CLIMATIC OSCILLATIONS AS REGISTERED THROUGH THE RUZIZI PLAIN DEPOSITS (NORTH LAKE TANGANYIKA) ZAIRE - BURUNDI - RWANDA

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ABSTRACT: The Ruzizi Plain deposits show evidence of alternating savannah and semi-arid climates deduced from geomorphology (calcretes - ferricretes - stone-line), sedimentology (meandering river - braided river -sheetflood deposits), and pedology (Gley - Pseudogley - Alfisol - Calcrete palaeosoils).

1. Introduction

Climatic oscillations are important markers of the Quaternary. They are commonly studied thanks to the sensitivity of the micro- and macrofossils in them. The aim of the present work is to show how these oscillations have been registered through the generally non fossiliferous Quaternary deposits of the Ruzizi Plain which borders Lake Tanganyika in the North. Geomorphologic (calcretes - ferricretes -stone-line), sedimentologic (meandering river - braided river - sheetflood deposits) , and pedologic (Gley - Pseudogley - Alfisol - Calcrete palaeosoils) features are used.

2. Lithostratigraphy of the Ruzizi Plain Deposits

The first lithostratigraphic study of the Quaternary deposits of the Ruzizi Plain (Fig. 1 & 2) is that by Direction de Géologie (1974) done with the collaboration of J. Lepersonne and some geologists of the "Bureau de Recherche Géologiques et Minières" (BRGM) of France. This study gives a general lithostratigraphic (informal) and relative chronostratigraphic

R. Paepe et al. (eds.), Greenhouse Effect, Sea Level and Drought, 287–299.

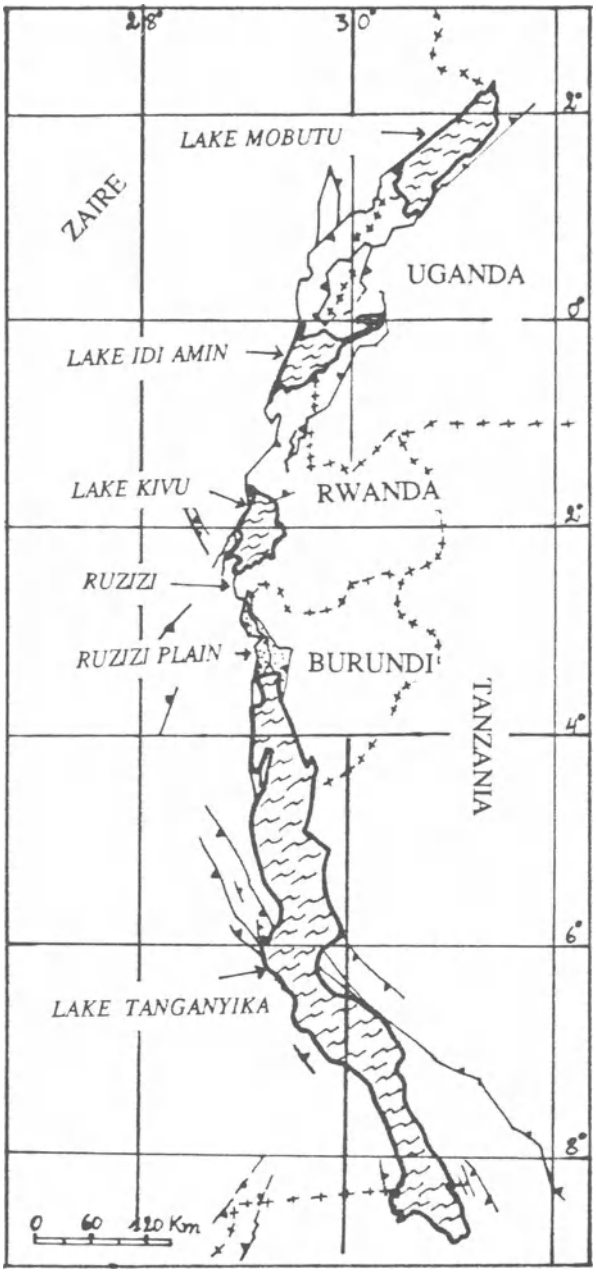

Figure 1. Ruzizi Plain in the Western Rift Valley.

