New chronology for the Early Miocene mammalian faunas of Kisingiri, Western Kenya

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Abstract: New total-fusion K-Ar ages indicate that all of the fossiliferous formations that make up the lower part of the Early Miocene Kisingiri sequence in western Kenya at Rusinga Island, Mfwangano Island, and Karungu were deposited during an interval of less than 0.5 million years at c. 17.8 Ma ago. This contrasts markedly with K-Ar ages previously published from these detrital-tuffaceous formations, which suggested that they were deposited over an interval of as much as 7 million years between 23 and 16 Ma, overlapping the age-ranges of all other East African Early Miocene sites including Koru, Songhor, Napak, Bukwa, Loperot, Muruarot and Buluk. In addition, the analytical problems revealed by the new Kisingiri results cast doubt on biotite ages which provide dating for the most important sites. Thus, the strong differences between the Kisingiri fauna and those of Koru, Sonhor and Napak, long held to be due to ecology because of the apparent overlap in ages, may actually be due to a difference in time. If this view of the geochronology is correct, it may now be possible to identify adaptive trends and evolutionary succession in the East African Early Miocene faunas.

The primitive catarrhines from the Early Miocene fossil beds of East Africa are now known to be a highly diverse group which includes the earliest true hominoids (Harrison 1986), and probably the ancestral cercopithecoids as well. Fifteen or more species are currently assigned to *Proconsul, Rangwapithecus, Nyanzapithecus, Limnopithecus, Dendropithecus, Micropithecus, Xenopithecus, Afropithecus, Turkanopithecus, Simiolus* and *Heliopithecus* (Andrews 1978; Harrison 1981, 1986; Bosler 1981; Leakey & Leakey 1986). These are associated with more than 90 other mammal species, from elephant-shrews to elephants (see Van Couvering & Van Couvering 1976). The richest sites are in paravolcanic sequences associated with the carbonatite–nephelinite volcanic complexes of Kisingiri (also known as Rangwa) and Timboroa (also known as Tinderet) in the Nyanza Rift of western Kenya (Fig. 1), and at Napak in eastern Uganda (Bishop *et al.* 1969). Among a wide variety of age values previously obtained by K-Ar dating of these sequences, the 'accepted' stratigraphically and palaeontologically consistent dates ranged between 23 and 16 Ma (Bishop *et al.* 1969; Van Couvering & Miller 1969) although younger ages were also presented (Evernden *et al.* 1964; Le Bas & Rubie 1977). However, the succession of Early Miocene fossil faunas in the Kisingiri, Timboroa and Napak sequences shows greater external than internal differences (Van Couvering & Van Couvering 1976) despite the fact that the published dating indicated that they were roughly coeval, and Pickford (1982) identified two groupings, termed 'Set I' for Timboroa, Napak and lower Kisingiri (Karungu, Kiahera) faunas, and 'Set II' for upper Kisingiri (Hiwegi, Kulu) faunas. Restudy of the collections and corrections of curatorial errors have tended to reduce the differences between the various Kisingiri faunas, and to enhance their difference as a unit from those of the

Timboroa and Napa, sequences (Andrews 1978, p. 110; Bosler 1981; see also the section on palaeontology below).

Other Early Miocene sites have also been dated, for the most part directly, within the 23–16 Ma time range. Bukwa on Mt Elgon has a Set II fauna (Pickford 1982) but is dated to 23 Ma (Walker 1969). Localities in northern Kenya sample an assemblage with characteristic differences from both Set I (Timboroa–Napak) and Set II (Kisingiri) that indicate either a younger age, a different environment, or both (Pickford 1986). These are the 'Tiati Grit' local faunas of Loperot and Muruarot (including Lothidok and Kalodirr) in the south-western Lake Turkana basin, between 18 and 16 Ma (Savage & Williamson 1978; Leakey & Leakey 1986); the correlative Mwiti sequence (Kajong and Loiengalani) in the south-eastern Turkana Basin (Savage & Williamson 1978); and Buluk in the Lake Stephanie basin, between 17.2 and 18 Ma (McDougall & Watkins 1985). Because of the apparent chronological overlap of all these Early Miocene faunas, virtually no evolutionary trends have been proposed until now for the East African Early Miocene mammals (e.g. Simpson 1967).

This paper presents a revison of the geochronology for the Kisingiri sequence, which includes the fossil beds of Rusinga (in the Wayando, Kiahera, Hiwegi and Kulu formations), Mfwangano (in the Kiahera, Rusinga Agglomerate and Hiwegi formations), Karungu and Uyoma (see Fig. 1). Our study suggests that the wide range in ages and anomalously old dates previously reported from the pyroclastic and hypabyssal biotites in the lower part of the Kisingiri sequence are the result of post-eruptive loss of potassium with only partial argon degassing, a type of alteration not previously described in near-surface environments (see, however, Shepherd *et al.* 1976). Inasmuch as biotite lapilli of the type found in the Kisingiri tuffs have
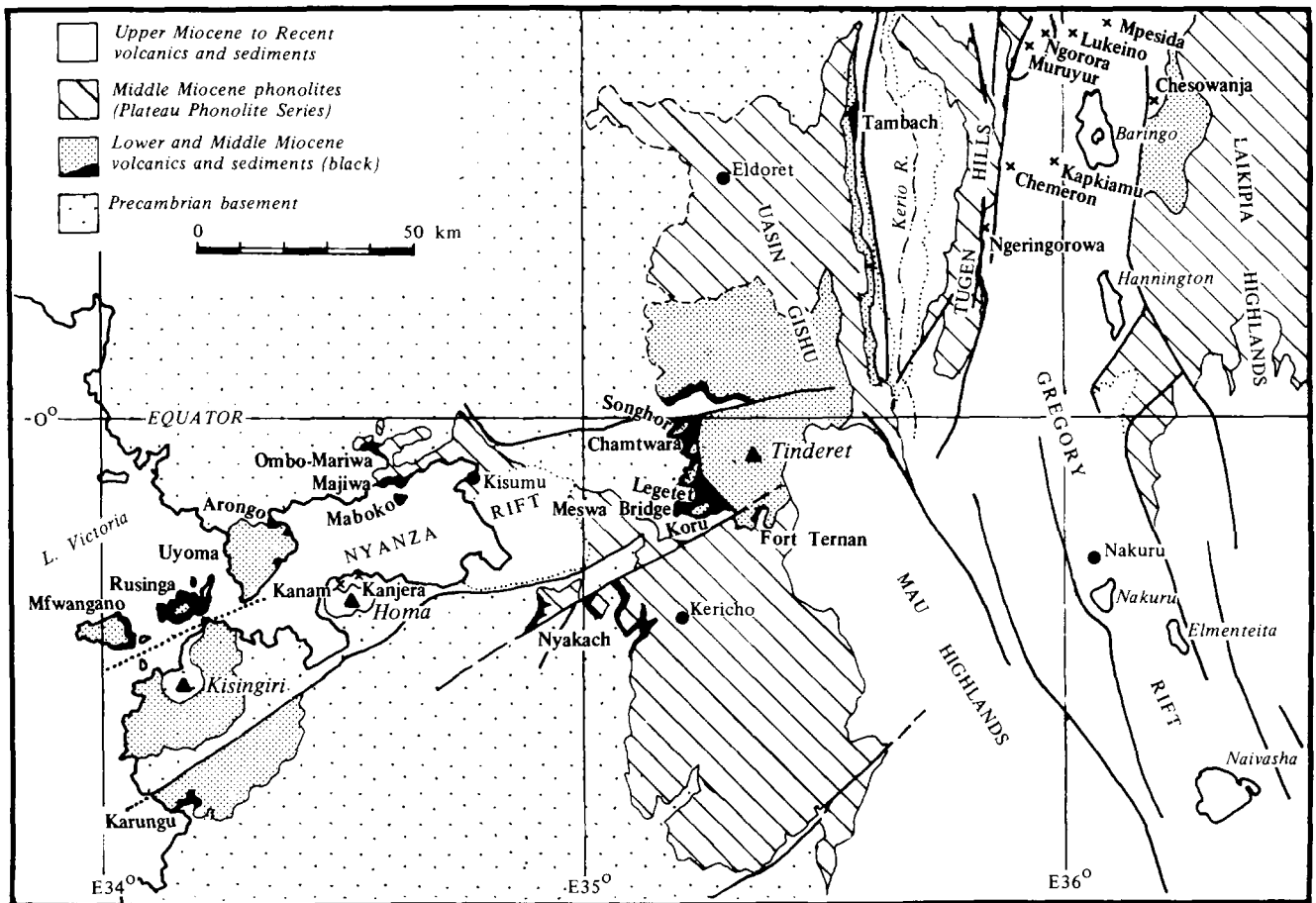
Fig. 1. Miocene geology and fossil sites of western central Kenya. Fossil-bearing Lower and Middle Miocene deposits, between *c*. 23 and 15 Ma in age, are indicated in solid black.

been the mainstay of dating in the East African Miocene, the other radiometric chronologies should also benefit from this re-examination.

