CHAPTER 6

New evidence on palaeoenvironmental conditions in SW Cameroon since the Late Pleistocene derived from alluvial sediments of the Ntem River

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ABSTRACT: An interior delta in the lower course of the Ntem River near the sub-prefecture Ma'an was identified after interpretation of satellite images, topographical maps of SW Cameroon and geological as well as hydrological references and a reconnaissance fieldtrip to the study area. Here neotectonic processes have initiated the establishment of a 'sediment trap' (step fault), which in combination with environmental changes strongly generated the fluvial morphology. It transitionally led to temporary lacustrine and palustrine conditions in parts of this river section. Inside the interior delta an anastomosing multi-branched river system has developed, which contains 'stillwater locations', periodically inundated sections, islands and rapids. Following geomorphological, physio-geographical and sedimentological research approaches, the alluvial plain has been prospected and studied extensively. 91 hand-corings, including three NE–SW transects, were carried out on river benches, levees, cut-off and periodical branches, islands as well as terraces throughout the entire alluvial plain and have unveiled multi-layered, sandy to clayey alluvia reaching up to 440 cm depth (Figure 1). At many locations, fossil organic horizons and palaeosurfaces were discovered, containing valuable palaeoenvironmental proxy data. At these sites, through additional detailed stratigraphical analysis (close-meshed hand-coring and exposure digging) a comprehensive insight into the stratification (lamination) of the alluvia could be gained, clarifying processes and conditions that prevailed in the catchment area during the period of their deposition.

32 Radiocarbon data of macro-rests (leafs, wood), charcoal and organic sediment sampled from these horizons provided ages between 48.230 ± 6.411 and 217 ± 46 years BP (not calibrated). This constitutes the importance of the alluvia as an additional, innovative palaeoarchive for proxy data contributing to the reconstruction of palaeoenvironment and palaeoclimate in western Equatorial Africa. The further examination of the alluvia will not only provide additional information on the dynamics of vegetation, climate and hydrology (esp. fluvial morphology) in SW Cameroon since the 'First Millennium BC Crisis' (around 3.000 years BP), the main focus of the DFG-research project, but also on conditions prevailing since the Late Pleistocene, during the Last Glacial Maximum (~18.000 years BP), the Younger Dryas impact (~11.000 years BP) and the 'Humid African Period' (~9.000–6.000 years BP). $\delta^{13}C$-values (–31,4 to –26,4‰) evidence that at the particular drilling sites rain forest has prevailed during the corresponding time period (rain forest refuge theory). The sampled macro-rests all indicate rain forest dominated ecosystems, which were able to persist in fluvial habitats, even during arid periods.

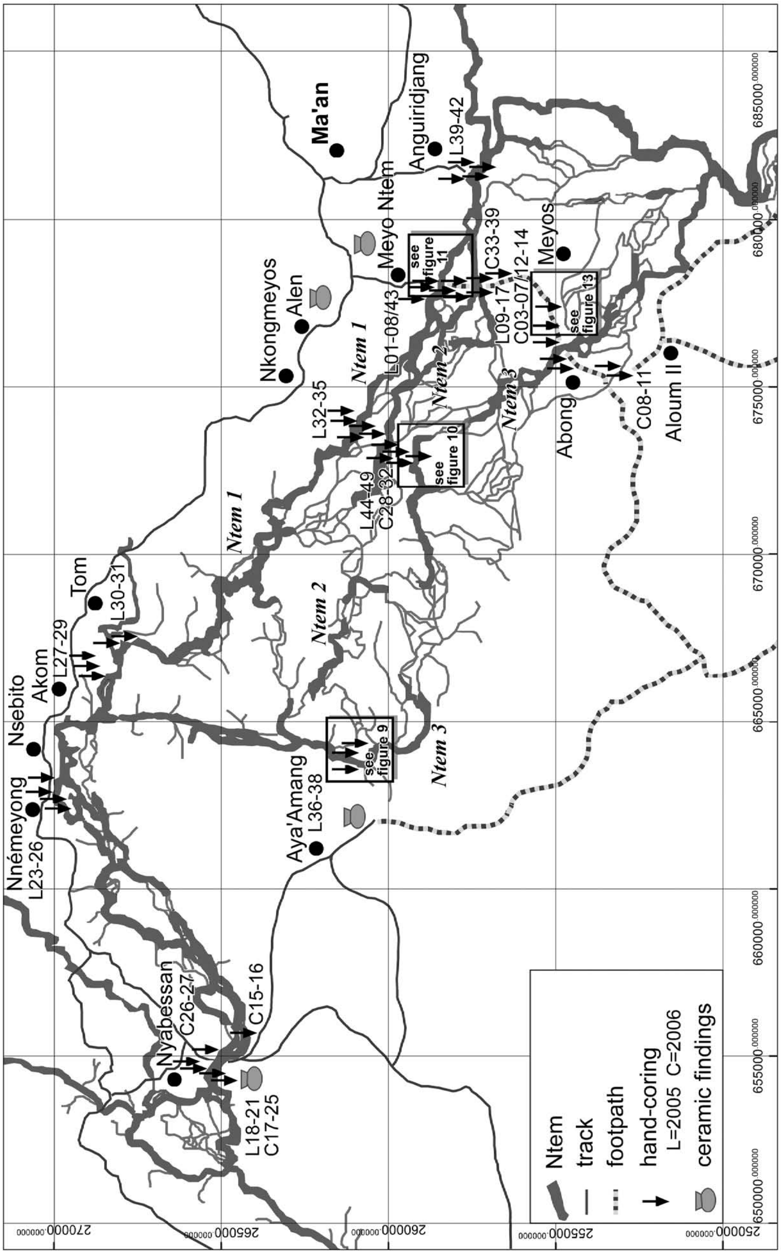

Figure 1. Map of the Ntem interior delta study area (210 km^2) showing the three main Ntem branches, hand-coring sites, locations where ceramic was found, infrastructure and other sights of interest, mentioned in the text.

6.1 INTRODUCTION

The ReSaKo (Regenwald-Savannen-Kontakt)-project (sub-project J. Runge, Ru 555 14-1) investigates climatic, ecological and cultural changes in the tropical rain forest of SW Cameroon on interdisciplinary basis with Archaeobotanists (K. Neumann and A. Schweizer, University of Frankfurt) and Archaeologists (M.K.H. Eggert and C. Meister, University of Tübingen) in the framework of the DFG Research Unit 510 of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). Evidence for interconnections between climatic fluctuations and modifications of the fluvial system Ntem and its sensitive eco-zones during the Late Pleistocene and Holocene are examined by methods of geomorphological, physio-geographical and sedimentological research. Climate fluctuations have strongly affected the hydrological cycle and composition of vegetation habitats (rain forest-savanna fringe), especially in Equatorial Africa's high sensitive and species-rich eco-systems (Gasse, 2000; Runge 2001 and 2002; Thomas, 2004). Alluvial sediments of the Ntem River's floodplain (Figure 1) serve as innovative palaeoenvironmental proxy data archives and the tentative interpretation of their multi-layered stratigraphical composition allows statements on processes and conditions during the time of their deposition. Besides, anthropogenic influence on landscape evolution in the study area will be recognized.

6.2 STATE OF THE ART

Cores of the deep-sea fans of the Niger (Zabel *et al.*, 2001; Lézine and Cazet, 2005) and Congo River (Marret *et al.*, 1998; Holvoeth *et al.*, 2005; Marret *et al.*, 2006), as well as lacustrine sediments of several lakes in West- and Central Africa (among others Barombi Mbo: Giresse *et al.*, 1994; Ossa: Nguetsop *et al.*, 2004; Reynaud-Farrera *et al.*, 1996; Wirrmann and Bertaux, 2001; Njupi: Zogning *et al.*, 1997; Bambili: Stager and Anfang-Sutter, 1999; Sinnda: Vincens *et al.*, 1998; Kitina: Elenga *et al.*, 1996; Bosumtwi: Talbot *et al.*, 1984 and Lake Tchad: Maley, 1981; Servant, 1983) have provided the most high-resolution and oldest proxy data for palaeoenvironmental, palaeoclimatic and palaeohydrological research in tropical West and Central Africa. These findings were mainly based on palynological studies initiated by ECOFIT (ÉCOsystèmes et Paléoécosystèmes des Forêts Intertropicales) in 1992. It focused on Holocene climate fluctuations and corresponding vegetation composition changes as well as rain forest–savanna margin dynamics (Servant and Servant-Vildary, 2000). In recent times, additional results derived from diatoms, phytoliths, stable organic carbon isotopic composition values ($\delta^{13}C$) and mineralogical data (reaching back to ~700.000 years BP) have been added to the research on palaeoclimate and palaeoenvironment of tropical Africa (Abrantes, 2003; Barker *et al.*, 2004). They substantiate changes in solar radiation (Milankovitch cycles: eccentricity ~100 ka, obliquity ~41 ka and precession ~21 ka) as the most logical reason for climatic fluctuations next to changes in ice-sheet extent (Heinrich events). These modifications were linked with changes of the sea surface temperatures (SST's) in the Atlantic Ocean (~2–6°C), south- and northward migration of the Inter-Tropical Convergence Zone (ITCZ), El- Niño events and non-linear feedbacks between atmosphere and ocean systems. According to the ECOFIT studies, this consequently provoked changes in energy- and moisture-fluxes in the Gulf of Guinea and strengthening/weakening of the African monsoon (Abrantes, 2003; Maley, 1997; Marchant and Hooghiemstra, 2004; Marret *et al.*, 2006; Nguetsop *et al.*, 2004). De Menocal *et al.* (2000) postulated a close coherence between the thermohaline ocean circulation and the intensity of the African monsoon. Mutations within this circulation system (e.g. occasional interruption of the up-welling of cold ocean waters in the Gulf of Guinea) can induce rapid and far reaching local climate changes. As assumed by Maley (1997), modifications of the Hadley and Walker cells trigger changes in energy and moisture fluxes between ocean, atmosphere and land surface. Also evidence for changes in seasonality (longer dry and shorter rainy seasons) in West Equatorial Africa were verified (Servant and Servant-Vildary, 2000).

