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GEOLOGY OF THE NEOGENE SYSTEM IN AND AROUND THE SAMBURU HILLS, NORTHERN KENYA

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ABSTRACT The Neogene System in and around the Samburu Hills, northern Kenya, is divided into seven main formations on the basis of stratigraphy and geochronology, which in ascending order are the Nachola, Aka Aiteputh, Namurungule. Nanyangaten, Kongia, Nagubarat and Tirr Tirr Formations. The Nachola and Aka Aiteputh Formations of Makinouchi *et al.* (1984) have been redefined.

The Nachola Formation, which is widely distributed along the Baragoi River, is the lowest part of the Neogene System and either unconformably overlies the Precambrian Basement Complex or is in fault contact with it. It consists mainly of basalts, phonolitic trachytes and their pyroclastics, and sediments. The Aka Aiteputh Formation conformably overlies the Nachola Formation and occurs in the Nachola area and the Samburu Hills. It is mainly composed of basalts intercalated with trachytes, trachytic pyroclastics and sediments. The Namurungule Formation consists chiefly of clastic sediments with intercalations of mud flow deposits and tuffs, and covers the Aka Aiteputh Formation. No structural gap between the Aka Aiteputh and Namurungule Formations is recognizable. The Nanyangaten Formation, consisting of basalt lavas, which is one of the "undifferentiated basalts" of Makinouchi *et al.* (1984), unconformably overlies the Nachola and Aka Aiteputh Formations.

Kenyapithecus occurs in the Aka Aiteputh Formation at Site BG-X of the Nachola area (Ishida *et al.*, 1984). The bed containing *Kenyapithecus* accumulated between 15.4 Ma and 12.8 Ma according to K-Ar dating of volcanic rocks (Itaya & Sawada, 1987). On the other hand, the Samburu hominoid fossil occurs in the Namurungule Formation (Makinouchi *et al.*, 1984; Ishida *et al.*, 1984) whose K-Ar age is between 10.8 Ma and 7.3 Ma (Itaya & Sawada, 1987).

A major structural gap is recognized between the Namurungule and Nanyangaten Formations indicating that a significant tectonic disturbance in the (northern Kenya Rift) took place between about 10 Ma and 7 Ma based on geological data obtained by this work and Makinouchi *et al.* (1984), and geochronological data of Itaya & Sawada (1987).

INTRODUCTION

The area east to the Rift Valley (Suguta Valley) in northern Kenya is an important field for studying hominoid evolution because hominoid fossils were discovered in Neogene strata exposed there. In 1982, *Kenyapithecus* and a large hominoid fossil were found in Neogene sediments of the Nachola area and the Samburu Hills by the Japan-Kenya Expedition (Ishida *et al.*, 1984). Makinouchi *et al.* (1984) described in detail the geology of the Nachola area and the Samburu Hills, and concluded that the horizons containing the Samburu hominoid fossils is stratigraphically higher than that which yielded *Kenyapithecus*. In 1984, we carried out geological mapping of the Baragoi River from Nachola to the Samburu Hills and in this paper we describe the geology, especially the Neogene stratigraphy.

GEOLOGICAL SETTING

The investigated area is situated on the eastern margin of the East Rift Valley, northern Kenya, from Nachola (10 km west of Baragoi town) to the Samburu Hills along the Baragoi River (Fig. 1). This area is physiographically divided into four parts: 1) El Barta plains, 2) Samburu Hills, 3) Tirr Tirr and Emuru Akirim Plateaux, and 4) Suguta Valley.

The El Barta Plains are the upper drainage area of the Baragoi River, and are mainly underlain by the latest Precambrian Mozambique belt which consists of gneisses, amphibolites, metabasic rocks, migmatites and granites (Baker, 1963).

Cenozoic volcanic and sedimentary rocks are widely distributed in a zone approximately 20 to 30 km in width, subparallel to the Suguta Valley and trending about N 10°E. The Nachola area ranges in altitude from 1150 to 1250 m, whereas the Samburu Hills (west of Nachola) ranges from 600 to 1100 m. In this area, there are many faults which trend between N-S and N20°E with fault blocks tilted stepwise toward the Suguta Valley. The Tirr Tirr and Emuru Akirim plateaux are situated to the north of the Samburu Hills and Nachola area and are underlain by Pliocene basalts and trachytes. Quanternary volcanic rocks and sediments occur in the floor of the Suguta Valley which ranges in altitude from 320 to 380 m.

STRATIGRAPHIC DIVISION

The Neogene System in the area is divided into seven formations based on geological data of this stndy and Makinouchi *et al.* (1984), and geochronology by Itaya & Sawada (1987). In ascending order these are the Nachola, Aka Aiteputh, Namurungule, Nanyangaten, Kongia, Nagubarat and Tirr Tirr Formations (Fig. 2). Makinouchi *et al.* (1984) termed the Miocene Series in the Nachola area the Nachola Formation and correlated it with the Aka Aiteputh Formation. Here, we redefine the Nachola and Aka Aiteputh Formations. The Nachola Formation is the lowest part of the Neogene System in the area and unconformably overlies Precambrian Basement rocks or is in fault contact with them. The Nachola Formation is chiefly composed of sediments, basalts,

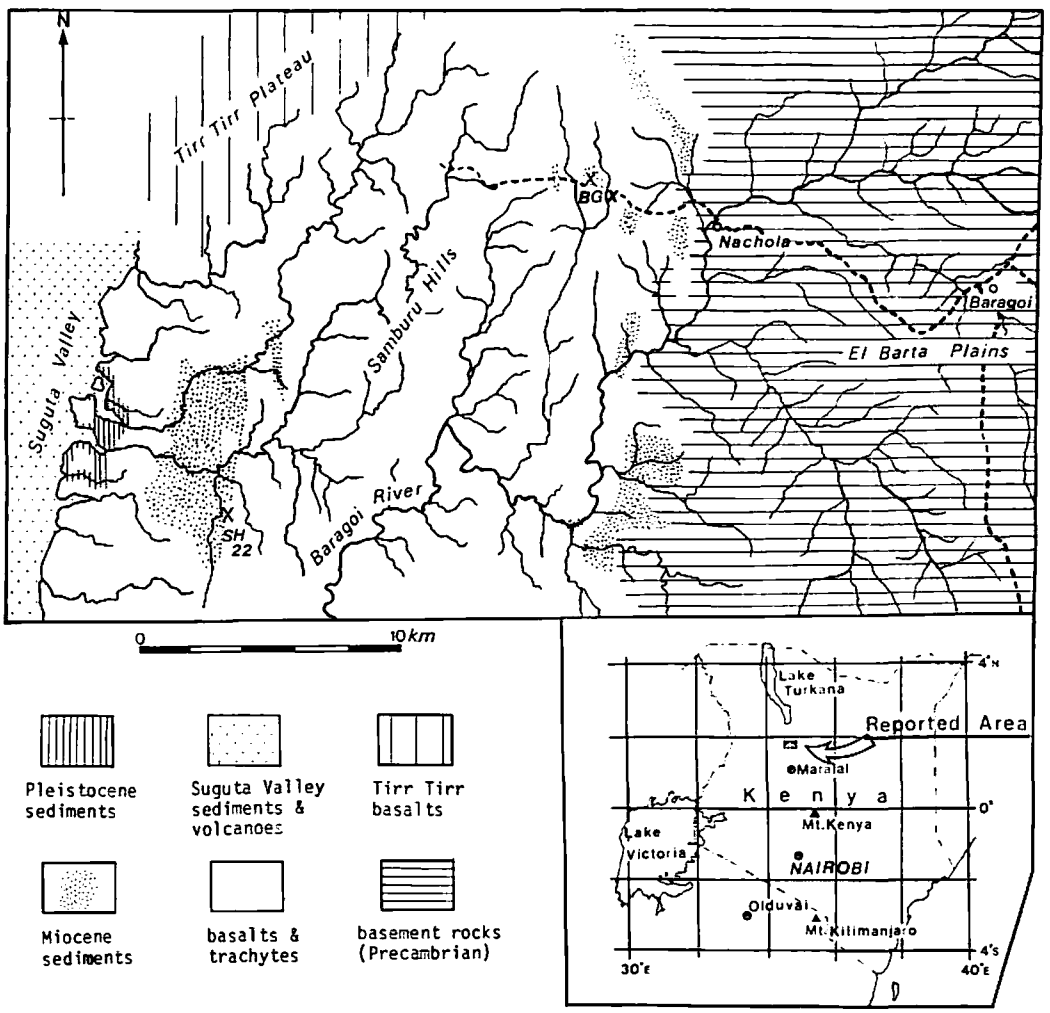

Fig. 1 Index map and simplified geological map of the Nachola area and Samburu Hills, northern Kenya.

phonolitic trachytes and pyroclastics, and its uppermost unit consists of phonolitic trachyte lava. The Aka Aiteputh Formation conformably overlies the Nachola Formation, and consists of basalt lavas intercalated with sediments, trachyte lavas and pyroclastics. Units 1 and 2 of the Nachola Formation of Makinouchi *et al.* (1984) correspond in our revised stratigraphic division to the Nachola Formation, while their units 3 and 4 correspond to the Aka Aiteputh Formation.

