

Developing a Coherent Stratigraphic Scheme of the Albertine Graben-East, Africa

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Abstract: The Albertine Graben is one of the most petroliferous onshore rifts in Africa. It forms the northernmost termination of the western arm of the East African Rift System. Its surface exposures were first studied by Wayland [1] and Pickford et al. [2] among others. Pickford et al. [2] especially developed the basic stratigraphic framework of the graben which was later modified by the government geoscientists and international oil companies using subsurface data. However, the stratigraphic units were not fully and formally described, and have been used informally in different and often confusing ways. The current study therefore aims to solve this challenge by establishing a coherent stratigraphic scheme for the entire graben through an integral study of surface and subsurface data. The study involves precise description of the type and reference sections for various formations both in exposure and wells; and has therefore led to the development of lithostratigraphic columns of different basins in the graben. The approach reveals that the Semliki area, south of Lake Albert, has the most complete sedimentary succession in the graben, spanning the period from middle Miocene (ca 15 Ma) to Recent. It also reveals that platform deposits, which form a small fraction of the thickness of the basinal succession, represent a highly condensed sequence which only saw deposition at times of Lake highstand.

Key words: Lithostratigraphy, subsurface and surface sediments, correlation, Albertine Graben.

1. Introduction

The Albertine Graben is one of the most petroliferous onshore rifts in Africa. It forms the northernmost part of the western arm of the East African Rift System stretching along Uganda's western boundary with the Democratic Republic of Congo from the Aswa shear zone at the border between Uganda and Sudan in the north to Lake Edward in the south, close to the border between Uganda and Rwanda (Fig. 1). It is a northwest-southeast striking transtensional pull-apart depression [3] characterized by highly asymmetrical basins and dominance of large boundary faults on one side and sets of smaller step faults on the other side. The sediments comprise

predominantly synrift fluvial-deltaic and lacustrine deposits, studied previously by various researchers including Wayland [1], Harris et al. [4], Bishop [5, 6], Cooke and Coryndon [7], Pickford et al. [2], Senut and Pickford [8], Roller et al. [9], Karp et al. [10] among others.

Pickford et al. [2] and Senut and Pickford [8] especially reviewed in detail the molluscan and mammalian biostratigraphy of the successions and introduced most of the stratigraphic units described in the current study. Their reviews made use of correlations to better-dated mammalian evolutionary lineages of the Kenyan and Ethiopian rift systems. They also tephrostratigraphically correlated the tuff horizons found in the graben to the established sequences of Ethiopia and Kenya [11] thereby providing age control for the Ugandan sequence and confirming the correlations previously established on the basis of fossil mammals.

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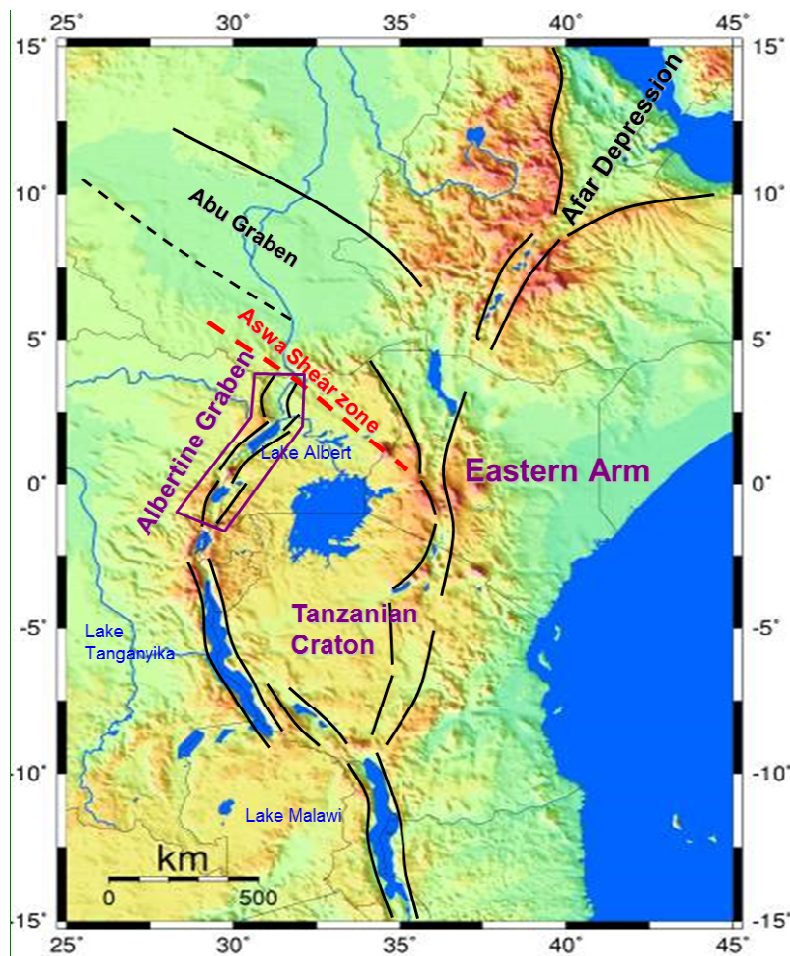


Fig. 1 Location of the Albertine Graben and the East African Rift System.

The basic stratigraphic frameworks established by the earlier workers have been further modified by the government geoscientists and international oil companies with the aid of recently acquired subsurface data. However, the units were not fully and formally described, and have been used informally in different and often confusing ways. The current study therefore aims to establish a coherent stratigraphic scheme for the entire graben through an integral study of surface and subsurface data. It involves review of presently available information/literature and precise descriptions of the type and reference sections for the various formations, both in exposure and in the drilled wells. Tephrochronological analyses of tuff beds in some of the basins [12] have especially given important markers in exposures. Otherwise correlation in exposures has used lithological and palaeontological

parameters [8]. In the subsurface, petrophysical, seismic and palynological data have been used extensively in lithological descriptions, correlations and assessment of depositional environments. Palynostratigraphical approach was especially used in the determination of the age of the subsurface sedimentary successions but with some uncertainty as shown by the greatly conflicting ages of some sections by different authors (see for example Refs. [2, 13, 14]). Field studies under the current study however established presence of tuffs in exposures not seen by previous investigators and therefore aimed to verify ages suggested by earlier work through radiometric dating.

The current study is being undertaken on a basin by basin basis and has so far covered the Semliki and the Kairo-Tonya Basins (Fig. 2) where the sedimentary

successions have been described in detail as detailed below. The Northern Lake Albert and Pakwach basins are still under detailed study to be completed soon while the Rhino Camp and Lake George-Edward

basins (Fig. 2) are yet to be studied in detail. In all areas studied so far however, it was a challenge correlating between the platform deposits represented in exposures and the basinal deposits in the subsurface.

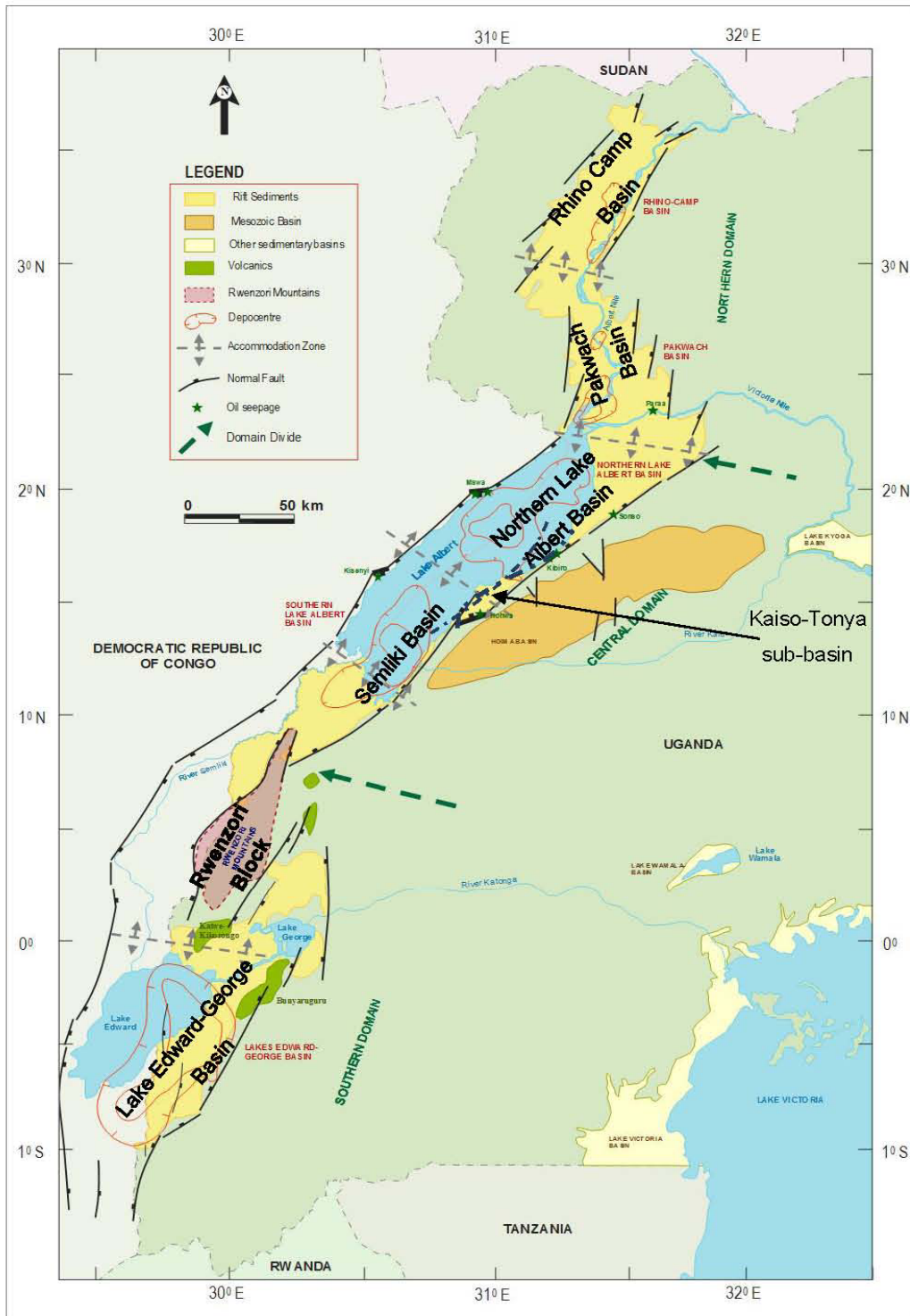


Fig. 2 A map displaying sedimentary basins and structural setup of the Albertine Graben.

2. Lithostratigraphy of the Semliki Basin

The Semliki Basin covers an area of approximately 740 km² in the Ugandan portion of the Albertine Graben. It comprises the Semliki Flats and the adjacent Toro Plain, immediately southwest of Lake Albert. It is bordered to the south east by a steep fault escarpment rising almost 1,000 m to the northernmost spur of the Rwenzori Mountains (Fig. 3). The area is distinct from the surrounding areas of Uganda and the DRC because of its low elevation of about 650 m above mean sea level compared with about 1,100 to 1,500 m for the adjoining rift shoulders to the east and 1,500 to 1,800 m to the west.

Up to 700 m of Neogene sediments are thought to be exposed in tributary valleys to the Semliki River in the area, although estimates have varied from Wayland [1] and Pickford et al. [2] who suggested around 600 m, to Bishop [5] with “at least” 1,300 m. A field visit during the current study confirms the thicknesses of 412 m as suggested by Pickford et al. [2]. In the subsurface, almost 3,000 m thick sequence was penetrated by the Turaco exploration wells without intersecting basement. Geophysical surveys suggest a maximum of 6 km sedimentary succession below southern Lake Albert immediately to the north of the Turaco area. The successions comprise of 8

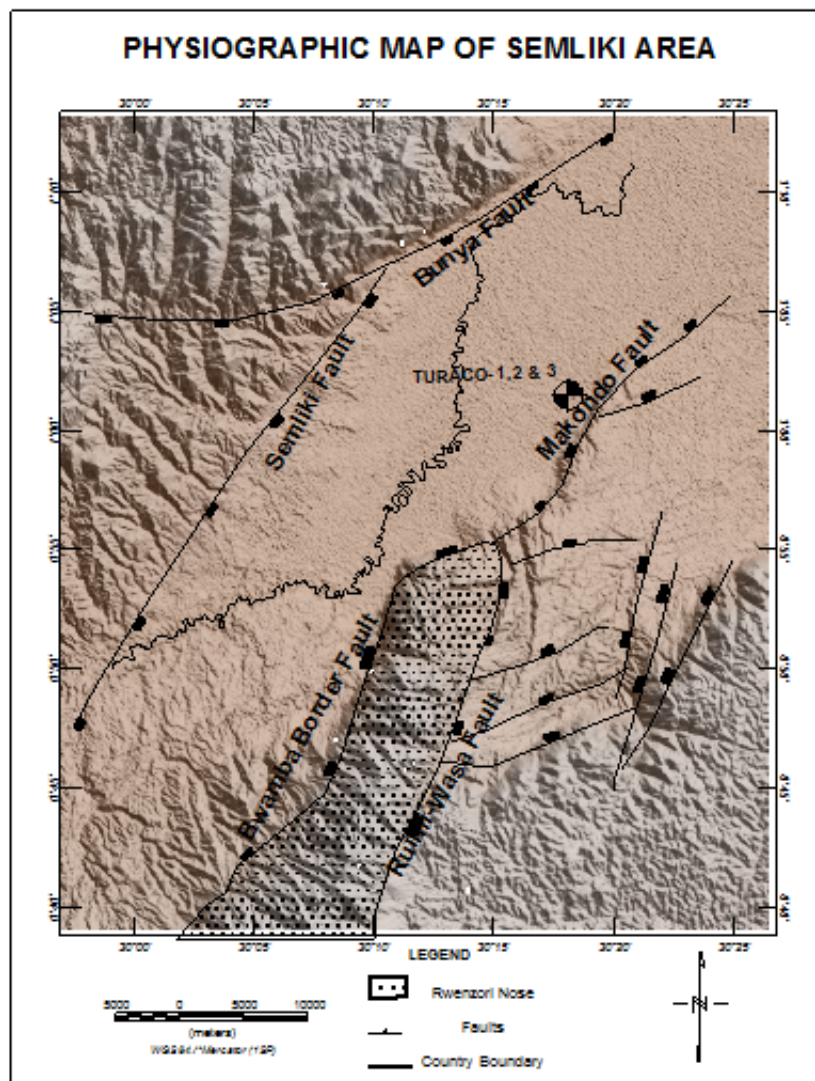


Fig. 3 Main physiographic features of the Semliki Basin area.

