3. THE MURSI, NKALABONG, AND KIBISH FORMATIONS, LOWER OMO BASIN, ETHIOPIA

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Although the Plio-Pleistocene Shungura and Usno formations have provided the great bulk of fossils recovered in the lower Omo basin, the fossil record is significantly complemented both by the Yellow Sands fauna of the older Mursi Formation and by the early *sapiens* hominids of the younger Kibish Formation. It is equally pertinent that the shorter sedimentary sequences of the basin margins not only extend the stratigraphy from 770 to 1,160 m but provide different perspectives on regional depositional environments than do sequences from the center of the basin. The purpose of this paper is to summarize the available information from the Ethiopian peripheries of the lower Omo basin. A comprehensive monograph presenting the mapping, key profiles, and laboratory analyses is in preparation.

Since the history of exploration of the basin, its regional environment, the geological setting, and the contemporary delta landscapes have all been discussed at some length in a previous publication (Butzer 1971*c*), no further introduction is offered here. However, it should be noted that the sediment interpretations are based on extensive laboratory studies and on a reasonably good personal knowledge of the modern Omo delta.

The Mursi Formation

The oldest sedimentary sequence known from the lower Omo basin is exposed under an extensive basalt, southwest of the Nkalabong range, at elevations of 400 to 560 m (see figs. 1-4). Defined as the Mursi Formation by Butzer and Thurber (1969; Butzer 1971*a*), after the local tribe of that name, the type area of Yellow Sands (5° 24'N, 35° 57'E) lies 85 km north of the present shores of Lake Rudolf. The Mursi Beds were first recognized as a sedimentary unit by the Kenyan Omo Expedition of 1967, which collected fossils in the type area but did not carry out a geological examination. In 1968, assisted by Claudia Carr, I studied the sequence in detail, mapping the type are at 1:10 ,500. I carried out further field checks in 1969, at which time G. Eck and Y. Coppens collected more fossils.

The base of the Mursi Formation is not exposed, although it presumably rests on Mio-Pliocene extrusives. It is represented by 143 m of deltaic and fluviolittoral deposits that have potential counterparts in the modern Omo delta sensu lato. Whole rock samples of the overlying basalt have yielded K-Ar dates of 4.4, 4.0, and 4.05 m.y. (Brown and Nash, this symposium; Fitch and Miller, this symposium), suggesting eruption of the lavas ca. 4.18 m.y.

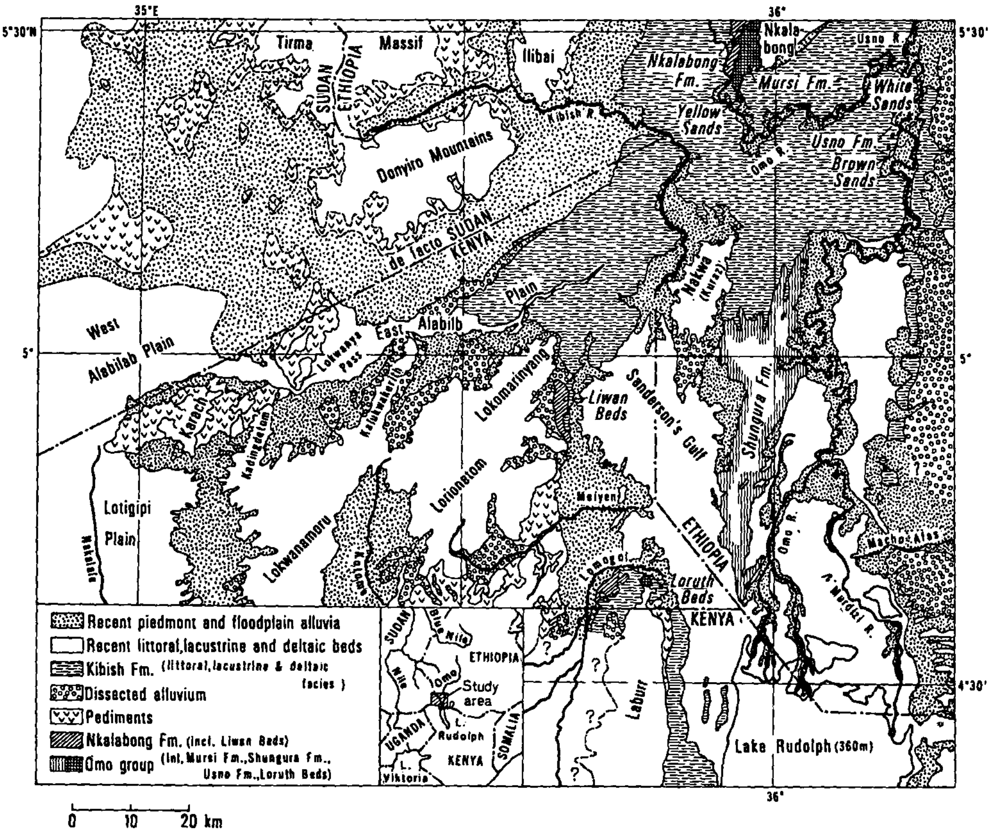

Figure 1. Surficial geology of the lower Omo basin, simplified from a 1:10,000 map (1968-69). (After Butzer 1971*a*, fig. 1.)