The definition of the Namurugule, Kongia, Nagubarat and Tirr Tirr Formations is the same as that of Makinouchi *et al.* (1984). This paper makes no mention of the formations other than the Namurungule Formation.

In the Nachola area, olivine basalt lavas, designated the "undifferentiated basalts" by Makinouchi *et al.* (1984), unconformably cover the Nachola and Aka Aiteputh Formations. One of these

	SUGUTA VALLEY	SAMBURU HILLS	BARAGOI RIVER	NACHOLA AREA
PLEISTO-CENE	basalts (0.12, 0.45) sediments	grey silts & fluviatile sediments	Alluvium (mud, sand & gravel)	Alluvium (mud, sand & gravel) basalts (1.75, 1.97)
PLIOCENE		TIRR TIRR F. alk. rhyolite tuff breccias sediments basalts (3.6, 3.8, 3.9)*		EMURU AKIRIM alkali trachytes basalts (4.11)
MIOCENE		NAGUBARAT F. basalts (5.34, 5.38)		
		KONGIA F. basalts (5.67, 6.03) sediments		
				NANYANGATEN F. basalts (7.29)
		NAMURUNGULE F. mud flow deposits, tuff, mud, sand & gravel		
		AKA AITEPUTH F. sediments basalts (10.8, 12.7, 14.5, 14.1, 14.2) trachytes (14.4, 14.9) pyroclastics basalts (14.5, 15.0)		AKA AITEPUTH F. basalts (11.8, 12.8) tuff sediments
		NACHOLA F. trachytes (15.0) pyroclastics (17.7) trachybasalts (18.2) basalts (17.7, 19.0, 19.2) sediments		NACHOLA F. trachytes (15.4) pyroclastics trachybasalts basalts sediments
PRECAM-BRIAN		PRECAMBRIAN BASEMENT COMPLEX		

Fig. 2 Stratigraphy of the Nachola area and Samburu Hills. Numbers show K-Ar ages (Ma); numbers marked*) are after Baker *et al.* (1971) and others after Itaya & Sawada (1987). The stratigraphy of the Kongia, Nagubarat and Tirr Tirr Formations is from Makinouchi *et al.* (1984).

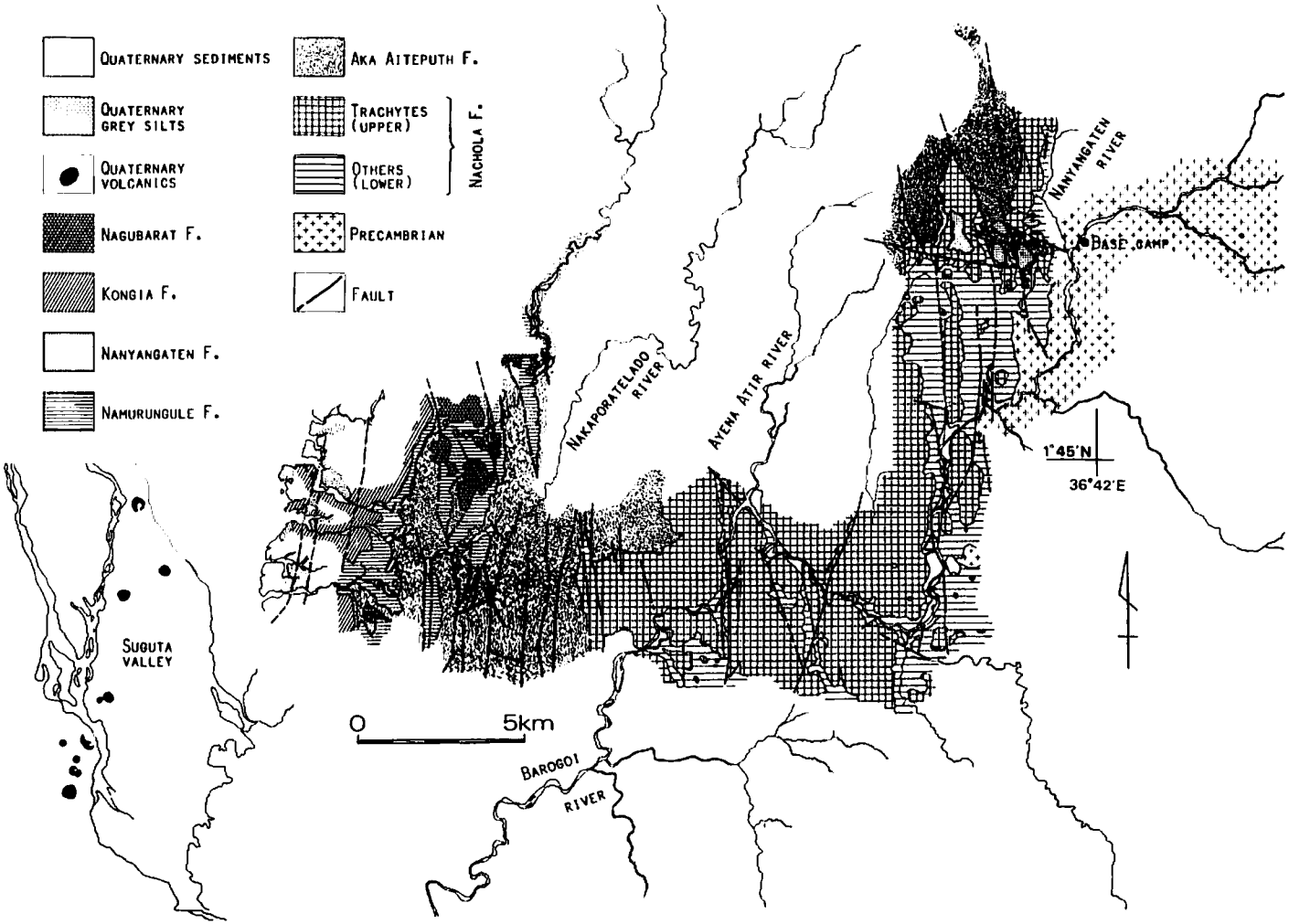

Fig. 3 Formation map. The geological map of the Kongia and Nagubarat Formations is after Makinouchi *et al.* (1984).

basalts has a K-Ar age of 7.1 and 7.4 Ma (Itaya & Sawada, 1987) indicating that basalts erupted between the deposition of the Namurugule and Kongia Formations. These basalts are assigned to the "Nanyangaten Formation".

A thin basalt flow with a K-Ar age of latest Pliocene to early Pleistocene (1.6 and 2.0 Ma by Itaya & Sawada (1987)) overlies Precambrian rocks 5 km east of the Nachola base camp. Pleistocene fluviatile and lacustrine sediments in the Suguta Valley are overlain by basalts whose K-Ar ages range from 0.1 to 0.6 Ma (Itaya & Sawada, 1987).

Terrace deposits with rounded pebble to cobble-sized gravels are sporadically distributed along the middle reaches of the Baragoi River. They lie between 120 to 130 m above the river bed around Loc. B-3 and B-5 in Fig. 6, and 80 to 100 m around Loc. B-8. Fluviatile deposits consisting mainly of gravel, sand and mud associated with limestone (probably of Pleistocene age) and Alluvium occurs along the Baragoi River bed.

