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Isotopic evidence for the past climates and vegetation of southern Africa

J. C. VOGEL*

ABSTRACT

The stable isotopes of hydrogen, oxygen and carbon can potentially provide evidence of past climates. The most detailed information has been obtained from variations in the oxygen-18 content of foraminifera from ocean floor cores, the analysis of which has produced a record of ocean temperature changes through the Quaternary and beyond. The use of isotope analysis of continental materials to reveal climatic change is more limited, but some advances have been made in recent years.

One approach has been to utilize the variations in the isotopic composition of precipitation as recorded in ancient groundwater. Thus groundwater samples from a confined aquifer on the southern Cape coast show a marked rise in temperature since the Last Glacial maximum. The temperature changes during the Upper Pleistocene and Holocene are also reflected in the oxygen-18 content of stalagmites from the Cango caves in the same region.

The widespread occurrence of C_4 grasses in the warmer summer rainfall areas of southern Africa provides a novel possibility of observing temporal shifts of climatic boundaries. The distinctly high carbon-13 content of C_4 plants is clearly reflected in the skeletons of grazers so that faunal material from suitably situated archaeological sites can be used to observe changes in the composition of the local grass-cover. The evidence thus far accumulated suggests only minor changes since the Upper Pleistocene.

The combined evidence to date indicates that temperatures and also precipitation in southern Africa have changed since the Last Glacial maximum, about 18 000 years ago, but that shifts in the boundaries of the various veld-types were probably not very extensive.

RÉSUMÉ

ESTIMATION AU MOYEN DES ISOTOPES DES CLIMATS ET DE LA VÉGÉTATION DU PASSÉ DE L'AFRIQUE DU SUD

Les isotopes stables d'hydrogène, d'oxygène et de carbone sont à même de nous renseigner sur les climats du passé. Les informations les plus détaillées ont été obtenues à partir de variations de la teneur d'oxygène-18 de foraminifères en provenance de carottes prélevées dans les fonds océaniques, dont l'analyse a fourni une indication sur les changements de température au cours du Quaternaire et auparavant. L'utilisation de l'analyse des isotopes pour des matériaux continentaux en vue de connaître les changements climatiques est plus limitée mais certains progrès ont été réalisés durant ces dernières années.

Une des méthodes a consisté à utiliser les variations de la composition en isotopes des précipitations prélevées dans d'anciennes nappes phréatiques. C'est ainsi que des échantillons de la nappe phréatique d'une couche aquifère retenue en inclusion sur la côte sud du Cap indiquent une nette élévation de la température depuis l'apogée de la dernière période glaciaire. Les changements de température pendant l'Holocène et le Pleistocène supérieur se reflètent aussi dans la teneur en oxygène-18 des stalagmites des grottes de Cango situées dans la même région.

La vaste distribution des graminées à C_4 dans les régions chaudes à pluies estivales de l'Afrique du Sud fournit une nouvelle possibilité d'observer les déplacements dans le temps des limites climatiques. La teneur incontestablement élevée de carbone-13 des plantes à C_4 clairement indiquée dans les squelettes des animaux brouteurs, de sorte que des ossements animaux en provenance de sites archéologiques appropriés peuvent être utilisés pour observer les changements dans la composition de la couverture herbacée locale. Les observations recueillies jusqu'à présent ne laissent constater que des changements mineurs depuis le Pleistocène supérieur.

Les données réunies à ce jour indiquent qu'en Afrique du Sud les températures et également les précipitations ont changé depuis l'apogée de la dernière période glaciaire, il y a environ 18 000 ans, mais que les déplacements des limites des divers types de veld ne furent probablement pas très importants.

INTRODUCTION

The stable isotope composition of the light elements hydrogen, oxygen and carbon provides information about the physical and chemical history of the compounds in which they occur. As a result of differences in the rates of processes in which the mixtures of isotopic molecules are involved, a small degree of isotope separation frequently takes place, and in natural systems the magnitude of the isotopic fractionation is often directly or indirectly governed by climatic conditions — specifically by temperature. By analysing the variations that occur in the ratios of the isotopes, i.e. $^2H/^1H$, $^{18}O/^{16}O$ or $^{13}C/^{12}C$, in fossil deposits evidence of past climatic change can, therefore, be derived. Measurements are usually expressed as the deviation of the isotope ratio (in per mil) from that of a standard sample,

$$\text{i.e. } \delta^{18} = \frac{(^{18}O/^{16}O)\ sa - (^{18}O/^{16}O)\ st}{(^{18}O/^{16}O)\ st}\ (^0/_{00})$$

Negative values for δ thus denote a deficiency of the heavy isotope in the investigated material.

