and nitrogen isotope measurements on the bone samples, where available.

The three original skeletons were dated twice. The first set of samples dated at Aarhus came from the collagen preparation at Illinois, described above. Because of concerns about contamination from the conservation, a second set of samples from the three original skeletons were prepared using a specified procedure – hexane treatment — for the removal of preservatives. The drilled bone samples were placed in a test tube with hexane for 15 minutes at 50 °C. The test tube was then transferred to an ultrasonic bath for 15 minutes. The hexane was then decanted and replaced by acetone, which was heated and ultrasonically treated as above. This procedure was repeated with ethanol and then with a double treatment using demineralized water to remove any trace of the previous solvents. The intent is to use a series of increasingly polar

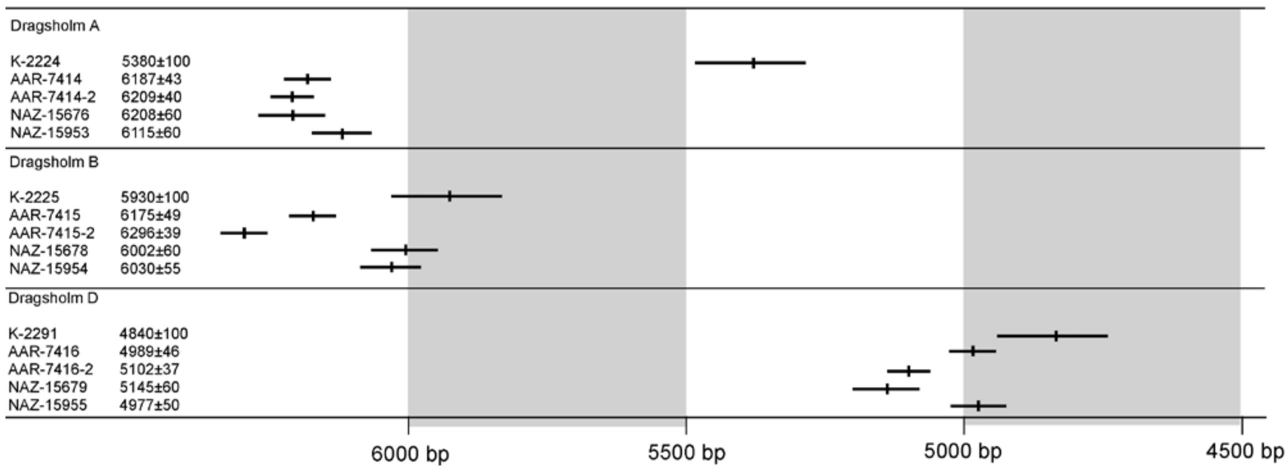


Fig. 8. Plot of multiple radiocarbon dates for the burials A, B, and D at Dragsholm.

solvents, ending with water, where each solvent is able to dissolve and remove the previous one. After decontamination the samples were subjected to normal collagen extraction procedures.

In addition to the dates obtained at the Aarhus AMS laboratory, three paired measurements were made on the human bone samples at the Rafter Laboratory, New Zealand, along with the stable isotope measurements discussed below. As can be seen in Table 6 and Fig. 8, there were differences in the dates between the two labs. For this reason, the Rafter Lab re-measured the three samples and obtained similar results to the first set of dates, with the exception of sample D. The second measurement on sample D was younger and in better agreement with the Aarhus date. As the two female individuals have clearly marine diets they both need to be corrected for the marine reservoir effect, which will change their ages by about + 400 radiocarbon years. However, even with this correction there is no overlap in dates between the female burials and the male burial.

In sum, four radiocarbon dates were obtained on bone collagen from each of the three Dragsholm skeletons. In general each set of dates show similar values but there are some anomalies (Fig. 8). The measurements on individual A show the closest values. Dates on individual B are scattered, ranging from 6030 to 6296 b.p. The Neolithic burial D also shows some variation, ranging from 4977-5145 b.p. This variation does not appear to be inter-laboratory as the values are scattered across each range. As noted, there is some difference due to preparation procedures and the removal of contaminants in the second series of dates from Aarhus. These decontaminated samples are slightly younger in date. It is also clear from the graph that the original dates from the Copenhagen laboratory are all younger than the AMS dates from Aarhus and New Zealand.

There appears to be a strong correlation between collagen preservation and the consistency of the dates between the labs. The best agreement among the dates was for Burial A which has the highest collagen concentration of 9.3%. Finally it is essential to note that the radiocarbon dates for individuals A and B should be virtually identical as these two individuals were buried in the same grave. Because of potential problems involving the marine reservoir correction for the two females with less negative stable isotope carbon isotope ratios, we also dated a bone from a terrestrial animal in the grave, the decorated spatula made from a red deer bone. The date on this artifact from a terrestrial animal should provide the most accurate date for the grave. This date (5983 ± 38 bp) is slightly younger than the youngest date on individual B from New Zealand (6002 ± 60 bp) and substantially younger than the youngest date from the grave, on Individual B, from Aarhus (6175 ± 49). This discrepancy suggests that the marine reservoir correction is not large enough and that marine-affected radiocarbon dates are still slightly in error. The best date for the contents of Grave I, including the two female inhabitants, comes from the bone spatula.

In the Neolithic Grave II, we also dated a terrestrial mammal in order to obtain results A similar different between marine and terrestrial samples from the same archaeological context has been noted elsewhere. For example, paired human and ungulate bone samples from Lepenski Vir in the Danube Gorges in Yugoslavia (Bonsall et al. 2000, Cook et al. 2001, 2002) showed systematic differences on the order of 540 years (uncalibrated) reflecting a freshwater reservoir effect in that region. Freshwater reservoir effects have been discussed in detail by Lanting and van der Plicht (1996), among others (e.g. Fischer and Heinemeier 2003).

A terrestrial mammal from Grave II was also dated for comparison with the results from Grave I. In Grave II we used a sample from the antler pick in the ground near the head of the male. The original sample vial exploded during air transport. The specimen was dated (AAR-7418) but not pretreated. This initial date did not match the Neolithic male (D). Because of the problem with the first date, the broken sample vial, and the known use of preservatives, a second sample was taken from the antler pick and dated. This sample (AAR-7418-2) was aggressively treated to remove preservatives. The new determination (AAR-7416-2) matches the Neolithic male in the grave very closely.

STABLE ISOTOPES: CARBON AND NITROGEN (MR)

We obtained measurements of the carbon and nitrogen stable isotopes of collagen extracted from the three Dragsholm humans as well as an ornamented spatula of red deer bone found in association with the female burials (Table 7). The two females have predominantly marine diets, reflected in the δ13C and δ15N values. These values are close to the end points that have been found in humans and mammals that that consume marine foods (Schoeninger et al. 1983, Chisholm et al. 1982, Richards and Hedges 1999). Individual A has a δ13C value that is less negative than many published human and marine mammal values, which usually are at −12±1‰ (see Richards and Hedges 1999 for references). The δ13C value of -23.7‰for the red deer marks the end of the terrestrial range of diet in this area and emphasizes the importance of marine foods in the Mesolithic.

The δ15N values are elevated, as expected for a marine diet (Schoeninger et al. 1983). Schoeninger and DeNiro (1984) suggested that values less than +9‰ would reflect fully terrestrial diets and values greater than +15‰ would be completely marine. Schoeninger et al. (1983) reported values ranging between 12.5‰ and 16.0‰ for unspecified Danish Mesolithic individuals. The high δ15N for the Mesolithic females reflects the high values of the marine foodweb. These values are normal for marine diets in the temperate zone. They are not as high as has been observed for other Mesolithic humans, which are often at 15 ± 10/00 (e.g., Richards and Mellars 1998, Richards et al. 2003, 2004), and likely indicate a diet of mainly fish and shellfish rather than marine mammals (Richards and Hedges 1999).

The male burial, individual D has δ13C and δ15N values that are consistent with a mainly terrestrial-based diet. The δ13C value is very similar to human values from the Neolithic in Denmark (Tauber 1981b) and the UK (Richards and Hedges 1999). The δ15N value is at the higher end of the scale observed for temperate Holocene Europe, and likely indicates a diet high in animal, rather than plant, protein. This value may reflect the relative importance of cattle during the Early Neolithic.

Methodology. Collagen was extracted from the human bone samples at the Department of Archaeological Sciences, University of Bradford. Approximately 200 mg of bone powder was demineralised in 0.5 M HCl at 5°C for 48 hours. The supernatant was discarded the remaining solid was then gelatinised in sealed tubes, in pH3 HCl at 70°C for 48 hours. The solution was then filtered through 8 μm filters before being filtered through 30 kD ultrafilters. The > 30 kD fraction was then freeze-dried. The carbon and nitrogen stable isotope values were measured at Isoanalytical, Cheshire, UK. For the spatula sample the collagen was extracted at the AMS Laboratory, University of Aarhus, Denmark and the carbon and nitrogen isotopes were measured at the Stable Isotope Laboratory, University of Bradford, UK. Errors on the δ13C and δ15N values are ±0.2 ‰.

In addition to the data presented above, there are additional δ13C and δ15N values on the four samples produced at two other stable isotope laboratories (Rafter, New Zealand and the University of Illinois, Champaign-Urbana), as well as δ13C values produced in conjunction with radiocarbon dating at the AMS laboratory at Aarhus. All of these data are presented in Table 8. As can be seen there is good agreement between all of the labs, despite the different equipment and collagen extraction methods used.

Collagen vs. Apatite (SA). Krueger and Sullivan (1984) initially documented the difference in stable carbon isotope ratios between the apatite and collagen compartments of bone in the same individual. They proposed that consumer collagen carbon was derived from dietary protein and apatite from dietary energy sources. They used this model to explain systematic differences in the isotopic composition of collagen and apatite of non-human herbivores versus carnivores and omnivores, and marine versus terrestrial human diets. Controlled diet experiments with rodents confirmed fundamental aspects of their model, by demonstrating that carbon isotopes in collagen preferentially reflected that of the protein portion of the diet, while apatite carbon reflected the isotopic composition of the total diet (Ambrose and Norr 1993, Jim et al. 2004, Tieszen and Fagre 1993). The results of these experiments are not directly relevant for interpreting the isotopic composition of apatite and collagen carbon isotopes of ruminants and other animals that generate substantial amounts of 13C-depleted methane during digestion (Metges et al. 1990).