STRATIGRAPHY

1. Nachola Formation

The Nachola Formation forms the lowest part of the Miocene Series in the Nachola area and Samburu Hills. The formation is distributed along the Baragoi River east of the Samburu Hills, and unconformably covers the Precambrian Basement Complex around the Nachola area. The basal sediments of the Nachola Formation abut or are in fault contact with the basement rocks in some places southwest of Nachola. Columnar sections of the Nachola Formation are shown in Fig. 6.

The formation generally consists of sediments, basalts, trachybasalts, trachytic pyroclastic rocks with welded tuff, sediments and phonolitic trachytes in ascending order. The formation is estimated to be a maximun 200 m thick. Phonolitic trachyte lava flows are widely distributed in the studied area snd are a good marker bed. Generally, the lithofacies and thickness of these formations are variable.

K-Ar ages of volcanic rocks from the Nachola Formation by Itaya & Sawada (1987) are as follows: 1) basalts of the lower part: 18-19 Ma; 2) welded tuff of the middle part: 17 and 18 Ma; 3) phonolitic trachytes of the upper part: 15 and 16 Ma.

a) Sediments

The sediments are divided into lower and upper portions which are bounded by basalt and/ or trachybasalt. The lower sediments comprise the base of the Nachola Formation and a extremely variable thickness. The sediments have a maximum thickness of about 35 m at Loc. B-4 in Fig. 6, and thin northwards and northeastwards. Around Loc. B-1, they are 4 m in thickness, and abut on the Basement Complex which is sporadically distributed. Base sediments mainly consist of sandstone associated with granule to cobble-sized conglomerate, derived from the basement in the basal part but from diverse sources in other strata in some horizons. The sandstone is mainly arkose and partly tuffaceous.

The sediments cannot be divided into two horizons west of Nachola, because volcanics are absent

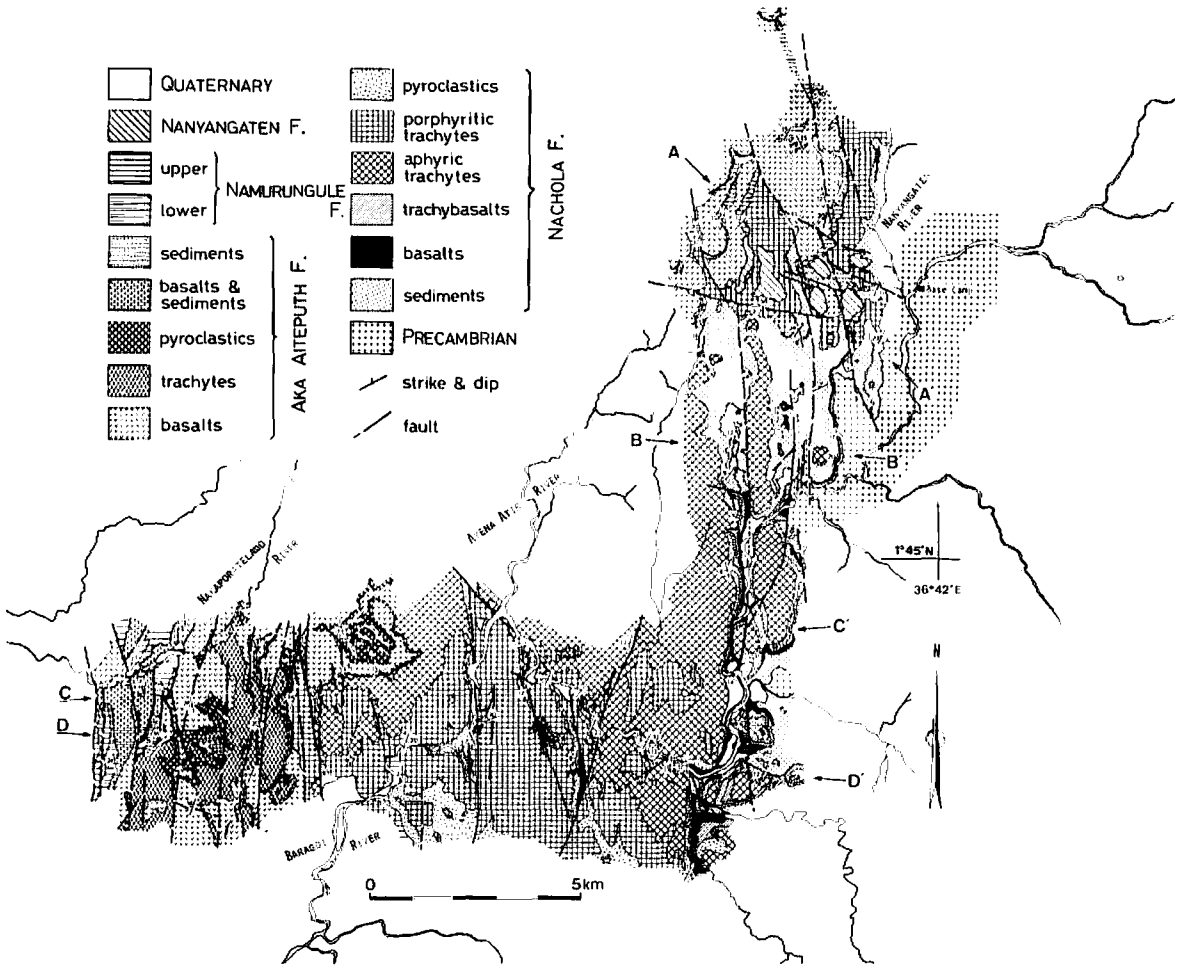

Fig. 4 Geological map of the Nachola area and Samburu Hills. Geological profiles of A-A' to D-D' are shown in Fig. 8.

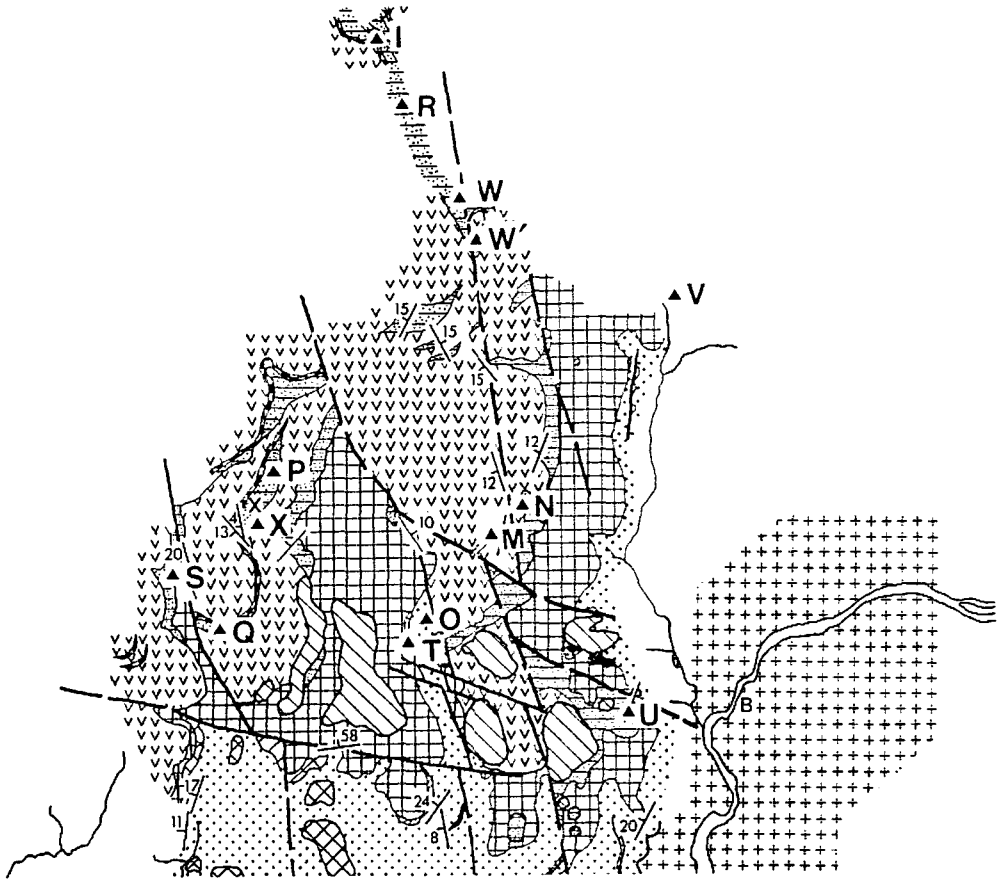

Fig. 5 Map showing fossil site numbers of the Nachola and Ake Aiteputh Formations around the Nachola area.
B: Base camp. Legend of the geological map is the same as that in Fig. 4.

