

# Holocene alluvial sequences: Problems of dating and correlation

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## Background

Geomorphology as a discipline derives from the intellectual ferment of the earth sciences during the late eighteenth and early nineteenth centuries. Initially, geomorphology represented a qualitative and often deductive search to identify modern processes that might serve to explain the origin of geological strata. It subsequently emerged as a subfield of geology and physical geography devoted to description and analysis of landforms. The geological legacy has remained pervasive, not only in the persistent concern with sequential events and related processes, but also through the many field procedures, laboratory techniques, and general perspectives that geomorphologists continued to share with geologists in general. The long tradition of denudation cycles and structural histories could be viewed as a counterpart to the geologists' interest in identifying stratigraphic complexes. On a finer scale, the development of historical geomorphology (not to be confused with the approach of W. M. Davis) went hand in hand with refinements in glacial geology, as part of the increasingly diverse contributions to an understanding of the Quaternary era. The most recent penchant for detailed micro-studies, increasingly quantitative and inductive, is once again shared with a wide range of specialized earth science subfields.

These links between geomorphology and the broader earth science tradition are logical as well as indispensable, but they have also been detrimental in that this tradition has generally been a conservative one. A half century elapsed between Charpentier and Agassiz on the one hand, and achievement of a majority view that Pleistocene glaciation had been extensive on the other. Similarly, Wegener's hypothesis of continental drift was derided for 50 years prior to the latter-day enthronement of plate tectonics. Geomorphologists, in their turn, failed to respond to the challenge to integrate their research in the evolving field of geography. They had almost no part in as logical an offshoot as soil science, which consequently developed in response to agricultural interests. Accelerated soil erosion, a pre-eminently geomorphological problem, was ignored by geomorphologists until after World War II. Hydrology owes its origins to engineering interests, with geomorphologists still assuming the role of consumers rather than innovators. The great upsurge of interest in environmental quality and management that began a decade ago found American geomorphology, on the whole, painfully unprepared to contribute a self-evident range of expertise.

The conservatism of geomorphology is also apparent in the lagging development of realistic temporal frameworks. The persistent misconception that 'denudation chronology' can be equated with Davisian cycles 'dated' by landform geometries underscores the continuing ignorance of many geomorphologists as to what timescales really are. The historical geomorphologist, in the strict sense, aspires to establish both relative and chronometric sequences of verifiable events.

The perspective of relative scale is critical. 'Polyglacialism' was firmly established by Penck and Brückner in 1911, in part on the basis of a complex sequence of glacio-fluvial 'terraces'. A subsequent generation of geomorphologists simply assumed that alluvial units corresponded to glacial-interglacial cycles. Functional floodplains were ascribed to the sum total of 'post-glacial' time, and most geological mapping services even now continue to equate such floodplains with 'Holocene'. A complex suite of distinct 'post-glacial' environments had been demonstrated for temperate Europe on palynological grounds, within a decade of Penck and Brückner's Alpine study. Yet geomorphologists chose to continue to work with the much coarser traditional timescales of the earth sciences.

### New Perspectives in Historical Geomorphology

A revolution in historical geomorphology was eventually made possible by the successful application of sedimentological techniques, by advances in isotopic dating, and by collaborative geo-archaeological efforts.

Multiple morpho-stratigraphic units of Holocene age were occasionally identified by field studies during the 1920s and 1930s, but they were often ascribed to non-cyclic channel shifts and little significance was attached to them. It is to the credit of Bryan (1941) and Hack (1942) that two alluvial cycles were specifically recognized and linked with mid- to late-Holocene settlement phases in the American Southwest. A similar interest in relatively small-scale, short-term events intricately related to human occupation can subsequently be discerned in other areas, for example in the Mediterranean Basin, Germany, and Britain. Archaeological associations, particularly potsherds or buried structures, were commonly employed to provide *maximum* possible ages, i.e. a deposit can be no older than the youngest sherds that were incorporated during transport. Such attention to detail is characteristic of most geo-archaeological work, and it can be safely said that the involvement of geomorphologists in archaeological research has contributed substantially to refinement of timescales, not only in fluvial, but also in cave, littoral, and eolian contexts. Despite this increasing awareness of temporal and spatial complexity, the traditional tendency to oversimplification has been persistent. For example, Vita-Finzi (1969) and Bintliff (1975) stress a single alluviation phase during the Holocene in the Mediterranean Basin and Greece, respectively. But it appears that, overall, geo-archaeological efforts in historical geomorphology have gathered sufficient momentum to set and maintain new standards of sophistication.