The deposits of Member I (over 43 m, 4 beds) are unusually sandy for typical deltaic sediments in the Omo delta, and individual lenses are far too extensive to represent mixed-grade channel beds. An alternation of massive-bedded, vertically structured units, including gypsum or sodium salts, with laminated or thin-bedded strata is also noteworthy. Each unit is intensively gleyed or ferruginized, with several horizons of carbonate or ferruginous cementation. Except for the steep foresets of unit Id, bedding was originally horizontal and inclined in a southwesterly direction. All together this suggests a broad fluviolacustrine environment of deposition, in which extensive fans from the Nkalabong piedmont contributed sands laterally to a delta-fringe environment of the Omo River. In this way suspended and bed-load sediments were mixed along a broad contact zone. Concretionary bands probably record intervals of partial emergence, and foreset complex of unit Id suggests the advancing core of a major tributary delta fan. The capping, fossiliferous crust implies partial emergence, possibly as a result of progradation, and the bone fragments speak for fluvial transport.

Member II (24 m, 6 beds) begins with extensive but thin beds of clayey silts and silty clays (IIa, IIb) suggesting a lacustrine environment and lake transgression. With unit IIc, conditions analogous to those coeval with Member I returned, namely, mixed fluviolacustrine sedimentation in fan proximity. Unit IId is similar, but the lenticular alluvial components

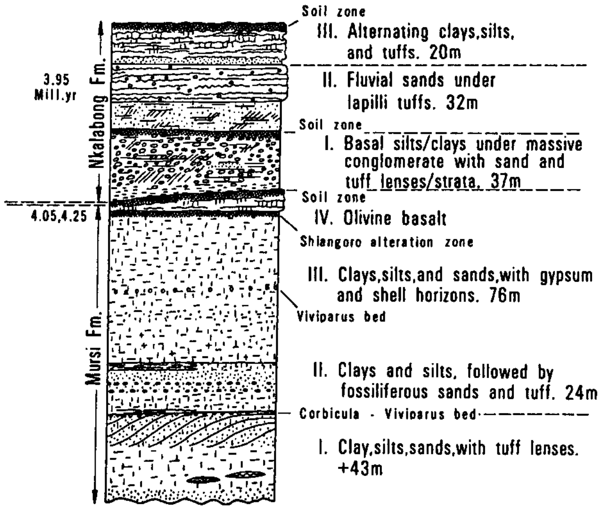

Figure 2. Generalized stratigraphic column of the Mursi and Nkalabong formation. (After Butzer 1971*a*, fig. 4.)

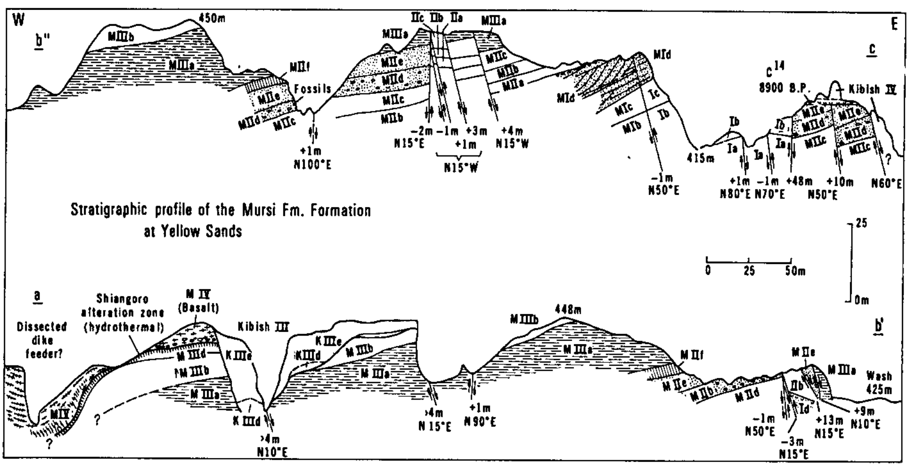

Figure 3. Stratigraphic profile of the Mursi Formation at Yellow Sands. Late Pleistocene-Holocene units of the Kibish Formation are shown in gray. (After Butzer 1971*a*, fig. 3.)

