Naturwissenschaften 58, 7—16 (1971)

The Lower Omo Basin: Geology, Fauna and Hominids of Plio-Pleistocene Formations

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The international Omo Research Expedition, working in the southwestern Ethiopia 1966—70, has established a unique late Pliocene to early Holocene sedimentary sequence, dating from before 4.2 to about 1.8 million years. Older than the classical Olduvai formations, these strata have provided a complex faunal stratigraphy for this poorly-known time range. At the same time, two, contemporary, hominid lineages, one a hyperrobust australopithecine, the other a gracile form, have been established as far back as 3.5 million years, extending the known time span and the enigmatic dichotomy of these early hominids.

Introduction

Lake Rudolf (Fig. 1) was the last of the great African lakes to be discovered, in 1888. It forms part of the Western or Kenya Rift. F. Toula [1], on the basis of L. v. Höhnel's accurate field observations, compiled a first geological sketch-map of the lake shores and the Omo Delta in 1891. M. Sacchi, the geologist of the ill-fated Bottego expedition, came down the Omo Valley in 1896 and observed a widespread suite of ancient lacustrine deposits there [2], while E. Brümpt of the Bourg du Bozas expedition collected the *first fossils* from what were to be known as the Omo Beds in 1902 [3]. These initial discoveries from the inaccessible Ethiopian borderlands prompted the first field-work of C. Arambourg in 1932–33; he collected and studied an amazing fauna from the faulted Omo Beds, considered as lacustrine or fluvio-lacustrine sediments of apparent early Pleistocene age. Overlying horizontal, lacustrine deposits with modern molluscan assemblages were attributed to the late Pleistocene [4]. At about the same time (1930–31 and 1934), V. E. Fuchs did exploratory geology along the Kenyan margin of Lake Rudolf, mapping bedrock, broad structural lines and a sequence of late Pleistocene lake beds [5].

These initial studies, although highly provocative, were not immediately followed up. In the Ethiopian sector, E. Zavattari [6] visited the Omo Delta briefly in 1939, but better Italian efforts were concentrated on the Ethiopian high country and little more was achieved 1941–45 when the border areas were temporarily open to British geologists. In 1959 F. C. Howell was first able to obtain permission for a re-examination of the Omo Beds, a development of which was the international Omo Research Expedition of 1967–70, jointly organized by L. S. B. Leakey, Arambourg and Howell, and enjoying the full support of the Imperial Ethiopian Government. A group from the National Museum of Kenya (R.E. and Margaret Leakey) searched for fossils in the north-central part of the Lower Omo Basin, one season only [7]. The French team (Arambourg, Y. Coppens, J. Chavaillon, R. Bonnefille) concentrated on the fossils of the Omo Beds, working each summer since 1967 [8–12]. The group based on the University of Chicago, supported by the National Science Foundation, has included members from the Universities of Chicago (Howell, K.W. Butzer, G. Eck and C. J. Carr), the University of California (F. H. Brown), and the Rijksuniversiteit Gent (J. de Heinzelin). With the aid of the Wenner-Gren Foundation, Brown was able to initiate the geological work of the Chicago Expedition in 1966. During the subsequent summers (1967–68) this multidisciplinary effort undertook a more systematic general study of the Lower Omo Basin [13–24], prior to focusing on the fossiliferous Omo Beds during the 1969–70 seasons, with further collecting and excavation projected for 1971. This more comprehensive work of the Chicago Expedition was made possible by 3 to 5 Land Rovers, a 4-wheel drive truck and, for part of the time, by charter of a Hughes-300 helicopter and a Piper Cherokee aircraft, all kept in communication by radio, to avoid fatal breakdowns or accidents in difficult or almost intraversible terrain. The helicopter, in fact, was a total loss after crashing in July, 1969.

In the Kenyan sector, T. Whitworth established a sequence of late Pleistocene to Holocene lake beds northwest of Lake Rudolf in 1959 [25], and a Harvard Expedition (led by B. Patterson) studied late Cenozoic fossiliferous deposits at Kanapoi and Lothagam west and southwest of the lake during several seasons 1963–68 [26–30]. More recently, since 1968, R. E. Leakey has been successfully surveying fossil-bearing deposits from deposits in the northeastern sector of the Rudolf Basin [31], an area of the basin previously quite unknown.

The purpose of this paper is to outline the present status of research in the Plio-Pleistocene formations of the lower Omo Basin.

Geology

The Lake Rudolf trough, and its extension up the lower Omo Valley, form part of the eastern or Kenya Rift. The peripheral highlands consist of late Oligocene to late Miocene or early Pliocene extrusives [32–33], resting on a basement of Precambrian igneous and metamorphic rocks, with local development of the coarse-detrital Turkana Grits (late Cretaceous) [34]. The exact age of the major faulting and folding that created the present basins and highlands is not yet