The Holocene 'African Humid Period' (De Menocal, 2000) in West and Central Africa (maximum phase ~9.000–6.000 BP) already started around 14.000 years BP in equatorial regions and was assumedly interrupted by aridity during the Younger Dryas (~11.000 BP) and further, shorter arid phases (9.600–9.400 BP and 8.400–8.000 BP) before it was terminated around 4.000 BP (Barker *et al.*, 2004; Lézine and Cazet, 2005). It is assumed that during this period the solar radiation reached a higher value (~4–5%, corresponding to a total of ~470 Wm^{-2}) and thereby induced an increase of temperature (around up to 5°C) and probably ~30–50% higher monsoonal precipitation (Thomas, 2000; Barker *et al.*, 2004). Holvoeth *et al.* (2005) gave evidence for fluctuating influx of terrestrial organic material into the oceans by rivers, changing vegetation composition as well as shifts in the hydrological cycle. During pluvial phases the input of terrestrial organic material into the Niger and Congo fans was immense higher. Barker *et al.* (2004), Gasse (2005), Kadomura (1995), Thomas (2004), Lezine and Cazet (2005) and Marret *et al.* (2006) among many others (esp. Maley) provide most detailed descriptions of palaeoenvironmental conditions in Equatorial Africa (esp. Cameroonian and Congolian regions) for different time-scales and based on various evidences. Hall *et al.* (1985), Preuss (1986), Runge (1992, 1996) and Thomas and Thorp (1980, 1995) were among the first scientists using fluvial-morphological and geomorphological approaches in the context of environmental changes in western and Equatorial Africa, apart of the early studies on the sedimentation dynamics of the Niger (Pastouret *et al.*, 1978) and Congo Rivers (Giresse *et al.*, 1982). Giresse *et al.* (2005) and Viers *et al.* (2000) have recently measured sediment fluxes in the Sanaga and Nyong Rivers. They proved that during the late Holocene, climate related phases of higher (2.800–2.000 BP) and lower (5.000–3.000 BP) sediment fluxes occurred in the Sanaga catchment.

Kadomura and Hori (1990) also found evidence for increased anthropogenic activities in the rain forest ecosystem around 3.000 years BP. This time period is also believed to be the onset of the hypothetical 'Bantu Migration' (Phillipson, 1980; Schwartz, 1992) within a time period defined as 'First Millennium BC Crisis'. The expansion of human activities might have been induced by regression of tropical rain forest and widespread savannization, favoured by changes in climatic and hydrological conditions, which led to the partial breakdown of the rain forest between 3.000 and 2.500 BP and its replacement by pioneer formations and savannas (Maley, 2002; Runge, 2002 and Vincens *et al.*, 1999). Settling and sedentariness in the tropical rain forest of Central Africa may additionally have caused major impacts on the distribution of the rain forest-savanna margin, at least since the initiation of metallurgy around 2.600 years BP (Schwartz, 1992).

Nevertheless, the majority of conclusions concerning the palaeoenvironmental conditions in Central Africa are based on palynological and lacustrine archives. It is however essential to integrate palaeohydrological investigations into the reconstruction of environmental changes because they offer indicators for realized hydrological changes in the past (Baker, 2000). Although still quite incipient and incomplete, Latrubesse (2003) and other scientists have already offered exemplary spectacular and detailed findings for the understanding of hydrological and environmental changes in tropical central South America. Similar studies and results are also necessary in tropical Central Africa to contribute to an improved understanding of environmental change in this region.

6.3 STUDY AREA: NTEM INTERIOR DELTA

6.3.1 Physiogeographical settings

The Ntem River is a perennial river, 460 km long, with a catchment area of 31.000 km^2, which stretches over the countries of Equatorial Guinea, Gabon and (mainly) SW Cameroon.

Around 100 km upstream the Ntem River's mouth into the Atlantic Ocean near Campo, an interior delta was formed by neotectonical activities (cp. J. Eisenberg, this issue). This section of the Ntem, which is located in the department Ambam near the sub-prefecture of Ma'an in the district 'Vallée du Ntem', shows an anastomosing, multi-channelled character with three main branches (Ntem 1–3, from NE to SW). It stretches from 2°14'N and 10°39'E to the NW, where it is limited by the waterfalls of Menvé'élé (2°24'N, 10°23'E) near the village Nyabessan. The surface of the alluvial basin (~210 km^2) has an SE–NW expansion of ~35 km and a maximum width (NE–SW) of 10 km (Figure 1). The northern section (Ntem 1) is marked by several rapids formed by outcropping basement (charnockites, gneisses and granites), whereas in the southern part (Ntem 3) many periodically inundated river sections occur, where thick fine-grained alluvia have been accumulated. At Meyo Ntem and bellow the waterfalls of Menvé'élé, thick (1–2 m) layers of ferruginized conglomerates (Ntem gravels, cemented by iron and manganese oxides) were observed, which indicate environmental modifications since their initial formation.

In the upper river course (from the source near Oyem in Gabon, ~700 m a.s.l., to the Gabon/Cameroon border at ~580 m a.s.l.) the Ntem River drains a cratonic peneplain surface with low inclination (2‰). From the Cameroon/Gabon border to Ma'an (518 m a.s.l.) the inclination decreases to 0,27‰ and the Ntem River affiliates its major tributaries (Kom, Kie, Kye, Mboro, Mgoro, Nlobo, Nye, Rio Bolo, Rio Guoro and Woro). Inside the interior delta, the Ntem confluences with the Mvila, Ndjo'o and Biwomé and inclination increases (4,5‰) to reach it's maximum of 5‰ behind the border of the interior delta (waterfalls of Menvé'élé, ~384 m a.s.l.). Here the Ntem River crosses an up to 80 m deep V-shaped valley, descending 200 m over a distance of 40 km (Figure 2).

The longitudinal profile of the Ntem's section which is described as interior delta shows the positions of outcropping basement but also plain stretches where multi-layered alluvial sediments have been deposited (Figure 3). The basement outcrops may have forced

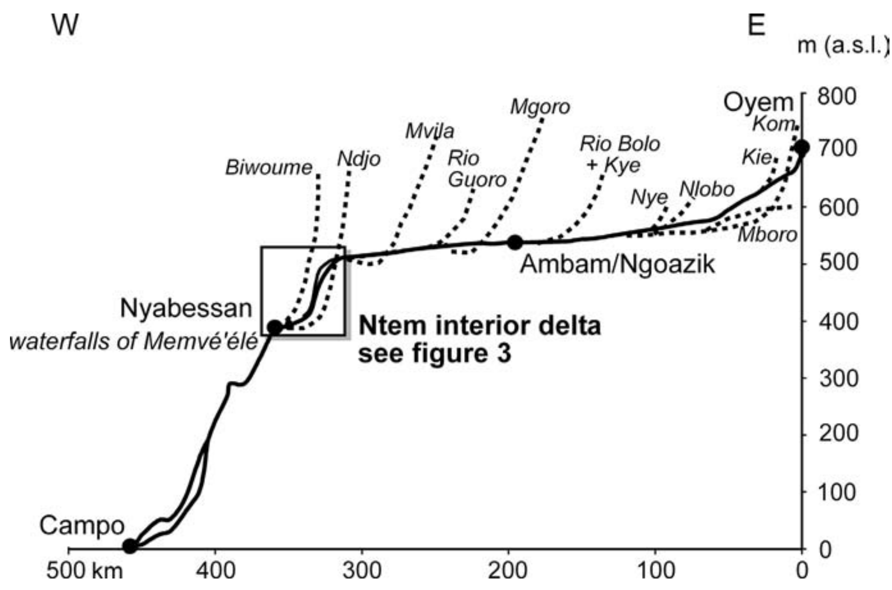

Figure 2. Longitudinal profile of the Ntem River from its source in Oyem (Gabon) to the mouth near Campo on the Atlantic coast. The figure shows major tributaries and locations of the gauging stations Ambam/Ngoazik and Nyabessan as well as the interior delta and the waterfalls of Menvé'élé (modified after Olivry 1986).