Age	Formation	Thickness(m) Turaco wells	Thickness(m) Exposures	Stratigraphic Column	Depositional Environment
Pleistocene	Nyabusosi	648	47		Fluctuating coastal to shallow lacustrine
Late Pliocene	Nyakabingo	207	60		Repeated prodeltaic to delta front progradations
Late Miocene - Mid Pliocene	Nyaburogo	437	120		Delta plain to delta front with switch from humid to semi-arid conditions uppermost
Late Miocene	Oluka	391	50		Lacustrine passing into delta plain with minor fluvial intercalations
Late Miocene	Kakara	542	20		Lacustrine to delta front to humid delta plain
Mid/Late Miocene	Kasande	106	31		Lacustrine to humid coastal mud flat
Middle Miocene	Kisegi	>310	>84		Stacked/amalgamated fluvial sandstones in semi-arid conditions

Fig. 4 Stratigraphic column summarizing the Semliki succession as defined by Pickford et al. [2] and PEPD (in prep).

- G7 – 0.5 Ma ----- Rwebishengo Beds
- G6 – 2-1.5 Ma ----- Nyabusosi Fm
- GX' – 2.3 Ma ----- Absent in Kis-Nyab area
- GX - 2.6 Ma ----- Absent in Kis-Nyab area
- G5 – 3 Ma ----- Nyakabingo Fm
- G4 – 3.5 Ma ----- Upper Nyaburogo Fm
- G3b – 4.9 Ma ----- Lower Nyaburogo Fm
- G3a – 6.2 Ma ----- Upper Oluka Fm
- G2b – 7.1 Ma ----- Lower Oluka Fm
- G2a - 8 Ma ----- In Congo
- G1 – 12-9 Ma ----- Kakara Fm
- G0 – 13 Ma ----- Kisegi Fm (upper part)

Fig. 5 Semliki exposures display the most complete succession of molluscan associations known in the Albertine Rift, but three associations (shown in blue) are absent (based on Refs. [2, 8, 15-19]).

formations, namely; Kisengi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo and Nyabusosi as summarized in Fig. 4 and described below in detail. These deposits show the most complete sedimentary succession in the entire Albertine Graben,

spanning the period from middle Miocene (ca 15 Ma) to Recent, with a great thickness of unfossiliferous sediment beneath the oldest fossils found, possibly extending downwards into the lower Miocene (Fig. 5).

Below are the detailed descriptions of the different formations of the Semliki Basin as summarized in Fig. 4. The descriptions make use of an integration of surface and subsurface data from the area. They also take into account previous work done in the area.

2.1 Kisegi Formation

Origin of name: Although the term “Kisegi” has been used in various ways since the early description of the Kisegi beds by Wayland [1], the present formation was first described in Semliki area by Pickford et al. [2], based on localities along the banks of the Kisegi River.

Type and Reference Sections: The type section of the Kisegi Formation is represented in a tributary valley to the Kisegi River around 192621E/102141N; 30°14'18" E, 0°55'23" N, where basal conglomerates apparently uncomfortably overlie crystalline basement. The reference section is defined in the Turaco-3 well from 2,540 m to TD (total depth) which penetrates the uppermost 310 m of the formation. Seismic data suggest an additional 500 to 1,000 m of sedimentary section between this well's TD and basement.

Lithology: The formation's basal conglomerates at the Kibuku seep (192621E/102214N; 30°14'18" E, 0°55'25" N) generally pass up into thick, channeled and cross-bedded sandstones with thin interbeds of suspected tuff and bleached silts and clays in the mid-section of the outcrop. Gypsum is common as veins and thin interbeds throughout in exposures. In the Turaco-3 well, the uppermost part of the formation shows a development characterized by varied proportions of approximately 40% sandstone and 60% shale, with a few clearly defined blocky to fining upward log patterns.

Thickness and distribution: The formation was estimated as 110 m thick in its type section by Pickford et al. [2], much less than the 300 m suggested by Bishop [5]. Recent detailed logging combining natural logs and field exposures suggest a thickness of 83 m, which accounts for the lower sandy

section of the unit suggested by Pickford et al. [2]. The upper shaly section of their formation is now assigned to the Kasande Formation, as described below. About 310 m of the formation was penetrated in the Turaco-3 well, just 15 km from the outcrop type section. Much of the underlying sedimentary succession below TD in Turaco-3 may also belong to this formation, although present interpretations are uncertain because of the complex structure and poor seismic definition. The formation is expected to have a great lateral extent in the deep subsurface.

Age: Greatly conflicting ages of early Miocene ([14]) and early Pliocene ([13]) have been suggested for the Turaco well sections on the basis of palynomorphs. Surface exposures of the Kisegi Formation have not been directly dated however, the overlying Kasande Formation was dated by Pickford et al. [2] and Van Damme and Pickford [17] to be of middle Miocene age on the basis of mollusc assemblages and scattered mammalian finds. Accordingly, surface exposures of the Kisegi Formation are believed to be older than the middle Miocene. We generally regard this interval to be of Early to Middle Miocene.

Depositional environment: In outcrop, alluvial fan conglomerates pass up into fluvial channels and minor floodplain deposits, all thought to have been deposited in semi-arid conditions. The outcrops show a series of meandering channels down cutting into each other with the uppermost abandoned channel filled with mixed silt and sandstone. In the subsurface, specifically in the Turaco-3 well, the penetrated 300 m of the formation suggest a dominantly fluvial environment in a relatively quiescent tectonic regime, with low energy small-scale channel systems. The climate at the time was warm to hot and dry (semi-arid conditions; [13, 14]). These conclusions are supported by the presence in outcrop of evaporitic minerals.

Lateral Correlatives: At present, none are formally identified, although the formation was probably deposited paracontemporaneously with the Edo Joh

horizon in the lower Mohari beds of the Sinda-Mohari area, approx. 25 km from Turaco in the Democratic Republic of Congo on the western rift margins [20, 21], which yielded the early Miocene proboscidean, *Deinotherium hobleyi*. The Edo Joh horizon, like the Kisegi Formation, directly overlies basement to the north along the western margin in the Nyamavi area of the DRC, about 50 km NNW of Turaco; the “Basal formation” there may possibly correlate to the Kisegi Formation [22], or it could be younger.

Other comments: Pickford et al. [2] and Van Damme and Pickford [16-19] have also used the terms “Kisegi time” or “Kisegi stage” to characterize what they view as a first phase of protogaben downwarping from 13 to 8 Ma, prior to major rifting in the region. The sandstones of the Kisegi Formation are considered a primary reservoir target in the area: hydrocarbon shows were detected in cuttings, and both CO₂ and methane were tested in the Turaco-3 well in this formation. The hydrocarbon seeps in surface exposures of the basal stratotype at Kibuku show sandstones impregnated with oil, reported to be derived from an algal type I source rock at threshold maturity (unpublished Petroleum Exploration and Production Department-PEPD internal reports).

2.2 Kasande Formation

Origin of name: The formation was informally named by Heritage Oil & Gas plc in 2002 after Mr. Robert Kasande, then Principal Geologist at PEPD, based on field mapping carried out by the company in the area.

Type and reference sections: The base and lower parts of the formation in type section are found in exposures directly overlying the Kisegi Formation at 192908E/101930N; 30°14'27" E, 0°55'16" N. The entire of this formation was also penetrated by the Turaco-2 and 3 wells. The basal hypostratotype is however defined in the Turaco-3 well at 2,540 m at the onset of an 80 m thick shale unit marked by a

rapid increase in gamma ray with corresponding changes in SP (spontaneous potential), sonic and neutron porosity log responses as shown in Fig. 6. This is followed by a 35 m interval with a more varied gamma ray response, with occasional high gamma ray spikes possibly suggesting maximum flooding.

Lithology: The exposures are characterized by dark brown to yellowish-brown mudstones, with channelized sandstones up to several metres thick. Two thin black coaly shales are seen uppermost in the unit. The well sections contain grey, brown-grey, dark grey to reddish-brown claystones and mudstones.

Thickness and distribution: The Kasande Formation is 31 m thick in exposures and 115 m thick in the Turaco-3 well. Its thickness is however uncertain elsewhere in the subsurface although a 76 m thick development is interpreted in the Kingfisher wells, approximately 55 km NE of Turaco wells. The formation is expected to have a great lateral extent in the deeper western subsurface of Lake Albert in the hanging wall of the main western border fault.

Age: Conflicting ages of early to mid-Miocene [14] and early Pliocene [13] have been suggested in the Turaco wells on the basis of palynomorphs. As noted above, surface exposures were dated as middle Miocene by Pickford et al. [2] and Van Damme and Pickford [17] on the basis of mollusc assemblages and scattered mammalian finds.

Depositional environment: The sequence in the subsurface (Turaco wells) marks the development of lacustrine conditions. Similar suggestions were made by Lukaye [14] who noted a change in palynofacies assemblage about 100 m under the formational base, marking a transition to warm and wet open lacustrine environments. Also, RPS Energy [13] suggested lacustrine conditions that pass up into a wet delta plain with fluviially derived marsh or swamp vegetation for the sequence. In exposures, transgression led to the development of coastal mudflats with meandering channels, interfingering with near-shore lacustrine deposits, replacing the totally sand-dominated alluvial

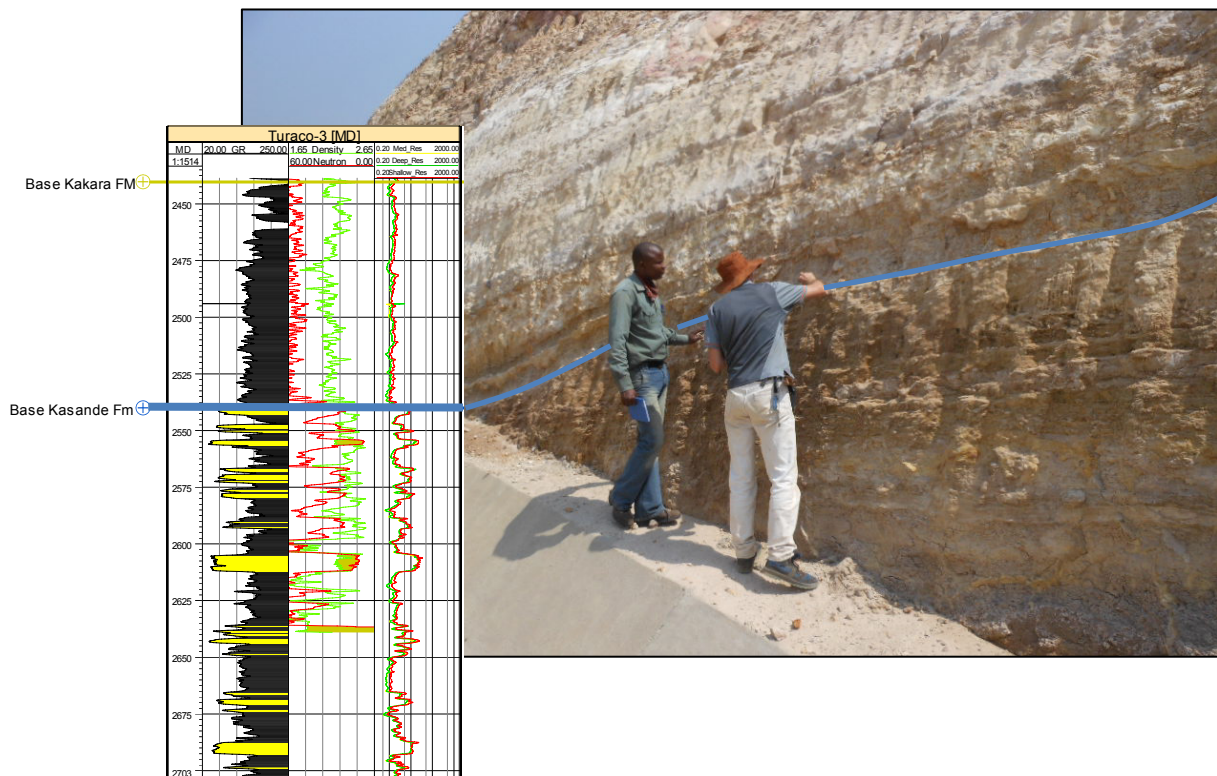


Fig. 6 Extracts from Turaco composite logs showing transition from Kisegi to Kasande Formation and photo showing same section in road cut.

deposits of the Kisegi Formation (Ref. [9]: Fig. 4, section 3 and the upper parts of section 2, although these workers assigned their sections to the Kisegi Formation, they clearly belong to our Kasande Formation).

Lateral correlatives: The lower parts of the Mohari beds in the Sinda-Mohari area, Democratic Republic of Congo [20, 21] were probably deposited paracontemporaneously with the Kasande Formation.

Other comments: The formation represents an important seal and potential source rock, with a probable wide lateral extent in the deeper parts of the basin; its distinctive log response in the wells also prompts our formal introduction of this new unit.

2.3 Kakara Formation

Origin of name: This name was introduced by Pickford et al. [2] for clays and silts with ironstones apparently overlying their Kisegi Formation. Our proposals also formally introduce the intermediate

Kasande Formation as described above, and suggest a possible model to explain great differences in the formation's development from exposure to subsurface.