These experiments showed that when the protein and bulk diet have the same δ13C values, collagen is enriched by 5.0‰, and apatite is enriched by 9.4‰ relative to the total diet, and the apatite-collagen spacing is 4.4‰. In these experiments, the enrichment factor for apatite relative to the bulk diet was effectively constant, regardless of the isotopic composition of the dietary macronutrients (proteins, fats and carbohydrates). However, consumer collagen-diet δ13C spacing values could be systematically varied by changing the δ13C value of dietary protein relative to that of the bulk diet, because more than half the carbon in collagen was derived from dietary protein. They determined that the spacing between whole diet and collagen δ13C values (Δ13Ccoll-diet) is greater when the protein component of the diet is enriched in 13C compared to the bulk diet; diet to collagen spacing is less when the protein component is less enriched compared to the bulk diet.

The results of these experiments permit more detailed reconstruction of the isotopic composition of prehistoric human diets. The bulk diet δ13C value can be reconstructed from the apatite δ13C value minus 9.4‰, and that of dietary protein can be reconstructed from the apatite-collagen difference (δ13Cap-coll). Specifically, a difference of 4.4‰ occurs when the protein and bulk diet have the same δ13C value. A spacing of less than 4.4‰ indicates that dietary protein is isotopically enriched relative to whole diet. If the spacing is greater than 4.4‰, then dietary protein is isotopically lighter than whole diet (Ambrose and Norr 1993, Ambrose et al. 1997, Ambrose et al. 2003, Harrison and Katzenberg 2003, Jim et al. 2004).

Marine foods, being rich in protein, will contribute disproportionately to the amino acids in collagen compared to terrestrial plants. Moreover, being enriched in 13C, marine proteins will disproportionately increase the collagen δ13C values relative to the bulk diet, and relative to apatite δ13C. In marine contexts with no C4 plants, protein comes from mainly from 13C-enriched marine animal resources, while carbohydrates and some proteins come from 13C-depleted C3 plants and C3-feeding animals. Because the marine protein source is more enriched in the heavy carbon isotope, the diet to collagen spacing (Δ13Cdiet-coll) should be greater than 5‰, and collagen to carbonate spacing (Δ13Cap-coll) should be less than 4.4‰. Because the marine protein source is more enriched in 15N, collagen δ15N values should also be high. In a coastal environment lacking C4 plants, a positive correlation should exist between collagen δ13C and δ15N, and a negative correlation should occur between δ15N and δ13Cap-coll (Ambrose et al. 1997).

In terrestrial high latitude diets, the entire foodweb is based on 13C-depleted C3 plants, so the bulk diet and dietary protein should have very similar δ13C values. The diet-collagen spacing should be 5‰ and the apatite-collagen spacing at least 4.4‰. Stable carbon isotope ratios were measured in the apatite of the Dragsholm samples. Values for the δ13Capatite and the spacing between apatite and collagen values (Δ13Cap-coll) are provided in Table 4. The values from the Neolithic Burial D are substantially different from the two Mesolithic females.

The δ13Cap-coll values of the Dragsholm Mesoithic and Neolithic humans are consistent with what is expected for marine versus terrestrial diets. The collagen δ13C value reflects mainly the protein 13C, plus a small amount of the non-protein 13C. For the marine diets of the Mesolithic women, the lower spacing reflects the high 13C of marine protein and thus a high collagen 13C value. The lower apatite δ13C value reflects the mix of marine foods plus C3 plants. For Burial D, both the protein and non-protein are C3, and the protein source is apparently more negative than the non-protein component (fats and carbohydrates). This pattern suggests that Neolithic people were consuming mainly terrestrial animals and plants, but the low value for protein compared to non-protein resources is unusual. This suggests diagenesis of apatite, which we shall discuss in greater detail below.

The carbon isotope ratios measured on collagen from the Dragsholm burials are -10.4 for Burial A, -11.4 for Burial B, and -19.2 for Burial D. If we use −10.0 as the end point for collagen with fully marine foods and −21.5 as the end point for fully terrestrial C3 foods, which is the equivalent of C3 and marine diet end-member 13C values of −26.5 and −15 , respectively, the Mesolithic women (A and B) appear to have had an almost completely marine diet (97% for A and 88% for B). The Neolithic individual (burial D) apparently had 16% marine foods.

Apatite 13C, on the other hand, reflects the total diet 13C value plus 9.4 per mil. Using the end-member 13C values for marine and C3 terrestrial end-member diet noted above (-26.5 and −15), plus 9.4 for the diet-apatite spacing, the apatite values of −8.3 for burial A, and −9.3 for burial B would indicate diets composed of approximately 76% and 67% marine foods. Burial D has a 13C value of −12.1 , and apparently consumed approximately 42% marine foods, although diagenesis may have affected this sample (see below).

The application of collagen 13C values for the calculation of diet greatly exaggerates the importance of marine foods. Because collagen is derived mainly from dietary protein, the terrestrial C3 plant dietary component has been substantially underestimated by analysis of collagen. Apatite provides a more accurate estimate of the whole diet carbon isotopic composition.

The bias of collagen toward the protein components of diet needs to be considered when evaluating the carbon isotope evidence for the transition from the Mesolithic to the Neolithic in northwest Europe. Several authors have noted the striking decrease in collagen carbon isotope ratios at the onset of the Neolithic in the British Isles, which has been interpreted as a shift to exclusive consumption of domesticated plants and animals (Hedges 2004, Richards et al. 2003, Richards and Schulting 2006, Schulting and Richards 2002, Tauber 1981a). Milner et al. (2004) have contested this evidence, but their arguments are not consistent with our knowledge of the relationship between the isotopic composition of collagen and diet (Hedges 2004). In Sweden, the collagen isotopic evidence suggests continued though significantly reduced reliance on marine protein (Lidén et al. 2004). The collagen δ13C value of −19.2‰ for Burial D indicates that marine protein was an important, though minor component of the Neolithic diet, comprising approximately 15-20% of the dietary protein.

Although apatite should accurately reflect the δ13C value of the whole diet, the Δ13Cap-coll value of 7.1‰ for burial D is higher than expected for a C3 plus marine foodweb. The high apatite δ13C value could reflect a diet with higher 13C than that indicated by collagen only when low-protein dietary resources have higher δ13C values. This would require the consumption of C4 plants. However, Denmark is far north of the distribution of C4 plants. Moreover, if the slightly elevated collagen δ13C value does reflect marine protein consumption, then the Δ13Cap-coll value for Burial D should be less than 4.4‰. Therefore it is likely that the apatite values have been shifted to somewhat higher values by post-mortem isotopic exchange. The diagenetic shift is at least 2.4‰, assuming no marine foods. The sample of bone from Burial D prepared at the University of Illinois had a significantly lower collagen concentration (5.3%) than burials A (14.3%) and B (9.3%) (Table 4). Burial D bone would be more porous and thus more susceptible to apatite diagenesis than burials A and B. Apatite-based estimates of terrestrial food consumption for burials A and B are likely to be more accurate, and suggest diets with approximately 70%, rather than >90% marine input.

STRONTIUM ISOTOPE PROVENIENCE (TDP)

Another avenue of research on the Dragsholm burials involved measurement of isotopes that provide information on individual provenience or place of origin. It is now possible, however, to obtain specific clues about the migration of people in the past directly from human bone using strontium, oxygen, and other isotopes. Strontium isotopes were measured on the Dragsholm individuals.

The basic principles of the method are straightforward. Strontium isotope ratios vary with local geology, specifically with the age and composition of bedrock. Virtually all strontium in vertebrate organisms is found in the skeleton. In human bones and teeth these ratios can serve as tracers of the geology of the areas where individuals grew up and where they died, respectively. Bone undergoes continual replacement of its inorganic phase so that measurements of bone strontium reflect the last years of the life of the individual. The enamel in teeth, on the other hand, forms during infancy and childhood and undergoes very little change during life. Differences in strontium isotope ratios between bones and teeth thus reflect the residence history of the individuals under consideration. Because strontium isotope ratios vary among geological formations, strontium isotope ratios in teeth that do not match those of the local geology indicate immigrants to an area.

A number of studies have been published demonstrating the utility of strontium isotope analysis (Ezzo et al. 1997, Montgomery et al. 2000, Price et al. 1994, 2000, 2001). Each of these studies involves contexts in which migration or other residential movement has been assumed or hypothesized. Each of these areas exhibits significant variation in local geology so that differences in strontium isotope ratios between bone and tooth can be expected in situations of residential mobility. In each area, a significant number of migrants were identified and estimates made of their original homeland. For the analysis, the strontium isotope ratio in human teeth is compared to levels in archaeological fauna, which provide a measure of the local ratio. Our methods require one tooth from each individual. The analysis is destructive but only a very small amount of material is required, ca. 20 mg of the enamel from a molar. A description of analytical procedures can be found in Price et al. (2002).

In the case of the Dragsholm graves, enamel samples were taken from the first molar of one female skeleton (Burial B), the male skeleton (burial D), and a tooth pendant from red deer canine (designated as artifact Dr256) associated with the female grave. The red deer canine was used to obtain a measure of the strontium isotope ratio in the local area around the site of Dragsholm. The teeth from the older female (Burial A) were heavily worn and there was little enamel remaining. We decided not to sample this individual.

The results of the strontium isotope analysis of the three graves from Dragsholm are shown in Table 9. These results are intriguing. The strontium isotope ratio in the four red deer canine (0.710499) provides a measure of local terrestrial levels in the largely moraine landscape of northwest Zealand. The values for the two humans are close together; the Mesolithic female has a value of 0.709614 and the Neolithic male has a value of 0.709391. On first impression these results suggest that the male and female individuals were local in origin. It is important to remember that the female consumed a diet that was largely marine in origin. Unless her diet in infancy and childhood was much more terrestrial, we would expect the strontium isotope values in her enamel to be close to that of modern seawater, which is 0.7092 (Howarth and McArthur 1997). In this study, however, the Neolithic male with a diet that is largely terrestrial shows a strontium isotope ratio that is slightly closer to modern seawater than the female. Interpretation of this result is not obvious. If we assume that the red deer value is characteristic of terrestrial deposits in the region of Dragsholm, we can understand the female value as shifted from the local value as a consequence of a marine diet. The male, however, with a terrestrial diet, should resemble the red deer. The fact that he does not suggests that he may in fact be from a different area, perhaps a region where marine deposits form the primary geological substrate. The uncertainty of these results suggests that more samples of terrestrial animals and humans from this period need to be analyzed.

