Determining Sheep Birth Seasonality by Analysis of Tooth Enamel Oxygen Isotope Ratios: The Late Stone Age Site of Kasteelberg (South Africa)

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Timing of birth of domestic animals is regulated by environmental and genetic variables, and can also be manipulated by the herder. For this reason it is difficult to predict birth distribution in a prehistoric context. Birth seasonality of prehistoric sheep from the site of Kasteelberg, South Africa, was investigated by high resolution intra-tooth analysis of enamel oxygen isotope ratios. The results show two birth seasons, probably in autumn and spring. This may reflect females lambing more than once a year, or subdivision of the flock into groups where births were scheduled at different times of the year. This result has important implications for food availability throughout the year, the role of sheep in the subsistence economy, residential mobility strategy of the human community and use of sheep mortality profiles for interpretation of season of occupation of archaeological sites. © 2002 Elsevier Science Ltd. All rights reserved.

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Introduction

Birth seasonality of livestock is an important element of pastoralist subsistence economies. The season and distribution of births determine the availability of animal resources throughout the year (Dahl & Hjort, 1976). The birth season inaugurates a period when females are lactating. It also can be a season of meat availability due to natural death or slaughter of the young. Meat production is not necessarily the primary purpose of slaughter but can be the consequence of culling young for control of milk production and/or adjustment of herd size (Payne, 1973; Helmer, 1991; Halstead, 1998). Better knowledge of livestock birth management in prehistoric pastoralist societies would provide valuable information on seasonal composition of diet and help to understand the complementarity of different livestock species. It would also aid in the interpretation of mortality profiles in terms of seasonality of slaughter and/or occupation of site, which relies on the assumption that births were restricted to a single season.

In a prehistoric context, where there is no direct evidence of livestock birth distribution, it is legitimate to assume that within a species, births are generally restricted in time and occur within a period of the year when climatic conditions do not compromise survival of the young and grazing conditions are favourable to the female, whose energy requirements are highest during lactation (Clutton-Brock *et al.*, 1989). A long-term behavioural study of primitive domestic animals breeds under free range conditions in the natural environment of the Marais Vernier (Northern France)

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has shown that Shetland sheep and Highland cattle parturition times tend to be restricted to a few months of the year. Shetland sheep give birth from mid-March to the end of April, when short tender grass is available. Highland cattle, which favour taller vegetation, give birth later, from May to the end of July (Lecomte & LeNeveu, 1986).

Seasonality of birth is due to a cycle of fertile and infertile periods. Anticipation of the most appropriate time of the year for survival and synchronization of the fertile period to this time is dictated by environmental variables. Experimental studies on sheep have shown that photoperiod is the most important environmental factor determining the timing of the breeding season (Hafez, 1952; Legan *et al.*, 1977; Karsch *et al.*, 1984). The seasonal cycle of day length regulates the neuroendocrine mechanisms underlying the reproductive cycle, and sets both the timing and the duration of the breeding season (Karsch *et al.*, 1984). The breeding season appears to be longer at lower latitudes, where it can sometimes extend over almost the whole year (Hafez, 1952). Cattle and goats are less seasonal breeders than sheep (Dahl & Hjort, 1976; Goodman & Karsch, 1981). Unlike the sheep, the cow does not have a true anoestrous season, however its fertility varies throughout the year (Hammond *et al.*, 1971). This explains why in cattle, although births can occur all the year round, most of them tend to occur within a few months, even under uncontrolled breeding (Dahl & Hjort, 1976; Bailey, 1982; Lecomte & LeNeveu, 1986).

The question of the duration of the breeding season is especially relevant when small stock is considered. Sheep and goats have a short gestation and become receptive soon after parturition. In the case of an extended breeding season, it is possible for them to give birth twice a year, or more generally three times in two years (Dahl & Hjort, 1976; Quittet, 1976). This reproductive capacity differs between breeds (Hafez, 1952; Quittet, 1976).

In addition to environmental limitations on the duration of the breeding period, the spread of births among domestic animals can be manipulated by the herder. When control of the reproduction cycle is exercised, the herder's choice to restrict or to extend the period of births in his flock depends on several factors, including (1) herd size, (2) choice of breeding partners, (3) management of food availability, and (4) residential mobility strategy of the human community.

(1) Herd size may influence birth management strategies. Because the young need intensive care, asynchronous births are easier to manage in a small herd than in a larger one. In the case of a large flock, the herder may choose to concentrate the required effort by restricting the breeding season, in order to reduce time conflicts with tasks at other times of the year (Digard, 1981).

(2) Careful control of the quality of breeding (choice of mates) can also indirectly lead to restriction of the mating period and of the number of gestations per

Figure 1. Maasai herders control the reproductive activity of their sheep by tying an apron in front of the males' genitals, which prevents mating (photo by M. Balasse).

year: effort is sometimes made to prevent a female from a second gestation within a year, because it could put a strain on her health (Dahl & Hjort, 1976; Bernus, 1988; Mace, 1993). Breeding can be controlled by separation of males and females (Barth, 1961; Mace, 1993), by preventing sexual excitement of the male by tying the penis to the scrotum (Bernus, 1988; Hjort af Ornäs & Dahl, 1991) or, in small stock, by preventing mating by tying a large apron in front of the males' genitals, as is currently practised among the Maasai herders of Kenya (Figure 1).