Archaeological dating, while useful and often essential, proved of limited help for stratigraphic discrimination in the Holocene record in many areas or time ranges. Pottery dating, even in areas with adequate seriation and firm links to historical chronologies, requires either large samples or diagnostic types that are seldom found in sedimentary contexts. Lithic artifacts in 'pre-pottery' deposits are still more equivocal, and even where, for example, a specialized projectile point does have specific temporal implications, supposed dating ranges tend to be uncertain or unreasonably broad. A fundamen-

tal problem, too, is that archaeologists have commonly sought dating controls for their assemblages in geological sequences, while geomorphologists have frequently attempted to date their sequences by archaeological inclusions. The two approaches are interdependent and complementary, but both require independent chronometric aids.

Until the advent of isotopic dating, absolute time controls were essentially lacking for prehistoric settings. Radiocarbon ( $^{14}\text{C}$ ) dating had a truly revolutionary impact for microstratigraphy and geomorphological interpretation in the 5000–40,000 year time range. The problems of such radiometric work, in terms of inherent methodology and of application, need no enumeration here. Despite persistent geochemical and sampling problems, geomorphological sequences have become rather more refined and detailed, while countless stratigraphic errors, often gross, have been eliminated. It is safe to say that in almost all morpho-stratigraphic work, the  $^{14}\text{C}$  assays are correct more often than the field assessments. A particularly impressive example of the impact of  $^{14}\text{C}$  dating is Haynes' (1968) revision of the alluvial chronology of the southwestern USA, showing the existence of five depositional hemicycles during the last 10,000 years, with a degree of temporal overlap between regions and even different valleys. Although other dating techniques, such as pottery thermoluminescence, obsidian hydration, or potassium–argon isotopic decay have been used in some situations, none has yet proved of similar, almost universal utility.

Geomorphological sequences are also intrinsically informative. Early work, even when correctly identifying alluvial cycles, paid scant attention to sediment variability or interpretation. Such variability may be 'normal' but it is never uninformative, and no two depositional hemicycles are identical. The tools to provide objective analysis and identification of facies sequences and palaeosols were initially derived from soil science, then applied to the rapidly growing field of sedimentology (critical in petroleum exploration), and more recently augmented by the experience gained from small-scale, contemporary process studies. A range of particle-size analyses, and morphometric, geochemical, and other techniques now provide the opportunity for identifying the fine details of alluvial aggradation (Gladfelter, 1977).

Contemporary short-term, small-scale changes, when properly measured, temporally analysed, and applied, have great potential for accurate interpretation and calibration (Thornes and Brunnsden, 1977; this volume, Section I). However, few process geomorphologists have acquired the requisite expertise in geochronology and palaeoclimatology to deal with complex landscape periodicities. In fact, the blanket dismissal by Thornes and Brunnsden (1977) of 'traditional' analytical work would appear to reflect a lack of familiarity with, or comprehension of, the better examples of historical geomorphology, as well as an inability to distinguish clearly between large- and small-scale features or events. Substantive disciplinary progress is possible only through informed dialogue between the practitioners of various specialities such as is attempted in this volume.