in the lower half of the Nachola Formation. In this area, the sediments are distributed along the western side of the Nanyangaten River and in a narrow strip north of Site BG-T. They are more than 10 m in thickness, consisting of poorly-sorted, granule-bearing, medium to coarse sand partly interbedded with pebble to granule-sized conglomerates. The upper part of the sediments near Site BG-O consists of greenish grey, laminated or massive silt containing silisified wood. Mammal fossils have been obtained from the silt layers (Sites BG-O and BG-T).

The thickness and lithofacies of the upper sediments ara also variable. They are widely distributed and are 18 to 25 m thick southwest of Nachola. They occasionally have intercalations of ankaramite lavas about 2 m thick. In this area, the upper sediments conformably overlie a trachyte welded tuff and are conformably covered by phonolitic tranchyte lava. Occasionally they are intercalated with a few beds of green tuff which are 0.5 to 3 m thick. The sediments are chiefly composed of sandstone with frequent intercalations of granule to pebble-sized conglomerate lenses.

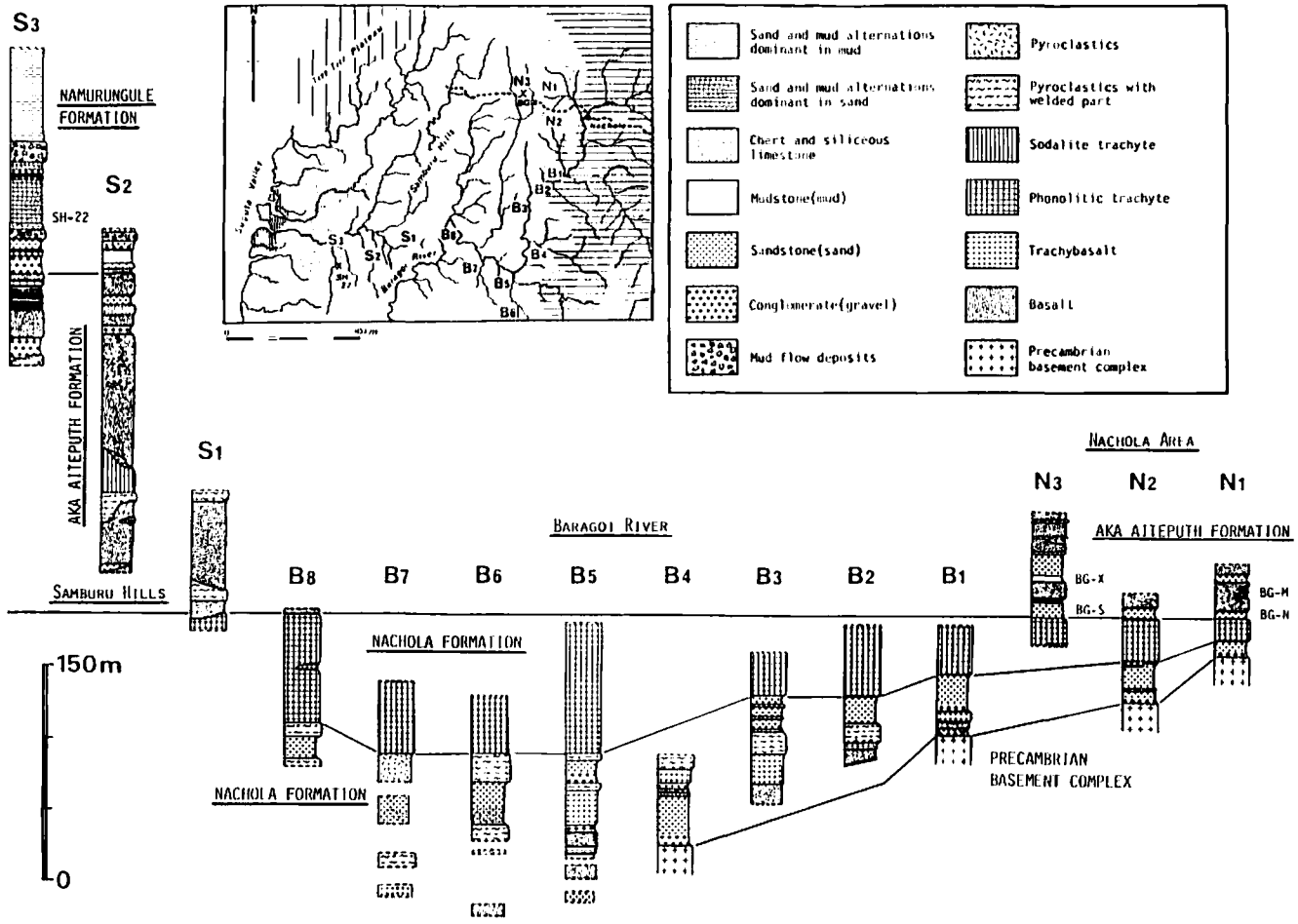

Fig. 6 Columnar sections of the Nachola, Aka Aiteputh and Namurungule Formations.

In the area west of Loc. B-5, the upper sediments are either intercalated with trachyte pyroclastic rocks or interbedded with them. Tuffaceous sediments are dominant with occasional alternating beds of tuffaceous sandstone and siltstone, conglomerate and tuff. Some massive sandstones have parallel and cross laminae.

b) Basalts, trachybasalts and ankaramites

Basalt lava flows attain 15 m in thickness along the Baragoi River, but are absent at west of Nachola. They consist of porphyritic and aphyric basalt. Phenocrysts in the porphyritic basalts are plagioclase, clinopyroxene and olivine (±) although olivine is mostly replaced by carbonate. Porphyritic basalt at Loc. B-5 includes clinopyroxene magacrysts up to 4 cm long.

Trachybasalt lava flows cover the basalts or the lower sediments. They are overlain by trachytic pyroclastic rocks south of Loc. B-2 and by the upper sediments northeast of Loc. B-2. Lave flows attain 24 m thick in the southern area, but thin northwards and are absent at west of Nachola. Around Loc. B-5, at least three lava flows are recognized occuring as aa lava with clinker and/or vesicles at their bases and tops. Trachybasalt is aphyric and shows a transitional major element chemistry between basalt and trachyte.

Ankaramite flows about 2 m thick are intercalated with the sediments. They contain abundant phenocrysts of clinopyroxene and olivine ranging from 1 to 8 mm long. Olivine is often replaced by carbonate.

c) Phonolitic trachytes

Phonolitic trachyte lavas constitute the uppermost unit of the Nachola Formation comprising aphyric and porphyritic types. Perlite rarely occurs in phonolitic trachyte at the junction of the Baragoi and Ayena Atir Rivers. The stratigraphic sequence in ascending order is aphyric, porphyritic and aphyric varieties east of the Samburu Hills. At west of Nachola the aphyric type is absent and porphyritic phonolitic trachyte covers the upper sdeiments. Porphyritic phonolitic trachyte lavas are very thick reaching a maximum 130 m in the area south of the junction of the Baragoi and Ayena Atir Rivers. At least three lava flow units are recognized in this area. The flow pile thins northwards and is only 10 to 20 m thick west of Nachola. The principal phenocrysts type is anorthoclase, which is often composed of long prismatic crystals up to 4 cm in length, with a few microphenocrysts of augite rimmed by aegirine augite, and magnetite. Aphyric phonolitic trachyte is up to about 70 m thick at and near Loc. B-7. It occurs as aa lava with a 1-5 m clinker or vesiculated part.

d) Trachytic pyroclastics

Trachyte pyroclastic beds occur at the lower and upper parts bounded by the trachybasalt. The lower part of the trachytic pyroclastics, which consists of tuff, lapilli tuff and tuff breccia, is restricted in distribution, and is only 2 to 5 m thick.