NEW FIELD INVESTIGATIONS

As part of the re-investigation of the Dragsholm burials, the site area was reopened in 2002 and excavations continued during the summer of 2003 and 2004. Here we describe the excavations, basic stratigraphy, and chronology of the site occupation in the context of the graves. The geological report by Nanna Noe-Nygaard focuses on the stratigraphy at the site with regard to changing sea levels in the context of the occupation on the site and the chronology of the graves. The focus in both discussions is on the nature of the Dragsholm site area at the time of shift from Atlantic to Subboreal conditions and the transition from the Mesolithic to the Neolithic, ca. 4000 B.C.

Archaeological Excavations. In the fall of 1973 Per Poulsen of the National Museum excavated a 3 x 1 m test pit (Test trench 2), approximately 40 m east of the grave site on a second, smaller rise along the Dragskanal. Several layers with cultural material were encountered in the excavations, including both Early Neolithic and late Mesolithic artifacts. These materials were taken to the National Museum.

The site was revisited 30 years later. Excavations at the site in 2002-2004 were conducted as a joint project of the University of Wisconsin-Madison and the Odsherreds Museum. The goals of these excavations were to obtain more settlement remains and to date the occupations at the site. Because of the graves and the 1973 test pit, the locality appeared promising for layers dating from the time of the transition to agriculture. A full report on the excavations will appear in another format. Here we provide a summary of the project and its findings.

In the recent excavations, a series of test pits and trenches were excavated, largely on the east side of the small island, between the Dragsholm burial site and the test pit from 1973 (Figs. 9 & 10). These excavations were largely in water-lain deposits and revealed a complex stratigraphy. The section from T11 at Dragsholm provides a good overview of the sequence of layers and the associated depositional context. T11 (Test 11) is a 2 x 1 meter unit, excavated to a depth of 2.20 m. This was the deepest section that we excavated and it exposes typical sediments in the southeast quadrant of the former small island at Dragsholm. This section is discussed both in the archaeology section as an introduction to the cultural layers and in the geology section as the sedimentary sequence at the site. The layers in this section are described in Table 10. The sedimentary history of this stratigraphic sequence is discussed in detail in a subsequent section on geology. Archaeologically layers 6, 7, and 8 are of particular interest.

Layer 6 is a heavily washed and redeposited fine sand horizon rich in flint artifacts, with some ceramics, and a few poorly preserved pieces of bone. Flint artifacts were marine patinated and rolled; ceramics were eroded and only larger pieces usually survived. Only TRB pottery is present in this layer. There is a fragment of a lugged jar, several knobs, and numerous sherds. The sherds come from medium to large Funnelbeakers and a possible clay disk. The lugged jar is probably Koch's (1998) type 2 with lugs in a ring around the base. Decoration was limited and only included stabbing and finger impressions below the rim on a few sherds. In general the ceramic assemblage would appear to belong in late ENII. Fish bone and nutshells were rare to absent. Two radiocarbon-dates on bone and charcoal from this layer suggest a date very close to 4000 B.C. the artifacts in this layer are a mix of Mesolithic and Early Neolithic that suggest these materials were eroded from higher areas of the site and redeposited here. One of the radiocarbon dates (4050-3770 B.C.) comes from a large chisel made from cow bone, reaffirming the Early Neolithic date.

Layer 7 is a complex of medium to coarse sand deposits that appear to represent a sequence of redeposition. Two radiocarbon dates from the upper and lower sections of layer 7 indicate a range from 4810-4520 B.C. to 5260-4800 B.C. This layer contains some archaeological materials. Flint was lightly rolled and patinated. Bone was concentrated in the lower part of this layer and included some fish bone. Ertebølle ceramics at the site were found in this layer. At least four medium to large vessels were represented. No small pots or lamps were recovered. Layer 7 appears to represent occupation materials from the middle Ertebølle period, given the radiocarbon dates and the presence of the pottery vessels and the absence of lamps.

Layer 8 is a deposit of gray to rust-colored fine sand with gravel and larger stones. Flint and bone were much fresher in this horizon. Bone was well preserved. Flint was sharp and unrolled. Fish bone and burned hazel nutshells recovered in these lower layers were plentiful and well preserved. The presence of small bone and flint pieces and the fresh condition of the material suggests that the artifacts in layer 8 are largely in situ, probably deposited originally in water. Two radiocarbon dates are available from Layer 8 in T11: 5320-5040 B.C. and 5480 – 5200 B.C., early Ertebølle in age. The artifact material generally fits this date and appears to be unmixed. Numerous projectile points and core axes were recovered in this layer and no pottery was present. A substantial number of bone and antler artifacts including fishhooks, bone points and awls, and three fragments of decorated antler axes were found as well.

The elevation of the site was measured from a fixed point at the Dragskanal bridge. This new elevation information indicated that the height of the small rise with the graves was less than 5m asl. Information from investigations at the Trundholm Mose, 10 km north of Dragsholm, documents a maximum transgression at the end of the Atlantic beginning of the Subboreal of +4 m asl. Clearly this area at Dragsholm would have been only a small piece of land above the water, a few tens of square meters and would have constantly been washed over by wave and storm. It is unlikely that there was any habitation at Dragsholm during this high water stand. This situation fits closely with the revised ages for the graves and the new data from the cultural horizons.

Geological Investigations. The geological context of the Dragsholm graves is discussed here on both a regional and local level. Emphasis is on changing sea levels in the area with regard to the chronology of settlement and burial. The landscape of northwest Zealand is characterized by steep end moraine ridges and eroded lowland just to the south. The ridges were formed by the Young Baltic ice stream during recessions and successive re-advances through the Storebælt strait between 18 -16,000 years ago.

The present day landscape is dominated by an end moraine arch called Vejrhøjbuerne, consisting of till and ice lake clay deposits to the northwest (brown) and a dead ice and melt water landscape to the southwest (yellow). The raised marine foreland is marked in blue. When sea level was higher in the middle Holocene, the only land passage to Odsherred, between the Sejerø Bugt and the Lammefjord, was across the narrow isthmus of land at Dragsholm. This land bridge was 2-3 km wide and consisted largely of wetlands and marsh. Much of this area is only 2 m above present day sea level and could readily be transgressed. When the adjacent Lammefjord was reclaimed in the 19th century, a primary drainage canal was dug at Drags Mølle (2 m asl), linking the former Lammefjord with the Dragsholm inlet, draining the Lammefjord region into the sea at the bay of Sejerø. Maximum sea level in the Dragsholm area during the middle Holocene was between+ 3.5 and +4 m asl (Mertz 1924). This estimate concurs with our own observations from the recent excavations at Dragsholm. The sedimentological record at the site indicates an open connection between Lammefjord and the Bay of Sejrø at +3 - +3.5 m asl. The narrow land barrier between the Dragsholm fjord and the Lammefjord was breached by the sea already during the High Atlantic transgression. The fjord became part of a strait connecting the Lammefjord with the Kattegat. Odsherred was then separated from the rest of Zealand. The formation of this connection and the estimated sea level at that time fits well with information from Trundholm Mose, 15 km to the north of Dragsholm (Kolstrup 1987, Christensen 1995).

Three major processes were involved in the changing sea levels of the mid-Holocene at Dragsholm. The local sea level is a result of the interplay between eustatic sea level, isostatic rebound after the down warping of the earth's crust from the weight of the ice cap, and the sediment input into the available accommodation space for deposition (Fig. 11). Eustatic (global) sea level rose approximately 120 m in the early and middle Holocene following the warming at the end of the Pleistocene. The rate of rise slowed substantially around 7000-6000 years ago. A rapid eustatic rise of sea level results in the sea moving over the land, a transgression. When the eustatic sea level rise decreases, the isostatic rebound of the land surface may overtake the sea, resulting in a regression, where the coastline moves in a seawards direction as seen in the coastal profiles from Dragsholm, for example from Test 11 (Fig. 12).

Fig 9. Airphoto of the 2003 excavations at Dragsholm. The Dragskanal runs through the left of the photo. The excavation skurvogn is the large white rectangle in the upper left. The location of the two Stone Age graves at Dragsholm are marked by three individuals lying on the ground in the top center of the airphoto. Courtesy of the Royal Danish Airforce.

As most of the near shore areas around the Denmark are flat and shallow, little accommodation space is available for sediment deposition. This means that even during highstands of sea level, regressions may occur as the space for infilling of sediment is limited and rapidly filled. The coastline then starts to prograde towards the sea resulting in a regression, in contrast to a transgression where the coast line moves inland. The terms transgressions and regressions thus refer to the movements of the coastline, irrespective of sea level. As the Storebælt area was flooded by the sea, beginning in the Boreal period, sedimentation changed from river, lake and bog deposits into marine silt and clays with a salt water mollusk fauna (Christensen et al. 1997). The marine transgressive surface is clearly detected in seismic profiles and sediment cores. This transgression had a major influence on adjacent areas such as northwest Zealand. A gradual degradation of low land areas and the lower reaches of the rivers took place, as ground water levels were raised by the ongoing marine inundation.

