QUATERNARIA

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Tirage à part de
"QUATERNARIA" XIII, Roma, 1970

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Following a two month geological reconnaissance by one of us (FHB) in 1966, four seasons of fieldwork by members of the Omo Research Expedition has added greatly to our previous, scanty knowledge of the late Cenozoic history of the lower Omo basin in southern Ethiopia. Eduard Suess (in: von Höhnel et al., 1891) was the first to associate the lower Omo basin with the Eastern Rift Valley after the explorations of the Teleki-von Höhnel expedition in 1888 (von Höhnel, 1938). M. Sacchi, geologist with the Bottego expedition, subsequently noted the occurrence of flat-lying, undeformed sediments in the basin and these were reported on by Angelis d'Ossat and Millosevich (Angelis d'Ossat and Millosevich, 1900; Vannutelli and Citerna, 1899). These sediments have since proved to represent an extensive suite of later Pleistocene to recent strata deposited during major northward extensions of Lake Rudolf and of the delta and floodplain of the Omo River (Butzer and Thurber, 1969). E. Brumpt first collected fossils from older, tectonically disturbed sediments in the lower Omo basin when the Bourg de Bozas (Bourg de Bozas, 1903) expedition traversed the area at the turn of the century. Haug (1912, p. 1727) recognized that these specimens were of some importance in the study of the Pleistocene of eastern Africa. Two decades later, the late Prof. C. Arambourg (Arambourg and Jeannel, 1933) made a geological reconnaissance of a part of this area and amassed a substantial collection of vertebrate fossils from these deformed deposits, which he termed the Omo Beds. His pioneer work placed on record the richness and diversity of this fauna which he regarded as of earlier Pleistocene age.

The international Omo Research Expedition has concentrated much of its efforts on geological and paleontological investigation of these older deposits. Some of the results of the work done by the contingent of the expedition from

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the Museum National d'Histoire Naturelle, Paris, have been published by Arambourg, Chavaillon, and Coppens (Arambourg, Chavaillon and Coppens, 1967, 1969; Arambourg and Coppens, 1967, 1968), by Chavaillon (Bonnefille, Chavaillon and Coppens, 1970; Chavaillon, 1970), and by Bonnefille (1970; also Bonnefille et al., 1970). Some of the results of the University of Chicago contingent of the expedition have been published by Howell, Butzer, de Heinzelin, Carmichael, Brown and coworkers (Howell, 1968, 1969 *a*, 1969 *b*; Howell, Fichter and Wolff, 1969; Howell, Fichter and Eck, 1969; Butzer, 1969; Butzer, Brown and Thurber, 1969; de Heinzelin and Brown, 1969; Brown, 1969; Brown and Carmichael, 1969; Brown and Lajoie, 1970). Here we have sought to set out what is now known of these Pliocene/Pleistocene formations in regard to their physical stratigraphy and the inferences which have been drawn from our observations.

Formal Lithostratigraphy

Prior to the recent intensive field studies in the lower Omo basin the informal term " Omo Beds " (" depots fluvio-lacustres de la vallée de l'Omo ") was generally employed to designate all deposits of Pliocene/Pleistocene age (Arambourg, 1943; Bishop, 1967). All the principal exposures of such deposits have now been located and surveyed in the field and mapped on aerial photographs. The earlier deposits unconformably underlying the Kibish Formation (Butzer, Brown and Thurber, 1969) have been considered as a group (Omo Group) and subdivided into formations on a geographical basis as the exposures are widely separated and it is not possible to correlate directly from one area to another though they are similar in age. There are three principal areas of exposure of such sediments within the basin.

Mursi and Nkalabong Formations. These formations crop out south-west of the Nkalabong highlands at the Yellow Sands locality (5° 24′ N, 35° 57′ E). Butzer (Butzer, 1970) describes the Mursi Formation as comprising nearly 150 meters of sediments divisible into four semiconformable members. Each of the first three members (I, II, II, in ascending order) is composed of clays, silts and sands, is sometimes tuffaceous, and rarely (in II) contains coarser, fossiliferous gravel lenses. These members are frequently limonite stained or mottled and have gypsiferous lenses and sodium salt horizons. The top of Member III is reddened, probably having been baked by the overlying basalt, and is termed the Shiangoro Alternation Zone. These three members are regarded by Butzer as deltaic in origin, with some upland piedmont and fluvio-littoral deposits in the fossiliferous horizons of Member II and littoral-foreshore beds in Member III. Member IV is an olivine basalt, step-faulted and dipping very slightly westwards.

The Nkalabong Formation overlies the basalt member of the Mursi formation a little to the north. It comprises nearly 90 meters of fluviatile and lacustrine sediments with intercalated aeolian ashes. Three members have been recognized by Butzer, ranging upwards from cross-bedded sands, silts and conglomerates, sometimes ash rich, through horizontal and cross-bedded channel sands and aeolian lapilli tuffs, to top-set silts, clays and tuffs. These deposits have unfortunately failed to yield any vertebrate fossils.

The foothills north of the Nkalabong highland reveal poor exposures of tuffs and sediments which underlie or are intercalated with a thick succession of thin basalt flows. No vertebrate fossils were observed by Brown during reconnaissance of this area in 1967. The basalts unconformably overlie an older group of volcanics.

Usno Formation. This formation crops out at eight exposures in the White Sands area (5° 18' N, 36° 12' E) toward the northeastern margin of the basin, downstream from the confluence of the Usno and Omo Rivers. de Heinzelin and Brown (1969) have divided the nearly 200 meters of sediments into an informal eightfold sequence. In ascending order these are: 1) sublava sequence; 2) lava sequence; 3) reddish sequence; 4) gravel sands sequence; 5) subtuffs sequence; 6) triple tuff sequence; 7) brown sands sequence; 8) flat sands sequence. The succession is composed largely of silts and clays, sometimes gleylike, with intercalated quartzitic limonite stained sands and fine gravels. These sediments probably reflect deposition in fluviatile situations, including floodplain, marsh and swamp environments, with a piedmont alluvial fan delivering detritus from the east. The silty and sandy tuffaceous deposits are reworked and redeposited rather than primary subaerial accumulations.

Shungura Formation. This formation crops out extensively between latitudes 5° and 5° 10' N between the Omo River on the east and the Nakua (or Korath) Range on the west. The complexity of this succession was suspected by one of us (FCH) during a short visit to the lower Omo in 1959, and was subsequently fully demonstrated in the course of a geological reconnaissance by Brown in 1966. Sections measured in 1966 showed that the sediments included in what is now called the Shungura Formation were at least 350 meters thick, and subsequent work has extended the total thickness to nearly 600 meters, with neither the base nor the top of the formation delimited. Our observations here focus on an intraunit analysis and are based on extensive mapping and measurement of sections, particularly in the northern part of the exposures where we have concentrated our field activities in 1968, 1969 and 1970. Tuffs A (at the base of the known sequence) and Tuffs I and J (at the top of the known sequence) are exposed only in the southern half of the area which has been worked since 1968 by the Museum National d'Histoire Naturelle (Paris), and these portions of the sequence are dealt with only summarily here.

De Heinzelin and Brown (1969) first suggested the name Shungura Formation for the beds exposed near the village of that name. Here we propose to define formally this formation and is members, as the use of the term has been accepted, and the precise meaning of the term should be somewhere set down for future reference.

