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Contemporary Depositional Environments of the Omo Delta

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Geomorphological and sedimentological studies of depositional environments of the modern Omo River delta and floodplain are essential to an understanding of the Pliocene to Pleistocene Mursi, Nkalabong and Kibish Formations of the Lower Omo Basin (south-western Ethiopia).

THE first field season of the Omo Research Expedition, in 1967 (ref. 1), made it very clear that, if the palaeoecology of the Pliocene and Pleistocene Omo Basin was to be understood, considerable work had to be expended on contemporary depositional environments and their ecology. I therefore carried out geomorphological studies of the modern Omo Delta and, to a lesser extent, of the basin peripheries, in 1967 to 1969. This work consisted of mapping, air photo interpretation and sediment analyses. Miss Claudia Carr of the University of Chicago also investigated the plant ecology of the area.

Many facets of the investigation were necessarily only exploratory, but none the less it is felt that the seventy modern sediment and soil samples analysed in detail are representative of six of the seven meso-environments discussed in this paper. The last, the pro-deltaic environment at the head of Lake Rudolf, would have required technical equipment not at our disposal. O. T. Owre (University of Miami) hopes, however, to report soon work carried out on bottom sediments. The interpretation of the Pliocene, Pleistocene and Holocene sedimentary sequences, reported earlier[2–5] and discussed more specifically here, is based on laboratory analysis of more than 175 samples. All textures cited were determined by the hydrometer method, and textural classes refer to the US Department of Agriculture system.

Erosion and Deposition in the Lower Omo Basin Today

The Lower Omo Basin has a semi-arid tropical climate. By extrapolation of climatic observations from northern Kenya, supplemented by local records from different sources, a mean annual precipitation of about 350 to 600 mm can be inferred, being lowest around the shores of Lake Rudolf (at 370 m), increasing rapidly among the highlands along the northern peripheries of the basin (at 1,000–2,000 m). Rainfall comes primarily in the form of thundershowers at intervals between late March and early June, supplemented by further but unreliable rains in July–August and October–December. Mean monthly temperatures probably range from 26° to 29° C in the lower country, with an annual range of as little as 2° or 3° C but with daily ranges in the order of 9°–15° C. July and August are the coolest months, but diurnal temperature variation is greatest in January and February.

As a result of these climatic patterns, the Omo River is the only perennial stream of the Lower Omo Basin and, for that matter, of the entire Rudolf Basin. The Kibish and Usno Rivers are seasonal, the former carrying flood waters after the spring equinox, the latter during summer. Although the Usno feeds into the Omo River from perhaps March or April to October, the Kibish is usually dry for most of the year, and its waters seldom reach Sanderson's "Gulf", let alone Lake Rudolf. The two other major affluents of Lake Rudolf, the Turkwell and Kerio, carry abundant waters from the equinoctial rains of the Uganda Escarpment but, except for seepage, only reach Lake Rudolf sporadically. Thus the Omo River is the principal feeder of Lake Rudolf, now providing perhaps 80–90 per cent of its annual influx. Correspondingly, all minor stream networks of the Lower Omo Basin are poorly integrated, and radial highland drainage fails on broad piedmont slopes. The net effect is that active sedimentation is restricted in terms of area, and strongly differentiated as to meso-environment.

Dissection and fluvial denudation are conspicuously dominant in hill or mountain topography (with a height of 500–2,000 m). Slopes average about 35°–45°, but there are numerous ridge tops and rolling platforms with gradients of only 5°–10°. Lithosols and immature, organic soils of *AC*-profile are characteristic, with extensive areas of thin and discontinuous, reddish brown soil sediments with a silt loam texture, alkaline reaction and no carbonates. Parent material is provided by basalt and rhyolite; more rarely, tuffs or crystalline basement complex. Such soils are commonly reworked within slope deposits or buried in very coarse screes. Stronger oxidation and more intensive weathering may have rendered the highlands even less suitable for bone fossilization in past situations. Volcanic accumulations, either of lavas or pyroclastics, cannot be observed in the study area at present.

The greater part of the Lower Omo Basin consists of upland plains in an elevation range of 400–500 m. Surfaces may be smooth, with minimal surface gradients and poor drainage, but there may also be intensive dissection along the margins. Three sub-environments can be recognized, none of them favourable for bone preservation or fossilization.

(*a*) *The pediment fringe.* Zones of rock plantation and rill erosion, with deflation of fines, border the highlands[4]. The thin and sub-continuous alluvial veneers consist primarily of well aerated, coarse sands, on which immature soils are dominant.