The rate of sea level rise slowed during the later Atlantic period. A combination of isostatic rebound and eustatic sea level rise resulted in a number of minor regional transgression and regression cycles called the Littorina transgressions (Iversen 1937, Berglund 1971, Christensen 1994, 1995 and 1997, Jakobsen 1981,1983). Around 6000 years ago, an interruption of the ebb and flood cur-

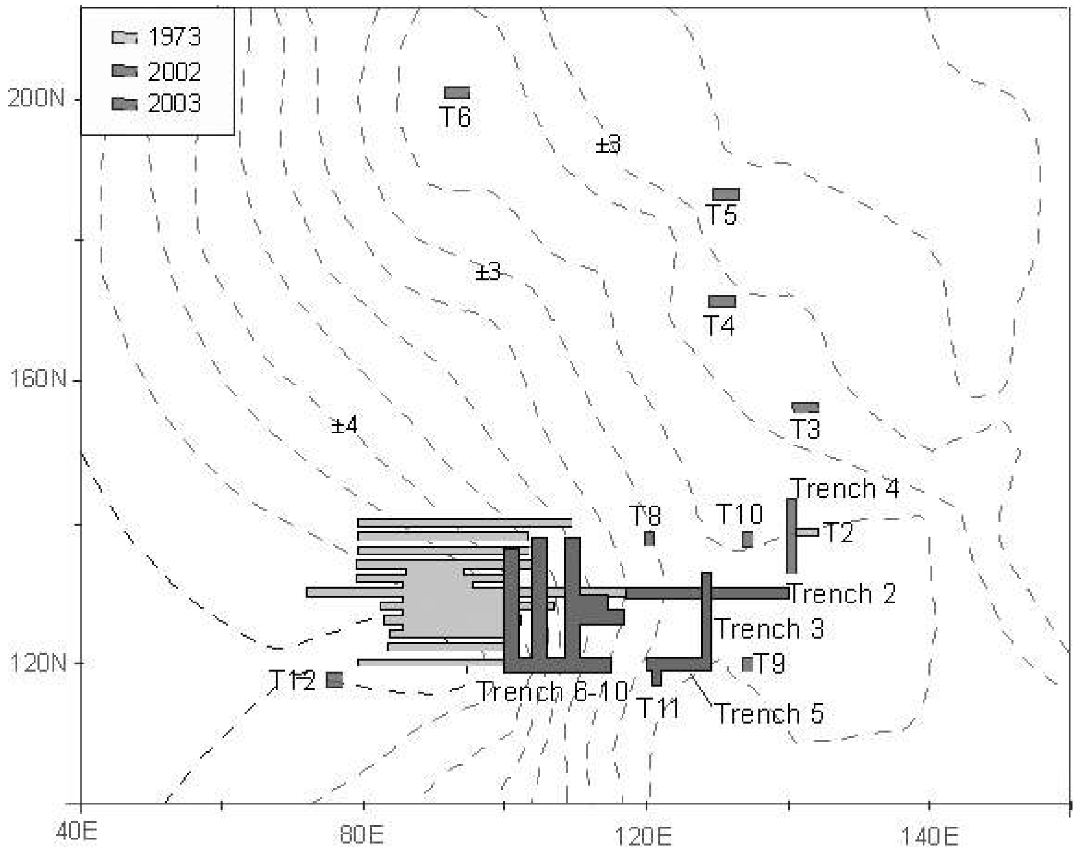


Fig. 10. Plan of the excavations at Dragsholm. The excavations from 1973 (shown in yellow) were a series of long trenches intended to look for additional burials around the first grave. T2 is the 3 x 1 m test pit that was excavated by Per Poulsen. Trench 4 is 10 m long; contour interval is 25 cm.

rent occurred, probably as a result of changes in the configuration of land and sea. That resulted in a much weaker tide with an amplitude of 0.5 m to 0.75 m, in contrast to a previously strong tidal system, with an amplitude up to 4 m, that had provided warm, salty, and well oxygenated to the inner fjords during the Atlantic time.

Around 4000 years ago, a change in the marine current system shifted the position of the tidal forces in the North Sea and cooler water foraminifera are found in the marine cores together with cold tolerant bivalves (Nordberg 1991). These changes are clearly reflected in the marine shell content of the kitchen middens. Before 6000 years ago, oysters (Ostrea edulis) were the dominant species together with other warmth and salt demanding species; after 6000 years ago low salt tolerant species such as cockles (Cerastoderma edulis) and mussles (Mytilus edulis) were predominant (Andersen 2000; Rowley-Conwy 1984). Not only did the molluscan fauna change, but also the species and distribution of fish.

The Dragsholm area is situated where highest beach lines of the Littorina transgressions occur between 3.5 m and 4.5 m asl. Based on sea level projections in this area, the small rise with the two graves was once an island in an area with a strong current and wave-dominated sea-connection between the Lammefjord and the Kattegat in Sejerø Bay. The very coarse grained sediments observed in the excavation trenches, the rather abraded state of some of the bone material, and the large amount of charcoal in many layers are characteristics of high energy and erosion on the upper foreshore and beach environment (Fig. 12). The stray finds of a human jaw from the waterlain deposits suggest that the site has been subjected to substantial erosion by the advancing sea.

Stratigraphy and Sedimentology at Dragsholm. The general stratigraphy and sedimentology is here shown on the Dragsholm profile from Test 11 at 116 N/123E (Fig. 12). The overall trend in the multiple successions that have been measured is an upwards coarsening indicating the increasing proximity of land regression. The sequence is around 200 cm in thickness and contains three major regressive /transgressive cycles from the High Atlantic, Late Atlantic and Early Subboreal Littorina transgressions. These transgressive events seem to be more prominent in the northern part of Zealand (Iversen 1937, Jakobsen 1981, 1983, and S. Ulfeldt Hede, unpublished data from Søborg Sø). The dating of the Dragsholm transgressions is based on the bone material and charcoal from the different layers and strengthened by comparison with the well-dated contemporary sequences from the Tengslemark bog only 40 km to the north (Jessen 1937, Mortensen pers. comm. 2004). The distribution of the dates confirms the stratigraphic evidence based on the interpretation of sediment facies.

The first of three transgression cycles at Dragsholm includes the sediments deposited from 170 cm to 140 cm below surface (Fig. 12). The lowermost 30 cm from 200 cm to 170 cm can be divided

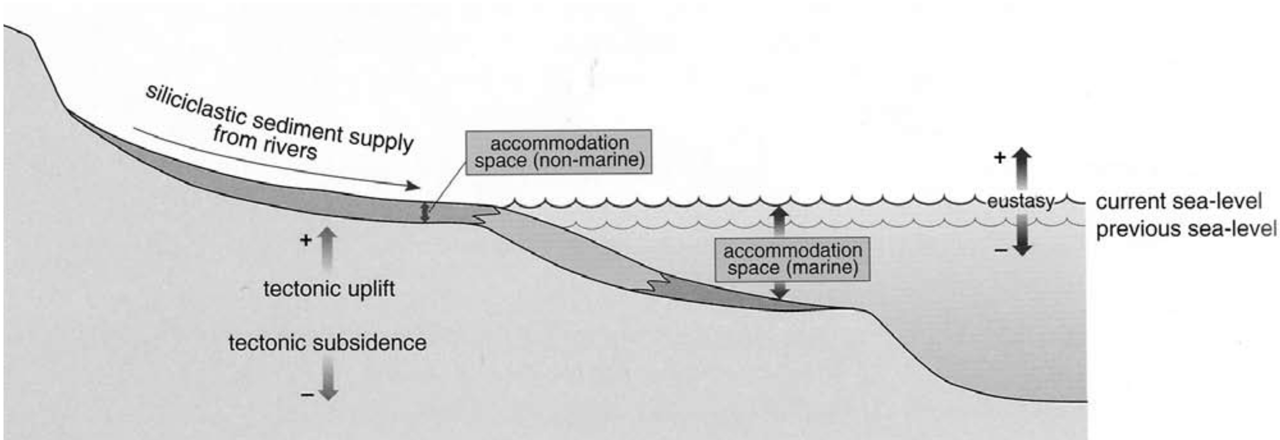


Fig. 11. Schematic illustration of the terms in near shore environment and the term accommodation space.

into two facies deposited during regression. Facies one, from 200 cm to 178 cm below surface, the lowermost exposed deposit, is a clean medium-grained cross-laminated, near shore, light-colored sand. The grain size and cross lamination indicate deposition in a near-shore, low energy, beach environment influenced by some wave activity. The sand facies at 178 cm below surface is abruptly cut by a surface of erosion (regressive), marked by a lag of cobble-sized stones.

The second facies, from 178 cm to 170 cm, is rusty, coarse-grained pebbly sand with cobbles and scattered blocks, maximum size of 20 cm in diameter. This sediment was deposited in a high-energy environment such as a wave-breaking beach zone and formed during regression in a low stand situation. On top of this facies are several rusty rotten blocks, indicating occasional exposure above Littorina sea level. The blocks originate in the adjacent moraine hill that was being eroded by the sea. The blocks have moved by sliding and tumbling, washed clean by the advancing sea, and left as a lag at the bottom of the layer.

The first transgression is, as mentioned, represented by sediments deposited between 170 cm to 140 cm (Fig. 12). The sequence starts with a drowning surface created during transgression at 170 cm below surface. The sediments consist of greenish, fine sand with clay and marine organic matter and scattered pebbles and charcoal. Throughout the facies, small bivalves (Cerastoderma edulis) and gastropods (Littorina littorea and Hydrobia spp.) occur in living position. The fine grain size and high content of glauconitic clay and organic mud indicate deposition in a low energy marine environment, either in deeper waters or in a protected area during a relative high transgression and early high stand. This green sand facies is abruptly cut by a regressive surface of erosion marked by a concentration of broken and complete shells in a gravel layer.

The second cycle occurs from 138 cm to 115 cm below surface. The shell lag is overlaid by coarse sand with large stones. The sequence becomes finer upwards into medium sand with stones (max. diameter of 20 cm). From 130 cm to 120 cm there is a gradual shift to more fine-grained, rusty sand with scattered boulders indicating deposition at lower energy, probably in deeper waters during transgression, perhaps in the upper shore zone. The boulders had a rotten, rusty surface indicating some period of subaerial exposure.

From 120 cm to 110 cm below the surface, a coarsening from medium to coarse sand occurred. The sediment now contains shell gravel and charcoal indicating an increasing proximity of land. This tendency is corroborated by the succeeding layer, from 110 cm to 95 cm, of coarse, rusty sand with plenty of charcoal and brownish streaks of oxygenated organic material. Cycle two ends with a bed, from 105 cm to 115 cm, coarsening upwards from coarse sand to pebbles with large quantities of charcoal and flint deposited in the waved-wash zone of the upper foreshore during a late high stand (Fig. 11).

The third cycle includes the deposits from 85 cm to 45 cm below surface. The pebbly sand from cycle 3 is from 85 cm to 75 cm, overlaid by light, fine to medium sand with rusty root and stem traces from in situ vegetation, probably from reeds (Phragmites comunis), indicating a water depth of less than 2 m. The fine grain size and the abrupt transition to the underlying layer indicate a drop in energy caused either by a rising water table or the closing of the passage from the Lammefjord to Sejerø bay. From 75 cm to 65 cm below surface, the sediment grain size increases to medium sand and horizontal streaks of peat occur. The sandy sequence is caped by coarse, pebbly sand with cobbles and sharp edged flint and an indistinct lamination with a sharp and erosive base. The very coarse grain size indicates deposition in a high-energy environment; the low angle, indistinct, cross-lamination suggests a beach zone. The wide areas covered by the sequence indicate rapid coastal progradation during a relative fall in sea level and erosion during regression. The regression is likely due to decreasing accommodation space caused by a combination of isostatic uplift and a low rate of sea level rise.