The Shungura Formation is here defined as the series of fluvial, deltaic and lacustrine sands, silts and clays with intercalated tuffs of late Pliocene to early Pleistocene age, having a thickness of about 600 meters, and being typically exposed between latitudes 5° and 5° 10' N on the west side of the Omo River north of Lake Rudolf in Ethiopia (see map in Butzer and Thurber, 1969). These sediments have been faulted and tilted to the west and are now exposed in a series of north-south trending ridges. There is no single east-west section without structural complexity which can be taken as the type section. However, a strip of exposures, about a half kilometer in width and extending west from Shungura some 6-7 kilometers, allows all recognized members to be included. The formation is unconformably overlain by the late Pleistocene to Holocene deposits of the Kibish Formation (Butzer, Brown and Thurber, 1969).

Nine of the tuffs in this formation are widespread and make excellent marker horizons. These have been designated Tuff A through Tuff I in ascending stratigraphic order. On the basis of these tuffs we have divided the Shungura Formation into ten members, each represented by a major tuff and its overlying sediments, with the exception of the Basal Member which comprises the sediments below Tuff A. Each member bears the name of its basal tuff; thus Member A is made up of Tuff A and all the sediments between it and the base of Tuff B. This procedure has been adopted since members so defined can be readily mapped following the prominent morphological features of the tuff cuestas. This procedure differs from Chavaillon's (Arambourg, Chavaillon and Coppens, 1969) use of " series " — comprising a set of sedimentary units and their capping major tuff — as it is impossible thereby to map easily the members, and also as some subsidiary tuffs (for example Tüff E supérieur, our Tuff S) are included in an inappropriate series. In view of fossiliferous localities, we fell that the method of subdivision employed here is the procedure of choice.

Only a general summary of the succession is offered below, as a detailed description of the lithology and petrology of the individual units is outside the scope of this paper. Before describing each member, a few remarks on the general features of the sediments are noted in order to facilitate and shorten the descriptions.

In the field it was noted that one particular lithologic sequence was repeatedly encountered through much of the section. This sequence consists of silt overlain successively by coarse sand, medium sand, fine sand, silt and clay, and is termed a cyclic unit in the descriptions which follow. These cyclic units vary in thickness and completeness, but are basically similar. In general the sands are gray to light brown, poorly cemented, cross-bedded, and composed of fragments of quartz, feldspar, lithic fragments and bits of chalcedony. The clayey silts are brown to reddish brown and may contain gypsum or halite. A more complete description and interpretation of the cyclic units is given later.

There are many minor tuffs in the sequence in addition to the major tuffs used to define the members. Each of these occurs only sporadically along strike, but, the position of each within a member is nearly constant, and is noted in the following descriptions. Wherever tuffs appear they are composed dominantly of volcanic glass with but small admixture of foreign fragments. The major tuffs have in general less contamination than the minor tuffs, but even the minor tuffs are made up almost wholly of glass. Pebbles and cobbles of pumice occur in many of the tuffs, but, most of the volcanic material is of sand and silt size. It should be noted that if the tuffs were not of such a distinct lithology, they would pass unnoticed as sands or silts of the normal sedimentary sequence, for their bedding characteristics, sorting and grain size are the same as those of the rest of the sediments.

Basal Member: This member is defined as those sediments which lie below the base of Tuff A. It is composed of medium to coarse reddish sands overlain by reddish brown clays and silty clays. The total thickness of this member is unknown, but is at least 15 meters.

Member A: This member is exposed at only one place where it is about 30 meters thick. The base of this unit, Tuff A, is seen in the major gully which enters the Omo River just north of the village of Shungura. Tuff A is a finely laminated blue-gray bed of volcanic ash 3.4 m. thick and is overlain by about 25 meters of sands, silts, and clays. The latter sediments represent two main sets of cycles, each with two units. At about 18 meters above the top of Tuff A, a gray, fairly well sorted sand bed about three meters thick appears which overlies 5 meters of reddish ferruginous sand with some small calcareous concretions.

Member B: The tuffaceous deposits at the base of Member B account for 12 meters of section and can be divided into four distinct parts. At the base B_1 is a blue-gray, moderately well indurated layer of cross-bedded pumiceous sand 2 meters thick which contains some quartzofelspathic sand lenses and root-casts. This is overlain by B_2 9 meters of stratified tuffaceous silty sands and clays which are succeeded by B_3 a 1-1.5 meter layer of light greenish, well-stratified fine to coarse pumiceous sand which has prominent spherulitic concretions. Incised into, or partly lateral to these sands is a channel filling B_4 of some 3.5 meters of cross-bedded coarse pumiceous sands, with some clay interbeds, containing sparse pebbles and cobbles of pumice. These pumice sands contain many mud balls and mud pellets composed of the same material as the small clay interbeds. A lenticular bed of finely laminated light blue to white silt may top the cross-bedded sands into which the channel is cut.

The sediments overlying Tuff B comprise ten cyclic units with minor tuff 0 about 40 meters above the base of the member. There is a change in color of the oxidized horizons from 2.5-5 YR at the base of these sediments to 7.5 YR beginning in the fifth cyclic unit from the bottom. Calcareous (1-10 cm.) concretions occur consistantly in the upper six cyclic units. The aggregate tickness of Member B is 87 meters.

Member C: Tuff C forms a continous line of several outcrops in one area. It rests on a variable thickness of sand and is about 5.5 meters thick. It is usually divided into two parts of nearly equal thickness. These two parts are separated by variable intercalations of silt and cross-bedded sand less than 1 meter in thickness and forming a prominent band across the outcrop.

The sediments in Member C make up ten cyclic units. The fifth and sixth of these contain well developed *Etheria* reefs. Two minor tuffs P and Q occur 40 meters above the base respectively. The total thickness of this Member C is 106.5 m.

Member D: Tuff D, the basal tuff of this member, is composed mostly of fine sand and silt-sized volcanic glass. Though the top of this tuff is in many places poorly defined, a reasonable value for its thickness is 4.5 meters, but in some exposures it may reach as much as 7 meters. Everywhere this tuff has been found it contains large rounded cobbles and even boulders of pumice, the largest noted being some 60-70 cm. in diameter. The pumice cobbles are usually confined to a layer 2 m. or so above the base, but occasionally are found at higher levels. The portion of the tuff below the pumice layer may have thin bedding or be essentially massive. The upper portion contains many small calcareous and oxide concretions, many believed to be rootcasts.

The sediments above Tuff D are coarse cross-bedded sands which have been channeled and filled by more material of the same sort. The minor tuff R is prominent in many exposures of this sequence and is quite variable laterally, sometimes appearing as a single bed, and sometimes as a succession of lenses. It may vary in color from blue gray to yellowish-green. The Tuff R is present, the sediments are divided into two parts D1 and D2, below and above the tuff, respectively, each composed of two cyclic units. The total thickness of Member D is 55.5 meters.

Member E: Tuff E, which is 5 meters thick, has three distinct ash layers at its base. The first layer is buff-colored fine sand and silt 10 cm. thick, the second is blue-gray sand 20 cm. thick, and the third is blue-gray fine sand and silt 20 cm. thick. These three thin layers are fairly well indurated, and in almost all exposures form an unmistakable blue ledge in the outcrop. Above these thin layers lie 4.5 m. of light tan tuffaceous silts which are either finely cross-bedded and laminated, or massive, and sometimes contain cobbles of pumice. Rootcasts and scattered fossils are common in these silts as are gypsum crystals along cracks.

The sediments of this member comprise five cyclic units and the minor tuff S appears in the fourth of these 25 meters above the base of the member. The total thickness of Member E is 41 meters.

Member F: The thickness of Tuff F is usually 4-4.5 m. and reaches a maximum of 7 m. In most places it is made up entirely of fine bluegray laminated pumiceous sand mixed at the top with quartzo-feldspathic sand, but in some places a coarse light tan pumice pebble gravel appears, channeled into the finely laminated and ripple-marked deposits. Rootcasts and what appear to be animal tracks may also be present.