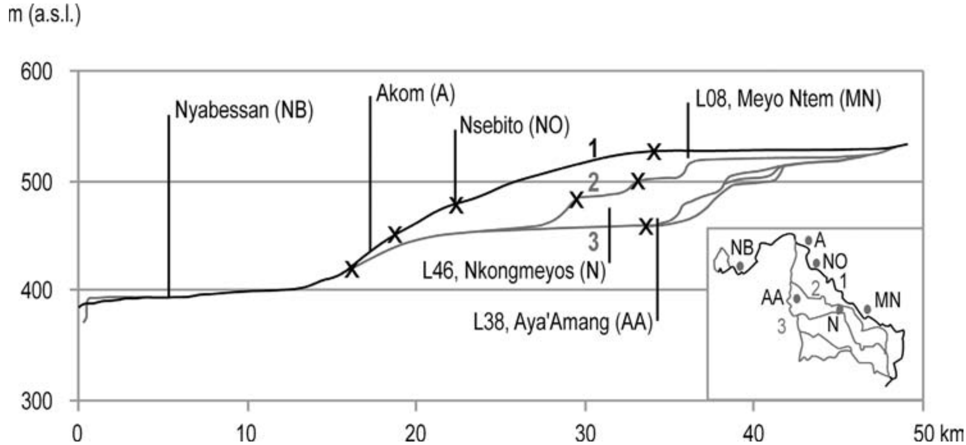

Figure 3. Longitudinal profile of the Ntem's multi-channelled interior delta showing positions of basement outcrops (X), rapids (Akom and Nsebito) and hand-corings mentioned in the text and in figure 8. Based on SRTM DEM data (obtained from the GLCF server of the University of Maryland).

the river to create nickpoints in its recent anastomosing to anabranching pattern by avulsion. Initially these locations would have served as sediment traps.

6.3.2 Climate and hydrology

The climate ('Equatorial Guinea Climate') in the catchment area is tropical to semi-humid with a mean annual temperature almost constantly around 25°C and a short (April–June) as well as a long (September–November) rainy season, corresponding to the seasonal shifting of the meteorological equator (ITCZ) and the African monsoon. Rain fall in the catchment area ranges between 1.500 mm on the plateau near Oyem and 3.000 mm on the coast near Campo. According to Olivry (1986) the mean annual rain fall averages 1.695 mm in the entire Ntem catchment and 1.675 mm at the meteorological station Nyabessan (2°24'N, 10°24'E; 385 m a.s.l.). Figure 4 shows mean monthly rain fall and temperature values for Ambam (2°23'N, 11°16'E) and mean monthly discharges of the Ntem at Ngoazik (~12 km S of Ambam) during the period 1954–1979. Annual discharges usually show two maxima in May and especially in November, associated with the rainy seasons.

Sometimes this for the Gulf of Guinea typical rain fall and river discharge regime is interrupted and rain fall as well as discharge in the short rainy season increases. Maley (1997) associates this with periodical ENSO-events, which modify moisture fluxes between ocean and land surfaces in the Gulf of Guinea.

At Ngoazik (2° 18'N, 11° 18'E; 535 m a.s.l.), 150 km upstream of Nyabessan, discharge valued ~260 m^3/s between 1954 and 1991 (catchment area: 18.100 km^2). The discharge shows high fluctuations and some kind of periodicity (3–4 years) in which dry as well as wet hydrological years occurred. Additionally, a slight wetter phase in the 1960s and a drier in the 1970's can be recognized (Figure 5). Mean monthly discharges of the Ntem at Nyabessan, with a catchment area of 26.350 km^2, range between 100 and 1.600 m^3/s and show high annual variability as well as discharge values in general. Between 1978 and 1991, mean annual discharges at Nyabessan averaged ~382 m^3/s.

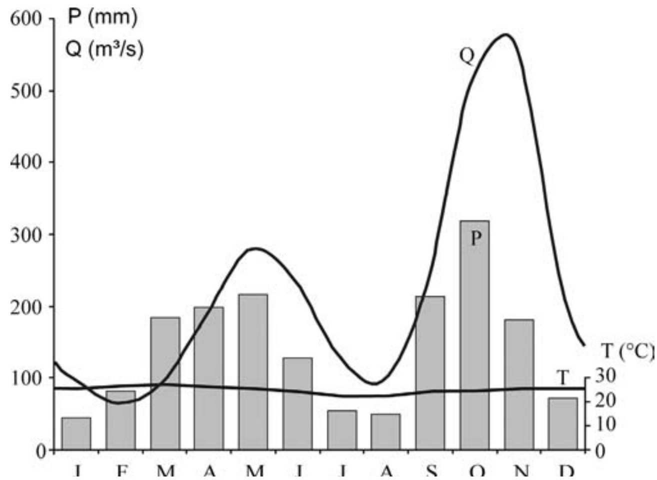

Figure 4. Mean monthly temperatures and rain fall at the meteorological station Ambam (2°23'N, 11°16'E; 561 m a.s.l.) and mean monthly discharges at the gauging station Ngoazik (2° 16' N, 11° 19' E; 535 m a.s.l.), located ~12 km S of Ambam, for the period 1954–1979.

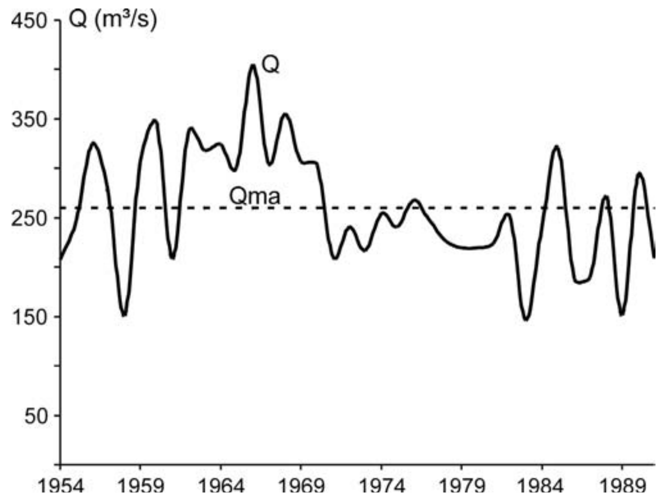

Figure 5. Fluctuating mean annual discharges of the Ntem at Ngoazik during the period 1954–1991, with an average discharge (Qma) of ~260 m³/s (modified after Olivry 1986, new data provided by J.-C. Ntonga, Centre de Recherches Hydrologiques, Institut de Recherches Géologiques et Minières (CRH-IRGM), Yaoundé).

The present river's suspended load is characterised by high content in organic material and minerals. The high outflow of organic suspended load into the Gulf of Guinea can be very good recognized on satellite images of the Ntem's fan near Campo. According to the dense vegetation cover in the river basin, erosion is nowadays very low where human activity is reduced. Coarse sands and pebbles which have been deposited in the initiative phase of the river basin evolution in a probably much less forested environment (braided river character), are presently only part of the sedimentary load during torrential flood events.

6.3.3 Vegetation

After Letouzey (1985) and Tchouto Mbatchou (2004) the potential vegetation in the study area can be described as tropical lowland evergreen rain forest (mainly Caesalpiniaceae) and mixed, semi-evergreen and semi-deciduous forest. On floodplains swamp forest with *Rapphia* spp., *Uapaca guineensis* and *Gilbertiodendron dewrei* occurs. Actually in most of the study area (Ntem interior delta) secondary forests of different ages occur because human impact (e.g. shifting cultivation, cacao cropping (*Theobroma cacao*)) has intensely modified the natural vegetation. Dominating species are *Ceiba pentandra*, *Elaeis guineensis*, *Musanga cecropioides* and *Terminalia superba* (K. Neumann, personal communication).

6.3.4 Soils

According to Segalen (1967) three major characteristic soils prevail in SW Cameroon: Yellow to brown tropical ferralitic (clayey) soils ('sols ferrallitiques jaunes sur les roches acides (gneiss)'), gneiss and granites covered by red to brown ferralitic soils ('sols ferrallitiques rouges sur les roches acides') and alluvial soils ('sols alluviaux') in floodplains and valleys.