Similar patterns in the stratigraphic record of the transgressions can be seen at Toftevang, Tengslemark, and Smakkerup Huse. The earliest marine transgression recorded at Toftevang in the Lammefjord is radiocarbon-dated 6450 years before present (Christensen 1994), contemporaneous with the high Atlantic transgression, and correlated by pollen analysis and other radiocarbon dates with evidence from the Søborg Sø (Iversen 1937, Hede unpub. data, Mortensen unpub. data 2003, Noe-Nygaard et al. in prep.). At Toftevang, the marine succession is overlaid by terrestrial peat dated to 5870 years before present.

The Tengslemark locality today is a lake connected to the

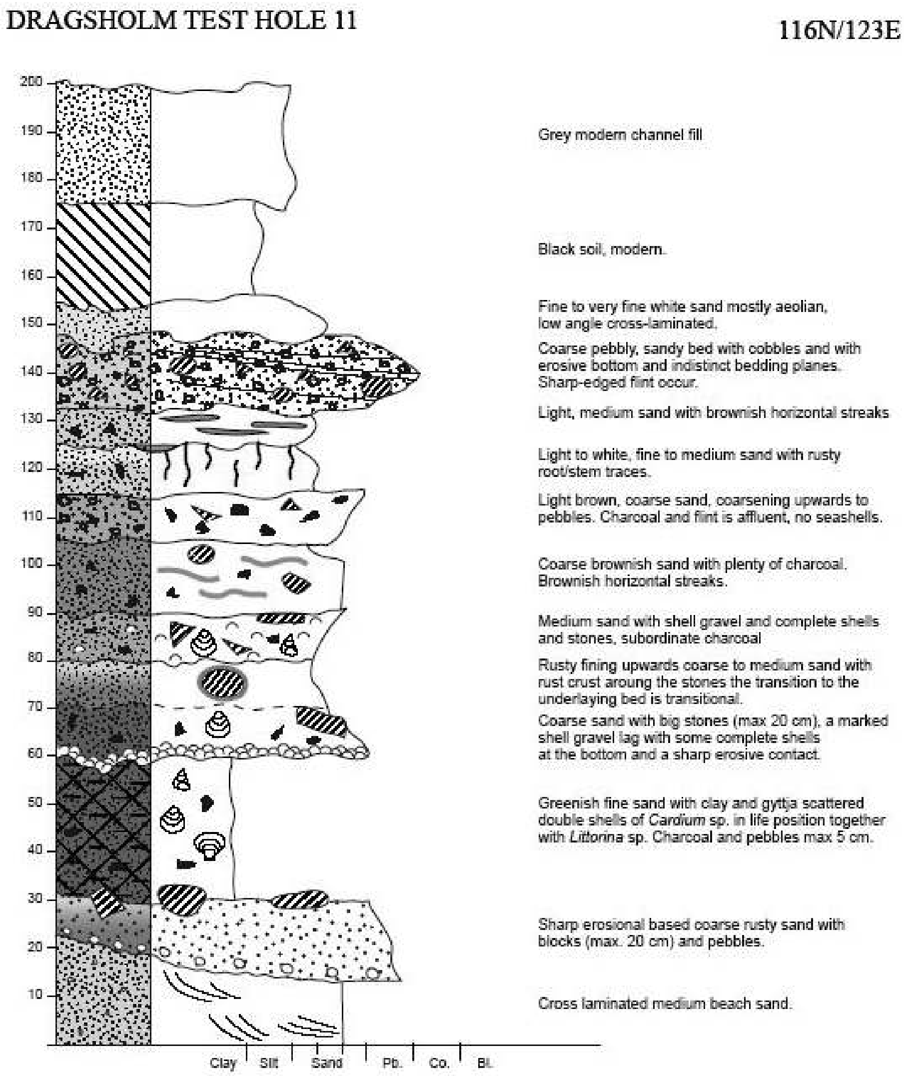


Fig. 12. Sequence stratigraphy at Dragsholm. A profile from test 11 showing the three transgression/regression cycles.

former Klintsø fjord on the north coast of Odsherred. The pollen spectrum from Tengslemark has been compared with a diagram from Søborg Sø (Iversen 1937) in order to establish the connection with the original type site for the four Littorina transgressions (Iversen 1937). The onset of the High Atlantic transgression at Tengslemark is dated to 6210±55 14C years before present. The transgression is marked by a steep raise in the total sulphur percentage in the sediment profile. The impact of marine conditions ceased at 5775±50 years before present and normal lacustrine conditions and sedimentation returned. The onset of the Late Atlantic Littorina transgression is dated to 5295±45 years before present and the Early Subboreal transgression is dated to 5095±45 years before present. This transgression continues into and merges with the early Subboreal transgression. The two transgressions are only separated by a short-lived low stand at the end of which the elm decline occurs. The first onset of marine transgression over terrestrial peat at Smakkerup Huse (Price and Gebauer 2005) is dated to 6140 ± 40 before present and further inland to 6100 ± 60. The onset of the late Atlantic/Early Subboreal transgression is dated at the site to 5040 ± 65 years before present.

CONCLUSIONS

A new study of the Dragsholm graves has involved more detailed investigation of the skeletal remains themselves, new isotopic analyses, and fieldwork to determine the settlement and stratigraphic context of the graves. The females' grave was originally dated to the latest Mesolithic with the possibility that calibration would place the two individuals in the Early Neolithic along with the male in the second grave. Carbon isotope analysis of the bone collagen indicated substantial differences between the two females and the male with a distinct marine diet for the two females. The burials from Dragsholm have been a contentious component of discussions of the transition from the Mesolithic to the Neolithic since their discovery.

New studies of the skeletal material itself have provided some important insights. The three skeletons and other bone fragments from Dragsholm were examined partly in order to establish whether there was any evidence of relationship between the 18 - 20-year-old and over 40-year-old Mesolithic women in the double grave, and partly to look for any evidence that may reflect different subsistence and lifestyles between the skeletons in the Mesolithic and Neolithic graves.

The two women exhibited a number of similarities with regard to the size and form of some bones and teeth, open sacral segments, short dental roots and signs of reduced dentition such as fused molar roots. They also exhibited dental differences, which are mainly attributed to cultural or environmental factors like polished areas produced by chewing hide (skeleton A) and the presence of linear enamel hypoplasia attributed to seasonal crises (skeleton B). This means that a close genetic relationship between the two women can neither be confirmed nor excluded. The more than 20-year age difference may indicate that the two women, if they were closely related, would more likely represent daughter and mother rather than sisters, although it cannot be demonstrated with certainty.

The similar patterns of dental wear in the young Mesolithic woman and the 30 year old Neolithic man, despite their age differences, may reflect the different subsistence during the two periods, different ways of preparing food and perhaps even different ways of using the teeth as a tool. It has been demonstrated that the latter produced more severe attrition in the young Mesolithic woman than is seen in the Neolithic population (Alexandersen 1988, 1989). The ochre-stained Mesolithic bones and the Neolithic grayish soil-stained bones express yet another cultural difference.

New isotopic investigations of the burials from Dragsholm were undertaken confirm the age of the skeletons and to re-measure carbon isotope values for carbon. In addition, nitrogen isotopes were measured in these materials, carbon isotopes in apatite were recorded, and strontium isotopes were measured in tooth enamel.

New radiocarbon dates were obtained on the bone collagen from the three skeletons. Two sets of samples were run using AMS dating at laboratories in Aarhus and New Zealand. These dates resulted in a correction of the original date on the two female burials. The best estimate for the age of this grave comes from the date 5983±38 bp (AAR-7417) on a red deer bone artifact in the grave. The corrected BC date lies between 4946 and 4773 BC (2 s.d., 97.7%). The dates from the human collagen of the two females, even after calibration, remain a hundred years or so too old. The date of the Neolithic male remains essentially unchanged, ca. 4989±46 (AAR-7416) on human bone collagen, corrected to between 3782 and 3637 BC (2 s.d., 99.7%). Thus the difference in age between the two graves is approximately 1000 years. They are in no way contemporary. The two females are clearly Mesolithic, while the single male belongs in the Early Neolithic period. The isolated mandible fragment found in 2003 was dated to 6310±60 BP, roughly contemporary with the two Mesolithic females from the grave.

Measurement of the carbon isotope content of bone collagen largely confirmed the original results of Tauber (1981a). A number of new measurements on the three individuals indicated a significant difference between the two females and the male. The δ13C values from the University of Illinois are A = -10.4, B = - 11.4, and D = -19.3. The new values are slightly higher (ca. 1 - 2‰ less negative) than the original measurements. The Mesolithic females have a higher, marine-based carbon isotope ratio while the ratio for the male is largely terrestrial. The isolated mandible fragment from 2003 had a δ13C value of -11.7, which is very similar to the two Mesolithic females. The values for the Mesolithic females are close to the most positive end of the range for marine sources and suggest a diet that was composed of 90% or more of seafood. The δ13C value of D is relatively high for an exclusively terrestrial diet, and may reflect the consumption of up to 15% marine foods.

Nitrogen isotopes were also measured on bone collagen in several laboratories. Nitrogen isotope ratios from the University of Illinois were A = 13.2‰, B = 13.5‰, and D = 10.0‰. Again a distinct difference between the two females and the male is indicated. The isolated mandible from 2003 had a nitrogen isotope ratio of 14.5‰ similar to the Mesolithic females. Nitrogen isotopes should reflect the trophic level of individual. Values greater than 15‰ should reflect purely marine diets; values less than 9‰ should represent completely terrestrial food sources. The values for the Mesolithic females and the isolated mandible indicate largely marine diets, with an emphasis on fish rather than marine mammals. The nitrogen isotope ratio in the Neolithic male indicates the largely terrestrial nature of his diet. This value is at the high end observed for temperate Holocene Europe and suggests that animal protein was the major component of the diet.

Carbon isotope ratios in bone apatite should reflect sources of dietary energy, which is effectively the whole diet, while collagen reflects mainly dietary protein. Measurements of apatite produced δ13C values of A = -8.3‰, B = -9.3‰, and D = -12.1‰. Apatite carbon was not measured on the isolated mandible from 2003. The δ13C values for apatite indicate a marine component in the diet of approximately 76% in individuals A, 67% in B, and 42% in D. The relatively poorly-preserved bone of Burial D may have been affected by diagenesis and may overestimate the consumption of marine resources. From this information it is clear that the marine component of the diet is exaggerated by the protein source for the collagen. Marine foods, rich in protein, contribute disproportionately to the collagen carbon.