The upper part of trachyte pyroclastics lies between the trachybasalt and phonolitic trachyte lavas of the uppermost Nachola Formation, and is frequently associated with sediments. A few pyroclastic beds also occur in the upper part of the phonolitic trachyte lavas. They are thickest south of the junction of the Baragoi and Ayena Atir Rivers where pyroclastics beds plus sediments

attain 70 m. They are thinner or absent to the north and northeast, similar situation to the phonolitic trachyte lavas.

To the west of Nachola (near Site BG-T), trachyte phyoclastics with a welded part overlie the sediments and are overlain in turn by phonolitic trachyte. The welded part is not observed in the northern part of the Site BG-T. Trachyte pyroclastics lie between the sediments in the southwest of Nachola. They comprise dull greyish green lapilli tuff with welded in part up to 2 to 5 m thick.

In the area between Loc. B-2 and B-4, trachyte pyroclastics consist mainly of lapilli tuff with welded tuff forming a single cooling unit which covers the trachybasalt and is overlain by sediments. A few green tuff beds occur in the upper sediments. The welded tuff ia a dull reddish purple or reddish brown and 4 to 15 m in thickness. It shows eutaxitic texture with grey of greyish purple collapsed pumices. Poorly-sorted lithic fragments are less abundant than essential fragments. They are mostly composed of volcanic rocks while lithic fragments derived from Precambrian Basement Complex are scarce.

In the area west of Loc. B-5, there are two to three beds of pyroclastic rocks which include one to two welded tuff beds. Each bed is 5-20 m in thickness. The pyroclastic rocks lacking welded parts are sometimes accompanied by interbedded sediments and grade laterally and vertically into tuffaceous sediments. The welded tuffs are red-brick in colour with abundant light grey pumice lenses accompanied by lithic fragments (mostly volcanics). Megascopic fragments of anorthoclase or sanidine crystals are found in the matrix.

2. Aka Aiteputh Formation

The Aka Aiteputh Formation is distributed in the Nachola area and Samburu Hills. In both areas, the unit is chiefly composed of basalts associated with sodalite trachyte, trachyte, trachyte pyroclastics with a welded part, and sediments.

a) Nachola area

In this area the Aka Aiteputh Formation is distributed from about 1.5 km west of the base camp towards the northwest and west, and consists of basalts, sediments and pyroclatic rocks. The lowest part is either basalt or sediment, conformably covering porphyritic phonolitic trachyte of the Nachola Formation. The formation in the area investigated is about 80 m in total thickness, divided into four units (1 to 4 in ascending order). Units 1 and 3 consist of sediments and units 2 and 4 are mainly composed of basalt lavas.

Unit 1 comprises 5-15 m of clastic sediments consisting of coarse to medium sand with occasional tuffaceous silts and gravels. Mammal fossils are scattered in this tuffaceous silt at Site BG-N. At Site BG-S, this unit shows an upward fining sequence, and contains silicified wood and mammal fossils.

Unit 2 consists mainly of aphyric basalt lava flows, with a thin intercalated sedimentary layer. In general, the basalt lavas cover the uppermost phonolitic trachyte of the Nachola Formation south of the road between Nachola and Napung, except in the neighbourhood of Site BG-S (Fig. 5). Intercalations of clastic sediments are distributed near the upper reaches of the Nanyangaten River where they comprise yellow green or grey white coarse tuffaceous granular sands, and fine to medium sand and silt. Silicified woods are contained in the bedded tuffaceous sediments south of

Muruilem peak and mammal fossils occur at Site BG-M.

Unit 3 is one of the most important beds, as many important fossils occur in it, including *Kenyapithecus*. It is distributed around the upper reaches of the Ayena Aturai River (Sites BG-X and BG-P), and around and to the north of the peak at Muruilem (Sites BG-H, BG-I, BG-R and BG-W). The unit is up to 9 m thick at Site BG-I, and up to 17 m near Site BG-X. It is composed of silt in the lower part, sand in the middle, and tuff layers in the uppermost part. The silt is yellow green or grey and is bedded and partly silicified to chert. It contains significant silicified wood and mammal fossils, such as *Kenyapithecus*. The sand is grey white, massive and tuffaceous, and contains granule to fine pebble sized pumice. The uppermost tuff layer is reddish purple or reddish brown and very hard. It has a thickness of up to 50 cm and can be traced over a length of 12 km from Site BG-Q to Site BG-H.

Unit 4 extends from the upper reaches of the Ayena Aturai River through the peak of Muruilem

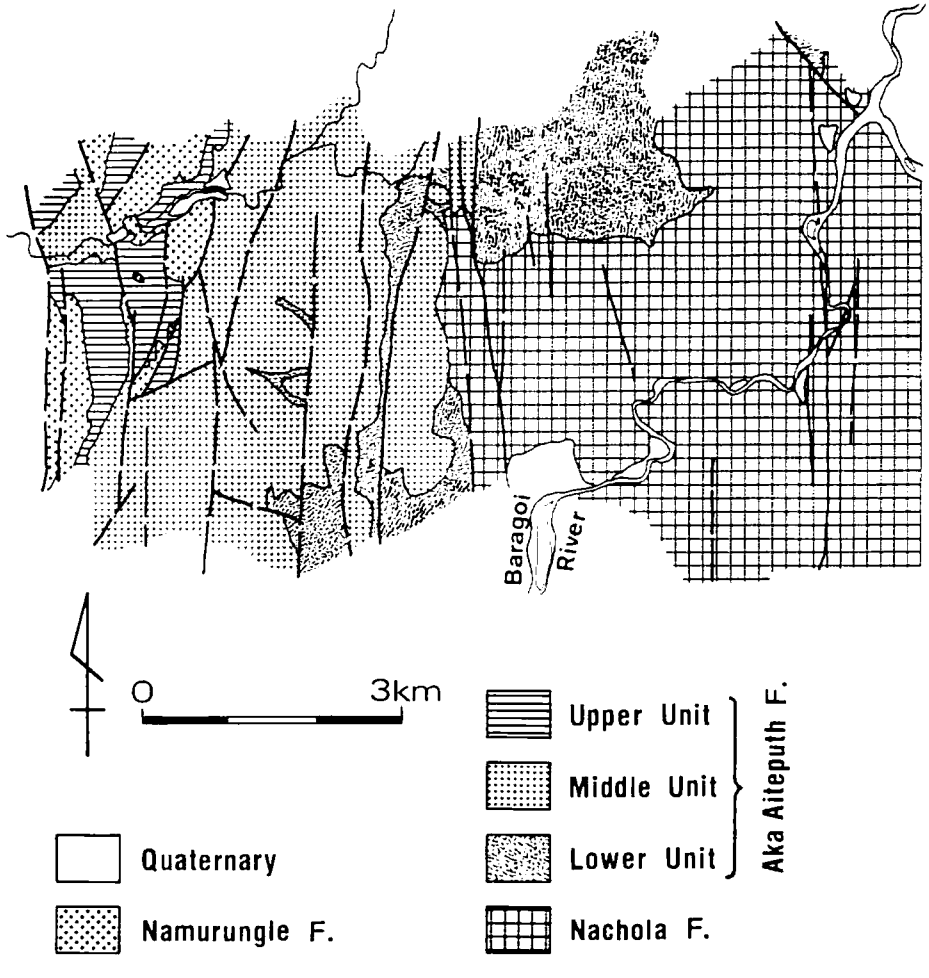

Fig. 7 Geological map of the Samburu Hills.

to the north. It consists chiefly of basaltic rocks containing intercalated welded tuff and clastic sediments attaining a thickness of more than 30 m. The basalts of both units 2 and 4 are chiefly aphyric or nearly aphyric and associated with basalts containing rare phenocrysts of plagioclase, clinopyroxene and olivine (±), which are generally less than 1.5 mm long. The groundmass consists of plagioclase, clinopyroxene, olivine (±), opaque minerals, glass and altered minerals, and occasionally contains biotite. Some of the basalts are altered and ankaramites occur at the foot of Muruilem. The tuff layer is grey to pale greenish grey and outcrops at west of Site GB-P. It is composed of 1 m of fine tuff layer containing pumice fragments. Clastic sediments up to 5 m thick crop out below the tuff layer. They are grey white coloured, and consist of coarse granular sand and poorly silt.