(3) When a major concern is sustaining food availability throughout the year, the spread of births in a small flock can be easily managed. A large flock can also be divided into several groups and births scheduled at different times of the year so food resources (essentially milk) are more evenly distributed over time (Cranstone, 1969).

(4) The residential strategy of the herding community is another important element in birth management. Vulnerability of both young animals and lactating females make them bad candidates for long distance mobility. Animals born during a long distance settlement relocation would have to be transported on top of the belongings for a few weeks (Barth, 1961). Nomadic pastoral societies sometimes have to schedule the births to move camp when the young and the females are strong enough to endure this sometimes difficult experience (Barth, 1961; Digard, 1981; Bernus, 1988).

Given the number of environmental, genetic, cultural and economic factors that may influence the breeding cycle of domestic animals, the distribution of births throughout the year is not easily predictable in prehistoric flocks. Different methods have been proposed to assess seasonality of death from tooth remains, including analysis of seasonal increments in dental cementum (Lieberman, 1994) and analysis of tooth development stage (Carter, 1998). The latter method relies on the assumption of seasonal births.
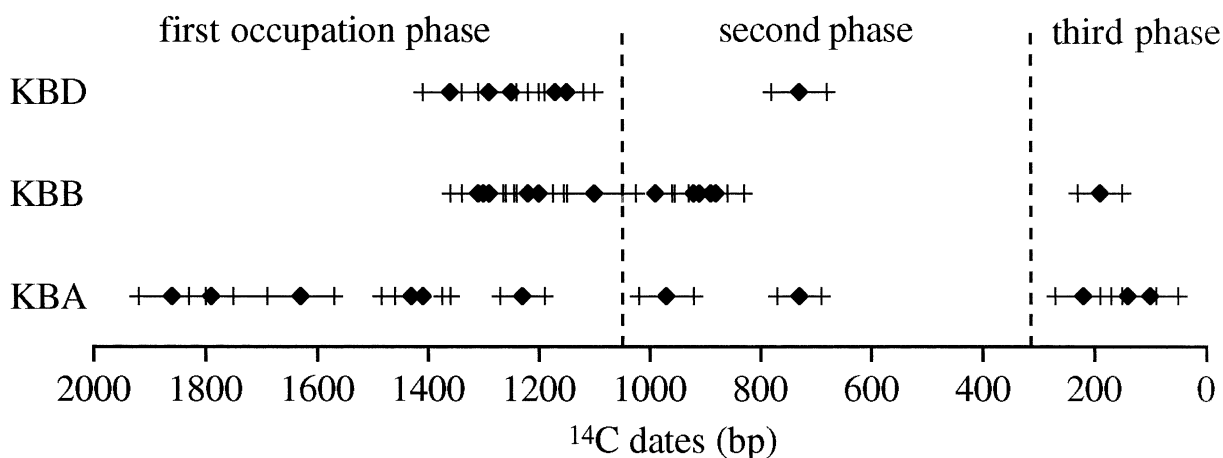
Figure 2. Distribution of radiocarbon dates and occupation phases at Kasteelberg pastoralist sites A, B and D.

The chronology of linear enamel hypoplasia might be very useful in establishing birth seasonality in domestic pigs (Dobney & Ervynck, 2000). However, none of these methods has been proven useful in assessing seasonality of birth in domestic bovids. Isotope analysis of domestic animal teeth can help to deal with this important issue.

Isotopic signatures of birth seasonality

Birth seasonality can be investigated by analysis of oxygen isotope ratios in teeth. Tooth mineral (hydroxylapatite, hereafter referred to as bioapatite) carbonate and phosphate oxygen precipitates in isotopic equilibrium with body water. Body water tracks the oxygen isotope composition ($\delta^{18}O$) of meteoric water (Land *et al.*, 1980; Longinelli, 1984; Luz *et al.*, 1984), which in turn is linked to local temperature. Some of the water ingested is obtained from plants, and the oxygen isotope composition of plants also tracks that of meteoric water and temperature (Sternberg, 1988; Flanagan & Ehleringer, 1991). In mid- and high latitudes, the highest $\delta^{18}O$ values occur during the warmest months and the lowest values during the coldest months (Gat, 1980). Tooth enamel bioapatite has been shown to be fairly resistant to diagenetic alteration (Lee-Thorp *et al.*, 1989; Lee-Thorp & van der Merwe, 1991).

In their study on mastodons and mammoths dentine, Koch *et al.* (1989) have shown that seasonal changes in environmental oxygen isotope composition is recorded in dentine bioapatite and is not erased subsequently by internal physiological processes. A number of studies of variability in oxygen isotope composition of enamel bioapatite within a tooth row (Bryant *et al.*, 1996a; Bryant *et al.*, 1996b; Fricke & O'Neil, 1996) or within a tooth (Sharp & Cerling, 1998; Fricke & O'Neil, 1996; Kohn *et al.*, 1998; Gadbury *et al.*, 2000) have shown that enamel also tracks such seasonal changes. In a study of fossil equid populations, Bryant *et al.* (1996a, 1996b) have observed

distinct patterns of variation in oxygen isotope ratios within a tooth row, due to differences in the timing of enamel mineralization. These whole-tooth data are interpreted as reflecting different seasons of birth. Because the mineralization of a tooth may span several seasons, a more accurate estimate of birth seasonality can be obtained by examining the patterns of variation in oxygen isotope ratios during the development of a tooth. Our high resolution intra-tooth isotope analysis of sheep from the archaeological site of Kasteelberg, Cape Province, South Africa, clearly shows seasonality of tooth development.

