

Climate patterns in an un-glaciated continent

by Karl W. Butzer

Great ice sheets of the Pleistocene which advanced from north and south brought sub-Arctic conditions to many regions of the world. Areas of glaciation in Africa were few but climate changes were dramatic. Karl Butzer, internationally renowned for his studies of African geomorphology, pieces together the continent's place in the Pleistocene jigsaw

THE WORD 'PLUVIAL' was originally coined to explain the fossil beds of the once-high lake in the Jordan Valley, but it is now more commonly used to describe African features that seem incongruent in terms of modern climate and, rightly or wrongly, suggest times of more abundant water. In 1947 the first Panafrican Congress of Prehistory, held at Nairobi under the aegis of the late Louis Leakey, declared the existence of four pluvials, in analogy to the presumed 'classic' glacials of higher latitudes. These pluvials were believed to be simultaneous throughout Africa, providing predictable time-horizons for the whole continent. Subsequent intensive field work in new areas, as well as the introduction of radiometric dating techniques, meant questioning the interpretation of many pluvial phenomena and showed that climatic changes were neither synchronous across Africa nor in phase with the glacial-interglacial cycles of Europe.

Nonetheless, features suggesting drier or wetter conditions remain the hallmark of the more recent geological record in Africa. Most of the rivers, small and large, permanent or intermittent, have left a record of stream deposits; although seldom forming the semi-continuous terrace staircases characteristic of high-latitude valleys, these alluvial residues can, with careful study, be used to infer the history of many informative drainage systems. But unlike northern Europe, where glacial till, loess, head, and alluvium provide thick and extensive mantles across most lowlands, surface deposits in Africa are generally thin and limited. About 70 per cent of the continental surface is formed by erosional plains and uplands, and widespread cover deposits are primarily found in a number of downwarped zones - alluvium or lake sediments in the Chad, Central Nile, and Congo-Zaire basins, and aeolian sands in the Kalahari Basin and several sectors of the Sahara. Yet the great alluvial basins have little relief and will defy traditional geomorphological study until deep core profiles become available. The sand sheets and dunes are mostly of great antiquity, Eocene to Pliocene, despite repeated surface remodelling; they are frequently fixed by soils or vegetation, and the paucity of the natural exposures explains why they have provided relatively little paleoclimatic information. Among the best opportunities for the geomorphologist are well-defined stream valleys and, above all, the rift grabens of Eastern Africa. The Rift System provides ample relief and a considerable range of volcanic, windborne, stream, and lake deposits, while repeated faulting has served to re-expose older formations for convenient examination. Not surprisingly the best environmental narratives have been reconstructed from the rifts and from a number of key river systems.

Records of former cold climates are few. Cirque and valley glaciation was well developed in the highest ranges of the Moroccan Atlas and Rif, with outwash terraces and several generations of periglacial deposits in some sectors indicating repeated glaciation. Elsewhere smaller

glaciers have been verified in the Algerian coastal ranges and the Atakor, in Ethiopia - Semien, Mt Badda - and on the great volcanic peaks of East Africa - Mts Kenya, Elgon, Ruwenzori and Kilimanjaro. On the slopes of Kilimanjaro, a lava over till allowed a potassium-argon minimum age of 463,000 years for one early glaciation. In addition, Pleistocene periglacial features have been identified in the Saharan Tibesti as well as in the South African Drakensberg, where there also are some large nivation cirques.

Frost weathering, not unknown in subtropical Africa today, was evidently accelerated during several past periods. But the resulting rubbles were not incorporated into specially sorted or low-angle slope deposits, like head, but rather into steep scree, water-transported hillwash, or alluvial fans. Such features, found at relatively low elevations in northernmost Africa, at the South African coast, and in some Ethiopian and Rhodesian mountains, do not deserve the designation periglacial. Finally there are multiple horizons of frost-weathered roof spall in many South African caves. The geomorphic record for greater cold is insufficient to provide a palaeo-environmental or stratigraphic framework, except in a few localized areas. But it finds a broad if sporadic base of support in the as yet scattered montane pollen record, in experimental work with amino acid behaviour and with carbon ratios in fossils, as well as in the isotopic composition of deep-sea cores from adjacent oceans.

The glacial Pleistocene so readily defined in Europe or North America is difficult, if not impossible, to isolate by geomorphic criteria in tropical Africa. Here the Tertiary and Quaternary form a continuum, complicated primarily by tectonic events. Any environmental shifts that can be discerned were commonly superimposed on more dramatic changes of a local nature, as were the two long stratigraphic columns from the Omo Basin of south-western Ethiopia and the Olduvai Gorge of Tanzania. These columns are unique in terms of their chronometric control, by multiple potassium-argon dating and detailed magnetostratigraphy, and sedimentological analyses.

The Omo column is far more complete and more securely dated than other geological sequences in the Lake Rudolf area, East Turkana and Lothagam. Regional climatic inferences are made on the basis of relative delta distance north of the present river mouth; lake elevation with respect to the Rudolf-Nile divide; facies, or deposition changes, between cyclic fluvial units and lake incursions; the many palaeosols, which are old soils, that range from argillic, illuvial to rudimentary calcic profiles; as well as the faunal and pollen record. When carefully screened to eliminate tectonic inputs, a relative scale of dry to moist climates can be implemented. The resulting column shows a sequence of wet and dry alternations, at several amplitudes and wave lengths. Palaeontological correlations indicate that major trends were parallel in East



Turkana and Lothagam, although control data there are inadequate to compare details.

The Olduvai column is also complemented by faunal data. Similar patterns of amplitude and wave length can be noted, but there are few conspicuous parallels with the Omo in terms of time or direction of change. Although the details of resolution may partly be at fault, the Omo and Olduvai are in different rainfall provinces today, and their late Pleistocene to Holocene records also do not compare well.

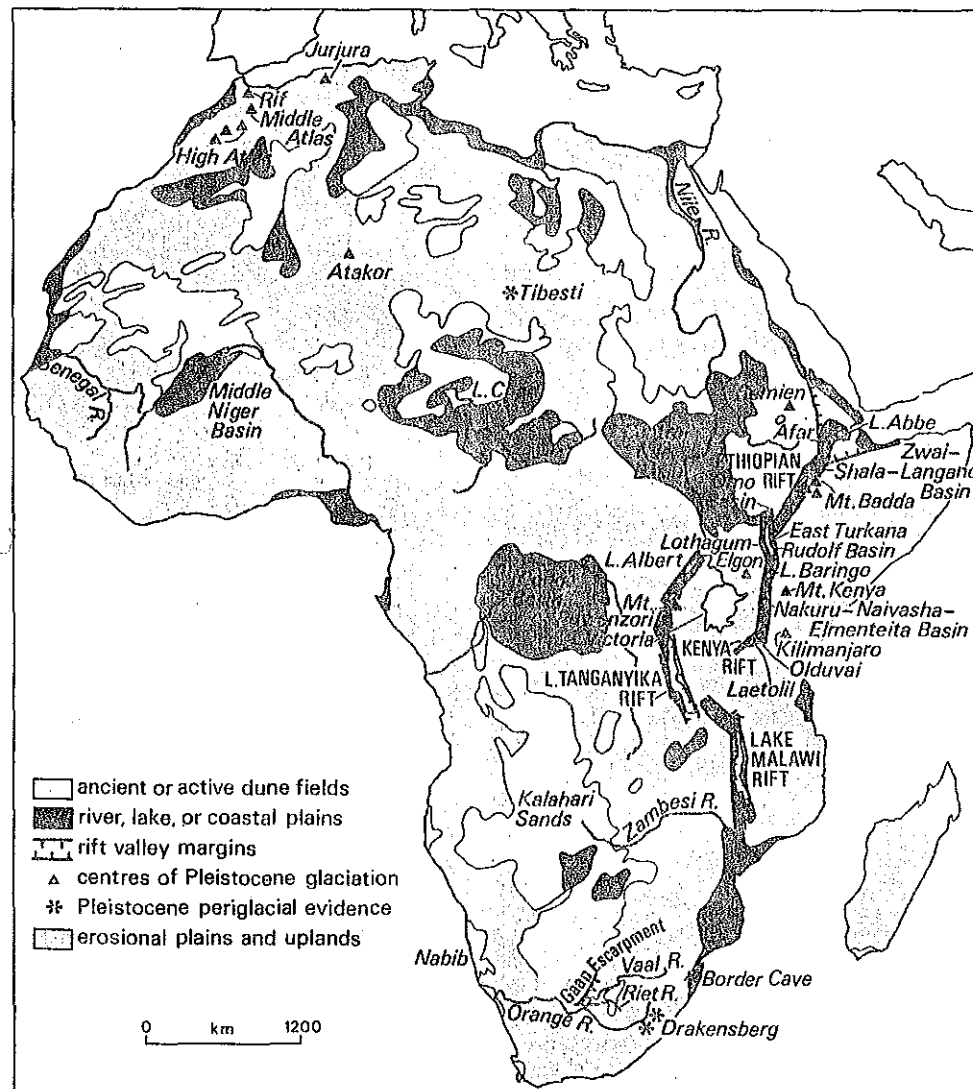
There is no obvious Plio-Pleistocene boundary in the Olduvai and Omo columns, any more than there is in the paleontological sequence. The pattern of environmental change shows no evident similarities with the record of higher-latitude glacial-interglacial cycles, as recorded in long deep-sea oxygen isotope curves. The more detailed late Pleistocene record suggests that dynamic interrelationships between the tropics and extratropical zones do indeed exist, but long-term Pliocene to Pleistocene moisture trends in Africa cannot yet be predicted from any available external criteria. The rhythm of environmental change does not demonstrate systematic trends. Although the degree of resolution varies within the geological columns, it is apparent that wave lengths have always ranged from less than 20,000 to more than 100,000 years. The differences between the Omo and Olduvai curves caution against attempts to derive a norm for tropical Africa. As today, secular weather trends in different parts of Africa are as often as not distinctive.