6.4 METHODS

After the interpretation of satellite imageries and topographical as well as hydrological data a reconnaissance field trip was made in 2004 (February–March), where the existence of an interior delta in the lower catchment area of the Ntem River could be proved (Runge *et al.*, 2005). This was followed by field work in the dry seasons of 2005 (January–March) and 2006 (February). During this physio-geographical, geomorphological and sedimentological field work, closer observations and 91 hand-corings were undertaken in the floodplain. The multi-layered alluvial sediments, which could primarily be found at stillwater locations (periodically inundated cut-off channels, terraces (rainy/dry season), levees), were recovered and mostly sampled until maximum depths of 440 cm. The sediments were sampled with Edelman-corer in 20 cm layers. At some locations, a thin percussion-probe (3 cm diameter, 50 cm length) was used when ground water level was reached and recovery with Edelman-corer was not possible.

After texture and soil colour were determined in the field, the samples were evaluated at the laboratory of the Institute of Physical Geography in Frankfurt. Here pH (solved in 0,1 n KCl, after Meiwes *et al.*, 1984), grain sizes (after Köhn), soil colour (wet and dry, after Munsell), organic material and carbon contents (with LECO EC-12), nitrogen (after Kjeldahl) and dithionite as well as oxalate solvable quantum of iron and manganese (after Mehra and Jackson, 1960; with AAS Perkin Elmer Analyst 300) were analysed.

During this work, samples of vegetation macro-rests, fossil organic horizons with charcoal and palaeosoils were collected for ^{14}C (AMS) radiocarbon dating and determination of stable organic carbon isotopic composition values ($\delta^{13}C$). The arising data provides preliminary (maximum) ages of the alluvial sediments as well as evidence on former vegetation composition (C3/C4 species; Runge, 2002). In total 32 samples from different locations and depths were extracted and analysed by the Friedrich-Alexander-University of Erlangen-Nuremberg.

During the investigations inside the interior delta also ceramic fragments have been found which could indicate abandoned human settlements in the tropical rain forest margin (Figure 1).

6.5 ALLUVIAL SEDIMENTS OF THE NTEM INTERIOR DELTA

During fieldwork in 2005 and 2006, 91 up to 440 cm deep hand-corings were carried out in the Ntem interior delta between the villages Ma'an and Nyabessan (Figure 1). At most locations multi-layered alluvial sediments have been found in the floodplain, between a recent lower (dry season) and an upper (rainy season) terrace and in periodically inundated river sections.

On the most northern branch of the Ntem (Ntem 1), between Anguiridjang and Akom, suitable coring sites were rare and mainly sandy sediments were recovered overlying basement rock. Here the river bed is generally formed by basement and at many locations rapids have developed. At some places on the rapids gravels were found, mostly contracted to conglomerates by iron and manganese and coated by a black (iron-manganese) patina.

To get an overview of the stratigraphy of the alluvial sediments inside the Ntem's interior delta, three N–S-transects were set up through the interior delta following existing small pathways through the rain forest (Meyo Ntem, Nkongmeyos, Nyabessan).

Additionally, selective hand-corings were made across the river course (N- and S-bench at each particular location) at many sites inside the interior delta. On the basis of these samples, three sites with different time slots were selected for detailed stratigraphical analysis during fieldwork in 2006. In order to achieve a particularized, comprehensive insight and documentation of stratigraphy and sedimentation structures of some of the drilling sites examined in 2005 (Meyos, Nkongmeyos, Nyabessan), additional corings were carried out. Also, several exposures were dug along natural levees, flood banks and nickpoints within the bore-hole transects (Figure 6).

The first transect between Meyo Ntem (Ntem 1) and Aloum II (behind Ntem 3) contains 39 bore holes (at locations Aloum II (5 bore holes), Meyos (12) and Meyos II (7)) over a distance of about 8,5 km. The next one was made near Nkongmeyos (16 bore holes) with a length of 5 km and the third one at Nyabessan (26 bore holes) with a length of around 2 km. In contrast to the locations in the middle part of the interior delta (Akom, Nkongmeyos, Nnémeyong and Tom), where relatively thin layers of sandy sediments (sand >80–90%) over basement occur, corings at Abong, Anguiridjang, Aya'Amang, Meyos and Nyabessan reached the greatest depths with 3–4 m.

In many profiles, coarse-grained sandy sediments were found in the deepest layers, indicating palaeochannels (fluvial strata) and/or the transition zone towards the saprolite and basement. From depths of 2–3 m upward, in most profiles coarse-grained sediments are replaced by fine-grained silty, clayey and sandy sediments. In some of the profiles these changes in texture are very abrupt. Besides Anguiridjang, at all these locations more or less fine-grained sediments (silt + clay >60%) occurred in the upper layers, indicating channel-fill and floodplain overbank deposits.

The coarse-grained sandy sediments at the base of most profiles are sometimes associated with organic material, alternating in very thin layers. Occasionally these organic horizons are overlying the saprolitisized basement or laterite. At the locations Meyos (between cores L16 and 17), Nkongmeyos (L44-46) and Nyabessan (L18, 19 and 22) this kind of fossil organic sediments occur in continuous horizontal layers. This has been proved during detailed investigations in 2006. The colours of the alluvial sediments are very similar at all investigated locations. The fossil organic horizons (20–80 cm thick), which occur in depths between 100 and 360 cm, are marked by brown to dark brown and black colours (2,5Y, 7.5YR or 10YR 5/1; 10YR 3/1), which change to lighter, greyer colours when exposed to the surface (oxidation). They mostly lie beneath the groundwater level and are thereby well preserved. At the base of this layer concentrated organic macro-rests occur and the often muddy sediments have putrefied character and mouldy smell, indicating swampy environment (gyttja) (Figure 7).

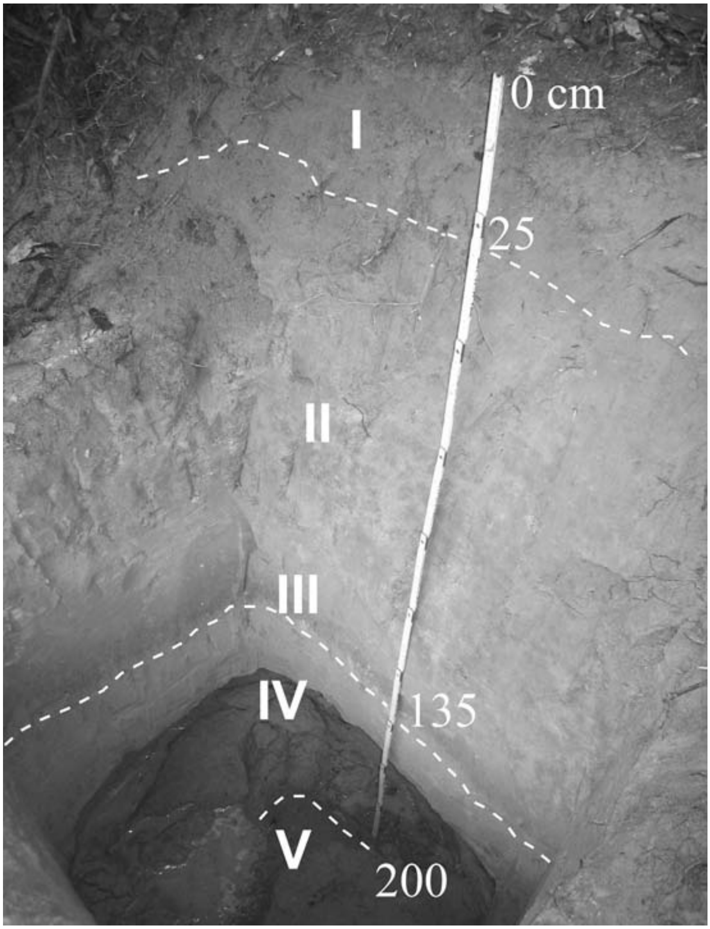

Figure 6. Exposure site at Meyo Ntem. The stratigraphic work was made near the cores L05 and L08 on the S-bench of Ntem 1 and evidenced the existence of a fossil organic horizon/palaeosurface, which was also found during hand-coring of L05 and L08 in 2005, several metres next to and behind this exposure site. V: fossil organic horizon, IV: layer showing reduction processes, III: thin, concentrated iron film, II: layer showing oxidation processes and I: humus top layer.