The Site of Kasteelberg

Kasteelberg is a large granite inselberg on the Vredenburg Peninsula (south-western Cape, South Africa), 4 km from the Atlantic Ocean coast. Its topographic setting, location near the coast, and the surrounding pastures made the site an attractive place for human occupation (Smith, 1992). The site has produced a long sequence of occupations by Late Stone Age pastoralist societies over the last two millennia (Smith, 1987a).

Three principal Late Stone Age open-air middens have been excavated: Kasteelberg A (KBA), Kasteelberg B (KBB) and Kasteelberg D (KBD). Occupation of KBA, KBB and KBD overlap in time (Figure 2). KBB has three main occupation horizons: the first is dated to *c.* 1300–1100 BP, the second to *c.* 990–880 BP and the last to *c.* 190 BP. KBA has produced older radiocarbon dates, *c.* 1860–1430 BP, but ceramic evidence shows that KBA mainly overlaps culturally with the bottom of KBB (Sadr & Smith, 1991). There are indications of limited occupation at KBA at the same time as the second and third occupations at KBB, *c.* 900–700 BP, and then *c.* 200 BP. KBD was occupied mainly during the first occupation phase of KBB, *c.* 1360–1150 BP (Smith, 1987a, 1992; Sealy & Yates, 1994).

The faunal assemblage is dominated by seals and sheep, indicating that human foraging and herding activities focused on these two species. This suggests that the site functioned as a stockpost and a sealing station. Mortality profiles of the faunal assemblage suggest that sheep flocks were managed to maximize meat and milk production. Cattle bones occur in deposits post-dating 1300 BP, but are relatively rare (Klein & Cruz-Uribe, 1989).

Klein & Cruz-Uribe (1989) and Cruz-Uribe & Schrire (1991) both assumed that Kasteelberg sheep had a single birth season, in late winter/early spring. However, European observers noted two lambing seasons for Khoekhoe indigenous sheep, while imported European breeds reproduced only once a year. At the beginning of the eighteenth century, Kolb (1968) describes a system where rams and ewes are herded together all the year round, with apparently no control of the reproduction cycle by the herders. This would have resulted in females lambing twice a year. Great caution is required when referring to descriptions by eighteenth century European observers, whose reports often perpetuated the medieval, non-civilized image of the Khoekhoen (Smith, 1993), especially when the idea of no control of reproduction of the flock fits well with the concept of savagery. However, two lambings a year was also observed in the first half of the eighteenth century by Mentzel (1944), whose description can be considered more objective (Smith, 1993). Whether prehistoric sheep at Kasteelberg had one or two seasons of birth has been assessed by isotope analysis of sheep teeth.

Material and Methods

Sheep second (M2) and third (M3) molars were chosen for isotope analysis. High crowned teeth were selected in order to obtain the longest temporal sequence. Eight individuals were sampled, including one from KBA, three from KBB and four from KBD. Three individuals furnished both M2 and M3. The sheep teeth from KBB come from the test pit and could not be attributed to a specific phase of occupation; the mandible from KBA comes from a unit contemporaneous with the first occupation of KBB; the specimens from KBD are all contemporaneous with the first occupation of KBB. The small sample size was imposed by the paucity of appropriate specimens in the faunal assemblage, and by the large number of isotopic samples per specimen. In total, 265 isotopic analyses of bioapatite are presented in this study. Carbon, oxygen and strontium isotope analyses of sheep, cattle, steenbok and eland from Kasteelberg, performed to evaluate seasonal mobility models, are presented elsewhere (Balasse *et al.*, 2002).

The sample set includes left, right, upper and lower teeth. The presence of left and right teeth is unlikely to increase variability in estimates of timing of birth
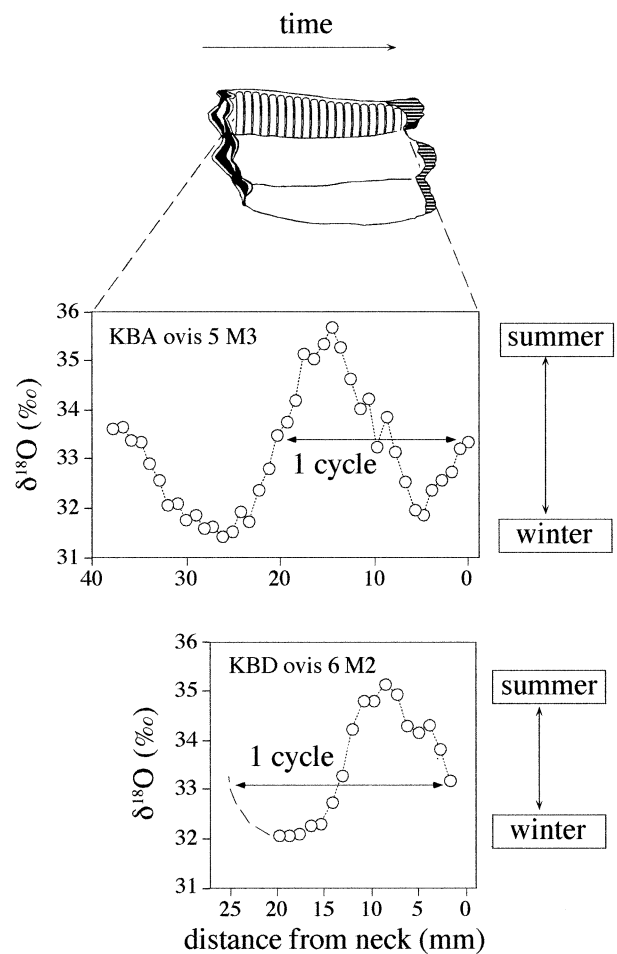

