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DETERMINATION OF SPECIES AND GEOGRAPHIC ORIGIN OF RHINOCEROS HORN BY ISOTOPIC ANALYSIS AND ITS POSSIBLE APPLICATION TO TRADE CONTROL

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ABSTRACT

The failure of the CITES ban to stop the illegal killing of rhinoceros for their horns, and the possibility of using horn from natural mortality among the growing populations in South Africa to promote the conservation of rhinos, is a subject of current debate. Because of the differing conservation status of the African and Asian rhinoceros species, and individual populations, a strict control of trade in the horn would be required. Such a control system is feasible if the species and origin of rhino horn could be independently established from small samples. Recent work on source-area determination of African elephant ivory indicated that isotopic analysis could provide such a method, because of differences in diet, rainfall and geology. We found that black and white rhinoceros horn could be definitively distinguished on the basis of $\delta^{13}C$ values alone. White rhinoceros, being grazers, yielded $\delta^{13}C$ ratios of -10.1‰ to -10.5‰ while black rhinoceros being browsers, yielded $\delta^{13}C$ ratios of -20.3‰ to -24.6‰ . Consideration of $\delta^{15}N$ and heavy isotope (strontium and lead) values indicated the area of origin of the samples.

INTRODUCTION

The banning of international trade in rhinoceros products by a CITES Appendix I listing in 1967 has failed to stop the trade in rhino horn (Cumming*et al.*, 1990). The continued slaughter of black rhinoceros *Diceros bicornis* for their horns is still a major threat to most populations outside of southern Africa. Even within the southern African region, where 90% of the continental black rhinoceros population and 99% of the white rhinoceros *Ceratotherium simum* population occurs, the illegal killing of rhinoceros remains a considerable threat.

By contrast, the rhinoceros populations of South Africa are relatively safe from poachers. They now number over 700 black and 4,800 white rhinoceros which have been spread by translocation to national parks, game reserves and privately owned ranches throughout the country. Their numbers continue to increase at rates of 5% - 9% per annum. This is entirely due to the very high level of expenditure on protection and management (Cumming *et al.*, 1990). The relationship between effective manpower and security has been recognised as the fundamental requirement for protection of rhinoceros in Africa (Cumming *et al.*, 1990; Leader-Williams and Albon, 1988). In addition to government or quasi-government expenditure, the motivation of the security forces (Hillman-Smith, 1990) and the derivation of material benefits from conservation by local communities (Lewis *et al.*, 1990), are now recognised as essential contributing factors to rhinoceros security. All these strategies for enhancing rhinoceros conservation, as well as the need to increase the habitat available in the mostly small reserves where the two species occur in South Africa, will require a significant increase in funding.

To accomodate rapidly growing populations (over 3,500 white rhinoceros and nearly 200 black rhino alone have been translocated out of the overcrowded Natal game reserves since 1960) more land will have to be purchased. Protection for the growing rhinoceros

populations requires constant vigilance, more funds and better equipment. It is increasingly evident, and propagated by the IUCN, that local communities must benefit from conservation. This is particularly necessary to address the land hunger of a rapidly increasing human population (e.g., Khan, 1990). Local support, as a deterrent to poaching and illegal trafficking in wildlife products, is a necessary part of the protection equation.

To satisfy these demands for more realistic conservation, it is necessary, and pragmatic to consider selling the rhinoceros horn derived from natural mortality to subsidise further conservation of the species. Utilisation of this horn as it becomes available, and the large stockpile built up over the years, has obvious advantages for the South African rhino populations. However, a means must be found for reconciliation of this strategy with continued protection of the remnant rhinoceros populations elsewhere in Africa and Asia.

Two recent studies of source tracing of elephant *Loxodonta africana* ivory using isotopic analysis (van der Merwe *et al.*, 1990; Vogel *et al.*, 1990; Vogel, Eglington and Auret, 1990) suggested that similar methods might be applicable to rhinoceros horn. The results of the ivory studies showed that stable carbon isotope ratios ($^{13}C/^{12}C$) reflected the density of tree cover (via the diet), stable nitrogen isotope ratios ($^{15}N/^{14}N$) were inversely proportional to rainfall, and strontium isotopic ratios ($^{87}Sr/^{86}Sr$) reflected local geology. In combination, these three isotopic ratios served to distinguish all of the study areas in different parts of Africa.

Similarly, a method using a combination of stable isotopes should identify the geographic source of rhinoceros horn. Some obvious differences between the present study and the elephant studies exist. Firstly, we are dealing with two separate species - *Diceros bicornis* and *Ceratotherium simum*, which have very different diets. The former is a browser and the latter a grazer. This has a positive value, since the stable carbon isotope ratios of browsers and grazers are clearly distinct in most African environments (Vogel, 1978; Lee-Thorp & van der Merwe, 1987; Lee-Thorp, 1989). This is because browse (tree and shrub foliage, forbs) consists mainly of plants following the C_3 (Calvin-Benson) photosynthetic pathway; these have carbon isotopic ratios distinct from savanna grasses, which follow the C_4 (Hatch-Slack) pathway (Smith & Epstein, 1971). Thus, there should be a clear differentiation between black and white rhino horns on this basis alone (an outcome which has application in forensics and criminal proceedings). Secondly, rhino horn consists of hair or keratin, a complex protein; the sample material in the case of ivory or bone is a calcified tissue containing collagen. It has been observed that a difference exists in $^{13}C/^{12}C$ ratios between bone or tooth collagen and hair of the same animal, such that hair is, on average, about 2.5‰ lighter (depleted in ^{13}C) than the former (Vogel, 1978; Lee-Thorp, 1989). Similar data are lacking for nitrogen isotopes, and for the purposes of this paper we have assumed no difference between bone and horn. Tissue differences are not expected for heavy isotopes such as strontium and lead, which are not fractionated to any measurable extent in metabolic systems. Some seasonable variation, however, may be found in the isotopic composition of different samples from the same horn since it is not a living tissue which is resorbed and reworked.