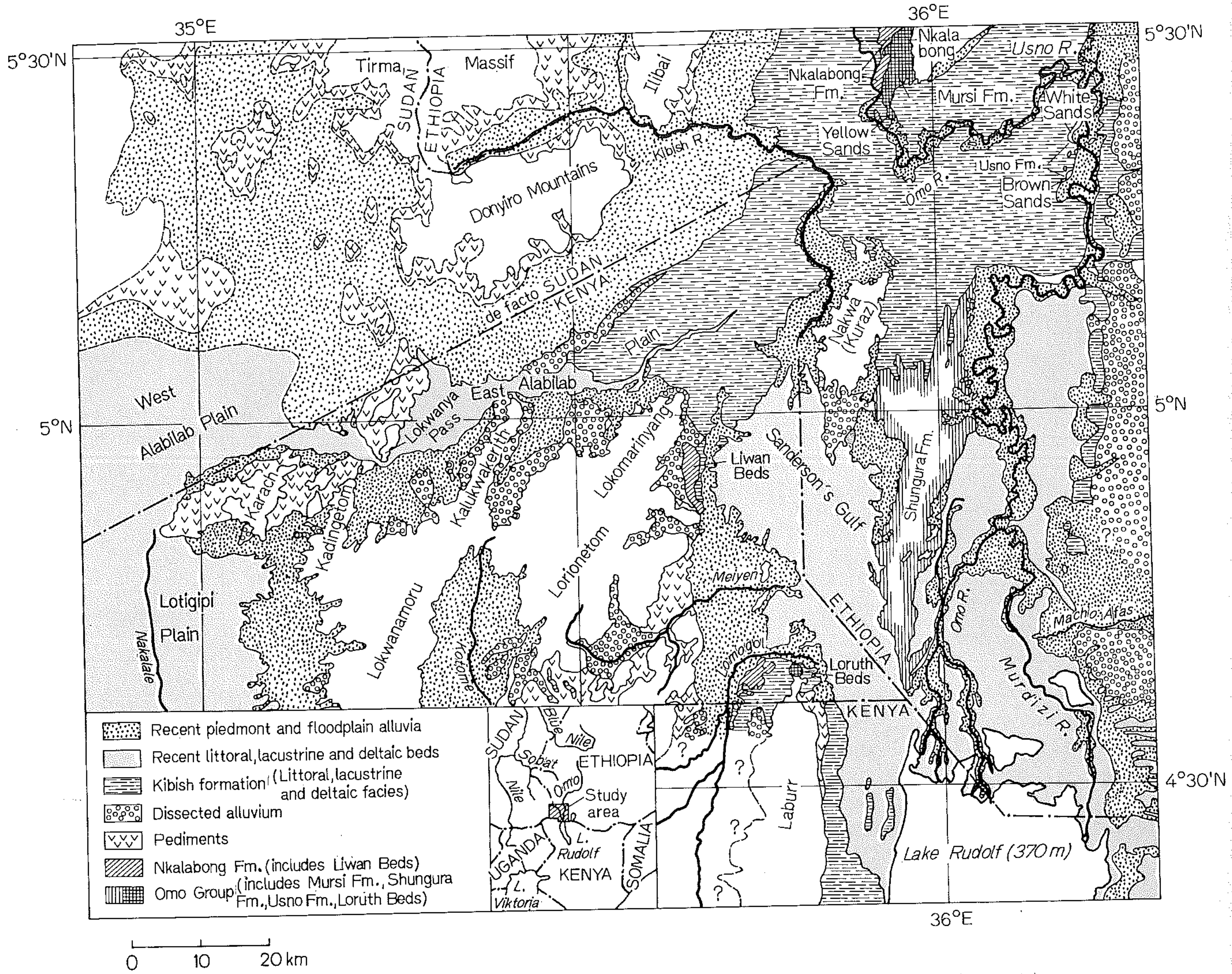

Fig. 1. Surficial Geology of the Lower Omo Basin. Simplified after a 1:100,000 map by the writer (1968–69)

known. However, lacustrine or deltaic sequences had begun to develop southwest of Rudolf prior to 5.0 mill. yr [28, 29] and in the Omo Basin prior to 4.18 mill. yr [14]. Subsequent deformations were not demonstrably universal and they do not appear to have effected more than modifications of detail. On these grounds it can be assumed that the gross tectonic and topographic lineaments had been established during the first half of the Pliocene.

The earliest depositional sequence known from the floor of the Omo Basin is the *Mursi Formation* (Figs. 1–4) [14, 17], with more than 143 m of deltaic and fluvio-littoral beds found under a capping basalt with K/Ar dates of 4.4, 4.1 and 4.05 mill. yr [16]. Member I (43+ m) consists primarily of poorly-sorted, horizontal loams of mixed littoral-alluvial origin, interbedded with sands and some lenses of clays, with sodium salts and extensive limonitic staining due to groundwater oxidation. A terminal unit of complex foreset and topset strata is uniquely deltaic, while the thin cap of concreted shell bed (*Corbicula*, *Viviparus*, some fish/reptile bone) is probably of littoral-foreshore facies. Member II (24 m) consists almost entirely of oxidized littoral-alluvial beds (sands, laoms, some gravel lenses), with extensive basal clays and a terminal, reworked tuff. This unit has provided a unique mammal fauna from one fossiliferous horizon (see below). Member III (76 m) is more uniform, beginning with massive deltaic clays, with sodium salts and gypsum lenticles, and continuing with an alternating sequence of delta-fringe clays and of littoral-alluvial loams adjacent to a piedmont alluvial surface to the east. Concretionary beds (siderite?) partly coincide with shell horizons (*Viviparus*, some *Cleopatra*, *Corbicula*, unionidae and rare vertebrate fossils). The terminal olivine basalt (Member IV), perhaps already heralded by abundant unworn feldspar in the top bed of Member III, rests directly on the deltaic units with an average thickness of 3–5 m. Locally, in what appear to be dike feeders, thickness exceeds 27 m.

Accumulation of the *Mursi Formation* was followed by faulting. At the type area the primary fault system strikes N 50° to 60° E, with most of the faults normal, the eastern sides of the blocks downthrown; maximum vertical thows exceed 58 m (Fig. 3). The minor fault system (N 15° W to 15° E, and N 80° to 100° E) have displacements of only 1–5 m.

The next oldest unit, the *Nkalabong Formation* (Figs. 2 and 4–5) [14, 17], rests unconformably on the step-faulted, corrugated and intensively weathered Mursi

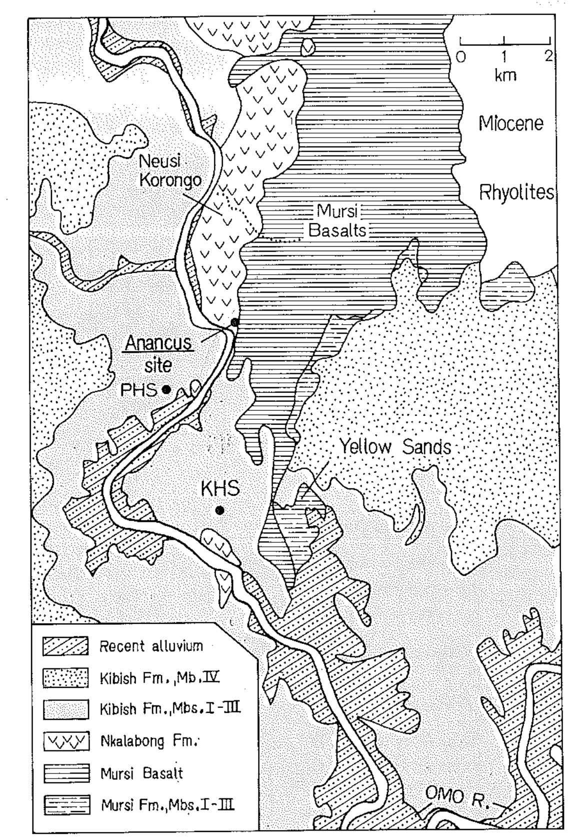

Fig. 2. Surficial Geology near Yellow Sands and Neusi Korongo. Simplified after 1:11,000 and 1:100,000 maps by the writer (1968). PHS and KHS refer to primitive *Homo sapiens* sites from the lowest member of the Kibish Formation (*c.* 130,000 B.P ? [22–23, 38])