Figure 3. Sequential sampling of enamel along the tooth, and intra-tooth variation in oxygen isotope ratios ($\delta^{18}O$) of enamel bioapatite. One seasonal cycle is recorded in the second molar (M2), two in the third molar (M3), which corresponds to the duration of mineralization of these teeth.

because they have the same timing of growth. The left and right lower M2 of one modern goat from Kenya have almost identical patterns of isotopic change (Balasse, unpublished data). There may be a slight offset in timing of growth of upper and lower teeth, especially in the third molar, if observations on goats (Bullock & Rakham, 1982) are valid for sheep. This will have to be considered when comparing upper and lower third molars. Enamel sampling was always performed on the posterior (distal) loph of the M2; the M3 was sampled on the anterior (mesial), middle or posterior loph.

Tooth surfaces were cleaned with a tungsten abrasive drill bit. A sequence of horizontal bands of enamel was sampled from the top to the bottom of the crown (Figure 3) through the whole enamel layer using a diamond drill. Up to 29 samples were obtained from a second molar (crown height=28 mm) and 40 samples from a third molar (crown height=39 mm). This sampling strategy crosscuts the appositional features in

enamel. Enamel mineralization is a complex discontinuous process during which successive fronts of mineralization proceed in different directions (Suga, 1982). Although the procedure applied in this study does not sample truly discrete amounts of time, the chronological order of seasonal change is preserved. Each sample includes some material mineralized after completion of mineralization of the previous sample and some material mineralized before completion of mineralization of the following sample. As long as this sampling strategy is applied consistently to all the individuals, this approach succeeds in identifying inter-individual variability. Inter-individual variability in the pattern of variation of $\delta^{18}O$ values along the tooth crown has been estimated using the neck of the tooth as a reference point for measurement, because it is the only fixed ontogenetic point.

Each sample consisted of 5 to 10 mg of enamel powder. The powder was treated with 2·5–3% NaOCl (0·1 ml solution/mg sample) for 24 h to remove organic matter, rinsed five times with distilled water, and reacted with 0·1 M acetic acid (0·1 ml solution/mg sample) for 4 h to remove diagenetic carbonates, rinsed five times with distilled water and freeze-dried. This treatment induced a weight loss of approximately 40% (Balasse *et al.*, 2002). Enamel powder samples weighing 600 to 750 µg were reacted with 100% phosphoric acid at 70°C in individual vessels in an automated cryogenic distillation system (Kiel III device), interfaced to a Finnegan MAT 252 isotope ratio mass spectrometer. The analytical precision for the oxygen isotope composition of CO_2, estimated from 30 analyses of the NBS-18 standard, is better than 0·1‰. Kasteelberg archaeological enamel samples, when analysed twice, show a mean difference in oxygen isotope composition of only $0·14 \pm 0·12$‰ ($n=26$).

Results

A bimodal distribution of births

Results of oxygen isotope analysis are shown in Table 1 and Figure 4. The cyclic variation in $\delta^{18}O$ values of enamel bioapatite along the teeth reflects the seasonal cycle. The highest $\delta^{18}O$ values are reached during the summer months and the lowest ones during the winter months. One annual cycle is recorded in the second molar; almost two annual cycles are recorded in the third molar (Figure 3). This observation is in agreement with radiographic data on the duration of formation of these teeth, which show one year for M2 and two years for M3 (Weinreb & Sharav, 1964).

Two distinct patterns of cyclic variation are observed in both the second and the third molars. Group A comprises ovis 2, 4, 5 and 7; group B comprises ovis 3, 6, 8 and 9. The pattern of variation of isotope ratios along M2 and/or M3 is the same within each group, but differs between the two groups (Figure 4). This dichotomy is not a sampling artifact. It does not

correspond to an upper/lower tooth distinction: both patterns are observed among the upper second molars (ovis 2 & 7: group A, ovis 8 & 9: group B), among the lower second molars (ovis 5: group A, ovis 9: group B), among the upper third molars (ovis 2: group A, ovis 3: group B) and among the lower third molars (ovis 4 & 5: group A, ovis 9: group B). Nor does it correspond to the choice of the loph sampled: the second molars were all sampled on the posterior loph. From its second molar, it is not clear whether ovis 5 belongs to group A or B: values recorded in the first half of this crown are similar to those measured in group B whereas those from the second half of the crown fit with group A. From the third molar however, ovis 5 clearly belongs to group A (Figure 4). Such uncertainties in attribution could be due to inter-individual variability in the timing of tooth development. They justify a rigorous statistical treatment of the data.

Statistical evaluation of bimodality

Statistical tests were performed in order to determine whether groups A and B are significantly different. Measures of $\delta^{18}O$ and distance from the tooth neck were plotted bivariately. We used nonparametric loess regression (Efron & Tibshirani, 1993; Wilkinson, 1999) to analyse the relationship between variables. Nonparametric regression describes relations between variables without reference to a particular function (linear, quadratic, polynomial, etc.). Specifically, loess regression locally smoothes overlapping portions of data scatter, then joins these segments to generate a regression line throughout the entire data scatter.