Here we describe the preliminary results of a pilot study on rhinoceros horn to test the feasibility of carbon, nitrogen, strontium and lead isotopic analysis for distinguishing between species and geographic source.

METHODS

A total of 42 specimens of black and 37 specimens of white rhinoceros horn were analysed. The specimens, each approximately 1g, were obtained from the horns of animals which had died of natural causes, or from the horns of immobilised animals during translocation operations. The black rhinoceros specimens were derived from 6 different protected areas in South Africa and Namibia, while the white rhinoceros specimens were obtained from three different areas in South Africa (Fig. 1). Samples were subdivided for heavy isotope

analysis in the Radiogenic Isotope Facility, University of Cape Town (UCT), and independent light isotopic analyses in the Archaeometry laboratories at Harvard University and UCT.

In both laboratories procedures for the preparation of samples for light isotope analysis followed standard procedures described elsewhere (Sealy *et al.*, 1987; van der Merwe *et al.*, 1988; Lee-Thorp, 1989). The method of production of CO_2 and N_2 gases, however, differed somewhat. In the Harvard laboratory a Carlo Erba Nitrogen Analyser coupled to a VG PRISM mass spectrometer was used for the measurement of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios. In the Cape Town Laboratory, CO_2 and N_2 was produced by closed tube combustion, the gases separated and purified by cryogenic distillation and the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios measured in a VG602E mass spectrometer. The results are reported in the δ notation as $\delta^{13}C$ and $\delta^{15}N$ values. An informal standard of gelatin was repeatedly analysed by both laboratories, with very close agreement in the results. In the Cape Town Radiogenic Isotope Facility strontium and lead were extracted and concentrated from ashed samples using conventional ion exchange techniques. Pb was further purified by anodic electrodeposition. $^{87}Sr/^{86}Sr$ and Pb isotope ratios were measured on a VG Sector thermal ionisation mass spectrometer. Repeated analyses of the NBS Sr standard SRM987 during the period of this study yielded a mean $^{87}Sr/^{87}Sr$ ratio of 0.710278 ± 3 (1 s.d.), corrected for mass fractionation using the ratio $^{86}Sr/^{88}Sr$ = .01194. Mass fractionation corrections for the $^{206}Pb/^{204}Pb$ (0.1% amu^{-1}) and $^{207}Pb/^{204}Pb$ (0.1% amu^{-1}) and $^{208}Pb/^{204}Pb$ (0.1% amu-1) isotope measurements were established by the repeated analyses of the NBS standard SRM981. The results are reported as ratios.

RESULTS

The results for the light stable isotopes are shown in Table 1 and 2 and those for heavy isotopes in Tables 3 and 4. The results and their implications are discussed in detail below.

Species separation

The distinct separation of the two species of rhinoceros by the frequency of $\delta^{13}C$ values is shown in Fig. 2, and absolute $\delta^{13}C$ values in Fig. 3. The species of African rhinoceros can therefore be definitively established from a small (5-10 mg) sample of horn, on the basis of a single $\delta^{13}C$ measurement alone.

The range of $\delta^{13}C$ values derived for the two rhinoceros species (Table 1 and 2) can be compared with values from elephant ivory and bone of other species of large African mammals. It has been mentioned above that hair is 2.5‰ lighter than bone so the absolute values derived for rhinoceros horn are, on average, displaced by -2.5‰ compared to those derived from bone collagen or ivory.

Taking this displacement into account, the range of $\delta^{13}C$ values for the black rhinoceros samples (-22‰ to -24.6‰) compare well with other African browsers and mixed feeders documented by Vogel (1978) and Lee-Thorp (1989), and some elephants in van der Merwe *et al.*, (1990) with the exception of those from the Addo Elephant National Park. The standard mean browser value is -21.5‰ based on a large number of samples in Lee-Thorpe (1989). The mean value of -20.3‰ at Addo represents a predominantly C^3 diet with a contribution from CAM plants (those plants in which carbon dioxide fixation proceeds initially through crassulacean acid metabolism). CAM plants are predominantly succulents (Mooney *et al.*, 1977) and these contribute a high proportion of the food intake of black rhinoceros at Addo (Hall-Martin*et al.*, 1982). The $\delta^{13}C$ values for Addo elephants of -17.0 (van der Merwe *et al.*, 1988; van der Merwe *et al.*, 1990) compare well with the black rhinoceros values when the 2.5‰ difference between hair and bone or ivory is taken into account.

The white rhinoceros is a specialist grazer. In the summer rainfall region of South Africa, which constitutes its range, more than 90% of the grass species are of the C_4 type (Vogel *et*

al., 1078). The $\delta^{13}C$ mean values for the white rhinoceros samples from the different areas in our study range from -10.1‰ to -10.5‰ (Table 2). When the -2.5‰ adjustment is made for the hair/bone difference, the resulting range of values of -7.6‰ to -8.0‰ compares very well with values for pure grazers (Lee-Thorp, 1989; Vogel, 1978). The mean value for a large range of grazers from South Africa is -7.5‰ and the highest value for a specialised grazer is -6.5‰ for Lichtensteins hartebeest *Sigmoceros lichtensteinii* from Malawi (Lee-Thorp, 1989).

To study variation, serial samples were taken at 5 cm intervals from the base to the tip of an 80 cm-long white rhinoceros horn from Umfolozi and the light isotope ratios were measured for each sample (Fig. 4). There is no obvious correlation between carbon and nitrogen that could be invoked to explain seasonal differences. However, for the samples up to 45 cm away from the tip of the horn there does appear to be a vague inverse relationship. The fluctuations in $\delta^{15}N$ values may well be related to rainfall, which shows distinct year to year variation in South Africa and $\delta^{13}C$ values may relate to differences in fodder quality linked to rainfall. The mean values of $\delta^{13}C$ (-10.2‰ ± 0.59 and $\delta^{15}N$ (-7.4‰ ± 0.71) clearly place the horn with other Umfolozi samples (c.f. Fig.3).