### **Basic Problems in Historical Alluvial Geomorphology**

Recent advances in historical geomorphology have primarily served to delineate a number of critical and persistent problems. These include the identification of successive phases of local cyclic events, their internal dating and external correlation, and their causation. Chronometric controls, consideration of complex geomorphic systems (rather than of single processes), and evaluation of multiple variables are all essential. In the case of Holocene alluvial sequences the specific issues can be briefly enumerated as follows.

*Internal Dating*

Alluvial deposits record only a fraction of an alluvial cycle (Butzer, 1976a), possibly a long period of slow, net accumulation with many equilibria, possibly a brief period of disrupted equilibrium with rapid mobilization and aggradation of valley floor sediment (Baker, 1977). Suitable samples for  $^{14}\text{C}$  dating are commonly limited and the range of statistical or contaminant error between any two assays may exceed the true age span of an entire sedimentary body. As a result, radiometric dating tends to be spotty, and frequently is based on fortuitous samples of differing materials from widely separated areas, sometimes not even from the same drainage. Yet dissection may begin downstream (or along a higher order stream) centuries earlier than it does upstream (or in a low-order valley), where dynamic equilibrium may still persist. In this way the drainage-wide selection of  $^{14}\text{C}$  samples that commonly is indispensable for even a rudimentary dating framework may introduce unwelcome error. It is consequently not surprising that the temporal components of Holocene alluvial cycles remain imperfectly understood, even in the best studied stream systems.

*Intraregional Correlation*

Fundamental to the establishment of regionally valid alluvial sequences is close attention to morpho-stratigraphic detail: relative sets of longitudinal gradients, vertical and lateral patterning of facies, disconformities or soils, and relationships between stream sediments, colluvia, and slope forms. Given a reasonable number of chronometric cross-checks, adjacent stream systems of intermediate order and comparable lithologies may allow for gross correlation and the identification of landscape periodicities with regional validity. A judicious combination of local detailed studies and broader reconnaissance is essential to such goals.

*Regional Delimitation*

Alluvial histories, like those of other environmental components, tend to be areally circumscribed. Sufficient field exploration will normally allow an appropriate definition of the region in which alluvial sequences are comparable. This in turn may coincide, for example, with a bedrock or terrain type, an ecozone, or a prehistoric culture area. Such spatial resolution is critical for assessment of various potential causative factors.

*Causation*

Given adequate temporal and spatial controls, it may be possible to consider the potential role of climatic change, human activities, or a host of other environmental variables, singly or interactively, in affecting ground cover, runoff volumes and periodicities, and sediment supply and mobilization. If the basic causes are isolated, then the timescales of landscape periodicities can be properly interpreted and, in turn, refined.

In effect, alluvial histories can only be explicated by holistic research projects that pay due attention to scale and multivariate interactions. Both the problems and realizations can be usefully illustrated by a selection of examples from different macro-environments at different latitudes on three continents. These studies have been deliberately chosen from areas where the author has some degree of field familiarity and can claim methodological comparability. The references cited provide the indispensable details for what can be no more than synopses.

### The Upper Danube Basin, Central Europe

The floodplains of central Europe are extensively veneered by flood silts and related colluvium of Mediaeval date, with more localized, earlier wash, mainly of the late Bronze or early Iron Age (Butzer, 1974a). These deposits (haugh loams) reflect accelerated runoff in the wake of intensive human occupation, including cultivation of upland loess soils, grazing on valley-margin slopes, and finally large-scale clearance and frequently abortive cultivation of irregular terrain prone to sheet, gully, and rill erosion. Haugh loam mantles have tended to obscure complex suites of alluvial bedload facies, resulting from reworking of late Pleistocene gravels, primarily during the last 5 millennia (Schirmer, 1977).