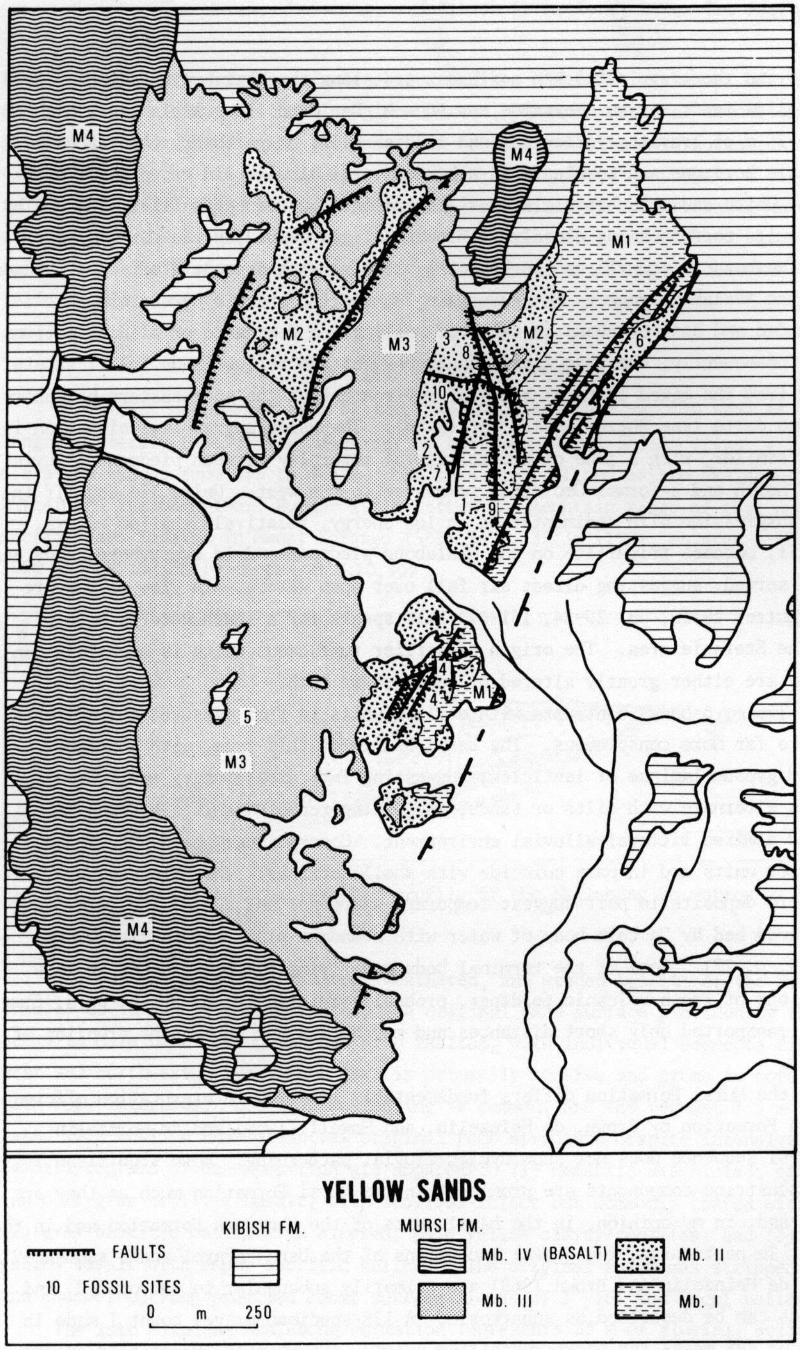

Figure 4. Surficial geology of Yellow Sands, 1968-69

are conspicuous, and the gravels thicken northeastward along the Nkalabong piedmont. Some 6.5 km NNE of Yellow Sands, at an elevation now 90 m higher, the IId gravels are 1 m thick, resting on some 20 m of grayish, yellowish, and reddish silty clays that are interbedded with conglomeratic horizons and terminate in a buried vertisol; the IId gravels are overlain by 4.5 m of white and pale brown clayey silts and interbedded tuffs (IIe, IIf) and by a further 50 m suite corresponding closely to Member III and capped by the Mursi basalt. In other words, Members II and III can be traced laterally, with appropriate facies changes, to the foot of the Nkalabong range. Not surprisingly, the IId gravels here are much coarser, subrounded and heterogeneous in terms of rolling: a dominance of sliding motions is indicated. Consequently, the best facies analogues for the Yellow Sands fossil strata can be obtained from the mixed littoral-alluvial environment at the southeastern periphery of the modern Omo delta (see Butzer 1971*c*, pp. 85-86). The paleogeographical situation is also remarkably similar, with a zone of fluviolittoral interplay between piedmont alluvia to the east and north and a former Omo delta somewhere to the west. Units IIe and IIf indicate a new transgression with sedimentation in low-energy, relatively shallow waters. The key tuff (IIf) becomes tripartite on the Nkalabong piedmont and is everywhere sandy and moderately well sorted, suggesting direct air fall over open waters. In view of the prevailing winds (Butzer 1971*c*, pp. 29-34, 161-67) this speaks for a southeasterly origin, possibly from the Stefanie area. The origin of earlier tuffaceous units is much less conclusive, as they are either greatly altered or reworked or both.

Member III (76 m, 6 beds) contrasts with earlier units in that massive, subhorizontal, deltaic clays are far more conspicuous. The basal bed is of this type, with abundant sodium salts and gypsum laminae or lenticles, suggesting interdistributary environments. Thereafter clays alternate with silts or sands, suggesting repeated shifts between the delta fringe and a mixed littoral-alluvial environment. Concretionary bands are found within the coarser units and in part coincide with shell horizons. These low-energy littoral-foreshore deposits in part suggest temporary emergence and agree with interpretation of a *Viviparus* bed by "a calm body of water with abundant plant growth" (Van Damme and Gautier 1972, p. 27). Some of the terminal beds underlying the basalt flow include sizable proportions of fresh volcanic feldspar, probably sanidine (F. H. Brown, pers. comm.), that have been transported only short distances and may herald the subsequent eruption of the Mursi basalt.

