



11 When it Rains it Pours: Legends and Realities of the East African Pluvials

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Attempts to reach well beyond the state of knowledge and existing conceptual frameworks are rarely embraced by the scientific community, typically as they mislead rather than guide. However, it is precisely these overextensions that can generate the most innovative perspectives and revolutionary breakthroughs in science. Alternatively they create chaos, splintering disciplines and sending many down tangential or even worse, dead-end trajectories. The integration of pluvial theory into paleoanthropological investigations in east Africa in the mid-1900s represents one such tangential journey. It was an attempt to frame human evolution within a series of alternating wet (pluvial) and dry (interpluvial) climatic intervals, primarily as a means of establishing a relative chronologic framework for fossil and archeological assemblages. While regarded as ill conceived in retrospect, pluvial theory was linked to novel, developing perspectives in meteorology, stratigraphy, and evolution and as such incorporated a number of then-revolutionary concepts. Reexamination of the discarded pluvial theory in east Africa and its origin reveals the insight and vision of researchers over a century ago and the circuitous path taken to achieve our current theories linking hominin evolution and climatic change.

Introduction

Approaching the margin of the east African Rift Valley, thick clouds enveloped Gregory's 1892–1893 expedition to Mount Kenya and Baringo, obscuring much anticipated panoramas of the great rift (Gregory 1896). Disappointed, the party descended through the cloudbank along the Kikuyu scarp that forms the eastern wall of the Rift Valley. As they navigated the cliff, gusts of wind cleaved passages through the clouds, revealing the plains below, stretching 30 miles across the rift floor to the western scarp. "Lost in admiration of the beauty and in wonder at the character of this valley", Gregory noticed on the cliff face to the north, what appeared to be some ancient

shoreline deposits. As he writes, "this was a point that had to be settled", and the group immediately camped and spent much of two days examining these relic lake terraces. Gregory traced the remnant shoreline sediments for a considerable distance along the rift margin, at points reaching a height of 400 feet above the present valley floor, leading Gregory to speculate that the extinct Lake Suess (in honor of the Austrian explorer and ornithologist Edward Suess) occupied a significant portion of the Rift Valley. He also inferred that the lake was long lasting and had gradually dwindled as the climate became more arid and/or as earth-movements altered drainage patterns in the basin.

Specific mention of this event in Gregory's journey highlights aspects of prevailing scientific inquiries at the turn of the nineteenth century that remain relevant to ongoing research more than a century later in equatorial Africa. Gregory's intense interest in lake systems in the rift was scaffolded on diverse developing theories as to the nature of continental rifting, global climatic shifts, terrestrial indicators of climate, establishing the effects of glacial-interglacial oscillations on low-latitude ecosystems, and effects of environmental change on the distribution and evolution of biota. At the time of Gregory's expedition, it was known that British East Africa incorporated a great depression or trough, which "begins with the Dead Sea, extends down the Red Sea, and ends at Tanganyika" (Galton, 1884). Associated with this trough was a chain of "fjord-like" lakes formed as a result of connected series of earth movements along this line (Suess 1888). Many of these lakes were of wide general interest in Europe as they featured in geographical expeditions undertaken to settle controversies regarding the source of the Nile, to verify "native reports" of the existence of great inland seas in Africa, and to locate the position of Lake Tanganyika in the african river system (Burton 1857; Speke 1857; Livingstone 1859; Stanley 1865; Thomson 1885; Teleki and von Hohnel 1892).

So unique were emerging topographic details associated with the depression that Gregory was compelled to compare the rift to a series of long narrow clefts on the surface of the moon (rills) and suggested that exploration of the Rift Valley offered the possibility of explaining the nature of the Moon's surface. More relevant for this paper, however, was Gregory's appreciation that the rift potentially provided an archive of past climates, fauna, flora and geologic history in a region that had been up to that point dismissed as scientifically monotonous, uninformative and devoid any geologic novelty, consisting of one vast expanse of metamorphic basement complex (Murchison 1852; Drummond 1891).

Relying on lithologic evidence of extinct lakes, the presence of empty river gorges, modern zoological and botanical distributions, coarse fluvial gravels, and glacial moraine deposits in African highlands, Gregory concluded that equatorial Africa had experienced multiple episodes of climatic change. Gregory (1894) interpreted a moraine several thousand feet below the level of existing glaciers on Mt. Kenya to reflect an interval of increased precipitation that was tentatively linked to the growth of Lake Sues and ultimately to Alpine glaciations, providing an opportunity to date climatic change in Africa. As the European glacial-interglacial sequence was considered well established, interpreting data collected worldwide within this framework was typical, despite the tenuous nature of the correlation. Gregory's discoveries and inferences, in part laid the groundwork for subsequent applications of pluvial theory in tropical and subtropical Africa. While continuing to support correlation of climatic oscillations in Africa with those in the Alps, Gregory later noted that the links were equivocal, as it was proving difficult to recognize and correlate glacial stages even in different parts of Europe (Gregory 1931). In addition, he noted complications in differentiating climatic signals from tectonic or volcanic disturbances in terrestrial proxies, a consideration that became obscured in subsequent assessments of East African paleoclimate.