(*b*) *Alluvial fans and piedmont alluvial plains.* Broad spreads of moderately deep, well stratified, sandy alluvium are most characteristic of the piedmont areas. Non-calcareous and neutral to alkaline, brown "grassland" soils (*AC*-profiles) are found on equilibrium surfaces, with immature soils or reworked palaeosol material in active channel or rill-wash situations. Significant fluvial activity is sporadic so that bone is "weathered" and reduced to a dehydrated, brittle state, often lying on the surface for years before possible burial—within fairly coarse alluvium with good aeration and a minimum of mineralizing compounds in solution. Some dissected, non-functional, alluvial deposits occur locally within both sub-environments (*a*) and (*b*). These are usually gravelly in nature and well oxidized, with truncated or reworked reddish or brownish palaeosols of *A*(*B*)*C* type, sometimes with carbonate horizons. Fossil bone has not been recognized in such sediments.

(*c*) *Non-functional plains on ancient deltaic sediments (Kibish Formation and Omo Group).* Although fine grained deposits are prevalent in the interior of the Lower Omo Basin, there is now little active sedimentation. Dissection, gullying and piping are common along the margins of lower-lying surfaces, locally producing badland topography with a local relief of as much as 40 m. Excellent exposures are thus opened in older deposits, but eroded fossils are subsequently reworked into colluvial and sheetwash deposits and rapidly destroyed. The undissected upland plains often have impeded drainage after rains, although deep cracking patterns may develop during the drier parts of the year when the water table is moderately low. Intrazonal soils are typical, with considerable lateral variation in response to facies changes or surface drainage. There may be subsurface accumulations of sodium salts, and corrosion of ferromagnesian minerals is apparent to many metres beneath the ground. Consequently, even when original conditions of sedimentation and mineralization may have been excellent in deltaic deposits, long-term emergence at a later date will have ultimately favoured destruction of all but well mineralized bone. There is, however, no decalcification of shell in Holocene deposits of the Kibish Formation, while preservation of partially decalcified shell (or shell impressions) in some Pleistocene or Pliocene beds of several formations is comparatively good.

Active sedimentation is optimal today in the lowland plains on floodplains, deltas, mudflats and in littoral situations. The facies of these rather different depositional environments are unfortunately seldom distinctive, at least if we exclude typical littoral deposits. The well stratified silts deposited by overbank discharge on floodplain levees or in flood basins are not necessarily distinct from those of distributary levees. The standing waters of interdistributary basins and bays, of the open pro-deltaic environment at the head of Lake Rudolf, of the lagoonal flats of Sanderson's Gulf, or of the seasonally flooded Alabilab and Lotigipi Plains can produce remarkably similar sediments. Emergent, all such deposits would appear as mudflats, prone to cracking. Differences and distinctions must be deduced from bedding properties, oxidation and/or reduction phenomena, evaporites, vertical and horizontal development, and geomorphological settings. Similar problems beset the identification of sandy horizons from floodplain or distributary channels, alluvial fans or littoral zones. Consequently, when it is even difficult to distinguish between the deposits of moving (for example, "fluvial") and standing (for example, "lacustrine") waters, it becomes necessary to interpret sedimentary sequences with great care, with reference to strictly defined concepts, and if possible with respect to modern depositional counterparts. The contemporary

