CHAPTER 17

A palaeoecological approach to neotectonics: the geomorphic evolution of the Ntem River in and below its interior delta, SW Cameroon

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ABSTRACT: The Late Tertiary to Quaternary evolution of the Ntem interior delta in SW Cameroon shall be modelled. A step fault was formed along neotectonically remobilized Precambrian structures. Uncalibrated ^{14}C-datations in this 'sediment trap' show Pleistocene to Holocene ages. Both within and below the interior delta pebbles and clasts which are cemented in an iron and manganese matrix were found. These 'fanglomerates' are used to discuss different processes of the younger evolution also concerning climatic fluctuations in the study area.

17.1 INTRODUCTION

In the framework of the subproject 'ReSaKo' (Rainforest-Savanna-Contact) of the DFG-Research Unit 510 'Environmental and cultural change in West and Central Africa' the palaeoenvironmental significance of alluvia of the Ntem interior delta in SW Cameroon will be investigated (see Sangen, this publication). To understand the sedimentation processes in the study area, it is important to comprehend the evolution of the interior delta in the context of neotectonics during the past 5–6 Ma.

17.1.1 State of the art

After the progressive opening of the southern Atlantic at about 95 Ma (Reyment and Tait, 1972; Robert, 1987) the drainage network was rejuvenated along the newly exposed continental margin (Summerfield, 1996; Moore and Larkin, 2001). Initially the drainage system was oriented towards the old cratons away from the centres of uplift, which triggered the opening. Along small passages (Congo River) or aulacogenes (Benue) the streams made their way into the proto-Atlantic Ocean. Consequent drainage systems flowed directly into the southern Atlantic. As a result, Summerfield (1991) distinguishes between basinward- and oceanward-oriented rivers. The majority of river catchment area on the African continent has a basinward orientation.

The collision of the African plate with Eurasia 30 Ma ago (Burke and Whiteman, 1973; Burke, 1996) initiated uplift and formed the typical African basin and swell structure, as well as increasing volcanic activity along the East African rift after a long period of inactivity (Burke, 1996). In Cameroon the uplift induced the formation of the 'surface côtière', the coastal surface which is recently separated from the 'surface intérieur' in the hinterland by a peneplain step (Segalen, 1967).

On the African continent, neotectonic impulses are generally associated with the young East African rift structures (Summerfield, 1991; McCarthy *et al.*, 1993) although a minority are associated with the passive Central African continental margin. Suh *et al.* (2001) investigated the neotectonic forms on the slopes of Mount Cameroon triggered by the most recent eruption of this active volcano in 1999. They interpret the Cameroon Volcanic Line (CVL) as an eastward offset of the panafricanic West African rift system which has been reactivated since the Tertiary by hot plumes originating in the asthenosphere (cf. Fairhead, 1985; Déruelle *et al.*, 1987). For southern Cameroon a seismologic map by Krenkel (1921, cited after Fairhead, 1985) states an 'area within which earthquakes commonly occur' (1–5 per year). Fairhead (1985) confirms the accuracy of this map by his own actual seismologic measurements.

Lucazeau *et al.* (2003) used thick sediment layers accumulated inside the Congo drainage system (cf. Karner *et al.*, 1997) to calculate the isostatic uplift of the Congo craton's swells by up to 500 m since the Miocene. Summerfield (1996) refers to the recent uplift in sub-Saharan Africa manifested by massive denudation and accumulation processes at the continental margin, which originate from the remobilization of Precambrian structures since the Phanerozoic (Summerfield, 1985; cf. Daly *et al.*, 1989).

Concerning African interior deltas McCarthy *et al.* (1993; cf. McCarthy, 1993) point out to neotectonic influences on the water dispersal of the Okavango delta in Botswana which is related to the southwestern prolongation of the East African Rift. A comparison with the Ntem interior delta is difficult due to different recent climatic and vegetation habitats. However, the Ntem study area is situated close to the Cameroonian northeast trending Pan-African belt which is described as 'a line of weakness' (McCarthy *et al.,* 1993).

17.1.2 Methods

Analysis and interpretation of topographic and geologic maps as well as Landsat 7 ETM+ scenes (21.02.2001; EarthSat), SRTM and JERS-1 radar data revealed several sedimentation areas in different catchments. These data layers were combined in a Geographic Information System (GIS) with basic information about infrastructure and physiogeographical characteristics (DCW—Digital Chart of the World). Outline maps were created for the field trips.

