

Past Climates of Central Africa

An Inaugural Lecture

GIVEN IN THE UNIVERSITY COLLEGE OF
RHODESIA AND NYASALAND

Professor G. Bond

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by

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I. INTRODUCTION

As human beings we have a natural tendency to judge time by reference to our own life span. One of the most difficult aspects of training geologists, though not one which is given much conscious effort, is to teach the student to think in the vast periods of time which the modern view of the subject demands. Even so it is doubtful if any of us can really visualize even a million years of time, yet this is only the period during which our own species has been on the earth. Because of this subconscious measurement of time, we tend to regard our present earth as having always been as now, with the same scenery, the same geography, and the same climate. Even an elementary acquaintance with geology soon shows that the crust of the earth is dynamic not static, and that the distribution of land and sea has changed radically throughout geological time.

Less attention has been paid to climatic change, yet the record is clear here too, that at any place on the earth's surface long and short period changes of climate have taken place throughout geological time. This country has not the benefit of detailed climatic records going back for more than about seventy years. However, the constant fear of farmers, particularly in the drier parts of the country, is that even since records began the climate has been drying up. The 'encroachment of the Kalahari' is a real fear, at least in Matabeleland. Seventy years is only the traditional life span of man. Is there likely to be any truth in the belief that our climate is now significantly drier than in 1890, or any substance in this fear? If so, this is a serious state of affairs

indeed. Considerations of this kind might be regarded as a kind of local justification for studying past climates.

Mountaineers will tell you that they climb mountains because they are there. To me the main reason for delving into past climates is simply that there must have been climates throughout geological time, and I want to know what they were like and perhaps find some of the underlying causes of change. Since present climates are influenced by present geography, and since geography has changed in the past, it might be inferred that climate has also changed, even if all other factors remained the same.

Palaeoclimatology is a controversial subject, although fewer people argue about it than over many other aspects of geology. Data on past climates are always second order, since they depend on interpretations of field observations. There should be no argument about the field facts, since these are mainly direct observation on the rocks themselves, but deductions on climate from these facts are particularly susceptible to challenge.

It rather reminds me of the story which went the rounds of the Commonwealth Mining and Metallurgical Congress, recently held in Southern Africa:

The big chief of a large mining house suddenly demanded that his company should advertise for one-armed geologists and eventually replace all those with two arms. There were very few applicants, but no one dared to ask the Managing Director for a long time why he wanted one-armed geologists. Eventually someone with more courage than the others did ask him. His reply was something like this: 'I'm tired of the ordinary kind of geologist. You ask them a simple question, and they always answer—"on the one hand it might be so and so, but on the other hand. . . ."' So it often is with the climatic interpretations of geological

field evidence. There are, however, some aspects on which there is general agreement.

II. SOME METHODS OF DEDUCING PAST CLIMATES

Although palaeoclimatology is only now getting on to a firm footing, the main principle on which it depends was stated a few years before 1800 by James Hutton, a Scottish lawyer, physician, farmer, and geologist (in those days it was possible to be a geologist as well as many other things—now geology has become a bit more complicated). Hutton demonstrated that the processes of weathering, erosion, and transportation which we can observe today, and which are the starting processes for the formation of new sedimentary rocks, had been going on since very ancient times. This was later stated by Sir Charles Lyell as the doctrine of Uniformitarianism.

The character of a sediment is greatly influenced by the conditions of weathering, transport, and erosion in its source area. The kind of sediments forming today under a wide range of conditions can be directly related to the environments in their source areas, or to the conditions under which they are deposited. One of the environmental factors is climate. Under conditions of marine sedimentation this factor may be obliterated or disguised, but if deposition takes place in a continental non-marine environment, the climatic factor may be predominant.

The climatic record, therefore, comes from the study of sedimentary rock sequences, and their contained fossils, by applying the simple principle that the study of the present is the key to the past. Palaeoclimatology is just one aspect of stratigraphy, the patient piecing together of earth history as far back in geological time as one can probe. It is best carried out by studying continental (that is, non-marine)

sediments. Unfortunately most of the sediments in the stratigraphic column are marine. Non-marine sediments such as lake, river, desert, and ice deposits are inclined to be temporary, being merely resting stages in the general tendency for all sediments to be dumped in the sea. It is only by accident, as it were, that such deposits stay long enough in continental basins to be consolidated into durable rocks. The climatic record, therefore, tends to be full of gaps. Africa has advantages in this respect, since it has not been submerged for a very long time, and has been subject throughout this long period to dimple-like depressions on its surface in which considerable thicknesses of non-marine sediments have accumulated. Even today such depressions exist, and are trapping sediments which will record the climatic events of the present and the recent past. The Makarikari Lake in Bechuanaland and the Bangweolu swamps in Northern Rhodesia should be recording present climates of about 15 in. per annum and 50 in. per annum respectively.

Oddly enough, the two most easily interpreted climatic sediments were formed under extremes of climate, and are the easiest to understand. These are extreme cold, leading to glacial sediments, and extreme heat giving either desert sands or beds of evaporites such as rock salt and gypsum. It is, of course, possible to have glaciers at the equator on high mountains. East Africa has such glaciers at the present day, but luckily it is possible to distinguish the products of high mountain glaciers from those of continental ice sheets which can only exist, under our present conditions, in high latitudes. On the other hand, it is difficult to imagine hot desert sands being formed anywhere except in the sub-tropical desert belts.