Type and reference sections: The entire formation was penetrated by the Turaco-2 and 3 wells, with its basal stratotype being defined in Turaco-3 at the first marked sandstone appearance at 2,425 m (Fig. 7). The base is defined by a sudden reduction in gamma ray, with corresponding changes in SP, porosity, density and sonic log responses. The reference section is shown in the new road-cut exposure at 193217E/101675N, 30°15'4" E, 0°55'50" N (Fig. 7), but the development here is totally sand-dominated and not typical of the formation otherwise. The contact with the underlying Kasande Formation is not seen in outcrops, but Pickford et al. [2] believed it to be marked by the first development of ironstones or ferruginous sandstones in the succession. Iron-stained sandstones in fact appear approx. 5 m above the base in the new road-cut exposure.

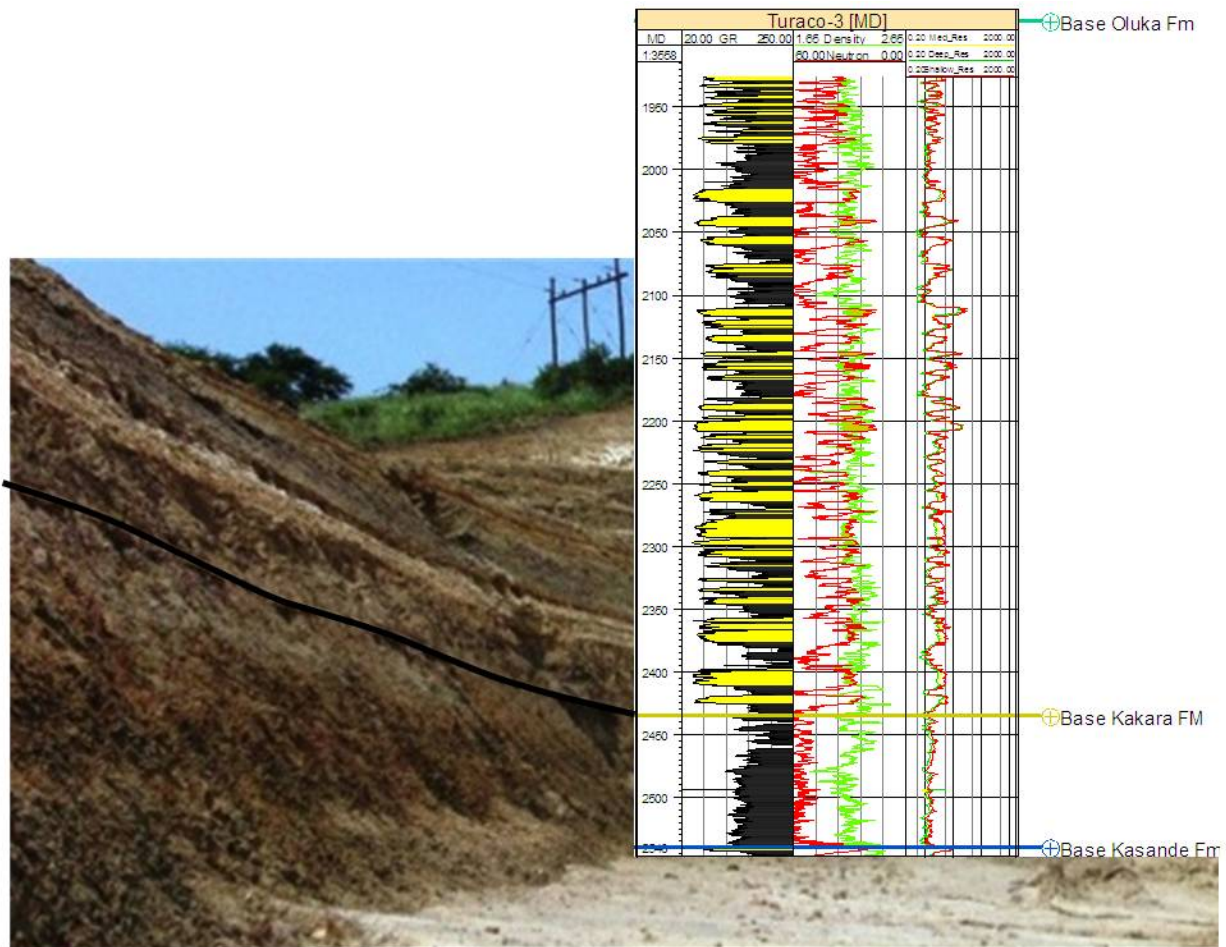


Fig. 7 Extracts from Turaco composite logs showing transition from Kasande to Kakara Formation and a photo of the same transition in new road cut.

Lithology: Log patterns in the Turaco-3 well suggest a coarsening and shallowing upwards sequence. The section's lowermost 57 m display coarsening upward rhythms, followed by a 185 m thick sandy section with erratic gamma ray response. This is then followed by 166 m with repetitive coarsening upward rhythms, and then 20 m of lacustrine shales. The formation is topped by interbedded sands and shales with a thickness of 104 m. In natural exposures, the much thinner 40 m development of the formation is developed as a dominantly dark claystone, with well-defined, mainly laterally continuous, thin ferruginous coarse sandstone beds. The formation's top in exposures is marked by a 40-50 cm thick bench of conglomeratic polymictic ferruginous sandstones.

Thickness and distribution: The Kakara Formation

is 542 m thick in Turaco-3; its thickness is uncertain elsewhere although a possible 500 m development is also seen in the Kingfisher wells, approximately 55 km NE of Turaco. Pickford et al. [2] estimated a thickness of about 40 m in reference area exposures, while the new road-cut exposures show a thickness of 20 m. The great differences in lithologies and thickness between exposures and subsurface have been discussed in detail below.

Age: Greatly conflicting ages of early middle Miocene [14] and late Pliocene [13] have been suggested on the basis of palynomorph assemblages in the Turaco wells. In surface exposures, Pickford et al. [2] and Van Damme and Pickford [17] suggest Late Miocene age on the basis of molluscs associations and mammalian fossils.

Depositional environment: The bulk of the Kakara Formation's exposed section was deposited on a coastal plain, with the intermittent coarse ferruginous sandstones introduced by crevasse splay from nearby channels; these channels are represented by the sandstone development of the new road-cut exposure. Increasing nearshore lacustrine interbeds in the upper parts of the formation were however noted by Roller et al. [9]. The thick Turaco section suggests a development which introduced coarse deltaic clastics into the basin. Palynofacies associations suggest a shift from more open lacustrine to nearshore environments about 200 m above formational base [14] or the development of humid fan delta/mouth bar deposits throughout [13].

Lateral correlatives: Pickford et al. [2] and Van Damme and Pickford [16-19] suggest a correlation with the Mohari beds of the Sinda-Mohari area in the DRC.

Other comments: The formation is a secondary reservoir target in the area. Pickford et al. [2] suggested that the exposed formation showed evidence for the onset of major rifting, with significant down throw of the rift floor. However, we suggest that rifting onset is represented by the underlying Kasande Formation's lacustrine shales as explained later in more detail. This formation also marks the introduction of ferruginous sediments, possibly reflecting a shift from semi-arid to humid environments. The most characteristic feature of the Kakara Formation's exposures is the presence of ferruginous sandstones rather than the concretionary ironstones that first appear in the overlying unit.

2.4 Oluka Formation

Origin of name: The name was introduced by Pickford et al. [2], after Mr. John Oluka, then a Game Ranger in the Semliki Game Reserve.

Type and reference sections: The formational base in the type section is exposed on the ridge between Nyaburongo and Kisengi rivers and in the Valley at

194061E/102934N; 30°15'5" E, 0°55'49" N. The base is defined by dark shales overlying a well-developed widespread conglomeratic ironstone with large (<5 cm) smooth, rounded quartz pebbles as described by Pickford et al. [2]. The basal hypostratotype is defined in the Turaco-3 well at 1,883 m at the development of a thick shale unit marked by a rapid increase in gamma ray, with corresponding changes in SP, porosity density and sonic log responses (Fig. 8). An additional reference section is provided by the new road-cut exposure 193217E/101675N, 30°15'4" E, 0°55'50" N where dark shales overlie a thin conglomeratic ironstone horizon (Fig. 8).

Lithology: Exposures comprise an association of interbedded claystones, shales, siltstones and sandstones. The claystone units are varicoloured, light to dark grey. A suspected tuff bed has been mapped in exposures assigned to the formation. Several thin beds of very hard, grey-green silica cemented sandstones and concretionary ironstone beds occur through the formation. Up to 15 to 16 concretionary ironstone horizons have been observed in natural outcrop, some of which thin and pinch out laterally. The subsurface lithology is characterized by a 23 m thick shale with high gamma ray character at the base, followed by a thinly interbedded sand/shale interval of about 100 m. This is then followed by thicker sandstones with somewhat erratic coarsening upward cycles. The top is marked by clear coarsening upward cycles (Fig. 8).

Thickness and distribution: The formation is over 390 m thick in Turaco-3 and about 50 m thick in exposures. In contrast, Pickford et al. [2] suggested a 50 to 60 m thick development in exposures.

Age: Conflicting late middle Miocene [14] and late Pliocene to early Pleistocene [13] ages have been suggested on the basis of palynomorphs from Turaco cuttings. Pickford et al. [2] suggested an age close to 7 to 8 Ma (Late Miocene), "perhaps a little older" for the middle part of the exposed unit of the Oluka Formation. We regard this interval to be of Miocene/Pliocene transition.

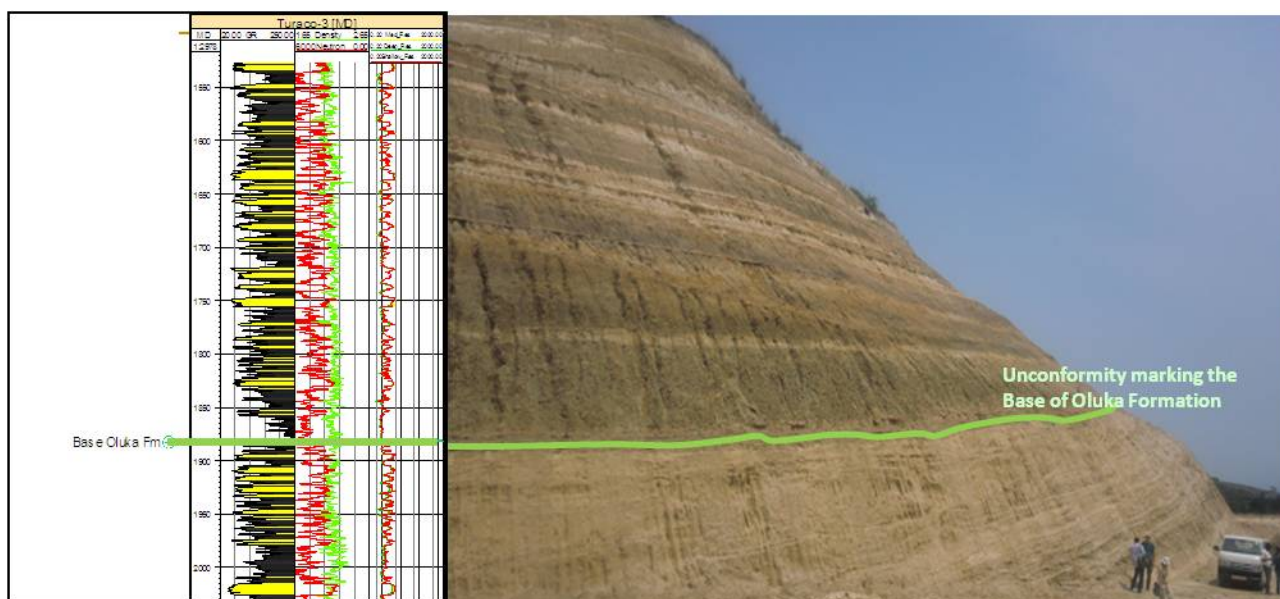


Fig. 8 Extract from composite log showing Kakara/Oluka formational transition in Turaco composite log and photo of the same transition in new road cut.

Depositional environment: Log analyses of the Turaco wells suggest basal lacustrine to prodeltaic shales passing up into delta plain or barrier sands, with an interplay between shoreface and delta front facies at the top. Palynofacies analyses [13] suggest humid/seasonal fan delta swamp conditions throughout. In outcrop, the lower section of the formation was interpreted by Roller et al. [9] to represent dominantly lacustrine to nearshore/coastal mudflat environments, while the upper parts of the outcropping formation suggest mainly distal fluvial to delta plain regimes, with minor nearshore lacustrine intercalations.

Lateral correlatives: Exposures of the upper Oluka Formation have been correlated to lowermost outcrops of the Nkondo Formation in the Kaiso-Tonya area. The full Nkondo Formation however extends into the subsurface to about 400 m below oldest exposures, so that the onlap of the basal Nkondo Formation onto basement may correlate to the transgression marked by the base Oluka Formation. Mollusc associations also suggest correlation of the formation with the members I to III of the Nyamavi beds in the western Albert area and the Kabuga to lower Ongoliba beds in Sinda-Mohari in Democratic Republic of Congo. The

presumed tuff has not yet been correlated to any specific volcanic source or age.

Other comments: The formation is both a reservoir target and potential seal in the area. Gypsum has been mined until recently from exposures near the reference locality. Pickford et al. [2] suggested that the formation marks the onset of major faulting in the rift, leading to the development of Palaeolake Obweruka (first named by Wayland, 1934, approximately 45 km wide and 550 to 600 km long). As previously noted, we believe that rifting started earlier, in Kasande Formation times at around 13 Ma.

2.5 Nyaburogo Formation

Origin of name: The formation was named by Pickford et al. [2] after exposures in the Nyaburogo River valley.