On-site, waypoints and exploration routes were edited with Magellan ProMark 2-GPS and OziExplorer software. Geologic lineaments were documented in the field. Bedding dips and inclination were measured using a Breithaupt clinometer, and altitudes were recorded with the Thommen Classic altimeter.

Bedrock samples and iron oxide-cemented river pebbles were collected along the Ntem River for petrographical and geochemical analyses. The mineralogical laboratory of *Institut des Recherches Géologiques et Minières (IRGM)* in Yaoundé prepared rock samples for thin section manufacture. The Institute of Geosciences in Frankfurt analysed four samples of ferruginous rock patina from different locations in the interior delta using X-ray diffractometry (RFA). In addition, the Department of Mineralogy produced several thin sections of a gravel fanglomerate for geochemical analysis (polarizing microscopy, electronic microprobe: element distribution map).

17.2 THE NTEM INTERIOR DELTA

The Ntem River catchment covers an area of about 31.000 km^2 (Olivry, 1986). The river has its source in Gabon at an altitude of about 700 m a.s.l. and flows into the southern Atlantic

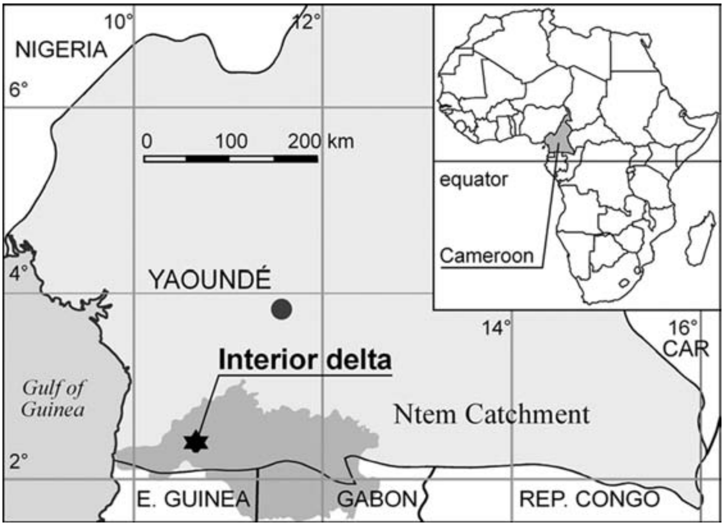

Figure 1. Location of the study area in SW Cameroon.

close to Campo/Cameroon; hence, according to Summerfield's (1991) definition, it is an oceanward draining river. At this location, the Ntem River represents the border between Equatorial Guinea and Cameroon (Figure 1).

In the sub-prefecture of Ma'an (prefecture Ambam/Vallée du Ntem, 2°22'N, 10°37'E), the Ntem River forms an interior delta, covering a surface of 210 km^2.

The river fans out into a multi-branched system over a length of ~25 km from SE to NW and a maximum width of up to 10 km. Near the settlement Akom (2°26'N, 10°29'E) the multiple branches rejoin again to a single channel due to the influence of a SSW–NNE striking inselberg ridge at this point. The river crosses this section in a sharp bow and subsequently flows in SW direction for a distance of ~10 km. Just downstream of the

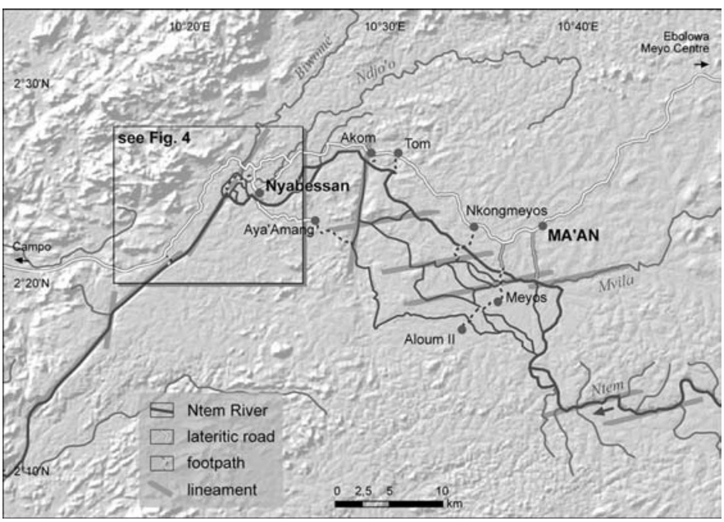

Figure 2. The Ntem interior delta with generalized lineaments interpreted as influencing the river course.

village of Nyabessan (2°24’N, 10°24’E) the river fans out once again. Here the Ntem flows into a SW orientated rectilinear V-shaped gorge, cascading down the ~10 m waterfalls of ‘Chutes de Menvé’élé’ (Figure 2 and 4).