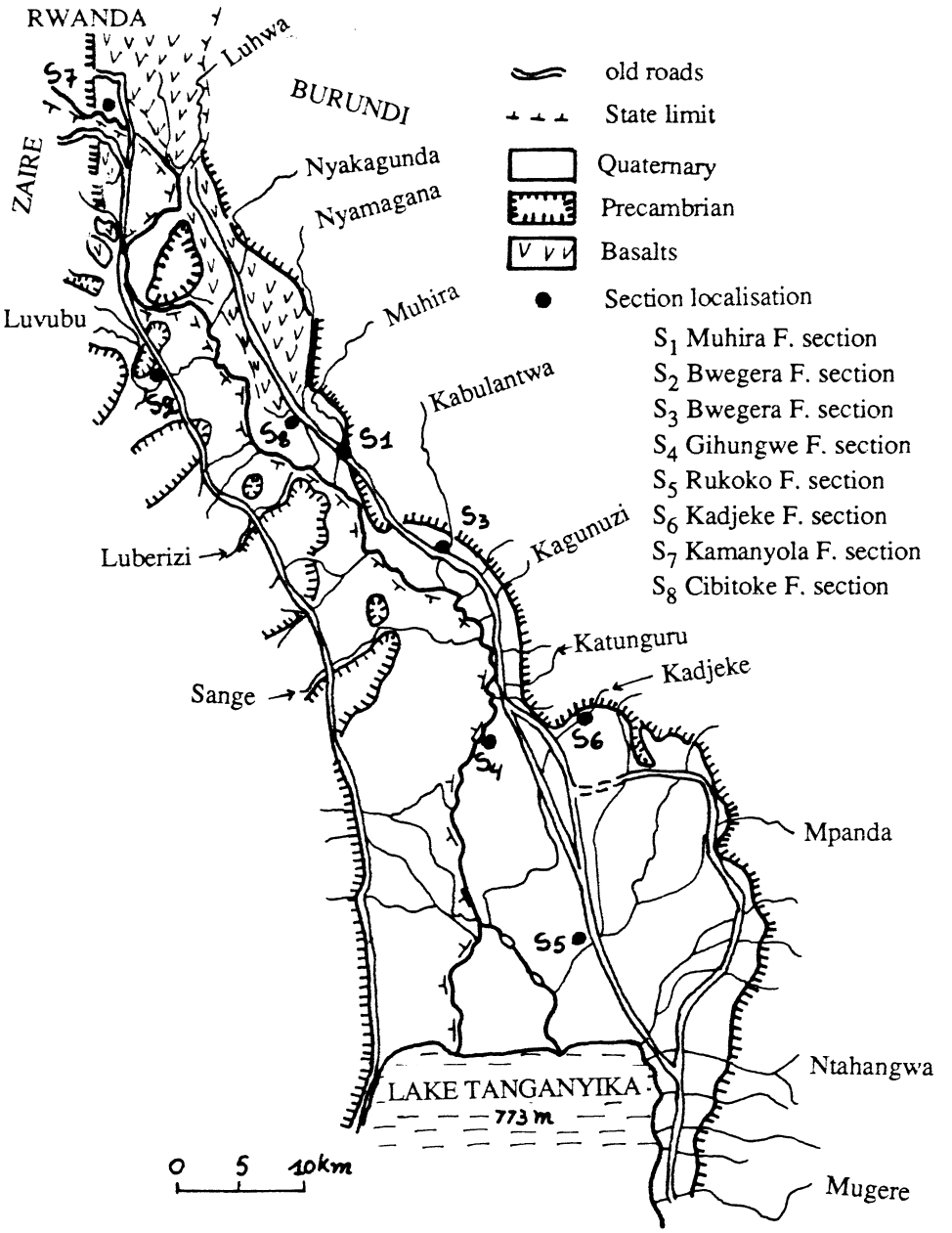

Figure 2. Ruzizi Plain Sections Map.

framework.

The second and more detailed study is that by ILUNGA and PAEPE (Geobound, in press) who subdivided these deposits into ten formal lithostratigraphic units (Table 1, Fig. 3 & 4) which are hereafter described and interpreted from a palaeoclimatic point of view.

Table 1. Lithostratigraphy of the Ruzizi plain deposits.

PROBABLE AGE	LITHOSTRATIGRAPHY		
HOLOCENE	KADJEKE F.		
	KAMANYOLA F.		RUKOKO F.
UPPER PLEISTOCENE	NAOMBE F.	TSHAMATE GROUP	
	GIHUNGWE F.		
LOWER TO MIDDLE PLEISTOCENE	LUVUNGI F.		
	BWEGERA F.		
LOWER PLEISTOCENE	CIBITOKE F.		
	MUHIRA F.		