A representative example of this Holocene dynamism in a temperate, mesic environment is provided by the Reichenhall Basin of the Saalach River in Bavaria (Brunnacker *et al.*, 1976). During mid-Atlantic times the Saalach still meandered in a channel incised only 4 m into an intact body of glaciofluvial gravels of terminal Pleistocene age. Then channel shortening led to 20 m of downcutting. Pollen diagrams from the silts and peats that subsequently accumulated in the new channels, as well as in the abandoned meanders, record the Atlantic-Subboreal transition and, in one core, the base of the Subatlantic. The former is dated *ca.* 4750–4450 bp in the general area, suggesting dramatic incision shortly after 5000 bp (all 'before present' dates represent uncalibrated  $^{14}\text{C}$  years). Subsequently, gravel and colluvial rubble were aggraded by tributary fans while 10 m of silt and clay rapidly buried a growing forest on the Saalach floodplain. This phase of sedimentation is linked to a late Bronze (Urnfield) cemetery and attributed to widespread deforestation *ca.* 1300 BC. After a period of stabilization, 2–3 m of coarse valley-margin fans and floodplain silts accumulated between AD 150 and 700. Minor downcutting (by 1 m) in late Mediaeval times was followed by building up of the modern floodplain with local, marginal fans.

This case study from the intermediate-order Saalach is complemented by work on the high-order Danube between Linz and Vienna (Fink, 1977). Here five major alluvial bodies are recognized, as dated by  $^{14}\text{C}$  and dendrochronology on logs or *in situ* stumps. After 5–10 m of end-Pleistocene dissection, a comparably thick fill aggraded *ca.* 9800–8100 bp, followed by a similar cut-and-fill cycle with alluviation *ca.* 7600–5100 bp. Both early Holocene alluvia are at similar elevations to the last Pleistocene glaciofluvial terrace, whereas later fills generally form one or two lower terraces. The next alluvial body is dated *ca.* 4500–3000 bp, with two further, minor fills between 2700 bp and AD 850. Accumulation of the modern floodplain began a little before AD 1400.

There is a reasonable degree of regional correlation along the Danube and its tributary systems, but details vary, in part due to variations in valley geometry, with downcutting along one stretch accompanied by local fan development at suitable points further downstream (Fink, 1977; Brunnacker *et al.*, 1976). The underlying readjustments in discharge, channel and valley gradient, as well as sediment yield, appear to reflect environmental inputs more complex than those of the standard Holocene pollen zones. The crude  $^{14}\text{C}$  frameworks suggest that intervals of downcutting may have averaged somewhat less than 5 centuries in duration, with aggradation and eventual dynamic equilibrium lasting 500–2500 years. Dendrochronological results are more precise (Becker, 1977), showing that Holocene phases of fluvial 'activation' in central Europe seldom exceeded a few centuries, but that fluvial systems continued to readjust in response to the initial triggering impetus for as much as several millennia.

The role of human occupation deserves close attention. Along the drier margins of the mixed deciduous forests of central Europe, prehistoric agricultural settlement had the effect of favouring a subclimax vegetation with reduced arboreal cover, lowered watertables, accelerated runoff, increased peak discharge, and reduced base flow. It has been usual to play down the potential impact of early Neolithic settlement, let alone of Mesolithic activities, in temperate Europe. However, Dimbleby (1976) presents a case for a less deductive approach, and Brunnacker (1971) has shown that soils in the proximity of Lepenski Vir, in the Iron Gate stretch of the Danube, were intensively disturbed by local settlement *ca.* 7300–6300 bp. A series of detailed local soil and molluscan studies along the interfingering forest–steppe boundary in Czechoslovakia show no disturbance prior to the late Atlantic (Smolíková and Ložek, 1973; Ložek, 1975, 1976). Local deforestation is first evident on a local scale during the 5th millennium bp.