Traditional estimates of errors are not possible with nonparametric regressions. However, confidence intervals for nonparametric regressions can be calculated using bootstrapping algorithms (Wilkinson, 1999). Bootstrapping provides confidence intervals based on resampling (with replacement) of the original data (Efron & Tibshirani, 1993). We generated bootstrapped confidence intervals by calculating loess regressions on 100 subsamples of the original data. The resulting 100 regression lines estimate a range of regression lines that represents a range of possible positions for the population regression line. In other words, the true population regression line is likely to fall along points within this scatter, and unlikely to fall outside the scatter. It should be noted that bootstraps do not represent prediction intervals on individual data points.

Bootstrapping allows us to ascertain whether or not groups A and B differ significantly in the pattern of change in oxygen isotope ratios. If changes in groups A and B are not statistically distinguishable, then bootstrapping should yield confidence intervals for each group that cannot be easily separated. In other words, the lack of a significant difference between groups should be reflected by confidence intervals with extensive overlap. Results of the test show minimal overlap

Table 1. Oxygen isotope ratios ($\delta^{18}O$) of tooth enamel bioapatite. Samples are listed from the top to the bottom of the crown in the chronological order of formation

$\delta^{18}O$ (‰) of enamel bioapatite										
M2						M3				
Ovis 2	Ovis 5	Ovis 6	Ovis 7	Ovis 8	Ovis 9	Ovis 2	Ovis 3	Ovis 4	Ovis 5	Ovis 9
33·2	32·4	32·1	33·7	34·0	31·8	34·2	31·9	30·5	33·6	34·3
33·2	32·6	32·1	34·5	34·0	32·2	33·2	31·7	30·9	33·7	34·1
32·7	32·4	32·1	34·9	33·4	32·8	33·1	31·1	30·7	33·4	34·5
33·3	32·4	32·3	35·1	33·2	32·6	32·6	31·2	30·4	33·3	33·9
32·7	32·9	32·3	35·4	33·8	33·1	32·5	31·5	31·4	32·9	34·0
32·8	32·8	32·8	35·6	34·0	33·4	31·9	31·5	30·6	32·6	34·1
32·8	32·8	33·3	35·6	33·8	34·1	31·9	31·7	32·0	32·1	33·8
32·4	32·7	34·2	35·7	34·1	33·8	31·3	31·6	31·8	32·1	33·6
32·0	32·9	34·8	35·5	34·7	34·4	31·6	32·1	31·7	31·7	33·6
32·1	33·1	34·8	35·2	34·4	34·7	31·0	32·0	32·6	31·9	33·3
32·0	32·6	35·2	35·1	35·4	34·5	30·1	31·5	32·7	31·6	32·9
32·7	33·0	34·9	34·1	35·3	35·0	30·5	31·6	32·8	31·6	33·1
32·7	33·3	34·3	34·2	35·4	34·5	31·3	31·5	32·8	31·4	32·9
32·9	34·2	34·2	33·1	35·1	34·5	32·4	31·3	32·6	31·5	32·6
33·1	33·6	34·4	33·2	34·7	34·2		32·0	32·8	31·9	32·6
33·1	34·3	33·8	32·5	34·6	34·2		32·2	32·7	31·7	32·4
34·7	34·1	33·2	32·4		34·0		32·8	33·1	32·4	32·5
	34·3		31·8		33·5		33·5	32·8	32·8	32·8
	34·3				33·2		33·3	33·8	33·5	32·8
	34·5				33·0		33·4	32·3	33·7	32·9
	33·9				32·8		33·1	32·4	34·2	32·9
	33·7				32·5		32·1	31·6	35·2	33·4
	32·9						31·1	31·9	35·0	33·3
	32·2						30·7	31·5	35·4	33·6
	32·1							30·8	35·7	34·3
	31·9							31·3	35·3	34·4
	31·5							30·8	34·6	34·2
	32·2							30·2	34·0	34·0
	32·5							30·4	34·2	33·6
								30·0	33·3	32·6
								30·0	33·8	32·2
								30·9	33·2	32·0
								30·1	32·5	31·1
								30·9	32·0	
								31·2	31·9	
									32·4	
									32·6	
									32·7	
									33·2	
									33·3	

between confidence interval of groups A and B, which means that groups A and B differ significantly (Figure 5).

At the age when the latest part of the second molar was being formed, sheep from group A recorded a winter isotopic signal (the lowest $\delta^{18}O$ values). At the same age, sheep from group B recorded a summer isotopic signal (the highest $\delta^{18}O$ values). Similarly, at an age when the latest part of the third molar crown was being formed, sheep from group A recorded a winter isotopic signal, whereas sheep from group B recorded a summer isotopic signal (Figure 4). The timing of tooth development is under strong genetic control within a species. Inter-individual variability in tooth growth rate does exist and probably resulted in slight differences in the pattern of variation between individuals within group A and within group B. However, it is unlikely that inter-individual variability in the timing of tooth development led to differentiation into the bimodal distribution of isotope values observed between groups A and B. A reasonable explanation is that these two groups began their ontogenetic trajectories in different seasons, which means that they were born at different periods of the year.