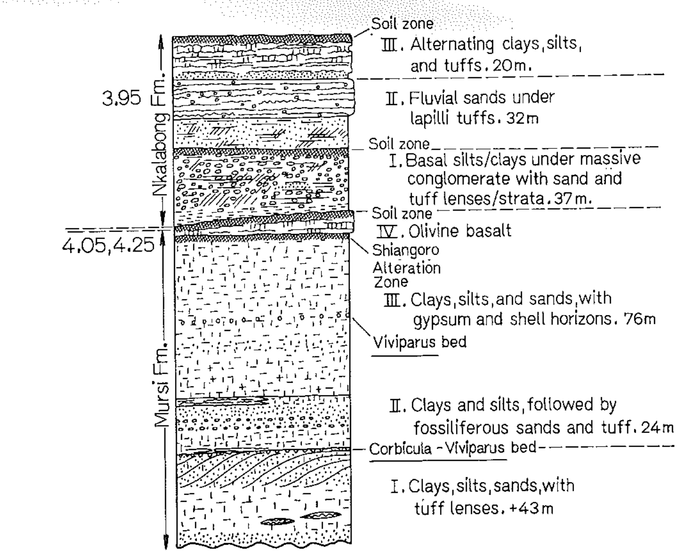

Fig. 4. Stratigraphic Column of the Mursi and Nkalabong Formations

basalt. With a thickness of 88 m in the type area, the basal beds are typically fluvial, followed by an eolian tuff, and terminating in a complex suite of littoral-foreshore beds derived largely from tuffs. Member I (37 m) includes typical floodplain silts and massive, gleyed bed-load conglomerates of an early Omo River, intercalated with tributary sands and capped by fluvial sands rich in volcanic ash. Calcretion and patination of this cap suggests subaerial weathering or hydrothermal activity in the wake of local vulcanism. After a long period of intensive dissection by the Omo tributaries, a massive primary tuff of eolian facies was deposited in at least one canyon, filling it with more than 18 m of unstratified lapilli tuff, resting on 14 m of fluvial sands (Member II). This tuff has K/Ar dates of 3.99 and 3.90 mill. yr [35]. Member III (19.5 m but thickening west of the type area) consists of an alternating sequence of massive-bedded, white tuffs and laminated, white, clayey tuff derivatives, with very rare lenses of spheroidal pumice. Laterally extensive and thickening downslope on a 5° incline, these littoral deposits may reflect on repeated vulcanicity.

The upper, littoral sequence of the Nkalabong Fm. appears to have been widely developed along the margins of the basin. At Liwan, in the southeastern

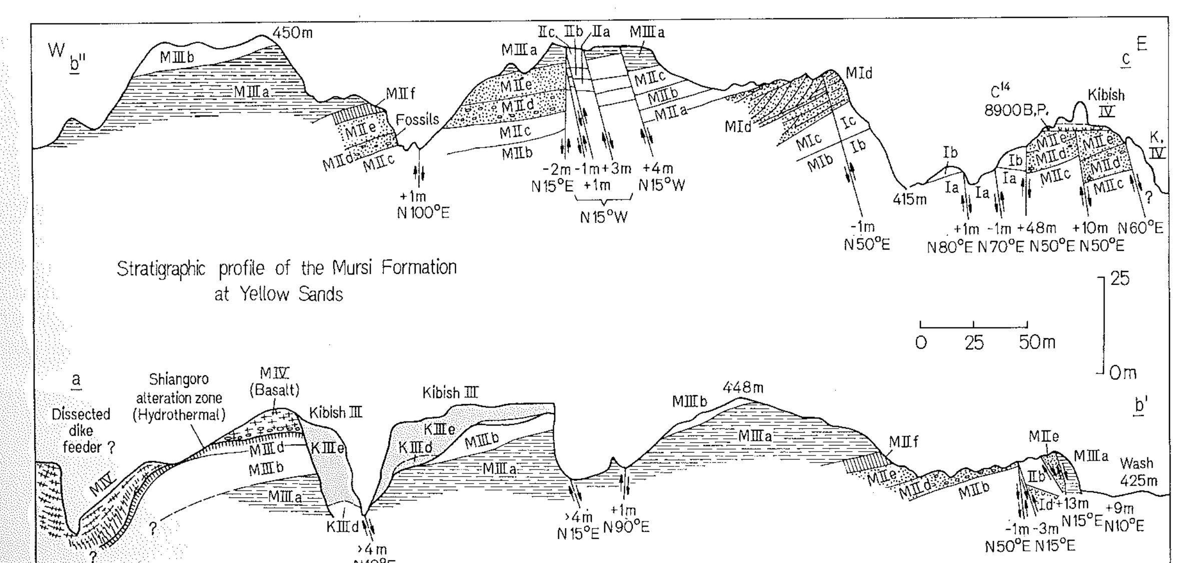

Fig. 3. Stratigraphic Profile of the Mursi Formation at Yellow Sands. The late Pleistocene to Holocene units of Kibish Formation are indicated in gray