Four cyclic units overlie this tuff, and the first contains the minor tuff T. The aggregate thickness of Member F is 35 meters.

Member G: For the most part Tuff G is made up of finely laminated and cross-bedded, fine, blue-gray pumiceous sand. However, Tuff G may consist of coarse sands with large-scale cross-bedding and occasional pumice cobbles. In most exposures this tuff is between 3 and 5 meters in thickness.

The sediments overlying Tuff G are exposed over large areas and consequently the variation of the units along strike is more perceptible than is the case for the more restricted exposures of some other members. The sequence between G and J is continuous, unfaulted and complete along a single East-West profile in an area termed the Embayment where the following measurements were made. Four cyclic units lie directly above Tuff G and make up 32 meters of section. The minor tuff U lies in the fourth of these. Above these units Member G is made up dominantly of clay and silt. A reddish-brown clay 26 meters thick with a blocky fracture containing small calcareous concretions, limonitic concretions and some gypsum, and a few small sand beds lies at the base of this finer-grained sequence. A medium to coarse grained, cross-bedded, angular feldspathic sand 5 meters thick interrupts this sequence of clays and silts at this point, but is followed by 15 meters of clay with many iron and lime concretions. This upper clay changes in color from brown at the base to light tan at the top and also increases markedly in gypsum content from the base to the top. Six meters of white silt and very fine sand capped by a carbonate cemented white sand 30-40 cm. thick overlie these clays. The next 54 m. of section is made up dominantly of green and brown clays, broken near the base by several reddish ostracod-bearing sands and near the center by silts with black platy concretions. The top is made up of two cyclic units 23 meters in total thickness. The total thickness of Member G is 165 m.

Member H: Tuff H consists of 2-3 meters of blue pumiceous silt. Successively following this unit are 4 meters of white silts and very fine sands, 4 meters of light brown clay and very fine sand with small calcareous concretions, 1.8 meters of white silt, and last, 2 meters of reddish medium to fine sand. The total thickness of Member H is about 15 meters.

Member I: There are four fine-grained tuffs near the base of this member, designated I_1 through I_4, which comprise 15 meters of section. Intercalated with these tuffs are light tan reddish sands and silts. Two of these tuffs contain pumice cobbles, and often gypsum is abundant on the surface of the outcrops.

Above Tuff I_4 the section consists of 31 meters of reddish cross-bedded, medium to coarse sand capped by a fine pumice gravel. About 15 meters above the base of these sands there is a bed 20-30 cm. thick which is extremely rich in mollusc shells, forming a useful marker bed in this part of the section. The total thickness of Member I is 46 meters.

The fine pumice gravel at the top of the section has been informally termed Tuff J, and as the areal extent and continuity of this tuff are unknown, this designation remains informal.

Depositional Environments and the Cyclic Units

Neither the mode of origin of the cyclic units nor their environmental significance are completely understood as yet. Here we merely enumerate some of the features of these units which must be considered in their interpretation.

Butzter (Butzer and Thurber, 1969) has noted that the outlines of the Omo Basin were delineated prior to the deposition of the Mursi Formation which is slightly over four million years old. The sediments in the Mursi Formation are similar to those of the Shungura Formation and are deposits of material carried by the Omo River. Lake Rudolf also existed at this time, although the position of its northern shore is not known. Indeed, it probably shifted considerably through time. The geographical features of the lower Omo Basin during the time of deposition of the Shungura Formation are believed to be essentially as they are today, except that the Korath Range was probably absent. The surrounding highlands may have been of different elevation, and the course of the Omo may have been removed from that of the present course, but there is little doubt of the presence of a large river flowing generally from north to south over a broad plain and emptying into a lake. Whatever interpretation is made of the deposits of the Shungura Formation must be consistent with this paleogeographical setting.

Leaving aside the silts which sometimes comprise the base of the cyclic units, the sequence of sediments beginning with coarse sand and becoming progressively finer upward will be considered. The coarse sands near the base of the cyclic units are moderately sorted, often crossbedded, and made up dominantly of quartz, feldspar and fragments of chert and chalcedony. Measurements of the attitudes of the cross beds indicate that the currents which formed them were flowing from north to south. The occurrence of *Etheria* in these sands is of importance, for their habitat is restricted to a stable bank to which they can attach themselves, which has a permanent supply of fresh moving water. In a fluvial situation these conditions can only be attained along the river channel below the normal low water mark. Channel bottom deposits are normally composed of the coarsest sediments which a river is carrying, and are normally fairly well sorted. Accordingly it is thought that the coarse sands at the base of the cyclic units represent sedimentation near the base of the channel and on point bars of meander bends.

The medium sand and fine sand which lie above the coarse sand described above have bedding characteristics like those of the coarse sands and are mineralogically identical. They are moderately sorted, and may contain silt interbeds. These sands may represent point bar deposits at higher levels on the bar due to hydraulic sorting; as the bar is built outward, the coarser sands at the bottom will be covered by the medium sands above. Beds of coarser sand and pebble gravel are not inconsistent with this interpretation, and may be flood deposits. Alternatively the medium and fine sands may be explained by lowering the deposits relative to the level of the lake. The same effect would be produced by a rise in the level of the lake which might cause the coarse sand to be deposited farther upstream and medium and fine sand to be deposited in its place.

The silts and clays are believed to be levee and overbank sediments deposited on the floodplain of the river. In some places the clays are reduced and contain small calcareous concretions and rootcasts which may reflect standing water in shallow basins formed along the river's edge. If the main channel of the river is migrating in one direction the silty sediments of the levees may be succeeded by clays of the flood basins, particularly if the level of the lake is rising at the same time.

As most of the sediments appear to be shallow water deposits, and as they make up several hundred meters of section, it must be assumed that the area in which they were being deposited was subsiding. In such a circumstance it would be possible for a river to migrate back and forth across its floodplain without completely eroding away the deposits which were laid down previously. In the section there are many examples of truncated cyclic units, and often well preserved channels can be seen. In at least two places Tuff F has been cut through by large channels which were subsequently filled with coarse sand and fine pebble gravel overlain by medium and fine sand. The distinctive lithology of the tuff makes the channeling relations much more apparent than is the case when a channel has been cut into sandy or silty material and refilled with more of the same.

Paleosols can be recognized at the tops of many of the beds of clayey silts. The soil development is weak and the grade of oxidation is moderate, generally having Munsell values of 7.5-10 YR, but occasionally reaching values of 2.5-5 YR. Calcareous concretions, and crack fillings along vertical breaks in the clay are believed to represent B horizons. Reduced clays (colors near 5 Y) are also seen and contain calcareous concretions and rootcasts. These are interpreted as swamp soils. Porous tops of tuffs which contain abundant rootcasts, concretions and scattered mammalian remains may also have very weak soil profiles developed.

The most prevalent types of deposits in the section have been discussed but other types also occur. The upper portion of Member G in the southern part of the exposures is composed largely of silts and clays, which are very finely laminated and often gypsiferous. Limonitic and calcareous septaria are abundant and ostracod-bearing sands present. The most abundant vertebrate fossil remains in these sediments are crocodile and fish. These clays and silts are considered to be lacustrine in origin. Deposition of these clays was very rapid and took place during a major northward extension of the lake. The coarser sediments intercalated with the clays may have been laid down in distributary channels and as mouth bars.