Discussion

Significance of the sample

The relevance of this study in terms of birth seasonality at the site depends on the significance of the sample. Considering our sample as representative of a
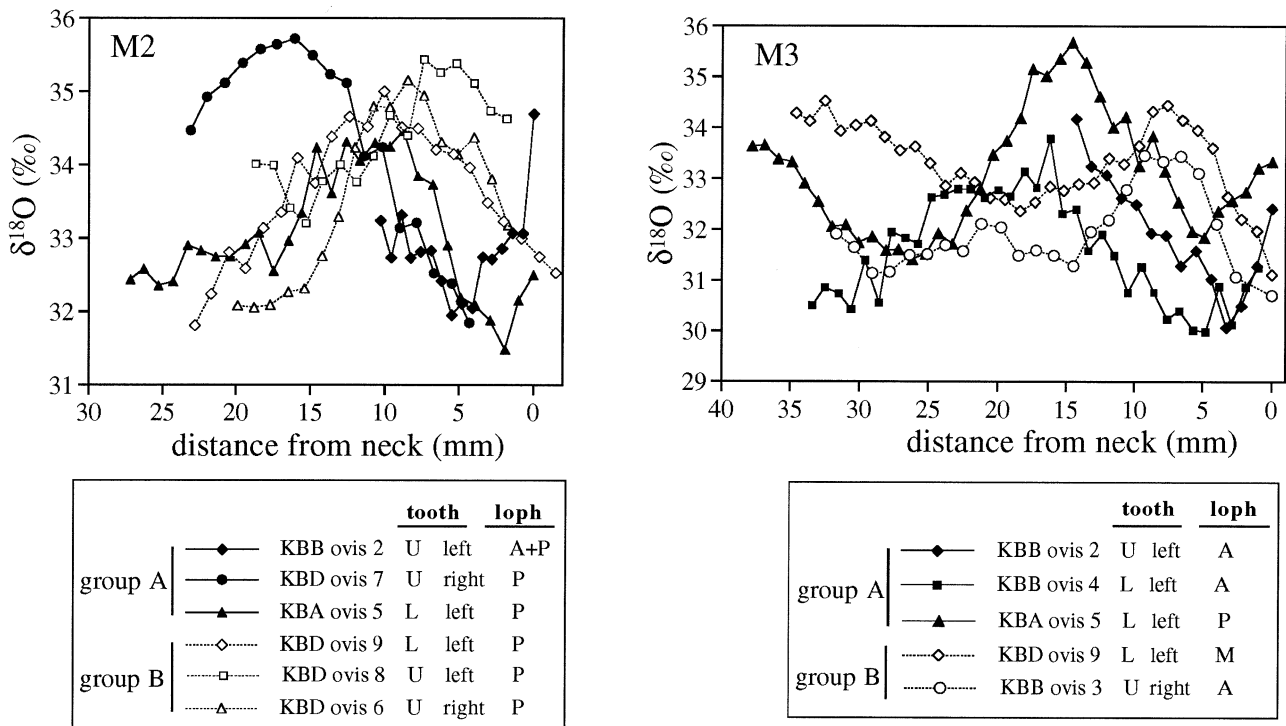
		tooth	loph
group A	KBB ovis 2	U left	A+P
	KBD ovis 7	U right	P
	KBA ovis 5	L left	P
group B	KBD ovis 9	L left	P
	KBD ovis 8	U left	P
	KBD ovis 6	U right	P

		tooth	loph
group A	KBB ovis 2	U left	A
	KBB ovis 4	L left	A
	KBA ovis 5	L left	P
group B	KBD ovis 9	L left	M
	KBB ovis 3	U right	A

Figure 4. Intra-tooth variation of oxygen isotope ratios ($\delta^{18}O$) of enamel bioapatite. The neck is defined as the point where the roots diverge; samples with negative abscissa values were drilled below this point. Sheep form two groups (groups A and B) according to the pattern of variation of $\delta^{18}O$ values. Anatomical identification of each tooth is given (U=upper, L=lower tooth) with location of the sampling (A=anterior loph; P=posterior; M=middle).
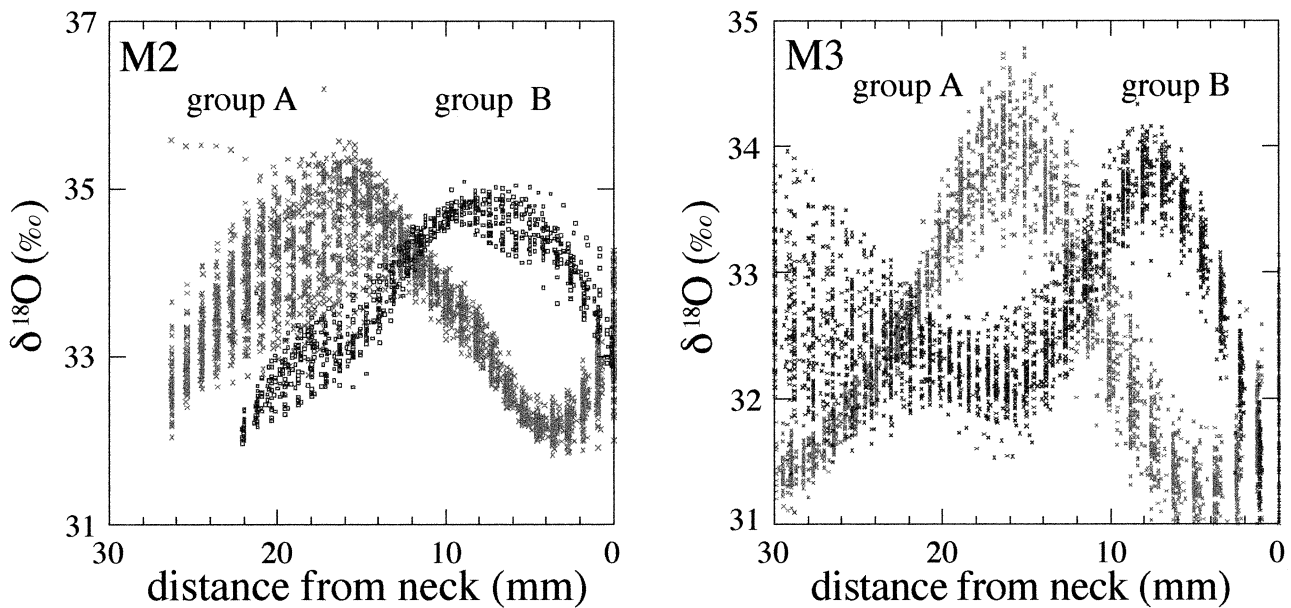