Other long geomorphic sequences that lack good chronometric controls basically support these conclusions.

In particular, the evolution of the Nile River in Egypt and Nubia can be traced from the Miocene to the present through a series of planation surfaces, stream terraces, and downcutting episodes that reflect semi-arid, arid and hyper-arid climates. Similarly, the spring cycles of the dolomitic Gaap Escarpment in South Africa produced massive lime tufas and interbedded breccias that document a sequence of wet, dry and, at times, colder climates which had begun by 3,500,000 years ago.

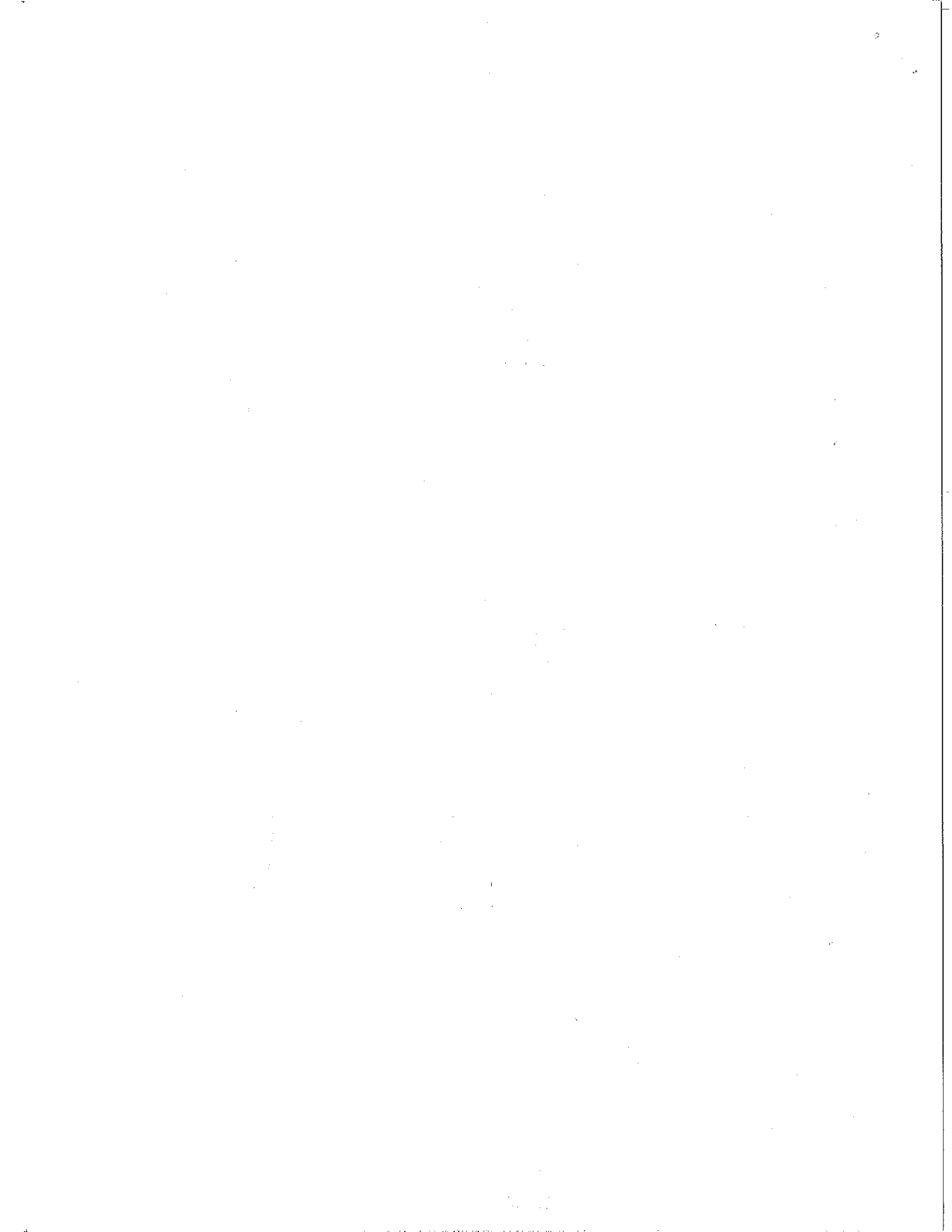
In view of the individualistic nature of African palaeoclimatic evolution, the background geological reference units are best defined by chronometric and magnetostratigraphic criteria, as selected from other terrestrial and marine records. The Pliocene is therefore accepted here as ranging from 5,000,000 to 1,800,000 years - the base of the Olduvai paleomagnetic event. The early Pleistocene is considered to begin 1,800,000 years ago, the middle Pleistocene 700,000 years ago (the Brunhes-Matuyama geomagnetic reversal), the late Pleistocene 130,000, and the Holocene 10,000.

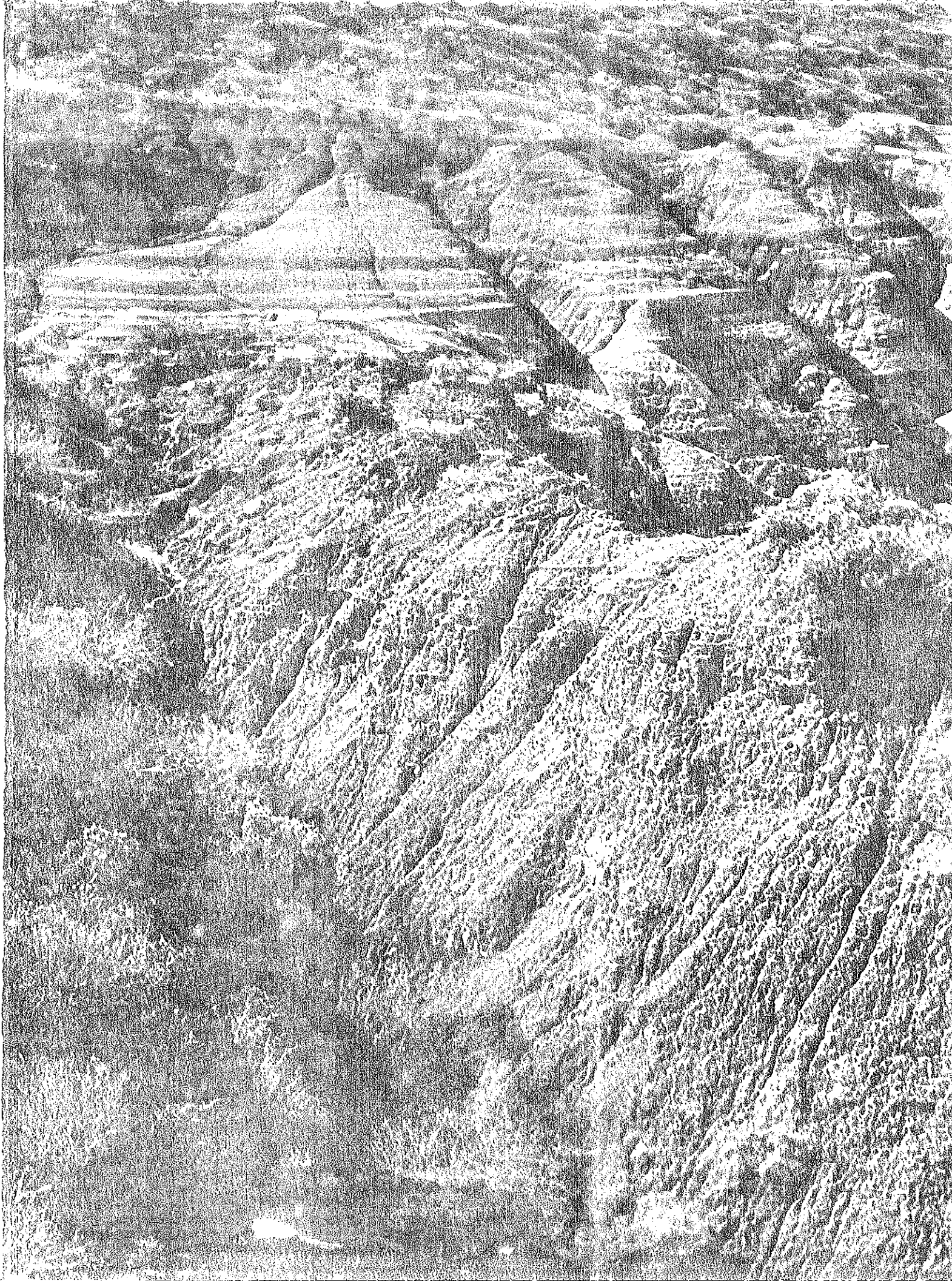
Early man evolved against this background of repeated environmental change. Reappraisal of the ages of the earliest human fossils and archeological residues places the oldest known advanced hominid remains, at Laetoli in Tanzania, around 3,200,000 years, in the Ethiopian Afar at 2,900,000, in the Omo at 2,750,000 and in East Turkana at about 2,100,000. The earliest incontrovertible evidence of human - manufactured - stone tools comes from a small stream channel in the Omo Delta dated 2,100,000 years, while both the Koobi Fora site in East Turkana and the earliest occupations in Olduvai Gorge