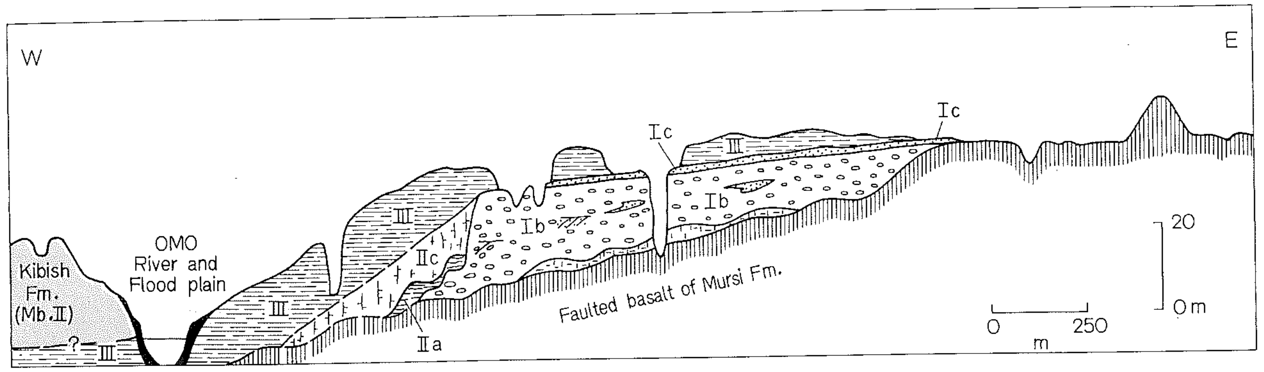

Fig. 5. Generalized stratigraphic Profile of the Nkalabong Formation

Sudan (Fig. 1), there are more than 17 m of massive white tuffs and interbedded, laminated, clayey strata recalling Member III [17]. Neither these *Liwan Beds* nor the Nkalabong Fm. have been faulted, and they are now found at identical elevations despite an intervening distance of 50 km, suggesting little or no displacement. Comparable facies development can be observed within the unstudied *Loruth Beds* (at the very least 30 m thick), near the Kenya border (Fig. 1) [17]; these tuffs and clayey lenses are associated with massive, reddish brown or brownish yellow clays typical of the Omo Beds *sensu strictu*. However, the Loruth Beds were subject to considerable post-depositional faulting and tilting, with a strike approximately due north and strata now inclined 10° or more to the west. Unlike the Nkalabong and Liwan units, which lack fauna entirely, casts of *Viviparus* and *Melanoides* were recognized in some strata of the Loruth sequence.

The top of the Nkalabong Formation is approximately contemporary with the oldest strata of the Omo Beds type area (Table). These "classical" exposures have been assigned to the *Shungura Formation* (Fig. 1) which has a cumulative thickness of at least 600 m [21]. Facies development is somewhat similar to the Mursi Fm., with fluvial (deltaic and alluvial) sediments dominant. However, massive fossiliferous sands are relatively common, and stratigraphic subdivision is facilitated by 10 persistant "marker" tuffs (designated A through J upwards) with 6 further, subsidiary and less persistent tuffs (P through U upwards) (Fig. 6).

11 K/Ar dates are now available on tuffs B, D, E_i, F, G, and I_2, consistently extending upward in age from 3.75 to 1.81 mill. yr [16]. 10 stratigraphic members have recently been defined (A through I), each represented by a major tuff and its overlying sediments [21], with exception of the Basal Member, which includes the sediments below Tuff A (Fig. 6, Table). Tuff J may eventually be included in a further member, once the stratigraphy of the topmost Shungura units—exposed in the southern part of the type area [10]—has been clarified. The stratigraphic cloumn [21] is given by Fig. 6 and can be stated in terms of members, giving the total number of fossil localities studied by the Chicago expedition as of 1969 [16]:

Basal Member. At least 15 m. Reddish sands overlain by clays and silty clays.

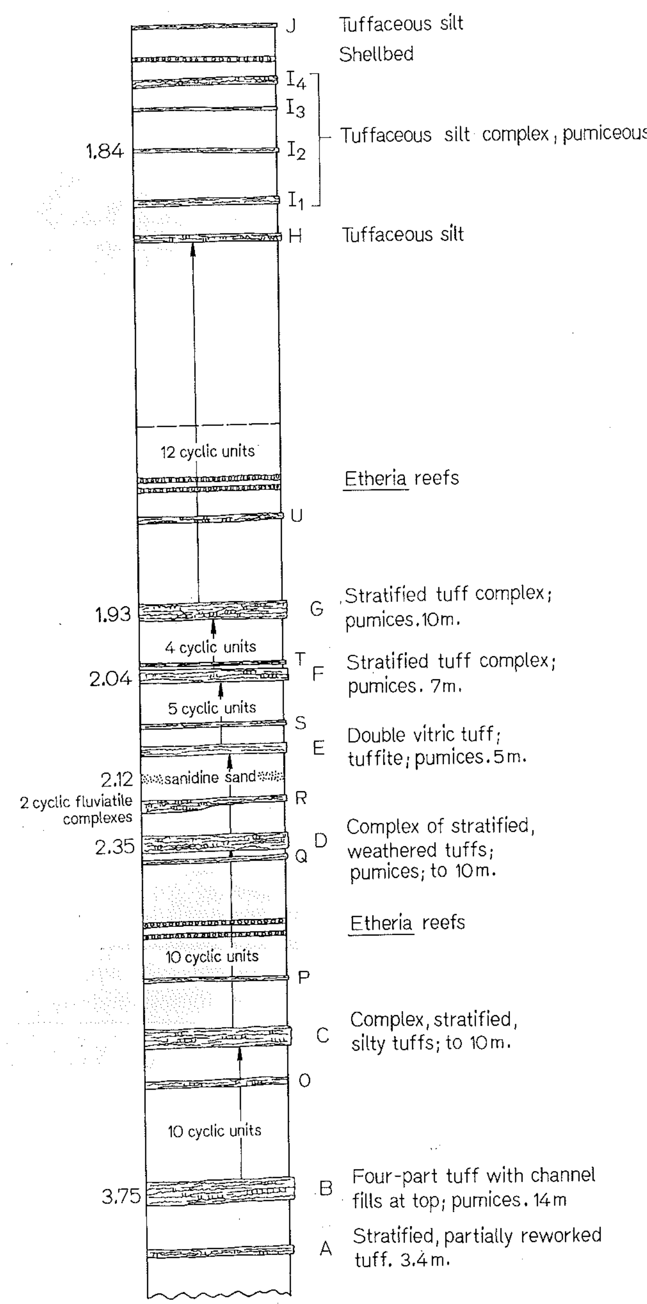

Fig. 6. Stratigraphic Column of the Shungura Formation. After [16, 21]

Member A. 30 m. The tuff is a laminated, volcanic ash (3.4 m), overlain by 2 cyclical sequences of sands, silts and clays.

Member B. (3.75 mill. yr) 87 m. The major tuff is subdivided into 4 units: (i) 2 m crossbedded pumiceous sands; (ii) 9 m tuffaceous silty sands and clay; (iii) 1.5 m well-stratified pumiceous sand; and (iv) 3.5 m of crossbedded pumiceous sands with clays. The succeeding sediments form 10 cyclical units, interrupted by a minor tuff (O), and marked by calcareous concretions in the upper half. 2 localities with fossil mammals (1 with hominids).

Member C. 107 m. The tuff (5.5 m) is subdivided by lenses of silts and crossbedded sands, and succeeded by 10 cyclical units containing 2 well-developed *Etheria* reefs and interrupted by 2 minor tuffs (P and Q). 134 fossil localities (8 with hominids).