An ingenious method of plotting ancient wind directions

has been developed from the directions of dune bedding in fossil desert dunes. This helps to plot the wind belts of these old deserts, and a present member of the Physics Department of this College has played a leading part in such studies (Opdyke and Runcorn, 1959).

These are perhaps the most direct and universally accepted evidences of past climates.

A further application of the study of the present as a key to the past is the use of organisms, both plant and animal, and application of the habitats of present species to their nearest fossil relatives. For the comparatively recent past, in particular during Pleistocene time which covers the last million years or so, this works fairly well. It varies in reliability from one group of organisms to another. The tiny marine foraminifera living in the surface layers of the oceans are perhaps the best indicators. They are entirely at the mercy of their environment, and various species indicate quite clearly the conditions under which they live. It is now possible to take quite long-core samples of ocean-bottom sediments which contain the shells of these minute animals, since they sink when the animal dies. The succession of species in these cores has given clear indication of changes in surface temperatures of the oceans, which presumably are governed by climatic changes (Bradley *et al.*, 1942). The sequence in the North Atlantic shown up by this method comprises warmer and colder phases, dated by radioactivity (Piggot and Urry *in* Bradley *et al.*, 1942), which correlate nicely with the advances and retreats of ice masses worked out on land for the last Ice Age in higher latitudes from glacial and interglacial sediments. This is qualitative evidence of climatic change, but the same cores can be made to yield quantitative evidence of the amount of change of temperature involved. To some extent this can

be deduced from the shells of the foraminifera, but as all living things are to some extent adaptable, this method is liable to increasing error with time, since we have to assume that extinct species have the same climatic tolerance as their nearest living relatives.

The study of the oxygen isotope ratios in carbonates from these cores is, however, independent of the living organisms, and can be made to give fairly exact temperature measurements, which correlate nicely with the qualitative changes deduced from the specific assemblages of foraminifera (Emiliani, 1958; Epstein, 1959).

Although the oxygen isotope technique has been mainly worked out for deposits formed during the Pleistocene (the last million years), it depends on physico-chemical laws which presumably are independent of time, and not on the variable climatic tolerance of organisms. It should, therefore, be applicable to much older deposits, and there is now some evidence that this is so, at least as far back as Cretaceous time, say 75-100 million years (Lowenstam and Epstein, 1954; Emiliani, 1956).

While still dealing with marine events as climatic indicators, there is a further 'inorganic' observation. On many of the world's coastlines there are indications that mean sea level has changed during the Pleistocene. This is shown by sunken forests and peat beds, indicating low sea levels, and by beaches and wave-cut platforms well above present sea level, formed when world sea levels were higher than now. The maximum changes shown by these features are of the order of 300 feet, and the succession of changes is reasonably consistent wherever it can be shown that the features are undisturbed by later earth movements. These changes of level of the sea were caused by the waxing and waning of the polar ice sheets during the last Ice Age. The amount

of water withdrawn from the oceans at glacial maximum and locked up in polar ice, and released in interglacials, is sufficient to cause these fluctuations, and the time factor involved is sufficient for recognizable features to be impressed on the coastal scenery. At present we are living in a moderate interglacial, and if complete melting of the polar ice took place, most of the important coastal cities of the world would be drowned. Rate of change of world climate is, therefore, a matter for serious consideration.

The results obtained from the study of sea-level changes tie in very well with the deductions made from other independent lines for the Pleistocene, but the method cannot be directly used for more ancient periods.

To conclude this brief review of marine matters, the case of reef-building corals may be mentioned, since far-reaching conclusions have been based on them for climatic conditions in the quite distant past.

At the present reef builders are limited by water temperature and cannot thrive in a mean annual temperature below about 65° F. This gives them quite rigid latitudinal limits. Yet in the past reef builders flourished in parts of the world which are now in much higher latitudes. To base climatic deductions on ancient distribution of reef-building corals is perhaps more chancy than usual, since it involves not one but two assumptions, both of which may be unsound. In the first place it assumes that the present latitude of the places where fossil reefs are found has always been the same (and I will show later that this is unlikely), and secondly that fossil reef-building corals had the same climatic tolerance as modern ones. While this may be roughly true, there is no foundation for the assumption until oxygen isotope studies give it a quantitative basis.

The use of fossil land animals is full of pitfalls, perhaps

because on the whole they are more complex than marine organisms. Living on land they are exposed to much wider diurnal and seasonal changes than is usual in the sea, and must therefore have wider temperature tolerance than marine forms. The elephants and rhinoceroses are good examples.

At the present day, elephants and rhino are confined to the warmer parts of the earth, yet remains of these beasts have for a long time been known from regions which are at present, even in a moderate interglacial, extremely cold. Fossil elephant ivory used to be a major export from Siberia, yet the deposits in which it was found indicated an arctic climate. In terms of modern distribution here was a major contradiction. Should one believe the sedimentary evidence, or the mammalian evidence based on present-day distribution?

This elephant species, the mammoth, is extinct, but until a few thousand years ago it was hunted by Stone Age man; and it was Stone Age man who provided the clue which resolved the difficulty. His cave paintings clearly show mammoths with a thick coating of hair. This adaptation of an apparently warm climate mammal to arctic conditions has been beautifully confirmed by the finding of whole mammoth carcasses preserved in the frozen bogs of Siberia, complete with their thick woolly coats. However, this kind of thing makes one highly suspicious of climatic deduction based on terrestrial mammals.

