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KERATIN C AND N STABLE ISOTOPE RATIOS OF FOSSIL CATTLE HORN FROM KERMA (SUDAN): A RECORD OF DIETARY CHANGES

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RIASSUNTO - Analisi dell'abbondanza isotopica del C e dell'N nella cheratina delle corna di bue provenienti da Kerma (Sudan): un metodo per studiare le variazioni nella dieta.
Sono state eseguite 100 analisi su otto campioni di cheratina prelevata da corna di bue provenienti dalla necropoli di Kerma (Sudan). E' stata analizzata la composizione isotopica del carbonio e dell'azoto per vedere se la cheratina è in grado di registrare informazioni sulla dieta e sulle strategie alimentari del bue oltre alle condizioni ambientali locali. La composizione isotopica del carbonio indica che gli animali seguivano una dieta mista a base di piante sia C_3 che C_4 con una dominanza di piante C_3 durante l'inverno e di C_4 durante l'estate. La composizione isotopica dell'azoto indica un ambiente piuttosto arido durante il periodo "Classico" di Kerma (1750-1500 BC). Inoltre, la diminuzione graduale dei valori di $\delta^{15}N$ dalla parte esterna verso quella interna della sezione di cheratina, riflette probabilmente il periodo di svezzamento. I valori molto positivi di $\delta^{15}N$ sono probabilmente il risultato combinato di una condizione di aridità ambientale e del fatto che, durante il primo periodo di formazione della cheratina, l'animale si trova ad un livello trofico più elevato rispetto all'individuo adulto. Il confronto fra i campioni mostra sostanziali differenze isotopiche sia per quanto riguarda il carbonio che l'azoto. Questo fatto probabilmente indica che i vari individui sono stati allevati in aree differenti e che quindi appartenevano a mandrie diverse.

ABSTRACT - A set of 100 analyses was carried out on eight samples of fossil cattle keratin horn from the necropolis of Kerma (Sudan). They were analysed for their carbon and nitrogen stable isotope composition to check whether keratin horn can provide information on cattle diet and cattle feeding strategies besides those on local environmental conditions. The carbon stable isotope composition suggests that animals grazed a mixed C_3/C_4 pasture with a seasonal dominance of C_3 or C_4 plants. The weaning process is probably reflected by the gradual decrease of the nitrogen stable isotope values from the outer to the inner section of the horn keratin. The $\delta^{15}N$ values suggest very arid environmental conditions during the Classic Kerma period (1750-1500 BC). The strongly $\delta^{15}N$ enriched values obtained are the result of both an arid condition and of the higher trophic level of the animals during the beginning of keratin formation in comparison to adults. Different specimens exhibit different ranges of nitrogen and carbon isotope values, that probably indicate that the individuals were raised in different areas belonging to different herds.

Key Words: cattle, keratin horn, Kerma, nitrogen, carbon, stable isotopes
Parole chiave: bue, cheratina, Kerma, azoto, carbonio, isotopi stabili

1. INTRODUCTION

Mammal carbon and nitrogen isotope composition is potentially useful for diet and environmental reconstruction particularly when simple ecosystems are considered (DeNiro and Epstein 1978; DeNiro, 1987; Ambrose, 1991). Most stable isotope analyses of archaeological material are made on bone and/or tooth collagen because these are usually the best preserved animal skeletal remains: only few isotope data were obtained from other tissues. Despite additional fractionation when carbon and nitrogen are transferred from the producers through food webs, the consumers are generally enriched in ^{13}C and ^{15}N. Different tissues have a potential to determine diet for different time frames of an individual's life. Analysis of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of bone collagen reflect the isotope ratio signature of the average diet of an individual over the last 25-30 years of his life (e.g. Stenhouse and Baxter, 1979; Bender et al., 1981; DeNiro, 1987). The isotopic composition of other tissues, such as skin, hide and hair is representative of food eaten throughout a short time period before death (Tieszen et al., 1983; Katzenberg and Krouse, 1989). On the contrary, teeth record an isotopic signature of diet and environment only during the very beginning of the individual's life (Bocherens et al., 1994; 1995; Sealy et al., 1995; Hobson and Sease, 1998).