The goal here of re-examining pluvial theory as applied to equatorial Africa is not to document the misapplication of the concept as a chronostratigraphic tool but rather to explore the many innovative elements underlying pluvial theory that remain highly relevant to ongoing research in developing an environmental context

for early hominin evolution. Interpretations of field observations in Africa associated with the pluvial theory were novel and anticipated many later discoveries and subsequent theories linking climate, ecology, and evolution. The key variable that lay beyond the grasp of these early investigators, and eventually undermined the pluvial concept, was a means of determining absolute time. Ironically, the pluvial theory was developed and nurtured in African archeology and paleontology primarily as a means of correlation and relative dating.

Pluvial Theory

The notion that glaciers were formerly far more extensive at times in the past become generally accepted with the publications of Bernhardt (1832), Agassiz (1840) and other pioneers of the glacial theory during the middle of the nineteenth century. No sooner had the concept become established when the effects of glacial climates on saline lakes in middle-latitude arid regions beyond the reach of great ice-sheets was perceived. Jamieson (1863) surmised that a decrease in heat and aridity associated with a glacial period would result in disruption of the evaporation/precipitation balance, resulting in rising lake levels in arid regions. Subsequently, expansion of arid-basin lakes correlated locally with montane glacial advances was documented for a number of lake basins globally including the Aral-Caspian system (Jamieson 1863), the Dead Sea (Lartet 1865), Lake Bonneville (Gilbert 1890), and Mono Lake (Russell 1889). These periods of higher lake level became known as pluvial ages, because it was inferred that they represented intervals of increased precipitation and decreased evaporation. As it was mistakenly assumed that the formation and expansion of glaciers and ice-sheets requires a general increase in precipitation, it was reasonable then to correlate pluvial conditions in tropical and subtropical lowlands with glacial conditions at higher latitudes and altitudes. This premise persisted well after it was recognized that the advance or retreat of glaciers as well as middle and low-latitude lake levels are a function not only of overall precipitation but also changes in the distribution of annual precipitation through the seasons, astronomically forced variations in the amount of energy received on the earth's surface through the seasons, fluctuations in solar emission, regional uplift/subsistence, and changes in atmospheric circulation patterns.

The term pluvial was apparently first used in this context to refer to an expanded lake in a geological report of a region that included the Dead Sea (Hull 1885). The English meteorologist Brooks (1914) formalized the pluvial-glacial correlation by evaluating the theory in the context of general atmospheric circulation and climatic patterns. While Brooks continued to advocate that maximum extent of glaciation coincided with the maximum of pluvial periods in unglaciated regions world-wide, he noted a number of key inconsistencies including difficulties in precise correlation of glacials and pluvials, differential effects of “glacial climates” on equatorial and polar regions, and complications in explaining why glacial events resulted in greater low latitude rainfall. Significantly, he interpreted anticyclonic circulation associated with glaciated regions to result in increased evaporation at low-latitudes and decreased precipitation at high-latitudes. The assumption was that the deficit of rainfall was made up in non-glaciated regions of the globe and anecdotal historical evidence was used to support this claim (Brooks 1914).

East African Pluvial Theory

Research in Africa figured prominently in the establishment and acceptance of the pluvial concept between 1920 and 1960 and later, no doubt in part because of the implications for early human evolution (Oakley 1964; Brooks 1926). As on other continents, dramatic climatic fluctuations in Africa were interpreted from oscillations in lake levels, raised river terraces, and montane glaciers (Grove and Pullan 1963; Hume and Craig 1911; Faure 1969; Flint 1971) and ultimately placed within a comprehensive pluvial-interpluvial scheme. Interestingly, the focus of these investigations was almost exclusively on providing a temporal framework rather than a climatic/environmental context for interpreting the fossil and archeological record.

In the course of twenty years of stratigraphic field investigation in east Africa, Wayland sought evidence to support Brooks’ Pluvial Theory and in 1920 first made reference to at least one and possibly three pluvial periods in eastern central Africa (Wayland 1920). Wayland (1930) provided a succinct definition of pluvials as “A period of geological significance during which rainfall was in general considerably heavier than in earlier times (and later times), and than it is to-day (sic), over an area

sufficiently large to be of some account in world events is called a pluvial period”. Pluvial and interpluvial phases were not interpreted as reflecting intense, catastrophic intervals of alternating precipitation or desiccation, respectively, but basically unstable climates (Wayland 1934). Like Gregory, Wayland was also aware of the need for caution in establishing a chronostratigraphy based on pluvials that allowed for regional correlations (Wayland 1930). Following Leakey and Solomon’s (1929) discussion of archeological discoveries in Kenya with respect to pluvial intervals, Wayland (1929) felt their conclusions premature and noted “an unjustified feeling of security among archaeologists with regard to the chronological correlations of stone-age industries in widely separated countries”. After additional field experience, Solomon (1939) later conceded that the pluvial hypothesis “rests on very slender foundations and the writer is inclined to disregard it completely as a basis for classification”.

Despite these concerns, the pluvial theory became widely adopted for application throughout Africa as stratigraphic units, and the names were applied wherever correlation with the type-area was corroborated by paleontological, archeological or geological evidence. Various pluvial schemes for east Africa were considered (Wayland 1931; Nilsson 1935; Huzayyin 1936; Leakey 1931, 1952; Zeuner 1951; Simpson 1934), differing primarily in the number of pluvials recognized, specific correlations made with European glacial intervals, and the ages of the pluvials. Evidence for increased precipitation associated with specific pluvial intervals was correlated regionally predominantly on the basis of associated artifacts (Leakey and Solomon 1929; Sohngé Visser and Lowe 1937; Zeuner 1961). As the pluvials schema was then utilized to develop a chronostratigraphic framework for interpreting fossil and archeological material, the rationale and utility of pluvials were clearly compromised by circularity. In 1947, the First Pan-African Congress on Prehistory (Leakey 1952) endorsed the resolution for a stratigraphic-climatic sequence and a modified version of the four-fold pluvial nomenclature based on research in east Africa (Figure 11.1a).