Widespread deforestation with rapidly expanding cultivation began with the late Bronze Age (late Subboreal), leading to a fundamental change of biota during the Hallstatt–La Tène period (early Subatlantic, last millennium BC). Later, during Mediaeval times, slopes of as much as 8° were brought under cultivation, with reworking of most soils and permanent establishment of steppic biota. This evidence suggests that cut-and-fill cycles after 3500 bp will have been significantly affected, if not controlled, by human activities, as in the case of the colluvial mantles or fans with late Bronze Age sherds found on footslopes or floodplains from the Iron Gate to the Lower Rhine and Weser. On the other hand, the major and universal phase of fluvial readjustment shortly after 5000 bp is difficult to relate to human activities, and significant alluviation in northwestern Lower Austria began 4850 bp, at a time when this area was not yet settled (Peschke, 1977; Fink, 1978).

It would appear that central European stream behaviour during early and mid-Holocene times included both minor channel readjustments and major floodplain changes, the latter in response to environmental oscillations lasting no more than a few centuries and perhaps too brief to show up in conventional biotic records. During the later Holocene such fluctuations in stream dynamism appear to become more common and, in areas of intensive settlement, their overall impact was magnified and linked to considerably more generalized environmental changes. It nonetheless remains uncertain whether human activities triggered the cut-and-fill cycles after 3500 bp, rather than merely creating fragile ecosystems that responded dramatically to relatively minor climatic stimuli.

### **The Prairie Peninsula, Illinois**

The central European cases outlined here suggest that Holocene environmental changes at several different timescales had a variable impact on geomorphic and vegetational patterns. The true complexity of differential scales is better illustrated along the margins of the Prairie Peninsula in the American Midwest, a continental environment with maximum precipitation in spring and late summer. Palynological and faunal evidence from Minnesota, Illinois, and Missouri (Wood and McMillan, 1976; Wright, 1976; King and Allen, 1977; King, 1977) shows that the grassland belt of AD 1800 was created at the expense of woodland shortly after 9000 bp, with maximum aridity during the 8th millennium bp, and partial forest recolonization of the prairie margin 6500–4500 bp.

The history of the lower Illinois River is presently understood in a similarly

generalized way, with evidence for at least 15 m of bed-load aggradation *ca.* 8000–5500 bp, stabilization of a braided-river floodplain by 5000 bp, then evolution into a high-sinuosity river with flood silt accretion, modified by several phases of channel simplification during the last 3 millennia (Butzer, 1977). The more complex details of repeated geomorphic change can be discerned in the better exposed, minor tributary streams and at the Koster archaeological site in southwestern Greene County.

The Koster sequence, as based on deep excavations, bore profiles, conventional drainage basin studies, and calibrated by a good array of  $^{14}\text{C}$  dates on charcoal (Butzer, 1977), begins with evidence for moderately active erosion of loessic slopes and colluvial accretion *ca.* 9700–8500 bp. Maximum geomorphic activity, accompanied by 50 cm per century net footslope deposition *ca.* 8000 bp, was followed by a degree of slope stability 7700–5500 bp, with renewed soil erosion until 5000 bp. Then dynamic equilibrium allowed deep soils to develop until cut-and-fill cycles were inaugurated *ca.* 100 BC and again AD 750. These late cycles involved initial gullying, followed by rapid loess fan accretion, and ultimately stabilization with soil development. Erosion in response to Anglo-American settlement has been prominent since AD 1830. Contemporary observations indicate that active slope stripping or gullying is linked with forest decimation, arguing that the period 9700–5000 bp was generally drier than today, with two incisive dry spells during late Holocene time. Similarities with the behaviour of the Illinois River are apparent, and there is also good correspondence with changes in the level of Lake Michigan (Larsen, 1979): the lake was generally low but fluctuating prior to a very high level 5000–3000 bp, since which it has oscillated strongly about its recent mean. Some of the short-term oscillations ( $\times 10^2$  years) that are superimposed upon the long-term trends ( $\times 10^3$  years) of Lake Michigan cannot yet be identified in the geomorphic record.