Isotopic analyses of small increments in certain tissues such as teeth and hairs can give information on the chronology of isotopic changes and this may have many potential archaeological and palaeoecological applications. For example, Jones et al. (1981) showed that in steers under controlled diet, the carbon isotope ratios of hair reflect the change from C_4 to C_3 and C_4 diet in sequence. Balasse et al., in press, also showed that in steers under controlled diet, $\delta^{13}C$ and $\delta^{15}N$ intra-tooth variation reflects the change from C_3 to C_3/C_4 diet and from the lactation to the adult diet. Multiple measurements carried out along the shaft of human hair suggested seasonal differences in consumption of C_3 and C_4 plants (White, 1993). Of the many different carbon- and nitrogen-bearing tissues, horn keratin too may potentially provide a continuous record of $\delta^{13}C$ and $\delta^{15}N$ changes during the keratin formation period. Because of seasonal changes in rainfall, humidity and temperature that affects forage, analyses of small growth increments in keratin horn may potentially reflect seasonal variations in diet that occurred over the span of its growth. $\delta^{13}C$ analysis for diet reconstruction in animals is based on the different photosynthetic pathway between C_3 and C_4 plant groups: temperate pasture species are C_3 plants and have $^{13}C/^{12}C$ ratios ranging from -37 to -21‰ (average -26‰) (Smith and Epstein, 1971; Vogel and Van der Merwe, 1978) whereas tropical pasture grasses are C_4 plants and have $^{13}C/^{12}C$ ratios ranging from -19 to -9.5‰ (average -12‰) (Bender, 1971; Smith et al., 1979).

The $\delta^{15}N$ values of animal tissues vary principally with the trophic level. However, at a given trophic level, the $\delta^{15}N$ vary also because of the influence of climate on the $\delta^{15}N$ of plants and soil and on animal physiology: a decrease in the total amount of precipitation and/or relative humidity causes a $\delta^{15}N$ enrichment (Cheng et al., 1964; Ambrose, 1986; Ambrose and DeNiro, 1986; 1987; Heaton, 1987).

The samples analysed in this study are keratin horn sheaths of fossil cattle specimens coming from the Kerma necropolis (Sudan) located on the right bank of the Nile (Fig.1). In this necropolis some of the tombs are surrounded by over 500 cattle bucrania including not only adult animals but also breeding females, young adults and very young calves (Chaix, 1982; Chaix and Grant, 1993). The age range of the cattle and the way that bucrania were placed round the tombs, suggest a simultaneous killing of a herd at the time of burial of an important personage. Excavation of town deposits has shown that cattle bone represent a significant proportion of the animals consumed whereas in the sub-desert condition of modern Northern Sudan, cattle form only a very small proportion of the livestock. The high proportion of cattle bones suggests a less arid climate than at

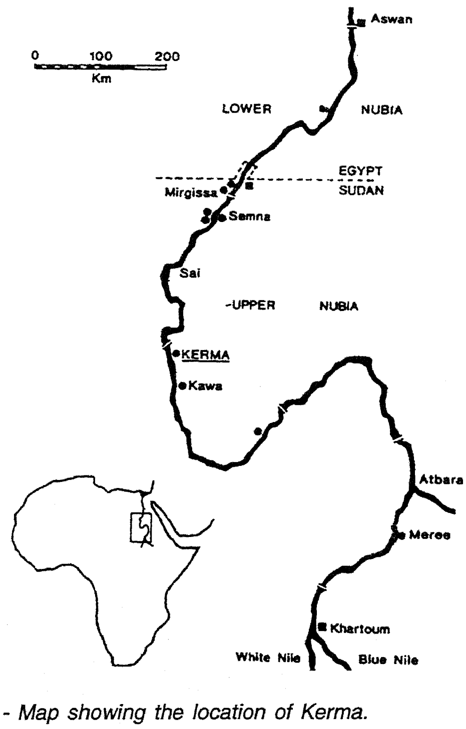

Fig.1 - Map showing the location of Kerma.

Fig.1 - Carta d'ubicazione di Kerma.

present, but there is evidence to suggest that cattle may have been brought to Kerma from other parts of the kingdom as a tribute to the death of some important man (Chaix and Grant, 1992).