As Bishop (1967) noted, the resolution included no mention of climate and also specifically recommended that the African nomenclature should be used as geologic units distinct from European terminology. This schema was ratified by the second and third Pan-African

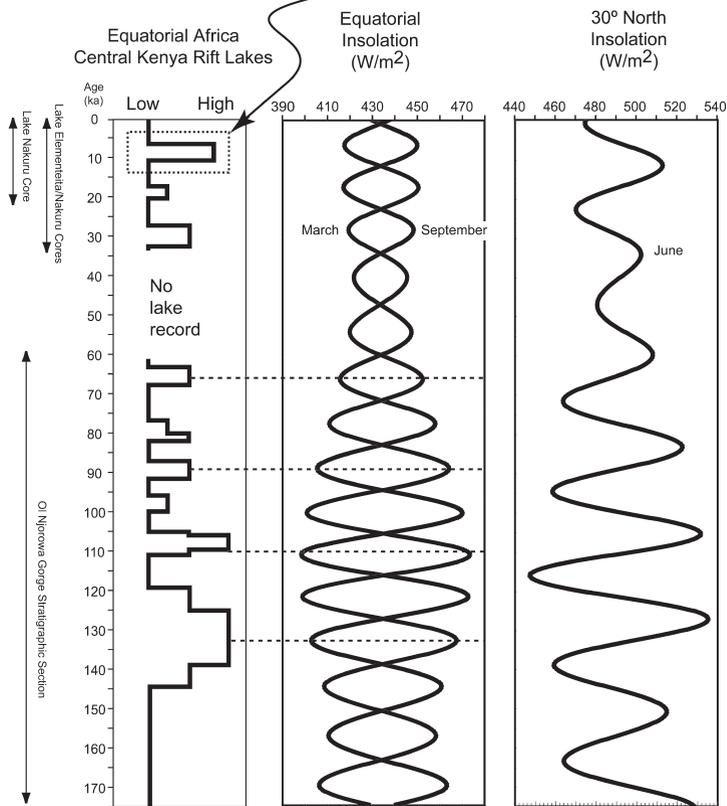
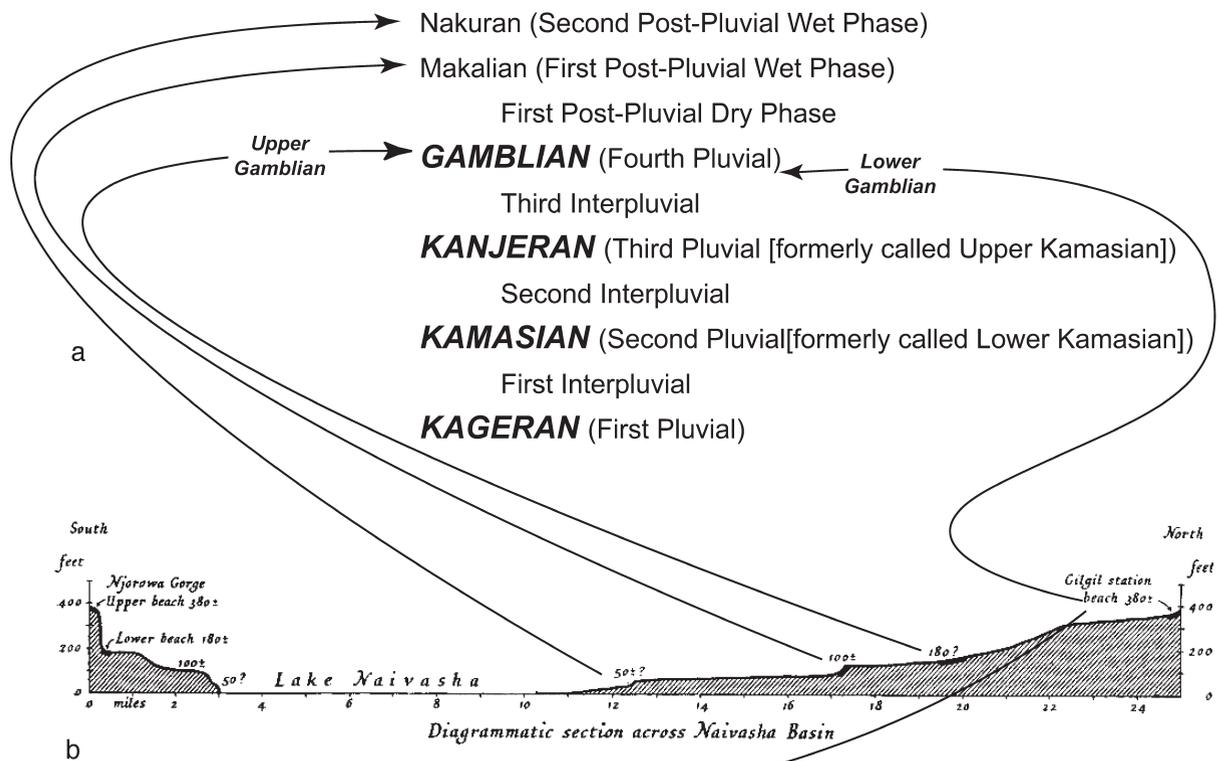