Source area determination

The overlap of $\delta^{15}N$ values for both species of rhinoceros and for different areas within each species, with the exception of black rhinoceros from the Addo Elephant National Park, is considerable (Fig. 3). The identification of source areas for rhinoceros horn on the basis of $\delta^{13}C$ and $\delta^{15}N$ values, as has been shown for elephant ivory (van der Merwe *et al.*, 1990) is not possible. The high $\delta^{15}N$ values for the Addo black rhinoceros compared closely with the high values obtained from elephant bone and ivory from the same area (van der Merwe *et al.*, 1990). This is explained partly by the relative aridity of Addo, where mean annual rainfall is 378 mm (Hall-Martin *et al.*, 1982). It has been shown that $\delta^{15}N$ values are higher for arid regions than for higher rainfall areas (Heaton *et al.*, 1986; Sealy *et al.*, 1987; van der Merwe *et al.*, 1990). It has also been pointed out, however, that the substantial presence of predominantly succulent CAM plants at Addo may be responsible for higher $\delta^{15}N$ values (van der Merwe *et al.*, 1988, van der Merwe *et al.*, 1990). Heaton (1987) reported enriched $\delta^{15}N$ values for some succulent plants at Addo. Such succulents form a high proportion of the diet of black rhinoceros at Addo (Hall-Martin *et al.*, 1982).

In Fig. 3 one Addo sample (No. 3958) is shown opposite a $\delta^{15}N$ value of 3.2‰ (Cape Town) and 3.3‰ (Harvard) which is way off the mean value of 11.6‰ for the other determinations of the Addo samples. This specimen was taken from the tip of the anterior horn of a black rhino bull that had been translocated to Addo from the Hluhluwe Game Reserve. The length of the horn at the time of the removal of the tip was 700 mm when the bull had been at Addo for seven years. It has been established that horn growth averages 57.6 mm per annum in adult black rhino (Pienaar *et al.*, 1991) and it is therefore clear that at least the upper 300 mm of the horn of this animal could not have been grown at Addo, but must represent horn growth which took place in Hluhluwe before the animal was translocated. As the mean annual rainfall at Hluhluwe is 1,000 mm, the low $\delta^{15}N$ value is not unexpected.

As was shown in the case of elephant ivory (van der Merwe *et al.*, 1990) overlapping distributions of carbon and nitrogen isotope ratios (such as seen in Fig. 3) can be separated by, among others, $^{87}Sr/^{86}Sr$ ratios determined on the same samples. The strontium isotope ratios reflect the age and average Rb/Sr ratios of the parent rocks in a particular geographical area. The $^{87}Sr/^{86}Sr$ ratios obtained for a selection of black and white rhinoceros horn analysed to date are shown in Tables 3 and 4. There is no known or theoretical metabolic fractionation which could be invoked to explain why these values should differ in different species from the same area. Results for both species from six areas are, therefore, plotted against their corresponding $\delta^{15}N$ values in Fig. 5. A fair separation of source areas is obtained. Once again the Addo (ex-Hluhluwe) horn tip is far

removed from the Addo samples. As could be expected this sample yielded similar values to Umfolozi which is only 20 km distant from Hluhluwe and has similar geology, but different rainfall. One of the Kruger samples (with a value of 0.71609) is far off the rest, and among Umfolozi values, reflecting the complex geology of the Kruger National Park (Schutte, 1986) and the need to have a wider data base for such areas.

Among the other isotopes measured to date for which sufficient data are available for preliminary analysis are lead isotope ratios (Tables 3 and 4). The $^{208}Pb/^{204}Pb$ ratio plotted against $\delta^{15}N$ is shown in Fig. 6. Clear separation of Pilanesberg and Addo samples is achieved. Separation of source areas on the basis of $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$ and $^{143}Nd/^{144}Nd$ ratios will be examined when more data are available. In Fig. 7, the strontium ratios are plotted against $^{206}Pb/^{204}Pb$ and a very clear separation of Pilanesberg, which is an alkaline complex of volcanic origin (Haughton, 1969), is the result.

The above data indicate that in the case of rhino horn, where source area determination is required, several isotopes will have to be measured. The results will have to be subjected to multivariate statistical analysis, or three dimensional plotting to achieve reliable separation. Sufficient evidence, however, has been presented here to indicate that discrimination between white and black rhinoceros horn is relatively straight forward, and that reliable source area determination is possible on the basis of isotopic analysis.

Rhinoceros status and distribution

All five species of rhinoceros are listed in Appendix I of CITES (Conservation on International Trade in Endangered Species of Wild Fauna and Flora) and international trade in their products is illegal. The demand for rhinoceros horn in particular as an ingredient in traditional medicines in the Far East (Martin, 1989) and for the fashioning of traditional dagger handles in Yemen (Martin, 1987) has, however, continued despite the CITES ban. In recent years the Yemen trade has slackened (Cumming *et al.*, 1990) due to changing economic conditions in that country. The medicine trade, has however continued despite all efforts so far to stamp it out. The use of rhinoceros products and in particular rhinoceros horn as a medicine is a strong tradition among Chinese communities. The medicinal properties of the horn have recently been substantiated in clinical trials (Hui *et al.*, 1990). The decline of the African rhinos in particular is due to the demand for horn (Cumming *et al.*, 1990) while the decline in numbers of Asian rhinoceros is partly due to shrinkage and fragmentation of habitats (Khan, 1989).

The status of Asian rhinoceros species gives cause for concern. There are about 1,334 Indian rhinoceros *Rhinoceros unicornis* in India and 388 in Nepal (Khan, 1989). The Sumatran rhinoceros *Dicerorhinus sumatrensis* still occurs in Indonesia with an estimated 420-750 animals, Malaysia with 63-152 and scattered remnant populations in Burma (6-7) and Thailand (6-15) (Khan, 1989). The Javan rhinoceros *Rhinoceros sondaicus* occurs in Udjung Kulon National Park in Java which has about 50-54 animals, a small remnant population in southern Vietnam, and scattered remnant populations reported from Laos and Cambodia (Khan, 1989).