Altogether the Mursi Formation differs fundamentally from the interpretation offered for the Shungura Formation by Brown, de Heinzelin, and Howell (1969) and de Heinzelin (1971). The Mursi sequence does not show cyclic-fluvial patterning. More significantly, lateral fluviolacustrine components are prominent in the Mursi Formation much as they are in East Rudolf, and, in my opinion, in the basal units of the Shungura Formation and in the Usno Formation. In particular, the gravel inclusions of the Usno "gravel sands sequence" at White Sands (de Heinzelin and Brown 1969) are primarily subangular to subrounded, and some of the sands can be described as subarkosic. A 128-specimen gravel count I made in 1967 consisted of 44% meso- and macrocrystalline quartz, 49% granite, "granitoid quartz" and pegmatite, and 7% granite-gneiss; in the eight 5-mm grade classes from 20-60 mm I used, the quartz maximum was in 31-35 mm, granite in 21-25 mm, and gneiss in 26-30mm. I feel that this does not suggest a floodplain (cf. de Heinzelin and Brown 1969, p. 45) so much as a piedmont alluvial fan derived from Basement Complex outcrops farther to the east and interfingering with a low wave-energy littoral environment.

The Mursi Formation was faulted at some point after extrusion of the terminal basalt member (typically 3-5 m thick) and its related dike feeders. A vector diagram for Yellow

Sands shows that the primary fault system strikes N50-60°E, with most of the faults normal and the eastern sides of the blocks downthrown. Maximum vertical throws exceed 58 m (see figs. 3-4) and, depending on the nature of the Mursi-Kibish interformational contact, may exceed 120 m. The minor fault systems (N15°W-15°E and N80°-100°E) have displacements of 5-17 m and 1-2 m respectively. Typical dips of initially subhorizontal Mursi strata are 4°-10° at Yellow Sands, increasing to 5°-15° farther north and 18°-25° at the southwestern terminus of the Nkalabong range; corresponding fault-plane angles decrease from 60°-90° at Yellow Sands to 36°-42° in the piedmont, and north-south fault trends become primary.

The Nkalabong Formation

The oldest undeformed beds of the lower Omo basin are exposed west of the Nkalabong range, primarily east of the Omo River at latitudes 5°23'-5°35'N (figs. 1-2, 5). Absolute elevation ranges from 405 to 475 m. The beds were defined as the Nkalabong Formation by Butzer and Thurber (1969; Butzer 1971*a*) after the mountain range of that name. The type sections are located in Neusi Korongo (5°25'54"N, 35°36'11"E), an area I first studied in 1968 and geologically mapped at 1:10,500 .