2.1. THE MUHIRA FORMATION (LOWER PLEISTOCENE)

The Muhira Formation (Lower Pleistocene) consists of four faulted units which are from bottom to top:

- The lower unit shows an upward coarsening sequence of fine silt to sand suggesting a deltaic environment. It is a yellowish, thinly laminated deposit of about 10 m. thick displaying to the top a large scale tabular cross-lamination with contorted laminae, slump structure and reactivation surfaces. The latter feature represents minor erosion surfaces

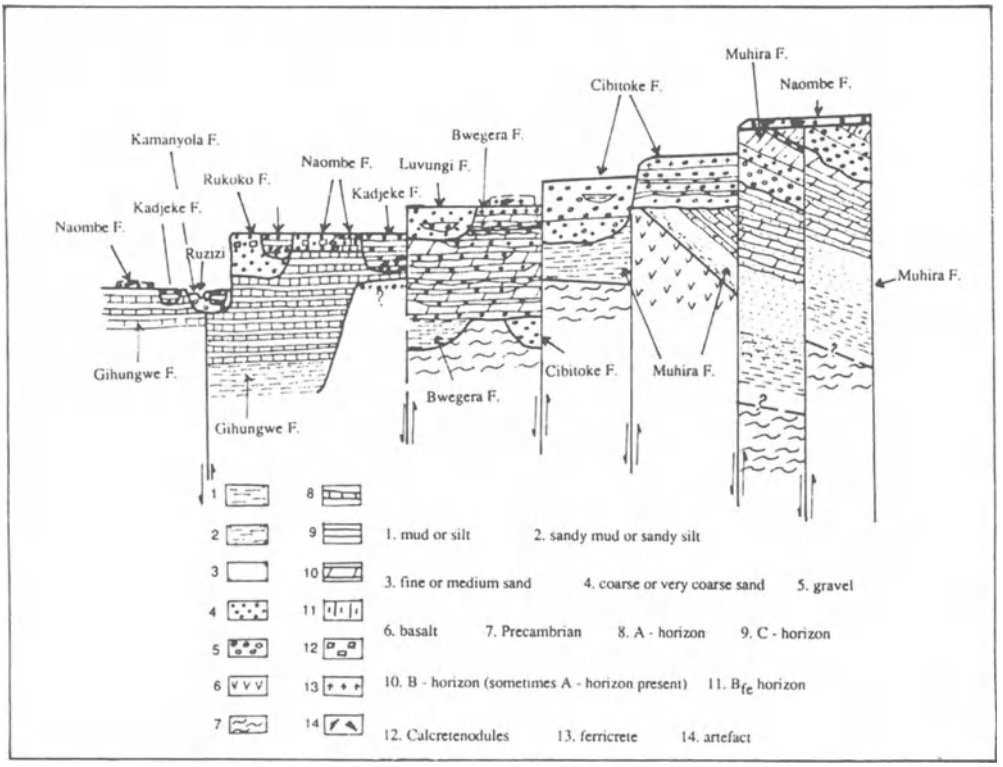

Figure 3. Ruzizi Plain Synthetic Lithostratigraphic Section.