In Africa the black rhinoceros has declined dramatically from an estimated 70,000 in the late 1960's to about 3,800 in 1987 (Cumming *et al.*, 1990), due largely to illegal killing of animals for their horns. About 73% of the remaining animals occur in Zimbabwe, South Africa and Namibia. About 14% occur in Kenya and the remainder are scattered in remnant and mostly declining populations elsewhere (Cumming *et al.*, 1990). A few animals, not recorded by Cumming *et al.*, 1990 survive in Angola and there are 6 in Swaziland (Reilly, 1990). Current estimates of numbers of black rhinoceros in South Africa exceed 700 animals.

The white rhinoceros has a discontinuous recent distribution with the northern white rhino *C.s. cottoni*, which numbered over 2,000 in 1960, in Sudan, Zaïre, Uganda and CAR (Martin and Ryan, 1990). There were 1,300 alone in 1963 in Garamba National Park, Zaïre

(Hillman-Smith, 1990). By 1984 the northern white rhino was virtually extinct in the wild and there were only 15 left in Garamba (Hillman-Smith, 1990). This small population had increased to 26 by 1990 due to a concerted conservation effort (Hillman-Smith, 1990). The history of the southern white rhinoceros *C. s. simum* has been very different with the species reduced to a remnant of about 100 animals in 1920 in the Umfolozi Game Reserve of South Africa which had increased to 5,236 by 1991. Of these about 4,838 (92%) were found in South Africa and the rest in translocated populations in the neighbouring countries. A further 697 southern white rhino were found in zoos and safari parks elsewhere in the world due to translocations from Natal and breeding in captivity (Klos and Frese, 1991).

Rhinoceros conservation and utilisation

The South African black rhinoceros populations are increasing at rates of 5.3% - 11.0% in the Zululand Game Reserves (Hitchins and Anderson, 1983) and 9.0% - 9.6% in National Parks (Hall-Martin, 1986). White rhinoceros populations continue to increase at 6.4% - 9.6% per annum (Owen-Smith, 1988) depending to some extent on the disturbance due to capture and translocation operations, rainfall and so on.

Natural mortality in white rhinoceros populations is estimated at 1.7% of adults and subadults. Mortality among calves is about 8.3% (Owen-Smith, 1988). In the adult/subadult sector (78.2% of the total: Owen-Smith, 1988) natural mortality alone could account for 64 animals from the South African population each year. With a mean horn mass (anterior plus posterior) of 6.38 kg per animal (Pienaar *et al.*, 1991) natural mortality alone could yield 408 kg of white rhinoceros horn per year. However, not all rhinoceros horn is recovered from large areas like the Kruger National Park, but most of it is. By a similar procedure it can be estimated that about 30 kg per year of black rhinoceros horn is being recovered from natural mortality in South African reserves.

This approximately 438 kg of rhinoceros horn per year, most of which is under the control of wildlife management agencies, is worth about $1 million. When translated into local currency at present exchange rates this gives R2.8 million. Land prices in areas suitable as rhinoceros habitat average about R600 per hectare. The sale of the annual production of rhino horn by natural mortality alone could thus purchase about 4,666 ha per annum which could be added to national parks and game reserves. At average population densities of 0.5 km^2 for black rhinoceros and 2.0 km^2 for white rhinoceros, additional habitat for 23 black and 92 white rhino per year could be acquired. The income from the sale of this horn, and the large accumulated stockpiles, could also be used to bestow material benefits on communities neighbouring the rhino sanctuaries. The case for rhino providing economic benefits to the agencies protecting them is being increasingly argued in South Africa.

Isotopic analysis and rhinoceros conservation

The work carried out in our laboratories is not intended to provide a stimulus for the marketing of rhinoceros horn by the South African management agencies. The market exists, and all efforts to kill it have failed. We wish, however, to explore possibilities of better control mechanisms for a legal, sustained trade in rhinoceros products. The technology we describe can also be of assistance to forensic elements of trade control should some form of differentiated trade in rhinoceros products (e.g. horns from ranched southern white rhinoceros) be contemplated.

Our single greatest reservation about pursuing this technology, and planning its application, lies with the status of the three species of Asian rhinoceros. We believe that any proposal to pursue the downlisting of the South African rhinoceros population, and the implementation of a controlled trading system will have to be thoroughly debated with responsible groups in Asia such as the various management authorities controlling the major populations in India, Nepal, Malaysia and Indonesia. The use of Asian rhino horn, however, differs from the use of African horn, and the dynamics of trade in these two categories are very different.

We expect that it will be possible to distinguish the horns of the three Asian species of rhinoceros from African horn on the basis of stable isotope ratios. As the habitats of the greater one-horned, Sumatran and Javan rhinos all receive in excess of 2,500 mm of rainfall per year, lower $\delta^{15}N$ values than seen in our African samples could be expected. The diet of the greater one-horned or Indian rhinoceros is reported to be predominantly composed of grass (up to 80%) and lesser amounts of forbs with some seasonal variation (Laurie, 1982). We therefore, expect that $\delta^{13}C$ values in the region of -12‰ to -13‰ may be found. Both Sumatran and Javan rhinoceros are browsers. The Sumatran is reputed to feed mainly on small trees or saplings consuming twigs, small branches and leaves, and fruits, with herbs and lianas forming an insignificant part of the diet (Borner, 1979; Groves and Kurt, 1972; van Strien, 1986). Javan rhino feed mainly on the twigs and branches of saplings (Schenkel and Schenkel-Hulliger, 1969). One might, therefore, expect $\delta^{13}C$ values of about -24‰ to -28‰ for these species, or less depending upon the density of tree cover in their habitat. In addition to our proposed ability to distinguish between rhinoceros horn of different species, it is worth noting that traditional Chinese medicine sellers in Taiwan claim to be able to distinguish African from Asian rhino horn and accordingly charge tenfold more for Asian.