To date neither the Shungura Formation nor any of the other Plio-Pleistocene formations have yielded any firm paleoclimatic data. The value of palynology is, as usual, hindered greatly by allochtonous contamination in deposits of this type. Bonnefille (1970; also Bonnefille et al., 1970) has shown, however, that substantial quantities of pollen may be preserved in crocodile coprolites from some of these deposits. In the future a major effort will be directed toward the study of the paleosols as this approach may prove to be useful in the appraisal of the paleoenvironment. If it is possible to determine the position of the lake shore at various times in the sequence and if its position can be shown not to be the result of tectonic movements, then reasonable inferences may be made as to whether the lake was rising or falling, and possibly this could be related to the climate at the time.

Rates of Deposition

Radiometric ages have been determined by Brown and Lajoie (Brown and Lajoie, 1970) on materials from a number of the horizons in the Shungura Formation. The age determinations are summarized in Table 1. Utilizing this series of ages it is possible to calculate the rates of deposition for the sediments included between any two dated tuffs (Table 2). There is no way to estimate the effect of differential compaction, but this factor should be given consideration.

Inspection of this table reveals that there was an increasing rate of deposition from the earlier to the later part of the record. The rates of deposition in the lower part of the section are near the average rate of deposition for Cenozoic time recorded by Holmes (1945, p. 105). Beginning with Member F the deposition

Table 1. - ANALYTICAL DATA FOR K-Ar AGE DETERMINATIONS.

Stratigraphic unit	Sample number	Material analyzed	Sample weight (grams)	K+ (%)	Air ^{40}Ar (%)	Calculated age (m. y.)	Average calculated age (m. y.)
Shungura formation							
Tuff I_2 . .	KA-2187	Feldspar	5.2886	5.182	54.8	1.81±0.09	1.84±0.09
	KA-2085	Feldspar	5.0010	5.111	—	1.87±0.09	
Tuff G . .	LKA-9	Feldspar	1.9868	5.899	59.3	1.93±0.10	1.93±0.10
Tuff F . .	LKA-11	Feldspar	1.6682	6.101	66.4	1.99±0.10	2.04±0.10
	LKA-21	Feldspar	2.0586	6.101	48.2	2.06±0.10	
Tuff Ei . .	LKA-14	Feldspar	2.3350	5.010	49.1	2.12±0.11	2.12±0.11
Tuff D . .	LKA-23	Feldspar	1.8013	5.151	52.4	2.16±0.11	2.35±0.12
	LKA-22	Feldspar	1.6478	5.151	37.3	2.31±0.11	
	KA-2176	Feldspar	5.0001	5.432	53.6	2.37±0.12	
	KA-2067	Feldspar	5.0023	5.151	51.0	2.56±0.12	
Tuff B . .	KA-2096	Feldspar	6.0050	4.625	50.3	3.75±0.20	3.75±0.20
Usno formation							
Triple Tuff .	LKA-25	Glass	0.7766	2.830	91.6	2.64±0.92	2.64±0.92
WS-1 Basalt .	LKA-2	Whole-rock	10.8442	0.7074	35.4	3.11±0.15	3.31±0.42
	LKA-20	Whole-rock	6.3263	0.7074	90.7	3.51±0.70	
Nkalabong formation							
Lapilli Tuff *a*	—	Feldspar	—	—	67.2	3.90±0.10	3.95±0.11
	—	Feldspar	—	—	67.1	3.99±0.12	
Mursi formation							
YS Basalt .	KA-2094	Whole-rock	10.1667	8.828	75.4	4.05±0.20	4.05±0.20

(a) These age determination by Fitch and Miller using the neutron irradiation total degassing technique.

Table 2. - INFERRED SEDIMENTATION RATES IN THE SHUNGURA FORMATION.

Members	Thickness (m)	Rate cm./1000 yrs.	# cy. units	Duration of cycle
G+H	181	181	?	—
F	35	70	5	10,000
D+E	96.5	31.1	9	34,400
B+C	193.5	13.8	22	63,600

is considerably more rapid, and the increase continues into Members G and H where the section is made up in large part of lacustrine silts and clays.

The rate of sedimentation encountered in Members G and H is high, but by no means impossible. Depositional rates in excess of 10 meters in 1,000 years have been estimated by Fisk (Fisk, McFarlan and Kolb, 1954) for the Mississippi River delta. The muds of San Francisco Bay, deposited in the last 7,000 years, in some places are more than 50 meters thick which yields a minimum average rate of 6.5 meters per thousand years. If we assume that the rate of deposition for the fluviatile part of Members G and H is similar to that of the older deposits, then it must be the silts and clays of these members that are responsible for the increased rates.

The period of deposition represented by Member G corresponded with a major northward extension of the lake. As a consequence the mode of sedimentation changed from a cyclic, fluviatile pattern, with substantial intervals of non-sedimentation (or even erosion), to deltaic and ultimately lacustrine sedimentation. The factors responsible for the northward extension of lacustrine conditions are still unknown. One can only speculate for the moment as to whether it was a consequence of protracted, or a more accelerated rate of subsidence, the result of tectonic movements, or the result of climatic change.

We can only speculate as to the probable rate of deposition which prevailed during the accumulation of the Usno Formation. It is reasonable to assume, on the evidence of the fossil vertebrates, that the top of that succession (i.e., the Flat Sands sequence of deposits) is somewhat older than Tuff D ($\pm$ 2.35 m.y.) of the Shungura Formation. The Basalt unit near the base of the sequence has a radiometric age of 3.1 m.y. In this case the rate would have approximated 30 cm. per thousand years. This value is greater than that for the Shungura Formation at a broadly comparable interval of time. If correct this rate could reflect the piedmont situation of the depositional situation or a difference in compaction of sediments due to the predominance of sands in that formation. Further field investigations may resolve this matter.

The Tuffs of the Shungura and Usno Formations

The tuffs in the Shungura Formation are composed almost exclusively of volcanic glass shards. The grains are fresh, angular and often small gas bubbles or elongate vesicles can be seen. Microlites are rare, but sometimes present. The refractive index of most of the glasses is near or slightly less than 1.500, which is indicative of a silica content in excess of 70% (Williams, Turner and Gilbert, 1944). In some tuffs (D, E, G, I_2, I_4) rounded pebbles, cobbles and boulders of pumice are found. Phenocrysts of anorthoclase are conspicuous in these pumice cobbles and have afforded excellent material for K-Ar dating. Ferromagnesian minerals separated from the pumice cobbles include aenigmatite, sodic hedenbergite, and a sodic amphibole which is probably arfvedsonitic in composition. The anorthoclase phenocrysts are extremely poor in calcium, and have compositions near $An_{0\cdot5}Ab_{61\cdot5}Or_{38}$. Selected trace elements were analyzed for in these tuffs, and representative values are given in Table 3. The high concentration of niobium, zirconium and zinc and the low values for strontium and rubidium are of particular importance. The petrographic and compositional features mentioned above are found in but one type of volcanic rocks-peralkaline rhyolites, of which pantellerites and comendites are particular types (Nicholls and Carmichael, 1969).

The trace element concentrations in the tuff collected from the Usno Formation (labelled Brown Sands in Table 3) are quite distinct from those of the tuffs in the Shungura Formation. Niobium, zirconium and zinc are less abundant, and rubidium and barium are much more abundant.

TABLE 3. - TRACE ELEMENTS IN OMO TUFFS (IN PPM).

