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Soil sequence-studies on the tropical Buganda-Catena (Masaka District, Uganda)

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During a two month fieldwork, soil profiles were dug along one of the numerous hill slopes of the Ugandan rolling hills in the Masaka District. The topsoil of each profile was sampled and analyzed on grain size distribution and pH-value, to get information about soil development caused by erosion processes and lateral water movement. The soil survey confirmed a catenary sequence in the studied area. Loamy soil had a massive thickness at the upper slope but showed a surprisingly stable formation at the steep shoulder position. Small clay particles that concreted as pseudosand were able to stand erosion while the waterlogged soils on flat spots got suspended. A translocation of unfixed and loose soil particles was caused by a highly developed lateral water movement. Soils on the foot slope showed hydromorphic features and accumulation of fine particles from the upslope at the bottom of the valley. Furthermore, seasonal variations of the ground water level led to an irreversible concretion at the foot slopes, called petroplinthit. It was remarkable that all soil layers were significantly enriched by quartz grains. The traditional catenary conception was used to derive the spatial distribution of soils from geomorphological field parameters.

Key words: Buganda catena, soil sequence, soil development, tropic soil, plinthit, lateral water movement.

INTRODUCTION

A soil catena is commonly defined as a topographical sequence of different soil profiles that occur down a slope. Birkeland (1999) has accurately described the soil catena as a chain, string, or a connected series of soils, related by their sequence in the landscape. So the variability of soils in a topographic sequence is a function of gradient and position on slope – and hence a function of time (Finck, 1963; McFarlane, 1991). Thus, a soil catena is also a chronosequence. Catenary soil sequences occur on hill slopes where the geology is uniform and there is no marked difference in climate from the top to the bottom of the slope. Rather, variations in soil profiles that occur down the slope are largely the result of the changes in slope gradient. The pedological term was

originally introduced in 1935 by the soil chemist Geoffrey Milne (1898-1942) during his studies on tropical soils in Eastern Africa near Amani Tanganyika. This region is affected by a wet tropical climate. But despite the high precipitation amounts, serious soil erosion processes are rarely reported. This fact is connected with the special soil texture, built by stable sand-size granules and pseudosand-structures. Both composed of the association of clay particles and iron oxides or hydroxides. Pseudosand plays a significant role in determining soil water fluxes and water-retention. Due to the high percentage of macro-pores, the water movement and infiltration in these soils can reach a flow rate of up to two meters per minute, just as fast as in sandy soils (Bremer, 1995; Bremer, 1999). Thus, on sloping surfaces, the rates of runoff are very low, but the rates of interflow may be high. This interflow causes leaching and wash-out of soil water solutions and the downward particle-transport of silt and

clay, which finally results in different pedogenetic processes and soil types along the transect on the hillslope (Faniran and Jeje, 1983; Bremer, 1995; Bremer, 2004).

The landscape of Buganda in the western part of the Lake Victoria basin in Uganda is characterized by flat ridges and monadnocks on a wide peneplain. The catena sites described by Milne (1936a) are located between the wooded hills and depressions with papyrus swamps. In a spatial relation to this region, this paper will present and discuss the results of our soil sequence studies which were carried out along a slope profile near Kyato in the Masaka-District (Uganda). The main aim of this study is to prove pedological dependences on the relief segments via the catenary approach and furthermore to verify the connection of the different soil types within these segments.

Physiographic characteristics of the study area

The investigated hillside is located in a hollow valley next to the Ugandan village Kyato (0°09 S/31°43 E) in the Masaka-District in the western part of the Lake Victoria basin at an altitude of 1200m a.s.l. (Fig. 1). Lower parts of this region are characterized by seasonal floods of tributary streams within the catchment area of the Nabajuzi River.

The region under study is characterized by an equatorial climate with seasonal maxima of precipitation from March to May and from September to November (mean annual precipitation is about 1500-2000mm) (Höller and Stranz, 1976; Manshard, 1965). During the dry season, lee-winds from the Ruwenzori Mountains affect the thermal conditions in this region with daily temperatures >30°C. The average annual temperature is about 21.5°C (Fungo et al., 2011). Due to the influence of the nearby Lake Victoria, the local climate is characterized by the land-sea-breeze wind system throughout the year (BakamaNume, 2010).