17.2.1 Physiogeography: Climate, geology and geomorphology

The climate within the Ntem catchment is tropical to semi-humid with a short (April–June), and a longer (September–December) rainy season. The mean annual rainfall amounts 1.675 mm at Nyabessan and 1.695 mm in the entire Ntem catchment (Olivry, 1986). Mean annual temperature is around 25°C.

The interior delta is situated on the northwestern swell of the Congo Craton just above the peneplain step slanting down towards the Atlantic Ocean. The Ntem crosses the transition from the higher and lower peneplain levels over several cataracts. The river drops 200 m in altitude over a distance of 40 km. Below the peneplain step the Ntem crosses the coastal surface (‘surface côtière’) which is about 150–200 km wide (Segalen, 1967).

The peneplain step is characterized by an escarpment (‘l’escarpement du Ntem’, Kuete, 1990) at an altitude of about 1.000 m a.s.l., formed by charnockites of the Precambrian basement. The escarpment subdivides the migmatitic gneisses of the ‘surface intérieur’ from those of the coastal plain (Kuete, 1990; Maurizot, 2000).

Three main strike directions of geomorphologic linear structures were identified using radar data: NNE–SSW, NE–SW and ENE–WSW. These show parallels to the southern Atlantic opening direction, the CVL, and the West African rift system, which is represented by the Sanaga Fault north of the study area (cf. Ngako *et al.*, 2003).

17.2.2 Fluvial lineaments

The river network is influenced, and locally oriented parallel to structures in the bedrock.

Within the interior delta the main NE flow direction of the Ntem River deviates at regular distances to a WSW flow direction. Extrapolation from the linear river reaches highlights lineaments with a length of up to several kilometres. The regular spacing suggests the existence of a step fault system which interrupts and deviates river flow, resulting in a change in river gradient and the formation of an interior delta defined by channel splitting (see figure 2 and 3). The occurrence of thick gravel layers in and below the river channel within this ‘interior delta’ suggests the influence of neotectonic controls on the present river morphology. The orientation of assumed lineaments could be the result of remobilization of Precambrian structures (Eisenberg, 2007; Runge *et al.,* 2006).

The rose diagram of the river channel orientations (see figure 3) highlights the subordinate influence of the structural lineaments discussed in 17.2.1 and the Ntem’s wide arc of channel orientations around the main north-westerly flow direction. The V-shaped valley, within which the Ntem River is confined below the interior delta where it crosses the peneplain step, is linear over a distance of about 30 km, with only two deviations. Neotectonic structural control is assumed to have influenced the river along this reach.

17.3 RESULTS

Downstream of the interior delta, three sites with gravel layers were identified. The matrix and clasts of these gravels are cemented by iron and manganese hydroxides. The expression *gravel fanglomerate* will be used in the description because the matrix contains both fluvial

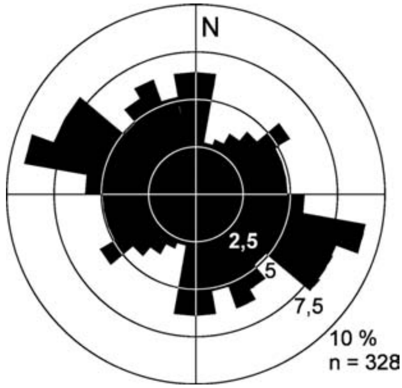

Figure 3. Rose diagram showing channel orientations within the Ntem River network in the study area.

rounded clasts and angular locally-derived detrital material. Three transverse valley profiles are presented to define the different characters of the gravel occurrences (Figure 4).