The main purpose of this study was to see whether horn keratin can effectively be used to obtain information on seasonal diet changes and local environmental conditions and to determine, if possible, archaeological killing strategy.

2. SAMPLE AND ARCHAEOLOGICAL INFORMATION

Samples of keratin were removed from the bucrania (that is the horn, frontal bones and some times the nasal bones of the skull) of eight individuals curated at the Museum of Natural History of Geneva. All of these bucrania come from the necropolis close to the ancient town of Kerma. The beginning of the Kerma culture can be dated at about 2500 BC, almost contemporary with the Old Empire in Egypt. It flourished for approximately a millennium, its fall being around 1500 BC after the Egyptian conquest (Bonnet, 1981). The Kerma civilisation has been divided into three cultural phases: Ancient Kerma (2500-2050 BC), Middle Kerma (2050-1750 BC) and Classic Kerma (1750-1500 BC) (for a synthesis, Bonnet, 1990). In particular, the samples analysed are from two tombs, the No156 and No175, of the Classic period. They were analysed for their carbon and nitrogen stable isotope abundances and a total of 100 data were obtained.

Kerma now lies within a desert zone with an annual rainfall of less then 50mm per year, the vegetation being confined to the banks of the Nile river (Chaix and Grant, 1993). Palaeobotanical works carried out at several sites in the desert of the Northern Province suggested that the limit of desert during the third millennium BC was 400 km further to the north than at present (Jackson, 1957; Ritchie and Haynes, 1987; Neumann, 1989). This situation was probably related to the volume of water brought down during the annual Nile flood which was greater than at present, allowing much larger areas of land to be cultivated and areas of pasture for feeding of domestic flocks. Recent palynological analyses carried out on sheep and goat coprolites from the tombs suggested that arid environmental conditions existed 4,000 years ago: pollen of Urticaceae and Graminaceae was dominant along with several species of acacia, jujube and Cyperaceae (Taylor, unpublished report).

A good proxy exists for $\delta^{13}C$ values of modern plants along the Nile Valley in Egypt (Batanouny et al., 1988). C_3 plants decrease with decreasing latitude, being mainly represented by winter annual and perennial grasses active in winter, while summer annuals and other perennials are C_4 species. These vegetation formations could be transported in Sudan considering a greater proportion of C_4 plants.

The remains of domestic animals are very abundant and particularly cattle whose remains represent over 50% of the animal bones in the food refuse and in the necropolis some of the tombs are surrounded by over 500 bucrania (Chaix, 1982; 1984; 1988). The killing of such a large number of animals, particularly as they appear to include both breeding females and calves, suggest not only the production of a large surplus, but also the organisation and social control of a large population that provide the animals for slaughter (Chaix and Grant, 1993).

3. METHOD

To avoid contamination during the sampling procedure, latex surgical gloves were worn and a small drill was used to sample small portions of keratin horn before their placement in tin capsules.

The keratin horn specimens were sampled in sequence (from 9 to 19 times), approximately every 0.3mm, in function of horn thickness which vary from 2.5 to 5 mm, along the growth direction. The sampling was replicated 3 times on each horn section to be sure of the accuracy and reliability of the sampling procedure.

Nitrogen and carbon isotope composition was measured by means of a CHN elemental analyser on line with a VG Optima mass spectrometer. The analytical precision is 0.2‰ for $\delta^{15}N$ and 0.1‰ for $\delta^{13}C$ analyses. The stable isotope composition is reported as δ values in per mil:

δ = (Rsample/Rstandard -1)*1000

where R=$^{13}C/^{12}C$ for $\delta^{13}C$ values and $^{15}N/^{14}N$ for $\delta^{15}N$. The standards for reporting carbon and nitrogen measurements are VPDB for carbon and atmospheric N_2 for nitrogen.

4. RESULTS AND DISCUSSION

4.1 $\delta^{13}C$ values

The total range of $\delta^{13}C$ values for keratin horn is wide (-20.7 to -7.5‰) as it also is for $\delta^{15}N$ (8.9 to 16.2‰). The $\delta^{13}C$ intra-tissue variation ranges from 3 to 8‰ not much larger than the δ15N variation that ranges from 2 to 6‰ (Tab. 1; Fig. 2A,B; Fig. 3).