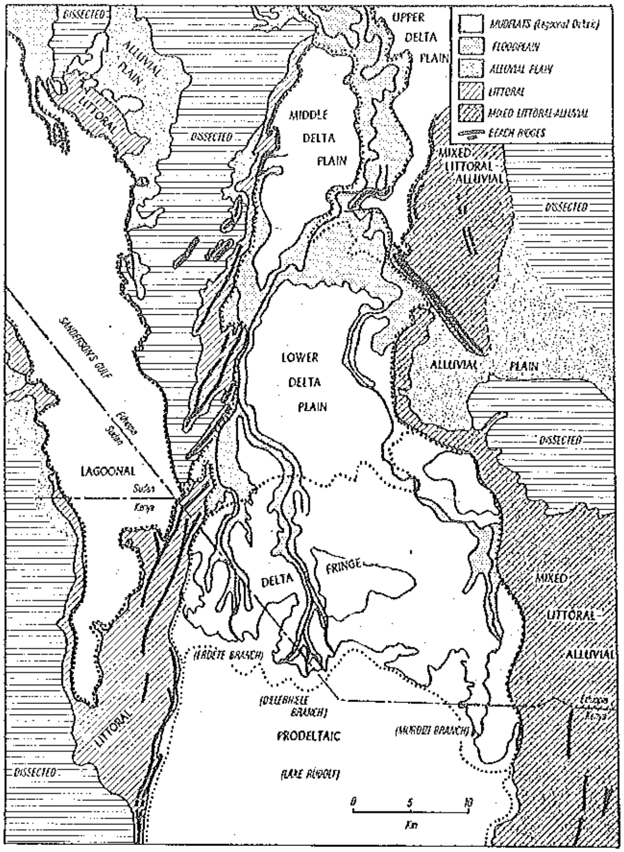

Fig. 1. Recent depositional environments of the Omo Delta. The 1959 shoreline is shown; today all of the delta fringe, except for the levee zones, is submerged.

depositional environments of the Omo Delta and Floodplain are ideal for this purpose.

Modern Depositional Environments of the Floodplain

The sub-recent floodplain of the Omo River, above the bifurcation of the Murdizi Branch (Fig. 1), is a typical convex floodplain with a maximum width of 2–4 km upstream. It is characterized by meander belts, natural levees, point-bar ridges and swales, flood basins with gathering streams and occasional backswamps, and it is marked by numerous abandoned channels and a few oxbow lakes. The levee crests rise 3–5 m above the highest channel bars near the apex of the delta, as much as 6–9 m further upstream. Local relief between levees and flood basin floors is about 1–3 m, proportional to the width of the floodplain.

Channel bars consist of stratified, well sorted, medium-grade sand, rich in biotite and heavy minerals. Disposition may be horizontal, current or cross-bedded, or ripple-marked. Muds may subsequently impregnate such sediments from above, changing texture to a moderately sorted loam or sandy loam. Sands appear to become coarser upstream, although gravel components are rare or absent. No Mollusca were observed in the channels, because of high water conditions, but the freshwater Nile oyster (*Etheria elliptica*) appears to affix itself on compacted bed shoals. Bird and insect tracks were observed on freshly emerged mud films and bone preservation is probably good. At any rate, the channel sands and silts now contain organic detritus such as fish, reptile or mammal bone, animal droppings or waterlogged tree flotsam. Mammals watering along the banks are repeatedly snatched by crocodiles, and sudden cavings of the banks in convex meander bends will occasionally sweep trees and animals into the river during a flood.

Levee deposits, as well as embanked flood silts within dissected channels, consist of brown (10 *YR*) well stratified, moderately sorted, silty clay loam, with occasional limonitic mottling, generally fine and not intense. Beds are very gently inclined and current bedding is very scarce. Bone or Mollusca were not observed at the surface or in sections, but crocodile slide marks appear along the channel banks.

Flood basin deposits are generally comparable with those of the levees, except that stratification is less marked. Backswamps are very few and of restricted development. They have cracking clays of brown, dark or greyish brown, and very dark grey (10 *YR*) colour, with no stratification, strong prismatic structure, silty clay or clay texture, and moderate to intensive oxidation mottling. The clay plugs of former oxbow lakes are formed of brown (10 *YR*) silty clay with a similar structure.

Generalizations concerning the floodplain are hampered by a minor cycle of dissection during the past few decades, so that much of the floodplain is actually non-functional at the moment, at least in terms of overbank deposits.

Modern Depositional Environments of the Omo Delta

(*a*) *The delta plain.* A delta plain (*sensu strictu*) has been defined as a river plain characterized by repeated channel bifurcation and divergence, multiple distributary channels and interdistributary flood basins[6]. In the case of the Omo Delta, this plain comprises wide tracts of abandoned deltaic environments that are essentially non-depositional at the moment, and which are crossed by comparatively narrow active riverine zones, seldom more than 500 m wide. Characteristic of this delta plain are functional or atrophied distributary channels, with poorly developed meander trains that are incised 2–5 m beneath a complex of topographically subdued, emergent delta forms. On this essentially fossil surface a multitude of features, now characteristic of the active delta fringe, can be recognized on the basis of surface forms, textural differences and vegetation. Repeated channel bifurcation and delta formation are indicated by abandoned distributary channels and their related levees, while gathering streams drain the former interdistributary basins and lagoonal mudflats. Upper, middle and lower delta plains are distinguished on the basis of recent submergence. The first two of these were repeatedly submerged during the nineteenth century but were reduced to a marsh and finally drained after about 1908 (ref. 7). The lower delta plain emerged as late as 1921 (ref. 8).