Type and reference sections: The stratotype is proposed in the Turaco-1 well where the base is placed at an apparent log break at 1,492 m immediately above a silicified sandstone bed at 1,500 m (Fig. 9). The base seems to be marked by a rapid reduction in gamma ray log response, although log patterns are somewhat obscured by the “51/2” casing shoe also at this level. The reference section is represented by

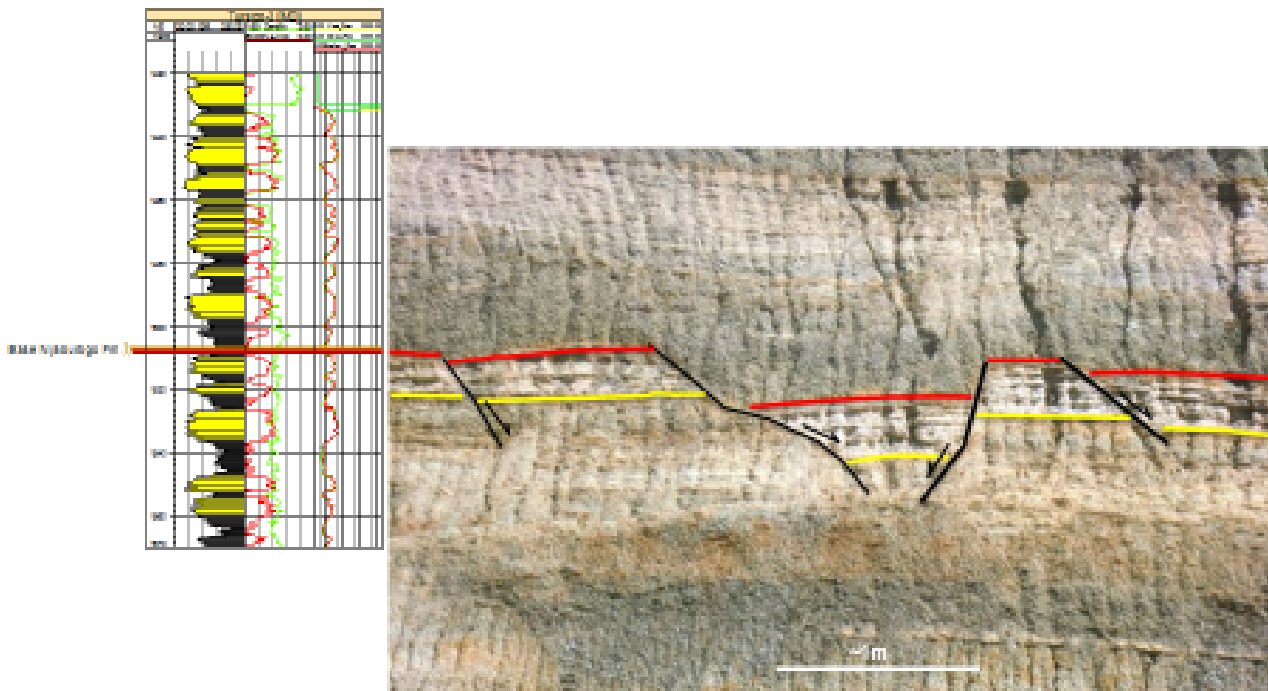


Fig. 9 Log extract showing Nyaburogo formational base in Turaco wells and Oluka/Nyaburogo transition in road cut, with development of micrograben.

exposures that are only partially exposed in the northern end of the Nyaburogo River valley at 196485E/102539N; 30°6'23" E, 0°55'36" N, where a silicified sandstone is also observed near the presumed formational base. The section, thought to represent most of the formation is seen in the new road-cut exposure where basal shales rest on a faulted and erosional surface of topmost Oluka shales and siltstones, here displaying a micrograben structure (Fig. 9).

Lithology: In outcrops, thick sequences of claystones with numerous rusty brown to yellowish brown siltstones, pisolitic ironstones, siltstones and palaeosols are seen. Large ironstone concretions <15 cm in diameter, with a typical “onion-skin” weathering, are characteristic of this formation. The uppermost parts of the exposures do show a several metre thick massive sandstone development (Fig. 9). In the subsurface, the base of the section is characterized by 152 m of serrated gamma ray response in a sand/shale sequence, followed by 185 m of thicker sandstones with blocky to fining upward character and topped by 100 m of relatively clear

coarsening upward cycles (Fig. 9).

Thickness and distribution: As suggested by Pickford et al. [2], a total of 120 m of the formation is exposed. It is however 447 m thick in the Turaco-1 well.

Age: Conflicting late Miocene [14] and early Pleistocene [13] ages have been suggested for well cuttings on the basis of palynomorphs. The exposed sections were dated late Miocene to middle Pliocene by Pickford et al. [2] on the basis of mammalian biochronology and molluscan assemblages supported by tuff correlations.

Depositional environment: In the subsurface, the lower parts of the formation are interpreted to have been deposited in a delta plain, followed by a mixture of delta plain and shoreface lithofacies. Palynofacies associations suggest a change to drier climates in the lower part of the formation [14]. In exposures, a partial section through the lower to middle parts of the formation suggests an uninterrupted 6 m lacustrine development with an abrupt break to 5 m distal alluvial plain then up into 2 m nearshore lithofacies

[9]. The uppermost part of the formation was considered by these authors to represent alluvial to delta plain environments.

Lateral correlatives: Molluscan assemblages suggest correlation of the lower parts of the exposed unit to the upper Nkondo Formation of the Kaiso-Tonya area and its upper parts to the uppermost Warwire Formation also in the Kaiso-Tonya Basin [11, 12]. Similar molluscan assemblages and mammal fossils also suggest correlation of the lower Nyaburogo Formation with the Kazinga beds of the east Lake Edward area, the Ishasha beds of Lake Edward-George Basin [23] and Member IV of the Nyamavi beds of Nyamavi, DRC [2, 16-19]. The middle/upper parts of the formation may correlate to the Nyakasia beds of the Upper Semliki area in the DRC.

Other comments: If the datings suggested by the mollusc associations and mammals are correct, then the middle parts of the formation should reflect major tectonic activity followed by erosion of exposed sediments, as seen at the Nkondo/Warwire formational boundary in the Kaiso-Tonya area [2]. This may also have caused a major extinction event in the molluscan community [16-19]. No clear evidence of such syndepositional tectonism has yet been observed in the Semliki area, either in exposure or the wells, but the sandy nature of the upper parts of the formation should be noted, especially in the new road-cut exposure. We also note that Roller et al. [9] (Fig. 10) suggest a major transition in regional development from their "Phase 2" to "Phase 3" at this level, although not stating their reasons for this conclusion.

2.6 Nyakabingo Formation

Origin of name: The formation was named by Pickford et al. [2] after exposures in the Nyakabingo river valley.

Type and reference sections: The type section is here defined in the Turaco-1 well. The basal stratotype

is defined by the base of a thick lacustrine shale unit at 1,055 m, marked by a rapid increase in gamma ray with corresponding increase in SP, porosity density and sonic log responses (Fig. 10). The reference section is represented by the partial exposures seen east of the Nyakabingo river valley (197801E/104576N; 30°17'6" E, 0°56'42" N), close to the Semliki Flats.

Lithology: Log response through the formation in Turaco-1 suggests four repetitive coarsening-upward cycles. Exposures show light grey to light greenish grey claystones, iron-stained siltstones, pebbly and coarse sands/sandstones and carbonate nodules. A massive amalgamated ironstone about 1 m thick, consisting of several individual thin beds of both concretionary ironstones and ferruginous sandstones, is found uppermost in exposures. No such ironstones have been reported from the subsurface although seismic suggests a major break and overlying transgressive episode at the formation's top.

Thickness and distribution: The formation is 207 m thick in Turaco-1, while Pickford et al. [2] suggested a thickness of about 60 m in outcrops.

Age: Late Miocene [14] and late Pleistocene [13] ages have been suggested on the basis of palynomorphs in cuttings from wells. Pickford et al. [2] suggest late Pliocene age in outcrops on the basis of mollusc associations. We note that two mollusc associations (GX and GX1 dated to 2.6 and 2.3 Ma respectively, Fig. 5) seem to be missing from exposures, perhaps supporting a significant break in deposition between the Nyakabingo and overlying Nyabusosi Formation in outcrop, although the exact relationship is obscured by faulting.

Depositional environment: Exposures have been interpreted as interbedded flood plain and/or lagoonal lithofacies reflecting lake level fluctuations. Partial sections through the lower and upper parts of the formation [9] (Fig. 6, sections 10/11 and 12 respectively) suggest a generally transgressive character, with intercalated coastal plain and nearshore

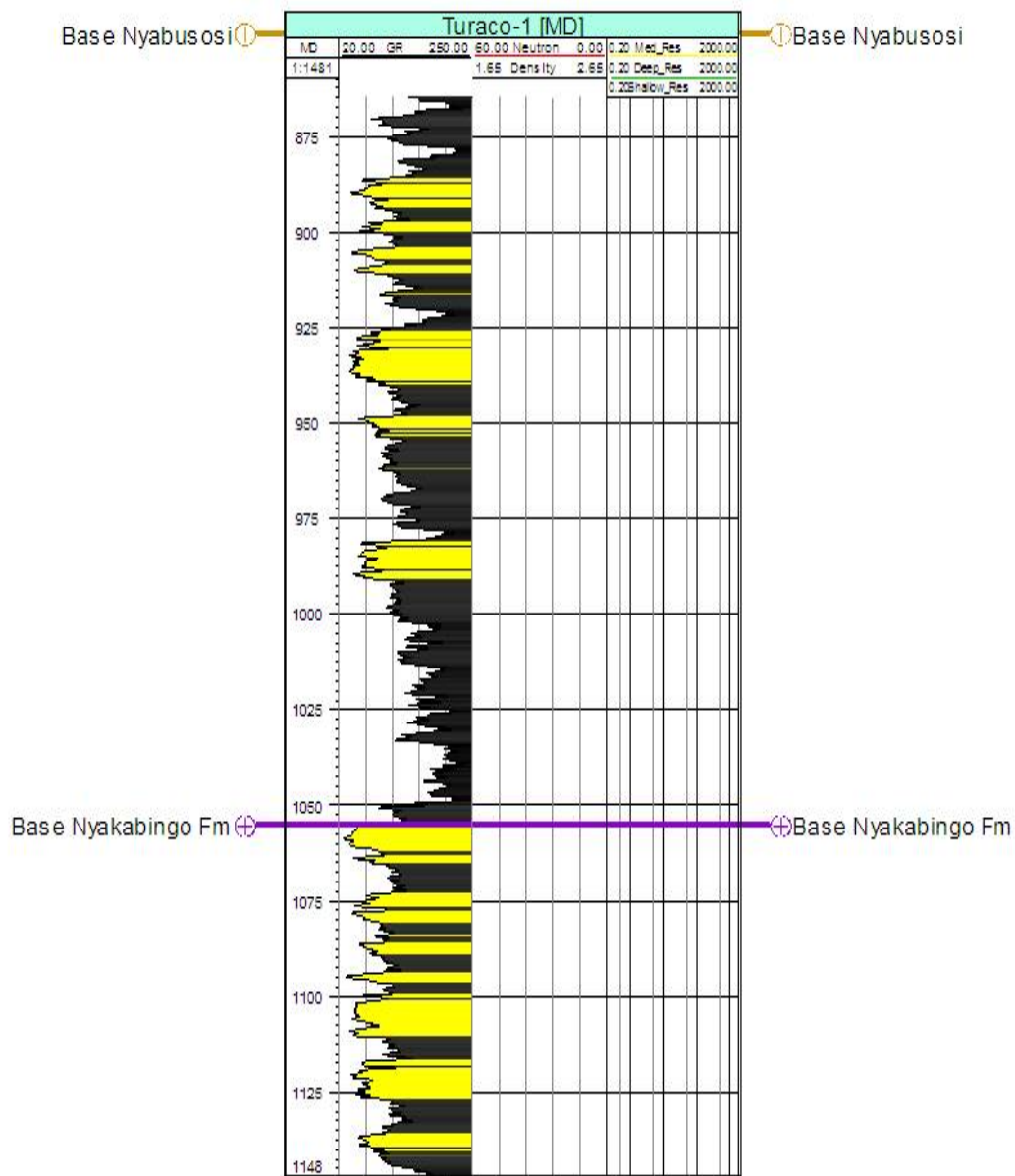


Fig. 10 Nyaburogo—Nyakabingo formational transition in Turaco wells.

environments passing up into more dominant lacustrine shales with nearshore to coastal incursions in the uppermost section. In contrast, the four log-based parasequences of prodeltaic to delta front lithofacies in Turaco-1 apparently show a generally progradational pattern over a markedly transgressive formational base.

Lateral correlatives: The Nyakabingo Formation is correlated to the Kyeoro beds of Pickford et al. [2] in Kaiso-Tonya, member C of the Sinda Beds in Sinda

Mohari, the Kanyatsi beds of Upper Semliki and members VI & VII of the Nyamavi beds of Nyamavi [16-19]. The Bushabwanyama beds exposed on the eastern shores of Lake Edward also contain ironstones, with “classic examples of molluscs of association G5” [2], suggesting a similar age to the ironstones near the top of the Nyakabingo Formation.

Other comments: The formation represents a potential seal in the regional subsurface. As with the Kakara/Oluka formational junction, the thick

composite ironstone bed uppermost in exposures may mark a significant hiatus on the platform, as also supported by the apparent absence in exposures of the two mollusc assemblages GX and GX1. Whether this break is represented in the basin by deposits of the Nyakabingo or of the overlying Nyabusosi Formation is still unclear.

2.7 Nyabusosi Formation

Origin of name: The formation was first named by Pickford et al. [2] after localities in the Nyabusosi

river valley (Nyabusosi meaning “hilly place” in Lutoro).

Type and reference section: The basal stratotype is defined in Turaco-1 at 848 m, below the first massive sandstones characteristic of this formation, and marked by a reduction in gamma ray and an increase in SP, with corresponding changes in porosity, density and sonic log responses (Fig. 11). The boundary between the Nyakabingo and Nyabusosi formations is not clear in outcrop as they are juxtaposed across the major Makondo Fault zone near Makondo village (see Fig. 3).