Close relatives of our modern African fauna have been found fossilized in various deposits of the Pleistocene of this continent, and have been used as indications of the climate of their time. Yet modern studies show how wide a tolerance many of these species have, and how unreliable their fossilized and often fragmentary ancestors are as climatic indications. (Bourlière, personal communication.)

A few examples will be sufficient. African elephants wander quite happily to over 13,000 feet on the mountains of the Albert National Park, so do buffalo. Even hippo have been found living, but not breeding, so high on the same mountains that the water temperature never exceeds 36° F. and occasionally freezes at night. Yet the presence of fossil hippo in interglacial sediments of the Thames valley has been held to indicate almost tropical temperatures there in interglacial phases of the Pleistocene Ice Age. Fossil hippos found in areas which are now arid may indicate wetter conditions, but can hardly be used as temperature indicators.

In fact most of our African mammals are astonishingly adaptable. Probably the most reliable is the common warthog, possibly such swamp-living species as *Sitatunga*, and forest forms like the bongo and okapi. Man himself is the most adaptable of all mammals. Our descendants will not be able to make any deductions from our remains, but our very early African relatives, the South African man-apes, the *Australopithecines*, were probably only able to survive in conditions as restricted as the warthog and, moreover, it was probably the same semi-arid savannah environment.

Certain birds, mainly the poor fliers, are, however, likely to prove good climatic indicators. The present discontinuous distribution of the purple-crested lourie is best explained by postulating a wetter climate in the fairly recent past, with a great extension of its habitat of riverine bush along the existing river courses. A considerable amount of this kind of evidence has been put together by Moreau (1952, 1954).

Plants, on the whole, are much more tied to their environment than animals. It is not necessary to have the whole plant. The pollen is sufficient, and luckily pollen is

extremely resistant and survives in certain kinds of deposit for a very long time. Very detailed work has been done on Pleistocene pollen in the northern hemisphere, and the results coincide beautifully with other methods to give a detailed record of climatic change in the Pleistocene Ice Age. Much less work has been done in Africa, but the results are promising. Most of this work has been done by van Zinderen Bakker (1961).

Some of the pollen work which deals with changes during the last 60,000 years has the advantage of being datable in years by the C^{14} (radiocarbon) method. Before this was possible, there was the major difficulty of comparing the relative chronologies of geological events built up by stratigraphic observations in glaciated areas of high latitude with the so-called pluvial and non-pluvial sequences in low latitudes. Meteorological theory suggested that pluvials should be equated with glacial maxima, but on the other hand it was also possible to construct theories which equated glacial phases with interpluvials. Until absolute dates became feasible, it was not possible to decide between rival theories. Many more such dates are needed, but the study of Searles Lake in North America (Flint and Gale, 1958) shows that in one case at least the correlation should be glacial-pluvial, and interglacial-nonpluvial. This pattern might be applicable to earlier phases.

A very complicated pattern of climatic change has been suggested for semi-arid parts of Africa during the last half of the Pleistocene. The interpretations of the field evidence have not always been very soundly based, but mere complexity should not be held against them. Hollingworth (1962) has reviewed evidence for rates of climatic change in the glaciated regions, and shows that oscillation of the order of one or two thousand years involved temperature changes

of several degrees centigrade in north-west Europe. If climates in low latitudes changed in sympathy, there is plenty of room in the geological record for all the changes which have been postulated in Africa.

The validity of the Pleistocene climatic succession in Africa has recently been the subject of a masterly review by Flint (1959). While he shows how slender is the basis for the earlier climatic phases, he does regard the latest major pluvial, the Gamblian, as well founded. This falls within the period which can be absolutely dated by the radio-carbon technique. The pollen studies of van Zinderen Bakker (1961) from sites so widely separated as Mufo in north-east Angola, Kalambo at the extreme north of Northern Rhodesia, and Florisbad in the Orange Free State, show cooler and wetter conditions in the Gamblian. Radio-carbon dates from the same deposits link the Gamblian Pluvial with the Würm glaciation of north-west Europe, and this strengthens the case for glacial-pluvial correlation.

For the detailed study of climatic changes in the later Quaternary, nothing could be better than the sediments of 'closed' basins. The Makarikari Lake in Bechuanaland is such a basin, in which the only outlet is evaporation. Consequently it is now very saline. It lies in a climatically sensitive semi-arid environment, and the saline waters should have preserved pollen blown into it while sedimentation took place. A mining company is at present exploring its possible exploitation for salt. Part of the programme involves core-drilling in the sediment of the lake floor. It may be possible to obtain some of this core for pollen analysis and sedimentological study. This could lead to a major advance in knowledge of climatic fluctuations in Central Africa.

This brief review of methods of climatic deduction is by no means complete, but I hope it has given some indication

of the range of methods now available. Perhaps the most startling result of their application to the past is that our present world climate, which we regard as normal, is in fact abnormal. Polar ice caps and the present strong latitude zoning of climate, which we regard as normal because we live in it, are probably only intermittent features of the world climatic pattern.