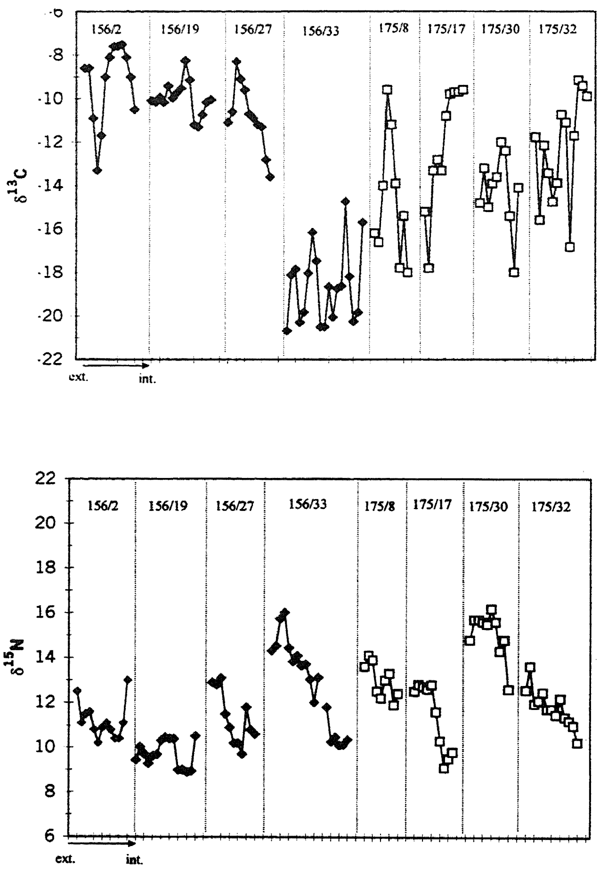

Fig.2 - The $\delta^{13}C$ (A) and the $\delta^{15}N$ (B) values of keratin horn samples from tomb 156 (diamonds) and tomb 175 (open square) analysed along the growth direction.

Fig.2 - Valori di δ13C (A) e δ15N (B) dei campioni di cheratina delle corna di bue provenienti dalle tombe 156 (diamanti) e 175 (quadrati vuoti) prelevati lungo la direzione di crescita.

156/2		156/19		156/27		156/33		175/8		175/17		175/30		175/32	
$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
-8.6	12.5	-10.1	9.4	-11.1	12.9	-20.7	14.3	-16.2	13.6	-15.2	12.5	-14.8	14.8	-11.8	12.6
-8.6	11.1	-10.2	10.0	-10.6	12.8	-18.1	14.5	-16.6	14.1	-17.8	12.8	-13.2	15.7	-15.6	13.6
-10.9	11.5	-9.9	9.7	-8.3	13.1	-17.8	15.8	-14.0	13.9	-13.3	12.7	-15,0	15.7	-12.2	12.0
-13.3	11.6	-10.2	9.3	-9.1	11.5	-20.3	16.0	-9.6	12.5	-12.8	12.6	-13.9	15.6	-13.4	12.1
-11.7	10.8	-9.4	9.6	-9.6	10.9	-19.8	14.4	-11.2	12.2	-13.3	12.8	-13.6	15.5	-14.7	12.5
-9.0	10.2	-10.0	9.7	-10.7	10.2	-18.0	13.8	-13.9	13.0	-10.8	11.6	-12,0	16.2	-13.9	11.7
-8.1	10.9	-9.73	10.3	-10.9	10.2	-16.2	14.1	-17.8	13.3	-9.8	10.3	-12.4	15.6	-10.7	11.7
-7.6	11.1	-9.53	10.4	-11.2	9.7	-17.5	13.6	-15.4	11.9	-9.7	9.1	-15.4	14.3	-11.1	11.5
-7.6	10.8	-8.2	10.4	-11.3	11.8	-20.5	13.7	-18.0	12.4	-9.7	9.5	-18.0	14.8	-16.8	12.2
-7.5	10.4	-9.1	10.4	-12.8	10.8	-20.5	13.0			-9.6	9.8	-14.1	12.6	-11.7	11.4
-8.1	10.4	-11.2	9.0	-13.6	10.6	-18.6	12.0							-9.2	11.2
-9.0	11.1	-11.3	9.0			-20.1	13.1							-9.4	11.0
-10.5	13.0	-10.7	8.9			-18.7	-							-9.9	10.2
		-10.2	9.0			-18.6	11.8								
		-10.1	10.5			-14.7	10.3								
						-18.2	10.5								
						-20.2	10.1								
						-19.8	10.1								
						-15.7	10.4								

Tab. 1 - $\delta^{13}C$ and $\delta^{15}N$ values of the keratin horn samples from tomb 156 and tomb 175.