The investigated area based on the East African Plateau is marked by hilly landscapes that are dissected by numerous rivers and watercourses. The most remarkable geomorphological feature of the countryside is the large number of mountain knolls with average inclinations of about 5% (Radwanski, 1960). The hill ridges are often covered by hard lateritic crusts of tertiary age. These concretionary ironstone layers, called "murrum", of varying thickness occur at different depths (Kalpagé, 1974). It is striking that there are no lateritic crusts on ridges with altitudes <1300m a.s.l. – especially in the central area of Buganda and the Masaka-District (Pallister, 1956). This can be explained by the higher rates of water supply from the Nabajuzi-Quag and Katonga-Swamp. Due to the higher content of soil moisture, the desiccation of the soils and the corresponding forming of lateritic crust is

prevented. In turn, the lack of lateritic crusts facilitates erosion and denudation of the hilltops (Baker, 1956; Pallister, 1956). According to Pallister (1956), Radwanski and Ollier (1959) and Radwanski (1960), the rich deposits of quartzite are crucial for this local phenomenon. Usually, the shape of mountain ridges is built by belts of quartzite. Preuß and Schmanke (2006) also underline the geomorphological and pedological relevance of these quartzite belts. They both mention exactly the same formations and geographic coordinates of the same area under investigation in the Masaka-District. Even within the framework of our own field studies, only rocks of quartzite and quartzitic weathering products were found.

The soils have developed from hornblende gneiss and acid granites of the basement-complex (Krenkel, 1910; Schlüter, 1997; Westerhof, 2014). Ferralsols and Plinthosols are the most dominant soils. The seasonal and partly permanent waterlogged conditions on the lower sites led to the development of Gleysols (Fungo et al., 2011).

The region under investigation is among the most fertile districts in Uganda. The cultivation of bananas and coffee dominates the agricultural land use. This cultivation and the cattle-breeding have reduced the natural vegetation of the woodlands and swamps (Pallister, 1956; Radwanski, 1960).

The Buganda-Catena

The classical Buganda-Catena covers mainly surfaces from 1000 to 1500m a.s.l. It consists of shallow, skeletal soils developed from either quartzite or ironstone on summits and upper slopes and deep red or red-brown clay loams occurring on pediments (ESG et al., 2001). The bedrock is built by the gneiss-granulite-complex and extends over the peneplain to the northwest of Lake Victoria. During the weathering, minerals like mica get lost, while the resistant quartz remains (Ollier and Radwanski, 1958).

On landscapes with inselbergs and monadnocks, the upper parts of the hillslopes are characterized by dark-gray skeletal soils on the weathered bedrock. This section is missing in the lower parts, just like in the district of Masaka (1200m a.s.l.). Instead of that, profoundly weathered red soils can be observed there – partly with hardened layers (named 'clinker-horizons') and accompanied by enrichments of Fe₂O.

Surface runoff results in the transportation and accumulation of particles on the slope toes. On these accumulations, there is a typical soil genetic development of dark Gleysols (also named 'mbuga') or Fluvisols (Milne, 1936a; Milne, 1936b).

Bremer (1995) describes the translocation-catena of Buganda as a topographical sequence of Lithosols and reddish earth soils followed by clinker-like horizons and mbuga-soils. Bremer points out that the occurrence of the