III. THE CLIMATIC RECORD IN CENTRAL AND SOUTHERN AFRICA

This region contains some of the oldest known rocks of the earth's crust, radio-active ages in excess of 3,000 million years having been recorded (Holmes and Cahen, 1955). Unfortunately the older rocks are not very co-operative climatically, as they are generally so altered by heat and pressure that their original nature is obscure. Yet here and there even some of the older rocks give some hints, generally of glacial origins.

Even as far back in time as the Bulawayan System, which has a radio-active age of 2,600 million years, the climate was such that life was at least possible. Macgregor (1940) has described what are probably fossil calcareous algae from a limestone near Turk Mine, some thirty-five miles north of Bulawayo. For all their great age, making them perhaps the oldest trace of life on Earth so far found, these algae (if they are proved to be truly organic) must have required climatically controlled temperatures not radically different from those possible on the modern world. It is not possible to guess more from such remains, the organic nature of which is not yet established. It is hoped soon to submit material to laboratory tests for amino-acids.

There have been suggestions that the sedimentary rocks of the Witwatersrand System, from which South Africa's

gold is won, have glacial or at least peri-glacial connexions. These rocks are of respectable antiquity, having been dated around 2,100 million years.

Other glacial episodes have been suggested during the deposition of the Table Mountain Sandstones of the Cape (Devonian, 350 million years) and in later Pre-Cambrian times (of the order of 600-700 million years) in Katanga and Angola. Although doubt has been cast on this Central African glacial phase, a review of the evidence by Haughton (1961) tends to reinstate them as glacial. As you can see, even glacial deposits may be open to different interpretations.

After these widely separated and suspect glacial phases, there is an absence of climatologically controlled sediments until the beginning of the Great Dwyka Ice Age at the base of the Karroo System. This began some 230 million years ago, and here surely is an ancient glaciation which defies the doubters. It formed part of a great southern glaciation whose remains are now found scattered over Southern Africa, India, Australia, and South America. The evidence is overwhelming. Not only are the sediments themselves convincing, but they often rest on rock pavements smoothed, polished, and grooved by the passage of ice, as typical as any exposed by the recent retreat of glaciers in the Alps.

Evidence of this glacial phase is known in Southern and Northern Rhodesia in rather remote parts of the Zambezi valley (Bond, 1952; Gair, 1959; Tavener-Smith, 1955).

From this point in time it is convenient to concentrate on a small part of the subcontinent and examine the changes which have taken place with time before turning to the even more controversial question of why wide climatic changes have taken place in so small an area.

At the time of the start of the Dwyka Ice Age, the middle

Zambezi was a 'dimple' depression, rather like the present Lake Victoria, actively subsiding and inviting deposition of sediment. A lake formed in this basin, a proto Kariba if you like, but much larger, probably 400-500 miles across in each direction. It had a sinking floor, but the rate of subsidence was never much faster than the rate of sedimentation, so that it was always shallow. This lake had an active life of about 100 million years, during which a maximum thickness of about 10,000 feet of sediment was accumulated. Much of this is coarse sediment which gives the impression of rapid accumulation. If the rate of sedimentation is averaged, it only amounts to 1 foot in 10,000 years. There is, however, one short section of quite fine-grained sediment where the rate can be counted, since it has annual bands rather like tree rings. About 2 feet of this was laid down in 150 years, a rate many times faster than the overall average. From this it could be inferred that for long periods the floor of the basin could not accept sediment, and what we see as an apparently unbroken sedimentary record is, in fact, a series of rapid accumulations over short periods separated by very much longer periods during which no sediment was formed.

From such a pile of sediment, full of gaps of non-deposition, no detailed record of short-term climatic changes can be inferred, but it is sufficiently complete for the longer-term changes to be deduced.

The record begins, as stated above, with undoubted glacial conditions, which formed part of a widespread episode of very cold climate of long duration. As there are no signs of fossils of either plants or animals, presumably the climate was too cold for life to become established in this area.

The final retreat of the ice was followed by the coloniza-

tion of the area by a cold-climate vegetation, at a time when the basin floor happened to be rather stable, particularly in the region of what is now Wankie. From the great peat moss which developed, the Wankie coal seam of more than 30 feet in thickness was formed (Watson, 1958). When it is realized that it takes about 12 feet of peat to form 1 foot of bituminous coal, the initial thickness of the peat moss can be imagined.

This sub-arctic phase of climate must have been of long duration, since thin coals occur frequently throughout a thickness of about 400 feet of rather fine sediment. Wherever fossils are found in this series, they are plants of the typically southern hemisphere *Glossopteris* flora, which seems to have flourished in cold conditions.

This flora is completely unknown in the northern hemisphere, where a distinct, probably warm-climate flora existed, related to that which had already given rise to the Coal Measures of slightly earlier date in that hemisphere. As far as is known, only once did one flora manage to invade the territory of the other. This happened at one brief period of time in the Zambezi basin. Northern species occur in a shale only a few inches thick associated with *Glossopteris* forms at Wankie and Tete in Portuguese East Africa. The two beds are probably of the same age, and it is tempting to suppose that a temporary oscillation of climate allowed the northern forms to penetrate so far south. Temporary in this sense must have involved a period of several thousand years, which by geological standards is brief. Apart from a few fish remains, no other animals have been preserved from this coal-forming phase.