The most detailed information on past climatic change has been obtained from variations in the ^{18}O content of foraminifera from ocean floor cores, the analysis of which has produced a record of global

* National Physical Research Laboratory, CSIR, P.O. Box 395, Pretoria 0001, South Africa.

ocean temperature changes through the Quaternary and beyond (e.g., Shackleton & Opdyke, 1973).

The effect of these global fluctuations in temperature on the continental climates depends on locality and must be determined separately for each region. The use of isotope analyses for this purpose is still in the developmental stage and has not yet produced spectacular results. One reason for this is the scarcity of suitable terrestrial materials which, it should be pointed out, must also be accurately datable by radiocarbon or other means. *Ice cores* from Greenland and Antarctica have provided excellent records of the change in the isotopic composition of precipitation (^{18}O) during the late Quaternary (Johnsen *et al.*, 1972). Such profiles can, of course, only be obtained in the polar regions. On the other continents the calcium carbonate deposits in caves (*speleothems*) offer good prospects (Hendy & Wilson, 1968). The problem here, however, is that the ^{18}O content of the carbonate is dependent both on the temperature of crystallization and on the ^{18}O content of the precipitation at the time of formation so that a temperature record cannot be derived without involving certain assumptions. Thirdly the deuterium content of *peat* has been shown to preserve a record of the changes in the isotopic composition of surface water (precipitation) with time (Schiegl, 1974), but the possibilities have not been further exploited. Finally, it has been suggested that the ^{18}O content of the phosphate (apatite) in fossil *bones* can also provide a record of climatic change in the past (Longinelli & Triglia, 1981).

CLIMATIC CHANGE ON THE SUB-CONTINENT

Isotopic evidence for climatic change on the southern African sub-continent is still very limited. At present we are concentrating our efforts on documenting the effects of the major increase of temperature that occurred since the last glacial maximum some 18 000 years ago.

Uitenhage groundwater

Between Uitenhage and the coast, just north of Port Elizabeth, there is a confined body of underground water which is slowly moving towards the ocean. By measuring the decrease in the radiocarbon content of the dissolved bicarbonate with increasing distance from the recharge area, it could be established that this artesian aquifer contains water representing the local precipitation over the past 28 000 years (Vogel, 1970). The change in isotopic composition of the water samples with age is shown in Fig. 1. To convert the change observed in the deuterium (or ^{18}O) content at the Pleistocene/Holocene boundary into temperature, the present-day variations of the isotopic composition of precipitation may be used. The latitudinal dependence of the average ^{18}O composition of precipitation at Atlantic coastal and island stations is shown in Fig. 2 (IAEA, 1969). Using this relationship, and taking the change in the isotopic composition of the oceans during the Ice Age into account, it may be deduced that the temperature change at Uitenhage since the last glacial maximum corresponds to an effective decrease of some 10° in latitude which, in turn, represents an increase in temperature of about 5,5°C. This may suggest a change in climatic conditions similar to the present-day difference between Sydney and Tasmania.

Cango cave stalagmite

The data obtained for the artesian aquifer at Uitenhage may be used in a rather less speculative manner in conjunction with isotopic measurements on speleothem material from the Cango caves near Oudtshoorn. As mentioned above, the oxygen isotopic composition of the calcite of cave-stone depends on the ^{18}O content of the groundwater dripping into the cave and the temperature at which