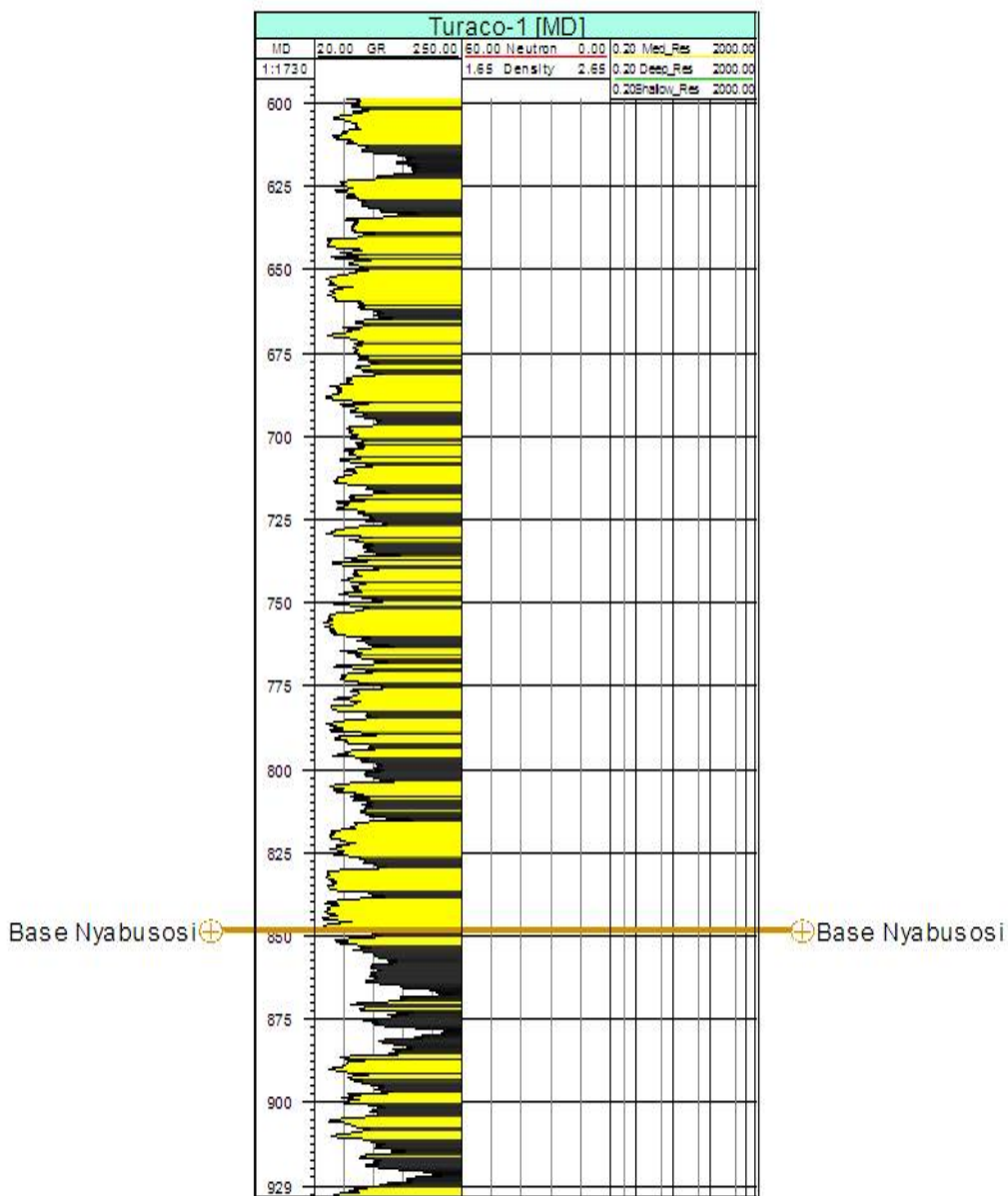


Fig. 11 Nyakabingo—Nyabusosi formational transition in Turaco-1.

Lithology: Alternating clays and silts are seen throughout the exposed parts of the Nyabusosi Formation. It is also characterized by 7 to 8 distinctive ironstone horizons which form the basis for the tripartite member division described by Pickford et al. [2]. The basal Makondo Member (without ironstones) is about 20 m thick, although its base is not exposed. This is conformably overlain by the 7-8 m thick cliff-forming Behanga Member, which does contain several ironstone beds. The uppermost clays and siltstones of the 20 m thick Kagusa Member are again devoid of ironstones, but display a thin tuff (dated 1.5 Ma) near the member's base. A tripartite division is also seen in the much thicker well development, with cuttings descriptions of "ferroan dolomite with gastropod fragments" between 490 and 606 m in the middle parts of the formation. The Makondo Member comprises shallow lacustrine sands and clays with blocky to fining upward gamma ray character from 850 to 535 m. The Behanga Member (535 to 389 m) is predominantly composed of claystones with a high gamma ray character and a few fining upward cycles. The Kagusa Member (389 to 200 m) starts with blocky sandstones with low gamma ray character, gradually passing up into claystones with high gamma ray response.

Thickness and distribution: The Nyabusosi Formation is 648 m and 47 m thick in the Turaco-1 well and exposures respectively. Pickford et al. [2] had suggested a total development of about 50 m in exposures.

Age: Miocene to Pleistocene [14] and late Pleistocene [13] ages have been suggested on the basis of palynomorphs in cuttings from the Turaco wells. Pickford et al. [2] dated the Nyabusosi Formation to be 1.5 Ma using correlation of thin tuff near the base of the uppermost Kagusa Member with a tuff from the Turkana Basin dated to 1.5 Ma. Cooke and Coryndon (1970) and Harris and White (1979) had estimated the Nyabusosi Formation in exposure to be 2.3 to 2.6 Ma.

Depositional environment: Coastal to near-shore

lacustrine environments are suggested, with considerable lake-level fluctuations; lake strandline deposits are indicated by shell-beds of the oyster-like *Etheria* in the Kagusa Member, while flood plain environments are clearly indicated by levels in the Behanga and Kagusa members, the latter with Oldowan artefacts suggesting hominid habitation. All workers [2, 13, 14] agree that the Nyakabingo to Nyabusosi formational transition marks a change from humid to drier climatic condition.

Lateral correlatives: The formation is correlated to the Museta beds of Pickford et al. [2] in Kaiso-Tonya, the Ndirra beds in Sinda Mohari (DRC), the Semliki beds of Upper Semliki, the Semliki series of Nyamavi (DRC) and the Mweya beds of eastern Lake Edward [16-19].

3. Lithostratigraphy of the Kaiso-Tonya Basin

The Kaiso-Tonya Basin comprises an area of approximately 280 km² on the southeastern shores of Lake Albert (Fig. 2). It forms a perched terrace of Neogene sediments between the basement footwall on the southeastern flanks of the graben and a major fault running generally along the lake shore marking the transition to the axial parts of the graben (Fig. 12). Like the Semliki area, the low-lying undulating areas of the Kaiso Plain are distinct from the adjacent areas of Uganda because of their low elevation of about 620 to 700 m above mean sea level, compared with about 1,000 to 1,500 m for the adjacent rift shoulders to the east and 1,500 to 1,800 m for the Blue Mountain flanks along the graben's western margins across Lake Albert in the Democratic Republic of Congo.

Sedimentary deposits of the Kaiso-Tonya Basin comprise of three formations, namely: Nkondo, Warwire, and Kaiso Village (Fig. 13). The three formations collectively display only ten of the complete succession of molluscan associations known in the Albertine Rift and displayed in the Semliki Basin [2, 8, 15-19] (Fig. 14). The exposures are generally



Fig. 12 The main physiographic features of the Kaiso-Tonya area.

Age	Formation	Member	Thickness(m)	Stratigraphic Column	Depositional Environment
Plio - Pleistocene	Kaiso Village		~330	[Stratigraphic Column visualization showing alternating green and yellow layers]	Shallow lacustrine
Mid - Late Pliocene	Warwire	Upper Warwire (Sebugooro)	280		Near shore lacustrine
		Lower Warwire	410		Delta plain
Late Miocene	Nkondo	Upper Nkondo (Nyaweiga)	15	Fluvial	
		Lower Nkondo	353	Progradation delta front para-sequences with an overall lacustrine regression	
				Deep lacustrine	
				Near shore lacustrine	
				Fluvial channels	

Fig. 13 Revised stratigraphic scheme for the Kaiso-Tonya area.

G7 – 0.5 Ma	-----	Absent in Kaiso-Tonya but present in the Semliki
G6 – 1.8 Ma	-----	Absent in Kaiso-Tonya but present in the Semliki
GX' – 2.3 Ma	-----	Kaiso Village
GX - 2.6 Ma	-----	Hohwa
G5 – 3 Ma	-----	Kyehoro
G4c – 3.4 Ma	-----	Upper Warwire (above Kyampanga Tuff)
G4b – 3.7 Ma	-----	Middle Warwire (Sebugoro)
G4a - 4.5 Ma	-----	Lower Warwire
	-----	Extinction event
G3b – 4.9 Ma	-----	Uppermost Nkondo (Nyaweiga Member)
G3a – 6.5 Ma	-----	Upper Nkondo shaley member
G2b – 7 Ma	-----	Not exposed but exposed in the Semliki Basin
G2a – 8 Ma	-----	Not exposed but exposed in the Semliki Basin
G1 – 12-9 Ma	-----	Not exposed
G0 – 13 Ma	-----	Not exposed

Fig. 14 Kaiso exposures display only 10 of the complete succession of molluscan associations known in the Albertine Rift [2, 8, 15-19].

thin, representing only a small fraction of the subsurface succession of up to 1,900 m in recently drilled wells.

Below are the detailed descriptions of the subdivisions of the sedimentary successions of the Kaiso-Tonya Basin summarized in Fig. 13. The descriptions, as earlier stated, are based on integration of surface and subsurface data acquired by the current and previous studies.

3.1 Nkondo Formation

Origin of name: The formation was introduced by Pickford and Senut [8] and Pickford et al. [2], based on localities around Nkondo village on the shores of Lake Albert (0262573E/0155145N; 30°51'59" E, 1°24'10" N).

Type and reference sections: No exposure shows stratigraphic contact with basement and indeed, deep wells indicate that exposures only show the uppermost 70 m of the approximately 400 m thick formation developed in wells just a few km to the north. The Mputa-1 well, completed in 2006, shows the formation's basal conglomerates onlapping weathered basement at 1,153 m. The formation is present in all wells in the area with full penetration to basement in most cases. Nzizi-1 also fully penetrated this formation and is defined as its reference section.

Lithology: The formation is characterized by dark grey to greenish grey claystones, grey to light greenish grey, to brown, medium to coarse grained sandstones and iron-stained siltstones. Claystones in lower parts of the formation in the subsurface contain isolated thin sandstone stringers which provide the main oil reservoirs in the area. Exposures of the upper parts of the formation close to the shores of Lake Albert display slightly fining-upward sequences from siltstones to claystones, occasionally overlain by slightly coarsening-upward sequences. The boundaries between these sequences are marked by richly fossiliferous ferruginous sandstone or concretionary ironstone bands, which form distinctive terraces in the landscape. These bands often comprise coarse sand, with numerous remanie pebbles with a basement or quartzitic composition. The formation also in part shows cross-bedded sandstones that grade upwards into fine sandstones, siltstones and claystones. In some places, the sequences give an indication of channel shifts, creating repetitive units.

Thickness and distribution: The formation is 345 m thick in Mputa-1, varying from 805.8 m to 1,151.7 m throughout the Mputa and Nzizi wells. It is 682 m thick in the Waraga-1 well. The total thickness of the formation in the southernmost parts of the Kaiso-Tonya

Basin is still unknown due to lack of seismic data and drilled wells in this particular part of the basin.

Age: A conflicting mid-Miocene age [14, 24] and late Pliocene age [13] has been suggested for cuttings from the Mputa-1 and Waraga-1 wells on the basis of palynomorphs. Pickford et al. [2] and Van Damme and Pickford [17] suggest Late Miocene for the surface exposures on the basis of molluscan and mammalian assemblages.

Depositional environment: Marginal lacustrine to deltaic deposits dominate areas towards the lake shores whereas coarser alluvial fan and fluvial deposits are more common towards the graben's marginal escarpment. The uppermost Nyaweiga Member's mudstones represent a lacustrine flooding event throughout the entire area.

Lateral correlatives: The lowermost exposed shales are correlated to the upper Oluka Formation of the Semliki area. Molluscan associations also suggest correlation to member III of the Nyamavi beds in the western Albert area and member A of the Sinda beds in Sinda-Mohari in DRC [2, 14-17, 19, 24].

Other comments: The informal "Nkondo member" used by Pickford and Senut [8] and Pickford et al. [2] to describe the exposures underlying their Nyaweiga member within the Nkondo Formation has been discarded due to the synonymous use of "Nkondo" and for the fact that at present nothing is known about the lowermost development of the formation in the southernmost Kaiso area as there is neither any drilled well nor seismic coverage in this area. However, two members, Mputa Sandstone Member and the Nyaweiga Member have been identified and described in this formation. The latter introduced by Pickford and Senut [8] and Pickford et al. [2] is found uppermost in the formation and is recognisable in all wells. The former was also encountered by all exploration wells in the area.

3.2 Mputa Sandstone Member

Origin of name: This unit has only been recognized

in the subsurface. Its proposed name is based on the first exploration well and oil discovery in the area (Mputa well).

Type and reference sections: The stratotype is defined in the Mputa-1 well (Fig. 15). The basal stratotype is defined at 976 m, marked by a decrease in gamma ray with corresponding changes in SP, porosity, density and sonic log responses. The member is also present in the Mputa-2, 3, 4 & 5, Waraga-1 and Nzizi-1 & 2 wells. It has not yet been observed in outcrop.