These examples from the Prairie Peninsula show that the critical thresholds for stream behaviour are lower than those for discernible regional vegetation change, even though rapid and significant changes in local groundcover were directly implicated in the cut-and-fill cycles. Only the gross configuration of the alluvial sequences is related to long-term trends spanning several millennia; the critical impulses that cumulatively effect major floodplain change appear seldom to have exceeded a century or two. Changes in land use patterns are immaterial for interpretation of the Illinois record prior to AD 1800, although very local, but at times intensive disturbance of Indian site proximity may have caused minor variations in sediment transfer rates.

### The Mediterranean Basin

The evidence for alluvial sequences in the semiarid, subtropical Mediterranean Basin has already been reviewed by Vita-Finzi (1969) and Butzer (1974a, 1975), with recent noteworthy contributions by Bintliff (1976), Büdel (1977), and Davidson (this volume, Chapter 11). Available data suggest that complex alluvial sequences, of the kind described from central Europe and Illinois, are either uncommon or poorly developed. There are, instead, widespread colluvial deposits, frequently grading into heterogeneous alluvial fills that, judging by archaeological associations, postdate the apex of intensive Roman land use. In the course of the author's work in different parts of Spain it became apparent that such 'post-Classical' deposits are limited to areas of intensive Roman agriculture or to the periphery of larger Roman settlements; colluvia or alluvial fills in other regions are much more recent, and can be linked to post-Mediaeval deforestation and agricultural expansion into marginal environments, or to over-exploitation of fragile

ecozones. Wherever found and whatever its age, 'post-Classical' detritus is the most conspicuous geomorphic feature in the Holocene landscape, even though no pollen profiles record drastic environmental change during the last two millennia. These facts, in combination with the variable age of initial geomorphic activation between the third and twentieth centuries AD, leave little doubt that the 'post-Classical' deposits were primarily a response to human activities.

The geomorphic record of human interference is not limited to the last 1500 years. In various sectors of earlier intensive settlement, both late Bronze Age and classical Greek, there are many instances where colluviation, alluviation, or rapid coastal siltation in deltaic regions can be firmly dated in the 1500–3500 bp time range.

The Mediterranean Basin record is therefore distinct from those of central Europe and the Prairie Peninsula. Early to mid-Holocene alluvial sequences may yet be deciphered from some river systems. But the dominant pattern is one of accelerated soil erosion in response to human misuse of the land—beginning locally during the late Bronze Age and becoming more universal after the economic decline of the Roman Empire. Climatic impulses may have favoured such geomorphic activation, but the variable timing, and the unprecedented extent and scope of these slope and valley changes within the Holocene record, remain inconceivable without a pre-eminently cultural impetus.

### **The Egyptian Desert**

With a hyperarid climate, most of the Sahara displays very little geomorphic dynamism. The only sector of the Egyptian Sahara that exposes an informative, Holocene alluvial record is the Eastern Desert where wadi valleys 'drain' the Red Sea Hills to the Nile (Butzer and Hansen, 1968; Butzer, 1974b, 1979). Approximate dating is provided by a limited number of <sup>14</sup>C dates and archaeological associations.

Sandy alluvial fills with basal gravels accumulated after *ca.* 11,000 bp, coeval with Nile aggradation, although well developed calcareous root tubules and snail proliferations indicate abundant desert vegetation. Building up of the nilotic floodplain continued until *ca.* 6000 bp but geomorphic activity in the desert wadis gave way to soil development some two millennia earlier. The resulting 30–100 cm cambic horizons record partial decalcification, rubefaction, and kaolinitic clay formation, indicating a fair amount of biochemical weathering that implies a period of repeated, gentle rains. Following an interval of wadi dissection, sheets of coarse piedmont colluvium were activated through much of the Eastern Desert, sweeping down into the gravelly sands filling the lower wadis, where such local alluvia interdigitate with nilotic flood silts aggraded during the 5th and 4th millennia BC. It can be shown that both the early and mid-Holocene wadi fills, as far south as the Egyptian–Sudanese border, were deposited while the Nile floodplain was desiccated, i.e. during the winter half year, in response to rains of westerly rather than monsoonal origin. A last phase of wadi activation is recorded by fine-grained alluvia in the larger wadis, and dated to the 11th century AD. In more recent times the localized heavy rains that appear to occur about once a century only suffice to transfer detritus for short distances along isolated wadi reaches.