They reflect the situation directly below the waterfalls of Menvé'élé (A–B), at the beginning of the V-shaped valley after all branches flow into it (C–D), and about 7 km in a southwest-ward direction (E–F). The sketch is based on SRTM data in combination with GPS tracks and detailed field observations (see figures 4 and 10).

17.3.1 Transect A–B

The 'Chutes de Menvé'élé' location can be reached via a pathway from Nyabessan along a deep gorge-like valley (increasing up to 20 m in depth). Four waterfalls lie on the opposite

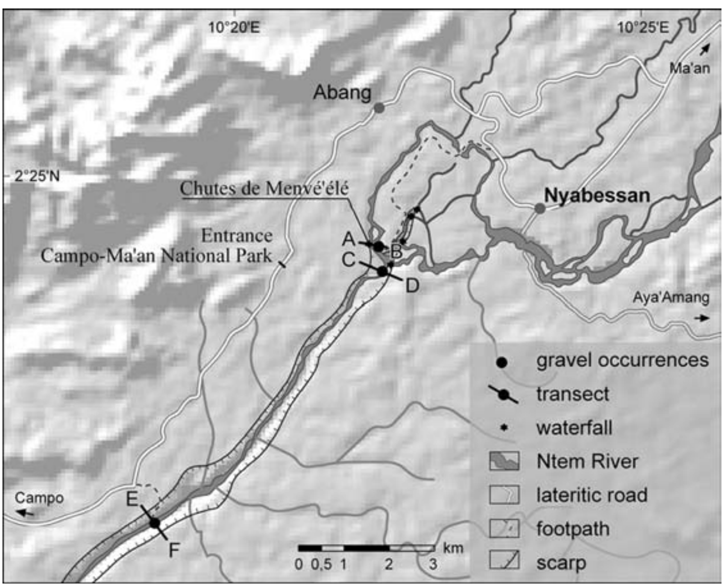

Figure 4. Detailed map of the V-shaped valley situated below the waterfalls of (Chutes de) Menvé'élé showing the location of the three valley profile transects, also shown in Figure 10.

Figure 5. Situation below the 'Chutes de Menvé'élé' waterfalls showing the gravel bed (thickness indicated), recent gravel cover, and the location of the fanglomerate which have been sampled. The Ntem River flow direction is outlined by the curved white arrow.

slope, flowing into this valley (see figure 4). The pathway branches off towards the WSW and leads to a large gravel plain below the Menvé'èlé waterfalls. Directly below the falls, the Ntem has incised into the gravels and formed an inner and outer-bank. The gravels comprise rounded to subangular clasts, mixed with angular rock fragments, coated by a dark brown to black patina. Examination of the patina composition using X-ray diffractometry (RFA) identified the coating as amorphous, presumably organogene material. The occurrence of goethite and manganese hydroxide was verified as the likely source of the black surface colouring.

At two sites gravel samples were taken: (1) at the inner bank, influenced by the ever drenching humidity of the waterfall, and (2) below a small tributary fan reaching into the Ntem's valley (see figure 5 for exact locations).

(1) A small hollow space below the sample permitted the removal of the fanglomerate from the gravel bed. The sectioned sample shows rounded clasts which are overlain by poorly sorted subangular to angular quartz grains. Underneath the clasts a ~2 cm reddish to dark brown, iron and manganese crust has formed. The coarse grains of the upper layer do not occur in the crust.
(2) The second sample contains subangular to rounded pebble clasts although the primary components of the fanglomerate are angular to subangular fragments of up to 10 mm in diameter. Two areas of angular quartz particles cemented by a bright brown matrix occur within the hardened gravel sample (see figure 6).

17.3.2 Transect C–D

At the northeastern border of the V-shaped valley a basin was formed where all branches of the Ntem channel amalgamate. The basin is surrounded by linear stretching steep valley sides of the outcropping bedrock with NNE and ENE striking, along which one branch of the Ntem flows into the basin.