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Table 1. Values of stable light isotopes from analysis of black rhinoceros horn from different regions.

Region	$\delta^{13}C$	s.d.	n	$\delta^{15}N$	s.d.	n
Addo	-20,31	0,70	16	11,66	0,51	17
KNP	-23,48	0,63	12	7,46	1,39	10
Mkuze	-24,23	0,20	10	6,57	1,17	10
Pilansberg	-22,53	0,22	4	6,20	0,55	4
Umfolozi	-23,80	0,28	2	6,50	.	1

Table 2. Values of stable light isotopes from analysis of white rhinoceros horn from different regions.

Region	$\delta^{13}C$	s.d.	n	$\delta^{15}N$	s.d.	n
KNP	-10,48	0,64	32	5,77	1,21	31
Pilansberg	-10,38	0,51	11	5,28	0,51	13
Umfolozi	-10,11	0,68	16	6,63	0,71	9

Table 3. Values of stable heavy isotopes from analysis of black rhinoceros horn from different regions.

Park	$^{87}Sr/^{86}Sr$	s.d.	n	$^{206}Pb/^{204}Pb$	s.d.	n	$^{207}Pb/^{204}Pb$	s.d.	n	$^{208}Pb/^{204}Pb$	s.d.	n	$^{143}Nd/^{144}Nd$	s.d.	n
Addo	0,71399	0,0017	6	18,2088	0,2477	5	15,6146	0,0309	5	38,2668	0,2878	5	0,51209	0,0000	6
Mkuze	0,71182	0,0019	5	.	.	0	.	.	0	.	.	0	.	.	0
Namibia	0,71772	0,0032	7	17,6877	0,1224	3	15,5803	0,0101	3	37,9853	0,4861	3	0,51168	.	1
Pilansberg	0,70548	.	1	20,1830	.	1	15,7940	.	1	40,2050	.	1	0,51158	.	1
Umfolozi	0,71860	.	1	18,2750	.	1	15,6440	.	1	38,3421	.	1	.	.	0

Table 4. Values of stable heavy isotopes from analysis of white rhinoceros horn from different regions.

Park	$^{87}Sr/^{86}Sr$	s.d.	n	$^{206}Pb/^{204}Pb$	s.d.	n	$^{207}Pb/^{204}Pb$	s.d.	n	$^{208}Pb/^{204}Pb$	s.d.	n	$^{143}Nd/^{144}Nd$	s.d.	n
KNP	0,71013	0,0029	6	18,7410	.	1	15,6590	.	1	39,2560	0,2878	1	.	.	0
Pilansberg	0,70520	0,0011	4	20,0997	0,5982	3	15,7570	0,0749	3	40,4103	.	3	0,51167	0,0002	4
Umfolozi	0,71666	0,0009	9	17,9520	0,2916	3	15,6217	0,0280	3	37,8967	.	3	.	.	0

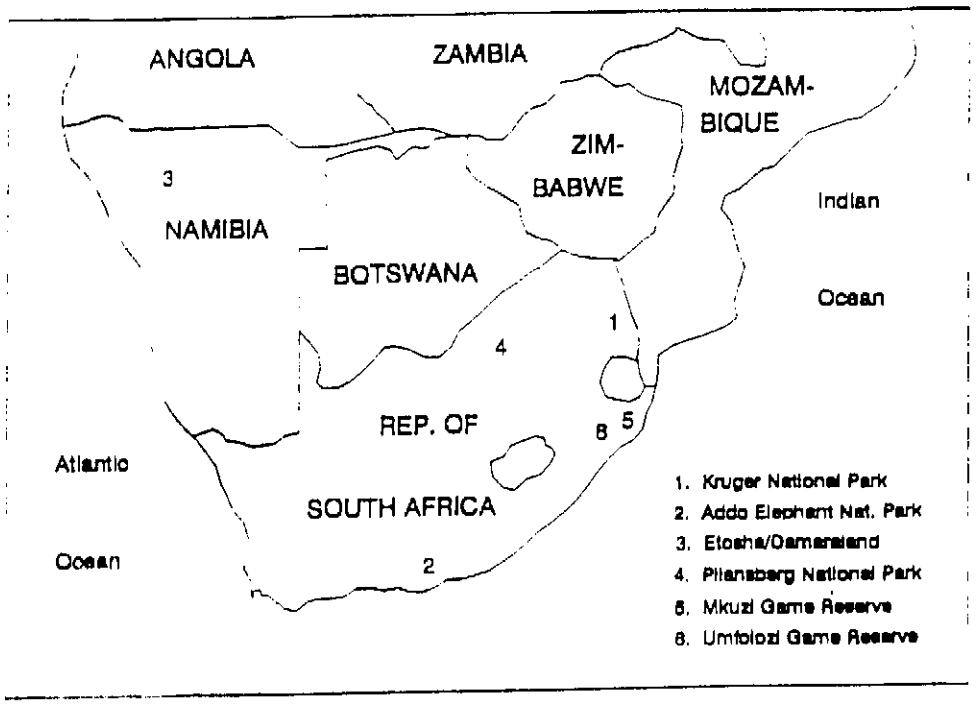

Fig. 1. : Sketch map of southern Africa showing location of six localities in South Africa and Namibia from which rhinoceros horn samples were obtained.