The flood silts of the distributary banks range from a brown (10 *YR*) silty clay loam to silty clay, all stratified and moderately sorted. Channel beds were nowhere exposed during the field seasons. The non-functional plains above present flood level may be seasonally inundated by seepage waters, but the surficial beds reflect delta fringe or even prodeltaic deposition before about 1910. In other words, except for the distributaries, the delta plain (*sensu strictu*) is not a zone of very active sedimentation today.

(*b*) *The delta fringe.* The delta fringe, as indicated in Fig. 1, accumulated between about 1920 and 1960, and has been submerged since 1962 except for the major distributary levees (K. W. B., in preparation). Apart from field survey by helicopter and boat, it was possible to infer sedimentation patterns both from 1957–59 air photos and from the subrecent delta fringe deposits now exposed on the delta plain. The contemporary shoreline has an exaggerated birdfoot profile, with the distributary arms extending as much as 14 km into the lake. The older aerial photography shows a similar but far less marked birdfoot profile, with the atrophying subdelta of the Erdete branch increasingly prone to cuspate remodelling by wave and current action. Distributaries, natural levees, flood basins, lagoonal mudflats, interdistributary bays, distributary mouth bars and barrier bars or spits are all clearly shown on these photographs and are essential in complementing such field observations as remain possible today. (The present tense is used for the remainder of this section, although conditions described are those applicable before submergence in 1962.)

The strictly fluvial sub-environment of the delta fringe is that of the distributaries and their natural levees. Bank overflow and occasional levee breaching develop conspicuous, convex berms and silt splays adjacent to the major channels. Repeated channel deterioration and channel shifts subsequently increase the surface extent of strictly fluvial deposits. Overbank silts of the levees consist of pale brown to dark greyish brown (10 *YR*), stratified, moderately sorted, silty clay loam or silty clay. Fine but distinct reddish yellow mottles are locally present, indicating oxidation, usually along former root zones; horizontal bands of ferric staining may be present at depth but were not observed. Bedding is horizontal although turbulent, and undulating lamination can be expected in silt splays or channel proximity. Typical channel beds were not sampled, but marginal samples suggest that the medium sand component (60–200 microns) is prominent. Presumably, these distributary channels form suitable depositional environments for rapid burial and mineralization of bone.

The interdistributary basins are occupied by lagoonal mudflats and marsh. Open water, partly or entirely camouflaged by vegetation, is found in the lower basins, often connected to the interdistributary or interdeltaic bays by small channels. The seasonally inundated marsh belt, at slightly higher elevation, is covered by a thin sheet of water for 2 to 5 months each year as the lake goes through its annual cycle with a vertical range of 80–90 cm, and a year to year variation of at least twice that amplitude. Sediments are mixed organic and mineral. Sedges, cattails, reeds and other grasses colonize these flats; the vegetation traps and binds suspended sediment. The resulting deposits normally consist of a finely bedded, brown (10 *YR*) clay, with neutral or slightly acid reactions (pH near 6·0 in H_2O, compared with 6·5–7·2 for other modern fluvial deposits). Limonitic mottling and diffuse or banded staining may be present, and bands of ferric concretions or more continuous limonitic bands are, theoretically, possible among these interdistributary clays at depth; they have not been observed in sections, however, and probably require quite long periods of suitable conditions in order to develop. Sodium salts, with a little gypsum, are precipitated in ponds or stagnant waters during periods of desiccation and, it would seem, particularly at times of receding lake level. Such salty waters can be more widely disseminated by wind driven lagoonal waters. (In 1932 the alkalinity of Lake Rudolf varied from 0·0194 to 0·0214 N in deep, open water[8]. The level of ions and anions in open lake water near Central Island [in mg/l.]: Na 770, K 23, Ca 5, Mg 4, Fe and Al 3, CO_2 652, Cl 429 and SO_4 56.) In general, the interdistributary environments of the delta fringe are not likely to be particularly fossiliferous, although there may well be exceptions.

(*c*) *The prodeltaic zone.* Turbid, yellow–brown waters are evident at the northern end of Lake Rudolf at all seasons, indicating active fluvio-lacustrine sedimentation. Persistent wave activity or a strong swell assure deep mixing of the lake waters so that oxygen is abundant at all levels and temperature gradients beneath 5 m depth are approximately isothermal[8]. Because sedimentation of suspended matter is not complicated by vertical temperature gradients, and because there is no evidence for a reducing environment in the lower layers of the lake, it is reasonable that the bottom sediments at the head of the lake appear to consist of broad expanses of undifferentiated clays[9]. Massive, lacustrine muds of presumed prodeltaic facies, that were deposited in the modern delta plain during the nineteenth century, consist of brown (10 *YR*) clays with little evidence of either oxidation or reduction. Until bottom sediments from the northern third of Lake Rudolf can be analysed, it seems that few systematic differences can be demonstrated between "lacustrine" or "prodeltaic" clays on the one hand, and interdistributary clays on the other.