Lithology: The unit predominantly comprises light grey, fine to medium, well sorted and cross-bedded sandstones which grade upwards from medium to fines and shales, siltstones and claystones.

Thickness and distribution: The member is 157 m thick in Mputa-1 and is present in all the wells in the Kaiso-Tonya Area.

Age: Mid-Miocene age [14, 24] has been suggested in the Mputa-1 and Waraga-1 wells on the basis of palynomorphs, whereas RPS Energy [13] suggested a late Pliocene age.

Depositional environment: The member's sandstones represent deltaic to fluvial sequences deposited by rivers thought to have flown down the ramp represented by the Kaiso-Tonya terrace.

Lateral correlatives: At present, this unit is assigned member status and is not believed to have any significant regional extent.

Other comments: The member represents the best potential reservoir in the area, but in most cases its sandstones are water-wet.

3.3 Nyaweiga Member

Origin of name: The member's name is taken from a river and village in the exposure area and was informally introduced by Pickford and Senut [8] and Pickford et al. [2]. The member is also clearly defined in the subsurface.

Type section and reference section: The basal stratotype in exposure has "its base defined by an oolitic

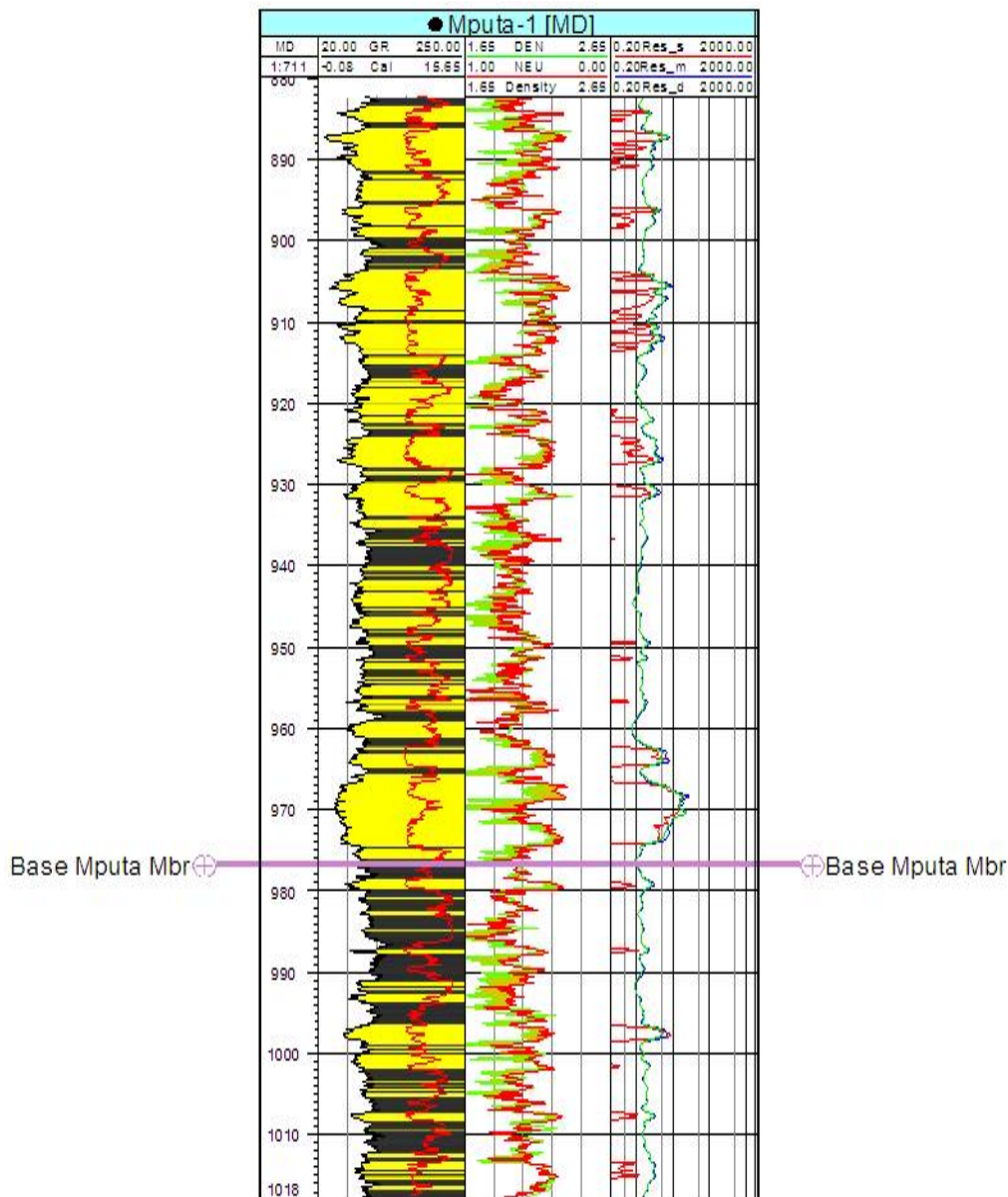


Fig. 15 Log extract showing base Mputa Member in the Mputa-1 composite log.

ironstone which is immediately overlain by huge (up to 1 m diameter) bouldins” [2]. The same authors noted that its upper surface is an erosional unconformity caused by faulting and subsequent erosion. The basal hypostratotype is defined in Mputa-1 well at 862 m, marked by an increase in gamma ray with corresponding change in SP, porosity, density and sonic log responses (Fig. 16). The member is recognised in all Mputa, Nzizi and Waraga wells.

Lithology: The unit predominantly comprises dark grey, firm, blocky claystones intercalated with

occasional light grey, fine to medium, well sorted thin sandstones.

Thickness and distribution: The member is 14 m thick in Mputa-1 and is present in all wells on the Kaiso-Tonya terrace.

Age: A mid-Miocene [14, 24] and late Pliocene to early Pleistocene [13] have been suggested in the Mputa-1 and Waraga-1 wells on the basis of palynomorphs. Pickford et al. [2] suggested Early Pliocene in exposures on the basis mollusc assemblages and mammalian remains.

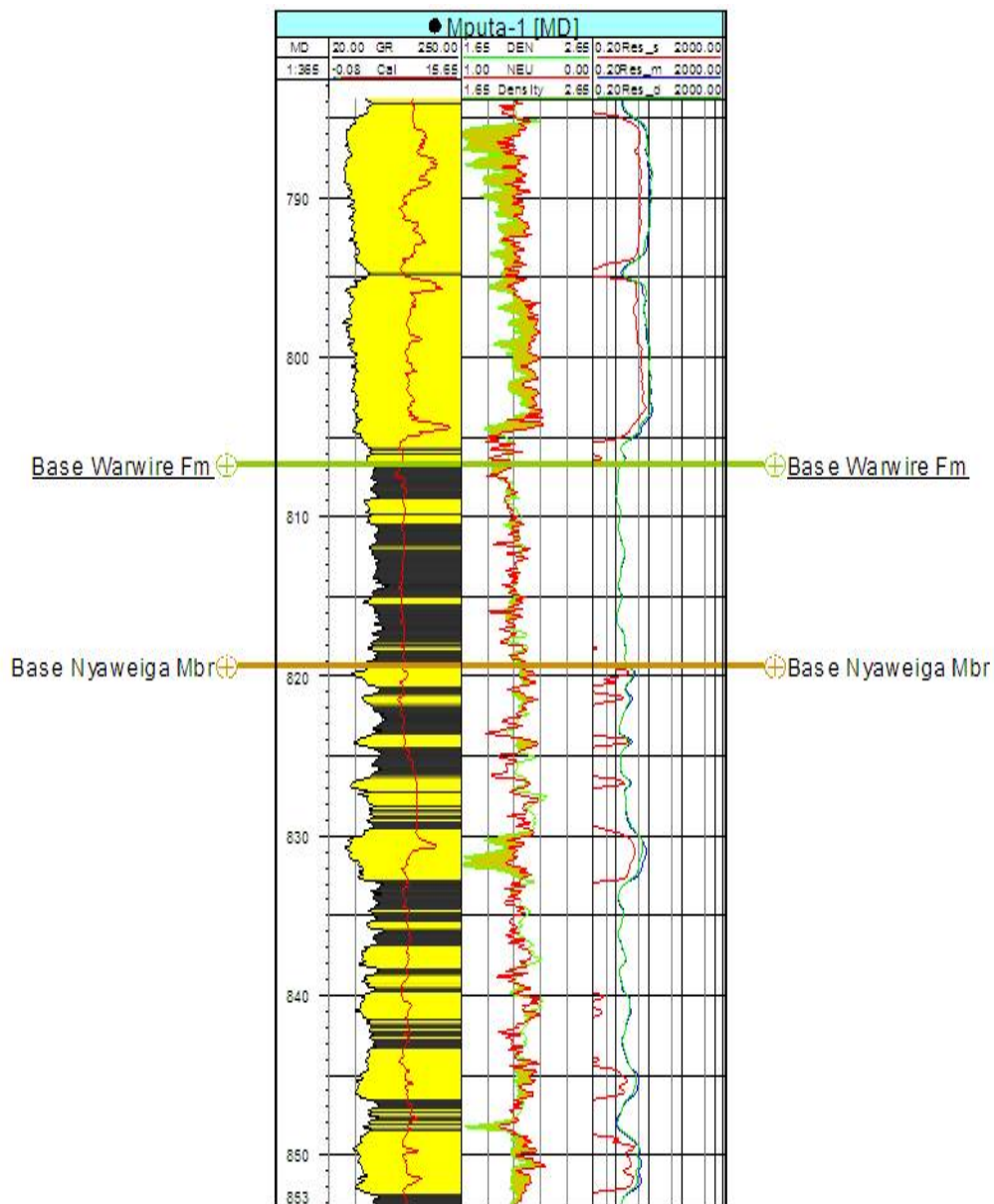


Fig. 16 Log extract showing base Nyaweiga Member in the Mputa-1 composite log.

Depositional environment: The unit is a marginal lacustrine claystone sequence that marks a highstand in Palaeolake Obweruka [1, 2] immediately prior to/accompanying tectonism which affected the entire Kaiso Tonya terrace.

Lateral correlatives: The member appears to correlate to the lower Nyaburogo Formation of the Semliki area, although that unit's base is not marked by any significant transgressive episode.

Other comments: The unit represents a significant

potential source rock and seal.

3.4 Warwire Formation

Origin of name: The unit was introduced by Pickford and Senut [8] and Pickford et al. [2] after localities in the Warwire River valley. The relationship between the unit as described by these workers in outcrop and that developed in the subsurface is complex and not yet fully clarified.

Type and reference sections: The formation is

exposed in the Warwire river area. Its basal stratotype is marked by an erosional unconformity characterized by draping of the formation's sediments over small eroded fault scarps in the underlying Nyaweiga Member at 262629E/155112N, 30°52'0"/01°24'09" [2] (Fig. 17).

The basal hypostratotype is defined in the Mputa-1 well at 805 m, marked by a reduction in gamma ray response, with corresponding changes in SP, porosity density and sonic log responses (Fig. 18).

Lithology: The formation consists of grey, brown-grey, dark grey, reddish-brown claystones, siltstones, sandstones, chert and coquinas. Laterally extensive subtly coarsening-upward sequences are observed lowermost in exposures, passing up into amalgamated sandstone facies. The boundaries between individual sequences are marked by fossilized ironstone bands. Sedimentary structures within the sandstones include planar and trough cross-bedding. These become more common towards the escarpment and are interpreted to be the proximal facies of an alluvial fan.

The lower parts of the formation were indicated by Pickford et al. [2] to contain an 8 cm thick tuff bed. This is yet to be confirmed however, the middle and topmost parts of the formation described the same authors were confirmed to contain a well-defined limestone horizon about 1 m thick—the Sebuguro

limestone and a 45 cm thick ash bed—the Kyampanga tuff at UPE locality 135, (E0269836/N0165295; 30°55'53" E/01°29'40" N; Fig. 19) respectively. The exact relationship between these different beds in exposure has yet to be determined in detail, while, as discussed below, the relation of these beds to the subsurface is also uncertain. The formation's top is marked by a metre thick amalgamated pedogenic ironstone bed in the cliff-top directly under Lake Albert Lodge.

The upper parts of the unit are here assigned to the Sebuguro Member, best exposed in cliffs between Lake Albert Lodge and the Sebuguro River (Fig. 19). We here propose establishment of this member, with a distinctively more claystone-rich sequence, with sporadic thin ironstone or sandstone horizons, and apparently containing the original Sebuguro limestone bed as first described by Pickford et al. [2] in its upper parts. The original name and rank of that marker bed is herein suppressed. As noted above, the middle and upper development of this member has still to be clarified because of the lack of adequate logging and surface mapping.

The Waraga-1 well shows a highly anomalous development of stacked coarse sandstones and conglomerates, herein provisionally assigned to the informal Waraga member and laterally correlative to



Fig. 17 Contact between the Nkondo and Warwire formations represented. The red sandy ironstone represents a break in sedimentation. Here the contact between the formations is paraconformable, but elsewhere it is angular or erosional.

