THE PLUVIAL THEORY — AN EVALUATION IN THE LIGHT OF NEW EVIDENCE, ESPECIALLY FOR AFRICA

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ABSTRACT

The recent evidence for former dry and more humid conditions in Africa has been discussed. These data are primarily of a biological nature. The explanation of the palaeoclimates of Africa should be based on the principle of "climatic actuality" as it will be impossible to explain the former climates without knowing those of the present day. The variations in temperature which have occurred simultaneously with the glacial history, should be taken into account in this respect.

Good, well-dated, proof has been found for hypothermal pluvials in some parts of Saharan and equatorial Africa. Convincing evidence has also been published for the existence of subpluvials of Neolithic (Atlantic) age in the Sahara. Dry interpluvial conditions of Würmian age have been described for the Stanley-pool area and for Ethiopia.

In Africa there is a great need for many more C^{14} dates of material which is of ecological interest. More radiocarbon stations should be available for this purpose.

INTRODUCTION

THE glaciations which mark the eventful history of the Quaternary have been the object of research for more than 130 years. The glaciers which spread and waned left more or less clear marks of their gigantic activity. Although these glaciers were restricted to certain areas, their stages and their chronological sequence are still a matter of much scientific dispute, while our knowledge of the non-glaciated areas is in a much more embryonic stage. The study of the climates of these areas is extremely difficult as former changes in rainfall and in temperature left only minor traces which are not easily discovered and understood. The setting up of a chronology for these palaeoclimatic changes is a complicated task as these climatic changes were not restricted to certain areas and were different in nature. This diversity of climates has not been understood by many Quaternary research workers and this explains why the pluvial theory had such a great following. It is because of its attractive simplicity that this theory has fascinated researchers, notwithstanding the slender evidence on which it was built and the wise warnings of its founders. For a long time it has been widely accepted that glaciations coincided with greater rainfall in the non-glaciated areas not only in the whole of Africa but also in other parts of the world.

Surveying the general state of our present knowledge we see that there exists good evidence for pronounced pluvials and for dry periods during the Quaternary in some parts of the world. Our present approach to the Pluvial Theory should be to search for more suitable localities for research, to see whether these secular variations in rainfall can be correlated with other phenomena such as the glaciations, and to try to explain their origin. For the understanding of the pluvials and their distribution in time and space we have to enlarge our knowledge of the present-day climatology of Africa.

The new evidence which has been obtained is of biological, physical and geological nature and has been summarized recently by Flint (1963). The interpretation of these data in terms of former climates is rather complicated as it is often difficult to separate and to evaluate the influences of the principal climatic factors such as temperature and general humidity.

The present day climatic pattern of Africa can be divided into drier and wetter belts. The position of these belts depends on the general global wind regime. West and Central Africa fall in the region of the equatorial rains and have perhumid, humid and subhumid climates. This centre of high rainfall is surrounded by a dry subhumid region, especially in East Africa. The semi-arid and arid belts, which cover the big northern part of the continent and most of southern Africa, are bounded at both extremities, along the northern margin and in the Southwestern Cape, by a small zone which receives winter rains. These small border areas are the only parts of

Africa which are at present dominated by the Westerlies which bring cyclonic rains. The rest of Africa falls in the area of the trade winds and " monsoons ".

CHANGES IN TEMPERATURE DURING THE QUATERNARY IN AFRICA

For our understanding of the palaeoclimates of Africa it is important that proof of variations in temperature, especially of cooler conditions, has been coming forward in recent years. The results of the analysis of pollen-bearing deposits from sites in Kenya and South Central Africa have shown that the vegetation belts of the mountains in these parts shifted downwards between 800 and 1100 m. during the last severe stage of the Würm glaciation (van Zinderen Bakker, 1964a, Coetzee, 1964). This downward shift only calculated according to the temperature gradient indicates a decrease in temperature of 4°C to 5°C. The actual value of this decrease will, however, have been bigger. More proof of this same phenomenon has also been coming from the southwestern part of Uganda (Livingstone, 1964; Morrison, 1964) Pollen evidence of cooler conditions has also been found by van Campo & Coque (1960) in Tunisia, by Quézel & Martinez (1962) from the Central Sahara, and by Beucher (1963) for the northwestern Sahara (near Béni-Abbes).

We can assume that Africa during the Quaternary not only experienced changes in rainfall, but that the temperature variations, which are well known for the northern hemisphere, occurred there also. It has been proved with C^{14} age determinations that the last important hypothermal period in Africa was co-eval with the last Würm maximum of Europe. The latest results show that other fluctuations in temperature, which are well known for Europe can also be detected in Africa by pollen analysis. These pollen results are supported by circumstantial evidence produced by phytogeographical and pedological work (van Zinderen Bakker, 1964b). The latest study on the glaciations on Kilimanjaro by Downie (1964) also strongly suggest a close correlation between the Quaternary temperature variations in Africa and those in the northern hemisphere.