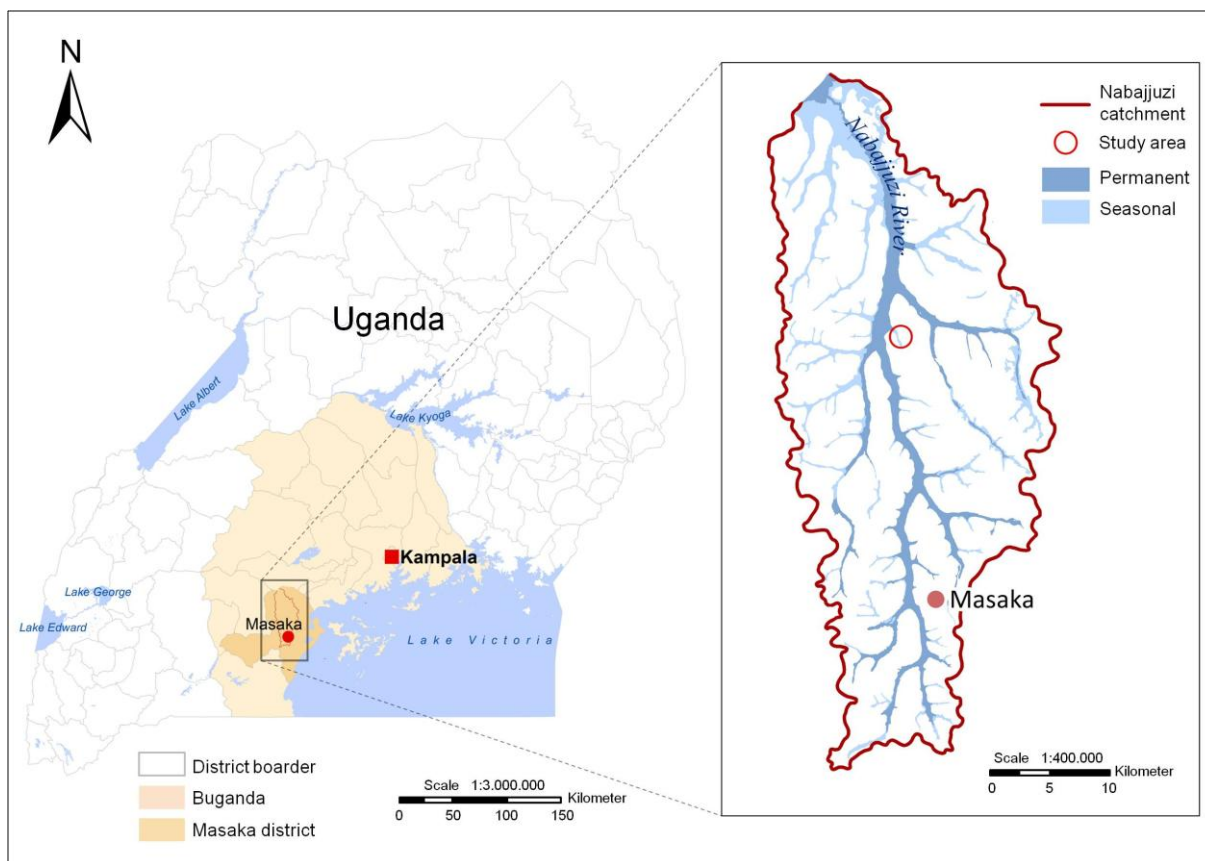


Figure 1. Location map of the study area.

reddish earth soils is mostly connected with high rates of loam. The Buganda-Catena may include relictic soils, like the thick layers of pisolith as well as excavated palaeo-soils (Bremer, 1995). The soil genesis of the hilltops may go back to the middle Tertiary period, whereas the Gleysols in the vales can be dated back to the Quaternary period (Pallister, 1956). Pallister subdivides the Buganda-Catena into four zones (A to D). Zone A represents the Hill-Brow-series with the very shallow (< 60cm) dark-grey soils of the hill tops. Zone B encloses the red earth topsoils with high rates of infiltration and far-reaching weathering. The deep red or red-brown soils on these pediments are often associated with truncated and ferruginized soil profiles occurring in the lower sections of the pediments (ESG et al., 2001). These soils may be vulnerable to soil erosion – especially on overstocked sites. Zone C is the transition zone with the gray and sandy soils of the Swamp-Fringe-series. The last section in this catena is zone D, which is characterized by the blue-grey and gleyic soils of the swamps and floodplains.

In existing soil studies about the Masaka district (Finck, 1963; Young, 1976; Emmerich, 1997), two significant

soils are usually described in the catchment area of the Nabajuzi River: Well drained and sandy loam Ferralsols on the hill slopes, which are partially enriched with laterite, plinthite and phyllite. In contrast, the humic and sandy Gleysols on the slope toes. Evidently, there are variations between the hillslopes within the Buganda Catena due to differences in rocks, levels of weathering and the influence of water. However, the Buganda Catena serves as a key model for the regional soil study on hand.

MATERIALS AND METHODS

There is a lack of detailed topographical, geological, hydrological or geomorphological maps in Uganda – especially for the rural areas and the outback. Existing maps are mostly generalized and useless for small scaled case studies. Hence, for the preliminary studies and prearrangements, aerial photos served as a basis for estimating biogeographical and geomorphological units and sections within the catena.