The fossil organic horizons are covered by a layer with characteristics of reduction processes, which is of clayey or loamy facies and occurs in grey colours (2,5Y 7/2 or 8/2; 10YR 8/1). It is covered by a clayey to loamy layer which is marked by oxidation processes. This layer is often more than 100 cm thick and shows beige to brown colour with orange (2,5Y 7/3, 7/4 or 8/2) to dark orange (10YR 7/8) oxidation spots. Both facies units are divided by a concentrated iron film, marking the groundwater level. Usually a thin (0–20 cm) brownish (10YR 5/2, 6/2 or 7/2) humus layer forms the top of the profile. Sediment organic matter (SOM), total carbon (C(tot.)) and nitrogen (N) contents reach maxima in the deepest facies units, i.e. in the fossil organic horizons and show again increasing regime towards the upper layers after reaching a minimum above these horizons. In fossil organic horizons they reach extreme maxima (L17 Meyos: SOM 17,07%, C(tot.) 9,9%, N 0,134% in 280–300 cm; L19 Nyabessan: SOM 16,9%, C(tot.) 9,8%, N 0,3% in 380–400 cm). These sandy to clayey

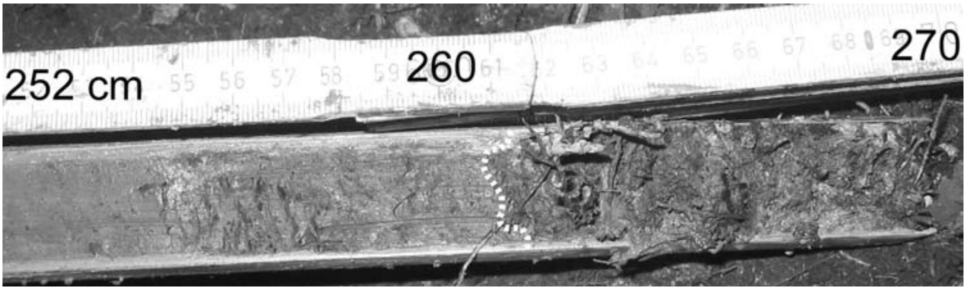

Figure 7. Concentrated fossil organic macro-rests occurred below 260 cm depth (dotted white line) at coring site C08. This material was widespread found in the hand-corings carried out at the site Meyos (see figure 13). Similar macro-rests, which were recovered from 280–300 cm at the coring site L17, were dated to a ^{14}C (AMS) age of 14.263 ± 126 years BP (not calibrated).

layers are also marked by dark colours: 2,5YR 3/1, 5YR 2/1, 7.5YR 3/2, 7.5YR 5/1 or 10YR 3/2, 4/1 and 5/1. Here, especially where (concentrated) fossil organic material occurs, pH is very low, between 3 and 4. The lowest pH values reach 2,28 (L17, Meyos), 2,70 (exposure Nyabessan) and 2,99 (L37, Aya'Amang). Contents of Fe and pH (always between 4 and 6) are low in the deepest facies units and increase towards the top of the profiles to reach one or more maxima and afterwards decrease again. C/N-ratio reaches high values in the fossil organic horizons, afterwards remaining low and stable towards the top. Figure 8 shows major characteristics of selected alluvial sediment profiles.

At the site Aya'Amang, hand-coring of L37 was undertaken on an upper terrace, some 50 m from the river bed on the E-bench.

From 300 cm onwards, a fossil organic horizon (min. 80 cm thickness) was found, where SOM, C(tot.), N and C/N rapidly increase in coarse to fine-grained sandy (~80%) texture, while Fe(tot.) and pH reach lowest values. Macro-rests from 320–340 cm were dated to a not calibrated ^{14}C (AMS) age of 30.675 ± 770 years BP. Cores L36 (3 m from river branch on E-bench) and L38 (5 m from river branch on W-bench) provided similar results, although fossil organic horizons already occurred in 140 cm (L36) and 200 cm (L38) with Middle Holocene ages of 4.341 ± 60 and 5.306 ± 64 years BP, respectively. The layers above the fossil horizons are characterized by sandy to clayey, fine-grained sediments, indicating floodplain overbank deposits. Silty and clayey facies decrease with growing depth together with SOM, C(tot.) and N contents, reaching minima in ~300 cm. Total iron content (Fe(tot.)) and pH show slightly increasing tendencies, with iron content maxima in 90 and 170 cm and pH maximum in 280 cm, whereas C/N-ratio remains stable.

At Nkongmeyos, across the Ntem branches 1 and 2, basement crops out and rapids are frequent. Nevertheless, on the N-bench of Ntem 3 a periodically (during rainy season) inundated upper terrace was sampled and stratigraphically studied. Another fossil organic horizon embedded in coarse- to fine-grained sandy sediments was identified in core L46 between 140 and 85 cm.

Organic macro-rests from this horizon provided ^{14}C (AMS) radiocarbon ages (not calibrated) of 8.291 ± 89 (in 80–100 cm) and 10.871 ± 99 years BP (120–140 cm). Sediment characteristics of L46 prove the existence of a palaeosurface. The Fe(tot.) maximum in ~70 cm marks the stratification shift and the high C/N-ratios, as well as SOM and C(tot.) in the deepest layers are evidencing indicators for a buried fossil organic horizon, which is again characterized by low pH. While SOM, C(tot.) and C/N show decreasing tendency towards the surface, N and pH values generally increase. Recent fine-grained overbank deposits are overlying these sandy sediments. During stratigraphical investigations in 2006,

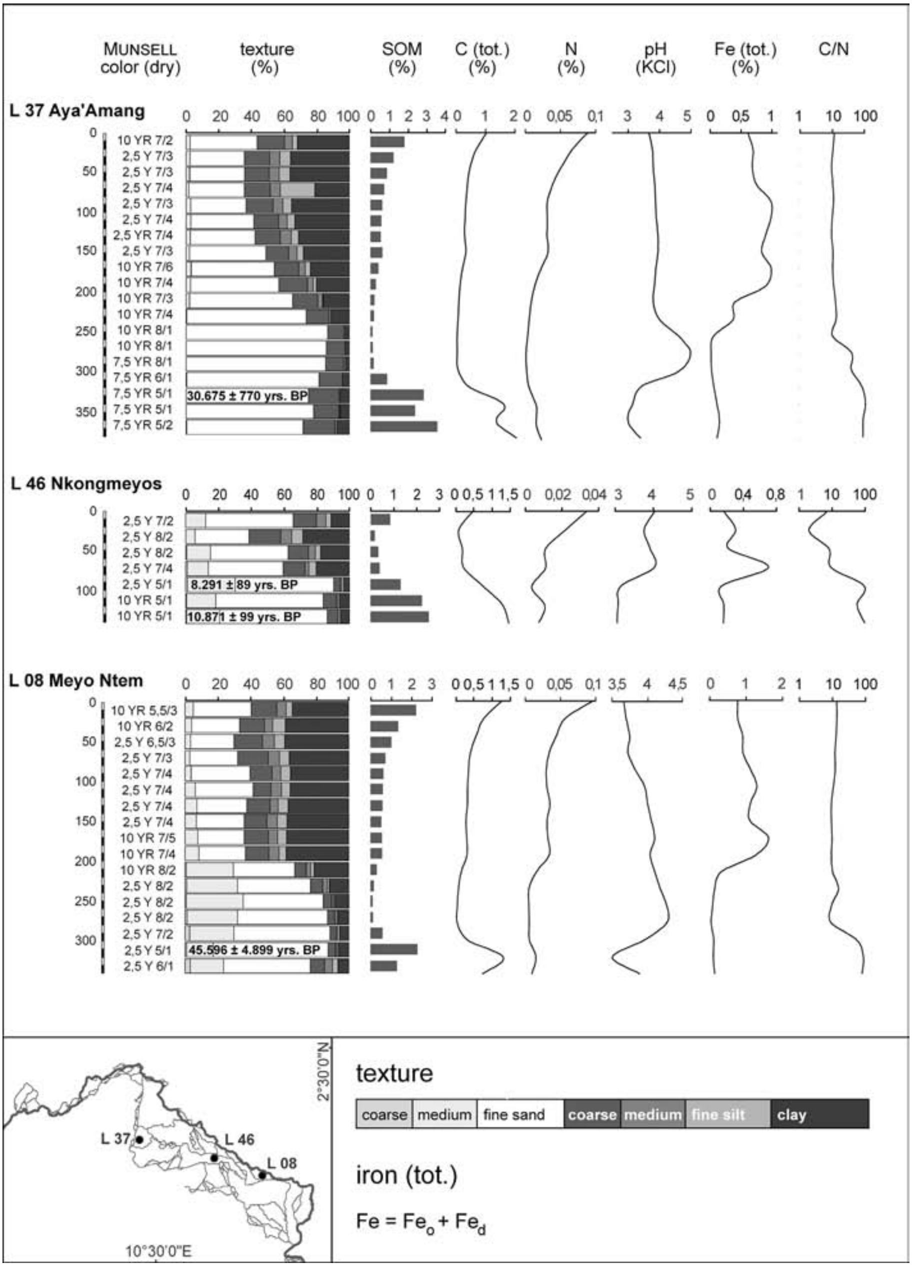

Figure 8. Some sedimentological characteristics of the alluvial sediments sampled at coring sites Aya'Amang (L37), Nkongmeyos (L46) and Meyo Ntem (L08) with appendant ^{14}C-data.

the existence of an extended fossil organic horizon (max. 50 cm thickness) below ~85 cm could be proved at this site in cores C29–32.