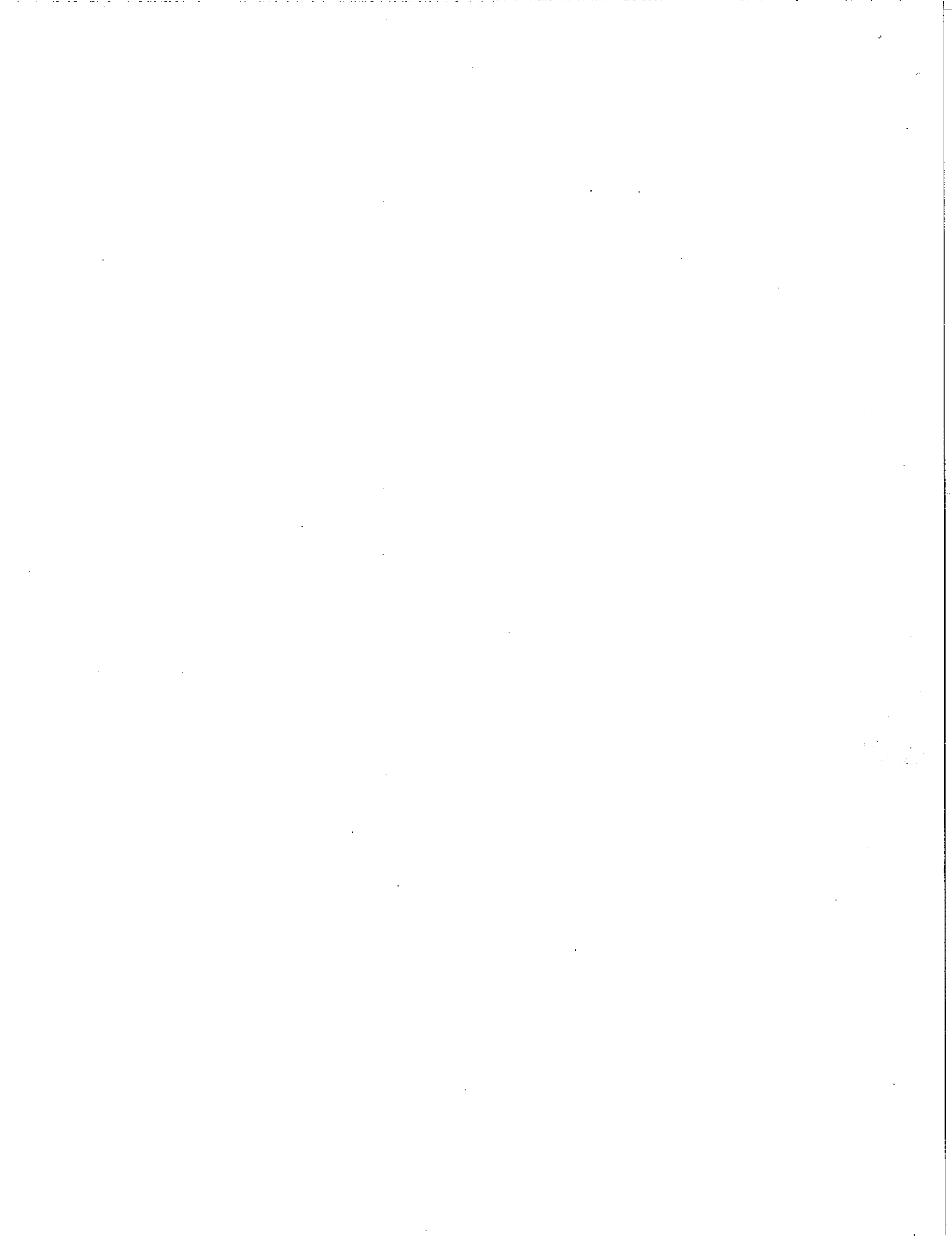


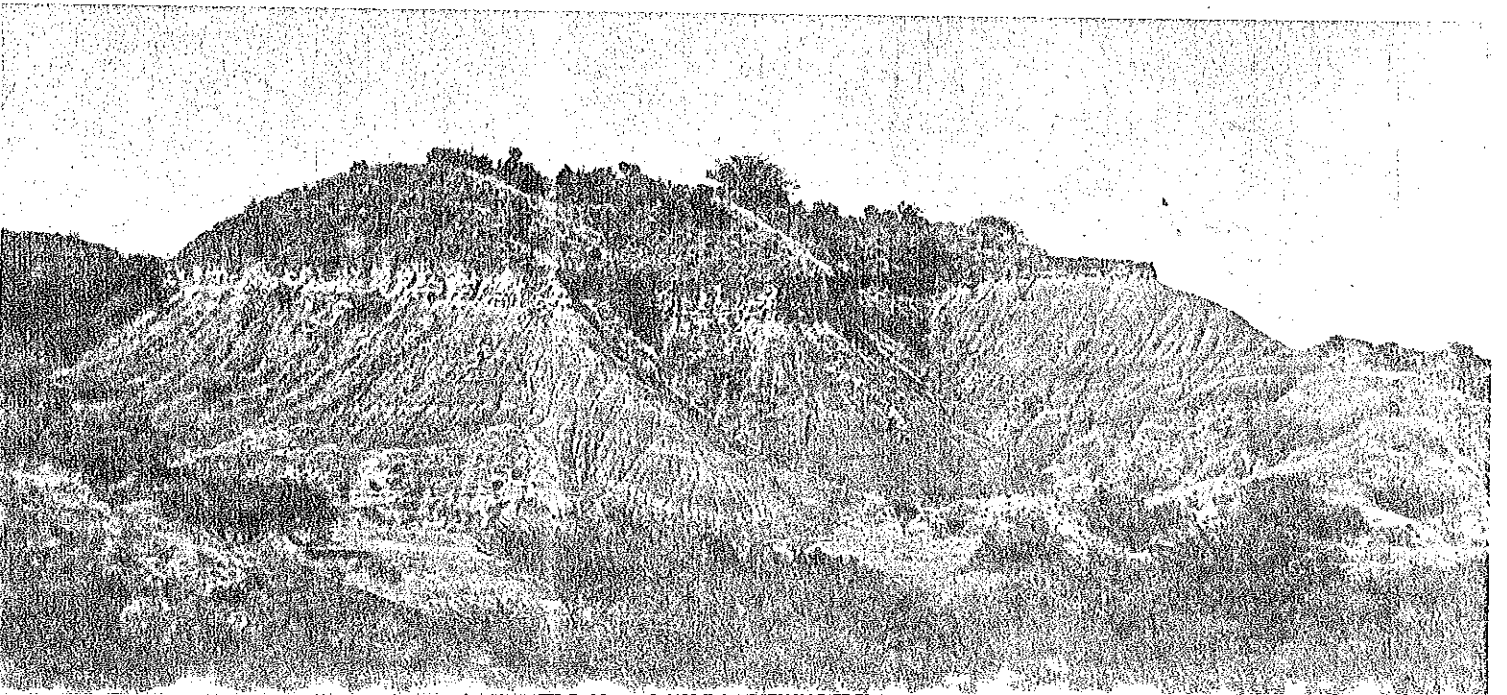
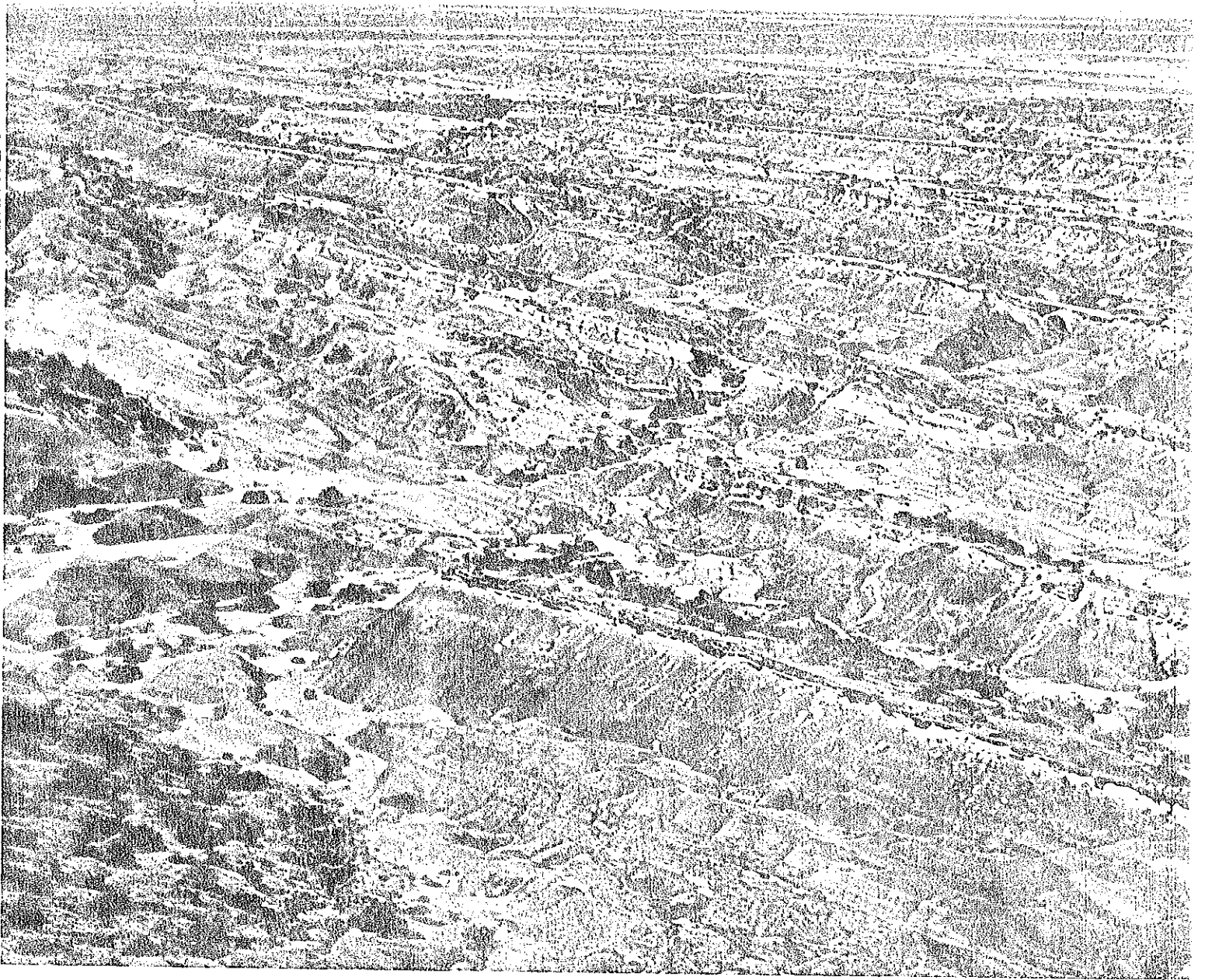
Clues to the recent geological past of Africa are few because 70 per cent of the continent's surface consists of erosional plains and uplands which do not preserve evidence (left). Deep cores from the sedimentary basins will eventually provide more conclusive records. In the meantime geomorphologists must look to well-defined stream valleys and the rift valleys of East Africa to reconstruct paleo-environments.