Strontium isotope ratios were measured in individuals B and D, along with four red deer teeth. Strontium isotopes can provide information on residential changes during an individual's lifetime. Strontium isotope ratios in tooth enamel are determined by the place of birth and can be compared to the local signature of the place of death to see if they are the same. The strontium isotope ratios in the red deer teeth (ca. 0.7105) provide the local terrestrial signal for the Dragsholm area. Seawater and marine foods should have a strontium isotope ratio of 0.7092. Both the Mesolithic female (B = 0.7096) and the Neolithic male (D= 0.7094) exhibited values below the red deer. The range from terrestrial to marine in these samples is approximately 0.0013 (0.7105 - 0.7092). The Mesolithic female strontium isotope value of 0.7096 is 0.0009/0.0013 between the two extremes. Given the high marine component of her diet documented in the carbon and nitrogen isotopes, this shift is not unexpected. In fact, the strontium isotopes might suggest that marine foods were 9/13 (ca. 70%) of the diet of the mother of individual B. This value is essentially identical to the prediction based on apatite carbon isotopes. The Neolithic male, however, did not consume as high a proportion of marine foods and his strontium isotope value even closer to seawater is surprising. This value in fact suggests that he may have been born outside of the glacial moraine that characterized much of the Danish landscape.

His place of birth was likely on marine deposits where strontium isotope values would have been 0.7092 and terrestrial foods in the diet of his mother would have shifted his enamel value slightly above the marine signal.

New archaeological excavations at the Dragsholm site have uncovered largely areas around the original burial location, collected new artifactual and human materials, and detailed the stratigraphic context of the site. These excavations opened a series of trenches along the eastern slopes of the small rise of the burial ground and in the adjacent waterlain deposits. The wide trenches on the slope of the rise did not expose any new features or burials. It appears that the graves discovered in 1973 were the only remaining intact burials at the site. At the same time it is clear from the discovery of the isolated mandible in 2003 that other graves may have been destroyed and scattered by the wave erosion of the site during the course of several transgressions.

The water lain deposits at the site indicate two major episodes of deposition. There is a lower horizon of early and middle Ertebølle materials that is largely in situ with little evidence of rolling or patination. This lower horizon contains well preserved fish bone and nut shell in great quantities along with other faunal remains. An upper horizon appears to contain late Ertebølle and Early Neolithic materials according to radiocarbon dates and the contents of the layer. This material is frequently rolled and marine patinated, bone is eroded and not well preserved. Fish bone and smaller artifacts are rare. This upper horizon appears to be secondarily deposited, presumably during a transgression or regression event at the end of the Atlantic climatic episode.

The artifactual materials recovered at the site document occupation in the late Mesolithic and Early Neolithic. Remains from the Ertebølle date from the early and middle parts of this period with little evidence of a late Ertebølle occupation. Distinctive artifacts included decorated antler axes, a greenstone trindøx, concave truncations on blades, and ceramics. In addition, there are ceramic and bone artifacts belonging the Early Neolithic in conjunction with radiocarbon dates that indicate the presence of Funnelbeaker (TRB) settlement at the site. TRB ceramics were common in the upper cultural layer at the site. Flake axes were found throughout the cultural horizons but no polished flint axes or fragments were recovered. In total, the artifactual remains and radiocarbon dates suggest a rather continuous occupation of this propitious location along the coast of the Kattegat in northwest Zealand. The fjord created here by rising sea levels during the Atlantic episode would have been a rich area for marine resources. In addition, the opening of this waterway between the Kattegat and the Lammefjord to the east may have created an exceptional situation for the capture of marine resources. The location also has strategic significance as a passage to the north into the peninsula of Odsherred.

The topographic and hydrological history of the area is revealed in the stratigraphy as Dragsholm. The sedimentary sequence documents three transgressive cycles. The dates of the three cycles were compared other northwest Zealand localities. Together they confirm that the High Atlantic transgression and the Late Atlantic/Early Subboreal were the most pronounced and the most inland-reaching transgressions. The time of the transgressions is well dated and established at four different localities in northwest Zealand (Table 1). The height of sea level (ca. 4 m asl) and the timing of the Late Atlantic/Early Subboreal transgression make it clear that the Dragsholm locality could not have been occupied at the end of the Atlantic period. At that time, this area would have been largely submerged just at the edge of a high-energy current connecting the Lammefjord and the Kattegat.

Taken together, the new investigations at Dragsholm provide an almost complete picture of the age and anatomical characteristics of the burials at the site, their bone chemistry and diet, the archaeological context of the graves and accompanying settlement, and the Holocene geology of the region. A great deal of new information has derived from these studies including strong evidence that the two graves are approximately 1000 years apart in age and that the two females date from the Mesolithic Ertebølle and that the male is certainly Neolithic. The stray humerus (individual C) found at the burial site comes from the Bronze Age. A new Mesolithic individual, identified from a mandible fragment, was discovered in the new excavations. Stable isotope study of the human remains replicated the earlier collagen carbon results but investigation of nitrogen and apatite carbon indicates that marine foods, primarily fish, were less important during the Mesolithic than previously believed. New flint, ceramic, bone, and antler artifacts document Mesolithic and Neolithic occupation at the site. Geological study of the sequence stratigraphy revealed a series of transgressions at Dragsholm, comparable to events elsewhere in Denmark. Sea level during these transgressions reached a maximum of +4.0 m asl and effectively prohibited human occupation at the Dragsholm site for some time at the very end of the Atlantic period. Early Neolithic materials accumulated at the site prior to this last transgression.

The Dragsholm area is rich in archaeological sites from the later Mesolithic and it is likely that new settlements and graves will be discovered in the coming years. It is our hope that the results reported here will assist in the understanding of new finds. At the same time, we believe our work has contributed to the resolution of questions regarding the age of the Dragsholm graves and the nature of the transition from the Mesolithic to the Neolithic at this place in northwest Zealand.[2]

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REFERENCES

Aaris-Sørensen, K. 1980. Depauperation of the Mammalian Fauna of the Island of Zealand during the Atlantic Period. Vidensk. Meddr. dansh. Foren. 142:131-138.

Albrethsen, S.E., & E. Brinch Petersen. 1977. Excavation of a mesolithic cemetery at Vedbæk, Denmark. Acta Archaeologica 47:1-28.

Alexandersen, V. 1988. The late Mesolithic dentition in southern Scandinavia. Rivista di Anthropologia, suppl. 66:19-204.

Alexandersen, V. 1989. Description of the human dentitions from the late Mesolithic grave-fields at Skateholm, southern Sweden. In: L. Larsson (ed.), The Skateholm Project: I. Man and Environment. Stockholm, Almquist: 106-163

Ambrose SH, 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. Journal of Archaeological Science 17: 431-451.

Ambrose, S.H. 1993. Isotopic analysis of paleodiets: Methodological and interpretive considerations, in Sandford, M.K. (ed.) Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Langhorne, Pennsylvania:Gordon and Breach Science Publishers. Pgs. 59-130.

Ambrose, S.H. & L. Norr. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In Prehistoric Human Bone: Archaeology at the Molecular Level (eds) J.B. Lambert & G. Grupe. Berlin: Springer-Verlag.

Ambrose, S.H., Brian M. Butler, Douglas B. Hanson, Rosalind L. Hunter-Anderson, Harold W. Krueger. 1997. Stable isotopic analysis of human diet in the Mariana Archipelago, western Pacific. American Journal of Physical Anthropology 104: 343-361.

Ambrose, S.H., J. Buikstra, and H.W. Krueger. 2003. Gender and status differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. Journal of Anthropological Archaeology 22:217-228.

Andersen, S. H. 2000. 'Køkkenmøddinger' (shell middens) in Denmark: a survey. Proceedings of the Prehistoric Society 66: 361-384.

Balasse, M., Ambrose, S.H., Smith, A.B. and Price, T.D. 2002. The seasonal mobility model for prehistoric herders in the Southwestern Cape, South Africa assessed by isotopic analysis of bovid tooth enamel. Journal of Archaeological Science 29: 917-932.

Bastian, W. 1962. Das jungsteinzeitliche Flachgräberfeld von Ostorf, Kreis Schwerin. Bodendenkmalpflege in Mecklenburg. Jahrbuch 1961: 7-130.

Bennike, P. 1985. Palaeopathology of Danish Skeletons. Akademisk Forlag, Copenhagen

Bennike, P. & Bohr, H. 1990. Bone mineral content in the past and present. In. C. Christiansen and K. Overgaard (eds.) Osteoporosis: 89-91

Bennike, P., Bohr, and Toft. 1993. Determination of mineral content and organic matrix in bone samples using dual photon absorptiometry. International Journal of Anthropology 8: 111-116.

Bennike, P., and V. Alexandersen 2002. Population plasticity in Stone Age Denmark. In: A. Fischer & K. Kristiansen (eds.) The Neolithisation of Denmark. 150 years of debate. J.R. Collis Publ., Sheffield

Berglund, B. 1971: Littorina transgressions in Blekinge, South Sweeden. A preliminary survey. Föreningens i Stockholm Förhandlinger 93: 625-652.

Bocherens, H., Pacaud, G., Lazarev, P., & Mariotti, A. 1996. Stable isotope abundances (13C, 15N) in collagen and soft tissues from Pleistocene mammals from Yakutia. Implications for the paleobiology of the mammoth steppe. Palaeogeography, Palaeoclimatology, Palaeoeocology 126: 31-44.

Bonsall, C., G. Cook, R. Lennon, D. Harkness, M. Scott, L. Bartosiewicz & M. Kathleen. 2000. Stable Isotopes, Radiocarbon and the Mesolithic—Neolithic Transition in the Iron Gates. Documental Praehistorica 27, 119-132.

Brinch Petersen, E. 1973. Dobbeltgraven fra Dragsholm. Nationalmuseets Arbejdsmark 187-188.

Brinch Petersen, E. 1974. Gravene ved Dragsholm. Fra jægere til bønder for 6000 år siden. Nationalmuseets Arbejdsmark 112-120.

Brinch Petersen, E. 1979. Kvindernes smykker. Søllerødbogen: 39-56.

Chisholm, B.S., D.E. Nelson, and H.P. Schwarcz. 1982. Stable carbon ratios as a measure of marine versus terrestrial protein in ancient diets. Science 216:1131-1132.

Christensen, C., F. Fischer, & R. D. Mathiassen. 1997. Den Store Havstigning i Storebælt, pg. 45-55 In: Storebælt i 10.000 år-mennesket, havet og skoven, ed. Pedersen, L., Fischer, A. & Aaby, B. Storebælt publikationer.