It was superseded by conditions unfavourable to the formation of coal, though a stunted *Glossopteris* flora survived, but the next series of rocks yield quite a varied animal

population which included fish, amphibia, reptiles, molluscs, insects, and bivalved crustacea. This surely indicates a milder, probably temperate climate. The flora changed its character, *Glossopteris* being replaced by different forms which were more at home in the warmer weather. The lake silted up about this time, and there is a considerable time gap before the next sediments began to form.

These are reddish in colour, and begin with spreads of coarse gravel. The general similarity is with fanglomerate deposits forming at the present day in inter-montane basins where the climate is generally dry and hot, but has short torrential wet seasons; in fact a climate rather like a drier version of Southern Rhodesia today.

The period so far covered goes from the Dwyka Series through the Ecca and Lower Beaufort to the beginning of Molteno times, and the gap referred to is the unconformity between the Lower and Upper parts of the Karroo System.

In the Molteno of the Middle Zambezi valley, the details of which have so far not been published, there is a striking reversal of the trend of climatic change so far seen. The Molteno sediments, which are several thousand feet thick, are of types which can only be regarded as indicating a reversion to wetter, more temperate conditions. In South Africa coals again formed at this time. In Rhodesia no coals are known, but carbonized plant fragments occur. The plants are not of the cold-climate *Glossopteris* flora, but of species which were more at home in a warmer climate. This is a strange and lengthy reversal of the dominant trend of climatic change which had up till now been towards progressively warmer and drier conditions. However, at the close of Molteno time this trend reasserted itself and was carried to extremes. The final sediments of the Karroo System were desert sands indicating a hot, dry climate. The

period closed with vast outpourings of basaltic lava, but thin wisps of sediment between the flows still indicate intense aridity.

This period of reasonably continuous evidence shows, therefore, a change from arctic to hot desert in about 100 million years. During the cold period there was one brief climatic accident of a few thousand years of warmer weather, and during later times (Molteno) a long reversal, which must have lasted many millions of years, to cooler wetter conditions. The difference in scale of these reversions may be significant when causes are considered.

After this 100 million years of climatic history there is an irritating gap in the record which a recent discovery may perhaps partly fill. This is not the place to give details, but large vertebrate bones, probably of dinosaurs, have been found in sandstones at Gokwe, which are younger than the Karroo basalts and older than the Kalahari sands. The sandstones are pinkish in colour, and have features suggesting accumulation in fresh-water conditions, perhaps under a warm climate. If more detailed work indicates the truth of this early guess, a further climatic reversal is indicated. These beds follow on the arid Upper Karroo, but are separated by a major break about which nothing is known. They are also followed by deposits (the Kalahari sands) which again indicate aridity. Their age is at present uncertain, but they may well prove to be Upper Cretaceous, that is, something over 70 million years.

How big a time gap separates these bone-bearing sandstones from the overlying Kalahari Beds is uncertain. A brief inspection seems to indicate a greater degree of unconformity below them than above.

The Kalahari Beds themselves pose a particularly difficult climatological problem. The chief member of the series is

the Kalahari sand, a loose reddish sand which never seems to exceed 300 feet in thickness, but stretches from the Congo river near Leopoldville almost to the Cape. Although its colour varies somewhat, it is monotonously lithologically similar throughout this vast length of about 26° of latitude. The south-western part is active desert at the present day, with mobile sand and dunes. This is in keeping with its rainfall of about 10 in. per annum. Part of the rest is semi-arid, some has more than 60 in. per annum rainfall, yet the indications are that it all accumulated by aeolian action in a near desert environment. No modern desert has a north to south extent of nearly 1,500 miles, since the present climatic belts are too tightly squeezed about the equator.

The Kalahari sand is of rather uncertain age, but is generally regarded now on geomorphological evidence as Middle and Later Tertiary. The rare fossils found in associated beds at its base are of forms which are hardly diagnostic of age. Unless the deposit is of different ages in different areas, a possibility to which I shall return later, it indicates uniform and rather arid conditions for a lengthy period of time over a large slice of Central and Southern Africa. To confuse the issue still further, since it was never consolidated into a compact rock, in some marginal areas it has shifted about in later geological times without having its character appreciably changed.

The end of the main Kalahari cycle of wind-blown sands seems to have come at the end of Tertiary time. This coincides approximately with the onset of the last great Ice Age, and may very well have been connected with this change. It also coincides with the beginnings of mankind about 1 or 2 million years ago.

While few people are much concerned with climates of older periods, once 'man' appears on the scene, the pre-

occupation of man with the study of mankind is such that Pleistocene climates have been the subject of most intensive study. An enormous literature exists on the climatic changes of this brief period. Much of it concerns the area glaciated and deglaciated during the waxing and waning phases of the Ice Age. This is soundly based on a variety of methods which give concordant results. There is less on tropical and sub-tropical Africa, and I regret that much of what there is may not be reliable. I can say this without fear, as I have contributed my quota over the last twenty years. Nevertheless, it is generally agreed that there have been fluctuations of climate in this part of the world. The field evidence, which is not easily interpreted, indicates changes, and meteorological theory supports the idea that advances and retreats of high-latitude ice sheets would impose changes of climate in lower latitudes.