The new geochronology is based on (i) 29 new ^{40}K-^{40}Ar age determinations from Rusinga, Mfwangano and Karungu; (ii) an improved stratigraphy for the fossiliferous deposits; and (iii) an updated, comprehensive inventory of the mammalian taxa (including hitherto poorly described and new material). Drake and Curtis are responsible for the age determinations, Van Couvering and Pickford for the stratigraphy and the K-Ar sample data, and Pickford for the palaeontological review; the text was prepared by Van Couvering.

Geology

'Kisingiri' appears on maps as early as that of Oswald (1914), as the name for the horseshoe-shaped range of mountains remaining from a Miocene volcanic cone at the mouth of the Winam Gulf in the Nyanza Rift Valley. However, the mountains are called Gwasi and Gembe by the local people, and the term 'Kisingiri' apparently originated as a misapplication of *Kaksingere*, a clan area on the coastal flats at the foot of the range.

The deeply eroded crater area, in which a subvolcanic dome and central vent complex are exposed at Rangwa Hill

(Shackleton 1951, p. 373), lies in a post-eruptive graben between north-west-oriented fault lines (McCall 1958; Le Bas & Rubie 1977; Rubie & Le Bas 1977). The northern wall of the graben forms the islands of Rusinga and Mfwangano, and slopes down further north to Ngodhe Island and the low mesa of the Uyoma peninsula (Fig. 1). The opposite graben wall to the south is the Olambwe (Kaniamwia) escarpment, beyond which lies Karungu. The original size of the volcano is shown by the fact that the preserved northern and southern limits of Kisingiri lavas are about 70 km apart. This is only slightly less than the mean diameters of Kilimanjaro, Mt Kenya or Elgon.

The clearest record of Kisingiri development is on Rusinga Island. At the top of the sequence are nephelinitic stratovolcano deposits of the Kisingiri Group (the mainland 'Kisingiri Series' of McCall 1958), lying on a nearly level surface, cut across tilted and faulted earlier formations which are not present on the central graben block. On Rusinga, the pre-Kisingiri strata of the external block are the mixed epiclastic–pyroclastic formations of the Rusinga Group, and the succeeding fluviolacustrine Kulu Group.

Parts of Rusinga were mapped by Shackleton (1951) and Whitworth (1953), and their stratigraphy was revised and extended to the whole island by Van Couvering (1972; see also Van Couvering & Miller 1969). Correlation to Mfwangano Island (Whitworth 1961), as well as to the
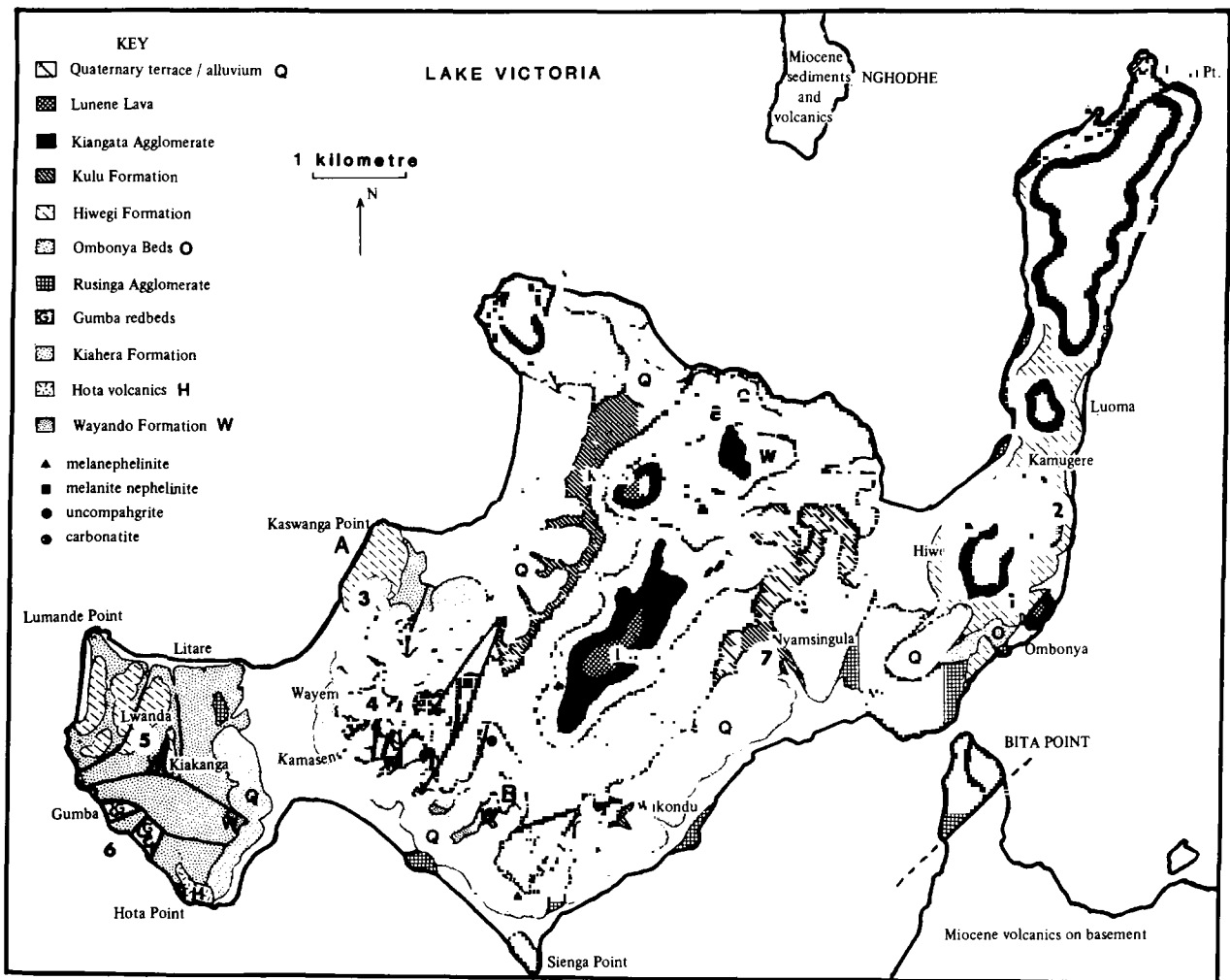
Fig. 2. Geology of Rusinga Island. Main fossil collecting areas in Hiwegi Formation are: (1) Hiwegi R1–R1A, (2) Hiwegi R3–R3A, (3) Kaswanga Point R5, (4) Kiahera R105–R106–R107 and Kamasengere R113, and (5) 'Whitworth's Pot Hole' R114. Others are (6) Gumba R74 and R75, (7) Kulu Fish Beds R2–R4 and (8) Wayando R76. Biotite lapilli sampled for K-Ar ages are mostly from Kaswanga–Kiahera area (Fig. 4) and also Gumba and Hiwegi. Whole-rock samples are from the lava caps of Lugongo and Wanyama. Points A and B indicate transect line for Fig. 4.

Uyoma peninsula and Karungu (cf. Oswald 1914) is based on fieldwork by J.A.V.C. and M.P. The regional stratigraphy that emerges from our work (see Fig. 3) supports the new dating, as certain earlier interpretations would not (McCall 1958; Le Bas & Rubie 1977). The brief discussion that follows shows how this is justified.