	Tuff A	Tuff D	Tuff F	Tuff G	Tuff H	Tuff I_4	Tuff Q	Brown Sands	Kibish
Nb . .	150	160	175	200	120	160	185	95	225
Zr . .	1,320	1,150	1,520	1,460	1,130	1,090	1,330	340	1,210
Y . . .	55	65	60	90	90	75	60	50	55
Sr . .	100	5	30	30	30	10	20	25	25
Rb . .	120	140	105	120	110	115	80	185	215
Zn . .	225	130	240	160	195	170	240	70	160
Ba . .	170	140	50	260	100	290	135	535	75

Standards used in XRF analysis were U.S.G.S. G-2 and W-1.

The precise mechanics of the deposition of the tuffs is still not fully understood. Most of the tuffs either have large current cross-beds, or climbing ripple marks indicative of rapid deposition by flowing water. The finely laminated tuffs were probably deposited in quiet backwaters, or in flood basins at the sides of the major river channel. Often the finely laminated tuffs lie over clays, and impressions of grass and the animal tracks (e.g., of Laridae and Anatidae in Tuff E) and rootcasts mentioned earlier support this hypothesis. Most of the minor tuffs fill channels, and may once have been more extensive, the greater part of them having been stripped away by migrations of the river across its floodplain, so that only those portions deposited in the lowest parts of the topography remain. The large pebbles and cobbles of pumice could only have been transported by water, for there is no volcanic source nearby from which they could have been ejected and they are too large to have been carried very far by the wind.

The source of the volcanic ash is unknown, but a number of arguments allow us to narrow the possible source area to the upper parts of the Omo Basin. Possible sources to the south and southeast are the Huri Hills (Dodson and Matheson, in press), the islands of Lake Rudolf (Brown and Carmichael, 1971), and the Korath range (Brown and Carmichael, 1969); all of these can be eliminated on petrologic grounds. The volcanic rocks of Nkalabong, Lorienatom and Naita which are exposed in highlands to the north, west, and northwest are too old to have yielded the ashes deposited here.

Examination of the tuffs in the Kibish Formation reveals that they are compositionally similar to those in the Shungura Formation (Table 3), and these tuffs are largely, but not exclusively restricted to exposures some 30 km. to the northeast of the outcrops of the Shungura Formation. Tuffaceous deposits are generally absent from the Kibish Formation where it overlies the Shungura Formation, which would not be the case if they were of primary aerial origin, particularly if the ash arrived from the south or southeast.

Volcanic ashes may be deposited over very extensive areas (Tsenidze, 1965, p. 19). Pantelleritic ignimbrites have been described by Mohr (1968) over much of central Ethiopia, including the upper Omo Basin. Though the inferred age of these ignimbrites is upper Pliocene, it is not impossible that eruption continued through earlier Pleistocene time. The ash deposits of the Shungura Formation are most likely composed of material erupted along with these ignimbrites and carried by the Omo River to its floodplain. The purity of the tuffs may be simply the result of dilution of the normal sediment load by vast quantities of ash, or may have its explanation partly due to the hydraulic characteristics of the glass fragments. Hydraulic sorting is possible, as the glass is less dense than the material normally carried by the river. Curtis (1969) has shown that in the Valley of Ten Thousand Smokes in Alaska several cubic miles of pumice and ash were erupted in the matter of at most a few days, and the bulk of this in even shorter time. Even a moderate portion of ash from an eruption of this type should be enough to glut the appetite of any river for sediment.

Taphoceonoses

The initial paleontological investigation of these Pliocene/Pleistocene formations, and particularly of the Shungura Formation, has concentrated on study at the member or sub-member level. This approach, particularly during the first two field seasons, was required in order to gain an appreciation of the vertical distribution of vertebrate taxa (Arambourg, Chavaillon and Coppens, 1967; Arambourg, Chavaillon and Coppens, 1969). It is now apparent that the nature of evolutionary change and rates of such changes in the rich mammalian fauna can best be evaluated in the long period represented by the deposition of Members A through F of the Shungura Formation. Thereafter differences in the vertebrate assemblages, particularly in the mammals, may well have been more markedly of an ecological nature. The environmental factors may have had subtle influences on faunal changes during the deposition of Member F and the earlier parts of Member G, more important in the cyclic unit G_4, and marked with the subsequent onset of lacustrine deposition. Some higher levels in Members H and I have still to be studied in detail, but a thin shellbed between Tuffs I_4 and J represents a lake foreshore taphocoenosis.

It is apparent that analysis at the unit level and at the intraunit level is required in order to obtain the requisite biotic data for correlation with microstratigraphic data. Such studies of taphonomy, which " involves all aspects of the transference of organic remains from the biosphere to the lithosphere, and includes both the biological and physical factors and processes that are involved " (Voorhies, 1969; Efremov, 1940; Rolfe and Brett, 1969) is a critical part of paleoecological analysis and interpretation. Such study has been carried out at the White Sands and Brown Sands localities (Howell, Fichter and Eck, 1969) and has been initiated by us already for the Shungura Formation. In the former instances the vertebrate fossils occur in dispersed, very incomplete condition, with scattered and mixed occurrences of various fragmentary skeletal parts. The assemblage includes several species of fish, uncommon chelonians and lizards, teeth and skull parts of two aquatic reptiles, and a sampling of just over 30 species of some twelve major groups or families of mammals including (number of species in parentheses): Proboscidea (2), Equidae (1), Rhinocerotidae (2), Hippopotamidae (2), Suidae (3), Giraffidae (2), Bovidae (6 minimum), Cercopithecoidea (6), Hominidae (1 minimum), Hyaenidae (2), Canidae (1 minimum), Machairodontidae (1), Felidae (2 minimum) and hystricomorph rodent (1). These occurrences exidently reflect fluviatile deposition by a meandering river, the mammalian assemblage reflecting a sampling of that environmental situation and the habitats relatively contiguous thereto.

A few of the sorts of fossil occurrences related to cyclic units of the Shungura Formation and the tuffs of this formation include: those on weathered clay-silt paleosols (with land mammals, including cercopithecoids and hominids); those in the porous tops of major tuffs (with land mammals, including cercopithecoids and hominids); those on grayish, reduced horizons which represent ancient swamp soils (with land mammals, including primates, as well as hippopotamus, aquatic reptiles and fish); those in washouts and derivatives of paleosols (with probably concentrations of hominid occupation surface debris); those in small pebble gravels where the sorting is particularly favorable to vertebrate tooth concentration; those in erosional channels, cross-bedded sands, and even coarse gravels (with allochtonous large and small vertebrate skeletal parts and some *in situ* aquatic reptiles). Fish and aquatic reptiles predominate in units of deltaic and lacustrine type, where variations from fresh to saline water, from open lake to closed bay, and from lake shore to lake bottom situations existed, but even here mammalian remains may be present. These latter occur either as abraded skeletal parts in deltaic sand channels or as unabraded remains of drifted cadavers.

Structure

The Shungura Formation, like the Usno Formation, has been strongly affected by tectonic movements. In order to deal with the resultant complexities, detailed geological mapping has been carried out by the senior author in the northern sector of the Shungura Formation exposures. The mean accuracy of this mapping, made possible through aerial photographs taken by R. I. M. Campbell in 1967 and a photo mosaic prepared subsequently by one of us (FHB), has been shown to be 10 meters, or 1 mm. on a 1:10,000 scale map.

Two examples of the tectonic pattern of the Shungura Formation are shown in Figures 1 and 2. The main faults are normal faults and trend approximately north-south, parallel to the strike of the bedding. Movement is mostly dip slip, with blocks downthrown to the east. However, in this type of structural collapse due to gravitational settling, irregularities are frequent, and faults branch, die out, become reversed, and are complex indeed. Blocks between faults are usually tilted about 14° W, but can also end in fault wedges, be gently folded, and even face east.