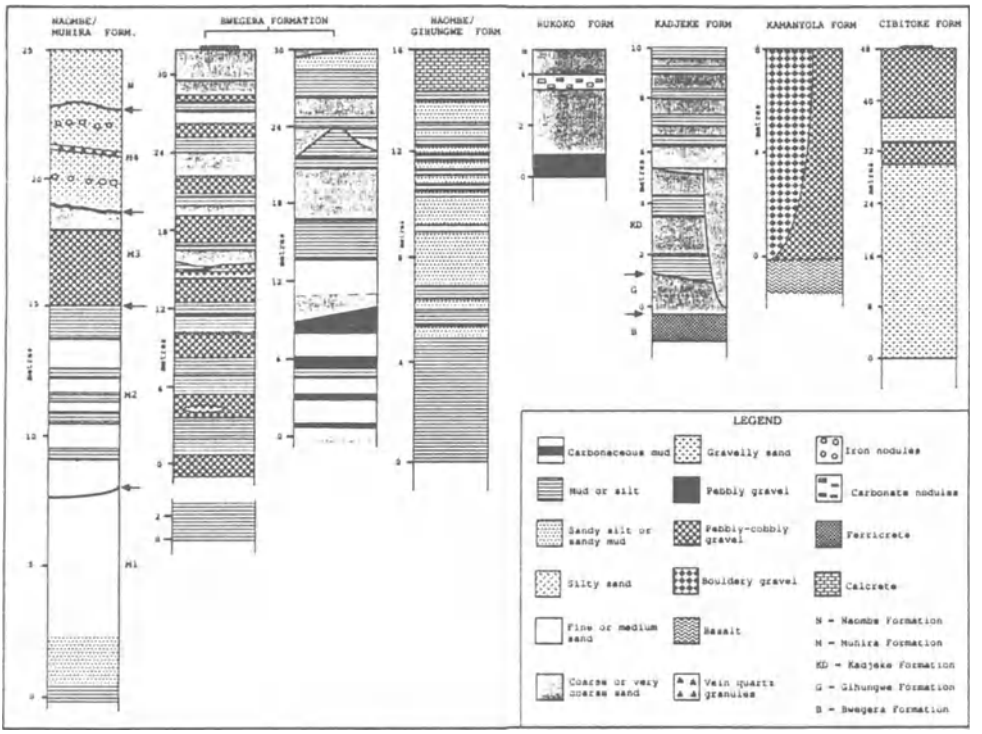

Figure 4. Ruzizi Plain Lithologic Sections.

on bedforms that were abandoned by a decrease in flow strength and then reactivated some time later (Collinson in Miall, 1985)

- The second unit shows cycles of yellow-brown fine sands alternating with grey-greenish muds in upward fining sequences suggesting a deltaic plain environment characterized by periodic flooding. These beds, especially the muds, are completely destratified, gleyified, and present burrow channels filled with red sandy material suggesting a humid climate (Duchaufour, 1977), probably strongly seasonal (Freyet, 1971).
- The third unit is made of gravel-sand facies probably of Allen's low sinuosity river type (Allen, 1965).
- The fourth unit is fluvio-colluvial made of two intensively bioturbated silty sand palaeosoils with iron nodules showing a predominance of illite 30% and smectite 25% over kaolinite 25% (Alfisol?) and separated by a stone-line of vein quartz granules mixed with lateritic concretions. The absence of the quartzite granules which constitute more than 90% of the Ruzizi plain gravel lithology and the presence only of vein quartz granules (residual) and iron nodules point to a colluvial process under semi-arid conditions on the Precambrean scarps. This semi-arid climate was preceded and followed by humid climates of the savannah type as suggested by the presence of iron nodules (Johnson, 1977).

2.2. THE CIBITOKE FORMATION (LOWER PLEISTOCENE)

The Cibitoke Formation consists of thick red or yellowish gravel deposits, with some intercalations of sand or mud layers of generally only a few dm. thick, capped by a ferricrete. Iron cementation of these gravel and finer beds can be seen from place to place where these gravels and mud facies become orthoconglomerates and mudstone lenses respectively.

These deposits present generally a G_m facies (massive or crudely stratified facies of MIALL, 1978), but sometimes a G_p (planar cross-stratified gravel) and a G_h (horizontal stratified gravel) facies. In some places a multistorey channel pattern is exposed displaying rapid alternation of lenticular S_p (planar cross stratified sands) and G_m facies capped by a S_h (horizontal stratified sands) facies extending out of the channel.

The river behaviour seems to have been braided. Indeed, the alternation of very coarse and fine deposits suggest fluctuating currents passing from the upper flow regime to the lower. The predominance of coarse clasts, the lenticular character of fine sediments as well as the presence of multistorey channels suggest a braided river environment (Costello & Walker, 1972). Such a behaviour contrasts with overbank flooding characterised by the predominance of fine materials and points to a dry phase probably of the semi-arid climate. This was probably followed by a savanna climate as suggested by the ferricrete cap well known to form under a savanna climate (Tricart, 1974).

2.3. THE TSHAMATE GROUP (LOWER TO UPPER PLEISTOCENE)

The name "Group" is used here for reasons of simplicity to put together all the sediments which represent some common features such as:

- younger than the Cibitoke Formation;

- a predominance of finer deposits (muds & sands);
- the greenish grey colour though locally some yellowish, dark and light colours are observed;
- the less exposed shale facies at the base of profiles;
- and the generally distributed carbonate concretions.