Member D. (2.35 mill. yr, average of 4 dates) 56 m. The tuff (4.5–7 m) consists of fine sand and silt-sized volcanic glass, with pumice gravel. The overlying sediments contain crossbedded sands, as well as a minor tuff (R). 68 fossil localities (3 with hominids).

Member E. (2.12 mill. yr) 41 m. The tuff (5 m) comprises several basal ash layers, followed by tuffaceous silts, in part crossbedded, laminated or pumiceous. The sedimentary sequence includes 5 cycles of sands, silts and clays, interrupted by a minor tuff (S). 77 fossil localities (2 with hominids).

Member F. (2.04 mill. yr, average of 2 dates) 35 m. A 4–7 m tuff of laminated, pumiceous sand, followed by 4 cyclic units of sediment and a minor tuff (T). 38 fossil localities (4 with hominids).

Member G. (1.93 mill. yr) 165 m. The tuff (3–5 m), a laminated or crossbedded, fine pumiceous sand, is followed by 12 sedimentary sequences including 2 *Etheria* horizons and a minor tuff (U). 31 fossil localities (2 with hominids).

Member H. 15 m. The tuff, a pumiceous silt (2–3 m), as well as the succeeding sediments contain little more than fish and reptilian bone.

Member I. (1.84 mill. yr, average of 2 dates). 46 m. A complex of 4 pumiceous tuffs intercalated with sands and silts, and including a stratigraphically-significant molluscan horizon.

This conformable sequence changes in facies through time. According to de Heinzelin [21], the lower and intermediate members reflect primarily on a cyclic, fluvial pattern of sedimentation, with long intervals of non-sedimentation or even of erosion; the upper members relate to deltaic and ultimately lacustrine deposition. Rates of net accumulation increased rapidly with time: 13.8 cm/1,000 yr for members B and C, 31.1 for D and E, 70 for member F, and 181 for members G and H. In fact, G marks a transgressive phase and, if de Heinzelin's interpretation is correct, a major regression of lake level must have followed upon Member III of the Nkalabong Fm. The rapid sedimentation rates of G and H are exceeded by the modern Mississippi Delta and are best interpreted by accelerated downwarping of the central part of the basin. The Shungura Fm. was extensively faulted after deposition. The strike of the major faults is N 0°–20° E and fault blocks dip westwards at 8–15° or more; slip planes dip steeply eastwards, and downthrusts may be as much as 100 m. Although 3 or 4 episodes of faulting are suggested in the type area, deformation did not affect localities on the western and northwestern margins of the basin [14].

The Shungura Fm. was partially coeval with other fossiliferous deposits exposed about 40 km southeast of the type area at White and Brown Sands [18]. Known as the *Usno Formation* (Figs. 1 and 7), these strata have a cumulative thickness of about 200 m, divided into 8 informal units as follows (from bottom to top) [16, 18]:

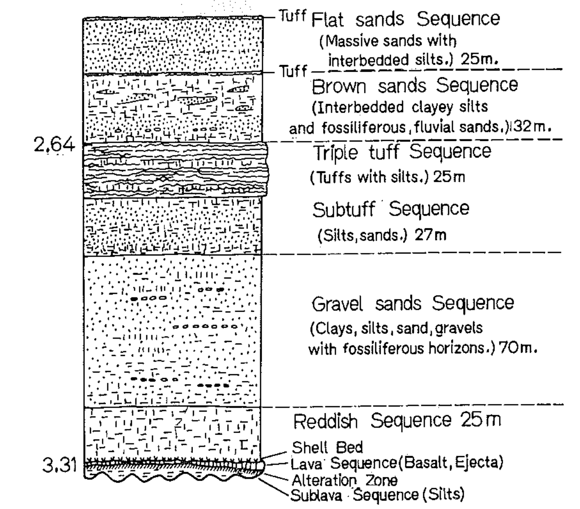

Fig. 7. Stratigraphic Column of the Usno Formation. After [18, 21]

Sublava Sequence. Silts, thickness unknown.

Lava Sequence. (3.31 mill. yr, average of 2 dates) 2.5 m. Basalt, derived volcanics, and scattered ejecta.

Shell Bed. 0.2 m. Cemented shell bed with *Viviparus*, *Cleopatra*, *Caelatura*, *Corbicula*, *Pseudobovaria* and dense ostracod accumulations.

Ash Sequence. 25 m. Reddish clays, possibly including weathered volcanic ash, with fish bone near base.

Gravel Sands Sequence. About 70 m. Clays, silts, sands and gravels, with a 2–3 m soil zone at base. The massive sandy strata include several concentrations of fossil bone, including some large mammals.

Subtuff Sequence. 27 m. Silts and sands, with some mottled gleys. Fish and crocodile bone.

Triple Tuff Sequence. (2.64 mill. yr) 25 m. 3 tuff strata, with interbedded silts.

Brown Sands Sequence. 32 m. (a) 5 m silts; (b) 7 m fluvial sands, marking 2 major fossiliferous horizons (including 2 hominid localities [19]) separated by a silt layer; (c) 20 m clayey silt with interbedded sands and rare bone; and a (d) thin capping tuff.

Flat Sands Sequence. 25 m of silts followed by massive sands, interbedded with silts, and a thin cap or tuff. The sands include some vertebrate fossils.

The Usno Formation suggests fluvial deposition in channel, floodplain, and marsh environments, with piedmont alluvial fans delivering detritus from the east. The tuffaceous beds are derived rather than primary. The isotopic dates, the facies sequence, as well as the faunas indicate that the Usno Fm. is contemporary with Members C and D of the Shungura Fm. After sedimentation had ceased, the Usno Fm. was disrupted by steep tensional faults, with a general strike of N 25° E; the fault blocks dip 10° to 14° to the west.