The K-Ar ages of the basalts of unit 3, which conformably overlie unit 2 containing *Kenyapithecus*, were determined as 11.8 and 12.8 Ma (Itaya & Sawada, 1987) but the isotopic age of the basalt of unit 1 has not been determined. As already stated, however, the phonolitic trachyte of the Nachola Formation was dated to be 15.4 Ma and it is concluded therefore that the age of the *Kenyapithecus* horizon is between 15.4 Ma and 12.8 Ma.

b) Samburu Hills

The Aka Aiteputh Formation is widely distributed in the Samburu Hills. In this area the formation is dominated by basalt lavas, associated with trachytes, pyroclastics and sediments. The lowest part of the Aka Aiteputh Formation is composed of basalts or trachytic pyroclastic beds with welded tuff which conformably cover the Nachola Formation in the eastern margin of the Samburu Hills. The formation is divided into lower, middle and upper units (Fig. 7). According to Itaya & Sawada (1987), K-Ar ages of the volcanic rocks from the Aka Aiteputh Formation are as follows; 1) the lower unit—basalts: 14.5 and 15.0 Ma; 2) the middle unit—sodalite trachyte: 14.4 and 14.9 Ma, basalts: 14.1 and 14.2 Ma; 3) the upper unit—basalts 14.5, 12.7 and 10.8 Ma. (1) The lower unit below the sodalite trachyte bed consists of basalts and at least three cooling units of trachytic pyroclastics with welded tuff. The lower Aka Aiteputh Formation is a maximum 220 m thick. Makinouchi *et al.* (1984) recognized more than 13 basalt lava flows below the sodalite trachyte. The basalts chiefly consist of lavas and a few dolerite dikes and sheets intruded into them.

Aphyric and nearly aphyric basalts dominate the lower part of the formation with subordinate amounts of porphyritic and microporphyritic basalts. The porphyritic basalts contain plagioclase, clinopyroxene and olivine (±) phenocrysts several mm long. The groundmass of the porphyritic and aphyric basalts has an intergranular and sometimes fluidal texture and consists of plagioclase, clinopyroxene, olivine (±), opaque minerals and other accessory meinerals. Some of the basalts are altered. The dolerite shows ophitic texture and is composed mainly of plagioclase, clinopyroxene and opaque minerals with small amounts of olivine and carbonate.

The trachyte lapilli tuffs with welded part are red-brick coloured, and their lithofacies are similar to those of the upper part of the Nachola Formation.

(2) The middle unit consists of basalts intercalated with beds of sodalite trachyte, aphyric trachyte and trachyte pyroclastics with welded tuff. Basalts are dominant in the upper portion. The trachyte lavas and pyroclastics are 110 m in maximum thickness whereas the basalts are less than

170 m thick.

Most of the basalts are porphyritic associated with a few ankaramites. The common phenocrysts are plagioclase, clinopyroxene and olivine, embedded in an intergranular groundmass of the same minerals as phenocrysts plus aegirine augite (±) and glass (±). In a few basalts and ankaramites, plagioclase phenocryst is absent or rare, and clinopyroxene phenocrysts up to 1 cm in length ocasionally occur.

Sodalite trachyte and trachyte are recognized at three horizons and are generally aphyric, but sometimes contain a few anorthoclase phenocrysts less than 4 mm in length. The sodalite trachyte is dull green and pinkish grey and shows typical trachytic texture with a fluidal groundmass of subparallel anorthoclase laths with sodalite, augite, magnetite, apatite, zeolite and altered minerals. Aphyric trachyte consists mainly of anorthoclase laths, augite-aegirine augite, apatite and magnetite with or without devitrified matrix.

(3) The upper unit is characterized by basalts and various kinds of sediments. Their maximum total thickness is about 90 m. Common basalt lavas are massive and associated occasionally with columnar and/or platy joints, and clinkers at the base and top. Some of the lavas are autobrecciated or hyaloclastite-like while others have subrounded blocks with radial cracks similar to pillow lavas. In some cases, clinker or scoria grades into volcanic conglomerate.

Porphyritic basalts are dominant and consist of several mm of plagioclase (±), clinopyroxene and olivine (±) phenocrysts in an intergranular groundmass of the same kind of minerals as phenocrysts, opaque minerals, accessory minerals and devitrified matrix. Some basalts lack plagioclase phenocryst and/or occur only as microphenocryst. In general, clinopyroxene phenocryst is intensely zoned occasionaly with sector zoning.

The sediments consist of conglomerate, sandstone, siltstone, volcanic conglomerate, siliceous limestone and chert.

3. Namurungule Formation

The Namurungule Formation is distributed in the western part of the Samburu Hills and it is especially observed well developed along the Namurungule and Nakaporatelado Rivers (Makinouchi *et al.*, 1984). Conformably overlying the Aka Aiteputh Formation, it attains 100 to 200 m in thickness. The sequence consists mainly of clastic sediments intercalated with tuff and two beds of mud flow deposits. It is lithologically divided into two members by the upper mud flow deposits (Fig. 6). The lithofacies of each member is briefly described on the basis of observation along the Nakaporatelado and Asanyanite Rivers. Detail sedimentary successions of the Namurungule Formation are described by Tateishi (1987).

a) Lower Member

The Lower Member along the Nakaporatelado River is composed of following sedimentary sequence.

1) lower: reddish brown gravel beds including significant pebble-sized breccia of basalt, and irregularly alternating beds of gravel, sand and silt.
2) middle: reddish brown mud flow deposits and pale greenish grey granule-bearing tuff.
3) upper: yellowish green and greenish grey alternating beds of sand and dominant silt.