This group is composed, from bottom to top, of the Bwegera, Luvungi, Gihungwe and Naombe Formations.

2.4. THE BWEGERA FORMATION (LOWER TO MIDDLE PLEISTOCENE)

The Bwegera Formation consists of upward fining cyclothems capped by a ferricrete. These cyclothems are made of thickly to very thickly bedded white to grey quartzite pebbly gravel (sometimes absent) - coarse to fine sand - greenish grey muds intensively bioturbated and displaying root channels, prismatic structures, carbonate root casts, ferruginous and carbonate material aggregations and sometimes slickensides. The most striking features of these palaeosoils are however the gley and pseudogley mottling appearing separately or sometimes together, the pseudogley being overprinted by the gley and the coexistence of lepidocrocite with the carbonate nodules.

The sedimentary environment is characterized by the high proportion of fines, suggesting periodic fluviatile overbank flooding. The overprinting of the pseudogley by the gley mottling suggests first of all a fluctuating water-table at the sedimentation time, followed by a permanent water-table subsequent to the continuous soil burial (Wright, 1989). The presence of burrows, root channels and well developed aggregations of ferruginous materials and scattered carbonate nodules reflect a tropical, strongly seasonal climate (FREYTET, 1971).

2.5. THE LUVUNGI FORMATION (MIDDLE PLEISTOCENE)

The Luvungi Formation consists of a terrace deposit of fine to medium sand facies of white-grey, sometimes yellowish colour, displaying lenses of pebbly gravel facies and suggesting Allen's low sinuosity river type.

2.6. THE GIHUNGWE FORMATION (UPPER PLEISTOCENE)

The Gihungwe Formation is constituted of laminated silts (shale) at the base, followed by alternating dark and light medium to thickly bedded sandy silts and silts containing scattered carbonate nodules and locally displaying fine sand thin beds. The light beds are grey-green sands, sandy silts or silts with some iron oxidation spots while the dark beds are black and carbonaceous silts with root traces, and gley mottling.

The Gihungwe Formation probably took place in a shallow lake (euplanctonic diatoms: *Melosira ambigua*) which evolved into an interdistributary bay which fluctuated a lot as evidenced by the mud zonation of grey and grey-black. The presence of root traces and gley mottling means that mud beds have been colonized by vegetation under a humid, probably savanna climate.

2.7. THE NAOMBE FORMATION (LATE UPPER PLEISTOCENE)

The Naombe Formation consists of red sand deposits displaying a pebble-cobble gravel facies in the piedmont zone. Its thickness shows a good amount of variation. From a little more than 6 m to less than 1 m, the thickness diminishes from scarps to the center of the plain where it subsists now as patches because of subsequent erosion. The depositional process seems to have been streamflood suggesting a semi-arid climate which is here confirmed by the presence of calcrete nodules. Indeed, carbonate concretions, some several d_m thick can be observed in several profiles.

2.8. THE RUKOKO FORMATION (LATE UPPER PLEISTOCENE TO HOLOCENE)

The Rukoko Formation consists of white-grey medium to very course sand facies with interstratified brownish undulating podzolic very thin beds (clay & humus). These very thin beds are decimetrically spaced, subparalel but locally cross-stratified. Towards the base, the facies become even courser of granule. At about 0.5 m from the top a pedological carbonate concretion bed (B_{ca} horizon) can be seen which suggests a semi-arid climate. The Rukoko Formation probably took place in a high energy beach environment.

2.9. THE KAMANYOLA FORMATION (HOLOCENE)

The Kamanyola Formation is the deposit of the outflow of Lake Kivu to Lake Tanganyika through the Ruzizi River. It is composed of two members. The lower is made of pebbly to cobbly gravel interstratified with lenticular small bouldery gravel. The upper is a very thick massive bouldery gravel which distally diminishes to become sandy towards Lake Tanganyika. It seems to be the consequence of the Lake Kivu overflow under a humid climate at the beginning of the Holocene (Hecky, 1978).