At the western flank, the tributary, which is fed by the waterfalls of Menvé'élé, flows into the basin across several bedrock steps, each a maximum of 2 m in height. At the

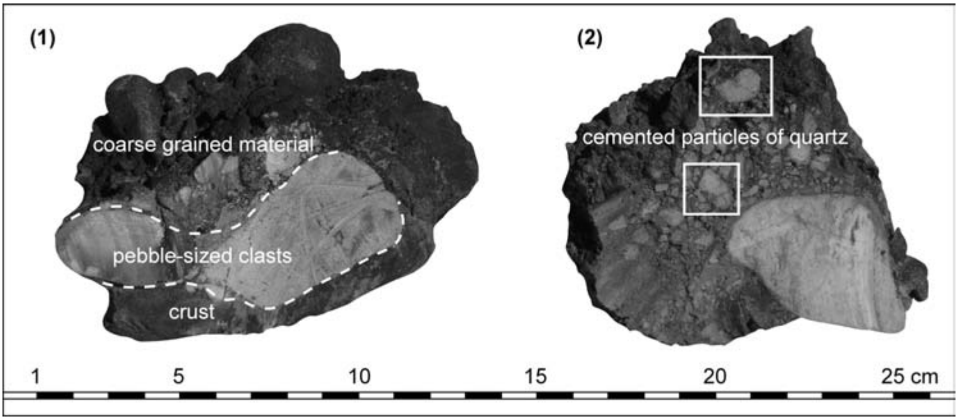

Figure 6. Cut sections through samples of the gravel fanglomerates taken below the waterfalls of Menvé'élé.

junction of the NNE and ENE aligned outcrops, the southernmost Ntem channel branch crosses a 5 m step to reach the basin (see figure 4).

About 150 cm above the dry season water level, a fringe of cemented gravels was observed at the ENE flank. At a similar elevation, gravels crop out on a small island within the basin. At two sites samples of the fanglomerate were taken: (1) from a small 50 cm wide cavity in the outcropping basement where the gravel was protected from erosional processes, and (2) directly from the gravel fringe.

(1) The sample has a breccia-like character (Figure 7 (1)). Most components are subangular, and are cemented by a fine-grained, brown to dark brown material. The parent rock is unitary weathered and it seems to originate from the same region.

(2) The fanglomerate comprises well rounded pebble clasts and angular rock fragments. The spaces are characteristically unsorted and coarse grained (Figure 7 (2)).

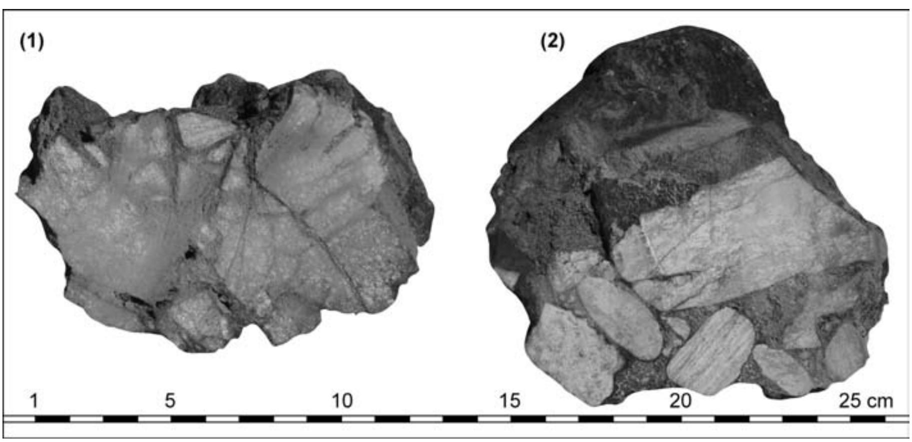

Figure 7. Cut sections through the gravel fanglomerates which were sampled from the basin at the northeastern end of the V-shaped valley (transect C–D).

17.3.3 Transect E–F

The Ntem river bed within the steep sided valley is marked by irregular beds of cemented gravel matrix and basement outcrops. In a few sections the gravel matrix is superficially eroded. Moreover, in several erosional hollows loose gravels have accumulated. On those gravels remnants of a dark patina give a hint to their origin from the hardened gravel matrix. Apart from those loose gravels, red to brown coloured sand banks exist behind large blocks of outcropping basement.

The fanglomerate sample which was collected at this site is characterized by two different areas (Figure 8: divided by the white line). The right side comprises strongly corroded, subangular to well rounded clasts which are cemented by a silty matrix. On the left side of the sample, the clasts are primary pebble clast fragments, cemented in a hardened matrix with coarse grained particles of quarzitic rock and some ferruginous pisoliths up to three millimetres in size. In this area there is also a clast fragment which is partially coated by a ferruginous coating or patina (see figure 8 inset). The photomicrograph from a thin section of this patina shows an alternating stratification of bright and dark brown coloured layers.