Inflation of the so-called Rangwa Dome was the earliest event in Kisingiri volcanic history. This subvolcanic structure eventually grew to a diameter of some 10–15 km and a relief of at least 700 m (McCall 1958; Rubie & Le Bas 1977), and was the locus of hyperalkaline metasomatism (fenitization) and intrusion of carbonatitic and hyperalkaline silicate magmas (Le Bas & Rubie 1977), as at other alkaline igneous centres, e.g. in Uganda (Trendall 1965) and South Africa (Wet 1975). In the stratigraphic sequence on Rusinga Island, the initial uplift of Rangwa Dome is represented at the base of the Rusinga Group by deposits of rubbly, poorly-sorted and relatively unweathered granitic debris, which in some sections was derived mainly or entirely from fenitized rocks and in others from unaltered

exposures. Associated with the fenitized material are blocks derived from intrusive carbonatite and ijolite. Despite this evidence for intrusive activity, no extrusive material has been found at this level. The basal unit, first recognized by Shackleton (1951) as 'Kiahera Brown Breccia' and called 'lower Kiahera Formation' by Van Couvering & Miller (1969), is here distinguished as a separate pre-eruptive unit, the Wayando Formation, with its type area in the Wayando syncline of east–central Rusinga (Fig. 2). The formation is absent on Mfwangano, and has not been observed on the Uyoma peninsula, but at Karungu arkosic sandy rubble eroded from a similar suite of fenitized basement and alkaline-carbonatite intrusives make up the lower half or more of the fossil beds (Fig. 3). On Rusinga, most fossils from the Wayando Formation (which may have included some of the first vertebrate discoveries on Rusinga; see Wayland 1931) occur in layers of poorly consolidated arkosic sand, and are generally stained red or brown with iron oxides.

Eruptive vulcanism at Kisingiri began with pyroclastic

Fig. 3. Correlation of Miocene stratigraphy in the Kisingiri complex. Note that the Kulu Group, deposited during a non-eruptive interval, represents a longer period of sedimentation than the much thicker Rusinga and Kisingiri groups. The transition from pre-eruptive to eruptive deposition at 17.8 Ma is recognizable at both Karungu and Rusinga. Fm, formation; Mb, member.

explosions that are recorded by copious and common tuffaceous admixtures throughout the deposition of the Kiahera, Rusinga and Hiwegi formations. The tuffaceous materials are mainly lithic lapilli of nephelinitic glass with phenocrysts of melilite, magnetite and biotite. Conspicuous individual crystal lapilli of biotite and large accretionary 'volcanic hailstones' are abundant at many levels. The pyroclastic suite indicates phreatic eruptions of a melilitic lava, apparently from the Rangwa centre (see below). Associated with the explosions at the central vent were parasitic local eruptions of fluid lava, mainly the several melanite garnet-nephelinite flows of the Rusinga Agglomerate, but also minor bodies of nephelinite and olivine-melilitite lava (Whitworth 1953; Van Couvering 1972).

The lapilli of mica are black (or chestnut brown in thin flakes) and extremely large, up to 3 cm in diameter and 1 cm in thickness. In the lapilli of lava fragments, the ground mass (?nephelinite glass) and melilite phenocrysts have been more or less completely replaced by montmorillonite clay, itself widely altered to coarse crystalline zeolite (analcime, natrolite and phillipsite in sequence) and calcite. The same sequence of alteration has lithified the intergranular dust of

the tuff-rich beds. The alteration is strata-bound and apparently proceeded near the surface, as a pedogenic process in the presence of highly alkaline groundwater (see discussion in Van Couvering 1972).

Hiwegi fossils are solidly calcified, and occur mainly in beds where coarse lapilli are lacking. The highest concentrations of fossils (other than in the unusual 'pot-hole' at R.114 in western Rusinga, recently re-excavated by A. W. Walker and R. E. Leakey; see locality 5 on Fig. 2) occur in brittle, red-weathering clayey silts, which are grey-green and solidly indurated below the soil horizon. Other specimens, many of them large whole bones, occur in massive red or grey sandy silts at the base of calcified grits. Larger fossils tend to be plastically distorted. The bones are creamy white to buff, and the teeth dark brown. Fine bright-grey sands within the grits yield leaf impressions.

A prolonged nonvolcanic hiatus following the Rusinga Group eruptions is recorded in the Kulu Group. This unit occupies a deeply incised surface with local relief of over 75 m, and is composed mainly of material washed from the Hiwegi Formation and Rusinga Agglomerate, including slump-blocks up to 5 m in length near palaeo-cliffs. Overall,

post-depositional diagenesis is not as intense as in Rusinga Group tuffaceous sediments, but the feldspathized 'Fish Beds' at Nyamsingula (loc. 7 on Fig. 2) and secondary travertines at Wakondu are exceptions (see Van Couvering 1972). Mammal and reptile fossils occur mainly in loosely-cemented grey or red silty sandstones; they are generally chalk-white with a red veneer and are somewhat more fragile than Hiwegi specimens, but with a similar high proportion of complete and undamaged pieces. Bird fossils, mainly legbones of waders, and disarticulated fish remains are common in contrast to Hiwegi faunas. Abundant small whole fish, together with small crocodiles and frogs, occur in cryptically layered mudstones (Van Couvering 1982).

The Gumba Beds, faulted inliers with an uncertain, possibly Kulu or possibly early Rusinga Group age (Whitworth 1953; also see below), consist of brittle red clays and pebble beds which yield heavily iron-stained, well-calcified but fragmented fossils, the majority of bones being those of large fish and crocodilians. Eruptive layers are absent.

At the top of the section, the lavas of the Kisingiri Group are equivalent to the thick extrusive section which rests directly on fenitized basement rocks in the Rangwa area (McCall 1958; Rubie & Le Bas 1977). On Rusinga, these lavas consist of a wedge of nephelinite agglomerates (Kiangata Agglomerate) capped by multiple flows of augite-rich melanephelinite (Lunene Lava). The Lunene flows are separated by weathering horizons and locally by red lateritic soils, one of which on Hiwegi Hill yielded a few mammal remains (Shackleton 1951, p. 354). On the Uyoma Peninsula, volcaniclastics and pond silts intercalated with the capping agglomerates and lavas (Pickford 1984) are more fossiliferous (Fig. 4). On the north side of Hiwegi Hill, and at Mbita Point, a distinctive augite-lapilli tuff is exposed, which appears to occupy a deep channel or depression beneath the basal Lunene flow (Fig. 2).

It is important to prove that the Rusinga Group is entirely older than the Kisingiri nephelinites. McCall (1958) considered that the Rusinga fossil beds were intercalated within the Kisingiri volcanics, and the dating performed on the Kisingiri lavas by Le Bas & Rubie (1977) is inconsistent with ages reported here for the Rusinga–Karungu fossils. The principal argument is lithologic: on the mainland there are no turjaitic pyroclastics in the Kisingiri lava sequence, and this also true of the lithologically correlative lava sequence that rests unconformably on the tuffaceous sequence of the islands. Kisingiri nephelinites are uniformly magnetite-rich and garnet-poor (Rubie & Le Bas 1977), in complete contrast to highly garnet and sphene-rich nephelinite lavas and agglomerates of the Rusinga Group that McCall (1958) included in the Kisingiri suite. Furthermore, no volcaniclastic strata with typical Rusinga Group lithology have been mapped in the central graben (cf. McCall 1958; Le Bas & Rubie 1977), neither at the base of the nephelinite lavas nor (more to the point) within them. Kulu-equivalent beds, however, may be represented by non-volcanic strata at Ikoro, at the eastern end of the Kaniamwia escarpment (Pickford 1984).

The second argument is structural–stratigraphic. Mapping on Rusinga (Whitworth 1953; Van Couvering 1972) shows that the Rusinga Group is a prism of strata which thickens and becomes markedly more conglomeratic north-eastward the Mfwangano fault of McCall (1958), which is seen at Mbita Point and on the tip of the Uyoma

peninsula (Figs 1 & 2). This, together with the absence of the pre-Kisingiri formations from the central block, is evidence that the Mfwangano and Kaniamwia faults are now reversed, and originally separated marginal downthrown blocks from an uplifted central horst which was shedding basement, intrusive and pyroclastic debris from the slopes of the Rangwa Dome. In this interpretation the Kisingiri nephelinites covered both the stripped dome and the sediments of the external downfaulted basins during the final stratovolcanic phase. When magmatic pressures relaxed and eruptions came to an end, the central block subsided and left the strata of the external blocks on the shoulders of the newly-formed graben.

Geochronology

Previous work

The 'Rusinga fauna' was one of the first to be dated (Evernden et al. 1964) with the advent of K-Ar age analysis for Tertiary continental strata. Five biotite samples from the R107 site at the foot of Kiahera Hill (loc. 4, Fig. 2) were collected to give an age to the famous '1984 skull' assigned to Proconsul africanus, found at the adjoining R106A site (see Clark & Leakey 1951). Of these, only the handpicked large euhedral crystals of samples KA336 and KA336R (repeat date) gave plausible ages: 15.0 ± 1.4 and 16.3 ± 1.5 Ma, respectively (Table 1). The other samples, consisting of fine-grained biotite concentrated from tuffaceous sediment, gave anomalously old dates that were ascribed to basement contamination. The 'good' ages, however, indicated that the Rusinga Proconsul fauna was coeval with the mid-Miocene Dryopithecus faunas of Eurasia (Evernden et al. 1964). This correlation was criticized by the late Leakey (1967), among others (e.g. Bishop et al. 1969), on the grounds that the African fauna was clearly more primitive. Leakey contended that the stratigraphy of Site R107 had been shown to be complicated by Shackleton (1951), and that the samples, collected by Evernden on an afternoon visit, might well have come not from the beds called 'Kiahera Series', to which the fossil beds at R107 were then attributed, but from nearby outcrops of more lapilli-rich but presumably younger strata assigned to 'Kathwanga Point Beds'.