The preoccupation with Pleistocene climates is understandable, since the record is clearer, but perhaps more attention should be paid, particularly in Africa, to Miocene and Pliocene climates. Man probably evolved from arboreal ancestors in Africa. If climates, and particularly climatic change, have anything to do with evolution by forcing animals to adapt themselves to new environments, the critical period in Man's past came before the Pleistocene. By this time his ancestors were already erect ground-living animals, with their forelimbs freed from locomotion and ready to be employed in other more skilled functions such as tool using and tool making.

In partial excuse for the lack of attention paid to this vital period, and in fairness to geologists, it must be admitted that sedimentary deposits of terrestrial origin and Mio-pliocene age are disappointingly rare in Africa.

The Pleistocene record in this part of Africa is not very

well understood, but seems to consist of a series of periods of wetter and drier climates—the so-called Pluvials and Interpluvials. These may well be the sub-tropical reflection of the waxing and waning ice sheets of higher latitudes. The general character of the period was wetter than in the preceding Kalahari times, but there were rapid fluctuations within it. This pattern of short-term cycles within much longer ones may have been characteristic of earlier periods, where, however, the sedimentary record is incomplete and the picture which emerges is a smoothed curve. However, any attempt to explain climatic change must take both long-term changes and short-period cycles into account.

IV. THE PROBLEM OF CAUSES—AND CONSEQUENCES

Factors affecting climate on the earth include solar radiation, latitude, and inter-related ones such as intensity of circulation, mountain ranges, and the distribution of land and water masses. These are all terrestrial factors except for solar radiation.

In seeking the cause of climatic changes disclosed by the Central African sedimentary record, it is hardly possible to start before the Dwyka Ice Age; before that the record is too fragmentary. It is also an advantage to restrict the argument to a small part of the continent, and Southern Rhodesia itself has many advantages.

The climatic record from the Karroo period, which covers almost 100 million years, begins with Arctic conditions consistent with a latitude of 80° – 90° , and ends with hot desert, which at the present day would be characteristic of 20° – 25° latitudes. What is simpler than to explain away this long climatic semi-cycle by suggesting that Southern Rhodesia changed its latitude by this amount during that time? This

TABLE I

Summary of Climatic Changes Recorded in Southern Rhodesia

	<i>Evidence from sediments</i>
Pleistocene	Semi-arid, wet. Rapid oscillations of Pluvials and Interpluvials.
Tertiary	{ U Arid L ?
Cretaceous	? Warm, wet.
Jurassic	Arid, hot.
Triassic	{ Arid, hot. Temperate, wet. Semi-arid, hot.
Permian	{ ? Dry. Temperate, wet. Cold, wet.
U. Carboniferous	Arctic.

(Very little evidence before this time.)

is the basic concept of Continental Drift, and a Symposium was held in this college on this subject not many months ago.

The idea that the continents are not fixed parts of the earth's crust, but have wandered about during geological time, was forced on geologists by this kind of climatic evidence. It was backed up by a great deal more purely geological evidence of structural and stratigraphic kinds. It has also been claimed that many aspects of biology can be accounted for if the continents were at one time differently arranged.

To me the biological evidence is on the whole unconvincing, though the survival of the Australian mammal fauna certainly seems significant. Animals and plants may be transported vast distances under rare freak conditions, without postulating drifting continents. A member of our

Botany Department recently told me of a fern which is only known from Mauritius and the Chimanimani mountains of our eastern districts. Mauritius is a comparatively recent volcanic island, and no one would suggest that such a distribution should be explained by so complex a machinery as Drift.

There is also a case involving birds. The common 'tick bird' of this part of Africa was unknown in South and Central America until a few years ago. It is now well established, and can only have got there through the accidental crossing of the South Atlantic by a breeding community, presumably in some freak storm. Such accidents may be rare, but the fact that they can happen leaves an alternative explanation for some at least of the biological evidence for Continental Drift.

This is not so with other geological evidence, particularly of the climatic kind. To find clear evidence of such diverse climates in one small area forces the idea of Continental Drift on the geologist.

The rate of drifting need not be very rapid. If the suggested change of latitude of Southern Rhodesia took place in 100 million years, and the shortest possible route was followed (this is unlikely, but does give the order of magnitude involved), it only works out at about a mile in 35,000 years, or about $\frac{1}{2}$ in. per annum, if my arithmetic is right. It is hardly surprising that attempts to measure this instrumentally at the present day have not been very successful. Such averages over geological periods can, however, be very misleading and should not be taken too seriously.

This particular problem is one in which modern Physics has come to the rescue of the geological 'Drifters'. It is only in recent years that it has become possible to measure the

direction of magnetization of rocks. One component of this magnetism was impressed on the rock at the time of formation, whether as a sediment or a cooling igneous rock. By measuring this it is possible to calculate the position of the sample relative to the earth's magnetic poles at the time of its formation; in other words, to find out what its latitude was at that time. If this proves to be significantly different from its present latitude, here surely is strong supporting evidence for polar wandering or some form of Continental Drift. Considerations of the earth's rotational and magnetic properties seem to indicate that the poles have remained the same, but that segments of the crust have moved.

The Physics Department of this college has a very active Palaeomagnetic team, who are doing work which delights the geologist. I very much doubt whether many geologists can understand the methods by which they achieve their results. This, however, does not prevent us from gratefully seizing the results and applying them to our own particular problems.

By patiently working their way through the Karroo stratigraphic succession, our team and others engaged on the same kind of work have been able to plot the progress of our piece of crust through this critical period of 100 million years; the results fit the climatic evidence from the rocks quite beautifully.