17.4 DISCUSSION

A fanglomerate is a cemented accumulation of unsorted material which contains rounded as well as clastic pebbles which formed during an arid climate. During excessive precipitation periods, the material originating from slopes will be loosed and accumulated at the valley bottom as a mud deposit (Murawski, 1992). This definition has to be adjusted to the study area. A tectonically triggered process has to be considered. The term 'alluvial fan' seems to be also suitable for the unsorted and cemented deposits. Blair and McPherson (1994) refer to all global climatic regimes in which the alluvial fans occur. However, some morphologic features which are related to this term beneath the texture of a fan deposit, particularly the V-shaped valley downstream the interior delta can not be applied to the study area

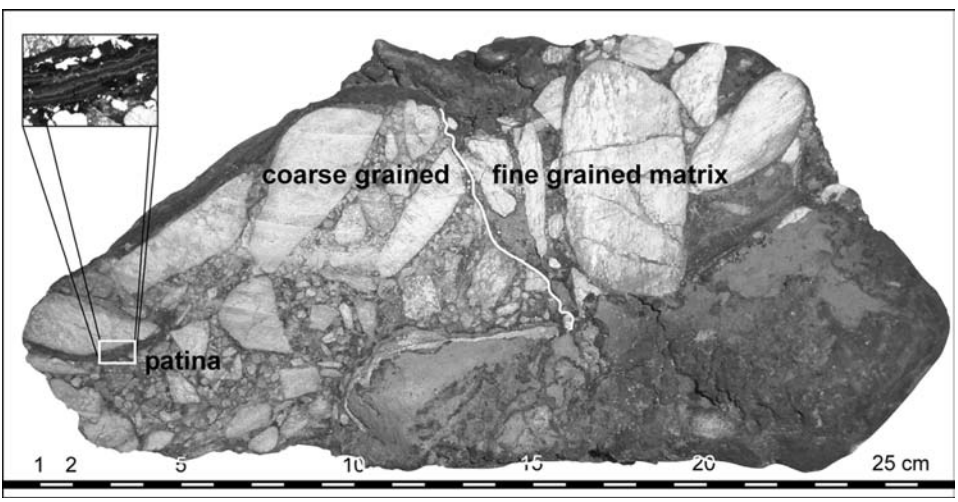

Figure 8. Cut section through the gravel fanglomerate from the Ntem River bed within the steep-sided valley (transect E–F).

This valley is defined by a distinct linear structure, offset by a fault which intersects the valley at a 40° angle, some 20 km SW of the waterfalls (Figure 2). The structure of this deep valley presumes a former fault or graben which was probably neotectonically remobilized below the Ntem escarpment in the undulating peneplain. The gravel layers, blocks of unweathered basement rocks and residuals of a ferricretic crust of up to 2 m in diameter below several waterfalls flowing into the northern end of the gorge (transect A–B, figure 9(1)), on the margin of the basin (transect C–D), and also downstream within the Ntem River gorge (Figure 9(2)) are indicators of a sedimentary regime that differs from the present one. This is probably the result of the neotectonic movement on fault planes.

Nearly all fanglomerates are composed of well rounded clasts, subangular rock fragments, and angular quartzitic particles. The rounded gravel indicates long-distance fluvial transport whereas the rock fragments and quartzitic clasts probably represent local debris flow deposits. The gravel composition suggests that an initial alluvial gravel layer accumulated along the NE–SW oriented, structurally controlled river gorge. Landslides triggered by the tectonic activity related to transported angular rock fragments into the valley. These deposits were admixed with alluvial gravels prior to cementation by the ferruginous matrix. These processes are documented by the different clast shape and textural composition exhibited in the cut rock section (transect E–F, figure 8).

The former extent of the gravel layer in the basin (transect C–D) is marked by small gravel remnants cemented to the outcropping rock. The gravel is also preserved in cavities and on an island within the basin. Directly below the waterfalls of Menvé'élé (Figure 5) and at the valley site the distribution of the incised gravel remnants suggests a wider distribution within the valley. The tectonic forces responsible for the formation of the linear gorge and the presumed former distribution of the gravel level are sketched in figure 10. The figure shows the position of the present Ntem river bed, incised into the cemented gravels (transect E–F).