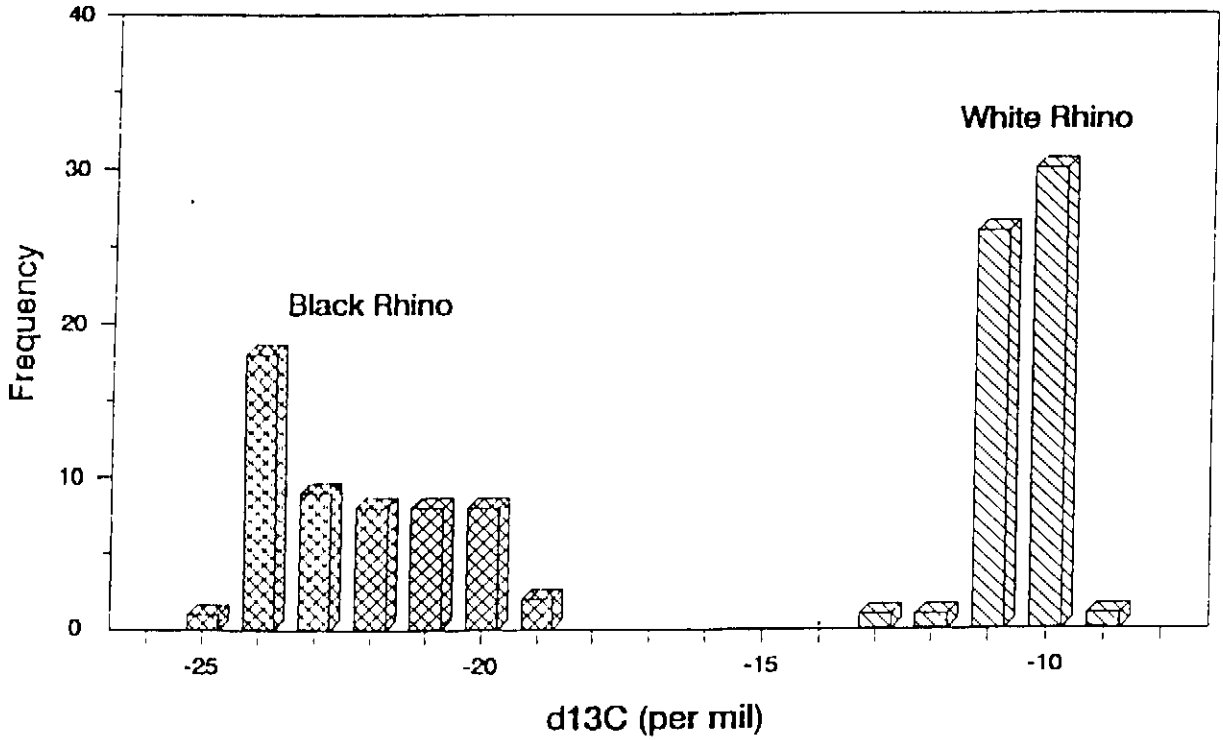

Fig. 2. : Histogram of the relative frequency of $\delta^{13}C$ values for samples of white and black rhinoceros horn, showing the clear separation of the two species.

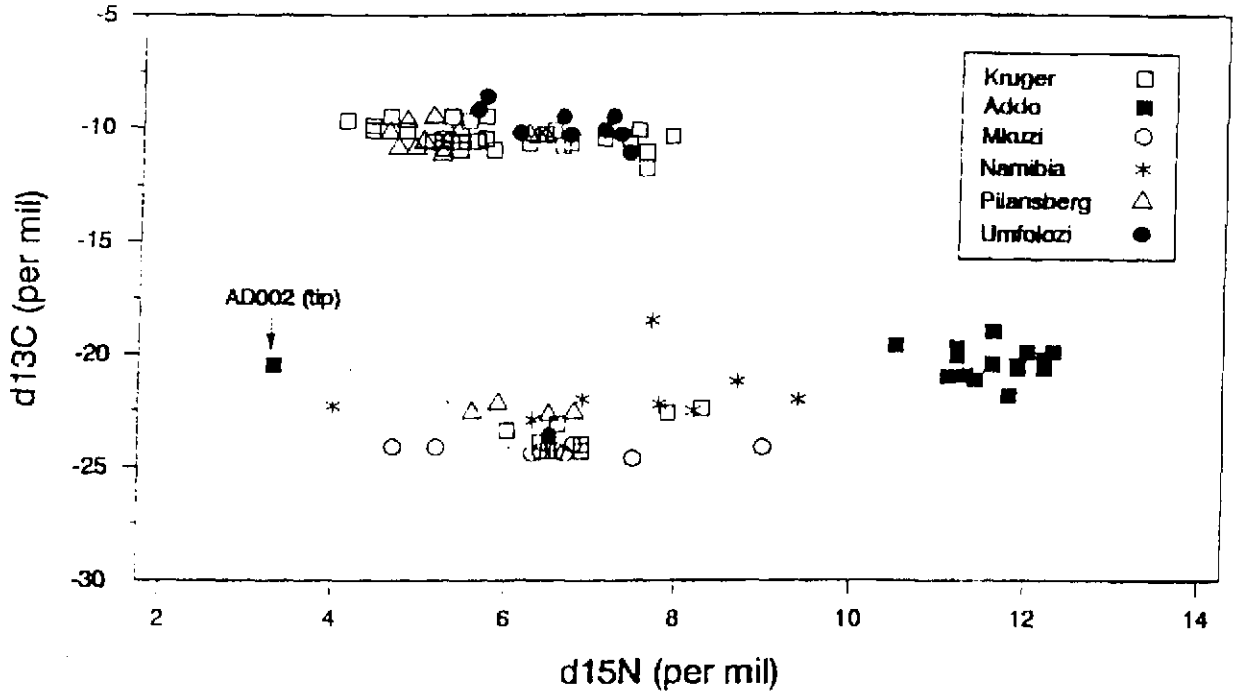

Fig. 3. : $\delta^{13}C$ and $\delta^{15}N$ values of rhinoceros horn samples from different areas in southern Africa.