Figure 5. Non-parametric (loess) regression with bootstrapped confidence intervals (100 subsamples).

population (herd) would presuppose (1) that the individuals involved in the study are contemporaneous, and (2) that they do not include individuals from environments with different patterns of seasonality, for example animals acquired by long distance exchange.

(1) The first assumption is very rarely true about archaeological bone assemblages, which can result from centuries of activities and should be considered palimpsests of populations. Occupation of Kasteelberg spans centuries, and our sample represents at best a

diachronic population. However, it is unlikely that the observed difference in lambing season corresponds to a change in birth management practices through time because both lambing seasons are observed at Kasteelberg D, whose occupation horizon can be considered as a single cultural and economic unit. The presence of different patterns of variation of $\delta^{18}O$ values in KBD specimens proves that two lambing seasons are not an artifact of temporal mixing.

(2) The presence of animals obtained by exchange is suspected at Kasteelberg. Results of strontium isotopic analyses of Kasteelberg animal teeth suggest some individuals, including a sheep (ovis 2) and a cow, fed in another grazing area during their youth (formation of M2). These animals might have been incorporated later in the herd after acquisition by exchange (Balasse *et al.*, 2002). However, difference of provenience is unlikely to be the cause of the observed bimodality in birth season. Despite the relatively small number of individuals included in this study, they are equally distributed in the two groups, and a difference of birth season due to difference of provenience would assume 50% of exchanged individuals in the herd. Such a high proportion of exogenous input to a herd can occur in traditional pastoral societies, via gifts, social payments, purchases and temporary loans (Goldschmidt, 1986). This would imply acquisition of animals from environments different enough from the south-western Cape for the main period of birth to be dramatically shifted. A marked environmental change does indeed exist between the winter rainfall area of the south-western Cape, where Kasteelberg is, and the summer rainfall area in the tropical interior of the continent. However, 400 km separate the site from the summer rainfall area and 300 km from the intermediate rainfall zone. Exchange of small stock over such long distances would have been unlikely during prehistoric times. The strontium isotopic data indicates ovis 2 fed on geological substrates that could be found as close as 50 km away (Balasse *et al.*, 2002). For these reasons we consider that two seasons of birth potentially occurred in the same herd.

Lambing seasons
The two periods of birth in these prehistoric sheep were offset roughly by half an annual cycle, or two seasons (Figure 4). The *seasons of birth* cannot yet be accurately established from the isotopic data, because the timing of tooth development in sheep has not been precisely documented, and because recent studies suggest that the time resolution of the isotope signal in enamel bioapatite might be influenced by the duration of enamel mineralization (Fisher & Fox, 1998; Balasse, 1999; Balasse, 2002). Controlled feeding experiments have established the timing of enamel mineralization relative to birth for modern cattle (Balasse, 1999; Balasse, 2002). Similar experiments using African sheep breeds are needed to accurately identify birth seasons in Kasteelberg sheep.

The presence of neonatal and/or very young sheep in the faunal assemblage (Klein & Cruz-Uribe, 1989) suggests that Kasteelberg was a lambing area. A hypothesis for the optimal seasons of birth at this site can be proposed after examination of the local vegetation dynamics. Kasteelberg is surrounded by renosterveld, a type of Mediterranean shrubland. The ground stratum (grasses and herbs/forbs) of this plant community sprouts with the autumn rains (Specht *et al.*, 1983). A late autumn birth would have been the most propitious for the feeding of both growing lambs and lactating females on the late autumn/early winter pastures. This is confirmed by the present owner of Kasteelberg, Mr P. Kotze, who uses the hill as his "maternity ward" during the lambing season in late autumn (May).

If autumn was one of the two seasons of birth, and if the two seasons of birth were separated by half a year, the second period of birth would have occurred in spring. The annual growth cycle of the renosterveld grass cover is not completed until the end of spring, which is also the season of shrub shoot growth (Specht *et al.*, 1983). Although preferentially grazers (grass-eaters), South African sheep also include some browse (bushes and forbs) in their diet (Owen-Smith & Danckwerts, 1997). Spring could be considered as a plausible lambing season, although probably less favourable to sheep than a late autumn birth.