### **The Omo–Rudolf Basin, East Africa**

The Lower Omo Basin, at the northern end of Lake Rudolf, provides the best Holocene alluvial sequence in East Africa. The record includes deltaic and alluvial formations of the Omo River that reflect regional conditions over a large montane



drainage system with a long summer rainy season, as well as local piedmont alluvial fans and terraces that reflect changes at generally lower elevations with short spring and autumn rainy seasons (Butzer, 1971a, 1976b, 1980; Butzer *et al.*, 1969, 1972).

During the terminal Pleistocene, Lake Rudolf was at a relatively low level, the Omo River cut down its channel by at least 15 m, while exposed alluvial surfaces were calcified, with local salt hydration of buried gravel and patination of surface lag. At the beginning of the Holocene, Lake Rudolf expanded rapidly and fluctuated between 60 and 85 m above its present level *ca.* 9800–7000 bp, judging by a representative suite of Holocene <sup>14</sup>C shell dates. Along the piedmont margins, associated lake beds may be interbedded with limonitic detrital units ranging in texture from silts to cobble gravels; such deposits grade laterally into stream terraces with as much as 12 m of fine alluvium. Shortly after 7000 bp the lake shrank rapidly to approximately its present dimensions, and the Omo River was entrenched by 40 m, piedmont streams by 8 m and more. A new transgression was under way 6600 bp and the lake fluctuated at +65 to +75 m from 6200 bp until 4000 bp, with development of shallow alluvial terraces on the piedmonts. A temporary regression of unknown amplitude was followed by transgression to +75 m *ca.* 3250 bp, at which time Lake Rudolf was last linked to the Nile Basin across a shallow divide.

After a rapid drop of level and downcutting by the Omo and various piedmont streams, Lake Rudolf fluctuated between +20 and +50 m about 4000–3500 and 3000–2500 bp; this stage includes fluviolacustrine deposits along the Lower Omo River as well as extensive lateral alluvial terraces or fans, at least 5 m thick, ranging from sandy silts to gravels. During the last 2500 years the lake fluctuated rapidly between 15 m above and 5 m below its present level, dropping 20 m between 1897 and 1955; adjustment of the lateral streams has been limited to fill-dissection, averaging 3–5 m along the Omo floodplain margins and across the piedmont alluvia. The major oscillations since the twelfth century AD had a mean amplitude of about 150 years.

Particularly striking about the Omo–Rudolf record is the amplitude and rate of hydrological and geomorphic changes that were clearly linked and apparently synchronous throughout the basin. Alluviation was evidently related to moister anomalies, dissection to drier trends. The rapidity of these changes and their replication through large parts of tropical Africa preclude a significant human impact.

### The Interior and the Cape Coast of South Africa

The Vaal–Orange Basin of South Africa provides a low-relief erosional landscape with a subtropical, semiarid climate, characterized by summer rains. Shallow alluvial fills are well developed and extensively exposed by gullying or through channel shortening and incision. Radiometric controls are a major problem since suitable sample material is rare. The resulting dating framework is poor, despite corroboration from spring sequences along the interfluvies (Butzer, 1974c; Butzer *et al.*, 1973, 1978, 1979).

Early Holocene downcutting was followed by 5–10 m of flood silt aggradation, capped by a vertisol that records seasonally wet floodplain surfaces with meandering streams. Broadly dated *ca.* 4500–1300 bp, this alluvial fill remained undissected in many lower order drainage basins until a century or two ago and, in the Vaal headwaters, some tributaries still retain marshy, meandering floodplains. Elsewhere, in large streams prone to high peak discharge, the Holocene fill is subdivided: temporary downcutting *ca.* 2600–2250 bp was followed by accretion of a smaller body of sandier alluvium that lacks the characteristic vertisol.