Figure 11.1 a) The four-fold pluvial sequence proposed to the International Geological Congress in 1948 (Leakey 1950); b) diagrammatic section across the Naivasha Basin depicting the relative elevation of terrace deposits exposed within the Rift Valley and along the escarpments (from Leakey 1931); c) Late Pleistocene and Holocene east African lake levels (Lake Naivasha, Lake Nakuru, and Lake Elementeita) correlated with March/September equatorial insolation and mid-latitude June insolation curves (after Trauth et al. 2003). Insolation curves from Laskar et al. (2004). These data suggest that long-term fluctuations in African lake-levels is in part driven by increased precipitation associated with maximum equatorial solar radiation in March or September rather than exclusively by monsoonal patterns influenced by insolation shifts at about 30 N in early summer.

Congresses of 1952 and 1955 with the provisions that the pluvial succession should be recognized as stratigraphic climatic divisions only in the east African region, that pluvial intervals should incorporate the following interpluvial as original definitions did not account for these arid stages, and that the Pleistocene fauna throughout Africa could be divided into four faunal stages that could be equated with pluvial phases.

Equatorial African Pluvial Theory ultimately floundered not so much because of the uncertainties in recognizing and correlating “pluvial events” between isolated tectonic basins in African and to temperate glacials, but rather as a result of codification of stratigraphic nomenclature (Flint 1959; Cooke 1958; Bishop 1962, 1967). Most geologists working outside of Africa recognized that climato-stratigraphic units or divisions reflected an inferred second-order phenomena rather than primary objective units such as grain size or fossil assemblages. Flint (1959) noted that pluvials were subjective concepts open for interpretation and differed fundamentally from conventional stratigraphic systems to the point that they represented obstacles to inter-regional correlation. The presumption of pluvials as stratigraphic entities led many to apply the terminology throughout Africa, creating confusion and misunderstanding of the relative temporal framework of fossil and archeological discoveries. In addition, a scrutiny of the empirical evidence on which the pluvial theory was based revealed the equivocal nature of environmental interpretations of the sedimentary deposits (Flint 1959). In 1959, the Fourth Pan-African Congress confirmed that the pluvial terminology was “in course of revision and will ultimately be defined in accordance with the normal practices in stratigraphic nomenclature” (Mortelmans and Nenquin 1962). In response, Bishop (1967) developed a lexicon to standardize pluvial-interpluvial terminology and relegated “pluvial events” to their localized context, essentially terminating their use in intra-and interregional correlation. The International Subcommission on Stratigraphic Classification (Appendix F [To ISSC Circular No. 99]) suggests that although lithologic evidence for paleoclimatic change provides valuable information for chronocorrelation, it must be used in combination with other specific methods such as absolute radiometric dates, geomagnetic polarity reversals, regional unconformities, or interrelations of strata.

Unfortunately, as the East African Pluvial Theory was discarded, so too were many details of climatic information gleaned from decades of field investigations as well as the emphasis on developing paleoclimatic proxies. One aspect of the pluvial theory on which all researchers converged was the notion that aspects of stratigraphy indicated multiple episodes of climatic change. While it was ultimately argued that much of the evidence for climatic flux should instead be attributed to changes in base level or drainage patterns due to tectonics or volcanic activity (Flint 1959), it was evident that certain features of the stratigraphic record were climatically controlled. Many questions regarding the nature and causes of these climatic fluctuations and the effects on the evolution of equatorial African ecosystems during the Pliocene remain unresolved. The remainder of this paper explores the history and development of research into climatic change in east Africa.

Causes of Glaciations and Pluviations

As elements of the glacial/pluvial theory were being assimilated, meteorological theory was maturing and developing a global and historical perspective to assess regional or local climatic patterns (Brooks 1914, 1926; Simpson 1934, 1940). Although it was acknowledged that interpreting past climates was critical in establishing climatic trends or documenting climatic change, empirical evidence of past climates was fragmentary and inconsistent (Simpson 1940). As a result of these limitations, theoretical meteorological modeling was utilized to develop perspectives of climate change, which were then subjected to verification. While this approach led to many ad-hoc explanations that had to be discarded, it also led circuitously to the development of concepts 150 years ago that are essentially correct and integral to current interpretations of controls on climatic variability (Adhémar 1842; Croll 1864). Even though the causes of climatic fluctuations and of glacial-pluvial ages are not the same, they are related and much of the early research on climate change was stimulated by attempts to explain glacial theory (Brooks 1914; Simpson 1934; Flint 1947 1971) and by extension, pluvial theory.

As glacial theory became established, a number of explanations for the ice ages were suggested (Imbrie and Imbrie 1979) including: 1) variation in solar activity

(Simpson 1940); 2) uneven distribution of cosmic dust along the earth's orbit; 3) shifts in atmospheric CO₂ levels (Chamberlin 1899); 4) volcanic eruptions; 5) large-scale vertical uplift of the earth's crust (Dana 1894); 6) abrupt sliding of large portions of the Antarctic Ice Sheet into the ocean (Wilson 1964); 7) internal dynamics of the air-sea-ice system (Ewing and Donn 1956); 8) stochastic climate change resulting from the cumulative effect of many small, random change in weather; and 9) astronomical phenomena controlling the amount of solar radiation reaching the earth's surface (Adhémar 1842).