These new data on the temperature chronology of Africa will assist us greatly in understanding palaeoclimatological conditions and in explaining the former and present biogeographical patterns of the continent. It has often been said that changes in temperature of the magnitude of only 5°C are of minor importance in a tropical continent such as Africa. These changes have, however, been of very great significance. They affected the regional climate both directly and also indirectly because of their influence on the humidity factor. Little but consistent changes of this nature can have an enormous influence on the distribution of plants and animals, and they must therefore also have been of great importance in the life of prehistoric man. Viewed in retrospect it is conceivable that in a tropical dry continent such as Africa the importance of temperature fluctuations has been overlooked, while the idea of pluvial periods was readily accepted.

THE SAHARA REGION

The explanation of the climatic regime of Saharan Africa is still little known especially for the changing conditions which existed during the Quaternary. Widely different theories have been put forward. Dubied (cited in: Monod, 1963) has stressed the importance of the Sudano-Saharan depressions " running east to west (Sudan), then north to northeast (Sahara) and finally west to east (Mediterranean)". This theory gives the Sahara a climatic regime which is more or less independent of the regions on its northern temperate and its southern equatorial border.

Balout (1952), on the other hand, thinks in terms of shifts of climatic belts. During the northern glaciations the more humid mediterranean climate should have invaded the Sahara and caused pluvial conditions, whilst the influence of the " monsoons " coming from the south brought rain to the desert during the interglacial periods. These last more humid periods, for which we now possess good proof, are known as " subpluvials ".

Büdel (1963) is of the opinion that the northern, central and southern parts of the Sahara had an entirely different climatic history. The northern region had a number of pluvials during the Quaternary, the central belt must mostly have been dry, while the southern zone was dry during the Lower and the greater part of the Middle Pleistocene. Others as K. W. Butzer expressed the opinion that pluvial conditions invaded the Sahara simultaneously from the Mediterranean and the Sudanese sides.

In recent years the astronomical theory of Milankovitch has been applied to Africa by Bernard (1962). He comes to the conclusion that "intertropical pluvials correspond .... with interglacials in the high latitudes, and warmer tropical oceans supplying through active evaporation a larger amount of water vapour to continental areas". He distinguishes two types of pluvials for the equatorial and subequatorial regions which alternate on both sides of the equator. Dry periods in the equatorial regions should correspond to glaciations in the high latitudes and to colder tropical seas. Pluvials of cyclonic winter rains, which occurred at the extremities of the African continent are supposed to correspond with a northern and a simultaneous southern glaciation.

Monod (1963) in his excellent review of the Sahara makes it clear that it is still too early to explain the many regional variations of the palaeoclimate which occurred in this vast and complex desert. He also points out that a small increase in rainfall can cause tremendous changes in the biological environment of certain parts of the desert. The term pluvial can, when applied to a dry region, lead to exaggerated ideas. So far there do not exist exact methods to assess the amount of former rainfall. The temperature factor will in this connection have been of great importance, especially during hypothermal periods.

In considering the extensive new data on Quaternary climates in the Sahara only those results, which can be correlated with more or less exact age determinations, will be discussed here.

(a) Cool humid conditions of Upper Würmian age

Beucher & Conrad (1963) described the pollen preserved in lignite of the age of $20{,}000 \pm 1000$ years in the southern Algerian Sahara. These dated samples give a most important proof of a "Würmian-pluvial" in this region.

Beucher (1963) also showed with the aid of fossil pollen that the climate became wetter in the same area during the Saourian, the last important Saharan pluvial.

Van Campo & Coque (1960) concluded from pollen evidence in southern Tunisia that during the Würm glacial the climate must have been semi-arid with cool winters.

The results described by van Campo (1964) from the Hoggar in the central Sahara show that cool, more humid, periods occurred here during the Quaternary.

Quézel & Martinez (1962) recorded valuable pollen data from the southern Sahara. Although the number of recovered pollen grains is small the records indicate that the Tchadian Sahara had a steppe vegetation during the last Würm maximum.

A very valuable proof of pluvial conditions in the eastern Libyan Sahara has been published by Knetsch *et al.* (1962). The artesian water in this region apparently has an age of 25,000-30,000 years.