Tab. 1 – Valori di $\delta^{13}C$ e $\delta^{15}N$ dei campioni di cheratina delle corna di bue provenienti dalle tombe 156 e 175.

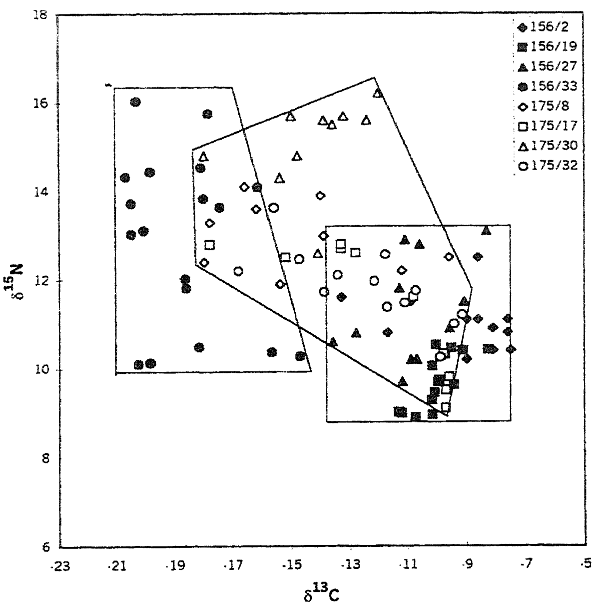

Fig.3 - $\delta^{13}C$ and $\delta^{15}N$ values of cattle keratin horn samples from tomb 156 (black symbols) and tomb 175 (open symbols). See text for the explanation of the three fields.

Fig.3 - Valori di $\delta^{13}C$ e $\delta^{15}N$ dei campioni di cheratina delle corna di bue provenienti dalle tombe 156 (simboli pieni) e 175 (simboli vuoti). Per la spiegazione dei tre campi indicati vedere il testo.

The difference between the $\delta^{13}C$ value of the diet and that of the keratin horn is not well known: there are no controlled-feeding studies which measured it, but from previous studies on keratin hair it appears to be between 1 and 2‰ (White, 1993; Jones et al., 1981; Minson et al, 1975; Tieszen et al, 1983). It is also of importance to assess, in case of a change in the animal's diet, the time period before keratin registers changes. It seems that cattle hair takes at least 74 days to equilibrate after a shift from C_4 to C_3 diet (Tieszen et al, 1983).

The data suggest that the animals grazed pasture composed of either C_3 species or C_4 grasses or both contemporaneously and, consequently, with variable $^{13}C/^{12}C$ ratios. Considering separately the different samples it is apparent that in the case of sample 156/33 the diet was dominated by C_3 plants with a minor C_4 plants contribution. On the contrary, the diet of samples 156/2, 156/19 and 156/27 was characterized by dominantly C_4 plants, the higher $\delta^{13}C$ values measured for C_4 grass in this region being closed to -10.3‰. The $\delta^{13}C$ values of the samples 175 indicate a mixed C_3/C_4 diet (Fig. 2A). The abrupt changes in $\delta^{13}C$ values found between the inner and the outer part of the keratin section suggest a seasonal effect on the cattle diet: a year-round shifting between C_3 and C_4 pasture which was probably related to the different mean temperature between winter and summer. Considering that the isotopic signal may take about two months to equilibrate after each dietary change, we roughly estimate that the negative peaks correspond to late winter and the positive peaks to late summer.