The total of these Plio-Pleistocene formations—the Mursi, Nkalabong, Shungura, and Usno, together with the Liwan and Loruth beds—are included within the Omo Group [21]. They span a *time range of about 4.5 to 1.6 mill. yr* B.P. and account for over 850 m of fluvial, deltaic, littoral, and lacustrine sediments. The upper limits are poorly defined, with the next studied sequence belonging to the horizontal Kibish Formation [14, 22–23] which dates from the late Middle Pleistocene to the mid-Holocene. There are, however, intermediate deposits that account for part of this apparent break. So, for example, there are over 35 m of tilted silts and sands in the Shungura type area that dip 10° to the west, but rest disconformably against basal units of the Shungura; the molluscan assemblages from several rich horizons are comparable to those of the Kibish Fm., rather than to the shell bed of Member I of the Shungura Fm. [A. Gautier, unpublished]. Furthermore, south of the Shungura type area there are some 100 m of thin, partly pumiceous tuffs, clays with gypsum lenticles and interbedded sands or conglomerates, shell beds, calcareous crusts, and ferricrete horizons (Chavaillon's "Série J" [10]). These beds are all younger than Tuff I and dip 8° in a westerly direction. Faunal and isotopic studies may ultimately sort out stratigraphically—uncertain units such as these and thereby help fix the last major episode of faulting in the Shungura type area—where the oldest undeformed strata (Kibish Member IVa) have been dated to 9300 B.P.

Interpretation of the Geological Record

Today the plains of Lower Omo Basin (400–500 m elevation) have a semiarid tropical climate (*BShw″* by the Köppen, *EA′d* by the Thornthwaite system), with an estimated *annual rainfall* ranging from perhaps 350 mm near the shores of Lake Rudolf (lake level at *c.* 370 m) to as much as 600 mm on the peripheral highlands (1,000–2,000 m elevation). Precipitation 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 in the low country probably range from 26° to 29 °C, with an annual range of as little as 2° or 3 °C but with daily ranges in the order of 9° to 15 °C. July and August are the coolest months, but diurnal temperature variation is greatest in January and February.

As a result of the limited and seasonal nature of the rainfall, *the Omo River* is the only perennial stream of the entire Rudolf-Omo drainage system. Drainage over the broad piedmont alluvial plains and pediments is ephemeral and poorly integrated. The Kibish and Usno Rivers (Fig. 1) are seasonal, the former carrying water after the spring rains, the latter reaching flood stage in summer. Whereas the Usno River feeds into the Omo from March or April to October, the Kibish River is usually dry for most of the year, and its waters seldom reach Sanderson's "Gulf". 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 percent of its annual influx.

A further inference can be made: changes of lake level will reflect primarily on rainfall over the Ethiopian catchment [36–37] of the Omo River and on evaporation over the water surface of Lake Rudolf. Thus periods of rising and high lake level will indicate a long-term positive hydrological budget in the Rudolf-Omo drainage, while falling or low lake levels indicate a long-term negative budget or one similar to the present [14]. Contemporary geomorphologic equilibrium and sedimentation patterns in different meso-environments of the Lower Omo Basin have recently been described elsewhere [17].

In effect, the geological record provides evidence of two kinds:

(1) the transgressions and regressions of Lake Rudolf, as directly inferred from reflected lacustrine or littoral deposits or indirectly from deltaic or alluvial formations of the Omo River; and

(2) local, piedmont or upland phenomena, including alluvial fans and terraces, pediments and paleosols [17].

The former category, which reflects on regional conditions over the entire drainage system, accounts for the great bulk of the Plio-Pleistocene record. The latter group would permit deductions on the more immediate, non-riverine setting, but is unfortunately poorly represented in the sedimentary sequences of the Omo Group.

Although the Rudolf-Omo drainage system is non-outlet today, there is a low-level divide (at about 450 m elevation) to the west, beyond which lie a series of extensive mudflats that form the watershed to the Pibor-Sobat, a Nile tributary. The topography, the disposition and elevation of the various sedimentary formations, as well as the mollusca, fish and reptiles [4] of the Rudolf-Omo system from the earliest times all indicate *intermittent hydrographic links to the Nile system*. Each of the formations culminate in 450–460 m elevation, i.e. at the level of the Rudolf-Nile threshhold, indicating that potential overflow across the divide set an upper terminus for littoral and deltaic sedimentation in the Lower Omo Basin [14, 17].

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). Present elevation of these deposits supports the inference that the almost the entire basin floor formed an extension of Lake Rudolf, and that some kind of overflow to the Nile system must be postulated. 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 (*c*, 3.9 mill. yr ?), is uniquely free of sandy wash from the adjacent uplands, and may indicate a lack of torrential runoff with an effective vegetation mat. The dissection of the Omo River prior 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 (*c.* 4.0 mill. yr) suggest a higher-competence stream. By contrast, present interpretation of the Shungura (Members A through F) and Usno Formations [21] 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 the Mursi deposition. Massive, coarse piedmont alluvia from the eastern uplands were repeatedly intercalated at this time (*c.* 3.8–2.0 mill. yr). The terminal Shungura units indicate a higher lake level, probably at the overflow threshhold to the Nile drainage, and possibly suggest a moister climate. The various intrazonal paleosols recorded within the Shungura and Usno Formations permit no paleoclimatic inferences [21], although the deep weathering evident after faulting of the Mursi basalt [17] does suggest a relatively moist climate at some time before aggradation of the first Nkalabong units. Unfortunately, no intact zonal soil profiles are preserved.

Table. *A Late Cenozoic Stratigraphy of the Lower Omo Basin*

Probable geological age	Isotopic dates	Rock units		Depositional environments
			Narok beds	Deltaic, littoral
Holocene	^{14}C 3,250–6,600 yr ^{14}C 7,900–9,500 yr	Kibish Fm. (115 m)	Mb. IVb Mb. IVa	Deltaic, littoral Deltaic, littoral
Upper Pleistocene	K/Ar "O"		Nakwa tuffs and basalt extrusions; last faulting in Shungura "type area" ?)	
	$^{14}C > 37{,}000$; Th/U 30,000		Mb. III Mb. II	Deltaic, littoral Deltaic
Middle Pleistocene	Th/U 130,000 yr (?)		Mb. I	Deltaic
		(One or more episodes of faulting in Shungura "type area") (Sedimentation in Shungura "type area" ?)		
Lower and Basal Pleistocene		(Faulting in Shungura "type area")		
	K/Ar 1.81, 1.87 m.y. K/Ar 1.93 m.y. K/Ar 1.99, 2.06 m.y. K/Ar 2.12 m.y. K/Ar 2.16, 2.31, 2.37, 2.56 m.y. K/Ar 3.75 m.y.	Shungura Fm. (600 m)	Mb. I Mb. H Mb. G Mb. F Mb. E Mb. D Mb. C Mb. B Mb. A Basal Mb.	(data not fully comparable) Usno Fm. (200 m) — K/Ar 2.64 m.y.; K/Ar 3.11, 3.51 m.y. (data not fully comparable)
Upper Pliocene	K/Ar 3.90, 3.99 m.y.	Nkalabong Fm. (88 m)	Mb. III Mb. II Mb. I	Littoral-lacustrine Alluvial, eolian Alluvial
		(Faulting, local or general)		
	K/Ar 4.05, 4.10, 4.4 m.y.	Mursi Fm. (148 m)	Mb. IV Mb. III Mb. II Mb. I	Basalt Deltaic, littoral-alluvial Mixed littoral-alluvial Littoral-alluvial, deltaic
		(Downwarping and downfaulting of Omo Basin and Rudolf Rift, one or more major episodes)		
Lower Pliocene to Lower Miocene		(Repeated volcanic episodes with massive extrusions of olivine basalts and rhyolites over pre-existing erosional surfaces developed on the Basement Complex; followed by cutting of one or more planation surfaces)		