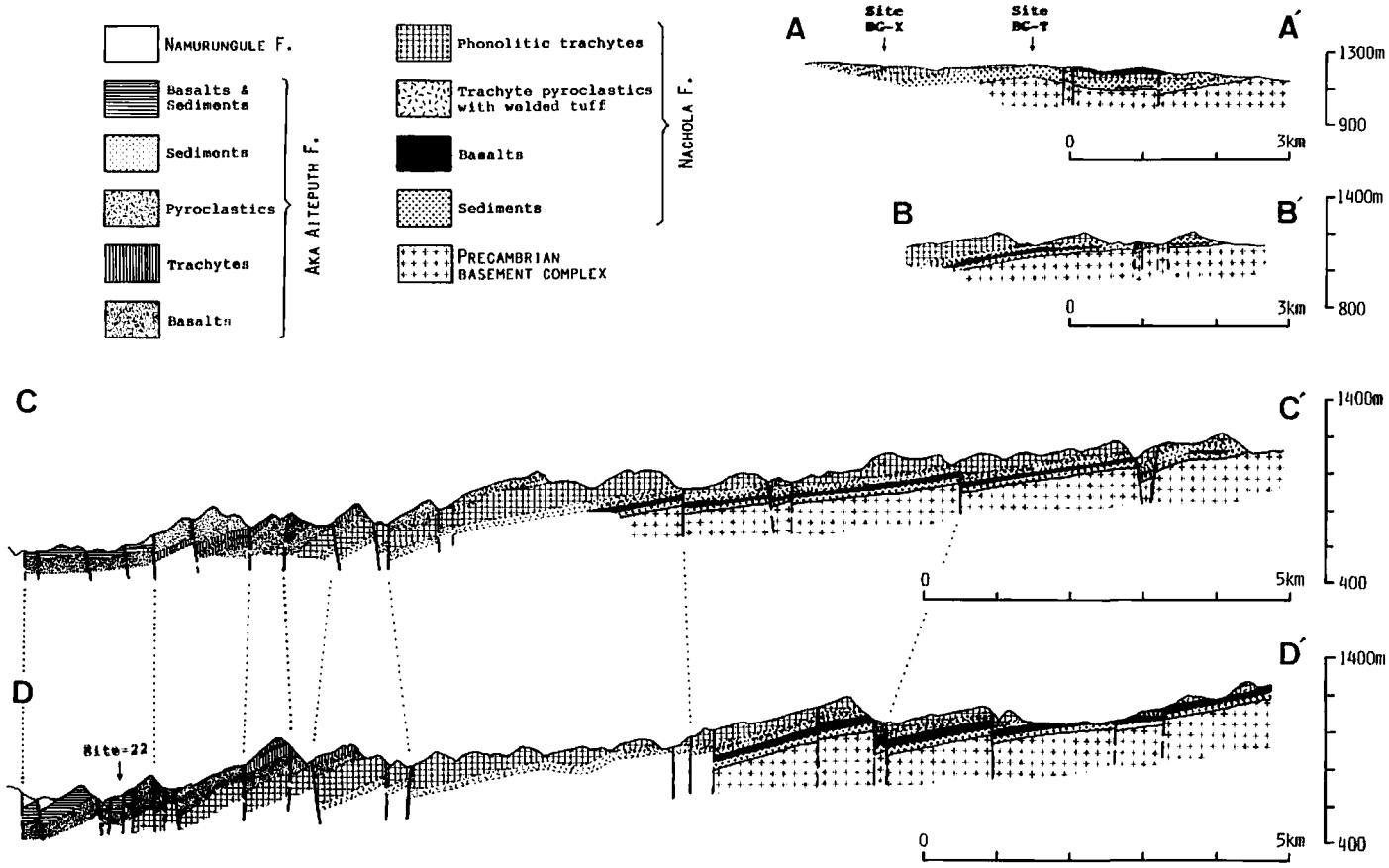

Fig. 8 Geological profiles of the Nachola area and Samburu Hills.

Termed the weathered basalt sediments by Makinouchi *et al.* (1984), the gravel bed at the base is partially trough-type cross laminated and is considered to have resulted fluid flow. Along the Nakaporatelado River, the mud flow deposit is 8 m in maximum thickness (including lapilli tuff bed at the middle part) and it grades southward into cobble beds.

The granule-bearing tuff (3.5 m thick 100 m north to Site SH-22) is almost massive (partly laminated), very fine to fine tuff with pumice and lapilli grains and crystal fragments of plagioclase and calcareous nodules. Grading locally into tuffaceous sand, the tuff is widely distributed and is observed at 5 km southwest of Site SH-22 in Molo Avenue. The alternating beds of sand and silt in the upper part consists of greenish grey massive or laminated silt of a few tens of cm to 3.5 m thick, and is yellowish green or greenish grey, fine to very coarse sand of a few to 70 cm thick with frequent intercalations of laminated yellowish white silt to fine sand with occasional calcareous layers. The sediments include many small spit-like trace fossils. The horizon yielding the hominoid fossil at Site SH-22 occurs 5.7 m above the tuff bed of the middle part.

b) Upper Member

Only the lower part of the Upper Member (about 80 m thick) is distributed along the Nakaporatelado River (Makinouchi *et al.*, 1984). It consists of 16 m of a reddish brown mud flow deposit at the base, and altermating beds of granule, sand and silt towards the top.

The mud flow deposit has an erosional base, cutting 2 m into the underlying sediments. It includes a lot of pebble-sized breccia at the base, large blocks up to 4 m in diameter in the middle, and boulder-sized volcanic breccia at the top. The gravel bed is composed of alternating units of pebble to granule-sized materisl, and grades upwards into coarse to fine sand. The base of the thick-bedded gravel beds is erosional and the overlying coarse sediments frequently show trough-type cross lamination. There are two types of silt. One is massive or laminated silt or sandy silt whereas the other is massive, granule-bearing, and ill-sorted silt. One fining upward sequence composed of gravel, sand and silt ranges from 30 to 200 cm thick.

4. Namyangaten Formation

The Nanyangaten Formation is sporadically distributed at the small hills and plateaux west to the Nanyangaten River and overlies the Nachola and Aka Aiteputh Formations with an anglar unconformity. The formation consists of porphyritic olivine basalt lavas estimated to be at least 30 m thick. The basalt is fresh and contains plagioclase ($\pm$), clinopyroxene and olivine phenocrysts (less than 5 mm in length) set in an intergranular groundmass of plagioclase, clinopyroxene, olivine, magnetite, biotite, zeolite and glass. Olivine phencrysts occasionally include minute crystals of chromite. Plagioclase phenocrysts are rare or absent in some basalts. The K-Ar age of the basalt is 7.3 Ma (Itaya & Sawada, 1987).

GEOLOGICAL STRUCTURE

As already stated, the investigated area and its surroundings are topographically divided into four part; El Barta Plains, Samburu Hills, Tirr Tirr and Emuru Akirim Plateaux, and Suguta Valley.

The Neogene System in the El Barta Plains and Samburu Hills is cut by N-S trending faults with the blocks between the faults generally tilting westwards (toward the Suguta Valley) with a gentle dip (Figs. 4 and 8). The Tirr Tirr and Emuru Akirim Plateaux are underlain by the Pliocene Tirr Tirr Formation which is nearly horizontal (Baker, 1963). The Quaternary sediments occupying the Suguta Valley are also nearly horizontal.

In general, the Nachola and Aka Aiteputh Formations in the study area trend nearly N-S, ranging from N20°E to N20°W and dip 10° to 20°W except in the following areas: the Nanyangaten Formation in the Nachola area seems to be nearly horizontal or dips gently westwards as inferred from its distribution. About 3 to 5.5 km southwest to the base camp, the Nachola Formation has a N65°E to N75°W strike and a gentle dip, 4° to 9°. In the area from about 1 km west of Loc B -5 to the junction of the Baragoi and Ayena Atir Rivers, the Nachola Formation generally strikes NE-SW and dips 10° to 15°NW. The Aka Aiteputh Formation in the eastern marginal zone of the Samburu Hills trends N65° to 70°E and dips 15°N. The general trend of the Aka Aiteputh and Namurungule Formations in the Samburu Hills is N-S, and these formations generally dip 10° to 20°W, but in some places dip steeply up to 30° to 40°W. In the vicinity of Site SH-22, the Aka Aiteputh and Namurungule Formations are disturbed by faulting.

In the Nachola area and Samburu Hills, there are many faults subparallel to the trend of the Suguta Valley, i.e., there is a major tectonic line accompanied by the formation of the rift system. According to Makinouchi *et al.* (1984), the synthetic faults in the rift system occur within a zone stretching about 2 km eastwards from the eastern margin of the Suguta Valley. In the investigated area, antithetic faults are dominant and occur in a 20 km wide zone eastwards from the above-mentioned synthetic fault zone.

In the area, the faults generally trend nearly N-S and downthrow to the east. The fault blocks incline westward. West and northwest of the base camp nearly vertical faults trending N10° to 20° W occur and their eastern sides are downthrown. Faults trending N70° to 80°W, which are righthanded, are also recognized in this area, and cut the above-mentioned faults. The N-S trending faults are dominant in the Nachola Formation along the Baragoi River from Loc. B-2 to Loc. B-4. There are two types of faults. One is a steeply dipping normal fault, downthrow to the east between 30 to 40 m. The other is a normal fault with downthrow to the west estimated to be 30 to 60 m but decreasing northwards. South of the junction of the Baragoi and Ayena Atir Rivers, N-S trending faults occur with nearly vertical fault planes. The eastern side is downthrown on most of the faults and maximum displacement is estimaied to be 80 m. In a few faults, downthrow to west is about 20 m.

Faults in the Samburu Hills are more abundant than those in the area along the Baragoi River and in the Nachola area. Most of them are nearly vertical or normal faults with downthrow to the east, reaching a maximum of about 70 m. In the vicinity of Site SH-22, there are many faults and folds. A block of the Namurungule Formation at site SH-22 has collapsed more than 40 m down into the surrounding Aka Aiteputh Formation. Faults to the west of site SH-22 trend N-S with a maximum downthrow to the east estimated to be 50 m.