4.2 $\delta^{15}N$ values

The $\delta^{15}N$ values measured (up to 16‰) are considerably higher than those of modern and fossil herbivores from the Kerma area (from 4 to 8‰) (Iacumin et al., 1998) and, in general, than those of modern African herbivores (from 5 to 9.5‰) (Ambrose, 1986). Values higher than 10‰ were measured in South Africa in the case of modern herbivores from low-watered (<400 mm per annum of rain) environments (Sealy, 1987). They lie within the variation field of omnivore and carnivore species, in a trophic level higher than that of herbivores, and consequently ^{15}N enriched when compared to the herbivores living in the same area. High values for herbivores were found in wild ox (*Bos primigenius*) at the Paglicci cave (S. Italy) (Iacumin et al., 1997; 1999) and in mammoths from Siberia (Iacumin et al., 2000) but they approach only the value of 13‰. However, these two species systematically show the highest $\delta^{15}N$ values among the herbivores from the same area. These high values were interpreted as the effect of water stress either on the plants eaten or directly on the animals.

In the case of our samples the high $\delta^{15}N$ values measured suggest arid environmental conditions. Moreover, the Classic cultural phase coincided with an arid period (Schneider, 1984). The climatic deterioration led to the disappearance of the Kerma civilisation (Chaix and Grant, 1987). However, the $\delta^{15}N$ values are less variable than the $\delta^{13}C$ values and the variation pattern normally shows a gradual decrease in $\delta^{15}N$ from the outer (older) to the inner (more recent) part of the keratin section (Fig. 2B). This may be, at least partially, related to the weaning process, the cow's milk being ^{15}N enriched in comparison to their diet (Steele and Daniel, 1978; Koyama et al., 1984). It follows that the calves are in a higher trophic level close to that of carnivores. The modern growth rate of cattle horn is very fast during the first 20 months of a calf's life slowing down afterwards (Marmet, 1971). In temperate zones the horn growth rate seems quite fast during summer slowing down considerably in winter time. In sub-tropical areas the seasonal difference in the growth rate may be less important. This means that the keratin horn may record the entire period of lactation and weaning and this could be the cause, along with the arid environmental conditions, of the high $\delta^{15}N$ values measured.

4.3 Comparison among samples

As regards the carbon isotope values, the differences among the mean values of the samples from tomb 156 and tomb 175 are statistically significant (P<0.02). Within the two groups of samples only the couples 175/8 - 175/30 and 175/17 - 175/32 exhibit similar mean $\delta^{13}C$ values (P>0.68). As regards nitrogen, samples 156/19 and 175/30 have mean $\delta^{15}N$ values different from those of all the other samples (P<0.001). Only one couple of samples (175/17 = 175/32) (Fig. 2A,B; Fig.3) has both similar $\delta^{13}C$ and $\delta^{15}N$ mean values.

This probably means that the bucrania found around the two tombs belong to animals that were not raised in the same area. The number of cattle remains strengthens the possibility that cattle were sent to Kerma from many places within or beyond the kingdom as a tribute to the death of a powerful leader.

5. CONCLUSION

The following conclusions may be drawn based on the results obtained:

- keratin horn can provide information on cattle diet and record diet changes related to pasture seasonal variations. It can also provide information on local environmental conditions;
- the $\delta^{13}C$ values of keratin horn from Kerma suggest that animals grazed a mixture of C_3/C_4 pasture dominated by C_3 or C_4 plants according to seasonal changes. This seasonal effect on the cattle horn is shown by the $\delta^{13}C$ minima and maxima peaks in the isotopic patterns from the inner to the outer part of the keratin section;
- the progressive lowering of the $\delta^{15}N$ values probably reflects the weaning process. This means that keratin horn records preferentially the very beginning of the calf's life;
- the very high $\delta^{15}N$ values measured suggest arid environmental conditions;
- the high $\delta^{15}N$ values measured are probably related to the composite effect of arid environmental conditions and a higher trophic level of the young specimens during the beginning of the keratin formation;
- the less positive values (close to 9 ‰) measured in the more recent part of keratin, being close to the $\delta^{15}N$ values of modern African herbivores suggest local climatic conditions similar to the modern ones;
- the different ranges of C and N isotope values of the eight samples studied clearly suggest that the animals were not raised in the same area. They probably belonged to different herds and were brought to Kerma from many places.

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