2.10. THE KADJEKE FORMATION (HOLOCENE)

The Kadjeke Formation consists of a series of thinly to medium bedded interstratified whitish-grey to reddish-brown sands or pebbly sands and dark grey sandy silts. These look to have been formed in a humid alluvial fan by streamflood processes as suggested by the sheet-like form of individual units. However, the presence of a few sharp cutbanks are evidence that channelization took place but was not predominant. The occurrence of rootlets, which later on have been oxidised, suggests that the stream was sluggish or the channel dry for long time, allowing extensive plant colonization and thus, the just beginning of the soil pedogenesis as confirmed by the light pedoturbation of mud units. From a climatic point of view, we notice that the association of braided sheet sands with abundant plant debris, especially in channels, the generalised fine texture of the deposits, their black colour, and the absence of caliche nodules are hard to explain without invoking a wetter climate. The presence of pottery clasts in channels dates this climatic wet phase of Holocene, probably that of about 8,000-6,000 y BP (Roche et al, 1988).

3. Climatic Evidence

As described, the Ruzizi plain deposits show many features of climatic meanings. These have been subdivided into geomorphologic, sedimentologic and pedologic features.
With its annual means of about 975 mm/year of rainfall, a temperature of 24 °C and a dry season of six to seven months, the present Ruzizi plain climate is of a dry savanna type. As the most humid palaeoclimate ever encountered in the deposits is of the savanna type, we can assume that we are dealing now with a relatively humid phase. It is probably less humid than the one which allowed the formation of the allochtonous ferricretes such as the ones covering the Cibitoke and Bwegera Formations. So the present climate can be considered as an intermediate one, however situated on the humid side. The dry side should be a semi-arid climate characterized by the excess of evapotranspiration over precipitation (Tucker, 1982) as suggested by calcrete nodules (Naombe Formation).

From a sedimentological point of view, observations of the present day behaviour of the Ruzizi plain rivers lead to the conclusion that they behave differently as a function of their distance from scarps. Generally of the straight type Ruzizi plain rivers, however, show a braided tendency near the scarps and a meandering one distally. Their general sedimentation is coarse with little overbank flooding. Such deposits correspond well with Allen's low sinuosity river model (Allen, 1965). The colour of the sediments is grey suggesting that the present climate produces enough humic acids to remove all the iron oxides. The analysis of the present behaviour leads to the conclusion that the development of the braided type, especially with red or yellow iron oxides colours may be interpreted as due to a drier climatic phase. This is the case for the Cibitoke Formation and for the proximal facies of the Naombe Formation. On the other side, the development of the meandering type favouring extensive overbank deposits with lenticular channel gravel and/or sand suggests a more humid climatic phase than the present one. This situation is encountered in the Muhira and Bwegera Formations. The sheet-like facies of the distal Naombe facies and of the Kadjeke Formation suggests a streamflood deposition which may occur under humid or dry phases. Here the colours of the sediments and the presence of plant debris can help to differentiate them.

Palaeosoils are also important tools for palaeoclimate recognition. In the Ruzizi plain, palaeosoils are more developed in floodplain muds which envelop subordinate to less ordinate gravel and/or sand. Five formations especially concerned are: the Muhira, Bwegera, Gihungwe, Naombe and Kadjeke Formations. In general, these deposits all show evidence of pedogenesis. In fact, pedoturbation is their common feature and is more pronounced in the overbank, than in the channel deposits. Many of the pedogenic features can also be observed. These are: the presence of organically enriched horizons (A-horizons) showing darkening by organic staining, mottling (gley, pseudogley and sometimes gley overprinted on pseudogley), and some biogenic features such as root traces, carbonate root casts and concretions, and iron rhizocretions. Prismatic structures with allochtonous materials from upward suggest expansion and contraction associated with wetting and drying. Aggregations of ferruginous materials as well as iron nodules can also be observed (Muhira and Bwegera Formations) A B_{ca}-horizon has been noted in the Naombe and Rukoko Formations (Late

Upper Pleistocene).

These features all have some climatic meaning:

- the presence of burrows, root channels and well developed aggregations of ferruginous materials and scattered carbonate concretions reflect a tropical, strongly seasonal climate (Freyet, 1971);
- the soils showing evidence for the illuviation of iron as well as carbonate compounds and perhaps clays suggest according to Johnson (1977) a savanna-woodland under the influence of a tropical seasonal climate;
- the caliche nodules (B_{ca}), where they are alone, are typical of semi-arid climatic areas where evapotranspiration exceeds precipitation (Tucker, 1982);
- a fluctuating water-table will result in pseudogley features developing in a buried soil, later overprinted by gley features as with continued burial (Wright, 1989). This hydromorphic situation suggests according to Duchaufour (1977) a humid climate.
- the presence of iron rhizocretions implies the presence of soluble iron in high concentration in the soil and thus of an acidic medium. The climate should be strongly seasonal and probably the savanna type. The carbonate root casts and segregations can be explained by the drying of the soil (evapotranspiration) leading to higher ion concentration and precipitation.