While aspects of a few of the theories remain relevant, most of these theories have either been rejected or remain untestable. The astronomical theory (number nine above), however, has endured and is now generally believed to represent the dominant extrinsic force driving climatic change, including glacial-interglacials.

Building on observations and calculations of earlier astronomers and mathematicians as far back as Hipparchus in about 120 B.C., the early pioneers of astronomical theory proposed that variations in the earth's orbit were responsible for changes in climate. Adhémar (1842) initially speculated that orbitally driven changes in solar radiation might in some way be linked to the growth and melting of ice sheets. Refining this idea, Croll (1864) and later Milankovitch (1920) developed the modern astronomical theory of climate, which mathematically demonstrated that astronomical variations were sufficient to produce ice ages by changing the geographic and seasonal distribution of sunlight. Due to gravitational effects of the sun, moon, and other planets on the earth, the geometry of the earth's solar orbit varies cyclically, altering the insolation (radiation arriving at the top of the earth's atmosphere) and dramatically impacting earth's climatic systems.

Key features of the astronomical theory are featured in Figure 11.2 which depicts the two fundamental motions of the earth's solar orbit—the earth's rotation around an axis that passes through its poles and the earth's once-a-year revolution around the sun. The position and orientation of the earth relative to the sun is not fixed over long intervals of time and variations occur in the degree of orbital eccentricity around the sun, the obliquity of the earth, and the seasonal timing

of perihelion and aphelion (precession of the equinoxes; Bradley 1999; Ruddiman 2001). These longer-term variations in earth's orbit result in cycles ranging from about 20 ka to 400 ka and cause cyclic variations in the amount of insolation by latitude and season. Changes in solar heating driven by variations in earth's orbit are the major cause of cyclic climatic change over the 10–100 thousand year time scale. In addition, the astronomical theory claimed it would be possible to calculate the amount of insolation at any given latitude at any time in the past, allowing the theory to be tested by comparing the radiation curves with empirical records of climatic change such as pluvial/glacial systems.

Despite the endorsement of many of Croll's and Milankovitch's contemporaries, astronomical theory languished, primarily due to difficulties in achieving a level of temporal resolution in climatic proxies in the stratigraphic record that would allow for validation of the length and timing of these periodicities. In addition, superimposition of variations in eccentricity, obliquity, and precession produces a complex, ever-varying pattern of insolation through time. The cumulative effects of these cycles through time are further complicated by the fact that the relative strength of the various cycles can shift at any given location, there are lag times, there can be varying modulation of amplitudes, and there are a number of additional astronomical and earth-intrinsic climatic feedback mechanisms that mediate external forcing. As these complications were not completely appreciated initially, testing the theory remained problematic and inconclusive (Imbrie and Imbrie 1979). It wasn't until the 1960s and 1970s that the theory was revived when theoretical astronomical signals were experimentally found in geochemical climatic data obtained from a suite of deep-sea cores (Hays et al. 1976; Berger 1977; Emiliani 1966; Shackleton 1967). These studies revealed the occurrence of numerous, quasi-periodic variations in isotopic parameters with almost constant amplitudes which could be related directly to glacial cycles by absolute dating. Since then, periodicities associated with orbital variations have been identified in many paleoclimatic records and it is clear that orbital forcing is an important factor in climatic fluctuations on the timescale of 10 ka to 1 Ma throughout most of the earth's history.

Significance of Astronomical Theory for Tropical and Sub-tropical Africa

As astronomical theory was integrated with glacial theory and absolute dating techniques were refined, the notion that glacial conditions were associated with increased precipitation at lower latitudes was completely overturned as it became apparent that the relationship was not simple or direct and that glacial intervals typically correlated with cool, arid conditions rather than moist “pluvial” climate in equatorial regions (Fairbridge 1964; Damuth and Fairbridge 1970; Galloway 1965). Although orbitally-forced changes in insolation have been implicated in environmental change in equatorial Africa, the precise mechanism of how orbital forcing is

translated into a climate response remains unclear and much research is currently exploring links between cyclic variations in insolation and climate change.

Linking astronomical theory to climate in Africa is further complicated by the markedly complex and highly variable climatic patterns that characterize equatorial Africa. Climate in this region is currently controlled by the intersection of three major air streams and three convergence zones, superimposed on and influenced by regional factors associated with topography, lakes, coastal currents and upwelling, and sea surface temperature fluctuations in the Indian and Atlantic Oceans (Nicholson 1996).