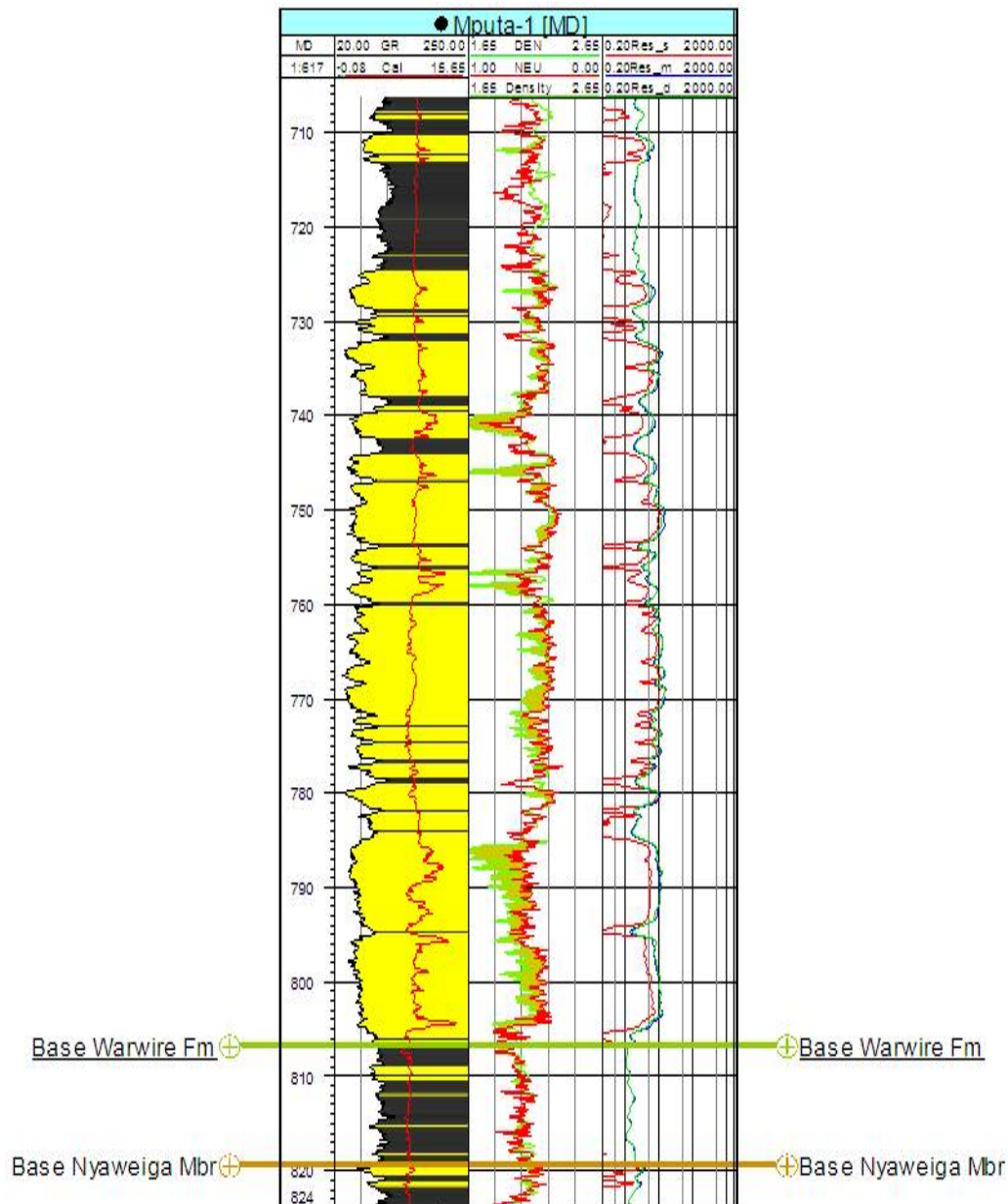


Fig. 18 Log extract showing base Warwire Formation in the Mputa-1 composite log base.

both the lower Warwire Formation and the Sebuguro Member.

Thickness and distribution: The subsurface unit is up to 700 m thick in the Mputa area and is present in all the wells in the Kaiso-Tonya area. Pickford et al. [2] further regarded the formation as being up to 70 m thick in exposure, but their correlation chart ([2]: Table A) clearly shows that this estimate was based on tentative correlations of several partial and generally thin sections, with few concrete tie horizons. As

discussed later, subsurface data now show that these correlations led to a severely underestimated thickness for the formation.

Age: A mid to late Miocene age was suggested by Lukaye [14, 24] in the Mputa-1 and Waraga-1 wells on the basis of palynomorphs. RPS Energy [13] however suggested an early Pleistocene age. Pickford et al. [2] suggested mid-Pliocene age for exposures on the basis of mollusc assemblages, scattered mammalian finds and tuffs which dated 3.6 Ma.



Fig. 19 The Warwire Formation at Kyampanga Cliffs viewed northwards. The black arrow shows the Kyampanga Tuff (3.6Ma) and the yellow arrow shows the prominent sandy ironstone that represents the boundary between the Warwire Formation beneath and the Late Pliocene Kyechoro Formation (Sebugoro Member) above.

Depositional environment: The sediments of the Warwire Formation display an interaction between lacustrine, fluvial and alluvial fan environments.

Lateral correlatives: At present, none can yet be ascertained pending reconciliation of apparently differing formational understandings.

Other comments: The formation's mixed lithologies and shallow depth render it a somewhat imperfect potential source rock and seal.

3.5 Sebugoro Member

Origin of name: This unit was informally mapped as a formation by PEPD (1995) after localities in the Sebugoro River Valley, although the name had first been used by Pickford and Senut [8] and Pickford et al. [2] for the Sebugoro limestone, a 1 m thick limestone unit in their Warwire formation.

Type and reference sections: The basal stratotype is defined in the Mputa-1 well at 615 m at the onset of a thick claystone unit marked by an increase in gamma ray with corresponding changes in SP, porosity density and sonic log responses (Fig. 20). Although its top has not yet been identified in the subsurface, seismic sections relating subsurface to coastal cliff exposures suggest a minimum thickness of around 800

m for the member (see discussion below). The reference section of the member can be observed in partial outcrop along the Sebugoro river valley at 0169570E/0269767N; 30°55'50" E, 01°31'59" N and along the shoreline cliffs of Lake Albert (Fig. 20).

Lithology: The sections logged consist of coarsening-upward sequences, predominantly composed of fossiliferous claystones and siltstones passing up into cross-bedded and ripple-marked sandstones with few or no fossils. These sandstones may indicate lacustrine shoreline drift. Most of the beds are thin and laterally continuous and fossiliferous ironstone beds separate the individual shallowing/coarsening-upward successions. Fossils consist mainly of gastropods and a few fish bones.

Thickness and distribution: The member is at least 615 m thick in Mputa-1, thickening to approximately 800 m under Lake Albert Lodge and its lower parts are preserved in all the wells in the southern Kaiso-Tonya area. The exposed section is apparently approximately 50 m thick in outcrop, but this clearly represents only a partial development of the member. The exact relationship between the limestone bed and the Kyamapanga tuff has yet to be established because of the partial nature of outcrops.

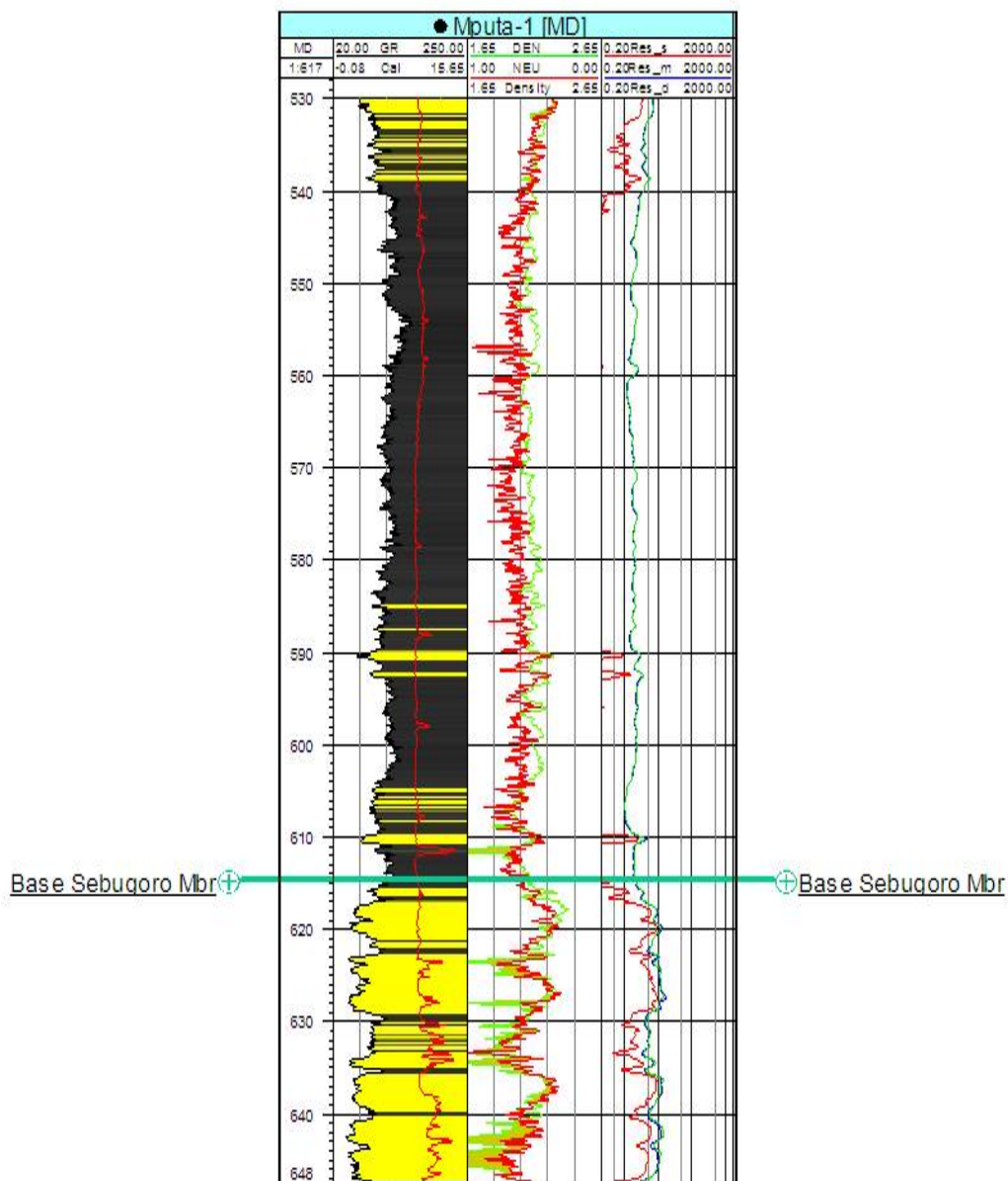


Fig. 20 Log extract showing base Sebugoro Member in the Mputa-1 composite log.

Age: RPS [13] suggested an early Pleistocene age for the mputa-1 well. Surface exposures were dated as late Pliocene by Pickford et al. [2] on the basis of Gautier mollusc assemblage G4, scattered mammalian finds and the Kyampanga tuff uppermost in the member.

Depositional environment: Marginal lacustrine to deltaic environments are suggested, with the coarsening-upwards rhythms indicating more than one episode of lake development and infill.

Lateral correlatives: At present none are formally identified, but the informal Waraga Member clearly developed simultaneously along graben margins further to the north.

3.6 Waraga Member

Origin of name: This unit has at present only been identified in the Waraga-1 well and is currently assigned informal status.

Type and reference section: The basal stratotype is

defined in Waraga-1 well at 715 m at the onset of coarse sandstones and conglomerates marked by a decrease in gamma ray and corresponding changes in SP, porosity density and sonic log responses.

Lithology: Stacked conglomerates and coarse sandstones in fining upwards sequences are suggested by logs. The occurrence of dark-coloured igneous clasts, perhaps of local footwall origin, should be noted.

Thickness and distribution: The member is about 354 m thick in Waraga-1 and has not yet been identified elsewhere.

Age: The interval was suggested to be of late Pleistocene age by RPS Energy [13] on the basis of palynological analysis of cuttings from the Waraga-1 well.

Depositional environment: Log patterns suggest stacked alluvial fan deposits near to a point source in the footwall of the adjacent graben margins.

Lateral correlatives: The member's coarse clastics were clearly deposited in a restricted area close to the graben margins contemporaneously with the lacustrine to coastal deposits of the Warwire and Kaiso Village formations.

Other comments: The member could represent a good potential reservoir in the area, but apparently has no effective seal.

3.7 Kaiso Village Formation

Origin of name: The formation was first named by Pickford et al. [2] after the locality name of Kaiso Village and clearly to distinguish it from the earlier and misused term of "Kaiso beds" (which would encompass all of the succession described herein).

Type and reference sections: The base is defined above the thick amalgamated ironstone in the cliff-top underlying Lake Albert. The formation is observed in exposures in the Hohwa river valley and in coastal exposures near Kaiso Village. Exposures there consist of "sands and silts with minor ironstones" (the Kyeoro formation of Pickford et al. [2]), "clays and silts with

oolitic ironstones and at its top, the Hohwa tuff" (their Hohwa member) and "clays and silts with ironstones" (their Kaiso Village member).

The Kyeoro formation, described by Pickford et al. [2] as an 8 m thick partial exposure, cannot be distinguished in the subsurface and is here considered as belonging to the lower parts of the Kaiso Village Formation until shallow coring proves otherwise. The Hohwa tuff is a distinct marker band in the Hohwa valley, described by Pickford et al. [2] as occurring uppermost in their 4 m thick Hohwa member but it has not yet been identified in the subsurface. These workers also described a 13 m thick "Kaiso Village member" (sic). The formation may also be represented in the Waraga-1 well, but logs from this interval are poor or non-existent: Better understanding of the full development and status of the Kyeoro and Kaiso Village formations and their Hohwa and "Kaiso Village" members must await further study by shallow coring.

Thickness and distribution: The formation may represent the uppermost 50 m in the Waraga-1 and Ngassa wells, but is otherwise not preserved in other wells in the Kaiso-Tonya area. Outcrops show only 20 to 30 m thick partial sections through the formation and these are not yet correlated to the subsurface.

Age: Surface exposures were dated as Plio-Pleistocene to Late Pleistocene by Pickford et al. [2] on the basis of mollusc assemblages and mammalian finds. The Hohwa tuff's age is currently being determined.

Depositional environment: The formation's sediments are interpreted to represent a fluvial to floodplain section that was close to the lake margin.

Lateral correlatives: The formation is laterally equivalent to the much thicker developments of the Nyakabingo and Nyabusosi formations in the Semliki area.