4. Cyclicities

Four types of cyclicities have been observed in the Ruzizi plain deposits. These are: the fluviatile, the fluvio-colluvial, the deltaic plain interdistributary bay and the alluvial fan or small river cyclicities.

The fluviatile cyclicity is encountered in the Muhira and Bwegera Formations. It is made of upward fining sequences of sand - mud for the Muhira Formation and of gravel (sometimes absent) - sand - mud for the Bwegera Formation. Gravel and sand beds are lenticular and represent channel deposits while mud beds are overbank deposits which have been totally transformed into soils so that C-horizons (undisturbed sediments) are no more observed. Only B-horizons, sometimes with A-horizons where they are not eroded can be observed.

Referring to the cyclicity cause, subsidence could have played a certain role as well as the to and fro lateral migration of river channels across their floodplains. The tectonic role should probably be reduced as the effects of its pulses are not evident. Indeed, Miall (1982) discusses the tectonic effects in generating large scale coarsening and fining upward cycles which have not been observed, the cyclothem textures being more or less the same throughout the sections.

However, in some of these palaeosoils we have noticed the coexistence of lepidocrocite and caliche nodules which normally should not form together. Indeed, Schwertmann and Taylor (1977) noted the absence of lepidocrocite in calcareous soils, although hydromorphic, which indicates that the introduction of CO_2 into the system favours formation of goethite rather than lepidocrocite. Such a situation probably implies that the Savanna climate responsible for the iron precipitation prevailed before the semi-arid one. If this is correct

such palaeosoils can be considered to bear the marks of climatic oscillations and thus suggest a climatic cycle (savanna/semi-arid) respectively for each of the palaeosoils found at the Muhira and Bwegera type-sections.

The fluvio-colluvial cyclicity is encountered in the upper part of the Muhira Formation. It is made of two silty sand palaeosoils exhibiting iron nodules and separated by a stone-line of vein quartz and iron nodules (lateritic granules). The presence of iron nodules (Bfe-horizons) suggests a savanna climate while the stone-line pavement implies a semi-arid one (sheetflood deposit). So the whole sequence shows a climatic oscillation of the savanna/semi-arid type.

The deltaic plain interdistributary bay cyclicity is that of the upper part of the Gihungwe Formation which took place in an interdistributary bay which fluctuated a lot as evidenced by the mud zonation of grey and grey-black with the latter colour being due to organic matter content.

The presence of root traces and of gleyification means that these muds have been colonized by vegetation and evoluated at least as hydromorphic soils with A-horizons well marked covering C-horizons (undisturbed sediments). Thus, the deltaic plain interdistributary bay cyclicity is made of cyclothems of the A-C horizons soil type.

The alluvial fan or small river cyclicity is encountered along small rivers such as Katunguru and in the alluvial fan environment. Its deposits correspond to the Kadjeke Formation which is characterized by the sheet like form of individual units of sand and/or granule texture alternating with mud beds containing plant rootlets which have been later on oxidised in a red colour. However, because of the very light soil development on these muds, we consider them as C-soils which are eight time repeated at the type section.

5. Conclusion

The Ruzizi plain deposits show several indications of wet and dry climatic phases respectively corresponding to savanna and semi-arid climates. These have been deduced from geomorphologic (calcretes-ferricretes-stone-lines), sedimentologic (meandering river - braided river - sheetflood deposits) and pedologic (Gley - Pseudogley - Alfisol - Calcrete palaeosoils) features.

Four main types of cyclicities have been studied: the fluviatile for the second unit of the Muhira Formation and for the Bwegera Formation, the fluvio-colluvial for the fourth unit of the Muhira Formation, the deltaic plain interdistributary bay type for the Gihungwe Formation and the alluvial fan or small river type for the Kadjeke Formation.

The soil development in muds seems to be very different throughout the lithostratigraphy. From well developed soils with A and B-horizons or only B-horizons where erosion is important for the Lower and Middle Pleistocene deposits, we pass to the A-C horizon soil type for the Upper Pleistocene deposits (Gihungwe Formation) and we end with the C-horizon soil type for the Holocene (Kadjeke Formation). Such a different soil development can be related to pedogenic time duration and can lead one to think of a certain periodicity becoming shorter with time during the Quaternary.

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