In February 1969, Van Couvering & Miller presented a revised stratigraphy of Rusinga, together with the results of a detailed study of the Kiahera Hill–Kaswanga Point section (cf. Fig. 5). Both the 'Kiahera' fossil beds and the 'Kathwanga Point Beds' at R107 were placed in the lower Hiwegi Formation, as were most other fossil sites on Rusinga (Fig. 3). New dates from nepheline in the Rusinga Agglomerate and from whole-rock samples of Lunene Lava bracketed the Hiwegi Formation with ages of 20.0 and 16.9 Ma (as recalculated in Table 1). Repeated analyses at Cambridge of handpicked giant biotite lapilli from the true Kiahera as well as from the Hiwegi Formation, including a resample of the site from which 'good' Berkeley dates probably came, gave results that were comparable to the original biotite dates only in their inconsistency, suggesting an inherent unreliability. From the non-biotite dates, it was concluded that the faunas from Rusinga were of Early Miocene age, as Leakey had claimed, and spanned an interval between 22 Ma (Kiahera) and 17 Ma (Kulu), with Hiwegi faunas interpolated to c. 18.5 Ma.

	WAY	KIA	KAR	RAG	HIW	KUL	UYK	GUM	UYU
Miorhyncocyon clarki (Butler & Hopwood)	.	.	.	x	x	x	.	.	.
Myohyrax oswaldi Andrews	x	x	x	.	x	x	.	?	.
Hiwegicyon juvenalis Butler	.	.	.	.	x	.	.	.	.
Parageogale aletris (Butler)	.	.	.	.	x	.	.	.	.
Protenrec tricuspis Butler & Hopwood	.	.	.	.	x	.	.	.	.
Gymnurechinus leakeyi Butler	.	.	.	.	x	x	.	.	.
Gymnurechinus camptolophus Butler	.	.	.	.	x	.	.	.	.
Amphechinus rusingensis Butler	.	.	.	.	x	x	.	.	.
Galerix africanus Butler	.	.	.	.	x	.	.	.	.
Propotto leakeyi Simpson	.	.	.	.	x	.	.	.	.
Molossid nov. sp.	.	.	.	.	x	.	.	.	.
Emballonurid indet.	.	.	.	.	x	.	.	.	.
Megalodermatid indet.	.	.	.	.	x	.	.	.	.
Komba minor (Clark & Thomas)	.	.	.	.	x	.	.	.	.
Komba robustus (Clark & Thomas)	.	x	.	.	x	.	.	.	.
Progalago songhorensis Simpson	.	.	.	.	x	.	.	x	.
Mioeuoticus sp. - Leakey	.	.	.	.	x	.	.	.	.
Dendropithecus macinnesi (Clark & Leakey)	x	x	x	.	x	x	x	x	.
Limnopithecus legetet Hopwood	.	.	.	.	x	.	.	x	.
Proconsul africanus Hopwood	.	x	.	x	x	.	.	x	.
Proconsul nyanzae Clark & Leakey	x	x	x	.	x	x	.	.	.
Rangwapithecus gordoni Andrews	.	.	.	x	x	.	.	.	.
Nyanzapithecus vancouveringi (Andrews)	.	.	.	x	x	.	.	.	.
Kenyalagomys rusingae MacInnes	x	x	?	.	x	x	.	.	.
Kenyalagomys minor MacInnes	.	.	.	.	x	.	.	.	.
Paraphiomys piggoti Andrews	x	x	x	x	x	x	.	x	x
Paraphiomys stromeri Lavocat	x	x	x	.	x	x	.	.	.
Epiphiomys coryndoni Lavocat	.	.	.	.	x	.	.	.	.
Elmerimys woodi Lavocat	.	.	.	.	x	.	.	.	.
Diamantomys luederitzi Stromer	x	x	x	.	x	.	.	x	.
Kenyamys mariae Lavocat	.	.	.	.	x	.	.	.	.
Simonimys genovefae Lavocat	x	.	.	.	x	.	.	.	.
Myophiomys arambourgi Lavocat	.	.	.	.	x	.	.	.	.
Proheliophobius leakeyi Lavocat	x	.	.	.	x	.	.	.	.
Paranomalurus soniae Lavocat	.	.	.	.	x	.	.	.	.
Paranomalurus walkeri Lavocat	.	.	.	.	x	.	.	.	.
Megapedetes pentadactylus MacInnes	x	x	.	.	x	.	.	.	.
Pedetid gen. et sp. nov.	.	.	.	.	x	.	.	.	.
Protarsomys macinnesi Lavocat	.	.	.	.	x	.	.	.	.
Vulcanisciurus africanus Lavocat	.	.	.	.	x	.	.	.	.
Teratodon enigmae Savage	?	.	.	.	x	.	.	x	.
Pterodon nyanzae Savage	.	.	.	.	x	.	.	.	.
Pterodon africanus Savage	.	.	.	.	x	.	.	.	.
Anasinopa leakeyi Savage	.	.	x	.	x	.	.	x	.
Metapterodon kaiseri Stromer	.	.	x	.	x	.	.	.	.
Leakeytherium hiwegi Savage	.	.	.	.	x	x	.	.	.
Hyaenodon andrewsi Savage	.	.	.	.	x	.	.	.	.
Hyaenodon pilgrimi Savage	.	.	.	.	x	.	.	.	.
Hecubides euryodon Savage	.	x	.	.	x	x	.	.	.
Hecubides macrodon Savage	.	.	.	.	x	.	.	.	.
Kichechia zamanae Savage	x	.	?	.	x	x	.	.	.
Afrosmilus africanus (Andrews)	.	.	x	.	x	.	.	.	.
Myorcteropus africanus MacInnes	.	.	x	.	x	x	.	x	.
Orycteropus minutus Pickford	.	.	x	.	.	.	.	x	.
Prodeinotherium hobleyi (Andrews)	x	x	x	.	x	x	x	x	.
Archaeobelodon sp. - Tassy	x	.	x	x	x	x	.	.	.
Eozygodon morotoensis (Pickford & Tassy)	.	.	.	.	x	.	.	.	.
Pachyhyrax championi (Arambourg)	x	?	x	x	x	x	x	x	x
Prohyrax bateae (Whitworth)	.	.	?	.	x	.	.	.	.
Chalicotherium rusingense Butler	x	.	x	x	x	x	.	x	.
Dicerorhinus leakeyi Hooijer	x	.	x	.	x	x	.	x	.
Aceratherium acutirostratum (Deraniyagala)	x	.	x	.	x	x	x	x	.
Brachypotherium heinzelini Hooijer	x	x	x	.	x	.	x	x	.
Chilotheridium pattersoni Hooijer	.	.	.	.	.	x	.	x	.
Hyoboops africanus (Andrews)	.	.	x	.	x	x	.	x	.
Masritherium aequitorialis (Macinnes)	x	x	x	.	x	x	x	x	.
Anthracotheriid nov. gen. sp.	.	.	.	.	.	x	.	.	.
Diamantohyus africanus Stromer	.	.	x	x	x	x	x	x	.
Libychochoerus jeanelli (Arambourg)	.	.	x	.	x	x	x	x	.
Kenyasus rusingensis Pickford	.	x	x	.	x	.	x	x	.
Nguruwa kijivium (Wilkinson)	x	x	.	x	x	.	.	.	.
Dorcatherium chappuisi Arambourg	x	.	x	x	x	x	.	.	.
Dorcatherium piggoti Whitworth	x	x	.	.	x	x	x	x	.
Dorcatherium parvum Whitworth	x	.	x	x	x	x	x	x	x
Dorcatherium songhorensis Whitworth	x	.	.	.	.	.	.	.	.
Canthumeryx sirtensis Hamilton	x	.	?	.	x	.	x	x	.
Propalaeoryx nyanzae Whitworth	x	x	x	.	x	.	.	x	x
Walangania africanus (Whitworth)	.	x	x	.	x	x	.	.	.