The turbid currents emanating from the Omo distributaries lack the competence to carry bone, let alone coarse sands. Consequently, fossils, except for occasional fish, can be expected to be very rare. Silicified wood could, however, be derived from the burial of waterlogged driftwood that reaches the head of Lake Rudolf.

Modern Depositional Environments of the Littoral and Lagoonal Zones

(*a*) *The Rudolf littoral.* The combined effect of the prevailing southerly to south-easterly winds, and of the waves and swell refracting shoreward, is a longshore current that becomes effective along the western fringes of the delta and on the relatively high wave-energy coast along the western shores of Lake Rudolf. As a result, silty sediments are probably typical of subaqueous bars and shoals that accumulate near the distributary mouths or as incipient barriers along the coast.

In 1957–59 the individual distributaries of the Dillerhiele branch, projecting 1–2 km into the lake, were built up of successive shallow bars, with cuspate forms on the western side of each distributary, and tongues of highly turbid water extending 1–2 km beyond each. Small, poorly defined barrier bars had formed in the broader, open, interdistributary bays. As a result of decreasing sediment influx in the deteriorating Erdete subdelta, wave and longshore action had here largely closed off the interdistributary bays by coalescent distributary mouth or barrier bars. Organogenic shorelines were correspondingly well developed where wave energy was reduced.

Two zones of well defined littoral sedimentation can still be observed on the edges of the Omo Delta. To the south-east, a low wave energy coast impinges on partly submerged alluvial fans, developing a cordon of vegetation in the foreshore zone. To the south-west, a higher wave energy situation has developed beach ridges with intraridge swales and aeolian mantles. These different settings have significant fossil analogies and deserve elucidation.

The eastern, low wave-energy sector is fringed by a broad, partly zoned belt of aquatic emergents that are used for cattle grazing today, with the animals standing up to their chests in water. Fish such as Nile perch are also speared in suitable parts of this meso-environment. Bottom sediments consist of only a thin layer of mud, resting on well-sorted, partly arcosic quartz sands of fluvial origin. Fluctuations of this setting, with some fluvio–lacustrine interactions, and accumulations of low beach ridges, produce sedimentary sequences of sandy loams and loamy sands, identical to many of the fossiliferous units of the Omo group. Because elephants were observed feeding among similar aquatic emergents in 1888 (ref. 10), such deposits may be expected to be fossiliferous.

The western and northern moderate wave-energy sector is defined by beach ridges or bars of coarse sand, including gravel near the mouths of major tributaries. Although no modern molluscan communities have yet been observed along any of the northern Rudolf coasts, possibly as a result of the alkalinity of the lake, extensive, sandy shell beds in the fossil record most probably represent foreshores on comparatively high wave energy littorals. During stormy weather, waves spill over these beach ridges into discontinuous adjacent swales, locally forming evaporation pans, rich in algae and that often dry out into salt flats. Similar salt precipitation presumably explains salt horizons alternating with sandy strata and occasional shell beds in fossil contexts. A final micro-environment of potential interest is provided by occasional, vegetated ponds among the intra-ridge depressions that are charged with ferric solutions of uncertain origin.

(*b*) *Sanderson's Gulf.* The mudflats once described as Sanderson's Gulf (Fig. 1) occupy a synclinal depression that still formed an extension of Lake Rudolf as late as 1921, with an interbarrier inlet near the south-western corner of the Omo Delta. Beach ridges, deltaic forms and broad alluvial fans are well developed, but restricted to the western peripheries. In recent decades the Omo River has overflowed through an inter-ridge depression during the overbank stage. These river waters flood the lower part of the basin for a few months, although the former sound to the open lake is now closed off. The most recently submerged, southern part of the "Gulf" has massive, calcareous and cracking clays of brown (7·5 *YR*) colour, with *Cleopatra* and *Pila* shells littering the surface. These clays are macroscopically unique: the very strong, medium, angular blocky structure is possibly related to peculiar clay mineral composition, and the reddish hue is enigmatic. Some of the sterile, massive, reddish brown (5 *YR*) clays of the Omo Beds may be related to such mudflats. The older, lake beds to the north are more silty and laminated, less strongly structured and have a pale brown colour (10 *YR*). Fresh *Cleopatra* shells also litter the surface. Fields of shallow dunes, of tied or "W" type and consisting of medium grade sands and small clay aggregates, can also be seen in the centre of these old lake flats. They grade northwards into fluvial deposits of the Kibish River, dark greyish brown (10 *YR*), moderately sorted, clays intersected by deep, polygonal crack networks. None of these settings seems favourable to fossil preservation, and the fish, reptile and mammal remains left behind by the receding waters during the 1920s and early 1930s[11] now seem to have disappeared completely.