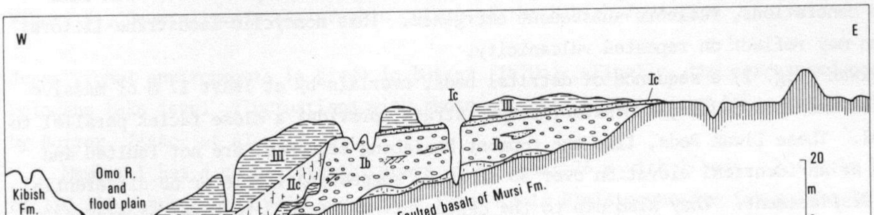

Figure 5. Generalized stratigraphic profile of the Nkalabong Formation at Neusi Korongo. (After Butzer 1971*a*, fig. 5.)

The base is formed by faulted, weathered, and eroded basalts of the Mursi Formation. Insofar as it can be reconstructed, the original land surface provided by the Mursi basalt seems to have been corrugated and step faulted, with individual segments dipping 3° to the west and northwest. The intact lava is primarily massive and prone to core weathering, with ropy interbeds. Zeolitic weathering is common, and the topmost 1.5 m forms a truncated (B)C horizon that preserves original rock structure despite intensive alteration. Several degrees of decomposition are apparent: (1) Hematite-discolored, mottled dusky red and dark gray zeolitic basalt, with zeolites intact but commonly coated with oxide rinds; (2) gray basaltic matrix with altered, pale yellow clayey zeolites; and (3) friable, pale yellow basalt with empty zeolitic hollows. The original solum was stripped by denudation, and channel cutting provided local surface slopes of 1°-10° and local relief of 18 m.

The late Pliocene Nkalabong Formation represents 88 m of fluvial, eolian, and lacustrine beds that generally fall outside the range of facies variation of the modern Omo delta.

Member I (37 m, 2 beds) records a succession from flood silts through bed-load deposits of an early Omo River to terminal units of tuffs and sands rich in volcanic ash. The coarse channel beds consist primarily of intensively gleyed conglomerates, interbedded with sands that interfinger laterally from local tributaries. Calcretion of the terminal unit may reflect on subaerial weathering, hydrothermal activity in the wake of local volcanism, or both. This floodplain sequence was followed by intensive dissection.

Member II (32.5 m, 3 beds) currently known from only one korongo, represents the filling of a tributary canyon that once drained the adjacent foothills. Basal sands of fluvial origin were weathered and dissected before they were buried by a massive, unbedded lapilli tuff of eolian origin, without reworking except for the lowest 50 cm.

Member III (18 m at the type section, 11 beds) is still different. A long succession of alternating massive-bedded and laminated silts rests upon basal detrital strata with derived lapilli tuff (IIc). Despite their consolidation, weathering--both 14 angstrom units nonexpandable and 15-16.5 angstrom units expandable clays, (F. H. Brown, pers. comm.) --and hydromorphic or terrestrial paleosols, these beds have a structure of more or less 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, appear to argue for ash falls in a littoral-foreshore setting. All the beds are white or light gray, with limited limonitic mottling but frequent pyrolusite discoloration; some horizons have carbonate concretions. These additional features are possibly but by no means necessarily explained by a former reducing environment. Cementation of the topmost bed, with some carbonate concretions, reflects subsequent emergence. This noncyclic lacustrine-littoral succession may reflect on repeated vulcanicity.

At Liwan (fig. 1) 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, like the topmost Nkalabong sequence, are not faulted and are found at an identical elevation over 50 km away, suggesting little or no differential vertical displacement. They also dip to the center of the basin. In terms of facies, Nkalabong III and the Liwan Beds appear to be linked to the Omo Group by lithologically intermediate but faulted sediments near Loruth Kaado (see Butzer 1971*a*; De Heinzelin 1971), north of the Labur range. It is therefore apparent that the upper, littoral sequence of the Nkalabong Formation was once widely developed along the northern and western margins of the Omo basin, marking the greatest expansion of Lake Rudolf, shortly after 3.9 m.y.

Since the basal Shungura Formation is believed to be fluvial (de Heinzelin 1971), the entire Shungura Formation must postdate the regression of Lake Rudolf from Nkalabong III-age shorelines along the Lokomarinyang and Nkalabong piedmonts. Thus there is no temporal overlap between the Nkalabong and Shungura formations.

There is no evidence for postdepositional deformation of any Nkalabong Beds other than a gentle tilting of the Nkalabong footslope region. The various episodes of faulting which affected the Shungura and Loruth Kaado Formations were restricted to the east of a line from Labur to Nakwa and thence to the eastern face of Nkalabong. They must be distinctly younger than the faulting of the Mursi Formation.