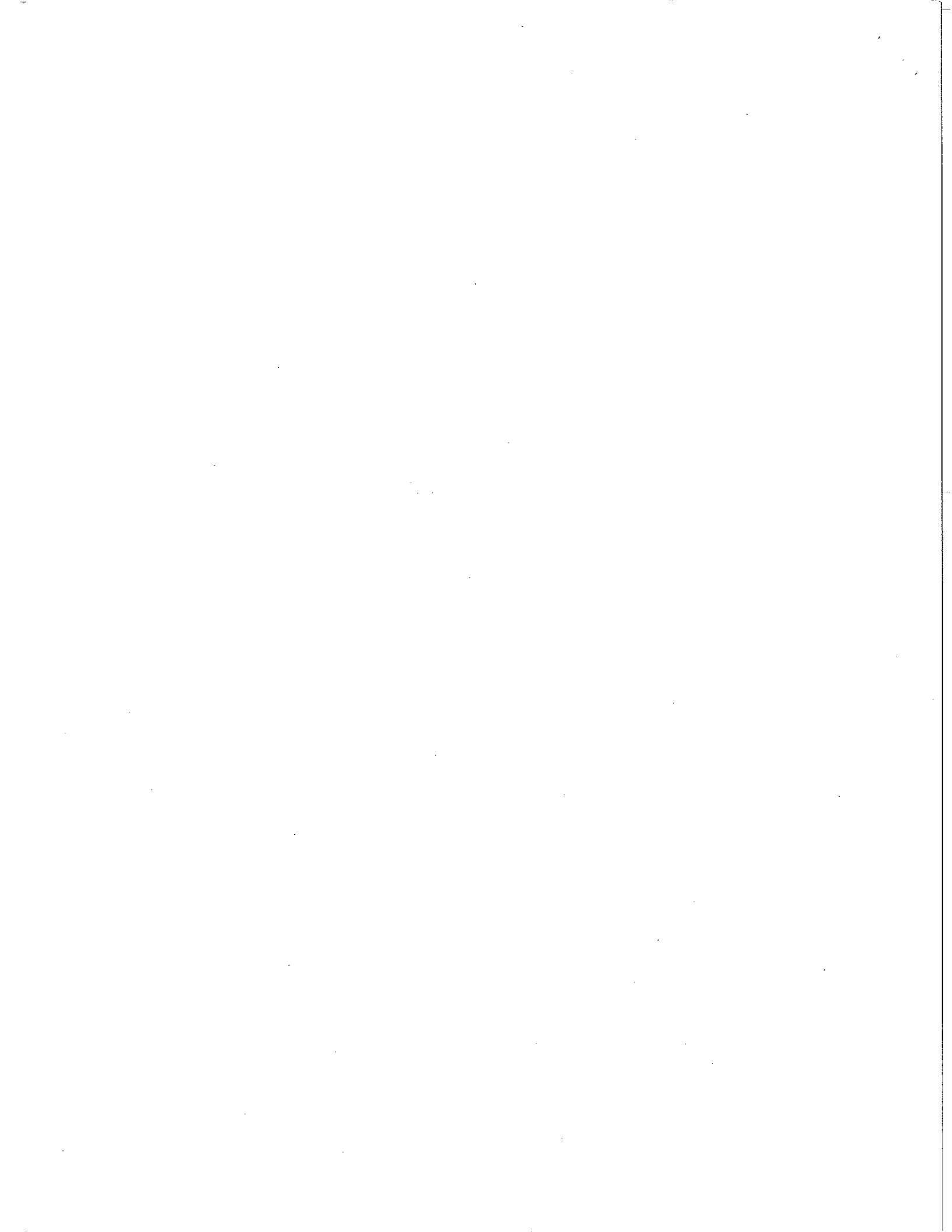
Tertiary and Quaternary periods form a continuum in African sedimentology. Pleistocene epoch is difficult to define. The sediments of the Omo Basin in south-western Ethiopia provide one of the longest and most easily verified stratigraphic records. (Right) distributary mouth deposits (foreground ridge) followed by river and lake deposits (background) are part of the Omo's Mursi Formation. They were laid down 4,400,000 years ago when ancestral Lake Rudolf was probably linked to the Upper Nile