Rapids and outcropping basement partially covered with pebbles in the river bed prevail close behind the site L08, Meyo Ntem. This core was taken from an upper terrace,

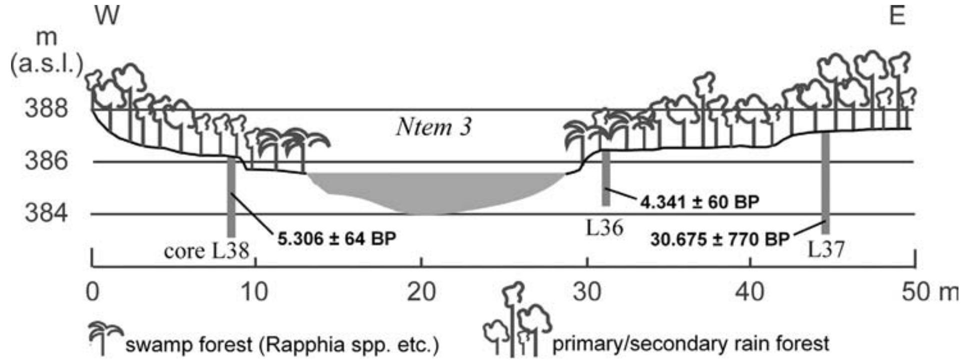

Figure 9. Sketch showing physio-geographical information (geomorphology, vegetation) and hand-corings carried out at the location Aya'Amang as well as appendant ^{14}C-data.

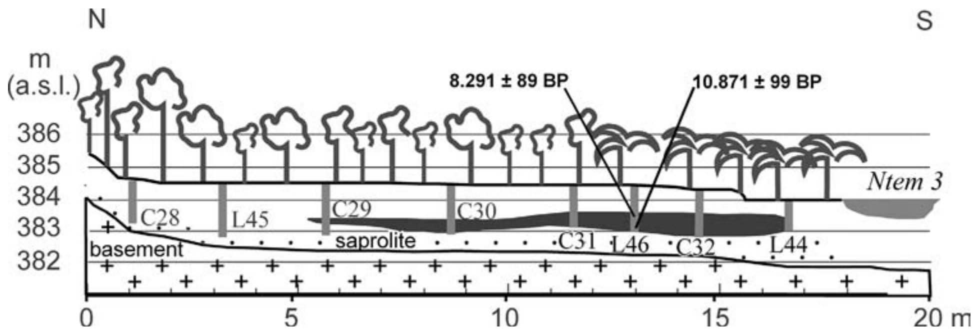

Figure 10. Sketch of location Nkongmeyos across the N-bench of Ntem 3, showing physio-geographical information (geomorphology, vegetation) and hand-corings as well as appendant ^{14}C-data.

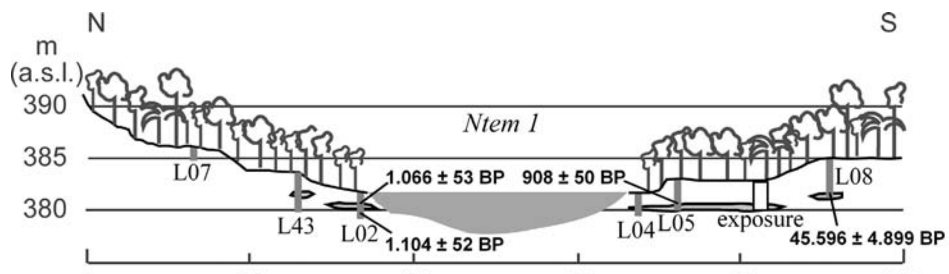

Figure 11. Sketch of the first part of transect Meyo Ntem-Aloum II on the N- and S-bench of Ntem 1, showing physio-geographical information (geomorphology, vegetation), the exposure site described in figure 6 and hand-corings as well as appendant ^{14}C-data.

marking the river bench in the rainy season, on the S-bench of Ntem 1, some 20 m from the water level in the dry season. After fossil organic sediments were found on the N-bench (L02 and 43) in 120 cm depth, a thin fossil organic horizon could be also verified on the S-bench. In profile L05, located 3 m from the river bed, it was found in 220–280 cm depth, in the exposure site below 200 cm (Figure 6) and in profile L08 in 290–340 cm.

Sediment analysis data of profile L08 shows almost similar dynamics to data analyzed from L37, with maxima in SOM, C (tot.) and C/N from the base of the profile until around 300 cm depth (total maxima in ~320 cm). Texture shows coarse- to fine-grained sands and again very low pH occurs, whereas Fe and N reach lowest values. From 280 cm upwards SOM, C(tot.) and N slightly increase to reach further maxima at the top of the profile. In contrast, pH continually drops until the top after reaching its maximum in 270 cm and C/N-ratio stays stable from 290 cm upwards. The Fe-maximum in ~180 cm marks the stratification shift between the lower coarse-grained and upper sandy to clayey fine-grained sediment layers. Macro-rests from the 320–340 cm layer gave a (not calibrated) ^{14}C AMS radiocarbon age of 45.596 ± 4.899 years BP. In L05 a quite young age of 908 ± 50 years BP was found. In 2006, near this site an exposure was dug, in order to achieve a comprehensive insight into the stratification of the alluvial sediments (Figure 6). The different stratigraphical layers and sediment units could be clearly verified and separated. Like in profiles L05 and 08, the deepest sediment units (from the base to ~200 cm depth) are coarse- to fine-grained sandy and of fluvial character towards the base. They are covered by silty to clayey fine-grained sediments representing channel-fill and overbank floodplain deposits.

6.6 RESULTS AND INTERPRETATION

The interpretation of stratigraphical sedimentary sequences found in tropical rivers is complex and fluvial models as well as conceptual frameworks for palaeohydrological research in tropical areas are still incipient and incomplete, although in the last years a lot of progress is made, especially in South America (Miall, 1996; Thomas, 2004; Latrubesse, 2005). Additional problems and difficulties complicating the studies of the fluvial-morphological, palaeogeographical as well as palaeoenvironmental and palaeohydrological history of the study area (Ntem interior delta) are the lack of appropriate geomorphological and topographical maps as well as aerial images of the study area. Along comes the inaccessibility of the sparse inhabited region, the lack of transport in the floodplain and the dense vegetation cover (tropical rain and swamp forest). Let alone the general problems interpreting fluvial deposits and connected forms in the tropics (e.g. interbedding of alluvial and colluvial sediments, inclusion/interstratification of laterite crusts and stonelines, hiatus problem, space-time correlation). Nevertheless, the alluvial sediments found in the interior delta of the Ntem River are an eminent suitable archive with appropriate proxy data for the reconstruction of Late Quaternary palaeoenvironmental conditions in the study area, covering the last 50.000 years.

According to the so far obtained ^{14}C (AMS) data, the inherited information covers Late Pleistocene, more precise Middle to the Upper Pleniglacial, as well as Holocene times (see table 1).

Baring in mind that the insights into the fluvial structure and sedimentary and depositional pattern of the Ntem River's multi-channelled system are very punctuated, interpolations and interpretations must be careful and speculative. Because of the fact, that access for over-viewing sedimentary structures for facies stratification analysis is very limited in the study area and sampled sediments were almost always disturbed, sedimentary units were mostly difficult to identify. Following the preliminary results and findings of the first field work campaigns and other studies from western Equatorial Africa, especially the ECOFIT programme (Servant and Servant-Vildary, 2000), some tentative interpretations and conclusions can be given:

Regarding the details mentioned before, it can be stated that in Middle to Upper Pleniglacial times mainly coarse-grained sandy sediments have been deposited on a lower

Table 1. 32 ^{14}C AMS radiocarbon ages (not calibrated) and corresponding $\delta^{13}C$-values obtained from organic macro-rests, organic sediment as well as charcoal, sampled from fossil organic horizons and palaeosurfaces inside the interior delta during field work. The ages range between 48.230 ± 6.411 and 217 ± 46 years BP. Analysis and data were provided by the AMS-Laboratory of Friedrich-Alexander-University in Erlangen-Nuremberg.