The Kibish Formation

Late Middle Pleistocene to mid-Holocene time in the Omo basin is adequately recorded by the widespread littoral, deltaic, and fluvial beds of the tectonically undisturbed Kibish Formation (figs. 1 and 6). Preliminary stratigraphic observations on these strata were made by F. H. Brown and by R. E. F. Leakey in 1967, before I did a systematic study in 1967-69. The formation was defined by Butzer and Thurber (1969; Butzer 1969) and named after the police posts of that name (at 5°19'N, 35°53'E). An interim report on the stratigraphy was provided by Butzer, Brown, and Thurber (1969), and a discussion of the

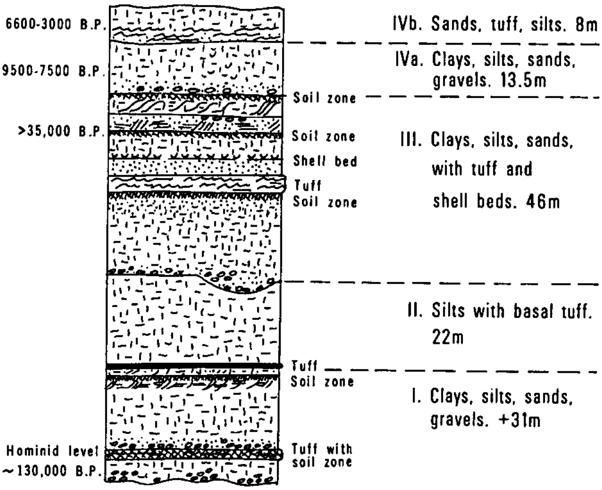

Figure 6. Generalized stratigraphic column of the Kibish Formation

depositional environments is given in Butzer (1970*a*). Finally, the correspondence of the Holocene lake level fluctuations with those of other East African lakes has been discussed by Butzer, Isaac, et al. (1972).

Member I has a cumulative thickness of at least 26 m with 7 beds. A single Th/U date of 130,000 years tentatively suggests a late Middle Pleistocene age for a lake level that was about 60 m higher than the present Lake Rudolf. Member I, which locally rests on the strongly dissected Nkalabong Formation, records at least one complex transgressive-regressive cycle (17 m of deposits in the Rhino Canyon-Kenya Camp type area), progressing from channel sands and silts to delta-fringe beds (alternating clays and silts), terminating with a calcareous paleosol. The basal beds (9 m), base unseen, probably mark a second but incomplete cycle. They include channel conglomerates, subaqueous clays, and tuffs of complex origin, followed by emergence, calcification, and dissection.

Following at least 19 m of dissection by the Omo River in the type area, Member II (22.5 m cumulative thickness, 2 beds) began with a tuff that mantled a highly irregular, dissected delta plain. Frequent detrital components indicate colluvial working on slopes (up to 20°), and gypsum laminae in depressions indicate subaqueous deposition near the shores of the lake (interdistributary bays?). The following 22 m of laterally extensive clay with silty interbeds and ferruginous horizons, or zones of carbonate and ferric concretions, indicates 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, noncyclic in the sense of Brown, de Heinzelin, and Howell (1970). There is only limited evidence of reduction.

At least 25 m of dissection preceded accumulation of Member III in the type area, where a minimum ^{14}C date of greater than 37,000 years was obtained for the youngest beds. Cumulative thickness is 45.4 m, subdivided into 12 beds. Two transgressive-regressive cycles are recorded, each cresting with +60-70 m lake levels, separated by emergence and a paleosol. The first 26.5 m of deposits range from distributary-channel beds up to laterally extensive delta-fringe clays (interdistributary?) with silty 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 tuff 2-3.5 m thick. This particular tuff, a well-sorted and fairly pure silt, is uniform and level over a stretch of 3.5 km across the modern valley and is certainly subaqueous. After 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, by massive, inclined clays related to channel/levee contacts.

The youngest Kibish Beds follow upon a long interval ca. 35,000-9500 B.P., during which Lake Rudolf must have been relatively low, and from which no contemporaneous deltaic or littoral sediments are preserved. Omo River dissection in the type area exceeded 15 m. Members IVa and IVb have cumulative thicknesses of 13 and 8 m respectively, preserve considerable surface morphology, are well exposed, and currently have 15 ^{14}C determinations. The initial transgressive sediments of Member IVa have not been identified, but the maximum level was attained by 9,500 years ago and the lake level fluctuated between about +60 and +80 m until a little after 7500 B.P., when Lake Rudolf shrank to about its present dimensions and the Omo River cut down its bed by 30 m. Member IVb records a transgression of Lake Rudolf that began shortly before 6600 B.P. and reached a high level of +65 to +70 m about 6200 B.P. This level was maintained until after 4400 B.P., then was followed by a temporary regression of unknown amplitude and a final transgression to +70 m a little before 3000 B.P. Lake Rudolf also has been relatively low since about 3000 B.P., with the level fluctuating rapidly within a range of over 40 m, and dropping from +15 to -5 m between 1897 and 1955 (Butzer 1971*c*).