The interpretation of the phases of gravel deposition and cementation can be interpreted in the context of climatic changes; the cementation of the fanglomerates occurred during

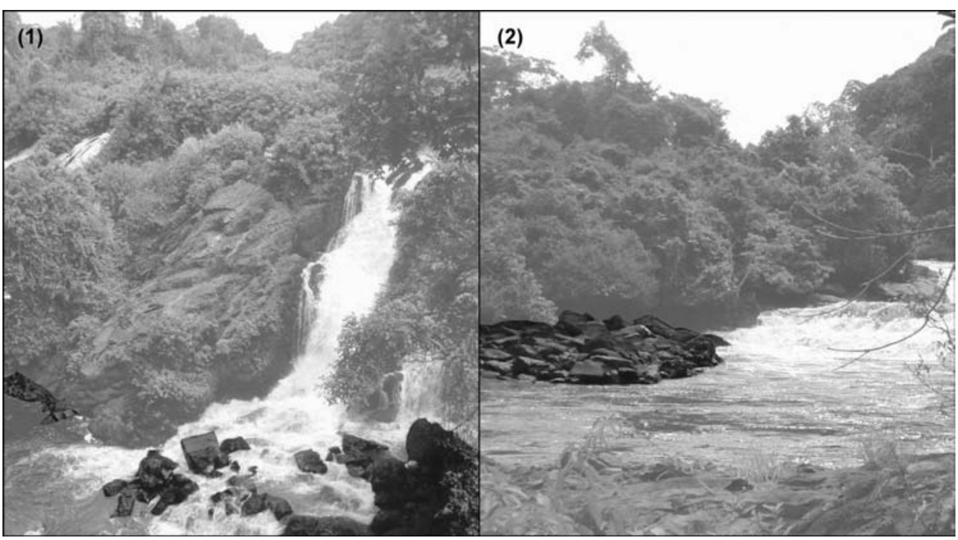

Figure 9. Boulders (marked) below several waterfalls across the pathway leading to the waterfalls of Menvé'élé (1) and close to some cataracts at the southernmost branch of the Ntem River (2).

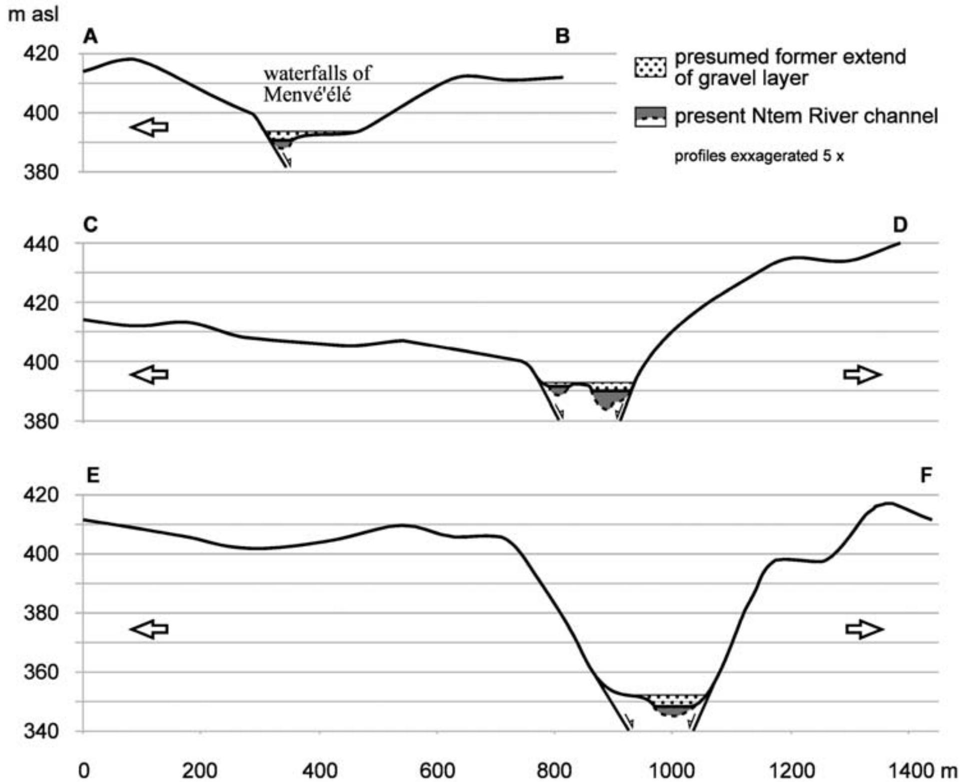

Figure 10. Valley profiles at transects A–B, C–D, and E–F based on SRTM DEM data (obtained from the GLCF server of the University of Maryland) and detailed field observations. The positions of the transects are shown in figure 4.