A structural gap is not observed between the Nachola, Aka Aiteputh and Namurungule Formations. As already mentioned, the Nanyangaten Formation coves the Nachola and Aka Aiteputh Formation with angular unconformity. Similarly, the Kongia Formation overlies the

Namurungule Formation with an angular unconformity (Makinouchi *et al.*. 1984). These facts indicate that a large-scale structural gap exists between the Namurungule and Nanyanten Formations, i.e., a violent tectonic disturbance in the rift system took place during the period which ranges from about 10 to 7 Ma (Itaya & Sawada, 1987).

DISCUSSION AND CONCLUSION

Based on the above-mentioned geological description of the Sumburu Hills, the stratigraphy, the horizons of Miocene fossil sites and Neogene tectonic events are briefly discussed.

1) Stratigraphy

Makinouchi *et al.* (1984) proposed the Nachola Formation for Miocene strata of the Nachola area, and the Aka Aiteputh and Namurungule Formations for Miocene strata in the western part of the Samburu Hills on the basis of geological investigations in the two separte areas. They correlated lithologically the lower part of the Nachola Formation with the lower part of the Aka Aiteputh Formation. One of the purposes of the 1984 expedition was to clarify the stratigraphic relationship between the two formations by surveying along the Baragoi River between the two areas. The geological survey revealed that phonolitic trachyte is widely destributed, and that thick basalt lavas overlying the trachyte in the western part of the Samburu Hills are correlated to basalt lavas previously considered to be the uppermost part of the Nachola Formation. Forthermore, the destribution and age of olivine basalts, resting unconformably upon the Nachola Formation and called "undifferentiated basalts" by Makinouchi *et al.* (1984) is made clear. As a result of this investigation, the stratigraphy of the Samburu Hills has been revised. That is, the Neogene System of the Samburu Hills is redefined and divided into the Nachola, Aka Aiteputh, Namurungule, Nanyangaten, Kongia, Nagubarat and Tirr Tirr Formations in ascending order.

The stratigraphic relationship between the Aka Aiteputh and Namurungule Formations has been considered to be unconformable on the basis of geochronological data available and a preliminary age estimate made on the basis of limited faunal evidence (Makinouchi *et al.*, (1984). However, a structural gap between the two formations is not recognized, and the facies change from the upper part of the Aka Aiteputh Formation to the Namurungule Formation is gradual. Therefore, both formations are considered to be essentially conformable. On the other hand, the stratigraphical relationship between the Namurungule and Nanyangaten Formations is considered to be structurally unconformable, though they are distributed in separate area. Accordingly, a striking tectonic event apparently intervenes between the Namurungule and Nanyangaten Formations.

2) Horizons of Miocene hominoid fossil sites

The 1982 and 1984 Japan-Kenya Expeditions collected a lot of Miocene fossils from the Nachola area and the western part of the Samburu Hills (Pickford *et al.*, 1984 a, b; Nakaya *et al.*, 1984). Sites BG-X and BG-I in the Nachola area, and Site SH-22 in the western part of the Samburu Hills are regarded as very important from the viewpoint of palaeoanthoroplogy (Ishida *et al.*. 1984).

Makinouchi *et al.* (1984) considered Site BG-X (*Kenyapithecus* site) to be underlain by the

upper sediments of the Emuruilem Member. of the Nachola Formation. *Kenyapithecus* occurred from the granule bearing silt of the basal part of the upper sediments. As mentioned above, however, the Emuruilem Member was revised to be correlated with the lower part of the Aka Aiteputh Formation (Fig. 6-A 3). *Kenyapithecus* was also collected from Site BG-I being at the same stratigraphic horizon as BG-X by the 1984 Expedition. It is concluded that *Kenyapithecus* is derived from the lower part of the Aka Aiteputh Formation, whose K-Ar age is 15 to 13 Ma (Itaya & Sawada, 1987).

Sit SH-22 in the western part of the Samburu Hills is underlain by the lower part of the Namurungule Formation (Makinouchi *et al.*, 1984). The Samburu large hominoid was obtained from yellow greenish, fine pebbly silt bed. The Namurungule Formation conformably overlies the Aka Aiteputh Formation dated 15.0 to 10.8 Ma. The Namurungule Formation has been affected by a striking tectonic disturbance and is overlaid by the Kongia Formation. The major tectonic disturbance took place after the deposition of the Namurungule Formation and before the formation of the Nanyangaten Formation dated 7.3 Ma. Therefore these data lead to the conclusion that a horizon containing the Samburu hominoid is 10.8 to 7.3 Ma.

3) Naogene volcanic and tectonic events

From the stratigraphy mentioned above and the K-Ar age data of Itaya & Sawada (1987), the Neogene volcanic and tectonic events in the region are inferred as follows.

The main volcanic activity in the investigated aresa is divided into two stages; the first: 19 Ma to 10 Ma, and the second: 7 Ma to late Quaternary. The volcanic activity of the first stage began with eruptions of basalt and trachybasalt. The phonolitic trachyte was extruded following the volcanic activity of the early phase of this stage. The volcanism of the late phase is characterized mainly by the eruptions of basalt. The volcanic rocks of 15 Ma to 13 Ma are most widely distributed, so the volcanic activity of this period was extensive. The volcanic activity was extinct or very weak in a period from 10 Ma to 7 Ma around the Samburu Hills. Volcanism characterized by basaltic eruption began at 7 Ma, and intermittently continued up to the late Quaternary. Most of the volcanic activity at the second stage were the eruptions of basalt except for alkali rhyolite around 4 Ma.

There are many normal faults subparallel to the general trend of the rift system. Generally, the faulting was downthrown eastward and most of fault blocks were tilted wesward, i.e., toward the rift floor. The degree of tilting becomes steeper toward the margin of the rift floor. As already mentioned, the volcanic rocks of the second stage clinounconformably cover the Namurungule and the underlying formations. It is concluded from these facts that the major tectonic events, both faulting and tilting, took place between the volcanic activity of the first and second stages, 10 Ma to 7 Ma.

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REFERENCES

Baker, B. H., 1963. Geology of the Baragoi Area, with coloured geologic map. *Rept. Geol. Surv. Kenya.* No. 53, 74 p., Goverment of Kenya.

— — — — —, L. A. J. Williams, J. A. Miller and F. J. Fitch, 1971. Geochronology of the Kenya Rift volcanics, *Tectonophysics*, 11, 191-215.

Ishida, H., M. Pickford, H. Nakaya and Y. Nakano, 1984. Fossil Anthropoids from Nachola and Samburu Hills, Samburu District, Kenya. *African Study Monographs, Supplementary Issue* 2: 73-86.

Itaya, T. and Y. Sawada, 1987. K-Ar Ages of Volcanic Rocks in the Samburu Hills Area, Northern Kenya. *African Study Monographs, Spplementary Issue* 5: 27-45.

Makinouchi, T., T. Koyaguchi, T. Matsuda, H. Mitsushio and S. Ishida, 1984. Geology of the Nachola Area and the Samburu Hills, West of Baragoi, Northern Kenya. *African Study Monographs, Supplementary Issue* 2: 15-44.

Nakaya, H., Pickford, Y. Nakano and H. Ishida, 1984. The Late Miocene Large Mammal Fauna from the Namurungule Formation, Samburu Hills, Northern Kenya. *African Study Monographs, Spplementary Issue* 2: 87-131.

Pickford, M., Ishida, Y. Nakano and H. Nakaya, 1984. Fossiliferous Localities of the Nachola -Samburu Hills Area, Northern Kenya. *African Study Monography, Supplementary Issue* 2: 45-56.

— — — — —, H. Nakaya, H. Ishida and Y. Nakano, 1984. The Biostratigraphic Analyses of the Faunas *African Study Monographs, Supplementary Issue* 2: 67-72.

Tateishi, M., 1987. Sedimentary Facies of the Miocene in the Samburu Hills, Northern Kenya. *African Study Monographs, Supplementary Issue* 5: 59-77.