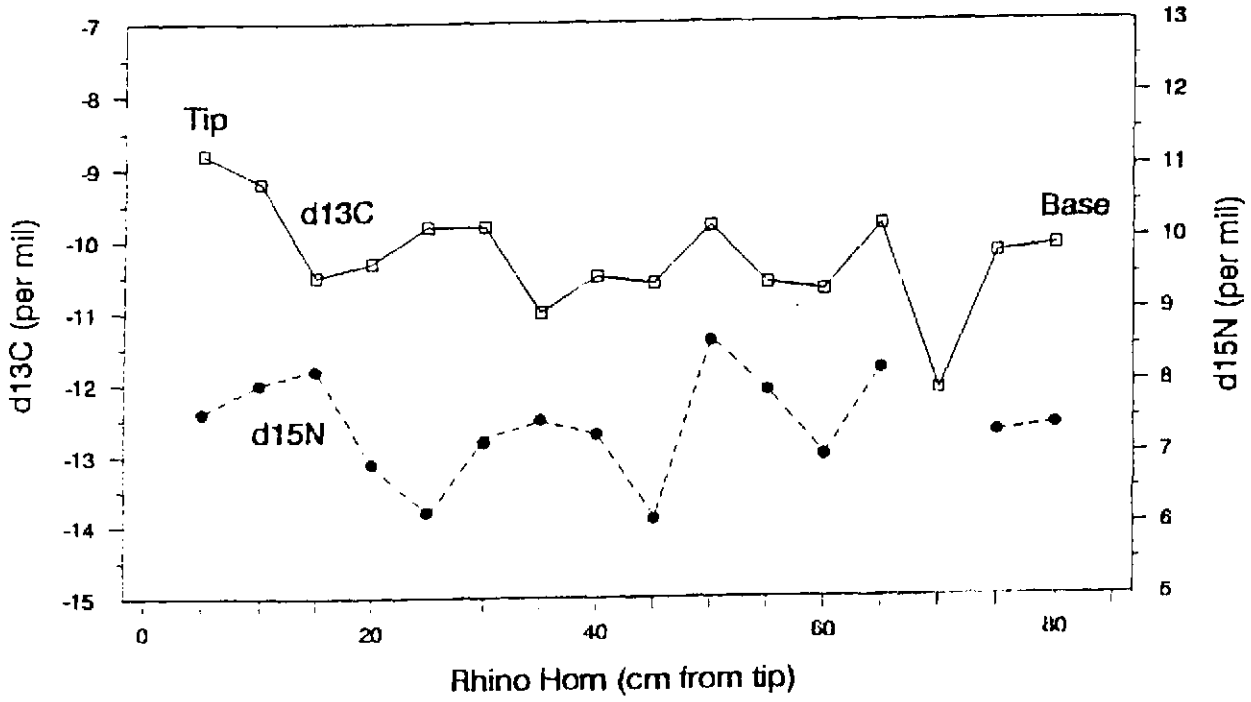

Fig. 4. : Relationship between $\delta^{13}C$ and $\delta^{15}N$ values taken from serial samples of a single white rhinoceros horn sampled from tip to base.

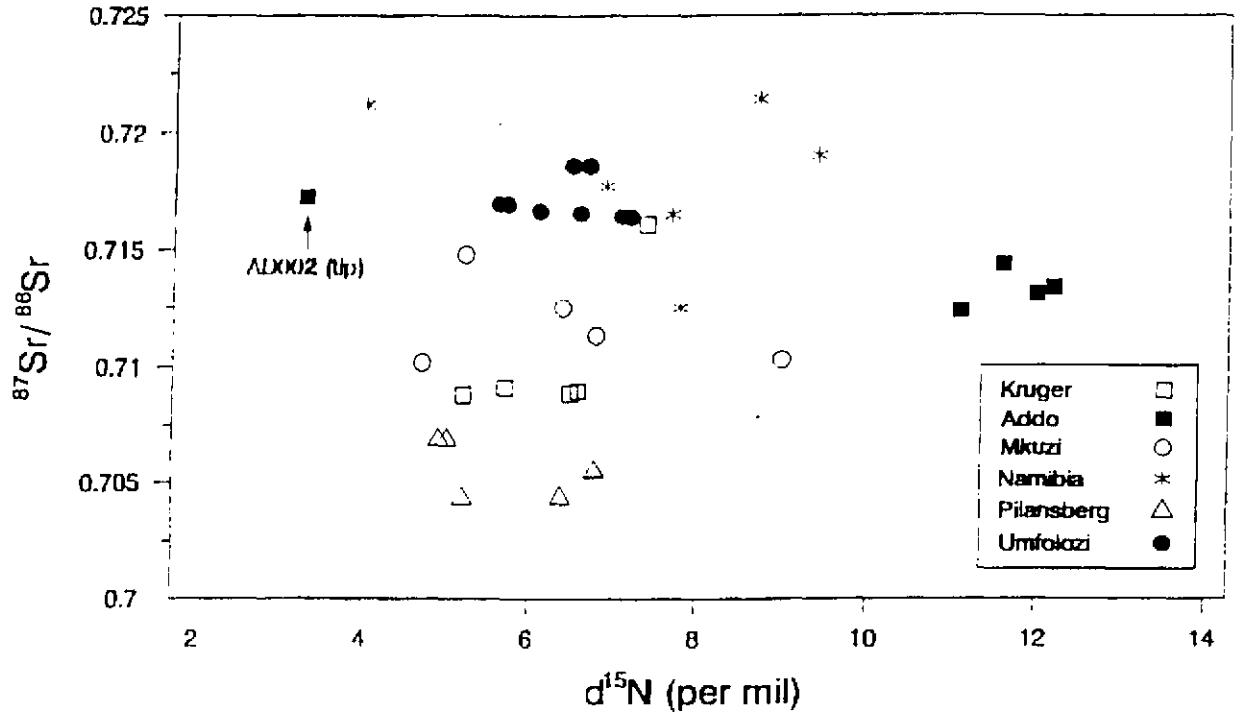

Fig. 5. : $^{87}Sr/^{86}Sr$ ratios plotted against $\delta^{15}N$ for samples of rhinoceros horn of both species showing the clustering of samples from the same source areas.