(*c*) *The Lotigipi and Alabilab Plains.* The great mudflats of the Rudolf–Nile divide[2] are often seasonally inundated after heavy rains. Suspended sediments, with minor variations of mineralogy, are carried in by the various streams and then deposited slowly by ponded or standing water. Brown to dark greyish brown (10 *YR*), deeply cracking, intrazonal soils of clay or silty clay texture are characteristic here. No shell and little bone is in evidence at the surface; exposures are lacking, but it is unlikely that fossilization occurs.

Soils of the Modern Depositional Environments

Considering the recent age of the modern depositional environments—at most 2 millenia and frequently less than a century[2,3]—soil development is seldom pronounced.

Dark, cracking tropical clays, that is, vertisols[12], are characteristic of the Alabilab, Lotigipi, the lower Kibish riverine zone, and the restricted clay plugs and backswamps of the Omo Floodplain. Major and minor crack networks penetrate such soils to 50–120 cm during the dry season, while inundation and surface waterlogging are common after rains.

Although montmorillonitic clays, with some non-expandable 14 Å clays, also seem to be typical of the Omo Delta and Sanderson's Gulf, the colloidal humates peculiar to dark vertisols are not general, and local or regional cracking frequencies are usually only indirectly related to soil genesis. An informative case of a dark vertisol was provided by a palaeosol under recent flood silts near the Omo–Murdizi bifurcation. The *A*-horizon was 40–60 cm deep, a brown (10 *YR* 4·5/3), silty clay with angular blocky/prismatic structure; fine, prominent, reddish yellow (7·5 *YR*) mottling is locally common. The parent material also was a silty clay, but has a 40·5 per cent clay fraction, compared with 45·5 per cent in the *A*-horizon. Comparable soils form today in the interdistributary basins of the delta fringe, where almost identical topsoil sediments were sampled.

Most of the other delta soils consist of weakly to moderately humified parent material, with limited oxidation caused by impeded drainage, but no apparent evidence of reduction. Organic content seldom exceeds 3–5 per cent and is highest under the galeria forests of the levees. The delta plain uplands and the unvegetated mudflats of Sanderson's Gulf only show incipient soil development and humification.

Interpretation of the Kibish Formation

Applying the preceding results to the Kibish Formation, as described in some detail elsewhere[3], we find, first, that the deposits of the youngest subunit (member IVb, *circa* 6500–3000 BP) are readily comparable in their surface and subsurface expression with contemporary depositional environments. Deltaic (*sensu lato*) sediments accumulated near the axis of the modern Omo, while beach ridges are widespread along basin peripheries—where they commonly grade into now dissected piedmont alluvia; the northern projection of Lake Rudolf to the Lotigipi–Nile watershed was probably a rather shallow bay—not unlike Sanderson's Gulf in the nineteenth century. To a certain degree these generalizations also apply to Member IVa (*circa*, 9,700–7,700 BP), although there are few landforms preserved.

Member I, dating from the Late Middle Pleistocene, records at least one complex transgressive–regressive cycle (17 m of deposits, in the type sequence), progressing from channel sands and loams to delta-fringe beds (alternating clays and loams), terminating with a calcareous palaeosol. The basal beds (9 m) probably mark a second but incomplete cycle. They include channel conglomerates, subaqueous clays and tuffs of complex origin, followed by emergence, calcification and dissection.

Member II begins with a tuff that mantles a highly irregular, dissected delta plain. Frequent detrital components indicate colluvial working on slopes (up to 20°), while gypsum laminae in depressions indicate subaqueous deposition near the shores of the lake (in bays ?). The following 22 m of laterally extensive clay with loamy strata and ferruginous horizons, or zones of carbonate and ferric concretions, indicate a delta fringe environment, prone to shifts in the position of adjacent distributaries and in the depth of standing water. This early Upper Pleistocene sequence is, then, non-cyclic according to J. de Heinzelin, F. H. Brown and F. C. Howell (unpublished results), although there is only limited evidence of reduction.