core	name	depth (cm)	Munsell col. (dry)	org. mat.	^{14}C (not cal.)	$\delta^{13}C$
L2 Meyo Ntem	Erl-8249	100–120	4/2 10 YR	wood, etc.	1.066 ± 53	–27,0
	Erl-8250	160–180	3/2 10 YR	wood, etc.	1.104 ± 52	–29,2
L5 Meyo Ntem	Erl-8251	220–240	3/2 7,5 YR	leafs, etc.	908 ± 50	–29,4
L8 Meyos Ntem 3	Erl-8252	300–320	3/2 2,5 Y	wood	45.596 ± 4.899	–31,4
L17 Meyos Ntem 3	Erl-8253	280–300	2/1 10 YR	wood	14.263 ± 126	–27,3
L14 Abong	Erl-8254	340–360	4/2 7,5 YR + 6/8 10 YR	wood	48.230 ± 6.411	–29,6
L32 Nkongmeyos	Erl-8255	60–80	6/2 10 YR	charcoal	217 ± 46	–28,0
L34 Nkongmeyos	Erl-8256	100–120	3/2 10 YR	wood	435 ± 51	–27,4
L49 Nkongmeyos	Erl-8257	180–200	6/2 2,5 Y + 4/1 2,5 Y	org. sediment	10.775 ± 144	–30,1
L46 Nkongmeyos	Erl-8599	80–100	5/2 2,5 Y + 3/1 10 YR	wood, etc.	8.291 ± 89	–27,5
	Erl-8258	120–140	4/2 2,5 Y	wood, etc.	10.871 ± 99	–28,3
L40 Anguiridjang	Erl-8259	360–380	3/1 10 YR	wood, etc.	2.339 ± 52	–27,9
L30 Tom	Erl-8260	140–160	5/2 10 YR	wood, etc.	1.381 ± 49	–28,2
L27 Akom	Erl-8261	100–120	4/1 10 YR	wood, leafs	443 ± 57	–26,4
	Erl-8262	160–180	4/2 10 YR	leafs	427 ± 52	–27,6
L36 Aya Amang	Erl-8263	140–160	3/2 10 YR	leafs	4.341 ± 60	–27,2
L37 Aya Amang	Erl-8264	320–340	6/2 2,5 Y + 4/1 2,5 Y	wood	30.675 ± 770	–30,8
L38 Aya Amang	Erl-8265	220–240	5/2 2,5 Y	wood	5.306 ± 64	–31,4
L24 Nnémeyong	Erl-8266	80–100	3/2 7,5 YR	wood	441 ± 46	–30,6
	Erl-8267	120–140	4/2 7,5 YR	wood	671 ± 52	–28,7
L25 Nnémeyong	Erl-8268	160–180	4/1 10 YR + 5/2 10 YR	wood	21.908 ± 302	–27,0
	Erl-8269	220–240	3/1 10 YR + 10/2 10 YR	wood	22.398 ± 316	–29,1
L18 Nyabessan	Erl-8270	140–160	4/1 2,5 Y	leafs, etc.	587 ± 64	–29,1
	Erl-8271	200–220	4/1 2,5 Y	leafs, etc.	2.337 ± 55	–31,9
L19 Nyabessan	Erl-8272	320–340	3/1 7,5 YR + 3/2 7,5 YR	wood, etc.	2.189 ± 52	–29,5
L22 Nyabessan	Erl-8273	140–160	5/1 2,5 Y	wood, etc.	3.894 ± 57	–28,1
C13 Meyos	Erl-9567	120–140	5Y 7/1 + 5Y 2,5/1	wood, etc.	14.020 ± 106	–28,1
	Erl-9571	250–263	5Y 2,5/2	org. sediment	18.372 ± 164	–27,6
Aloum II	Erl-9574	78–88	10YR 7/1 + 10YR 6/8	org. sediment	8402 ± 67	–30,6
C11 Aloum II	Erl-9575	120–140	10YR 6/2 + 10YR 4/2	wood, etc.	6979 ± 58	–30,1
C20 Nyabessan	Erl-9576	430–440	n.a.	org. sediment	2479 ± 43	–28,8
C27 Nyabessan	Erl-9577	270–280	n.a.	org. sediment	3829 ± 46	–28,5

terrace of the Ntem River with braided sandy character. This unit is intermixed with high content of organic material and macro rests. This sedimentary unit was found at the locations Abong L14: 48.230 ± 6.411 BP (340–360 cm), Meyo Ntem L08: 45.596 ± 4.899 BP (320–340 cm) and Aya'Amang L37: 30.675 ± 770 BP (320–340 cm). These are up to now the oldest sediments found in the Ntem River's interior delta. In this phase the river was morphogenetically more active, moving coarse sandy sediment and aggrading the fluvial system. These findings are conform with earlier results from Central Africa of

Kadomura (1995), Schwartz and Lanfranchi (1991) and Thomas and Thorp (1995), who describe cool but moist semi-arid to sub-humid conditions with rivers showing braided character until around 40.000 years BP (70.000–40.000 Maluékien, after Schwartz and Lanfranchi, 1991) followed by a relative sub-humid period until around 30.000 years BP (Njilien) with enhanced erosion and meandering rivers. It is remarkable, that at the base of all hand-corings no gravels or pebbles could be found. Only near rapids at Meyo Ntem and Nsebito as well as below the waterfalls of Menvé'élé layers of ferruginized conglomerates (Ntem gravels and pebbles, coated with iron and manganese oxides) were observed, which prove an arid climate of origin. It is assumed that the formation of these ferruginized gravel layers took place in an earlier, initial phase of river system development and was probably accompanied by neotectonic events.

The next sedimentary unit is comprised of medium to fine-grained sandy sediments, which are generally lacking organic material. Some organic material (wood etc.) found in the profile Nnémeyong (L25) provided ^{14}C-dates of 21.908 ± 302 (in 160–180 cm) and 22.398 ± 316 years BP (220–240 cm). This unit may represent a cooler and sub-humid period occurring until the onset of the LGM aridity around 20.000–18.000 years BP (Léopoldvillien, after Schwartz and Lanfranchi, 1991). The LGM was associated with striking forest regression (Maley and Brenac, 1998), but preserved forested zones (rain forest refuge theory; Maley, 1998 and Lezine, 2005) especially across river systems, and probably also across the interior delta. This period was marked by aggradation with erratic and inhibited discharge, but river bed erosion and avulsion processes during broader floodpeaks occurring with rainstorms. As ^{14}C-data is very scarse, this assumption is very tentative. As climate became more humid after the LGM with enhanced runoff and probably catastrophic stripping of sediments, hiata might widespread occur in the sedimentary record. Nevertheless, one profile representing this time period, more precise the terminating LGM, was found at Meyos.

Here a sandy to clayey palaeosurface is overlying coarse sandy sediments and saprolite. The palaeosurface has a swampy character and probably constitutes an abandoned palaeochannel which was transformed into a back-swamp during the LGM, when rain fall and river runoff was considerably reduced. The oldest organic material from location Meyos yielded a ^{14}C (AMS) radiocarbon age of 18.372 ± 164 years BP at the base of the swampy palaeosurface (Figure 13). The overlying muddy and clayey organic sediments indicate periodical inundation of the site and accumulation of overbank deposits.

After this, more humid conditions for the period between ~14.000 and 8.000 years BP. are assumed, with a possible interruption around ~11.000 (Younger Dryas). This might indicate the prematurely onset of the 'Humid African Period' (Barker *et al.*, 2004; DeMenocal, 2000; Lézine and Cazet, 2005) in SW Cameroon. More likely, the swampy sediments at Meyos might be buried by deposits representing the Pleistocene-Holocene transition (~13.000–10.000 BP), when climate became unstable and high floods as well as frequent and increased storms occurred, which were also documented in the deposits of the Niger (Pastouret *et al.*, 1978) and Congo Rivers (Giresse *et al.*, 1982; Marret *et al.*, 1998) and the record of several lakes (mentioned in part 2), where lake levels rapidly increased. During this period, hill-wash and colluviation might have been severe. Simultaneously, the older deposits of the alluvial plain were vertically and laterally excavated, ancient deposits largely eroded and new channels created by river shifting in a more anastomosing river pattern.

With the onset of the Holocene Pluvial around ~10.000 BP, these processes might have intensified, but with the following reforestation of the study area (since ~9.500 BP; Maley and Brenac, 1998) also terraces and river banks were stabilised. The transition of the Ntem River's pattern from braided to anabranching or anastomosing might more likely fall into this period. The stabilisation of the landscape and climate (towards recent seasonal conditions) might have promoted a less migrating river pattern carrying an abundant rate

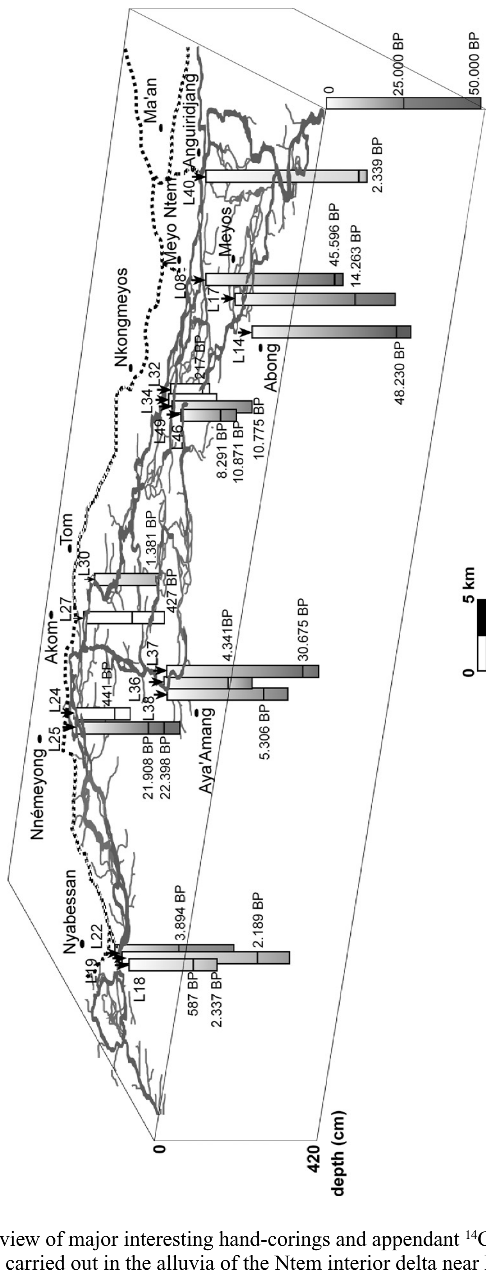

Figure 12. General overview of major interesting hand-corings and appendant ^{14}C AMS radiocarbon ages (not calibrated) carried out in the alluvia of the Ntem interior delta near Ma'an in 2005.