These recent studies give extremely important evidence for more humid and cooler conditions, especially in the northern Sahara and in the mountains of the southern Sahara, during the Upper Pleistocene. The C^{14} age determinations prove with certainty that this period was coeval with the last severe maximum of the Würm glacial. These pluvials have also been discussed by Schwarzbach (1953), Flohn (1959, 1963), Büdel (1963), Monod (1963) and others.

It has been widely accepted that these humid conditions were caused by a southward movement of the climatic belts during the northern glaciation. The depressions, which at present bring much rain to western Europe, originate above the Atlantic Ocean and only in winter reach as far south as the Mediterranean area. These cyclone tracks must have moved much further south during the glaciations and will have traversed the northern Sahara.

During hypothermal periods which were coeval with glaciations the same phenomenon could have occurred at the southern end of the continent. So far we do not however possess good evidence for cool humid periods in that part of Africa.

(b) Subpluvial conditions of Neolithic age in Saharan Africa

In recent years it has become known that more humid conditions occurred in the Sahara not only during the last northern glaciation, but also during the warmer interglacials. Balout (1952) was one of the first to describe these humid phases, which are now known as "subpluvials". He went so far as to state: "Le dernier interglaciaire a donc été pour le Sahara la dernière grande période d'humidité, très supérieure en ampleur à celle du Néolithique ..." The best known of these subpluvials is of the same age as the post-glacial climatic optimum in Europe. The very interesting industries of Neolithic age, found as far south as the Ténéré area point to habitation in many parts of the desert which are at present inhospitable. Rock paintings, deposits of diatomite, biogeographical and geological data, and also the results of pollen analysis show without doubt that this warm Subpluvial preceded the process of the slow drying out of the desert. Quézel & Martinez (1962) presume that this humid period had already begun in Late-Glacial times. In Neolithic times, between 5000 and 6000 years ago, a number of mediterranean trees occurred in the Central Sahara, especially on the mountains. Some of the archaeic specimens of *Olea laperrini*, which still grow there, may have survived since then.

Fairbridge (1963) stated that the erosion phase of the Nile, which represented a humid phase with may oscillations, lasted from 10,000 to 3,000 B.P. These dates could be correlated with the pollen results of Quézel and Martinez.

The first results of van Zeist (1963) of his pollen studies in the mountains of southwestern Iran also point to an increase in precipitation about 5,500 years ago. A decrease in temperature could theoretically according to van Zeist, have caused the same effect.

The interglacial subpluvials can be explained by assuming a northward shift of the climatic belts so that the Sahara came under the influence of the tropical zone and received rain from the so-called "monsoons". Flohn (1963) has discussed this explanation using the interesting abnormal meteorological conditions which can, even at the present day, bring rain from the south to the mediterranean coast of Egypt in late summer.

EVIDENCE FOR ARIDIFICATION IN THE AFRICAN EQUATORIAL REGION DURING THE WÜRM MAXIMUM

Pollen evidence indicates that during the Würm glaciation the climate was not always humid. The Central Sahara was apparently arid, just as southwestern Iran (VAN ZEIST, 1963) and British Guiana (V. D. HAMMEN, 1961). Fairbridge (manuscript) warns that desert dunes should not automatically be correlated with former warm phases, but possibly with cold episodes. In his study of the Nile sediments (1963) he comes to the conclusion that the "Siltation Stage", which lasted from about 25,000 to 10,000 years ago, and was broadly coeval with the last Würm maximum, indicates aridity not only in the Nile catchment area but also of the entire tropics. Fairbridge agrees with Bernard that during the glaciation the evaporation from the cool tropical oceans must have decreased substantially, and this could have caused aridification in the tropical belt. It should however not be overlooked that the Nile receives much of its flood water from the high mountains of Ethiopia. During the Würm the temperature would have dropped in these mountains about as much as has been demonstrated for the East African mountains. This lowering in temperature which caused the vegetation belts on the East African mountains to shift about 1000 m. downwards could have brought the greater part of the Ethiopian mountains above the tree line. The rainfall on the East African mountains diminishes rapidly above the tree line and the sedimentation of the Nile may in consequence be primarily a proof of a lower temperature during the Würm. This point will have to be studied carefully from the botanical-ecological point of view before the siltation stage of the Nile can be used as an indification for aridification in the tropical belt of Africa.

Interesting proof for semi-arid conditions during the greater part of the last Würm maximum has recently also been produced by de Ploey (1963) for the region of Stanleypool on the western side of the Congo basin. This dry phase fits well in time with the "siltation stage" of the Nile mentioned above, as can be deduced from the two pollen dates given by de Ploey. The pollen evidence described from north-eastern Angola (VAN ZINDEREN BAKKER, 1963) and the redistribution of the Kalahari sand (CLARK, 1962) could both point to semi-arid conditions in the area adjoining the northern border of Angola.