4. Discussion

We have herein attempted for the first time to

correlate and integrate information from the surface and subsurface Neogene sequences of the Semliki and Kaiso-Tonya areas in the Albertine Graben. Important differences, not least in thickness, have previously led some workers to disconnect these two successions: surface and subsurface successions. The former are particularly characterized by an abundance of various ironstone beds and constitute a small fraction of subsurface thickness, representing a highly condensed sequence which only saw deposition at times of lake highstand. The ironstone units represent remanie beds and are less common in the subsurface. They are suggestive of condensation and major breaks on the platform, while their less occurrence in the subsurface agrees with the clearly higher rates of continuous deposition represented by the basinal situation. Chan [25] also viewed a well-developed oolitic ironstone bed in the Cretaceous Mancos Shale of western USA as representing a condensed section, expressing a good marker in an otherwise monotonous offshore shale section, while the general review of ironstone occurrences by Macquaker et al. [26] concluded "...ironstones formed either at sequence boundaries, major flooding surfaces or maximum flooding surfaces".

The contrast in the subsurface and surface sediment thickness reflects important differences in sites within the overall graben setting where outcrops reflect development on small half-grabens situated on the main graben margins (Fig. 21) while the thicker subsurface displayed by seismic and wells are on the deeper margins of the main graben, with significantly greater subsidence and sediment input both from graben margins and axial flow. The developments in both cases are related to changes in regional sedimentation style, reflecting lacustrine "transgressive" and "regressive episodes". These episodes themselves result from either climatic change, major rifting events, or changes in sediment input (or combinations of all the three processes) leading to changing lake levels in the graben.

Incorporation of original lithostratigraphical proposals by Pickford et al. [2], sedimentological interpretations by Roller et al. [9] and Karp et al. [10], and our own seismic and well log interpretations, suggest the development of the infill in the Semliki Basin as highlighted in Fig. 22. Four evolutionary phases of the development of the Semliki exposures have been distinguished on the basis of vertical stacking patterns, prograding and retrograding trends and mineralogical climatic indicators [9]. The four phases include ca. 14.5 to 10.0 Ma (Kisegi to mid-Kakara Fm) interpreted by Roller et al. [9] as representing pre- and early synrift sedimentation in a semi-arid climate. However, palynofacies data suggest that arid environments only persisted until base Kasande Formation times which marked the onset of local lacustrine (and probably regional humid) environments [13, 14]. This development (Kasande development) rather than the younger Oluka Formation basal transgression, probably also marked the onset of large-scale rifting and the nascent development of Palaeolake Obweruka [2].

The Kasande transgression was followed by a gradual increase in terrestrial clastic input with the first development of ironstones marking the basal part of the overlying Kakara Formation, represented in exposures by a bypass and development of remanie ironstones (Fig. 22). It is as yet uncertain whether the first development of ironstones has any regional climatic significance although they probably reflect a shift from semi-arid to humid environments.

The marginal lacustrine to coastal conditions of the Kakara Formation continued through to near base Nyaburogo Formation (Fig. 4) interrupted by the basal Oluka Formation transgression (Fig. 22), which seems to have been a regional phenomenon, flooding all marginal terraces around the graben. This transgression itself marks the rifting which appears to have led to widespread inundation of marginal graben areas, including the Kaiso-Tonya terrace (Fig. 21), which had hitherto not been depositional site, thus producing

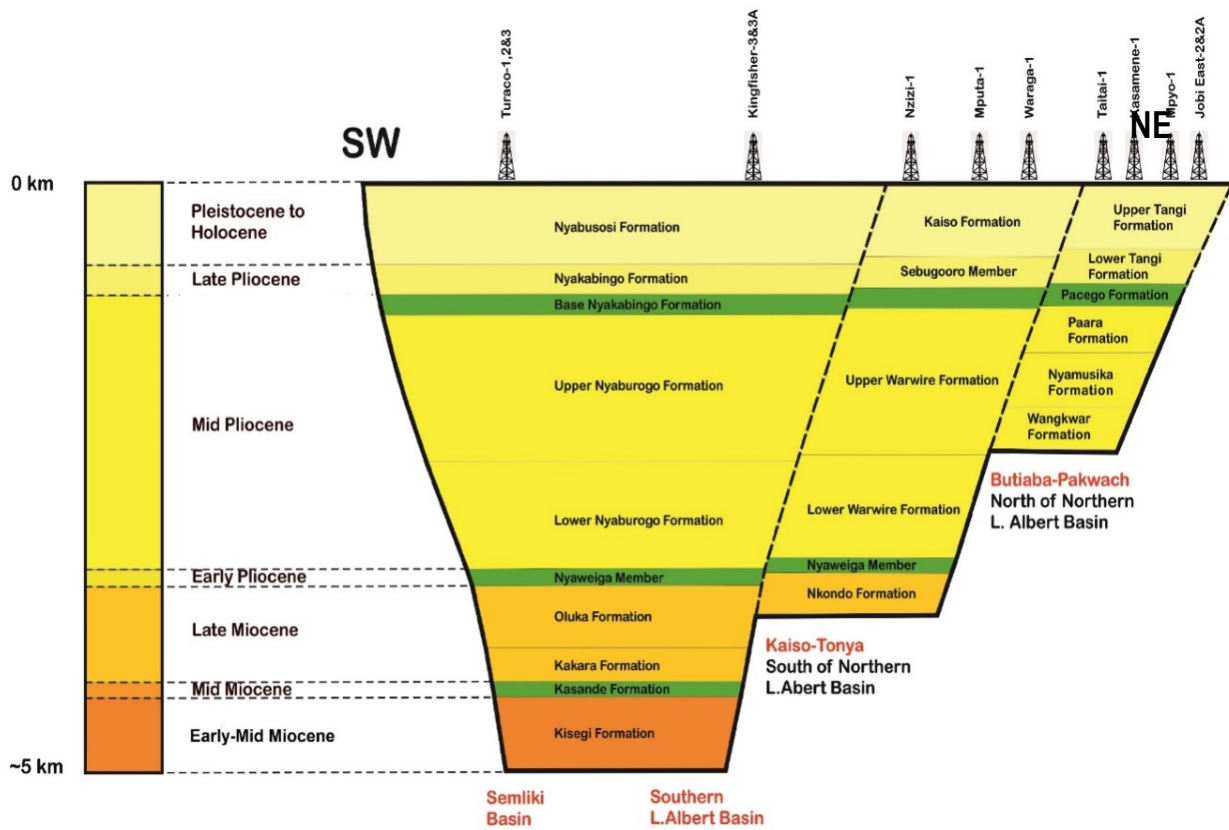


Fig. 21 Proposed depositional model of the Albertine Graben (modified from Tullow Oil’s internal report).

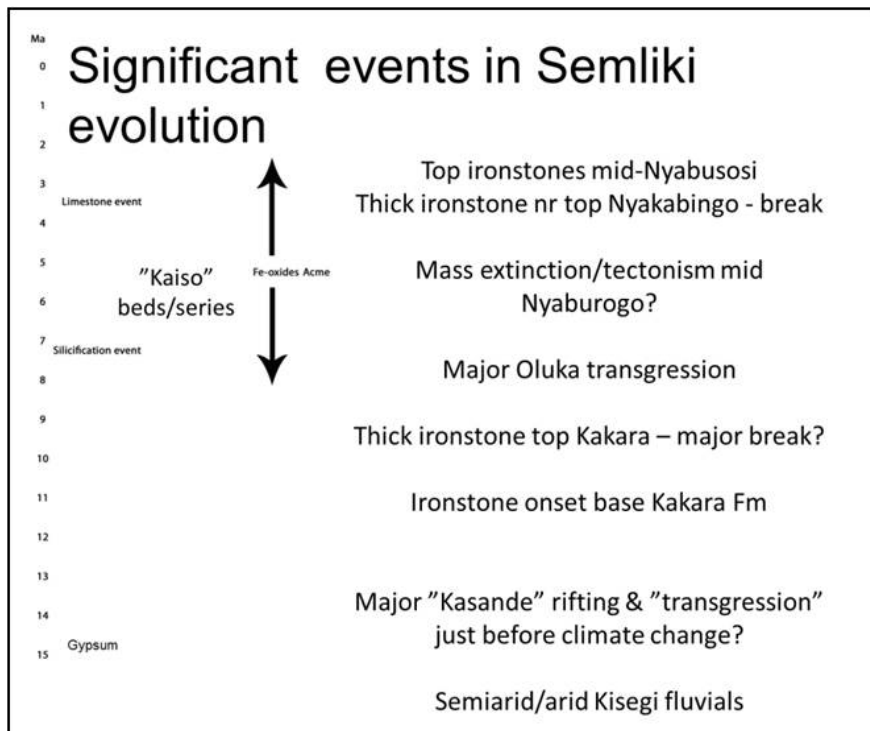


Fig. 22 Summary of main climatic and tectonic events (and ironstone development) in the Neogene succession of Semliki.

development of more widespread lacustrine conditions. Accordingly, the Oluka Formation in the Semliki Basin correlates to the Nkondo Formation of the Kaiso-Tonya terrace/Basin while the lower part of the Nyaburogo Formation correlates to the Nyaweiga Member of the Kaiso-Tonya Basin.

Within the middle parts of the Nyaburongo Formation [9] (Fig. 10) suggest a shift from their phase 2 (shallow lake) to phase 3 (large and deep lake) coinciding with the major tectonic phase proposed by Pickford et al. [2] although no major change in sedimentational style has been suggested. However, if the datings suggested by the mollusc associations and mammals are correct, it's likely that the middle parts of the Nyaburogo formation indeed reflect a major tectonic activity which may have caused a major extinction event in the molluscan community [16-19] followed by erosion of exposed sediments (Fig. 22) as also seen at the Nkondo/Warwire formational boundary in the Kaiso-Tonya area by Pickford et al. [2]. No clear evidence of such syndepositional tectonism has yet been observed in the Semliki area, either in exposure or wells.

The upper Nyaburogo and entire Nyakabingo Formation outcrops of the Semliki Basin represent intercalated delta plain and nearshore deposits, still with frequent ironstones [9]. The prominence of ironstones especially at the top of the Nyakabingo Formation probably indicates long-term condensation/bypass on the platform, while high subsidence rates in the graben produced accommodation space repeatedly filled by prograding deltaic sequences. The nature of Nyakabingo/Nyabusosi transition in outcrop is still unresolved, but the Nyabusosi Formation is agreed by all authors to represent drier conditions, with oscillating coastal and lacustrine environments. This perhaps represents a general drying trend related to the ongoing rise of the rain barrier represented by the Blue Mountains together with accelerated rift-flank uplift and strong subsidence of the rift floor.

In the Kaiso-Tonya Basin, deep wells generally show that the deposits increase systematically in thickness from the southern parts to the north over a major down-stepping fault (Fig. 12) into the much more complete succession. Its oldest sediments, the Nkondo Formation, show a shift from a fluvial setting to a lacustrine depositional environment evidenced by the change from predominantly sandstone deposits at the base of the formation to predominantly clay/shale deposits towards the top. The change in depositional environment could have been due to regression and transgression of the lake, allowing fluvial input to areas that were once occupied by lakeshores. The ironstone layers were probably due to localized high input of terrestrial waters.

The overlying Warwire Formation generally displays lacustrine sequences that change to fluvial environments towards the top with thin ironstone beds. The coarsening-upward rhythms probably indicate more than one episode of lake development and infill which in turn reflect episodic tectonism and/or climatic variation, with thin ironstone beds marking minor hiatus. The upper clean blocky sands interpreted on the Waraga-1 well herein described as the Waraga Member in the Warwire Formation are possibly as a result of a different depositional setting from the rest of the formations in the southern part of Kaiso-Tonya and hence, uncorrelatable. The sands were deposited near the point source in the footwall of the adjacent graben margins.

The youngest deposits of the Kaiso-Tonya Basin show fresh water lacustrine system which then change to fluvial depositional environment probably due to regression of the lakeshore resulting from either increased aridity or movement on the major border fault.

5. Conclusions

Surface exposures in the Semliki and Kaiso-Tonya basins of the Albertine Graben constitute a small fraction of subsurface thickness and are characterized

by an abundance of ironstone beds. The ironstone beds represent remanie beds which suggest condensation and major breaks on the platform. The surface exposures generally represent a highly condensed sequence which only saw deposition at times of lake highstand. They reflect development on small half-grabens situated on the main graben margins while the thicker subsurface are on the deeper margins of the main graben, with significantly greater subsidence and sediment input both from graben margins and axial flow. The developments both in the subsurface and surface are related to changes in regional sedimentation style, reflecting lacustrine “transgressive” and “regressive episodes” probably as a result of either climatic change, major rifting events, or changes in sediment input (or combinations of all the three processes) leading to changing lake levels in the graben. They generally correspond well to the models for rift sequence stratigraphy ably summarized by Martins-Neto and Catuneau [27].

Six formations ranging in age from lower Miocene to Pleistocene characterize the Semliki Basin. The formations include the Kisengi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo and Nyabososi Formations. Among these, the Kasande formational development marked the onset of large-scale rifting while the Oluka Formation transgression marked a rifting phase which appears to have led to widespread inundation of marginal graben areas, including the Kaiso-Tonya terrace, producing more widespread development of lacustrine conditions that covered both basins.

Although this study avails a good understanding of the lithostratigraphy and development of the Semliki and Kaiso-Tonya basins, more work remains to be done especially in regard to harmonizing the conflicting ages of the sediments by different authors, solving challenges related correlation of platform deposits to basinal deposits in the subsurface, establishing the mode of origin of the variety of ironstones, and understanding the development of

exposures in the Warwire Formation. It is important therefore that further surface mapping and drilling of shallow wells, and radiometric dating of suspected tuff beds are undertaken in future especially to harmonize the ages of the sediments, elucidate the missing intervals between present deep wells and shoreline exposures, and also fully understand the development of the Warwire Formation of the Kaiso-Tonya Basin.

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