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 C4 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 C4 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.

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 isotopic 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. $^2H/^1H$, $^{18}O/^16O$ or $^{13}C/^12C$, 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,

$$\delta^{18} = \frac{\left(\frac{^{18}O}{^{16}O}\right)_{\text{sample}} - \left(\frac{^{18}O}{^{16}O}\right)_{\text{standard}}}{\left(\frac{^{18}O}{^{16}O}\right)_{\text{standard}}} \times 1000$$

Negative values for $\delta$ 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, if 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 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 $^{18}O$ decreases by 2‰, whereas the average temperature decreases by 5 to 6°C. During the last glacial maximum $^{18}O$ 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 6^1/20 in the deuterium content corresponding to 0.8%° in ^18O, 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 ^18O 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 ^18O analyses of CaCO₃ (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 ^18O record of climatic change since Upper Pleistocene times (Vogel & Talma, in preparation.).](image-url)

**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 C₄ pathway of photosynthesis in southern Africa provides a unique opportunity of investigating changes in their distribution with time by means of isotopic analyses.

C₄ plants are clearly distinguishable from C₃ plants on the basis of their stable carbon isotope ratio, ^13C/^12C, 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 C₃ and C₄ digested by the animal and to establish any changes in the C₃/C₄ ratio of the plant cover.

In a previous study (Vogel *et al.*, 1978) it was found that C₄ grass species were dominant in most of the summer rainfall area of the sub-continent, whereas C₃ 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 C₄ species, and it is to be expected that the lower temperatures prevailing during the Ice Ages would have resulted in an expansion of the C₃ 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 ^13C content of collagen in modern zebra bones from the C₄ 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% C₃ plants, whereas the diet of the Pleistocene specimens increased to over 80% C₃. This suggests a clear shift to C₃ grass dominance in the environment of Melikane at the time, presumably due to the lower prevailing temperatures.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Approx. age (yrs)</th>
<th>δ¹³C (%°o)</th>
<th>% C₃ in diet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Melikane Cave, Lesotho</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLK2</td>
<td>1 500</td>
<td>−12.8</td>
<td>38</td>
</tr>
<tr>
<td>MLK5</td>
<td>&quot;</td>
<td>−12.2</td>
<td>34</td>
</tr>
<tr>
<td>MLK9</td>
<td>20 000</td>
<td>−18.0</td>
<td>75</td>
</tr>
<tr>
<td>MLK10</td>
<td>&quot;</td>
<td>−18.3</td>
<td>77</td>
</tr>
<tr>
<td>MLK12</td>
<td>&quot;</td>
<td>−18.5</td>
<td>79</td>
</tr>
<tr>
<td>MLK13</td>
<td>35 000</td>
<td>−19.2</td>
<td>84</td>
</tr>
<tr>
<td>MLK14</td>
<td>&quot;</td>
<td>−18.2</td>
<td>76</td>
</tr>
<tr>
<td>MLK20</td>
<td>42 000</td>
<td>−18.8</td>
<td>81</td>
</tr>
<tr>
<td><strong>Apollo 11 Cave, SWA/Namibia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B156/Z1</td>
<td>recent</td>
<td>−12.6</td>
<td>36</td>
</tr>
<tr>
<td>B157/Z2</td>
<td>7 000</td>
<td>−14.1</td>
<td>47</td>
</tr>
<tr>
<td>B158/Z3</td>
<td>20 000</td>
<td>−14.9</td>
<td>53</td>
</tr>
<tr>
<td>B159/Z4</td>
<td>70 000</td>
<td>−14.9</td>
<td>53</td>
</tr>
</tbody>
</table>

A similar set of zebra teeth from the Apollo 11 cave in southern Namibia indicates a much smaller increase in the C₃ 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 C₃/C₄ 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.

ACKNOWLEDGEMENTS

I am indebted to Dr D. Bredenkamp of the then Department of Water Affairs for originally drawing my attention to the Uitenhage aquifer; to Mr M. Schultz, Town Clerk of Oudtshoorn for permission to remove a stalagmite from the inner part of the Cango Caves for analysis; to Prof. H. J. Deacon for his assistance during the initial stages of the project; and to Mr J. Blacquire for his invaluable help in securing the specimen. Dr W. E. Schiegl and Mr A. S. Talma performed the isotope analyses reported here, while Annemarie Fuls, Lies Lursen and Ute Kiso prepared the collagen samples for measurement.

REFERENCES