The pollen spectra of the end of the Würm maximum (14,503$\pm$560 B.P., Lamont, L-

3991) indicate a montane forest type which is found at present in small patches in southern Angola at an altitude of 800-1200 m. above the altitude of the fossil pollen site. The climate must therefore have been cool in northeastern Angola. It is very possible that, during the last Würm maximum, this forest type survived along the river as a fringing forest, while the higher ridges between the river valleys had a very open type of vegetation, so that the forest would, as far as water is concerned, have depended on the local edaphic conditions. The climate may have been dry or at least characterized by long pronounced arid seasons.

A dry interval in the intertropical region during a maximum glaciation fits well with the scheme proposed by Bernard (1962) who calculated that this period of aridification has lasted from 33,000 B.P. till 18,000 B. P. Much more proof is, however, needed before this scheme can be accepted. A better understanding of the present meteorology of Africa will also be necessary for an interpretation of former climatic conditions.

EVIDENCE FOR PLUVIAL CONDITIONS IN EQUATORIAL AND SOUTHERN AFRICA DURING THE WÜRM MAXIMUM

Exact data for the age of pluvial conditions in these parts of Africa are still lacking, but a considerable body of circumstantial evidence for higher rainfall in many parts is at present available. Many more C^{14} age determinations of material of ecological importance are required before we can correlate the pluvial-interpluvial alternation of these regions with the glacial chronology.

The new evidence for more humid conditions is mainly ecological in nature. The phytogeographic study by Morton (1962) of the vegetation of the mountains and hills in West Africa points to former cool and more humid conditions. The present vegetation pattern clearly shows that contacts must have existed with the East African mountain vegetation and even with that of more remote areas.

The present distribution of the montane forest patches in East and Southern Africa indicates that this forest type must have covered extensive areas on the high plateaux and the mountain ranges right down to the southwestern Cape, and also across the continent along the Congo-Zambesi water divide (v. Z. BAKKER, 1964a). This contact is also demonstrated by the close taxonomic affinities which exist between the present forest relics as far south as the Cape (AUBRÉVILLE, 1949). The extensive montane forests may have existed during hypothermal periods, such as have been demonstrated by pollen analysis for East and Central Africa. This period consequently, must have had a humid climate, at least on the mountain slopes and on the high plateaux.

This phytogeographical evidence is strongly supported by the results Moreau (1963) obtained from the distribution patterns of birds and by the map published by Minter (in v. Z. BAKKER, 1964b) of the relic areas of the sandfly *Phlebotomus guggisbergi* Kirk & Lewis in the montane forests. The same interesting results have been obtained by the zoogeographical study of the African butterflies by Carcasson (1964), who stresses the " close similarity of the butterflies of all the mountains of tropical Africa " (p. 130). His map of African vegetation during a pluvial maximum show much resemblance with the map published by the author for the hypothermal phase (1962).

The study by Streel (1963) of the woody vegetation of the Lufira valley in Katanga also points to a pronounced heterothermic climate duting the Quaternary. The interesting ecological work of Lawton (1963) and of Fanshawe (1961) on the woodland and forest of Northern Rhodesia indicates that more temperate and humid conditions must have existed in the recent past.

Pollen analytical research has shown that cooler pluvial conditions occurred in most of the higher parts of East and Central Africa during the last Würm maximum. We can assume that climatic conditions of this type have existed in Africa several times with different intensity.

DATA ON DRY CONDITIONS OF UNCERTAIN AGE

Biological evidence of dry conditions will always be much more rare than proof for humid climates. The pollen evidence from the oldest horizons of the Florisbad deposits, which can, unfortunately, not be dated with the C^{14} method, shows that the climate must have been semi-arid. Considering all the other evidence from this site it is possible that this semi-arid period belongs to the Eemian (Riss-Würm Interglacial).

Some very interesting facts on the distribution of plants and animals have in recent times been added to our knowledge of the former dry climates. De Winter (in v. Z. BAKKER, 1964b) has pointed out that there exists a strong taxonomic affinity between the arid zones of eastern and of southwestern Africa. Moreau (1963) has discussed the distribution of the larks (Alaudidae) and other birds in these same dry habitats in the north and in the south. Van Bruggen (1964) has published maps on the distribution of *Xerocerastus* which show that the low arid Limpopo valley can act " as a corridor from the arid interior into the dry areas of the lowlands of Mozambique . . . ". This very important result shows that " dry migration routes " must have played a part during the Interpluvials. Pollen evidence indicates that the wide low Limpopo valley must also have been dry and warm during the Upper-Pleistocene hypothermal period.

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