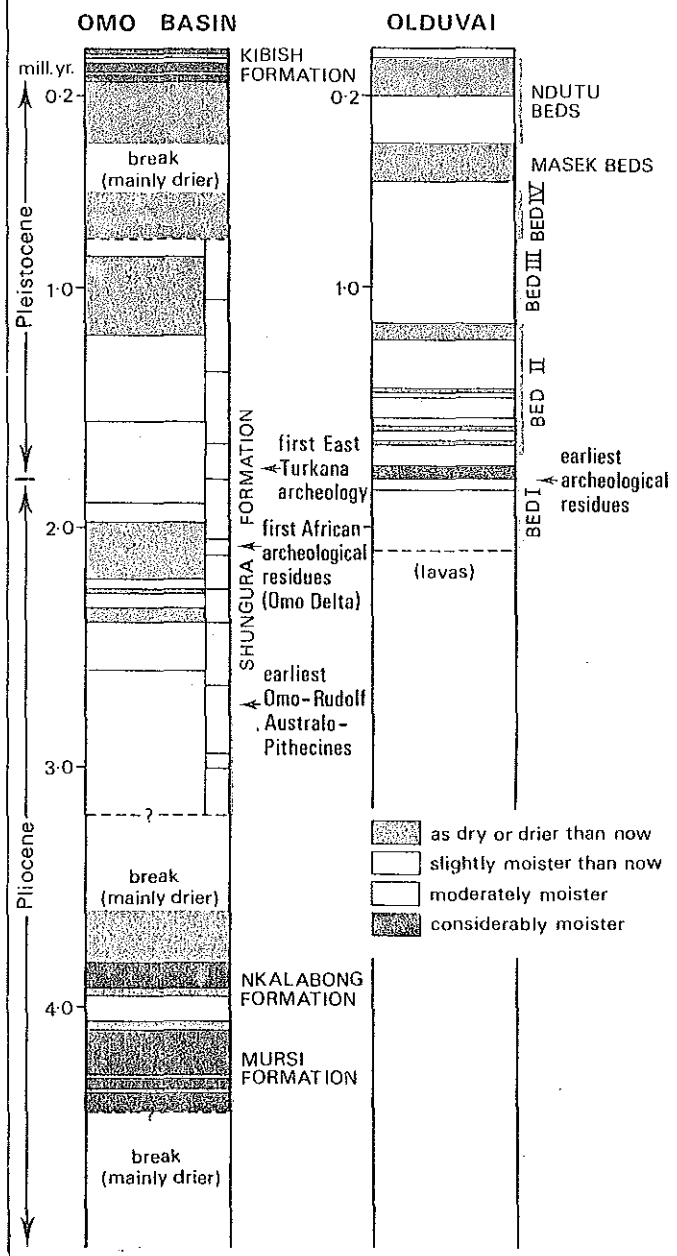








LONG TERM TROPICAL AFRICAN
MOISTURE TRENDS-PLIOCENE
TO END OF PLEISTOCENE



are now known to be no older than 1,850,000 years. The earliest hominid or archaeological sites were preferentially situated within the semi-arid macro-environments of eastern Africa, but in close proximity to the more luxuriant woodland vegetation at river-margins or lake-shores. The formalized artifacts of the Acheulian are first verified about 1,400,000 years ago in the Olduvai sequence, and related hand-axe assemblages are primarily found near water sources within relatively low-lying areas characterized mainly by open vegetation. The simple and seemingly unprogressive Acheulian tool assemblages were replaced by increasingly diversified lithic industries, beginning about 250,000 years ago in southern Africa.

(Above left) Shungura Formation was deposited in the lower Omo Basin between 3,200,000 and 800,000 years ago under climatic conditions similar to those of today. River and delta sediments are punctuated by layers of resistant volcanic ash. Tilted and eroded, the formation now forms a series of ridges. (Left) Kibish formation was deposited as a delta in an upper Pleistocene lake sixty to eighty metres higher than Lake Rudolf

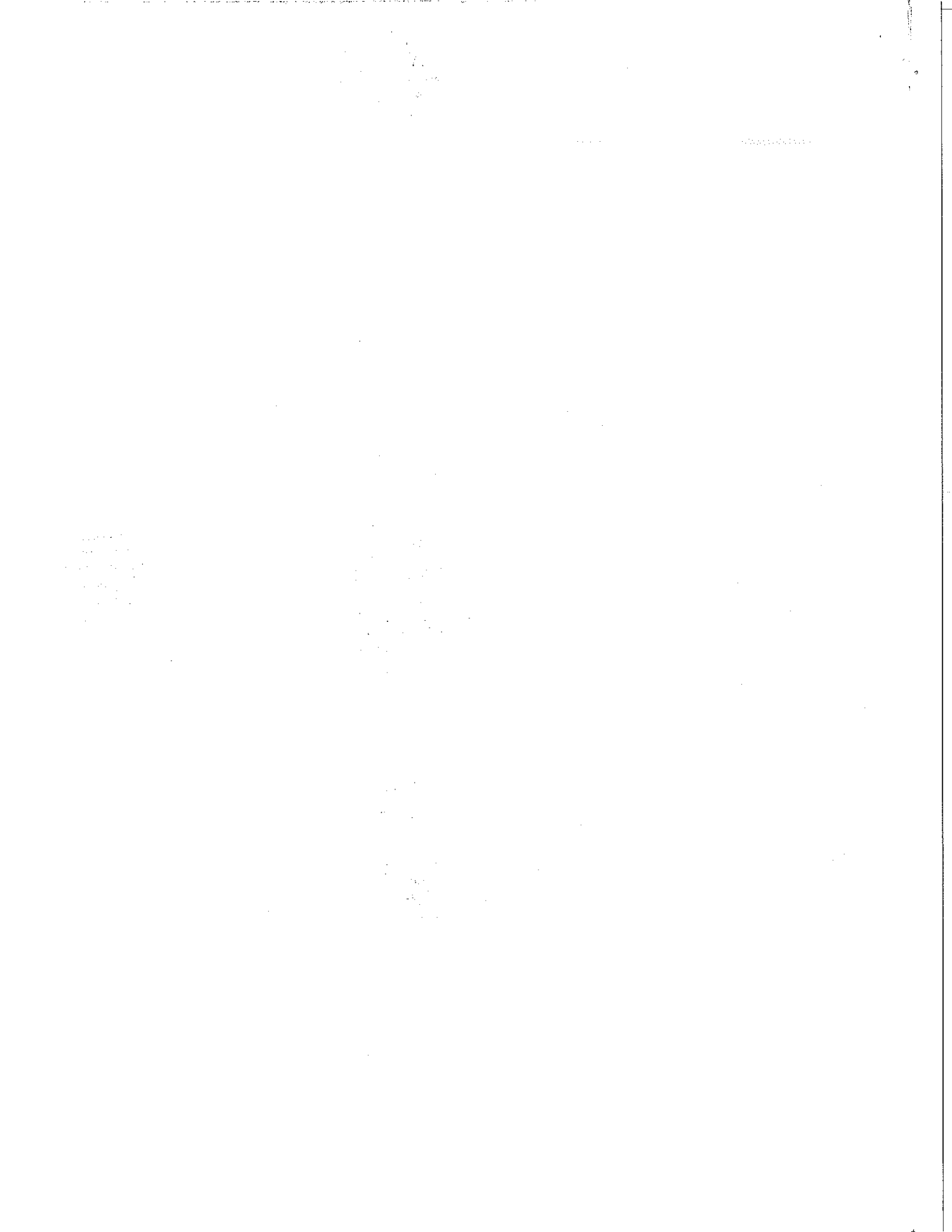
The earliest fossils of anatomically modern *Homo sapiens* are at least 95,000 and more probably 115,000 years old, in Border Cave, on the Swaziland frontier. It therefore appears that the evolutionary transition that brought modern peoples into Europe 35,000 years ago began along the southern peripheries of the African continent 80,000 years earlier.