Christensen, C., 1994: Lammefjorden, Undersøgelser på 4 lokaliteter i fjorden giver informationer om havniveauændringer og afkræfter formodet forekomst af tektoniske bevægelser af landjorden i atlantisk tid. Nationalmuseets naturvidenskabelige Undersøgelser 16: 1-31.

Christensen, C., 1995. The littorina transgressions in Denmark. In Man and Sea in the Mesolithic p 15-21. A. Fischer (ed.), A. Oxbow Monograph pp 440.

Clark, R.M. 1975. A calibration curve for radiocarbon dates. Antiquity 49: 251-266.

Cook, G.T., Bonsall, C., Hedges, R.E.M., McSweeney, K., Boroneanţ, V. & Pettitt, P.B. 2001. A freshwater diet-derived 14C reservoir effect at the Stone Age sites in the Iron Gates gorge. Radiocarbon 43(2A): 453–460.

Cook, G.T., Bonsall, C., Hedges, R.E.M., McSweeney, K, Booneant, V., Bartosiewicz, L. and Pettitt, P.B. 2002. Problems of dating human bones from the Iron Gates. Antiquity 76: 77-85.

DeNiro, M.J. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction. Nature 317: 806-809.

Ebbesen, K. 1988. The long dolmen at Grøfte, South-west Zealand. Journal of Danish Archaeology 7: 53-69.

Ezzo, J. A., C.M. Johnson, and T.D. Price. 1997. Analytical perspectives on prehistoric migration: a case study from East-Central Arizona. Journal of Archaeological Science 24: 447-466.

Ferembach, D. 1963. Frequency of Spina Bifida Occulta in prehistoric human skeletons. Nature 199 (4888): 100-101.

Fischer, A. 2002. Food for Feasting. In The Neolithisation of Denmark. 150 Years of Debate (eds) A. Fischer & K. Kristiansen. Sheffield: JR Collis Publications.

Fischer, Anders, and Jan Heinemeier. 2003. Freshwater reservoir effect in 14C dates of food residue on pottery. Radiocarbon 45: 449-466.

Frayer, D.W. 1988. The supra-acetabular fossa and groove: a skeletal marker for northwest European Mesolithic populations. Human Evolution 3:163-178.

Harrison, R.G., and M.A. Katzenberg. 2003. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from southern Ontario and San Nicolas Island, California. Journal of Anthropological Archaeology 22: 227-244.

Hedges, R.E.M. 2004. Isotopes and red herrings: comments on Milner et al. and Lidén et al. Antiquity 78: 34-37.

Heier-Nielsen, S., J. Heinemeier, H.L. Nielsen and N. Rud. 1995. Recent reservoir ages for Danish fjords and marine waters. Radiocarbon 37-3: 875-882.

Howarth, R. J. & McArthur, J. M. (1997). Statistics for strontium isotope stratigraphy: a robust LOWESS fit to the marine Sr- isotope curve for 0 to 206 Ma, with look-up table for derivation of numeric age. Journal of Geology 105: 441-456.

Humlum, O. 1983. Dannelsen af en disloceret randmoræne ved en avancerende isrand, Höfdabrekkujölkull, Island. Dansk Geologisk Forening 1982: 11-26.

Iversen, J. 1937. Undersøgelser over Littorinatransgressioner i Danmark. Meddelelser fra Dansk Geologiske Forening, Bd. 9, 223-236.

Jim, S., S.H. Ambrose, and R.P. Evershed. 2004. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: implications for their use in palaeodietary reconstruction. Geochimica et Cosmochimica Acta 68: 61-72.

Koch, E. 1998. Neolithic Bog Pots from Zealand, Møn, Lolland and Falster. Copenhagen: Nordiske Fortidsminder.

Kolstrup, E. 1987. Late Atlantic and Early Subboreal vegetational development at Trundholm, Denmark. Journal of Archaeological Science 15: 5.

Krueger, H. W., & Sullivan, C.H. 1984. Models for carbon isotope fractionation between diet and bone. In Stable Isotopes in Nutrition, edited by J.R. Turnland and P.E. Johnson, pp. 205-220. American Chemical Society Symposium Series, No 258.

Lanting, J.N., and J.van der Plicht. 1996. Wat Hebben Floris V, Skelet Swifterbant S2 en Visotters Gemeen? Palaeohistoria 1998: 1-39.

Larsson, L. 1990. The Mesolithic of Southern Scandinavia. Journal of World Prehistory 4: 257-309.

Lidén, K. G. Eriksson, B. Nordqvist, A. Götherström, and E. Bendixen. 2004. "The wet and the wild followed by the dry and the tame" - or did they occur at the same time? Diet in the Mesolithic - Neolithic of southern Sweden. Antiquity 78: 23-33.

Lunt, D. A. 1969 An odontometric study of Medieval Danes. Acta Odontol. Scand. Suppl. 55,27.

Mertz, E. L. 1924: Oversigt over de sen- og Postglaciale Niveauforandringer i Danmark. Danmarks Geologiske Undersøgelser. II række, 41.

Metges, C, K. Kempe, H.L. Schmidt, 1990. Dependence of the carbon-isotope contents of breath carbon-dioxide, milk, serum and rumen fermentation products on the delta-C-13 value of food in dairy-cows. British Journal of Nutrition 63: 187-196.

Milner, N., O.E. Craig, G.N.Bailey, K. Pedersen, and S.H. Andersen. 2004. Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations. Antiquity 78: 9-22.

Montgomery, J., P. Budd & J. Evans. 2000. Reconstructing the lifetime movements of ancient people: a Neolithic case study from southern England. European Journal of Archaeology 3: 407-422.

Noe-Nygaard, Nanna, T. Douglas Price, and Signe Ulfeldt Hede. 2005. Diet of aurochs and early cattle in southern Scandinavia: evidence from 15N and 13C stable isotopes. Journal of Archaeological Science 32: 855-871.

Nordberg, K. 1991: Oceanography in the Kattegat and Skagerak over the past 8000 years. Palaeocenography 6: 461-484.

Pavelka, M.S.M. and Fedigan, L.M. 1991. Menopause: A Comparative Life History Perspective.

Pedersen, P.O. 1949. The East Greenland Eskimo Dentition. Numerical variations and anatomy. Meddelelser om Grønland 142,3.

Persson, P. 1998. Neolitikums början. Undersökningar kring jordbrukets introduktion i Nordeuropa. Uppsala, Göteborg.

Price, T.D. 1989. The Chemistry of Prehistoric Human Bone. Cambridge: Cambridge University Press.

Price, T.D., 1995. Agricultural origins and social inequality. In T.D. Price & G.M. Feinman (eds.), Foundations of Social Inequality, pp. 129-151. New York: Plenum Press

Price, T.D. 2000. Europe's First Farmers. Cambridge: Cambridge University Press.

Price, T.D., Johnson, C. M., Ezzo, J. A., Ericson, E., and Burton, J. H. 1994. Residential Mobility in the Prehistoric Southewest United Stated: A Preliminary Study using Strontium Isotope Analysis. Journal of Arcaeological Science 21: 315-330.

Price, T.D., & A.B. Gebauer (eds.). 1995. Last Hunters — First Farmers. New Perspectives on the Transition to Agriculture in Prehistory. Santa Fe NM: School for American Research Press.

Price, T.D., & A.B. Gebauer (eds.). 2005. Smakkerup Huse. Excavations at a Late Mesolithic Coastal Site in Denmark. Aarhus: Aarhus University Press.

Price, T. Douglas, Gisela Grupe, and Peter Schröter. 1998. Migration and mobility in the Bell Beaker period in Central Europe. Antiquity 72: 405-411.

Price, T. Douglas, Linda Manzanilla, & W.H. Middleton. 2000. Residential mobility at Teotihuacan: a preliminary study using strontium isotopes. Journal of Archaeological Science 27: 903-913.

Price, T. Douglas, R.A. Bentley, Jens Lüning, Detlef Gronenborn, & Joachim Wahl. 2001. Prehistoric Human Migration in the Linearbandkeramik of Central Europe. Antiquity 75: 593-603.

Price, T.D., J.H. Burton & R.A. Bentley. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. Archaeometry 44: 117-135.

Richards, M.P., and R.E.M. Hedges. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. Journal of Archaeological Science 26:717-722.

Richards, M.P., Price, T.D. & E. Koch. 2003. Mesolithic and Neolithic subsistence in Denmark: new stable isotope data. Current Anthropology 44: 288-295.

Richards, M.P., R.J. Schulting & R.E.M. Hedges. 2003. Sharp shift in diet at onset of Neolithic. Nature 425:366.

Richards, M.P., and R.J. Schulting. 2006. Touch not the fish: the Mesolithic- Neolithic change of diet and its significance. Antiquity 80: 444–458.

Rowley-Conwy, P. 1984. The laziness of the short-distance hunter: the origins of agriculture in western Denmark. Journal of Anthropological Archaeology 3:300-324.

Schoeninger, M. J., M. J. DeNiro, and H. Tauber. 1983. 15N/14N ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220: 1381-1383.

Schoeninger, M. J., and M. J. DeNiro. 1984. Nitrogen and carbon isotopic compositionof bone collagen from marine and terrestrial animals. Geochemica and Cosmochemica Acta 48: 625-639.

Schuldt, E. 1961. Abschließende Ausgrabungen auf dem jungsteinzeitlichen Flachgräberfeld von Ostorf 1961. Jahrbuch für Bodendenkmalpflege in Mecklenburg 1961:131-178.

Schulting, R.J. & M.P. Richards. 2002. Finding the coastal Mesolithic in southwest Britain: AMS dates and stable isotope results on human remains from Caldey Island, Pembrokeshire, South Wales. Antiquity 76: 1011-1025.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., v.d. Plicht, J., and Spurk, M. 1998. INTCAL98 Radiocarbon age calibration 24,000 - 0 cal BP. Radiocarbon 40:1041-1083.

Szilvássy, J. 1986. Eine neue Methode zur intraserialen Analyse von Gräberfeldern. A new method for intraserial analysis of burial sites. In: B. Herrmann (ed.) Innovative trends in prehistoric anthropology. Mitt. Der Berliner Gesellshaft für Anthropologie, Ethnologie und Urgeschichte, Berlin 7: 51-62

Tauber, H. 1973. Copenhagen radiocarbon dates X. Radiocarbon 15: 86-112.

Tauber, H. 1981a. 13C evidence for dietary habits of prehistoric man in Denmark. Nature 292: 332-333.