Emerging data indicates that equatorial African climate is affected not simply by insolation changes at

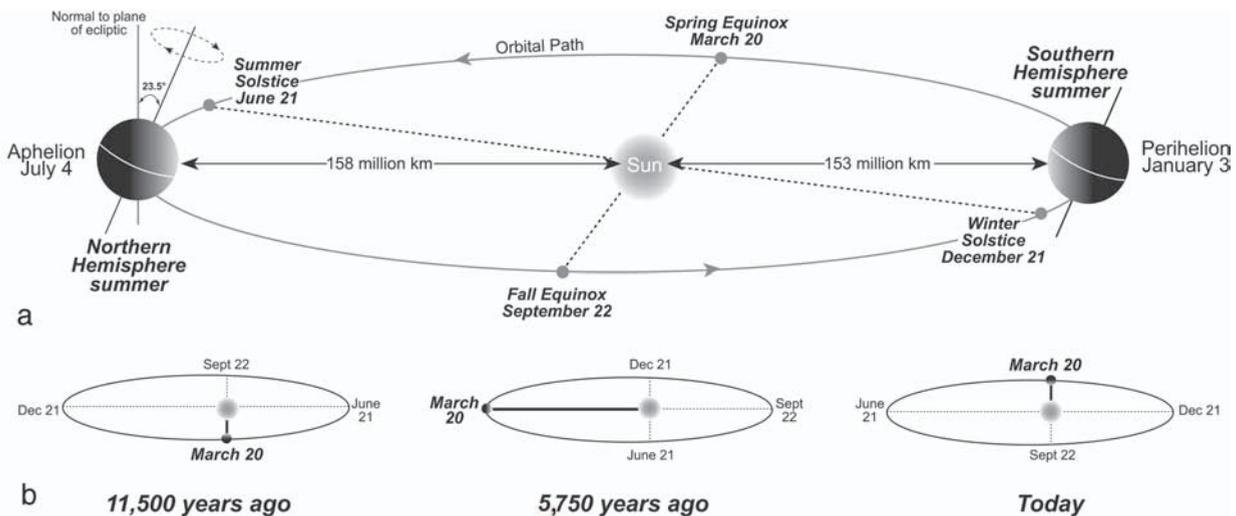


Figure 11.2 a) Current geometry of the earth's orbit around the sun depicting key variables that control the amount of solar radiation hitting the earth's atmosphere (insolation). The earth's orbit, an ellipse with the sun at one focus, defines the plane of the ecliptic. As the earth moves around the sun in the direction shown by the arrows, the distance from the sun and consequently the amount of solar radiation received by the earth varies along the orbit. Through time, the orbit has varied from almost circular (essentially no difference between perihelion and aphelion) to maximum eccentricity when insolation varied by about 30% between perihelion and aphelion. Variations in orbital eccentricity are quasi-periodic with two main periods, one eccentricity cycle consists of four cycles of nearly equal strength and with periods ranging between 95 ka and 131 ka, which blend to form a single cycle near 100 ka. This cycle controls insolation variability typically associated with glacial/interglacial cycles. The second major eccentricity cycle has a wavelength of 413 ka. The axis of the earth's rotation is tilted relative to the normal of the ecliptic. Over time, the axial tilt (obliquity) varies periodically in a narrow range, cycling back and forth between 22.2° and 24.5° (currently 23.5°) with a mean period of 41 Ka. Changes in tilt cause long-term variations in seasonal solar insolation received on earth and the main effect is to amplify or suppress the seasons. Variation in obliquity has relatively little effect on radiation receipts at low latitudes but the effect increases towards the poles. Increased tilt amplifies seasonal differences whereas decreases in tilt diminish the amplitude of the seasonal differences; b) changes in the seasonal timing of perihelion (closest to the sun) and aphelion (furthest from the sun) result from a slight wobble in the earth's axis of rotation as it moves around the sun. The earth's wobbling motion (axial precession) is caused by the gravitational pull of the sun and moon on the slight bulge in earth's diameter at the equator and effectively results in the slow turning of earth's axis of rotation through a circular path with one full turn every 25.7 ka. Axial precession, when combined with the slow rotation of the elliptical shape of earth's orbit in space in time (precession of the ellipse), causes the solstices and equinoxes to move around the earth's orbit, completing one full 360° orbit around the sun every 23 ka (precession of the equinoxes). The diagram shows how the relative position of the March 20 equinox shifts around the earth's orbit in half of a 23,000-year cycle.

low-latitudes but also by mid- to upper-latitude insolation that controls systems such as the Asian monsoon and Atlantic sea surface temperatures that are central ingredients in African climate. Climatic flux in equatorial Africa has been linked to high-latitude glacial-interglacial obliquity and eccentricity amplitudes as well as low-latitude precessionally controlled insolation changes driving monsoonal circulation intensity.

As in Gregory's day, investigations of lake records continue to provide compelling evidence of paleoclimates. Lacustrine sediments, like marine deposits, have the potential to accumulate slowly and remain generally intact, providing a high resolution archive of environmental conditions. Fluctuations in Pleistocene and Holocene lake-levels in Africa document important changes in the precipitation-evaporation balance and indicate that the timing and duration of humid and dry periods are controlled by a number of factors including equatorial insolation, northern hemisphere insolation, and monsoonal intensity (Pokras and Mix 1985, 1987; Street-Perrott and Harrison 1984; Kutzbach and Street-Perrott 1985; Gasse et al. 1989; Lamb et al. 1995). These direct and indirect lacustrine climatic proxies indicate hydrologic patterns in North Africa consistent with precessional cycling at 23 ka in which stronger insolation drives stronger summer monsoon maxima, ultimately creating larger lakes.