At the Brown Sands locality the Usno Formation is undisturbed by faulting, but the beds have a general dip WNW of some 10-14°. However, at the White Sands locality the same formation has been greatly disturbed by a series of faults

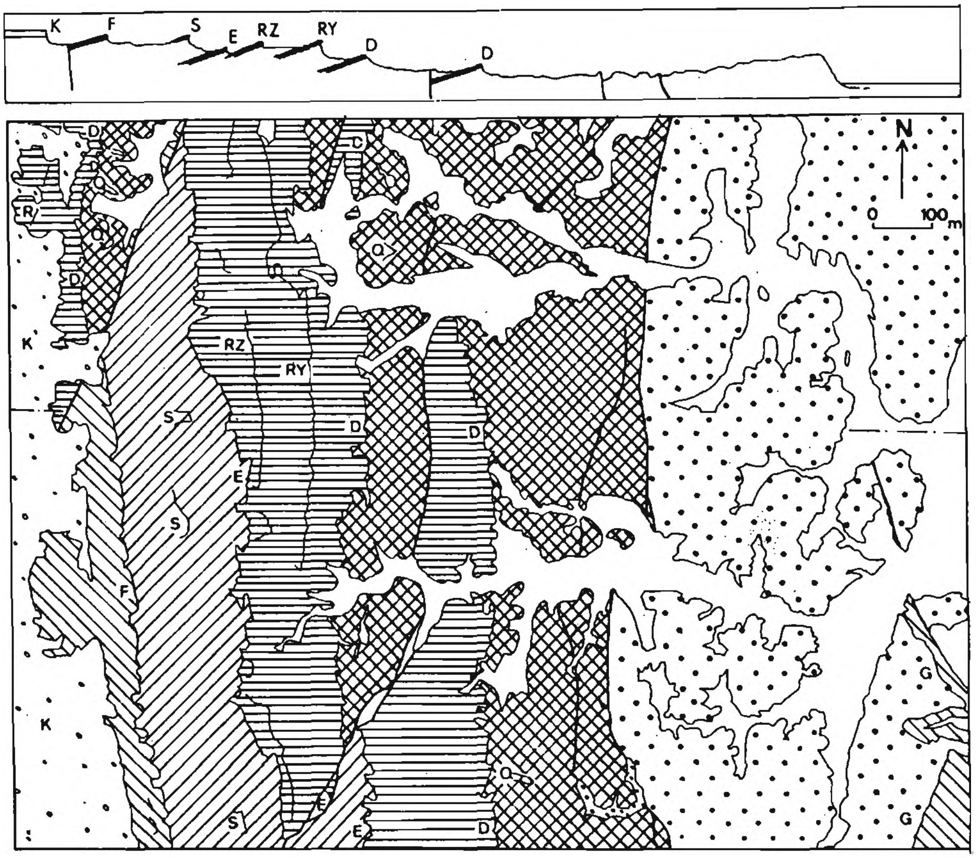

Fig. 1. - Geological map of sector 10 of the northern part of the Shungura Formation exposures. Main tuffs = D, E, F; secondary tuffs = Ry, Rz, S; Kibish Formation = K (elevation of section × 2).

and flexures (de Heinzelin and Brown, 1969). There are six main faults, some doubled and several otherwise complex, with blocks generally downthrown to the west, and with what appears in general to have been collapse at several points of a broad, arched structure.

No evidence of pre-depositional faulting has been found in the case of the Shungura Formation, which is interesting in view of the substantial faulting of the Mursi Formation which must have taken place at approximately this time, prior to the accumulation of the Nkalabong Formation. Similarly there is no indication of faulting during the period of Plio-Pleistocene sedimentation represented by any of these other formations.

The uppermost member (IV) of the Kibish Formation, with an age of ± 9,500 B.P., or less, rests unconformably on the tilted blocks of the Shungura Formation as it does on the Usno Formation as well. Judging from the advanced degree of planation of the Shungura Formation the major faulting must have occurred considerably earlier. A succession of three major stresses can be demon-

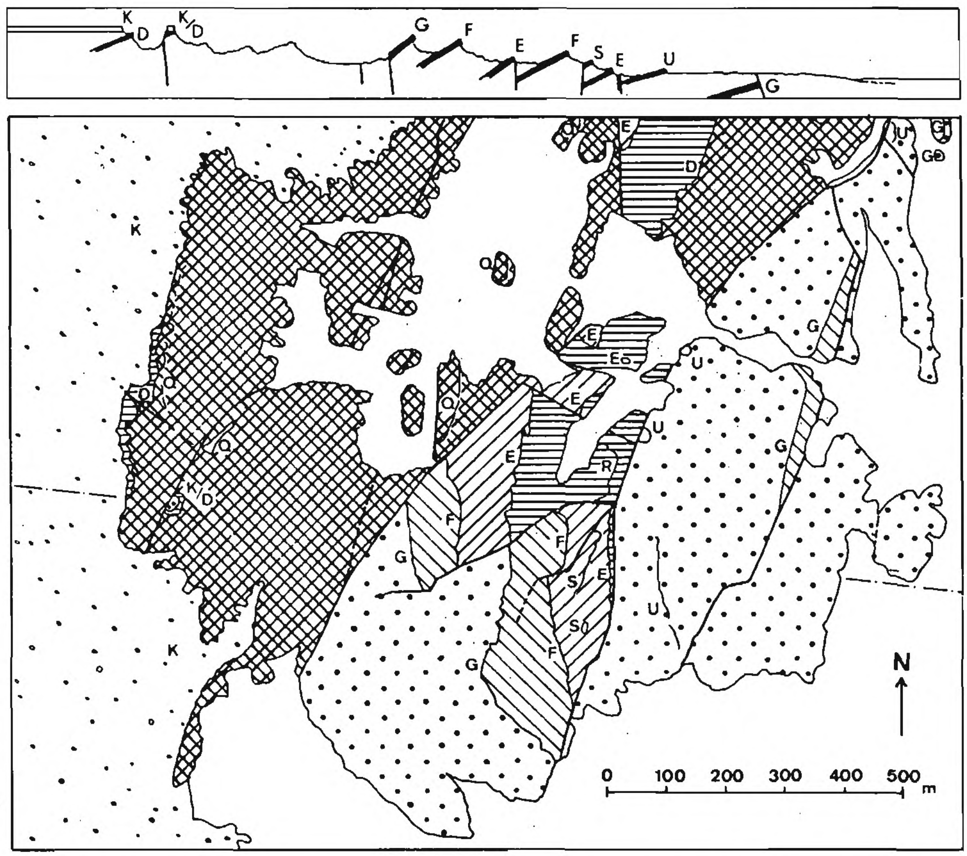

FIG. 2. - Geological map of sector 4 of the northern part of the Shungura Formation exposures. Main tuffs = D, E, F, G; secondary tuffs = S, U; Kibish Formation = K (Elevation of section × 2).

strated locally, but since true intersecting faults are unknown, these do not have a broader significance.

In a restricted area (our P. 336) of the Shungura Formation exposures, near the western edge of the present Omo floodplain, there are fossiliferous sediments distinct from those of the Omo group. These are tilted to the west, and banked against a fault line. The invertebrate fauna from these exposures has been shown (Van Damme, 1969) to be very similar, but perhaps not identical, to that of the Kibish Formation. It is substantially different from that of the shellbed below major Tuff J at the top of the Shungura Formation. Consequently these (P. 336) sediments might be correlative with the Kibish Formation, but have been disrupted by another, still younger episode of tectonic activity. The sediments are banked against a fault-line which can be followed in places along the western margin of the modern floodplain, and which seems to delineate the present trough of sedimentation.