Fig. 4. Miocene fossil mammals of Kisingiri. Biostratigraphic levels: WAY, Wayando Fm. of Rusinga, Excluding Gumba and R.113 (Kamasengere) sites; KIA, Kiahera Fm. (mainly Mfwangano sites); KAR, Karungu; RAG, Rusinga Agglomerate (mainly Mfwangano sites); HIW, Hiwegi Fm. (mainly sites on Rusinga but also Mfwangano Pisolithic Tuffs and Uyoma Magare); KUL, Kulu Fm. (Rusinga); UYK, Kulu(?) equivalents on Uyoma; GUM, Gumba redbeds of Rusinga; UYU, Kiangata and Lunene of Uyoma peninsula. ×, confirmed presence; ?, provisional identification.

Table 1. *Previously published age determinations*

Sample	Material	K (%)	Age (Ma)	Source	Locality
(Evernden et al. 1964)					
KA 336	Biotite	2.72	15.0 ± 1.4	Hiwegi (not 'Kiahera')	Loc. R107, north side Kiahera
KA 336R			16.3 ± 1.5	Formation lapilli	Hill, Rusinga
(Van Couvering & Miller 1969)					
RK-5	Melanephelinite	1.20	13.9 ± 0.4	Dike in Hiwegi Fm.	Kaswanga Point, Rusinga
			13.9 ± 0.4		
RK-8	Melanephelinite	1.61	17.2 ± 0.6	Lunene Lava	Cap of Wanyama Hill,
			16.7 ± 0.5		Rusinga
RK-9	Melanephelinite	0.87	16.9 ± 0.7	Lunene Lava	Cap of Lugongo Hill,
			13.9 ± 0.4		Rusinga
RK-11N	Nephelinite	4.33	20.1 ± 0.2	Rusinga Agglomerate	Wayando Hill, Rusinga
			20.0 ± 0.2		
(Bishop et al. 1969)					
Al 218	Biotite	8.27	19.5 ± 0.3		
			19.5 ± 0.3	'Biotite uncompahgrite'	Rangwa uncompahgrite
	Biotite	8.19	19.7 ± 0.3	(?Turjaite)	complex
			18.8 ± 0.3		
Al 243	Phlogopite	1.80	43 ± 5	Carbonatite intrusive	Ekiojango carbonatite, Rangwa
RF.B1	Biotite	—	23.1 ± 0.4	Upper Karungu Fm.	Karungu
(Le Bas & Rubie 1977, Appendix)					
RFA 7	Biotite		18.0 ± 0.5	Turjaite intrusive	Rangwa uncompahgrite
					complex
K 38	Melanephelinite		14.2 ± 0.5	Kisingiri Series	Base of Gembe inner scarp
K 176	Melanephelinite		11.4 ± 0.6	Kisingiri Series	Summit of Gwasi (Kwirathia)
K 271	Melanephelinite		14.4 ± 0.4	Kisingiri Series	Kaniamwia Escarpment

All previously published ages have here been recalculated with current decay constants and isotopic proportions (Steiger & Jaeger 1978).

In June, 1969, Bishop *et al.* published a regional geochronology based on K-Ar dates, mostly of biotites, from fossiliferous Miocene sequences of western Kenya and Uganda, such as Songhor, Napak and Fort Ternan, and also from the Kisingiri complex at Rangwa and Karungu (but not Rusinga). They concluded that "... the main Rusinga fossil mammal assemblages [meaning Hiwegi] are probably younger than 19.5 to 19.8 million years but older than 16.3 ± 1.5 million years" (Bishop *et al.* 1969, p. 669). The older age limit was taken from dating on hypabyssal biotite from the 'uncompahgrite complex' in the Rangwa vent (but see below), because fragments of this rock had been

reported from Rusinga (McCall 1958), whilst the younger age limit was quoted from the discredited Berkeley sample, KA 336R. Although this dating was stratigraphically inconsistent with that given by Van Couvering & Miller (1969), by coincidence the cited values for 'age limit' of the fauna were almost the same.

Included among the other dates reported by Bishop *et al.* (1969) was one of the first ^{40}Ar-^{39}Ar analyses to appear in the literature. This was an age of 23.1 ± 0.4 Ma, obtained from a single pyroclastic biotite flake (RF.B1) handpicked from a level near the top of the Karungu Beds. Although this is one of the two oldest ages applied to an East African
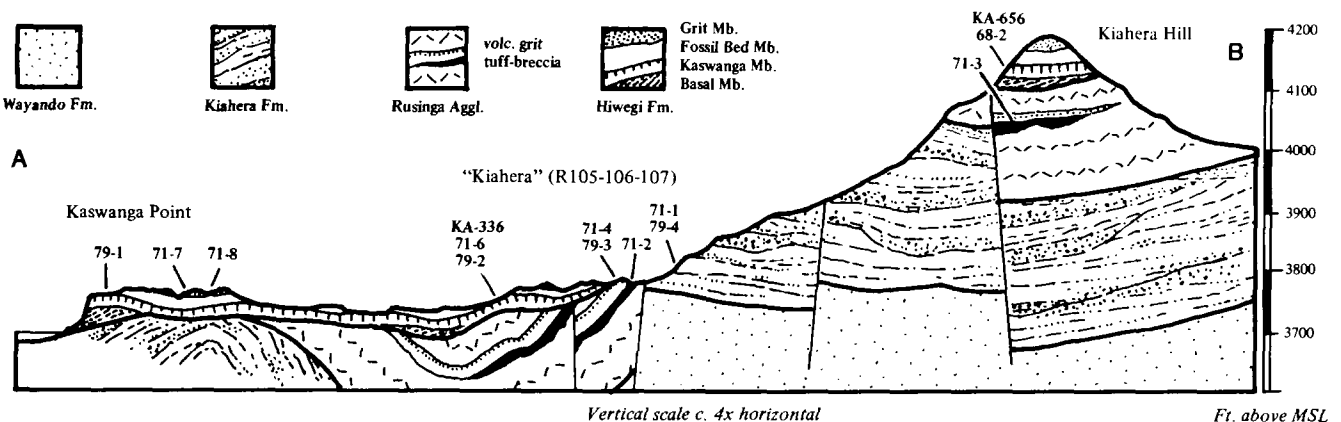

Fig. 5. Sample locations along the Kiahera Hill–Kaswanga Point transect A–B. Details of structure and stratigraphy are diagrammatic.

Miocene mammal site, the Karungu fauna cannot be distinguished on the basis of standard similarity tests from the Rusinga Hiwegi fauna (Van Couvering & Van Couvering 1976; Pickford 1982). Thus, this single age determination from Karungu, although presented with a certain caution, went far to strengthen the impression of a prolonged evolutionary stasis in the African Early Miocene.

A second age determination of *c*. 18.0 Ma on the 'uncompahgrite complex' (Table 1), obtained at Oxford, was subsequently published with a detailed description of the Rangwa vent geology and petrology (Le Bas & Rubie 1977). In this complex, uncompahgrite (melilite–pyroxene–biotite rock with accessory magnetite) is intimately penetrated by hypabyssal cone-sheets of turjaite (melilite–biotite–nepheline pegmatite). In the uncompahgrite the biotite is phlogopitic and mostly interstitial whereas the turjaite is notable for 'huge crystals of brown mica' (Le Bas & Rubie 1977, p. 59) up to 3 cm in diameter. Turjaite micas collected by I. Findlay were used in the Oxford age determination (Le Bas & Rubie 1977) and it seems most likely that this would also have been the source of the biotite sample which Dr Findlay had earlier submitted for dating to Cambridge, and which was published as the 'Rangwa biotite uncompahgrite' sample dated at 19.6–19.8 Ma (see Bishop *et al.* 1969). It should be noted that the Oxford total-fusion age is the same, within the analytical limits, as the age given here for the turjaite biotite lapilli on Rusinga, whereas the Cambridge age is not.

Lavas in the Kisingiri Group on Gwasi and Gembe gave 'acceptable' whole-rock dates at Oxford (Le Bas & Rubie 1977) ranging from *c*. 11 to 14 Ma (Table 1). The younger ages were used to set an upper age limit on volcanic activity at Kisingiri (Rubie & Le Bas 1977).

Present work: analytical methods

The radiometric age analyses shown in Table 2 were all obtained in the geochronology laboratory in the Department of Geology and Geophysics, University of California, Berkeley. Argon isotopic abundances in gas extracted after total fusion of sample splits were measured on Reynolds-type rare-gas mass spectrometers using isotope dilution by calibrated ^{38}Ar spikes, metered from a pipette system. The ^{38}Ar calibration is established by control dates on inter-laboratory and international standards of known age and also from first principles using gas laws, atmospheric argon abundance and isotopic composition, and assumptions of invariant volumes in the precisely manufactured air-pipettes.