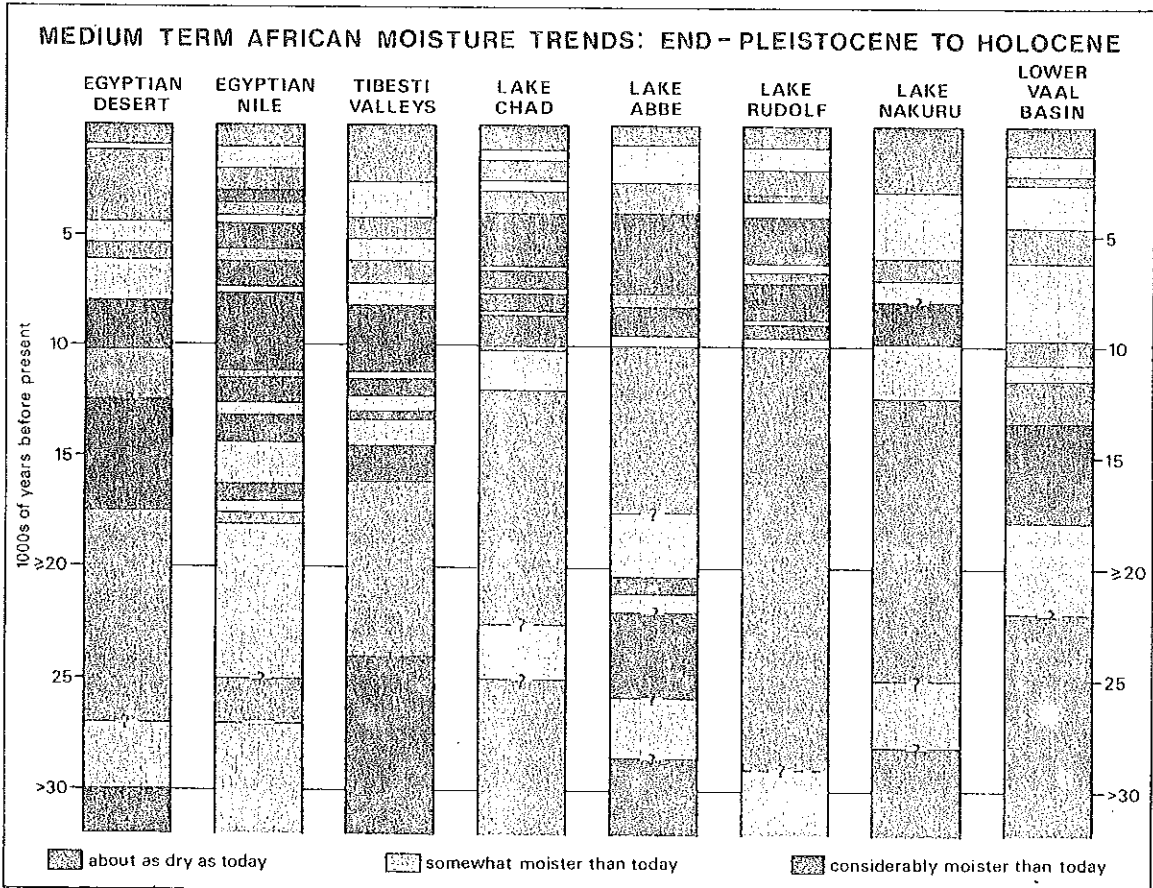
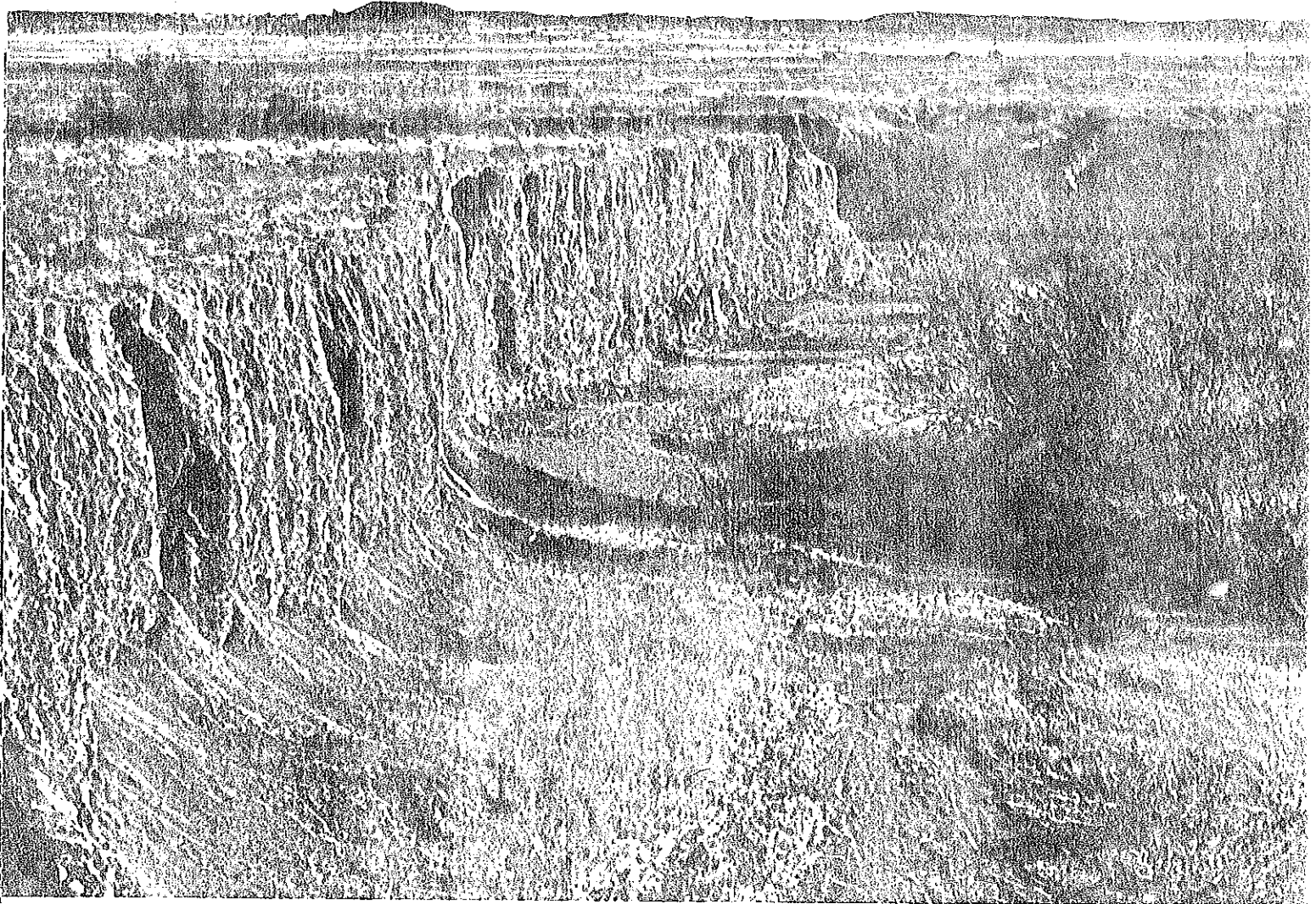
Late Pleistocene and Holocene palaeoclimates have recently been deciphered in considerable detail in many parts of Africa. This can be attributed to the good preservation of the younger geological record as well as to widespread application of radiocarbon dating. A selection of the better sequences from different areas includes four lake records, from basins tectonically stable during the period in question, where low, intermediate, or high levels provide a direct index of water volume and a correspondingly good appreciation of hydrological trends.

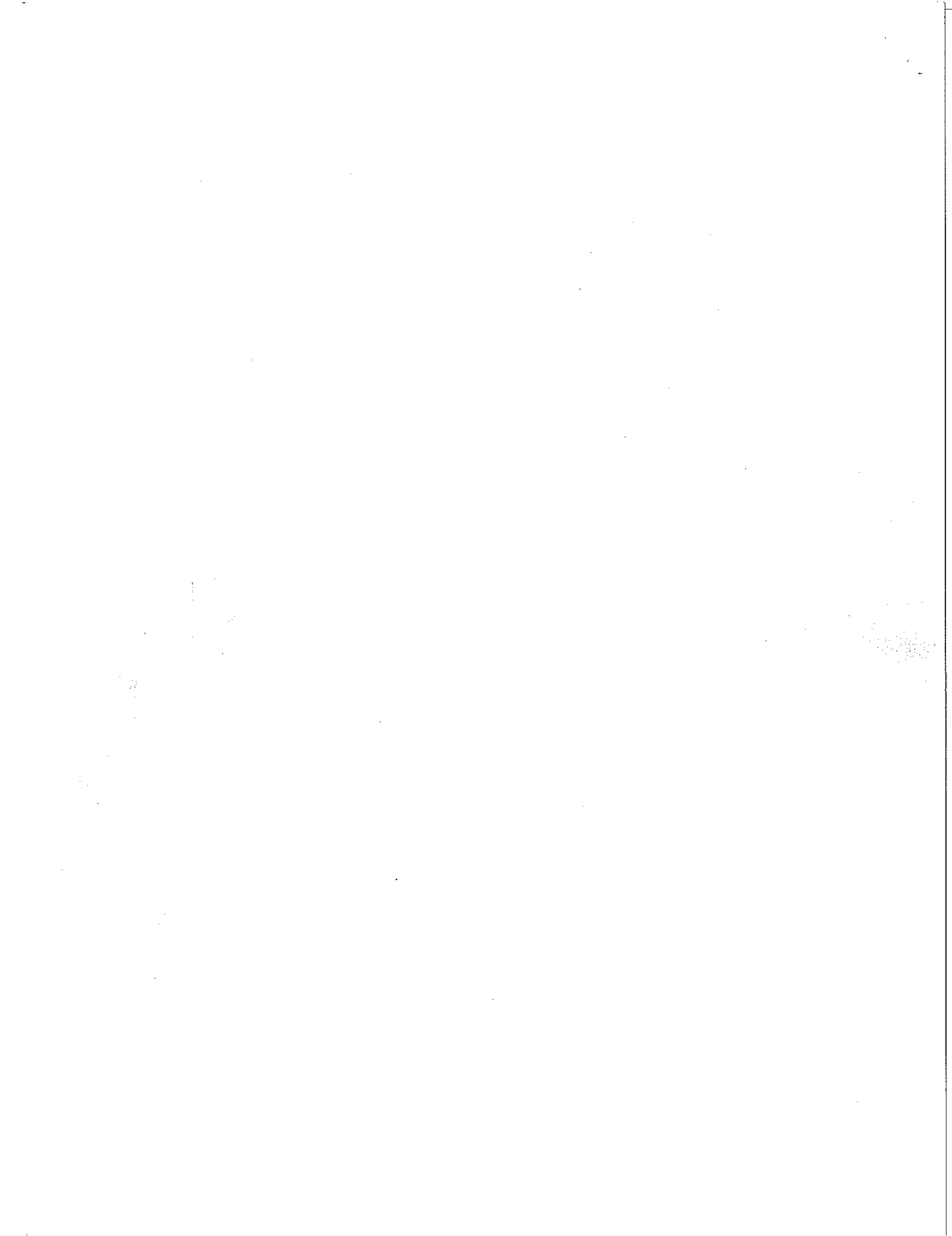
Chronometric controls for the last 10,000 years are generally good. Minor differences are probably a result of differing geomorphological thresholds, interregional climatic contrasts, the vagaries of the geological record, idiosyncrasies of interpretation, and erroneous or insufficient dates. Major differences, such as those between Egypt, the inner-tropical zone, and South Africa, clearly have greater significance and indicate diverging paleoclimatic trends on the subtropical margins of the continent.