Beach ridges, cuspate bars, and other shoreline features at +65 to +70 m indicate an interconnection between Lake Rudolf and the vast Lotigipi mud flats to the west through a low-level, swampy divide. The expanded lake must have periodically overflowed to the Lotigipi for much of the time about 6200 to 3250 B.P., with the threshold elevation essentially determining the maximum lake level. Temporary maxima near or above +80 m about 9500 to 7500 B.P. probably induced overflow across the flat watershed to the Pibor-Sobat River and ultimately to the Nile.

All of the Kibish mollusks described by Van Damme and Gautier (1972) derive from Member IV, and there are no stratigraphic grounds for distinguishing two faunal stages, since the microfaulted type site of their A1 assemblage has a ^{14}C date of 9300 B.P. nearby (Butzer 1972).

To 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 most of the sediments reflect a deltaic (sensu lato) environment. The delta-fringe deposits--including many fluvial beds of distributary origin--are best represented and are certainly far better preserved than the littoral deposits so prominent in the surface expression of Member IVb.

Mountain Paleosols, Pediments, and Piedmont Alluvia

A great part of the 3.6 m.y. sedimentary hiatus between the Nkalabong and Kibish formations is spanned by the Shungura and Usno formations in the center of the lower Omo basin. The question remains to what extent the peripheries of the basin (see Butzer 1970*b*) provide independent evidence that may complement that of the dissected deltaic-lacustrine plains.

Most complete is the record east of Lorienatom, where the following sequence of development can be delineated for the Liwan piedmont and the Karenga valley entrant. The base is formed by an extensive piedmont surface cut across warped, late Tertiary basalts:

(*a*) 1.5 m. Accumulation of brown claystones, interbedded with subangular, coarse-grade conglomerates, filling in topographic irregularities and derived from reddish, argillic paleosol.

(*b*) 6 m. Aggradation of weakly stratified, nonhomogeneous reddish clay with basalt grit, sandy interbeds, and concentrations or lenses of coarse, subangular gravel. Inclined 3° to east and conformable with overlying tuffs.

(*c*) 17 m. Aggradation of stratified to laminated white tuffs with interbedded clays of tuff derivation and rare lenticles of sandstone or fine conglomerate. Lacustrine Liwan Beds (Nkalabong Member III, indicating apparent lake level of 450 m).

(*d*) Emergence may have been followed by pedogenesis of a reddish soil, implied by subsequent aggradation of 2 m pink to reddish or yellow silts and silty, gritty sandstones. These include tuff derivatives and suggest sheet and slope wash.

(*e*) Extensive denudation of surface, with at least 10 m stream downcutting.

(*f*) Aggradation of +30 m piedmont surface with more than 20 m of coarse to cobble-grade gravel with a brown, sandy matrix.

(*g*) Denudation of surface, with at least 20 m stream downcutting.

(*h*) Aggradation of +20 m piedmont surface (like *f*), contemporary with or followed by development of gravelly beach ridge at 460 m (Kibish Member III?).

(*i*) Development of a now degraded brown paleosol on both the piedmont alluvial fans (*f*) and (*h*). Original profile depth was 2.5-4.0 m, with strong brown (7.5YR 5/6) loams or clay loams in the B-horizon; parent material was basalt, rhyolite, and chert gravel in a matrix of quartz and ferromagnesian sands (coeval with Kibish Member III?).

(*j*) Denudation and mechanical eluviation of soil clays, with at least 20 m stream downcutting.

(*k*) Secondary calcification of the previous paleosol, with formation of a 5-cm Ca-horizon at -25 to -30 cm depth within the former B-horizon. The partly decomposed pebbles in the top 30 cm of such profiles were often split in situ by salt hydration, and surface lag is normally patinated.

(*l*) Aggradation of at least 7.5 m of fluvial and lacustrine beds, both horizontal and inclined, ranging from coarse to cobble-grade gravels to sands and silts, commonly limonitic, with abundant aquatic shells dominated by *Melanoides*. Lake level 425 m, equivalent to Kibish Member IV, grades upstream into fine-grained +12 m valley floor terrace.

(*m*) At least 8 m stream downcutting.

(*n*) Aggradation of fine-grained +3-3 m valley floor terrace.

(*o*) At least 4 m stream downcutting; development of modern noncalcic brown soil begins.