Organic-rich sapropel layers in the subsurface of the east Mediterranean Sea have been linked to high freshwater and organic influx from the Nile whose headwaters drain east African highlands and therefore reflect east African precipitation patterns (Rossignol-Strick 1982; Krom et al. 2002). Cyclical patterns in sapropel deposition also indicate that precessionally controlled insolation changes drive monsoonal circulation intensity exerting control over hydrological patterns in equatorial Africa (Rossignol-Strick 1983; Hilgen 1991; Lourens et al. 1996).

Eccentricity and obliquity amplitudes or timing have also been recognized in paleoclimatic proxies relevant to African paleoclimates (Gargas and Wilkens 2002; D'Argenio et al. 1998; Johnson et al. 2002), suggesting that sub-Saharan moisture patterns are linked to glacial/interglacial cycling as well. Marine records of terrigenous eolian and biogenic dust transport from subtropical African source areas (de Menocal 1995a, 1995b;

Pokras and Mix 1987; Clemens et al. 1991; de Menocal et al. 1993; Moreno et al. 2001) have been interpreted to reflect source-area aridity and indicate a dominance shift from 23 ka precessional periodicity to 41 ka obliquity variance at about 2.8 Ma, suggesting that the African climate became more arid and dependent on high-latitude climatic forcing (de Menocal 1995a, 1995b).

Evidence of short-term climatic change in the East African Rift has been documented at a number of early hominin sites, including Olduvai (Hay 1976; Liutkus et al. 2000; Ashley and Driese 2003), Olorgesailie (Potts et al. 1999; Behrensmeyer et al. 2002) and Turkana (Feibel et al. 1989; Bobe and Behrensmeyer 2004), but it has been difficult to unequivocally link these perturbations to astronomically mediated insolation patterns and seasonality patterns. Environmental variability, reconstructed from pollen data, at Hadar corresponds with global climatic events documented in the marine record and may track a precessional cycle (Bonnefille et al. 2004). Ongoing studies in the Baringo Basin of the Central Kenyan Rift Valley have identified lake cycling 2.5 to 2.7 Ma at hominin localities consistent with 23 ka precessional periodicity (Kingston et al. 2000; Hill et al. 2003). Shifts in paleohydrological patterns in Baringo and at Hadar represent a window on a much more pervasive pattern of environmental change that is generally obscured locally and regionally by rifting activity.

The co-existence of all main astronomical cycles in spectral data provides evidence for a complex interdependence and influence of high and low-latitude orbital parameters influencing climatic regimes in equatorial Africa. Cumulatively, these data indicate that astronomical cycles are highly relevant to understanding variation in climate and seasonality in equatorial Africa.

Biotic Response to Astronomically Forced Climate Change in Equatorial Africa

The nature of the response of the biosphere to orbital pacing of global climates has been well documented in the marine realm (Webb and Bartlein 1992) but terrestrial data remains limited. Orbitally-modulated cycling of precipitation and seasonality patterns in the east African Rift Valley presumably resulted in dynamic fluctuations in the physiognomy and taxonomic representation of flora in the region, with more arid and seasonal climatic

regimes associated with more widespread open woodland and grassland habitats. Studies of Quaternary paleovegetation records indicate that equatorial African ecosystems are highly sensitive to orbitally forced climate change and the associated shifts in atmospheric CO₂ and vegetation-soil feedbacks. The effects of these climatic oscillations have been documented in rapid changes in pollen assemblage indices (Prell and Van Campo 1986; Lezine 1991; Bonnefille and Mohammed 1994; Elenga et al. 1994), charcoal-fluxes (Verardo and Ruddiman 1996), and relative proportions of C₃ and C₄ biomarkers (Huang et al. 1999; Ficken et al. 2002; Schefuß et al. 2003). These data suggest that the main response of vegetation to short-term climatic variability would likely have involved a reshuffling of the relative coverage of different plant communities rather than whole-scale extinction or speciation events.

Linking mammalian evolution with climatic change has been notoriously difficult, primarily because of a general lack of stratigraphic, taxonomic, and temporal resolution in fossil data. Given the uncertainties in documenting terrestrial faunal response even to major climatic events, including the early Oligocene transition from the “greenhouse” to “icehouse” world (Prothero 2004), unraveling evolutionary responses to short-term climatic change remains a considerable challenge. Most of the fossil vertebrate record is not resolvable to the tens of thousands of years level necessary to develop correlations implying cause and effect. A number of adaptive strategies have been proposed as options for terrestrial fauna faced with environmental instability including habitat tracking, phenotypic plasticity, developmental plasticity, or behavioral flexibility (generalism). Recurrent and rapid climatic oscillations are thought to favor speciation resulting in higher taxonomic diversity and phenotypic disparity (Valentine 84; Vrba 1992; Moritz et al. 2000). Shifting periodicities can affect the duration of phases during which species’ geographic distributions remain continuously fragmented and organisms must exist beyond vicariance thresholds (outside optimal range), increasing the incidence of speciation and extinction (Vrba 1995). Bennett (1990) suggested that orbitally forced climatic shifts generally increase gene flow directly by reshuffling gene pools and that any microevolutionary change that accumulates on a time scale of thousands of

years is consequently lost as communities reorganize following climate change. Fluctuations indirectly select for vagility (dispersal ability and propensity) and generalism, both of which reduce extinction in the long run and also slow speciation rates (Dynesius and Jansson 2000; Jansson and Dynesius 2002). Potts’ Variability Selection Hypothesis (Potts 1998) proposes that the complex intersection of orbitally forced changes in insolation and earth-intrinsic feedback mechanisms results in extreme, inconsistent environmental variability selecting for behavioral and morphological mechanisms that enhance adaptive variability. Research by Graham (1986) and Bennett (1990) suggests that specific taxa appear to respond individually to climate change and that communities are massively and repeatedly rearranged. Strong selective pressures may develop in response to cumulative effects or shifts in mode of dominant oscillations, resulting in differential response of various lineages. Evaluating the relative validity of these evolutionary models ultimately hinges on developing a level of resolution in the faunal and stratigraphic record to anchor speciation and extinction events in the context of short-term environment shifts—currently a difficult task.