Member III (terminated *circa* 30/35,000 BP) records two transgressive–regressive cycles, separated by emergence and a palaeosol. The first 26·5 m of deposits range up from distributary channel beds to laterally extensive delta fringe clays (interdistributary ?) with loamy units (channel or channel-mouth shoals ?). A terminal period of emergence is indicated by calcium carbonate concretions and crack fillings, before deposition of a widespread, 2–3·5 m thick tuff. Pyroclastics have no modern analogues in the Omo Delta, and remain difficult to interpret. This particular tuff, a well sorted and fairly pure silt, is absolutely uniform and level over a stretch of 3·5 km across the modern valley and is certainly subaqueous. Following a period of dissection, the second cycle (20 m) begins with thin but extensive sands or shell beds, with root drip, that suggest littoral-foreshore (and fluvial ?) environments. Subsequent delta fringe clays are followed by current bedded channel or littoral sands and, finally, massive, inclined clays related to channel/levee contacts.

In overview, the Kibish Formation can be adequately interpreted in terms of contemporary depositional environments in the Omo Delta. There are indeed some littoral and floodplain deposits, but the bulk of the sediments reflect a deltaic (*sensu lato*) environment. The delta fringe deposits—including many fluvial beds of distributary origin—are represented best and certainly far better preserved than the littoral deposits so prominent in the surface expression of Member IVb.

Interpretation of the Nkalabong Formation

The late Pliocene Nkalabong Formation[2] generally falls outside of the range of facies variation of the modern Omo Delta.

Member I (37 m) records a succession from floodplain silts through coarse channel beds to a terminal, fluvial sand rich in volcanic ash. The coarse beds consist primarily of intensively gleyed (with 5*B* reduction zones) conglomerates, interdigitated with sands interfingering laterally from local tributaries. The calcretion and patination of the terminal unit may reflect sub-aerial weathering and/or hydrothermal activity in the wake of local vulcanism. This floodplain sequence was followed by intensive dissection.

Member II (22·5 m) is currently known from only one korongo, and represents a unique filling of a tributary canyon that once drained the adjacent foothills. Basal sands of fluvial origin are buried by a massive, unbedded lapilli tuff ($^{39}Ar/^{40}Ar$ date of 3·95 m.y.)[13] of aeolian origin—without reworking except in the lowest 50 cm.

Member III (18 m at the type section) is different once again. A succession of alternating massive bedded silt loams and laminated beds, what are inferred to have once been silt clay loams, rests on basal detrital strata with derived lapilli tuff. In spite of their consolidation and apparent weathering (both 14 Å non-expandable and 15–16·5 Å expandable clays), these beds have the structure of ±primary tuffs interbedded with tuff derivatives and very rare lenses of spheroidal pumice (< 1 cm diameter). The disposition and regularity of these strata over a wide area, dipping 5° away from the foothills and thickening rapidly from 5–10 m to at least 22 m, indicate a littoral foreshore setting. The beds are all white or light grey (10 *YR*–2·5 *YR* hues), with no limonitic staining but frequent pyrolusite discoloration of ped faces; there are some horizons with carbonate (siderite ?) concretions. These additional features could possibly but by no means necessarily be explained by a former reducing environment. Cementation of the topmost bed, with some carbonate concretions, reflects subsequent emergence. This non-cyclic lacustrine–littoral succession may reflect on repeated vulcanicity.

At Liwan, a sequence of detrital beds, overlain by at least 17 m of massive white tuffs and interbedded laminated, clayey strata, provides a close facies parallel to Member III. These Liwan Beds, as the topmost Nkalabong sequence, are not faulted and are found at an identical elevation more than 50 km away. They also dip to the centre of the basin. In terms of facies, Nkalabong III and the Liwan Beds seem to be linked to the Omo group by lithologically intermediate but faulted sediments near Loruth Kaado, north of the Labur Range (unpublished results of J. de Heinzelin, F. H. Brown and F. C. Howell). F. H. Brown and I have recognized at the very least 30 m of sediments here, including both the massive white tuffs and clayey lenses of "Liwan facies", and the massive reddish brown or brownish yellow clay units typical of parts of the Shungura Formation[13].

Interpretations of the Mursi Formation

Yet another picture of depositional environments is presented by the late Pliocene Mursi Formation[2], with three sedimentary members underlying a terminal basalt (K/Ar dates of 4·05–4·25 m.y.) (ref. 14 and F. J. Fitch and J. A. Miller, in preparation).