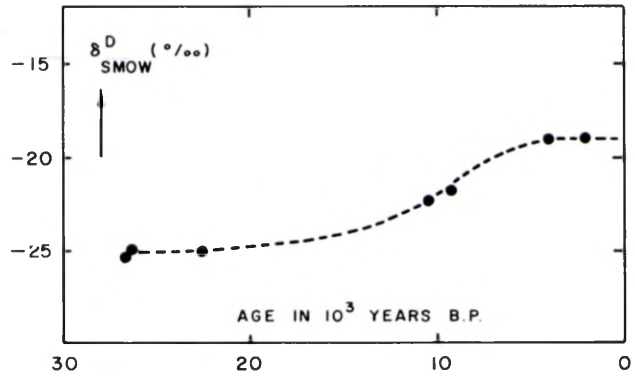

FIG. 1.—Deuterium content (δ^D) of groundwater relative to the SMOW standard, from a confined aquifer near Uitenhage, Cape Province. The age of the groundwater as determined by radiocarbon dating (Vogel, 1970), increases regularly from recent near the recharge area to 28 000 years Before Present, some 18 km down-dip. The results show a distinct change in the isotopic composition of the water between the Upper Pleistocene and the Holocene, from 6‰ in δ^D or 0,8‰ in δ^{18}

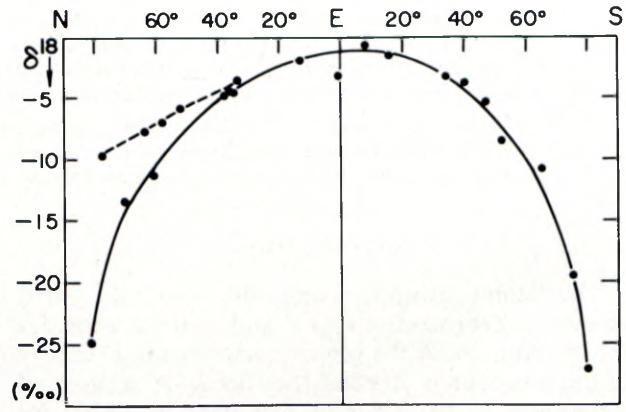

FIG. 2.—Latitudinal dependence of the average ^{18}O composition of precipitation (rel. to SMOW) at Atlantic coastal and island stations derived from data published by the Intern. Atomic Energy Agency (IAEA, 1969). The dashed line connects stations along the west coast of Europe and reflects the influence of the warm Gulf Stream on this area. Between 34°S and 44°S δ^{18} decreases by 2‰, whereas the average temperature decreases by 5 to 6°C. During the last glacial maximum δ^{18} of precipitation at Uitenhage (Fig. 1) was 0,8‰ more negative and ocean water was 1,2‰ more positive, therefore indicating a total change of 2‰ corresponding to a temperature drop of about 5,5°C.

the carbonate is precipitated from this water. If it is accepted that a shift of 6‰ in the deuterium content corresponding to 0,8‰ in ^{18}O, as observed at Uitenhage, applies generally to the southern coast of the Cape Province, temperatures of crystallization for the Late Quaternary can be calculated. For this purpose a stalagmite, 2,8 m in height, was selected from the inner part of the Cango caves. Radiocarbon analyses show that this stalagmite had developed over the past 45 000 years. The relative ^{18}O content as a function of age is given in Fig. 3. Using these data, a temperature increase since the last glacial maximum of 5°C is calculated.

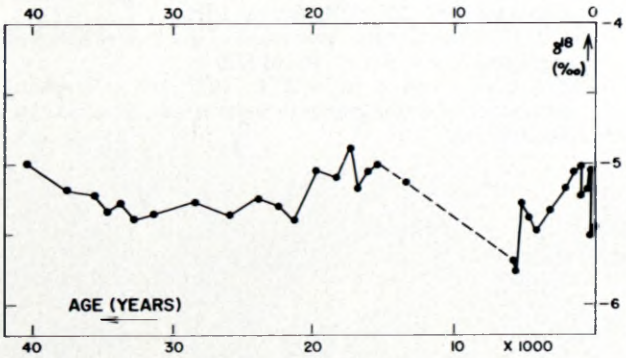

FIG. 3.—Preliminary ^{18}O analyses of $CaCO_3$ (rel. to the PDB standard) in a stalagmite from the Cango Caves near Oudtshoorn, Cape Province. Radiocarbon dating of the stalagmite shows that it has been growing in a more or less regular manner since 40 000 years ago. Samples taken along its growth axis thus provide an ^{18}O record of climatic change since Upper Pleistocene times (Vogel & Talma, in preparation.)