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 no unequivocal paleoclimatic conclusions can be drawn from the geological evidence [21], although the broad inferences tentatively suggested above do seem to have some validity. Considering that the level of Lake Rudolf was *c.* 80 m higher than today as recently as 3250 B.P. [22], and that the lake has fluctuated with an amplitude of at least 16 m since 1888, the Plio-Pleistocene transgressions and regressions—as inferred from the horizontal delta displacements—do not necessarily imply *major* climatic changes. For all intents and purposes, the geology and geomorphology suggest that a semiarid climate has been characteristic throughout the late Cenozoic [17].

Pollen and Vegetation

The modern vegetation [C. J. Carr, unpublished] of the well-drained upland plains is a *tree-shrub-savanna* with extensive stretches of grassland; this semi-deciduous wooded savanna includes dominant genera *Acacia*, *Cordia*, *Grewia*, *Maerua*, and *Cadaba*, with many succulents present in badland topography or on excessively permeable substrata. Seasonally-wet lowland plains are characterized by grassland or shrub steppe, while a thorny shrub thicket, with patches of shrub steppe, covers the piedmont and foothill country along the northern margins of the basin. The levees of the Omo, and to a lesser extent, of the other floodplains, are covered with a closed, galeria woodland, dominated by *Ficus sycomorus*, *Acacia sieberiana*, and *Cordia gharaf*, while the alluvial plains have tree-shrub savanna, shrub steppe or shrub thickets. Finally, in the Omo Delta there are extensive tree-shrub steppes and thickets on drier ground, with some galeria woodland, and a complex of wetland vegetation (*Cyperus*, *Phragmites*, *Typha*) and open water in the interdistributary basins.

The sediments of the Omo Group have so far yielded negligible macro-remains of plants—occasional root drip, a few unidentifiable leaf impressions. However, *pollen analyses* have been successfully initiated by Bonnefille [11], who has presented a spectrum of over 1000 identified grains from a crocodile coprolite recovered from Member C, Shungura Fm. Dominant are gramineae (45.5%), the montane forest genus *Podocarpus* (17%), marsh cattails (*Typha* cf. *angustifolia*) (10.5%), sedges (cyperaceae) (3%), chenopodiaceae and amaranthaceae (5%), another montane form, *Juniperus procera* (2%), and euphorbiaceae (1.5%). Grouped according to major associations there are represented: montane forest (20.5%), riverine forest (2.5%), tree-shrub savanna (5%), and herbaceous plants (61.5%). Presumably the pollen of montane genera are exotic, introduced by the Omo River; the remaining groups suggest a mosaic of grassland, tree savanna, riverine, and wetland vegetation similar to that of the present day. This is in agreement with the geological and faunal evidence. Further studies should serve to fill out this as yet scanty picture.

Faunas and Taphocoenoses

In recent times, the Lower Omo Basin has or at least had a varied and abundant "ethiopian" megafauna [20] comparable to other East African "savannas". Elephant, rhino, buffalo, giraffe, zebra, gerenuk, and ostrich, although much decimated by hunting, are still found in the tree savanna east of the Omo River, while oryx, topi, Grant's gazelle and to a lesser extent, zebra, hartebeest, and ostrich, are still quite abundant in "protected" areas west of the river, particularly in the southeastern Sudan. The riverine zone and adjacent thickets harbor colobus and cercopithecine monkeys, baboon, warthog, waterbuck, kudus, duikers, dikdik, hippopotamus (now rare), crocodile (abundant), etc. Carnivores include lion, leopard, cheetah, caracal, wild cat, spotted and striped hyaena, silver-backed jackal, bat-eared fox, genet and mongoose.

Turning to the Plio-Pleistocene record we find the same ecological diversity represented. The Mursi Fm. (Member II) has yielded elephant (*Loxodonta adaurora* sp. nov.) [29], *Dinotherium bozasi* [9], a pig (*Nyanzachoerus*), an equoid (*Stylohipparion albertense*), a rhinoceros, a tragelaphine antelope, *Hippotamus* cf. *protamphibius* [21], crocodile, the gavial-like *Euthecodon brumpti*, Nile perch (*Lates* cf. *niloticus*) and other, unidentified fish. Primates are absent. The beds in question suggest a low-energy littoral environment, encroaching upon alluvial fans. Comparable situations are now found at the northeastern end of Lake Rudolf, where thin layers of organic muds are deposited within broad belts of aquatic emergents, and intercalated with fluvial silts, sands and gravelly sands. A rolled tooth of the gomphothere *Anancus* appears also to have been derived from the Mursi Fm.

The faunas of the Shungura Fm. [4, 9, 13, 20] vary with time and depositional environment, and several archaic genera or species disappear within the 2-mill. yr time span of this sequence. The basic list includes

elephant (*Elephas recki*, showing considerable evolution through time),
Dinotherium,
white and black rhinoceros (*Ceratotherium simum efficax* and *Diceros bicornis*),
a camel (*Camelus* sp.),
Stylohipparion,
Hippopotamus protamphibius, *H.* cf. *imaguncula*,
pigs (*Nyanzachoerus*, *Pronotochoerus jacksoni*, *Notochoerus* spp., *Mesochoerus* = *Omochoerus*),
giraffidae (*Libytherium*, *Giraffa gracilis*, *Giraffa* sp., *Okapia*),
reduncine antelopes (*Menelikia*, *Kobus sigmoidalis*, *Redunca ancystrocea*),
a tragelaphine anelope (*Tragelaphus nakuae*),
undetermined alcelaphine antelopes,
impala (*Aepyceros* sp.),
gazelle (*Gazella praethomsoni*),
a caprine-like antelope of uncertain affinities,
porcupine (*Hystrix*),
aardvark (*Orycteropus* sp.),
hyaenids (*Crocuta* sp., several hyaena-like),
canids (*Canis* sp., *Lycaon* sp.),
several felids (sabretooths, *Felis* cf. *leo*),
an extinct lutrine (*Enhydriodon* sp.), and
primates (*Colobus* sp., *Cercopithecus* sp., *Parapapio* sp., *Simopithecus* sp., *Papio* sp.).