This evidence for wetter floodplains and reduced discharge seasonality implies a more equable climate, particularly during the 4th millennium bp. Parallel sequences are provided by organic spring deposits, expanded lakes in closed depressions, accelerated karstic spring discharge, and soil formation. Since subsequent dissection and gullyng through much of the basin began at least 800 years ago, it predates local intrusion of Bantu and Afrikaner pastoralists and farmers. Nonetheless, overgrazing, fencing, and deliberate burning have favoured range deterioration during the last century and thus accelerated erosional processes already under way. There appears to be no alluvial record of the moister conditions indicated by karst springs and local lacustrine beds *ca.* 9700–6500 bp.

The mesic woodlands of the southern Cape Province have an analogous Holocene alluvial record, despite a significantly different Pleistocene trajectory (Butzer and Helgren, 1972; Butzer *et al.*, 1978b).

During the early Holocene, coastal dunes, related to the glacio-eustatic transgression, invaded areas well inland, while slope erosion brought thick colluvial deposits into the valleys. Humic or weak podsolc soils temporarily stabilized the dune fields during part of the 8th millennium bp. General slope stability was only established *ca.* 4200 bp, after which slow organic accumulations, including local palmetto peats, indicate ponded stream beds with high watertables. Renewed downcutting *ca.* 1000 bp was followed by rapid aggradation of sands along steeper stream channels. Fresh gullyng during the last two centuries was accompanied by reactivation of the coastal dunes, probably in response to Afrikaner pastoral activities and burning, and more recent deforestation. Pollen profiles and faunal changes bear out these interpretations, with a predominantly open vegetation during the early Holocene, and forest establishment during the mid-Holocene.

The comparative simplicity of the South African alluvial record may reflect higher geomorphic thresholds or a lower degree of resolution, or both. In fact, occasional, minor erosional shoulders cut into various fills suggest readjustments of stream gradient that did not produce tangible, primary deposits.

### Conclusions and Prospects

The alluvial sequences outlined here serve to underscore the basic problems of internal dating, intraregional correlation, regional delimitation, and causation discussed earlier. It is apparent that each sequence is complex, that events of both greater and lesser wavelength must be distinguished, and explanations can only be offered and evaluated within a broader context of palaeoenvironmental indicators. Each of the areas discussed has a unique record. Some areas were moister during the early Holocene, others during the mid-Holocene; some areas were geomorphologically uneventful during the early Holocene, others during the middle or late Holocene. Those generalists prone to searching for hemispheric or even global parallels and periodicities will be disappointed and, hopefully, cautioned. Simplistic, long-range correlations are more likely to be wrong than right because dating is only approximate, multiple short-term changes are difficult to pin-point with accuracy, and directions of change may well differ in different regions. Periodicities that are real and hemispheric or global in scale are unlikely to be truly synchronous because specific geomorphic thresholds are defined by several variables and can be expected to vary both spatially and temporally.

The alluvial cycles identified in this paper reflect complex ecological readjustments that involve channel and floodplain geometry, rainfall seasonality, intensity, and

periodicity, as well as runoff patterns, ground cover, and sediment calibre and amount. The critical, immediate variables are ground cover, runoff, and sediment supply. But the ultimate variables are climate and human activity. Climatic variation during the course of Holocene time has not been of the same scale that demarcated glacials and interglacials or that delineated the fluctuations of the deep-sea isotope curves. But it has sufficed to affect geomorphic trends repeatedly and significantly.

These Holocene events provide as yet little appreciated information on environmental interactions that would not only help elucidate the details of Holocene palaeoclimatology, but could provide useful models for more effective interpretation of gross Pleistocene changes. They further offer critical contextual information for prehistoric settlement trajectories. Last, but not least, they provide a challenging geo-archaeological opportunity to examine the spatial and temporal dimensions of human interference in complex ecosystems.

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