CHANGES IN VEGETATION PATTERNS

From a botanical point of view, the effect of climatic change on vegetation patterns is of more importance than the magnitude of the temperature change since the Last Ice Age. The widespread occurrence of grass species utilizing the C_4 pathway of photosynthesis in southern Africa provides a unique opportunity of investigating changes in their distribution with time by means of isotopic analyses.

C_4 plants are clearly distinguishable from C_3 plants on the basis of their stable carbon isotope ratio, $^{13}C/^{12}C$, and this difference in isotopic composition is in turn reflected in the bones of animals feeding on such vegetation (Vogel, 1978). Thus, for instance, the fossil bones of a grazer species such as the zebra can be used to observe the relative amount of C_3 and C_4 digested by the animal and to establish any changes in the C_3/C_4 ratio of the plant cover.

In a previous study (Vogel *et al.*, 1978) it was found that C_4 grass species were dominant in most of the summer rainfall area of the sub-continent, whereas C_3 grasses dominate the winter rainfall area of the western Cape and the summits of the mountain ranges of the eastern Cape and the Drakensberg. The distribution pattern is ascribed to differences in the temperature during the growing season — with high temperatures favouring the C_4 species, and it is to be expected that the lower temperatures prevailing during the Ice Ages would have resulted in an expansion of the C_3 grass area. To establish whether changes in this pattern in the past can be detected, fossil bone samples from two archaeological excavations situated in sensitive areas have been investigated. The first site, Melikane Cave, lies in the upper Orange River Valley in Lesotho and the second, the so-called Apollo 11 Cave, is some 50 km north of the Orange River in South West Africa/Namibia.

The average relative ^{13}C content of collagen in modern zebra bones from the C_4 grass areas in South Africa is −9,3‰ (Vogel, 1978). The results for a set of fossil zebra teeth from the archaeological excavation in Melikane Cave, Lesotho, are shown in Table 1. The two Holocene samples indicate that the diet of the animals consisted of about 35% C_3 plants, whereas the diet of the Pleistocene specimens increased to over 80% C_3. This suggests a clear shift to C_3 grass dominance in the environment of Melikane at the time, presumably due to the lower prevailing temperatures.

TABLE 1.— Carbon-13 content of collagen, δ^{13} (rel. to PDB), of collagen from *Equus* teeth of various ages, collected from archaeological excavations in Lesotho and South West Africa/Namibia. The last column lists the contribution of C_3 plants to the diet of the animals as can be deduced from the isotopic composition, δ^{13}. The results clearly show a different composition for the vegetation cover during the Upper Pleistocene

Sample	Approx. age (yrs)	δ^{13} (‰)	% C_3 in diet
	Melikane Cave, Lesotho		
MLK2	1 500	−12,8	38
MLK5	"	−12,2	34
MLK9	20 000	−18,0	75
MLK10	"	−18,3	77
MLK12	"	−18,5	79
MLK13	35 000	−19,2	84
MLK14	"	−18,2	76
MLK20	42 000	−18,8	81
	Apollo 11 Cave, SWA/Namibia		
B156/Z1	recent	−12,6	36
B157/Z2	7 000	−14,1	47
B158/Z3	20 000	−14,9	53
B159/Z4	70 000	−14,9	53

A similar set of zebra teeth from the Apollo 11 cave in southern Namibia indicates a much smaller increase in the C_3 plant component of the diet available to grazers in the area during the Upper Pleistocene (Table 1). It can therefore be concluded that the winter rainfall area along the west coast was not extended appreciably further northwards during the Last Ice Age.

Many more sites still need to be investigated, but the results gained thus far suggest that changes in the C_3/C_4 ratio of the grass cover could ultimately be reconstructed in some detail. It may also be mentioned that there are several other possible variations on this general theme; for instance,

springbok bones from suitably situated archaeological sites could be used to reveal shifts in the boundary between the Karoo flora and savanna during past changes in humidity. It, therefore, seems clear that this new isotope tool has the potential for providing useful data on palaeoclimates and their effect on the vegetation.

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