Hominids will be discussed further below. Obviously none of these elements would appear out of place in the present ecological mosaic and its more modern but similar faunal assemblages. The overall picture is rounded off by the aquatic reptiles and amphibians (*Crocodilus niloticus*, *Euthecodon brumpti*, several chelonians and lizards), fish (*Potamotrygon*, *Polypterus*, *Lates niloticus*, *Tilapia*, *Clarotes*, *Bagrus*, *Synodontis*), and a suite of nilotic mollusca.

Several taphocoenoses have been provisionally related to fossil occurrences in the Shungura Fm. [21]:

(a) weathered clay-silt paleosols and porous caps of major tuffs, with land mammals, including cercopithecoids and hominids;

(b) reduced, swamp paleosols, with land mammals (including primates), hippo, aquatic reptiles and fish;

(c) sorted, fine gravels, with vertebrate tooth concentrations;

(d) channel gravels and crossbedded sands, with derived vertebrate bone and some *in situ* aquatic reptiles; and

(e) deltaic, littoral or lacustrine beds, with fish and aquatic reptiles, and rare unabraded land mammals (drifted cadavers).

The fossiliferous assemblage from the Usno Fm. [18, 20–21] is not quite as complete, but otherwise comparable in its diversity. Here the vertebrate fossils occur in dispersed and incomplete condition, with scattered and mixed occurrences of various skeletal parts found in channel-type sands. These taphocoenoses seem related to fluvial deposition by a meandering river (or mixed littoral-alluvial situations? [14]), the fossil assemblage providing a sample of several contiguous habitats.

Fig. 8. Fossils from the Shungura Formation. Top left: mandible from locality 7 (Member E); bottom left: hemimandible from locality 74 (Member G); middle: partial mandible from locality 58 (Member E); and right: mandible from locality 18 (Member C). (Photo courtesy of F. Clark Howell and Yves Coppens)

The faunas of the Omo Group are being augmented steadily as field work continues, and study by several specialists assures the proper identifications that will be necessary before detailed ecological and stratigraphic inferences can be attempted. Even so the Omo faunal sequence is unique for this time range in eastern Africa and should provide a baseline against which other, less adequately dated fossil assemblages must be compared and evaluated.

Hominids

The first discovery of hominid remains from the Shungura and Usno Formations in 1967 [8, 13] dramatically extended the time-range of the australopithecines from 1.8 mill. yr at Olduvai (Bed I) to greater than 2.5 mill. yr in the Omo Basin. Further discoveries in 1968–1970 have pushed back this lower terminus to about 3.5 mill. yr (9, 13). As of the fourth season (1970), *a total of 51 hominid localities* have been recovered by the Chicago and French expeditions from the Shungura (49) and Usno (2) Formations, including over 100 isolated teeth, 6 partial or complete mandibles (Fig. 8), and a partial skull. These have been found in each member from below Tuff C (Member B) to below Tuff J (Member I) [13; F.C.Howell, unpublished].

At least 2 hominids are present in this remarkable collection. One is a robust australopithecine that is tentatively referred to *Australopithecus* cf. *boisei*; it is represented by at least 3 mandibles (locality 7, Member G; locality 58, Member E; locality 18, Member C), a number of isolated teeth, and possibly by the partial skull (locality 136, Member C). The other partial mandible (locality 74, Member G) also has robust australopithecine affinities, but the extreme enlargement and attendent molarization of the anterior premolar falls outside of the range of known early hominids [13]; it is tentatively assigned to *Australopithecus* sp.

A series of isolated teeth from numerous localities, spanning Members B through F, diverge dimensionally from the robust australopithecines; instead their overall morphology, particularly the pattern of the primary fissure system and the lack of talon development in the premolars, strongly resembles that of the gracile australopithecines. The great majority of these specimens are therefore referred to *Australopithecus* cf. *africanus* [13].

Although further discoveries and ongoing detailed comparative studies will undoubtedly add further precision to this scheme, the co-existence of no less than 2 australopithecine taxa is evident throughout the early Pleistocene, *at least as far back as 3.0 mill. yr.* Both forms have been verified together at several sites, and there can be little question that both occupied broadly similar habitats. Pending detailed sedimentological studies of the individual sites and associated faunas at each, the respective ecological niches of these gracile and robust australopithecines remain enigmatic.

Discoveries of the 1969 and 1970 seasons raise the possibility that *artifactual horizons* do occur within the Shungura Fm. Chavaillon [10, 12] has reported a potential *sol d'occupation* from the top of Tuff E (locality 71). Present are a transversally-fractured pebble, a "side-chopper", a scraper-like flaked bone, and a broken bone with evidence of wear at one end. Some 33 pieces of animal bone (elephant, hippo, suid) were recovered by excavation of a 2×2 m square. Needless to say such a discovery of a handful of problematical items is insufficient. However, other artifactual occurrences have been found and hopefully excavations now underway and projected for the 1971 season may recover traces of occupational concentrations. It seems only a matter of time before statistically-adequate and convincing tool assemblages will be recovered from a 2.5–3.0 mill. yr time range in the Omo Basin.

Acknowledgments. The field and laboratory studies of the writer were supported in part by grants from the National Science Foundation (GS-1471 and GS-2506) to the University of Chicago (F. Clark Howell). Assistance of the government of Ethiopia, the Institut Ethiopien d'Archéologie, the Ethiopian Mapping and Geography Institute, and Mr. J. Walsh, the Kenyan Commissioner of Mines and Geology, are all gratefully acknowledged. This is Contribution No. 18 of the Omo Research Expedition (Universitiy of Chicago Group). The paper is dedicated to the memory of Dr. Emil Brumpt, who discovered the fossiliferous Omo Beds in 1902, and Professor Camille Arambourg, who initiated their systematic study in 1932–33 and indomitably led the French expeditions of 1967—69 until his death Nov. 19, 1969 at the age of 84.

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Received July 13, 1970

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Printed in Germany