Potassium values were all made in duplicate with a Zeiss PF–5 flame photometer. Variation in K content between duplicate analyses is reflected in the two-sigma (i.e. double standard deviation) confidence figure calculated for the age.

Interpretation of new K-Ar dates

The first attempt to improve the chronology of the Rusinga fossil localities, in 1974, used samples of giant biotite lapilli from the Rusinga Group, collected by J.A.V.C. in 1968 and 1971. The results were again inconclusive, with ages ranging from 15.7 to 34.5 Ma (see Table 2). Since only large handpicked crystals were used, the spread could not be attributed to basement contamination as before. It was noted, however, that many of the biotite lapilli showed anomalously low potassium values, some less than a tenth of the values found in 'normal' biotite. Most such lapilli also had calcite laminae in the

basal cleavage planes, and appeared to be moderately to severely bleached. Specimens of this biotite varied strongly in K content, even between different crystal lapilli in the same sample. New samples collected in 1979 by J.A.V.C and in 1981 by M.P. and R.D. prompted a renewed effort to date Rusinga biotites, which revealed that only the dates from biotite lapilli having K > 6% were reproducible, and hence reliable. Figure 6 is a compilation of the published dating of Rusinga Group biotites, and shows that with decreasing K content, biotite ages tend on the one hand to be anomalously old (Fig. 6a), and on the other to be less reproducible due to increasingly higher proportions of atmospheric ^{40}Ar to radiogenic ^{40}Ar* (Fig. 6b).

These plots indicate that the process by which potassium is lost from the biotites does not result in total loss of ^{40}Ar*, as would be expected. Why, and when, the alterations(s) take place is unknown. The alteration is analogous to the uncoupled partitioning of K vs Ar in some highly alkaline hydrothermal environments (Shepherd *et al.* 1976), and has the opposite to the usual effect of near-surface diagenesis on the K-Ar* ratios in Neogene volcanics. The variability of the alteration, from site to site and even from crystal to crystal, indicates that a simple burial effect, or other general influence, may not be the cause.

Only five biotites, all from the Rusinga Group on Kiahera Hill (Fig. 5), have K > 6%; these are shown in boldface in Table 2. Three are from the Kiahera Formation (R71-1a, R71-1c, R79-4), one from the Rusinga Agglomerate (R71-3), and one from the Hiwegi Formation (R68-2). These high-K samples give extremely consistent dates with a mean of 17.9 ± 0.16 (two-sigma) Ma.

There is a tendency toward anomalously old dates as K loss becomes severe (Fig. 6a), indicating that K loss gradually exceeds ^{40}Ar* loss, but it is the increasing fraction of atmospheric ^{40}Ar as K decreases that is the cause for the increasing scatter in ages (Fig. 6b). In support of the date recommended above, it should be noted that the 10 biotite samples with the relatively highest fraction of radiogenic argon (which includes the five samples with highest K, above) also cluster around the same mean, with a combined age value of 17.9 Ma but with a variance an order of magnitude greater at ± 1.2 (two-sigma) Ma.

Age of the Rusinga Group

The impressive coherence of the five best dates, with a double standard deviation of only 0.16 Ma, strongly indicates that the entire Rusinga Group, including the Kiahera Formation, Rusinga Agglomerate and Hiwegi Formation, was deposited during a time interval of probably less than half a million years, with a mean age of about 17.9 Ma. The previous age estimate of 20.0 Ma for the Rusinga Agglomerate, based on total-fusion K-Ar analysis of nepheline crystals (Van Couvering & Miller 1969), must now be regarded as anomalously old. The interpolation from this age to that of the Kisingiri nephelinites (see below) as the basis for estimating the age range of the Rusinga Group is no longer valid (or necessary).

Age of the Kulu and Kisingiri Groups

The dates we obtained on the RK-8 and RK-9 samples from the Lunene Lava, as shown in Table 2, were 1 to 2 million

Table 2. *K-Ar dating results: Rusinga Island and at Karungu*

Lab no. (KA-)	Field no.	Material	K (%)	$^{40}Ar^* \times 10^{-11}$ (mol g^{-1})	$^{40}Ar^*$ (%)	Age (Ma)	Location	Remarks
Lunene Lava, Rusinga								
2733	RK-9	melaneph.	1.08	2.81	10	14.9 ± 0.5	Lunene Peak	Previously dated
2732	RK-8	melaneph.	1.58	4.33	13	15.7 ± 0.9	Wanyama Hill	Previously dated
Hiwegi Formation, Fossil Bed Member, Rusinga								
2679	R71-7	biotite	3.76	16.3	11	24.8 ± 0.5	Kaswanga Point	Low K, anomalously old
2679R	R71-7	biotite	0.95	—	13	26.0 ± 0.3	Kaswanga Point	Low K, anomalously old
2680	R71-8	biotite	1.35	8.15	6	34.5 ± 1.6	Kaswanga Point	Low K, anomalously old
2680R	R71-8	biotite	4.35	13.6	23	18.0 ± 0.3	Kaswanga Point	Highest K, Ar this location
4086	WK-18	biotite	5.20	16.7	60	18.4 ± 0.4	Hiwegi Hill	Coll. Drake 1981, pers. comm.
Hiwegi Formation, Kaswanga Point Member, Rusinga								
2681	R68-2	biotite	**7.66**	**23.8**	**43**	**17.8 ± 0.2**	Peak of Kiahera	Resample of KA-656 site
2678	R71-6	biotite	3.56	13.0	13	21.0 ± 0.3	Locality R107	Resample of KA-336 site
3730	R79-1	biotite	2.53	7.62	15	17.3 ± 0.5	Kaswanga Point	Low K
3731	R79-2	biotite	4.12	12.1	51	16.9 ± 0.2	Locality R107	Resample R71-6, KA-336 site
Rusinga Agglomerate, 'Grey Hard' Member, Rusinga								
2763	R71-4	biotite	5.83	17.1	21	16.9 ± 0.1	Locality R107	Small lapilli
2763R	R71-4	biotite	5.48	15.0	22	15.7 ± 0.2	Locality R107	Small lapilli
3740	R79-3	biotite	5.97	18.2	54	17.5 ± 0.1	Locality R107	Resample of R71-4 site
Rusinga Agglomerate, basal tuff-breccia, Rusinga								
2671	R71-2	biotite	3.46	13.2	22	21.9 ± 0.2	Locality R107	Giant lapilli
2671R	R71-2	biotite	2.74	7.95	15	16.6 ± 0.3	Locality R107	Giant lapilli
2672	R71-3	biotite	**6.99**	**21.8**	**49**	**17.9 ± 0.1**	Kiahera Hill	Giant lapilli
Kiahera Formation, Micaceous Member, Rusinga								
2682	R68-3	biotite	4.08	16.3	11	22.9 ± 0.7	Gumba Point	Large euhedral lapilli
2682R	R68-3	biotite	4.76	15.0	9	18.1 ± 0.7	Gumba Point	Large euhedral lapilli
3716	R68-3a	biotite	4.27	13.3	29	17.9 ± 0.3	Gumba Point	+22 mesh fraction
3715	R68-3b	biotite	4.38	13.1	66	17.2 ± 0.2	Gumba Point	22-30 mesh, acid washed
2670	R71-1	biotite	2.54	8.31	23	18.7 ± 0.3	Kiahera Hill	Large euhedral lapilli
2670R	R71-1	biotite	1.94	7.09	15	20.9 ± 0.6	Kiahera Hill	Large euhedral lapilli
3750R	R71-1a	biotite	**7.62**	**23.7**	**60**	**17.9 ± 0.4**	Kiahera Hill	+22 mesh fraction
3718	R71-1b	biotite	5.99	19.8	41	19.0 ± 0.5	Kiahera Hill	30-70 mesh fraction
3717	R71-1c	biotite	**6.38**	**19.9**	**59**	**18.0 ± 0.2**	Kiahera Hill	22-30 mesh, acid washed
3732	R79-4	biotite	**7.26**	**22.7**	**68**	**18.0 ± 0.3**	Kiahera Hill	Resample of R71-1 site
Karungu Beds, Bed 4, Karungu								
3917	K81-1	biotite	**7.48**	**23.0**	**76**	**17.7 ± 0.06**	upper slopes	Agglomerate layer
3917R	K81-1	biotite	**7.48**	**22.8**	**73**	**17.5 ± 0.2**	upper slopes	Agglomerate layer
Walangani Beds, Mfwangano Is.								
4093	MF 3-81	biotite	**1.11**	**4.19**	**19**	21.7 ± 2	Walangani Beds	Low K