Comparative Stratigraphy

The comparative stratigraphy of the several formations which make up the Omo Group is set out in Figure 3.

The oldest succession is represented by the fluviolittoral and deltaic sediments and capping basalt of the Mursi Formation. The fossil vertebrate assemblage, unfortunately quite limited in the number of species represented, from Member II of this formation is thus the oldest known from the basin. On almost any criteria it must be regarded as of terminal Pliocene age. The characteristic suid is a species of *Nyanzachoerus* (H. B. S. Cooke, personal communication) and the characteristic hippopotamus is a primitive hexaprotodont, perhaps of the *H. protamphibius* lineage (S.-C-Savage, personal communication). Maglio (Maglio, 1970 *a, b*) has recently shown that the characteristic elephantine species at this locality is an ancient loxodont species, assigned by him to *Loxodonta adaurora* sp. nov. This form is also represented at the Kanapoi, Ekora and (upper) Lothagam localities in the southwestern reaches of the Rudolf basin, as well as at Kanam, and in the Chemeron Beds of the Baringo basin. On the other hand the characteristic elephant throughout the Shungura Formation is *Elephas recki*. The fluviatile, aeolian and lacustrine members of the Nkalabong Formation are only slightly younger than the uppermost (basalt) member of the Mursi Formation. In the interval, however, an important episode of faulting occurred. The Nkalabong Formation would thus appear to correspond temporally with the known basal units of the Shungura Formation.

The successive units which comprise the members of the Shungura Formation are now known to represent deposition over an interval of some two million years. Hence the series of fossil vertebrate assemblages from the Mursi and Shungura Formations now provide a unique baseline against which less adequately dated fossiliferous occurrences elsewhere in eastern Africa may be compared and evaluated.

The temporal relationship of the Usno Formation and the Shungura Formation can now be assessed. The radiometric age of the Basalt Sequence of the Usno Formation affords a maximum age for that succession. It is younger than the base of Member B, and older than the base of Member D of the Shungura Formation (Brown and Lajoie, 1970). The tuff at the triple tuff sequence has yielded a minimum age slightly older than the age of Tuff D. The deposits of the Usno Formation thus probably fall within the depositional sequence represented by Members B and C. A more precise correlation suggests equivalence of the Basalt Sequence with Tuff C of the Shungura Formation, and equivalence between the Triple Tuff Sequence with minor tuff P of the latter formation.

This interpretation is consistent with the occurrence of fossiliferous sands and light gravels, comparable to those of the Brown Sands Sequence, in channels cut into minor tuff P of the Shungura Formation. In each case also the essential and comparable elements of the respective fossil mammal assemblages are the same (Howell, Fichter and Eck, 1969). Unfortunately the exposures in the White

Sands area are too shallow to expose the very distinctive Tuff D which would give an incontrovertible answer to the question.

Closing Remarks

The sediments and associated pyroclastics extensively exposed in the lower Omo basin of southern Ethiopia are now known to have been deposited over several million years of the late Cenozoic era. These have now been subdivided on geographic grounds into four principal formations which make up the Omo Group: the Mursi, Nkalabong, Usno and Shungura Formations. Radiometric age determinations now indicate that the formations of the Omo Group range in age from > 4.0 m.y. to < 2.0 m.y. They therefore must span what has been regarded traditionally as portions of both the Pliocene and Pleistocene epochs (de Heinzelin, 1969). The Kanapoi fossiliferous locality (Patterson, 1966) now appears to be as old as the oldest fossiliferous sediments (Mursi Formation) of the Omo Group. And the nearby Lothagam locality (Patterson, Behrensmeyer and Sill, 1970) is evidently substantially older, probably of an age approximating 5 m.y. or slightly older.

Within this succession of the Omo Group, somewhere, is that elusive time-stratigraphic boundary between the Pliocene and Pleistocene series. Definitions of the delimitation of the post-Pliocene time range from the Pliocene have been many and the criteria employed have been nearly equally varied. The matter will be discussed in some detail elsewhere (Howell and de Heinzelin, in preparation). However, the authors do believe, in agreement with Flint (Flint, 1959) and with Bishop (Bishop, 1968), that a climatic definition is both unwarranted and impracticable as this is really a second order concept. Fortunately, it has been possible to date the deposits of the Omo Group radiometrically, which makes their inclusion into the Pliocene or Pleistocene epoch at this time of little more than academic interest; for, having a good idea of their absolute age, they may be placed into one or the other whenever those concerned with this problem finally decide on a definition.

As the formations of the Omo Group encompass end-Pliocene as well as earlier post-Pliocene time this succession is a critical one by which less complete or less protracted sedimentary situations of Pliocene/Pleistocene age may be better evaluated. The substantial assemblages of fossil vertebrates from this long succession are of major importance for improving interlocality correlations and, particularly, for analyses of rates and processes of differentiation and evolutionary change in the successive mammalian faunas of eastern Africa. The paleo-environmental investigations now under way will afford pertinent new evidence relevant to this subject as well as to questions concerning the origin, differentiation, and adaptations of early representatives of the Hominidae.

ACKNOWLEDGEMENTS

All of our field studies have been supported by grants-in-aid to one of us (FCH) from the National Science Foundation and from the Wenner-Gren Foundation for Anthropological Research, and represent a part of the interdisciplinary

studies being carried out in the lower Omo basin by the Omo Research Expedition. We are most grateful to the government of Ethiopia, and in particular to the Antiquities Administration of the National Museum, Addis Ababa, and to the government of Kenya for their continued cooperation and assistance in facilitating this work. The second author would like to thank E. J. Helley of the U.S. Geological Survey and O. F. Huffman of this department for many useful suggestions in improving the manuscript. This is Contribution no. 16 of the Omo Research Expedition (University of Chicago contingent).