Both Members I and II consist primarily of loamy facies, with a high proportion of sandy beds. Member I (over 43 m) includes a non-cyclic sequence of loams with relatively poor sorting but good stratification, and extensive, horizontal, limonitic (7·5–10 *YR* hues) staining. More clayey units, with hygrophitic salts, occur primarily as lenses. The terminal, concreted shell bed (*Corbicula*, *Viviparus*), with some fish/reptile bone, is probably of littoral foreshore facies; it immediately overlies a complex of topset and foreset strata, whereas other beds are horizontal. Except for some laterally extensive, basal clays, Member II (24 m) consists of non-cyclic loamy units with some finer lenses. Ferruginization is quite intensive, with abundant horizons of small to large ferric concretions. The terminal bed here is a discontinuous tuff, primarily represented by a reworked silty clay loam.

The poorly sorted loamy strata of Members I and II can, at least in part, be traced to the adjacent foothills, where grades are coarser and sorting more pronounced. Gravel lenses in the key fossiliferous horizons of Member II can be followed up the Mount Nkalabong footslopes, where gravels become more common and less rounded. The best facies analogues for these strata can be obtained from the mixed littoral–alluvial environment at the southeastern periphery of the modern Omo Delta. The palaeogeographical situation is also remarkably similar—with a zone of fluvio-littoral interplay between piedmont alluvia to the east and north, and a former Omo Delta somewhere to the west.

Member III contrasts with the earlier units in that massive deltaic clays are far more conspicuous. The basal unit is of this type, with abundant sodium salts, and gypsum laminae or lenticles, suggesting interdistributary environments. Thereafter, loams alternate with clays, suggesting repeated shifts between the delta–fringe and a mixed littoral–alluvial environment. Concretionary bands (siderite ?) are found within the loamy units and in part coincide with shell horizons, chiefly *Viviparus*, but also *Cleopatra*, *Corbicula*, Unionidae, and cf *Pseudobovaria*. These littoral-foreshore deposits, in part, suggest temporary emergence. The terminal beds, underlying the basalt flow, include sizable proportions of fresh volcanic feldspar, probably sanidine (F. H. Brown, personal communication), that have only been transported short distances.

The Usno Formation[3,15] and its facies display certain similarities with the Mursi sequence, also reflecting on the presence of a piedmont alluvial plain—although a much more extensive one—nearby. Depositional environments for the key Shungura Formation are considered by J. de Heinzelin, F. H. Brown and F. C. Howell (unpublished results).

In conclusion, the facies of the different Pliocene and Pleistocene formations of the Lower Omo Basin are by no means simply repetitive and "merely" deltaic, in spite of the many superficial resemblances, both laterally and vertically. None the less, the contemporary depositional environments of the Omo Delta are crucial to a proper understanding of the different sedimentary sequences. In fact, meaningful palaeogeographical reconstruction can only be made in analogy with modern mesoenvironments.

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1 Howell, F. C., *Nature*, 219, 567 (1968).
2 Butzer, K. W., and Thurber, D. L., *Nature*, 222, 1139 (1969).
3 Butzer, K. W., Brown, F. H., and Thurber, D. L., *Quaternaria*, 11 (in the press, 1970).
4 Butzer, K. W., *Nature*, 222, 1133 (1969).
5 Butzer, K. W., *Troll-Festschrift, Erdkunde*, 24 (in the press, 1970).
6 Bernard, H. A., and LeBlanc, R. J., in *The Quaternary of the United States* (edit. by Wright, H. E., and Frey, D. G.), 137 (Princeton University Press, 1965).
7 Gwynn, C. W., *Geogr. J.*, 38, 113 (1911).
8 Beadle, L. C., *J. Linn. Soc.* (*Zool.*), 38, 157 (1932).
9 Worthington, E. B., and Ricardo, C. K., *J. Linn. Soc.* (*Zool.*), 39, 353 (1935).
10 Höhnel, L. v., *Discovery of Lakes Rudolf and Stefanie* (trans. by Bell, N.), 2, 110, 149 (Longmans, London, 1894).
11 Champion, A. M., *Geogr. J.*, 89, 97 (1937).
12 Dudal, R. (ed.), *Dark Clay Soils of Tropical and Subtropical Regions* (Rome, FAO Agric. Developmental Paper, 83, 1965).
13 Fitch, F. J., and Miller, J. A., *Nature*, 222, 1143 (1969).
14 Brown, F. H., *Quaternaria*, 11 (in the press, 1970).
15 de Heinzelin, J., and Brown, F. H., *Quaternaria*, 11 (in the press, 1970).

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