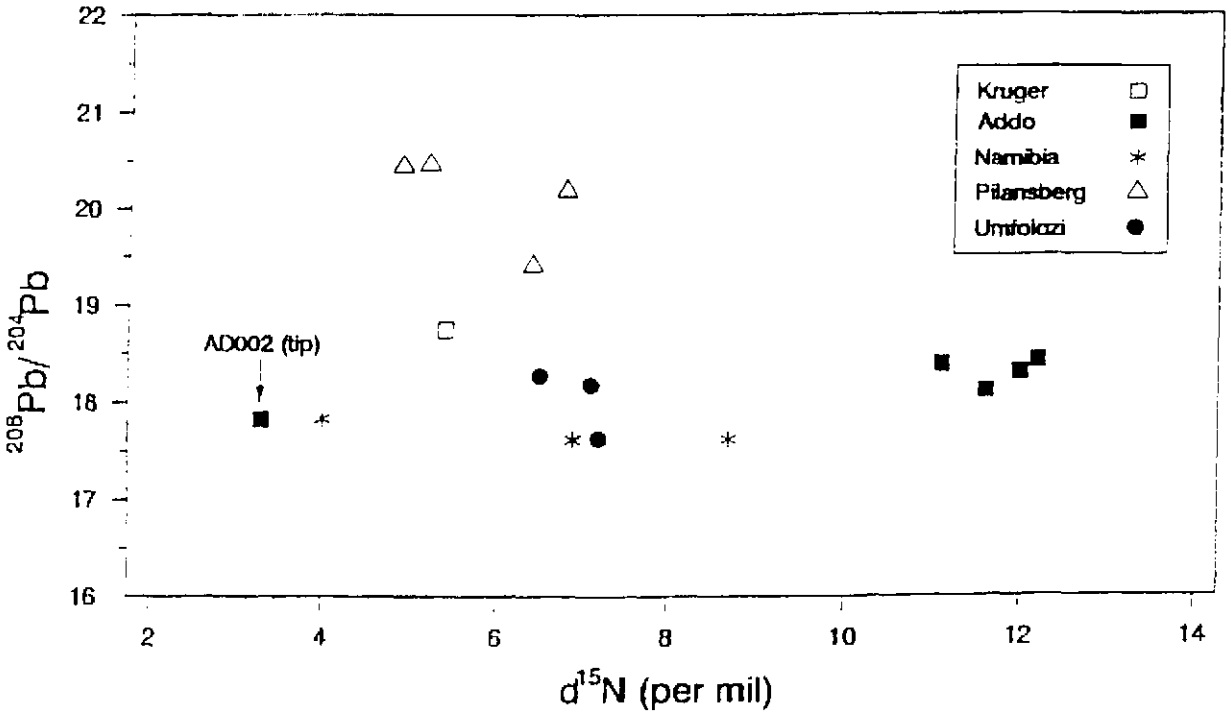

Fig. 6. : $^{208}Pb/^{204}Pb$ ratios plotted against $\delta^{15}N$ values for white and black rhinoceros horn from different areas.

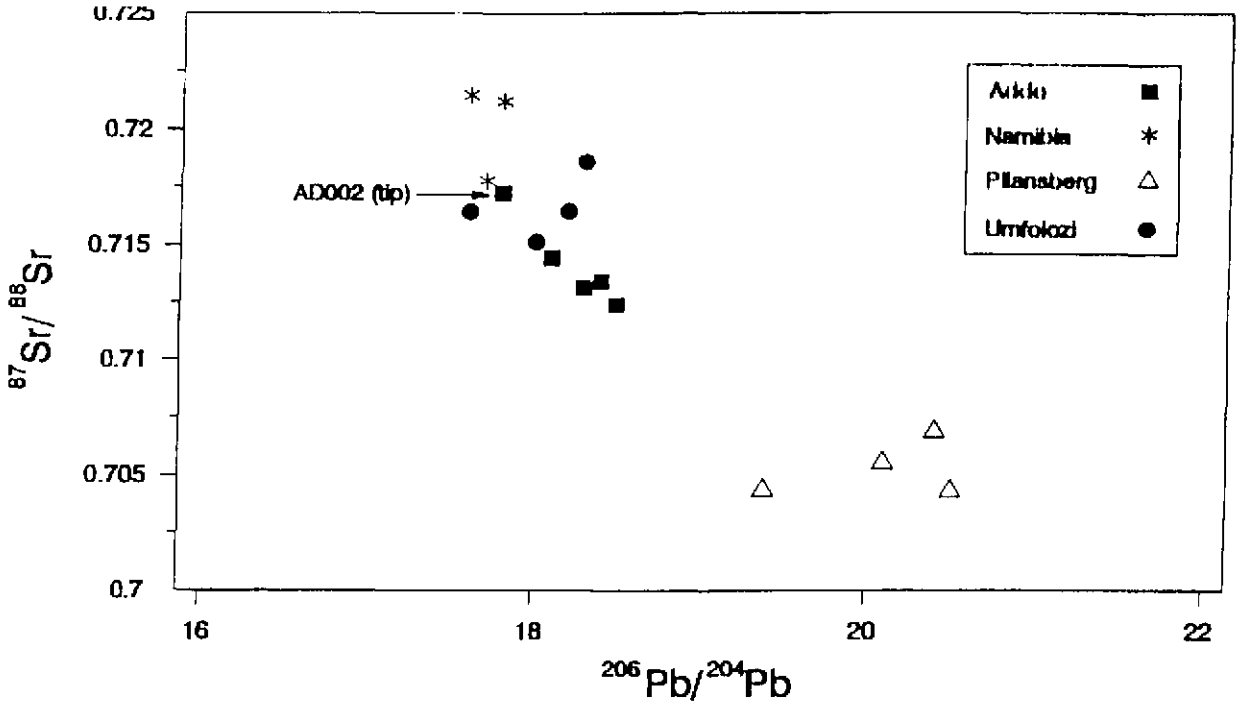

Fig. 7. : $^{87}Sr/^{86}Sr$ ratios plotted against $^{206}Pb/^{204}Pb$ ratios for rhinoceros horns showing the clear separation of Pilanesberg samples.