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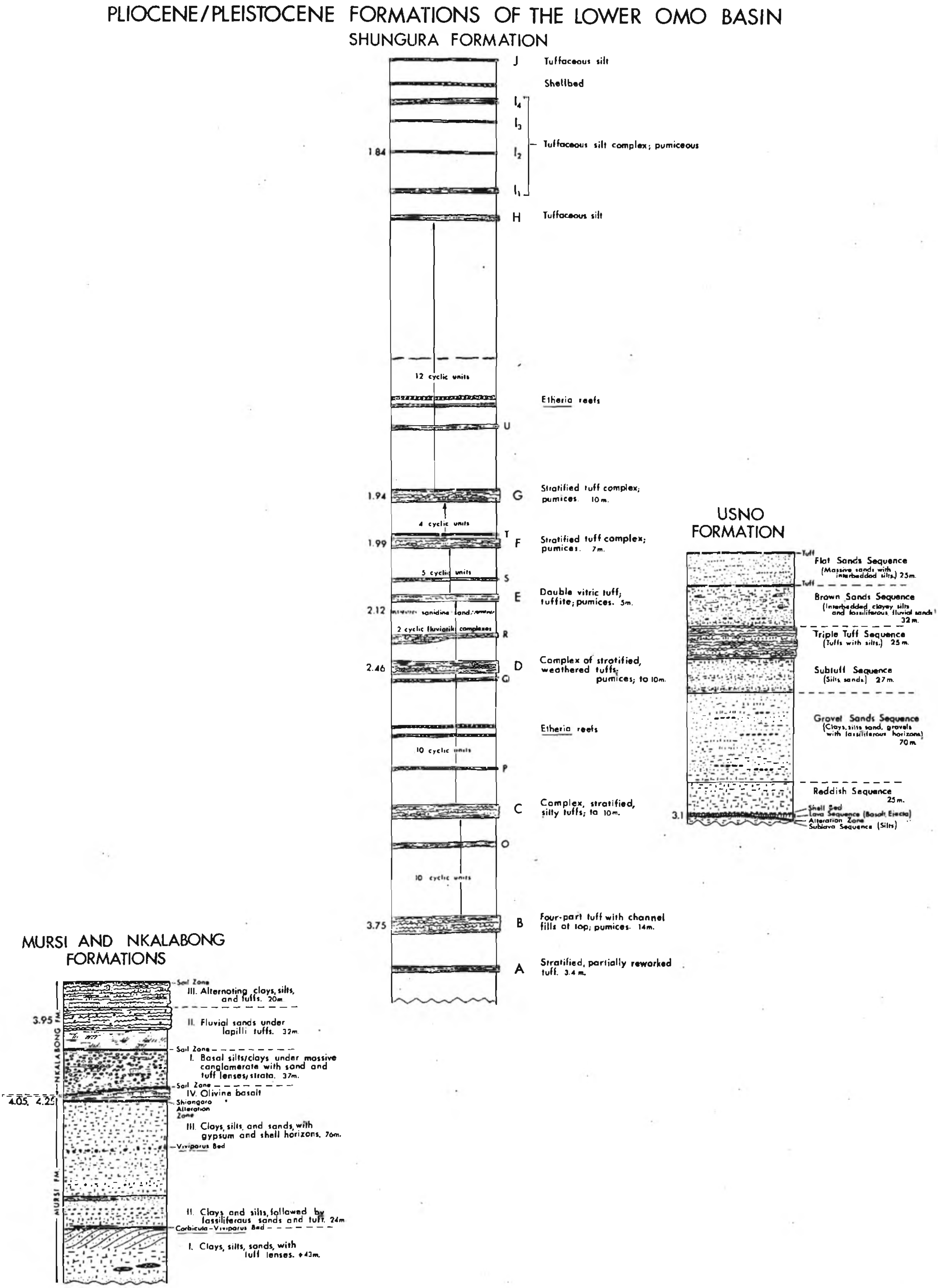
RIASSUNTO

In diverse località del bacino inferiore dell'Omo (Etiopia sud-occidentale) si trovano sedimenti e piroclastiti che secondo quanto è stato documentato abbracciano un notevole spazio di tempo dal Pliocene al Pleistocene. In base alle misurazioni al Potassio/Argon le quattro formazioni principali del gruppo dell'Omo vanno datate da >4 milioni di anni a $<1.800.000$ anni. Le formazioni Mursi e Nkalabong, situate ai piedi dei monti Nkalabong, nella parte settentrionale del bacino, sono le più antiche unità sedimentarie, e comprendono depositi deltizi, fluvio-litorali e fluvio-lacustri. La formazione Usno è nota per una serie isolata di affioramenti nel settore nord-orientale del bacino, con deposizioni di conoidi fluviali e alluvionali. La più estesa è la formazione Shungura, che è composta da più di 600 metri di sedimenti fluviali, deltizi e lacustri e di prodotti vulcanici intercalati. Tutte queste unità stratigrafiche sono ricche di vertebrati fossili; inoltre sono stati rinvenuti resti di Ominidi nella formazione Usno come pure in tutti i membri della formazione

Shungura. Nell'insieme il gruppo dell'Omo rappresenta la più lunga serie stratigrafica, datata con metodi radiometrici, del Cenozoico recente dell'Africa. Essa offre dunque un punto di riferimento, con il quale possono essere messe a confronto per essere interpretate altre sequenze sedimentarie meno complete e meno prolungate, di età plio-pleistocenica.

ZUSAMMENFASSUNG

In verschiedenen Teilen des unteren Omobeckens (Südwestäthiopien) treten Sedimente sowie Pyroklastika auf, die nachweislich einen erheblichen Zeitabschnitt des Plio-Pleistozäns dokumentieren. Auf Grund der Kalium-Argon Bestimmungen sind die vier Hauptformationen der Omogruppe zwischen >4 bis <1.8 mill. Jahre zu datieren. Die ältesten Ablagerungen (Mursi und Nkalabongformationen), am Westfuss des Nkalabonggebirges, d.h. am Nordrand des Beckens, umfassen deltaische, fluvio-littoral und fluvio-lakustrische Bildungen. Die Usnoformation tritt dagegen in vereinzelten Aufschlüssen im nordöstlichen Becken auf und deutet auf Ablagerungsverhältnisse in Fluss-sowie Schwemmkegelbereichen hin. Am besten aufgeschlossen ist die Shunguraformation, die aus mehr als 600 Metern fluvialen, deltaischen sowie lakustrischen Sedimenten und zwischengeschalteten Aschenlagen besteht. Sämtliche stratigraphische Einheiten sind reich an fossilen Vertebraten; dazu treten Hominidenreste in der Usnoformation sowie in allen Abteilungen der Shunguraformation auf. Insgesamt stellt die Omogruppe die längste, radiometrisch-erfasste, stratigraphische Folge des afrikanischen Spätkainozoikums dar. So bietet sie einen kritischen Anhaltspunkt, mit dem andere weniger vollständige oder kürzere Sedimentpakete Plio-Pleistozänen Alters verglichen und ausgewertet werden können.



PLIOCENE/PLEISTOCENE FORMATIONS OF THE LOWER OMO BASIN
SHUNGURA FORMATION
J
Tuffaceous silt
Shellbed
I4
I3
1.84
I2
Tuffaceous silt complex; pumiceous
I1
H
Tuffaceous silt
12 cyclic units
Etheria reefs
U
1.94
G
Stratified tuff complex; pumices. 10 m.
4 cyclic units
T
1.99
F
Stratified tuff complex; pumices. 7 m.
5 cyclic units
S
E
Double vitric tuff; tuffite; pumices. 5m.
2.12
sanidine sand
2 cyclic fluviatile complexes
R
2.46
D
Complex of stratified, weathered tuffs; pumices; to 10m.
Q
Etheria reefs
10 cyclic units
P
C
Complex, stratified, silty tuffs; to 10m.
O
10 cyclic units
3.75
B
Four-part tuff with channel fills at top; pumices. 14m.
A
Stratified, partially reworked tuff. 3.4 m.
USNO FORMATION
Tuff
Flat Sands Sequence (Massive sands with interbedded silts.) 25m.
Tuff
Brown Sands Sequence (Interbedded clayey silts and fossiliferous fluvial sands) 32 m.
Triple Tuff Sequence (Tuffs with silts.) 25 m.
Subtuff Sequence (Silts sands.) 27 m.
Gravel Sands Sequence (Clays, silts sand, gravels with fossiliferous horizons) 70 m.
Reddish Sequence 25 m.
3.1
Shell Bed
Lava Sequence (Basalt Ejecta)
Alteration Zone
Sublava Sequence (Silts)
MURSI AND NKALABONG FORMATIONS
Soil Zone
III. Alternating clays, silts, and tuffs. 20m
3.95
NKALABONG FM.
II. Fluvial sands under lapilli tuffs. 32m.
Soil Zone
I. Basal silts/clays under massive conglomerate with sand and tuff lenses/strata. 37m.
Soil Zone
IV. Olivine basalt
4.05, 4.25
Shungura Alteration Zone
III. Clays, silts, and sands, with gypsum and shell horizons. 76m.
Viviparus Bed
MURSI FM.
II. Clays and silts, followed by fossiliferous sands and tuff. 24m.
Corbicula–Viviparus Bed
I. Clays, silts, sands, with tuff lenses. +43m.

Fig. 3