Summary

Over a century after the pluvial and astronomical theories were first formulated, we find ourselves on familiar ground from a historical perspective, attempting to evaluate human evolution in equatorial Africa in the context of local climatic oscillations intimately linked to global climatic systems. The ancient lake margin deposits noted by Gregory (1896) plastered against the escarpment 400 feet above the floor of the Rift Valley were subsequently explored (Nilsson 1935; Leakey 1931) and ultimately incorporated into the pluvial scheme as a wet-phase or high lakestand level representing the late Gamblian Pluvial (Figure 11.1a–b; Leakey 1931). More recent work in the Naivaisha Basin, utilizing laser fusion ⁴⁰Ar/³⁹Ar geochronologic control, has linked shifting lake levels in the basin to orbitally forced variations in the temporal and spatial distribution of solar radiation (Figure 11.1c; Trauth et al. 2001, 2003). Gregory’s 400-foot terrace deposits reflect the most recent lake highstand in the Central Kenyan Rift between 10 and 6 kyr BP (Richardson and Dussinger 1986; Richardson and

Richardson 1972) and have been correlated to a humid period documented in other east African lake basins (Gasse et al. 1989) and ice cores from Mt. Kilimanjaro (Thompson et al. 2002). Evaluated in the context of Holocene insolation curves, this 10–6 kyr humid phase suggests a complex link between insolation and climate change in east Africa (Trauth et al. 2003).

This specific example demonstrates that although intrinsically flawed, Pluvial Theory incorporated and anticipated many concepts that currently influence perspectives on climatic and environmental change in tropical and subtropical Africa. Most of the field observations invoked to support the pluvial theory were essentially correct but the inferences were wrong. Applied primarily as a chronostratigraphic tool in east Africa, local evidence of pluvial events was interpreted and justified at a global level (by correlation with temperate glacials) to ultimately allow for regional inter- and intra-basinal correlation of artifacts and fossils within Africa. The correlation strategy was highly circular and in general not supported by the available data. Many researchers at the time expressed concern over the difficulties in differentiating tectonics, climate, and volcanism as causal effects but in general agreed on the multiplicity of the oscillations in climate. The pluvial theory generated much discussion of climatic proxies in the stratigraphic record of equatorial Africa and figured prominently in the early development of links between low-latitude climatic patterns and glacial-interglacial cycles. Ongoing research investigating climatic cycling and evolutionary patterns in east Africa has benefited greatly from these discussions and should acknowledge this historical framework, particularly as much useful information remains to be gleaned from investigations associated with, and discarded with, East African Pluvial Theory.

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David Pilbeam is one of a small group of paleoanthropologists of his generation who always recognized the importance of a multi-disciplinary approach. He has been keen to bring into the study of hominoids data and ideas from other fields: geology, climatology, molecular biology, for example. By this means the subject has been enriched, and he has influenced in this way those who have had the pleasure of his company and conversation over the years.

A. H. first had a sighting of David when an undergraduate, when he made a pilgrimage in 1967 to the British Association meetings in Leeds, to witness him giving a plenary lecture, and shortly after they met in Bill Bishop's office at Bedford College when David came to search for hominoid scraps among the Napak material that AH was playing with. In 1968 they were both on Alan Walker's first Bukwa expedition, and after that A. H. met him again in Kenya, then as a member of the Pakistan Siwaliks expedition, the Baringo Paleontological Research Project; there was the Louis Leakey Memorial Institute for African Prehistory adventure, and then an escape for A. H. to Harvard for a few years in a research position. After that David's apparently very small home range has diminished actual personal contact, but A. H. still thinks of him often, fondly, and with gratitude.

Interested but not sufficiently stimulated by issues confined to the geologic realm, J. K. was given a unique opportunity by David to enter into a graduate program in biological anthropology in 1986 and explore the intersection of paleoanthropology, paleoecology, stratigraphy, and evolution. David's graduate seminars provided a foundation for many research agendas subsequently being pursued by J. K. The questions and issues raised during these meetings remain essentially unanswered and provide fertile ground for many lifetimes of investigation. In addition, David has always emphasized the need for the collection of empirical data from the field and J. K. is indebted for the opportunities for field investigations in Pakistan and Africa. David's seamless pursuit of knowledge across numerous disciplines has inspired a whole generation of anthropologists to avoid the narrow academic niche concept that is pervasive today and push for the integrative, holistic approach to scientific inquiries. For David's 65th birthday we offer this informal essay on the intricate conjunctions of climate and hominins. This paper, although not much of its data comes from it, is essentially a product of mutual musings stimulated by our work on the Baringo Paleontological Research Project (BPRP). This is the project begun by David, now located at Yale University and directed by A. H., carried out in association with the National Museums of Kenya.

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