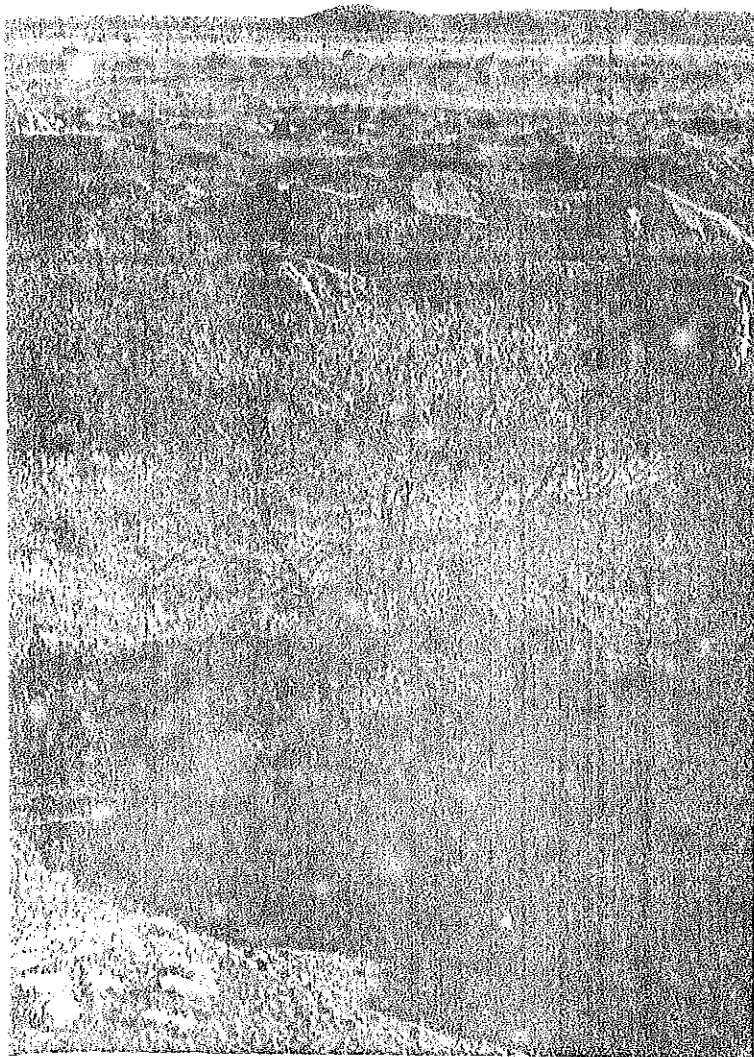
The radiometric precision prior to about 15,000 years ago is far less satisfactory. Dates are almost exclusively based on radiocarbon assays with shell, inorganic carbonates, or bone (apatite or collagen). Technically, such materials might be expected to include a percentage of derived, 'dead' carbon dioxide, so yielding ages that are too old. In practice, each of these materials provides an open chemical system into which younger solutions penetrate and, in the process of repeated solution and recrystallization, introduce substantial quantities of younger carbon dioxide. As little as one per cent of modern carbon dioxide added to a sample 23,000 years old will decrease the apparent age by 5 per cent. Consequently, although radio-carbon counters can theoretically date back 40,000 years or more, at least 90 per cent of African carbonate-based dates in excess of 15,000 years are substantially too young, often by 50 per cent or more. In fact only one per cent of contaminant to samples of infinite age - beyond 70,000 years or so - is required to simulate an apparently finite age of 35,000 years. The Abbé column illustrates this problem particularly well: the available charcoal and carbonate dates in the 16,000- to 17,000-year range are highly inconsistent. Extrapolating from the older charcoal dates, the Abbé column would require a doubling of all apparent ages beyond 20,000 years.

The late Holocene, the last 3000 or 4000 years, have been generally dry, while the early to mid-Holocene, the first 4000 to 6000 years, have tended to be wet in Africa. Early Holocene moisture in the innertropical zone rivalled that of even the wettest Pliocene or Pleistocene 'pluvial'. Also, wet conditions persisted longest in this same belt, until 4000 years ago. In subtropical Africa, early to mid-Holocene moist episodes were relatively modest, compared with some Pleistocene pluvials, and they terminated earlier than those in the tropics. Finally, on the northernmost and southernmost coasts of Africa, poleward of latitude 33°, the early Holocene was drier than today. These features indicate significant latitudinal contrasts. In Nubia the desert rains occurred during the winter or transitional seasons, out of phase with the summer Nile floods; this precludes an unusual poleward penetration of the tropical monsoonal rains during early





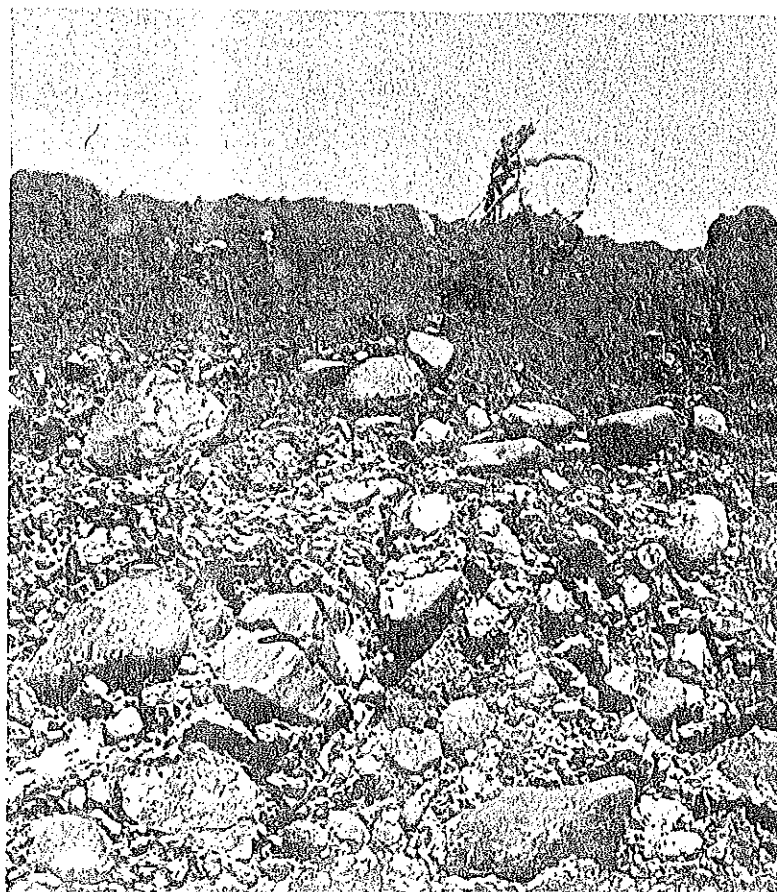




to mid-Holocene moist intervals. Perhaps the Holocene wet phases of the Sahara were due to a much greater incidence of the spring and summer rains that are now linked to complex interactions of atmospheric moisture or upper-air weather controls between the tropical easterly and circumpolar westerly circulations.