Analyses highlighted in boldface type are those with least apparent potassium loss (%K > 6%). These provide the most reliable ages so far obtained from the Kisingiri sequence.

years younger than the ages reported by Van Couvering & Miller (1969), shown in Table 1. RK-8 from Wanyama Hill has relatively higher K content than RK-9 from Lunene Peak, due to a higher ratio of nephelinitic matrix to pyroxene phenocrysts. Both samples came from the lowest part of the cap lavas in each area, and possibly from the same flow unit. For RK-8 and RK-9, the mean of all six dates is 16.4 ± 1.8 Ma. This is consistent with the position of the Lunene Lava at the top of the preserved Miocene sequence on Rusinga, and is not contradicted by the somewhat less consistent Oxford dates obtained from similar lavas at the top of the mainland Kisingiri sequence (Table 1). Non-eruptive, virtually undeformed coarse volcaniclastic grits and fine-laminated lacustrine sediments of the Kulu Group were deposited against steep erosional scarps cut into the folded and faulted Rusinga Group, prior to eruption of

the Kisingiri lavas (according to indirect evidence, such as the absence of eroded nephelinite debris in Kulu strata). To estimate the age of the Kulu Group between the rough limits of 18 and 16.5 Ma provided by this stratigraphic relationship, we assume that the Rangwa dome deflated during the first part of the indicated 1.5 million years or more of volcanic dormancy. Compensatory uplift in the marginal basins would lead to canyon-cutting in Rusinga Group strata, followed by near-equilibrium drainage conditions and lateral widening of stream channels. The next stage of volcanism would have been preceded by renewed inflation of the dome and uplift of the central block, with subsidence of the marginal basins and rapid sedimentation and local ponding a likely consequence. Most of the Kulu strata would thus most likely date from this phase, at c. 17.0 Ma or younger.
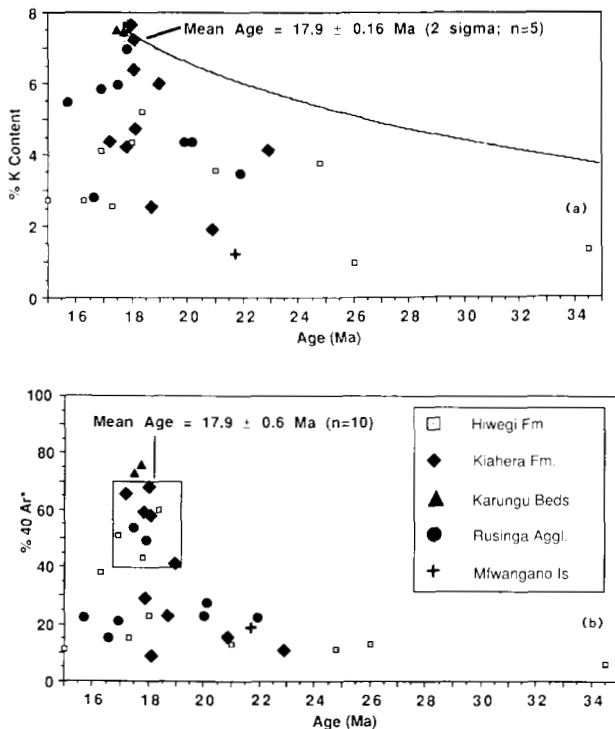
Fig. 6. Relationship of alteration to age determinations from Kisingiri biotites. (a) shows variation in apparent age with respect to K content of biotites from Rusinga, Mfwangano and Karungu. The curved line is the limiting case for K loss without Ar loss. (b) shows increasing scatter of apparent age with decreasing percentage of radiogenic ^{40}Ar in this sample. The biotites which combine high K and high percentages of radiogenic ^{40}Ar are those which group very closely around 17.8 Ma (see Table 2), whereas the most widely scattered ages correlate to the biotites lowest in these measurements. Note the shift towards older ages as ^{40}Ar falls below 40%.

Age of the Karungu fossil beds

The single ^{40}Ar-^{39}Ar date of 23.1 ± 0.4 Ma, obtained on a biotite flake (sample RF.B1; Table 1) from the upper part of the fossiliferous deposits in the Kisingiri sequence at Karungu is inconsistent with the present dating. The K content of the biotite was presumably not analysed, and it is possible that this was a low-K (altered) specimen.

We obtained dates of 17.7 ± 0.06 and 17.5 ± 0.2 Ma on a biotite sample (K-81-1) collected by M.P. from an agglomerate bed (Bed 4 of Oswald 1914) at Karungu (Table 2). These dates, derived from biotite with a K content of 7.48% and radiogenic/atmospheric argon ratios over 70%, are higher analytical quality than any date obtained on biotites from Rusinga Island. Their mean age of 17.6 ± 0.2 Ma is only slightly younger than the mean of 17.9 ± 0.16 Ma for the mica-tuffs on Rusinga Island, and is consistent with the lithostratigraphic and palaeontological correlation (Van Couvering & Van Couvering 1976; Pickford 1982) of the Karungu and Rusinga Group deposits. In particular, the very distinctive onset of extrusive vulcanism at Rangwa Dome, represented in the sharply marked transition to turjaitic tuffites at the base of the Kiahera Formation on Rusinga, is also clearly seen midway in the Karungu sequence. The Karungu biotite ages have

therefore been averaged with those of Rusinga in estimating the true age of this brief episode at c. 17.8 Ma.

Mfwangano Island

The stratigraphy and fossils of Mfwangano Island are similar to Rusinga Island 5 km to the east (McCall 1958; Whitworth 1961). Unpublished fieldwork by J.A.V.C and later work by M.P. (Pickford 1984) documents direct correlations (see Fig. 3), which show that collections on Mfwangano have come mainly from the Kiahera Formation and sedimentary intercalations of the Rusinga Agglomerate, neither of which (as it happens) are very fossiliferous on Rusinga Island (Fig. 4). Attempts to date the Mfwangano sequence were not successful because no biotite with sufficiently high K content was collected. A single date of 21.7 ± 2.0 Ma from the Kiahera Formation was derived from biotite with only 1.1% K (MF 3–81; Table 2), and by our criteria (Fig. 6) should be considered suspect.

Uyoma Peninsula

Archdeacon W. E. Owen first found Miocene fossils in lakeside gullies on the Uyoma peninsula in the 1930s, but his announcements were modest (Owen 1936, 1939) and received little attention. The Chianda (Arongo) site was reinvestigated in 1974 during work at Maboko Island (Andrews *et al.* 1981); more recently Pickford (1984) located others of Owen's sites and several new fossil-bearing areas. Most of the sites—Chianda, Nyakongo, Rangoye, Nyabera, Angulo and Nyamsore—appear to be correlative to the Kulu level because they are in volcaniclastic sediments without any primary volcanics, and are overlain by the Kiangata Agglomerate. Sites at Magare and Magare Beach appear to be tuffaceous sediments similar to those of the upper Rusinga Group, e.g. Hiwegi. Fossils also have been found in sediments intercalated in the Kiangata Agglomerate at Kunya, and in the Lunene Lava at Kagwa.

Palaeontology

In the Early Miocene faunas from West Kenya sites, two main groups or 'faunal sets' have been identified by the degree of overlap of taxa in common (Pickford 1982). Set I is best represented at Songhor in the upper fossiliferous levels of the Timboroa sequence. Set II is best represented in the fauna from the Hiwegi Formation of Rusinga. Middle Miocene faunas are assigned to Set III, best represented in the fauna from Maboko Island near Kisumu (Fig. 1). Songhor (Set I) has been dated at c. 19 Ma (Bishop *et al.* 1969) from turjaitic biotites like those of Rusinga. This age is being re-evaluated in a programme parallel to the one reported here, but the new limitations on the age range of the Hiwegi faunas immediately makes it probable that part, at least, of the difference between Faunal Sets I and II may simply be due to a greater age of Set I, for which there is also some fossil evidence. The Set III sites (Maboko, Majiwa, Kaloma and the newly-reported Nyakach sites: see Thomas 1984), are not well dated but appear clearly to be younger than Set II on both palaeontological and geological evidence (Van Couvering & Van Couvering 1976; Pickford 1982). The northern Kenya 'Tiati Grit' sites (Muruarot, Kalodirr, Mwiti, Loperot) and at Buluk have been placed in Set IIIa by Pickford (1986), based on the more derived condition seen in many of the larger mammals, but may be time-equivalent to the later Set II faunal levels.