Tauber, H. 1981b. Kostvaner i forhistorisk tid - belyst ved C-13 målinger. In Det skabende menneske, pp. 112-126. Copenhagen: National Museum.

Tauber, H. 1983. C14 dating of human beings in relation to dietary habits. In The first international symposium on C14 and archaeology, Groningen 1981. PACT 8.

Tieszen, Larry L. and Thomas Fagre 1993. Effect of diet quality on the isotopic composition of respiratory CO2, bone collagen, bioapatite and soft tissues. In Molecular Archaeology of Prehistoric Human Bone, edited by J. Lambert and G. Grupe, pp. 121-155. Springer, Berlin.

Trotter, M. and Gleser, G. 1958 A re-evaluation of estimation of stature based on measurements of stature taken during life and long bones after death. American Journal of Physical Anthropology 9:79-125.

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Lab #	Burial	^{14}C Years bp	Cal. ^{14}C Years BC	Years BC Cal.	δ^{13}C
K-2224	A	5160± 100	3210	4000	-11.4 ‰
K-2225	B				-12.1 ‰
K-2291	D	4840± 100	2890	3675	-21.7 ‰

Table 1. Original radiocarbon data on Dragsholm Burials (Tauber 1973).

Lab Number	Skeleton	^{14}C Years bp
K-2224	A	5380± 100
K-2225	B	5930± 100
K-2291	D	4840± 100

Table 2. The three original dates from the Dragsholm skeletons in the archives of the Radiocarbon Laboratory at the National Museum Copenhagen.

Burial	^{14}C Date	δ^{13}C‰	Original Calibration	New Calibration
Mesolithic Female	5160±100 b.p.	-11.4	4000 B.C.	3650-3520 B.C.
Neolithic Male	4840±100 b.p.	-21.7	3650 B.C.	3670-3500 B.C.

Table 3. Original and New Calibration of 14C Dates from Dragsholm. Published in Brinch Petersen (1974) and Tauber (1981b).

	Collagen						Apatite			
Burial	Wt. % Collagen	Wt. %N	Wt. %C	Atomic C:N	δ^{15}N ‰	δ^{13}C ‰	Wt. % apatite	Wt. %C	δ^{13}C ‰	δ^{13}Cap-coll ‰
A	14.3	14.7	40.4	3.21	13.2	-10.4	70.8	1.06	-8.3	2.1
B	9.3	13.6	37.2	3.18	13.4	-11.3	65.7	0.99	-9.3	2.0
B*		14.4	39.3	3.17	13.6	-11.5				2.2
D	5.3	12.0	34.0	3.29	9.9	-19.3	70.2	0.91	-12.1	7.2
D*		13.1	35.9	3.19	10.1	-19.2				7.0

Table 4. Elemental and isotopic composition of bone collagen of Dragsholm human burials, determined at the University of Illinois. δ^{13}Cap-coll is the difference between apatite and collagen δ^{13}C values. Replicate analysis of collagen, indicated by *, was performed on burials B and D.

AAR#	Sample	Material	^{14}C Age (BP)	Reservoir Corrected	Calibrated BC Range (2 s.d.)	δ^{13}C	δ^{15}N
7414	Dragsholm A	bone	6187 ± 43	5787 ± □43	4722 (94.4%) 4535	-10.52	--
7414-2	Dragsholm A	bone	6209 ± 40	5809 ± 40	4730 (86.8%) 4540	-10.82	14.03
7415	Dragsholm B	bone	6175 ± 49	5775 ± 49	4720 (96.7%) 4499	-11.47	--
7415-2	Dragsholm B	bone	6296 ± 39	5896 ± 39	4860 (94.2%) 4680	-11.67	13.74
8724	Dragsholm C	bone	3097 ± 44	2995 ± 44	1390 (95.4%) 1050	-18.84	11.30
7416	Dragsholm D	bone	4989 ± 46	4903 ± 46	3782 (99.7%) 3637	-19.17	--
7416-2	Dragsholm D	bone	5102 ± 37	5030 ± 37	3950 (95.4%) 3710	-19.47	10.40
8725	2003 Mandible	bone	6310 ± 60	5910 ± 60	4940 (95.4%) 4610	-11.72	14.45
7417	Bone Spatula	Cervus	5983 ± 38	--	4946 (97.3%) 4773	-23.47	--
7418	Antler Pick	Cervus	5799 ± 50	--	4767 (97.3%) 4552	-22.57	--
7418-2	Antler Pick	Cervus	5090 ± 65	--	3965 (97.3%) 3795	-21.46	--

Table 5. New radiocarbon dates, calibration and light isotope ratios from the Dragsholm graves. All data from the AMS Dating Laboratory, University of Aarhus.

Sample	Code	δ^{13}C‰	Age BP
A	NZA-15676	-10.7	6208 ± 60
A	NZA-15953	-10.7	6115 ± 60
B	NZA-15678	-11.4	6002 ± 60
B	NZA-15954	-11.4	6030 ± 55
D	NZA-15679	-18.9	5145 ± 60
D	NZA-15955	-18.9	4977 ± 50

Table 6: AMS Radiocarbon dates from the Rafter Laboratory, New Zealand.

Sample	Description	^{13}C‰	^{15}N‰	:N	C	
A	Adult female (18 years)	-10.7	13.3	3.4	44.0	15.3
B	Adult female (40-50 years)	-11.7	13.7	3.5	43.4	14.7
D	Adult male	-19.6	10.0	3.4	43.1	15.0
AAR-7417	Ornamented spatula	-23.7	4.6	3.2	36.0	13.0

Table 7: Stable isotope and carbon:nitrogen data for the Dragsholm samples measured at Bradford. Errors on the δ^{13}C and δ^{15}N values are ± 0.2 ‰.

Sample	$\delta^{13}C$ T	$\delta^{13}C$ B	$\delta^{13}C$ I	$\delta^{13}C$ NZ-I	$\delta^{13}C$ C NZ-AMS	w$\delta^{13}C$ A	$\delta^{15}N$ B	$\delta^{15}N$ I	$\delta^{15}N$ NZ-I	C:N B	C:N I	C:N NZ-I	%C B	%C I	%C NZ-I	%N B	%N I	%N NZ-I
A	-11.4	-10.7	-10.4	-10.4	-10.7	-10.5	13.3	13.2	12.5	3.4	3.2	3.1	44.0	40.4	33.7	15.3	14.7	12.5
B	-12.1	-11.7	-11.4	-10.9	-11.4	-11.5	13.7	13.5	14.1	3.5	3.2	3.1	43.4	38.3	33.6	14.7	14.0	12.6
D	-21.5	-19.6	-19.3	-19.1	-18.9	-19.2	10.0	10.0	11.3	3.4	3.2	3.2	43.1	35.0	39.5	15.0	12.6	14.6

Table 8. All stable isotope data produced for the three Dragsholm human samples. Codes are T=Tauber, B=Bradford, I=Illinois, NZ-I= New Zealand isotope lab, NZ-AMS=data produced during ^{14}C dating, A=Aarhus.

Grave B	Human Tooth Enamel	First Molar	0.709614
Grave D	Human Tooth Enamel	First Molar	0.709391
Trench	Red Deer Tooth Enamel		0.710572
Trench	Red Deer Tooth Enamel		0.710465
Trench	Red Deer Tooth Enamel		0.711222
Grave B	Red Deer Tooth Enamel (Dr256)	Canine	0.710499

Table 9. Strontium isotope ratios in tooth enamel from Dragsholm graves.

Layer 1 is the plowzone, a dark brown sandy humic layer composed of the sediments removed during the excavation of the canal.
Layer 2 is the fill of the canal cut which have been redeposited along the canal. This material is a dark brown mix of humic and sandy layers also containing archaeological materials and shell. This layer may also contain (layer 3) dark decomposed sandy peat that probably represents the former ground surface following the retreat of the sea here in the middle Holocene. This area was likely a wetlands from the time of that retreat until the recent drainage of the region for agricultural purposes. Layer 3 could not be distinguished in this section. Layer 4 is drainage pipe ditch fill that was encountered in other parts of the site but was not visible here.
Layer 5, beneath Layer 2, is an aeolian fine white sand deposit with some gravel, perhaps formed during the period of marine transgression when the "dobberne" (sand dunes) to the west were developing along the coastline. This layer is sterile and continuous across the site area except above +4 m asl.
Layer 6 is a regression horizon with fine white sand, gravel, and large rolled stones, artifacts, bones, and some shell and charcoal. The cultural material in this horizon is both Early Neolithic, confirmed by several cattle teeth and bones and TRB pottery, and Ertebølle. Flint artifacts are moderately rolled and marine patinated. This mixed deposit must represent a final episode of erosion and deposition at the site as the sea was retreating from its high stand of the early Subboreal.
Layer 7 was a rich and complex sequence of gray medium sands with two major lenses of cultural material in the middle and lower parts of the layer. The cultural materials in this layer are Mesolithic, belonging largely to the middle Ertebølle. This layer likely represents a series of transgression deposits. The upper part of the layer (7a) is often leached with vertical streaks of oxidation and in some areas substantial accumulations of iron oxide. This layer contains some artifacts. A second horizon 7b is largely sterile coarse sand grading into 7a above with a few artifacts. Layer 7c is a darker, gray sand layer with substantial cultural material. Charcoal likely provides the gray color here. Shell lenses are present above 7c in some parts of the stratigraphy. Finds include ceramics and distinctive projectile points. This material is lightly rolled and probably secondarily deposited by the transgression and wave action.
Layer 8 was a layer of rust to gray colored sand and stone (variable in color across the excavation units) with lots of fish bone and hazelnut shell along with artifacts and other bone. This layer is likely largely in situ; the flint is fresh and unrolled. The cultural material in this layer is outcast material. Cultural material appears to be middle Ertebølle, confirmed by radiocarbon date on red deer bone of 6104±46 BP, 5019-5000 BC (AAR-8189).
Layer 9. Gray brown clayey sand, likely marine deposits during early transgression of the inlet here. Sterile. These lowest three layers are likely marine deposits during the early transgression of the fjord here.
Layer 10. Bedded, down-sloping coarse orange-brown sands, leached with accumulation of iron in bottom of layer. Sterile.
Layer 11. Fine, medium orange brown sand, bedded, sterile. Excavations ended in this layer at a depth of -2.2 m below ground surface, -0.73 m asl.

Table 10. Archaeological layer descriptions for T11, Dragsholm 2003.