of fine-grained clayey, silty and sandy suspended load, which formed an upper floodplain in the Holocene. This sedimentary unit is widespread found in the interior delta. The fine-grained overbank deposits in the floodplain have evolved from lateral accretion, avulsion and crevasse processes during regular seasonal flooding in the rainy seasons. In this way, since ca. 10.000–8.000 BP many previously existing channels have become infilled with sediment and formerly active channels have been buried.

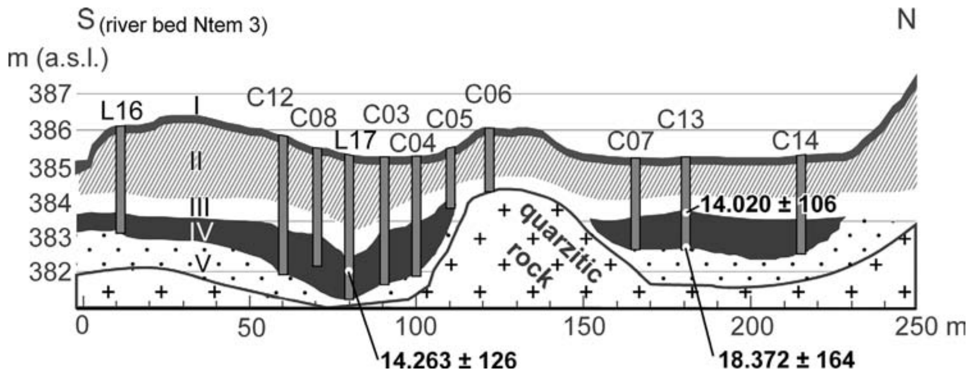

Figure 13. Results from stratigraphical field work in 2006 at the site Meyos. An extended palaeosurface (IV, min. age 14.020 ± 106 BP (120–140 cm, C13)) is overlying alternating thin layers of coarse sandy and organic sediments and basement (quarzitic rock) with a saprolitic transition layer (V). It is covered by layers with characters of reduction (III) and oxidation (II) processes and a thin humus top layer (I).

At locations where Early to Middle Holocene ^{14}C (AMS) dates were found in the alluvia (Aloum II: 8.402 ± 67 (in 78–88 cm) and 6.979 ± 58 BP (120–140 cm); Aya'Amang L36: 4.341 ± 60 BP (140–160 cm) and L38: 5.306 ± 64 BP (220–240 cm); Nkongmeyos L46: 10.871 ± 99 (120–140 cm) and 8.291 ± 89 BP (80–100 cm)), generally stable climatic and fluvial conditions in forested environment combined with accumulation of fine-grained clayey to sandy deposits are assumed. The organic material found at these locations was intermixed with thin fine-grained sandy layers. This period was marked by aggradation with multiple shifts from vertical to lateral accretion and initial floodplain construction in response to lower peak discharges.

Across the unified single Ntem channel near Nyabessan, a periodically inundated small-scale floodplain in swampy environment was discovered. These fine-grained clayey to loamy organic sediments of dark colour and up to 440 cm thickness indicate stillwater or even occasionally lacustrine conditions. They are most suitable for investigations and statements on the time interval quested by the interdisciplinary DFG-Research Unit 510. ^{14}C (AMS) radiocarbon ages yielded a maximum Late Holocene age of 3.894 ± 57 years BP (L22, 140–160 cm) and two ages falling into the period denominated as the 'First Millennium BC Crisis' (L19: 2.189 ± 52 (320–340 cm) and L18: 2.337 ± 55 years BP (200–220 cm)). First archaeobotanical results indicate that after 2.820 ± 70 years BP again drier conditions prevailed connected with a loss of primary and swampy species in the vegetation composition (A. Schweizer, personal communication). Textures of recovered alluvia (L18 and 19) from the same site show an increase of fine-grained sandy sediments (30–70%) for this time period. This time period might mark another drier climate impact, which is conform to results from Maley for the SW Cameroon region (Maley, 2002).

Although texture profiles might provide information on the evolution of processes at each particular coring site, their interpretation must remain tentative. In a further step eventual similarities among different sites might provide evidence for underlying causes leading to modified fluvial processes. Abrupt texture composition changes in the profiles can for example manifest transitions to modified fluvial behaviour, which can be induced by natural evolution, climatic changes, tectonic influences and manmade modifications. As the alluvia allow only inferences for several locations instead of the entire interior delta, the evolution of the whole multi-channelled river pattern inside the interior delta is still widely unclear and unknown.

Several stillwater locations were probably generated by remobilization of basement structures and successional formation of a step-fault inside the delta. Here multi-layered fine-grained alluvial sediments containing embedded palaeosurfaces have been identified as proxy data archives for palaeoenvironmental conditions in the Ntem catchment. Across the river bed of Ntem 1 (Anguiridjang, Nkongmeyos, Tom and Akom), which is widely fixed by basement structures, younger coarse- to fine-grained sandy alluvial sediments (up to 90% in the upper layers) indicate turbulent fluvial conditions. Processes like cut-and-fill cycles, channel incision, large-scale cross-bedding and slope erosion might have removed older sediments and replaced them by younger sandy sediments at these locations. The young age of these coarse sediments might also indicate the amplified influence of human activities inside the catchment area on the fluvial dynamics. The fact that across Ntem 1 the youngest and across Ntem 3 the oldest sediments occur, leads to another assumption and may be interpreted as a consequence of tectonic activity which forced the Ntem River to displace its main river bed northward successively.

Stable carbon isotopic values ($\delta^{13}C$) allow allocation of the dated organic remains/macro-rests to C3 (rain forest trees) or C4 (savanna grasses) dominated vegetation (species) units (cp. Runge, 2002). In the interior delta they range between –26,4 and –31,9‰ and all indicate that at the particular drilling sites rain forest (C3) has prevailed during the corresponding time period (rain forest refuge theory). This implies that across the sampled sites conditions were adequate for rain forest ecosystems to persist, even during periods before, during and after the Last Glacial Maximum. Palynologic research, which is carried out by Archaeobotanists from Frankfurt University (K. Neumann) will provide detailed vegetation reconstructions (pollen diagrams) from three sites inside the interior delta (Aya'Amang, Meyos and Nyabessan), where cores (percussion probe) were recovered in 2005. It is assumed that across the interior delta temporarily lacustrine (Nyabessan) and palustrine (Meyos, Nkongmeyos) conditions prevailed, which favoured the preservation of small rain forest refuge zones also during arid periods (LGM, Younger Dryas?, First Millennium BC Crisis).

The SW of Cameroon has been explicitly prospected by the sub-project ReSaKo of the DFG Research Unit 510 regarding the existence of alluvia suitable for palaeoenvironmental research. Starting from the assumption, that the rain forest-savanna margin has shifted southward during the last 4.000 years, special attention was drawn to the catchments recently covered by tropical rain forest. After primary the forming of the interior delta was supposed to be attributed to the Holocene, the fossil organic horizons however subsequently manifested a much longer time-scale, spanning from 48.230 ± 6.411 to 217 ± 46 years BP. The alluvial sediments inside the interior delta display a very high spatial and temporal resolution, which deserve a very local, small-scale approach concerning the interpretation of radiocarbon data and depositional as well as sedimentary patterns. The rain forest-savanna border probably never reached as far south as the Ntem River, because no evidence for savannization was found inside the interior delta's alluvia. The new findings will be correlated and compared with the results of ECOFIT (Servant and Servant-Vildary, 2000), especially concerning the assumed aridification around 3.000 years BP. They will also supplement the results derived from lacustrine and marine data archives.

Further-going research must lead to the interpretation of suitable information from the alluvial sediments, especially the origin of sandy sediments (aeolian/fluvial), in spite of all the complications and uncertainties coupled with research on tropical fluvial sediments (Thomas, 2004; Latrubesse, 2005). The influences of neotectonics and human interactions (Bantu question) on the evolution of the river system is still uncertain for the most part.

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