The present inventory of fossil mammal species in the Kisingiri sites (Fig. 4) has been revised from the last previous list (Van Couvering & Van Couvering 1976, appendix), partly through work on the curated material, and partly due to new observations, especially on the Uyoma peninsula. Correction of some curatorial errors affects the literature, as indicated by the formational distribution of species summarized in our table, but most errors (such as misreading field numbers and field catalogues) are significant only for the site-by-site distribution of the taxa in detailed studies. The Hiwegi Formation of Rusinga has provided the bulk of mammalian and other fossils in the Kisingiri sequence (Fig. 4), and is a major standard of reference in the African Early Miocene. Four genera previously listed from this faunal level (Bishop 1967; Van Couvering & Van Couvering 1976)—*Bathyergoides* Stromer, *Afrocricetodon* Lavocat, *Notocricetodon* Lavocat and *Kelba* Savage—are removed from the list, and several new taxa, including two new genera and one new species of suids (Pickford 1985), and a new molossid bat (A. Walker 1984 pers. comm.) have been added; an undescribed pedetid noted by Lavocat (1973), and an undescribed anthracothere, both representing new genera, are also newly included. We have retained *Proconsul africanus* in our list, although a consensus is growing that the Kisingiri specimens are probably females of *Proconsul nyanzae*. These various changes and considerations all accentuate the difference between the Kisingiri and Timboroa assemblages. Subjective (nomenclatorial) revisions, mainly from the studies in Maglio & Cooke (1978) also create differences between the new list (Fig. 4) and earlier ones, but these need not be discussed here.

Eighteen collecting areas in the Hiwegi Formation, most with more than one site, are now known from Rusinga (Clark & Leakey 1951; Van Couvering 1972; Pickford 1984), although only a few of these, all in the Fossil Bed Member (see Van Couvering 1972), have yielded more than 20 taxa (Fig. 2). The largest and most diverse collections come from three areas: the stretch along the east coast at Hiwegi Hill, the gullied headland of Kaswanga Point, and the patch of badlands at the west side of Kiahera Hill. Just south-west of the last is the 'Kamasengere' or Kidiwa site (R113), which appears to be reworked from Kiahera beds but older than Rusinga Agglomerate. Closely similar beds, also with abundant reworked biotite but without numerous fossils, make up the 'Lone Hill' deposit that unconformably overlies the Gumba Beds at Uoya (Whitworth 1953; Van Couvering 1972). The R113 fauna does not differ in any taxon from that of the Rusinga Group, and to be conservative we have not separated it from the Kiahera fauna (see also Pickford 1984).

The largely, if not entirely, nonvolcanic Gumba beds have been a problem to correlate (Clark & Leakey 1951; Whitworth 1953). The lithology of red sandy clays with pebble bands, and even more the associated aquatic molluscs and lower vertebrates (bivalves, lung-fish, Nile perch, *Euthecodon*) is unusual for Rusinga and indicates seasonally flooded, low-gradient areas near a large watercourse (Whitworth 1953; Van Couvering 1982). On the other hand, the Kiahera and Hiwegi formations show flysch-type sedimentary fabrics and structures characteristic of very rapid accumulation (Van Couvering 1972), in agreement with the new dating. It is difficult to reconcile the active subsidence indicated for this interval with the

environment at Gumba. One of us (Pickford 1984) has recently reinterpreted the field evidence to suggest that Gumba Beds project beneath adjacent exposures of lower Kiahera Formation. The correlation of the overlying 'Lone Hill' beds to the R113 Kamasengere exposures would support this interpretation. The discovery of clasts of (Miocene?) volcanics in channel fills indicates, however, that the Gumba beds may not be as old as Wayando; as noted, they also do not resemble lower Kiahera beds.

On the grounds that the Gumba fauna shares the rhinoceros *Chilotheridium pattersoni* only with the Kulu fauna in the Kisingiri sequence, Gumba might alternatively be of post-Hiwegi age. *C. pattersoni* is recorded from Loperot and the later early and middle Miocene of Kirimun, Maboko (Guérin 1980) and Ngorora (Hooijer 1978), all of which are younger, or in the case of Kirimun probably younger, than Hiwegi (Hooijer 1971; Andrews *et al.* 1981; Pickford 1982). This species is also known from Bukwa, presently considered the oldest know East African Miocene site on the basis of its radiometric age of 23 Ma (Walker 1969). However, with doubts newly cast on the dating, the fact that Bukwa's palaeontological age fits best with later early Miocene sites (Pickford 1982) must now be given a significance at least equal with that of its radiometric age.

Even with evidence for a markedly different palaeoecology, the Gumba mammalian fauna differs positively from the much larger fauna of the main Kisingiri levels by only this one rhinoceros, and this suggests that the exact age or correlation of Gumba within the sequence is not a pressing matter.

According to the present review (Fig. 4), except for the rare *Orycteropus minutus* all of the taxa known from the lower Rusinga group are also known from the Hiwegi fauna, and we have confirmed that all taxa in the Karungu fauna are known from the Hiwegi fauna as well (Van Couvering & Couvering 1976; Pickford 1981). Thus, there is no faunal indication of any difference in age from the lowest to the highest levels in the Rusinga Group, and this agrees very well with the conclusions we have drawn from the present K-Ar dating. As for the Kulu fauna, on the other hand, the hitherto unreported presence of *Dorcatherium songhorensis* in the Rusinga Group collections is a clearly recognizable difference between these levels and the Kulu Formation, in addition to the presence of an undescribed and probably new anthracothere in the Kulu. The apparent restriction of the rhinoceros *Chilotheridium pattersoni* to the Kulu and Gumba faunas may be equally significant, depending on the correlation of Gumba. The relatively slight faunal difference is consistent with the short time interval which we have estimated to separate the 17.8 Ma Hiwegi fauna from the overlying Kulu fauna, at *c.* 17 Ma.

Summary and discussion

The geology of Kisingiri is complex in detail, but the broad history is clearly documented in the stratigraphy of the distal basins. The sequence of uplift, intrusion, explosive eruption, quiescence, extrusion of nephelinitic lavas and final subsidence, thought previously to have been protracted over *c.* 8 million years, now appears to have been both more rapid and more episodic. The phreatic phase lasted only a few hundred thousand years around 17.8 Ma, and the stratovolcanic phase followed a dormant interval of approximately 1 million years. That the prevolcanic phase

did not long precede the phreatic phase is indicated by the 100% match (in terms of the Simpson resemblance index) of the mammal faunas from the strata formed during these respective intervals. Likewise, the fact that new fossil finds in the Kisingiri stratovolcanic deposits of Uyoma are much more similar to late Early Miocene Hiwegi, rather than to 16 Ma early Middle Miocene Maboko faunas (Van Couvering & Van Couvering 1976; Andrews et al. 1981; Pickford 1981, 1982) appears to rule out nephelinite eruptions at Kisingiri being long protracted after they began at c. 17 Ma, let alone continuing to c. 11 Ma, as some earlier-published dates suggest (Le Bas & Rubie 1977).

The brevity of the phreatic phase, evident in the new dating, implies that as much as 100 m of fine to medium-grained detritus and tuff may have accumulated in less than 0.5 million years, equating to rates of subsidence in the paravolcanic basin greater than 2 cm per 100 years. The abundance of fossils from this interval may be due in great part to such rapid sedimentation, abetted by the anomalously high levels of alkalinity induced by leaching of the turjaitic lapilli in poorly-drained, rapidly-subsiding depocentres (Van Couvering & Van Couvering 1976).

Many differences between the Set II faunas of the Kisingiri sequence and the Set I faunas of the Timboroa sequence (i.e. Meswa, Koru, Songhor) have been noted (Van Couvering & Van Couvering 1976; Pickford 1981), and between the hominoid assemblages in particular (Andrews 1978; Pickford 1986). Mainly because of the confusion over Rusinga dating, such differences were previously attributed to geographical and environmental factors. It now seems more likely that the faunal differences are time-sequential and represent changes over a significant period of time. Proconsul nyanzae and Nyanzapithecus of Rusinga, and also Afropithecus, Turkanapithecus, Simiolus and Heliopithecus in the northern (paratropical?) fauna, all appear to date from rocks younger than 18 Ma. The derived features which characterize these forms, if younger than the homologous characters seen in the Set I proconsulines, may also be taken as relatively unambiguous evidence for crucial early Miocene trends in hominoid evolution.

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