In Dwyka Ice Age times Southern Rhodesia, according to the magnetic evidence, was almost over the South Pole. No wonder the climate was Arctic. By the end of the period it was somewhere about latitude $25-30^{\circ}$, which fits nicely with the desert sands of the period.

The details of the path followed are not yet all worked out, but from what is known so far it does not appear to

have been a straight line. Since the palaeomagnetic evidence is entirely independent of the geological interpretation of climate, the agreement between them is most gratifying and provides a very reasonable explanation of the general climatic trend throughout the period.

One puzzling anomaly remains. In Molteno times the rocks indicate a reversal, as though the climate had for quite a long period reverted to wet-temperate conditions. This has been one of the gaps in the palaeomagnetic record, but I am told that unpublished work has recently shown that at one time in this period our position was in more temperate latitudes. If this is so, then agreement between the two lines of reasoning is almost uncomfortably close! Such long-term climatic changes can, therefore, be reasonably explained in terms of purely terrestrial causes.

There remain two further major problems, the wide extension of desert in Kalahari times, and the rapid short-term oscillations of climate in the Pleistocene.

Palaeomagnetic evidence from other parts of the world indicates very little Continental Drift since the Middle Tertiary (say 30 million years ago), so that this cannot apparently be invoked to account for it. However, it would be nice to know whether the Kalahari sand represents one long desert phase of wide extent forming sands all of the same age, or whether the desert focus moved progressively, so that sands at each end of the present belt are of different ages. If magnetic studies could be done on such sands and Drift ruled out, we could look elsewhere for an explanation. Nor can Continental Drift be accused of causing the rapid fluctuations of climate during the Quaternary, which only covers the last 1 or 2 million years.

Most of the special methods evolved for the study of climatic change in the Quaternary were worked out in the

northern hemisphere, and are applicable only to glaciated and peri-glacial areas. Some, such as eustatic changes of sea level and pollen analysis, are universally applicable. Even snowline studies can be applied on the high mountains of East Africa. Generally speaking, the work in high latitudes discloses temperature changes, while in low latitudes rainfall changes are looked for. This may be partly conditioned by the feeling that changes in the extent of glaciation involve temperature, while pluvials involve precipitation. But ice caps cannot form without precipitation, and rainfall is only one climatic factor in the African Pleistocene.

As an example of quantitative results from England, Shotton (1960) has suggested an annual mean temperature in Worcestershire 3.5° C. below the present during the last glaciation. Such a modest fall in temperature combined with increased precipitation may have lowered the snow line sufficiently to produce ice sheets in the mountainous parts of Scotland and northern England, since the summit of Ben Nevis is only just below the altitude of the snow line for this latitude under present climatic conditions.

Snow line and glacial studies in East Africa are not yet complete, but old moraines are known on the high mountains there, as much as 3,000 feet below the end of the present glaciers. On the basis of present knowledge, Flint (1959) suggests that a fall in temperature of $5-7^{\circ}$ C. at maximum extension of the glaciers of Mt. Kenya and Kilimanjaro is probable. Changes of precipitation cannot yet be evaluated.

Pollen studies by van Zinderen Bakker (1961) at Kalambo suggest change in both rainfall and temperature during the Gamblian, and perhaps earlier. At a period dated by C^{14} as greater than 52,000 years B.P., when late Acheulean man lived in the Kalambo valley, the climate was more tropical than at present. From about 40,000-12,000 years B.P., the

climate was cooler and wetter. This corresponds to the Gamblian pluvial and the absolute dates correlate it with the last glaciation of Europe and North America. van Zinderen Bakker considers that the changes in vegetation are equivalent to a present altitude range of 1,500 feet, which indicates a temperature change of about 4° C. There is a strong suggestion, therefore, that during the last Glacial/Pluvial phase world temperatures fell $\pm 5^{\circ}$ C.

His pollen work on the Florisbad spring deposits in the Orange Free State leads more to rainfall figures than temperature, and covers the same period as Kalambo, that is the Gamblian pluvial. He suggests that the pollen evidence is a little ambiguous, and he cannot distinguish between the indications of an increase in rainfall of about 100 per cent., or 400 per cent.

Even the first of these possibilities is a very large increase, and conflicts with quantitative estimates based on geological considerations. Brain (1958) has devised an elegant and ingenious method of deducing quantitative rainfall figures for the much earlier period when the Australopithecine-bearing cave breccias of the Transvaal were being formed. This was probably in the Lower Pleistocene, and his curves show a climatic cycle which ranged from about 50-150 per cent. of present rainfall.

By a different line of reasoning it is suggested (Bond, in press) that at Lochard in Acheulean times, but before the final Acheulean, 'Dambo' conditions prevailed in the flat country forming the headwaters of the Bembesi drainage basin. The present climate has about 25 in. of rain per annum, and dambos only form when rainfall exceeds about 40 in. per annum. These conditions were followed by a period of calcium carbonate concretion formation with an optimum of about 18 in. per annum.

collected from various papers, and are quoted from Zeuner (1951, pp. 37-38).

All these observations on fossil sun-spot cycles give approximately the same period for this form of solar activity, which seems to have been going on in much the same way as at present as far back in time as we can trace it.