Birth management and consequences for subsistence
Historical sources mention two lambings per year for South African indigenous sheep (Mentzel, 1944; Kolb, 1968). The minimum possible interval between lambings is slightly more than six months, including a five-month gestation and six weeks before receptivity re-occurs (Dahl & Djort, 1976; P. Kotze, pers. com.). The isotope data indicate two birth seasons separated by roughly six months, which could be in agreement with the historical reports of two lambings per year.

Sheep breeds lambing twice a year are not rare and have been reported in various parts of the world (Hafez, 1952; Quittet, 1976; Dahl & Hjort, 1976). It should be noted, however, that a system where ewes would give birth twice a year is a risky strategy over the long-term. Repeated gestations can strain the health of the females, and make them weak and more susceptible to disease and predation by carnivores. This could ultimately impact negatively on flock size and fertility. Such a strategy would have required very careful control and sometimes restriction of births. Rather than two lambings per year, we could reasonably envision three lambings over two years, as occurs more generally nowadays (Dahl & Hjort, 1976; Quittet, 1976). Three lambings over two years could have easily been mistaken for two lambings per year by eighteenth-century European observers.

Two seasons of birth could alternatively be explained by subdivision of the flock into two groups,

with planning of two birth periods in order to spread the birth and lactations events (Cranstone, 1969), which would imply one birth per sheep per year.

Whether bimodal birth seasonality was due to more than one lambing a year, or two groups of females giving birth at different times, one important consequence of two birth seasons would have been extension of the period of milk availability. This suggests that sheep may have played a dominant role in the subsistence economy of these pastoral groups.

Two seasons of birth for Kasteelberg sheep also has important implications for the interpretation of the mortality profile. It has been suggested that prehistoric pastoral communities of the south-western Cape might have led a nomadic way of life, similar to that of their historic descendants (Smith, 1984, 1987b). From examination of seal and sheep mortality profiles, Klein & Cruz-Uribe (1989) concluded there was a seasonal occupation of Kasteelberg B. Interpretation of the sheep mortality profile might have to be reconsidered because it assumed a single birth season whereas our results suggest that there were two.

In any faunal assemblage that includes individuals born in different seasons, demonstration of non-occupation of the site at a certain period of the year based on identification of gaps in the mortality profile might be extremely difficult due to the uncertainties in age attribution and therefore the width of age classes. Even in the case of a seasonal occupation, animals born six months apart and slaughtered at the same time of the year would produce a mortality profile without clear gaps in age classes. At Kasteelberg B, seasonality of occupation was suggested from the bimodal distribution of the dP_4 crown heights (Klein & Cruz-Uribe, 1989). No clear gap separates the two modes. This should have precluded interpretation of the profile as reflecting seasonal occupation because no period of non-occupation can be shown if a single birth season is considered. The absence of a clear gap could be explained by the two lambing seasons. Even in that case however, a period of non-occupation of the site cannot be truly shown from the sheep dP_4 profile at KBB. From examination of seal mortality profiles based on mandible length as an age indicator (Woodborne et al., 1995), Woodborne concluded to two seasons of occupation in the middle horizon of Kasteelberg B (Woodborne, 1996). It could be envisaged that these two seasons of occupation were also the sheep birth seasons, and that the site was a preferred lambing area because its granite boulders could have created a protected space for the lambs, while the lactating females would have benefited from the good surrounding pastures.

The model of seasonal mobility for the prehistoric herders of the south-western Cape (Smith, 1984, 1987b) is not confirmed by an isotope study of Kasteelberg sheep teeth: long-term residence within the strandveld habitat is indicated, although more work needs to be done before we come to a solid conclusion

(Balasse et al., 2002). Two lambings per year does not preclude a nomadic way of life, but this could have reduced the degree of mobility of the human communities. Conversely, a high degree of mobility could have compromised survival of a higher number of young animals and reproductive adults.

Conclusions

Sequential sampling and analysis of intra-tooth cyclical variation in oxygen isotope ratios of enamel bioapatite has been shown to be of great use in establishing birth seasonality patterns in archaeological faunas. For this new methodology to gain general acceptance, studies on modern sheep and goats with known birth seasons are still warranted. They would be useful for mapping out the inter-individual variability within populations with a single birth season.

This technique has provided important information about sheep birth distribution at the Late Stone Age pastoralist site of Kasteelberg, although our conclusions must remain suggestive due to the small number of individuals analysed. The results indicate that sheep were lambing seasonally, and that there were two lambing seasons. These seasons were separated by approximately six months, and may have occurred in late autumn and spring. This timing of births could reflect either a system where rams and ewes are herded together all year round, mating more or less freely, resulting in more than one lambing a year, or control of the reproduction cycle with planning of two lambing seasons, with two cohorts, each giving birth once a year.

This result would have several consequences for (1) food availability, (2) methodology of faunal analysis and (3) residential strategy of the human community. (1) Two lambing seasons would have resulted in extension of the period of milk availability, suggesting that sheep may have played an important role in the subsistence economy of these communities. (2) Two lambing seasons have important implications for interpretation of the sheep mortality profile in terms of seasonality of occupation, which was based on the assumption that all sheep were giving birth at a single time of the year. (3) Two lambing seasons would have compromised, or have been compromised by, a high degree of mobility of prehistoric herders.

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