recurrent moistening and desiccation of the gravel layer (personal communication with Prof. G. Brey, Department of Mineralogy, Frankfurt; cf. Alexandre and Lequarré, 1975). This process can be triggered by a different seasonality with long lasting dry seasons and only short but intensive rainy seasons.

The patina which partially coats a gravel fragment (see figure 8) also suggests cementation under climatic conditions that differed from that experience by the area today. The stratified ferruginous coating could point to longer dry and shorter rainy seasons and to distinct changes between arid and humid climatic cycles. The bright layers indicate a phreatic groundwater regime, whereas the darker layers are presumed to have formed under vadose groundwater conditions (personal communication with Dr. G. Ries, Department of Mineralogy, Hamburg). It is speculated that this stratification could have formed in response to the short-term alternation between arid and humid phases which were postulated by Taylor *et al.* (1993) for the Late Pleistocene interglacials.

In this context the quartz particles found below the waterfall also have to be discussed. They have been fixed in a bright brown matrix and hardened within it (Figure 6: second sample). The preservation of ferruginous coatings on some clasts within the cemented gravel points to polyphase cementation and reworking of gravel beds in the river valley.

The first accumulation of pebbles along the structurally controlled course of the Ntem River occurred >50 kyrs BP—due to the sediment ages in the interior delta—and was associated with the formation of the step fault which lowered the river gradient and formed the interior delta (see section 17.2.2). There are no absolute age determinations on the gravels or cement although Colin *et al.* (2005) have shown that such materials can be dated using the $^{40}Ar/^{39}Ar$ technique. The age of the hardening of the deposits is assumed to be Late Pleistocene.

17.5 CONCLUSIONS

In the rain forest of SW Cameroon the Ntem River has formed an interior delta above a peneplain step slanting down towards the South Atlantic. It is assumed that the delta was formed by neotectonic activity due to the accumulation of pebbles along the structurally controlled Ntem River course. Organic horizons found in the sediments of the interior delta were dated to (uncalibrated ^{14}C-) ages of up to nearly 50 kyrs BP (see Sangen, this publication).

The clasts provided by the evolution of the study area were accumulated and cemented both within and below the interior delta along the V-shaped valley. The cut sections of the samples show indications of landslide processes which can be related to tectonic activity. Besides, the deposits are marked by fluvial deposition, and also cementation processes of a climate different from todays. By finding datable material in the fanglomerates, different cementation phases could be identified and correlated to the palaeoenvironmental work which was done on the lacustrine sediments and deep sea fan deposits of Central Africa (Giresse *et al*., 1994; Marret *et al*., 1998; Nguetsop *et al*., 2004; Zabel *et al*., 2001; Zogning *et al*., 1994).

ACKNOWLEDGEMENTS

This research was supported by grants of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), Bonn, within the DFG-Research Unit 510: ‘Ecological and cultural change in West and Central Africa’ (sub-project RU 555/14-3; Prof. J. Runge). I am grateful to the Cameroonian colleagues from the ‘Département de Géographie’ at the ‘Université de Yaoundé I’ (Prof. Dr. M. Tsalefac, Dr. M. Tchindjang) for assisting and supporting fieldworks in 2004, 2005, and 2006, and to Dr. B. Kankeu from the MINRESI/IRGM (Ministère de la Recherche Scientifique et l’Innovation/Institut de Recherches Géologiques et Minières). I thank Prof. G. Brey and Dr. H. Höfer from the Department of Mineralogy at the University of Frankfurt and Dr. G. Ries from the Department of Mineralogy at the University of Hamburg for the inspiring discussion, and finally Dr. G.A. Botha for several critical and constructive remarks on this text.

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