There may well be long-term cycles of change in other forms of solar radiation, but as yet no way of inferring them from the geological record has been discovered.

But Ice Ages seem to recur fairly regularly in the pattern of terrestrial climates, and reduction of solar radiation leading to a general lowering of temperature is a convenient trigger mechanism for initiating them.

A rhythm of glacial phases about every 250 million years has been suggested (Umbgrove, 1947), and a solar cycle of the same length, based on nuclear energy considerations, has also been suggested (Opik, 1958).

From the geologist's point of view, this is also a convenient passing of the buck to the astronomers.

Perhaps Hoyle's idea of cosmic dust clouds through which we occasionally pass and which partially absorb solar radiation before it reaches our planet is a likely solution.

The rate of change of climate in the shorter cycles can nowadays be obtained with some accuracy by radio-carbon dates during the very latest part of the geological record. From 12,000-4,000 B.C., deglaciation and release of water from ice-caps raised world sea levels 200 feet (Godwin, Suggat, and Willis, 1958). Although this is long term by the standard of a human life span, the human race as a whole must have had to do some adjustments. Areas of northern Europe, Asia, and northern America, which had previously been covered by ice, became available for habitation, while previous land areas such as the North Sea bed were flooded

The range indicated here is for about 50-150 per cent. of present rainfall. On quite different evidence at Khami, where hill wash deposits formed during the Gamblian, it has been suggested that the rainfall varied from 60-150 per cent. of present rainfall (Bond, 1957). In terms of familiar things, our Salisbury climate may have oscillated between extremes, one of which was like the present Copperbelt at wet maxima, and the other like Bulawayo. The vegetation and pollens must have changed in sympathy, and so must soil-forming processes and animal populations. If the period of change has been as suggested by radio-carbon dates, it is doubtful if any of the biological factors, or even the soil itself, are fully in equilibrium with the present climate.

The pattern of rainfall variation for these periods in the Pleistocene in this part of Africa is, therefore, that the changes during Pluvials and Interpluvials have been in the range 50-150 per cent. of present rainfall. The pollen evidence from Florisbad is at variance, and this needs attention in the future.

The causes of Ice Ages have for long been argued without any general agreement being reached. Once an ice age is established, numerous theories have been advanced for the fluctuations within it. Most of these involve purely terrestrial causes, but there is a body of opinion, and it seems to be growing stronger, which is inclined to blame variations in solar radiation for the onset of major ice ages, though not for the fluctuations within them. It is, however, difficult to get direct geological evidence for variations in solar radiation.

The best-known form of solar variation is the 11½ year sun-spot cycle. This has been well documented for more than two centuries, but it is very hard to get meteorologists to admit any connexion between sun-spots and terrestrial weather conditions.

Many things on earth have been correlated with sun-spot activity. One example within the Federation is the surface level of Lake Nyasa. The changes in the level of the lake have been linked by one geologist with the sun-spot cycle (Dixey, 1953) and by an engineer with the rate of change of sun-spot numbers (Cochrane, 1957, 1960). Since the amount of water in the lake must in some way be connected with weather, some relationship may be evident here. It is also suggested by some climatologists that world temperatures are slightly lowered at sun-spot maximum. Rather surprisingly there are fossil records of sun-spot cycles in sediments which are annually banded. The best known of these are formed from glacial meltwaters which run into fresh-water lakes. The coarse sediment settles at once in summer, but as the streams freeze up in winter the finer mud goes on settling, forming an annual pair, or 'varve'. Plots of the thicknesses of these varves against time have occasionally shown cycles likened to the sun-spot curve. These have been seen in the Pleistocene glacial deposits of Europe of less than 1 million years in age, Eocene evaporites in America of about 60 million years, Dwyka glacial beds in Southern Rhodesia about 230 million years old, Upper Devonian and Lower Carboniferous of Thuringia about 275 million years, Permian evaporites in Texas about 200 million years, Oligocene clays in Germany about 30 million years, and even in the Pre-Cambrian Nama beds of South West Africa, which must be over 500 million years old.

Other cycles have been observed in some of them, notably one of about 21,000 years which may reflect the precession of the equinoxes. As this has also been claimed as a contributory factor in climatic changes, it is interesting to see it appearing in the fossil record. These records have been

by eustatic rise in sea level. As the total human population was then small and nomadic, the adjustments were probably easy. But if changes of such magnitude are going to happen again at the same sort of rate, it will be much more complex. At a new glacial maximum, Canada and much of Europe would be covered in ice sheets. By the time it happens again, the earth's population will be vastly increased in numbers, and even more highly organized and static than at present. How will they work out a problem of this kind?

Before they have to face this problem, the reverse may very well intervene. If present deglaciation trends continue, and accelerate as the record of previous events of this kind suggests, the consequent rise of sea level may render all the present ports of the world unusable by drowning them.

On the one hand, to be cynical, this problem may be resolved if the present human race annihilates itself by atomic stupidity. On the other hand, by the time such problems become acute, there may be some form of world-wide wisdom in the management of human affairs, which will deal smoothly with it on a global scale.

To conclude on a purely local note, the geological record shows that we and our immediate descendants probably need not worry unduly in this country. If the correlation between high latitude interglacials and dry phases in the sub-tropics is correct, then it is probable that Central Africa is getting gradually more arid, but certainly not at a rate which is measurable in terms of the human life span.

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