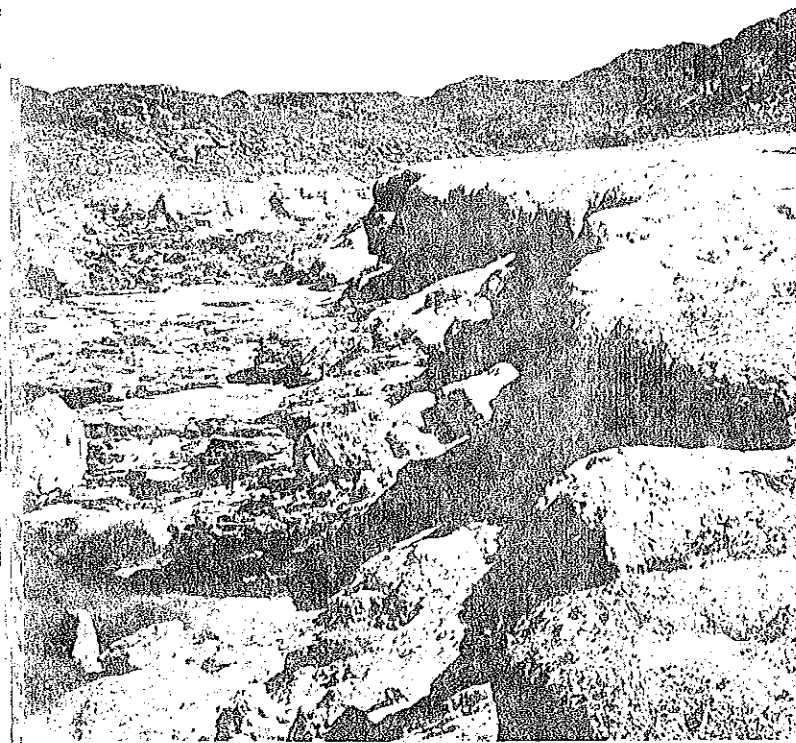
The Pleistocene-Holocene boundary at 10,000 years ago stands out as a clear climatic division almost everywhere. Equatorward of about latitude 15° the terminal Pleistocene was dry, poleward it was comparatively moist to latitude 33°, with southernmost Africa and the Mediterranean borderlands quite dry. The Nile, which today derives its waters from the innertropical zone, was marked by considerable flood volumes and unusual competence 17,500 to 11,200 years ago, although its present source area was much drier. A clue is provided by the masses of chert entrained from tributary valleys in the central Sudan and swept downstream to beyond Cairo. Evidently a mid-Saharan moisture source, comparable to that recorded in the Tibesti highlands, was responsible. The integral transport of Ethiopian flood silts and Saharan debris appears to suggest a remarkable intensification of summer or autumn rains of tropical origin across the central axis of the Sahara about 15,000 years ago. A similar extension and alternation of summer rains is indicated in the Kalahari at this time, perhaps influenced

Climates of Africa oscillated between wet and dry during the Pleistocene and Holocene but changes do not correlate with glacial phases elsewhere. (Left) ancient gully drains towards the Alexandersfontein Depression near Kimberley, South Africa. Up to 14,000 years ago a lake twelve metres deep was maintained here. (Below left) gully system, draining into the Vaal River at Riverton, exposes clays, silts and sands four alluvial cycles of the Vaal, responding to late Pleistocene changes of climate. More than 250,000 years ago calc-cemented boulders of the Vaal River's Younger Gravels (below) were swept together by a stream. Darker surface material was wind accumulated, weathered and reworked in successive climatic shifts



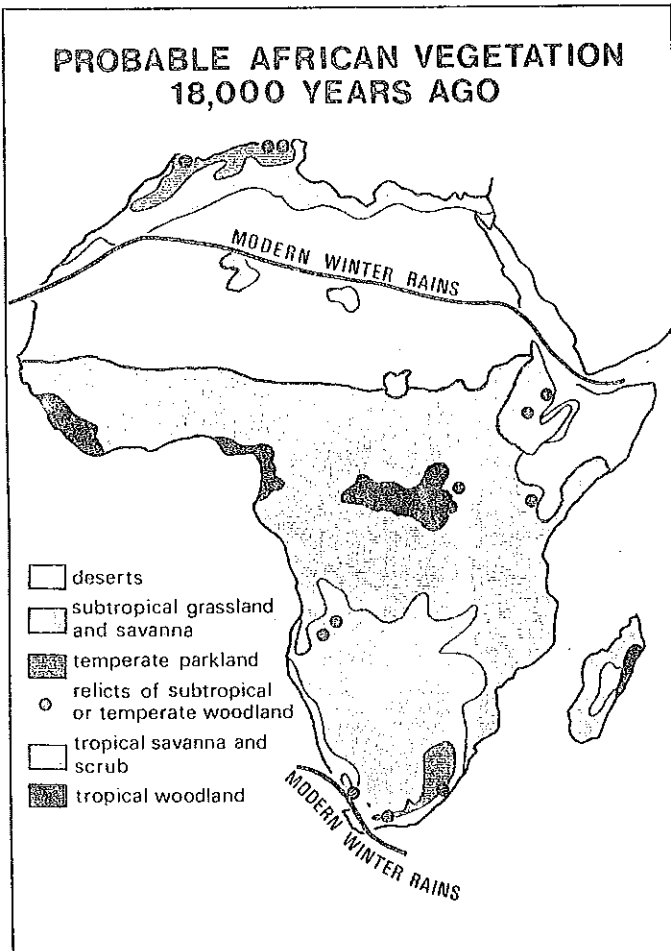
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Terrace in a wadi in the Nubian desert was cut by a vigorous, braided, River Nile in the late Pleistocene. Nile may have been augmented by increased rainfall in its source area at that time by reduced upwelling along the south-western coasts.

Moisture trends between about 20,000 and 30,000 years ago are somewhat enigmatic. Parts of this time may have seen slightly wetter conditions, perhaps due to reduced glacial-age evaporation, in several areas. The coincidence between high Nile floods and high lakes in



some parts of Ethiopia appears to be significant, but may have been a regional phenomenon, perhaps limited to the tropical montane zone.

Precipitation patterns during the early Upper Pleistocene are beyond the range of radiocarbon dating and therefore difficult to correlate. It is probable but unprovable that older lake beds in the tropics are mainly related to non-glacial periods.

The wave-length of late Pleistocene and Holocene variation ranges from less than a century to several millennia; whether the different time scales, compared with the Plio-Pleistocene record, are due to finer resolution or to greater climatic instability during the last 100,000 years or so, is uncertain. The amplitudes of these more recent changes match those of the earlier Pleistocene and Pliocene, at least in tropical Africa.

Regional data can be complemented by a wealth of other information in order to attempt a synthetic picture of African macroenvironments during maximum glacial conditions of the global atmosphere, 18,000 to 15,000 years ago, assuming a 7° to 10°C reduction of mean temperature, a value consonant with evidence of expanded mountain glaciers, depression of montane ecozones, frost-weathering in now frost-free areas, as well as data from East African bone. A scattering of pollen data can be utilized in several areas. Otherwise the shifts of climatic vegetation belts are based on geomorphic evidence. Generalized ecozones probably allow a reasonable if tentative outline of the major environmental anomalies: reduction of the subtropical and temperate woodlands poleward of latitude 33°, expansion of semi-arid habitats into the northern Sahara Desert, a moister, cooler Kalahari, an expansion of subtropical or temperate geofloras in the high country of Ethiopia, Angola, Zambia, Rhodesia, and South Africa, a drastic opening-up of vegetation along the southern periphery of the Sahara, where dune fields invaded former savanna while lakes dwindled, and diminution of the Congo and Guinea Coast rainforest to a few disjunct areas. While preserving habitat for gregarious African herbivores, such ecozation can represent a dramatic change for floras, faunas, and prehistoric human subsistence. Yet on most parts of the continent no dramatic ecological or geomorphological threshold was crossed, with relative shifts within biotic communities and processual systems more common than wholesale displacements or replacements. It is this subtlety of response to change that makes the African record so difficult to interpret.

The long and medium-term climatic trends of Africa, viewed over millions of thousands of years, cannot be examined or explained by European or North American models. Wave-lengths vary continually. The amplitudes of short-term moisture changes, like that between 1890-95 and 1950-55 in East Africa, are at least 50 per cent of the magnitude of maximum change between the wetter parts of the Pliocene and the dry 1950s. The dramatic, irregular patterning so produced does not lend itself to ready definition of large blocks of time, such as a glacial or interglacial. Neither does the geographical patterning of any one phase provide a model readily applied to long spans of that continent's past. Interregional and intra-regional biophysical response to such complex atmospheric deviations from the present norm can, at present, only be determined by empirical research. Consequently deductive models for African paleoclimates will continue to be as misleading as inductive models based on inadequate data. Both favour misinterpretation of evidence and minimization of true complexity.