(*p*) Modern alluviation of gravelly alluvium, including small lateral fans. Pedogenesis continues.

The brown paleosols must record periods of longer or more intensive chemical weathering, since they contrast strongly with the zonal soil profiles found at lower elevations (below 1,500 m) today. At least two generations are indicated east of Lorienatom. However, the geomorphologic and pedogenetic record (Butzer 1970*b*) of the piedmont environments suggests that late Cenozoic climate has generally tended to be dry. The geomorphologic record indicates alternating pediment-cutting, aggradation of coarse alluvial spreads (by higher-competence rills and streams), and fill-dissection (by lower-competence watercourses). The equally variable pedogenetic record suggests contrasting trends such as rubefaction with intensive pedogenesis; noncalcic grassland soil formation; secondary calcification; salt-weathering; and patination. This suggests that ecological conditions have at different times been subhumid, semiarid, or arid.

General Interpretation

The geological records reviewed here provide two categories of evidence:

1. Transgressions and regressions of Lake Rudolf, as directly inferred from related lacustrine or littoral deposits or indirectly from deltaic or alluvial formations of the Omo River.

2. Piedmont or montaine phenomena, including alluvial fans and terraces, pediments, and paleosols.

The first type of evidence, which reflects on regional conditions over the entire drainage system (see Butzer 1971*c*, chap. 5), accounts for the great bulk of the Plio-Pleistocene record. The second category permits deductions about the more immediate, non-riverine setting but unfortunately is poorly represented in the predominantly deltaic sedimentary sequences of the basin floor.

Although the Rudolf-Omo drainage system has no outlet today, there is a low-level divide (at about 450 m elevation) to the west, beyond which lie a series of extensive mud flats that form the watershed to the Pibor-Sobat, a Nile tributary. The topography, the disposition and elevation of the various sedimentary formations, and the mollusks, fishes, and reptiles of the Rudolf-Omo system from the earliest times all indicate intermittent hydrographic links to the Nile system. Each of the formations culminates in 450-460 m elevations, that is, at the level of the Rudolf-Nile threshold, indicating that potential overflow across the divide set an upper terminus for littoral and deltaic sedimentation in the lower Omo basin.

The Plio-Pleistocene record indicates that the Omo River mouth was situated 90-120 km north of the present delta fringe (fig. 1) during the deposition of the Mursi Formation (Members I-III) and the later Nkalabong units (Member III, Liwan Beds). The present elevation of these deposits supports the inference that almost the entire basin floor formed an extension of Lake Rudolf and that some kind of overflow to the Nile system existed. Regional climate must have been moister, although the alluvial sands injected into the Mursi sediments are more compatible with an adjacent piedmont alluvium and a semiarid climate. The terminal Nkalabong facies, marking the highest late Cenozoic transgression of Lake Rudolf (ca. 3.9 m.y.), is uniquely free of sandy wash from the adjacent uplands and may indicate a lack of torrential runoff because of an effective vegetation mat. The dissection of the Omo River before and after deposition of Nkalabong Member I (channel gravels and flood silts) indicates long-term lake regressions and presumably a drier climate, although the coarse conglomerates in Member I (ca. 4.0 m.y.) suggest a higher-competence stream. By contrast, present interpretation of the Shungura (Members A through F) and Usno formations suggests that the Omo delta was situated less than 50 km north of its present position, and the lake level may have been intermediate between that of today and that during Mursi times. The terminal Shungura units indicate a higher lake level, possibly at the overflow threshold to the Nile drainage, and may therefore again imply a moister climate. The various intra-zonal paleosols recorded within the Shungura and Usno formations (Brown et al. 1970) permit no paleoclimatic inferences, although the deep weathering evident after faulting of the

Mursi basalt does suggest a relatively moist climate at some time before aggradation of the first Nkalabong units. Unfortunately, no intact zonal soil profiles are preserved.

These apparent climatic changes may have been in part obscured or even simulated by tectonic deformation. It would be unrealistic to assume that modern elevations are meaningful for faulted strata, and other deformations have almost certainly affected the depth of the Rudolf trough and the relative level of the Rudolf-Nile divide. Thus, except for the Kibish Formation, no unequivocal paleoclimatic conclusions can be drawn from the geological evidence, although the broad inferences tentatively suggested above do seem to have some validity. Considering the rapid and significant recent changes in the level of Lake Rudolf (Butzer 1971*c*), the Plio-Pleistocene transgressions and regressions--as inferred from the horizontal delta displacements--do not necessarily imply *major* climatic changes. To all intents, the geology and geomorphology suggest that a semiarid climate has been characteristic throughout the late Cenozoic.

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