Site selection and field studies

To cover the existing soil heterogeneity as well as possible, representative sites along the whole hillslope were selected. The site selection was primarily based on the hue differences of topsoils as well as on different patterns of existing vegetation and current land use. Field trips complemented the site search by providing information about topography, geomorphology and detailed differences in the vegetation cover. All the sites and the topography were located with GPS and the coordinates attained were entered into digital map worksheets. Furthermore, the transect distances were dimensioned by hand.

Geological sections or outcrops could not be found in close proximity to the study sites or in the surrounding areas. Also, no manifestations of soil erosion or accumulation could be detected there. But a simultaneous well construction within the hillslope during the field studies enabled the evaluation of the geological conditions of the subsoil through the drilled borehole within a depth of 40 meters (Fig. 2). For this reason, it was nonessential for this study to dig soil profiles >1meter. All soil profiles under investigation were reviewed strongly according to the German Guideline for Soil Mapping (BRG, 2005) under the consideration of the World Reference Base of Soil Resources (IUSS Working Group WRB, 2014). The main aim of the excavations was the determination and identification of the crucial soil-forming processes to categorize the corresponding soil types in combination with laboratory tests.

Figure 4 summarizes all sites of investigated soil profiles and their topographic positions along the hillslope. The soil profiles were spaded along the transect A to B (Fig. 2), which is free of any natural or man-made obstacles, with an exception of profile № I on the highest point within the catena, because of its position in front of a sloping terrace. Furthermore, the topsoil layer of site № I differs from the other sites due to the high content of skeleton mineral grains within the soil matrix and a dense cover of *Pennisetum purpureum* (Radwanski, 1960). Soil sites № II and № III are located amongst agricultural areas. Sites № IV and № V are currently under grazing. The aerial image (Fig. 2) shows the situation of soil site № V in the hollow with the expanse of water and the estuary into the Nabajjuzi-River.

Laboratory studies

The pedological field-research was complemented by particle-size analysis in the laboratory (according to the international standards for the soil fraction that passes a 2-mm sieve). Soil samples with stable micro-aggregates of ferrite and alumina (pseudosand) were pretreated by controlled crushing. Fragments of roots were separated

from the soil samples manually. The analysis for particles <0.063mm was done with the pipette-gravimetric method according to the Law of Stoke and for particles >0.063mm by sieving (according to DIN 19683-1; DIN 19683-2; DIN 52098; DIN 66115-2). The soil samples were pretreated with 30%-H₂O₂ (elimination of organic fractions) and with Na₄P₂O₇·10H₂O (dispersion medium) (Hartge and Horn, 1992). The gravimetric method was performed with the pipette apparatus and the sieving was executed with the granular composition test set (both devices of EIJKELKAMP®)

The content of organic matter was measured by weight loss during burn up in a muffle furnace. Weight loss on ignition and annealing was performed on the soil samples at 550°C for eight hours.

The soil pH-values were measured in a 0.01 M CaCl₂ suspension at a soil-to-solution ratio of 1:2 with a potentiometer (HI 98150 of HANNA® instruments) in laboratory and according to DIN ISO 10 390. The pH meter was calibrated using buffers of pH 4.01 and pH 7.01.

RESULTS

Topography

The hillslope under investigation stretched to a length of 300 meters with a difference in altitude of 30 meters. The hillside faced southwest with a mean slope of 6° (with a minimum of 2° and a maximum of 12°). The upper segment is shaped like a convex surface, while the lower segment is clearly dished.

Organic Matter and pH-values

The organic matter in this area gains values between 4-8% which is enough for cultivation (cf. Fig. 4). In wet-dry tropical areas or in savannah regions like Buganda, it is a practice to prepare and till the fields just when the first precipitation of the raining season starts. Depending on the duration of the wet season, the amount of fertilizers and of planting in general can vary. Another typical agriculture method is to amass the topsoil on the fields, where water demanding crops used to be planted to support the water budget of the soil and control erosion processes (Drechsel and Stache, 1997; Jahnke, 2000). The loss of minerals is minimized by spreading organic matter directly on the fields to be decomposed by ants and termites (Beck et al., 1997). If a large amount of organic waste is available, it is burnt for an additional nutrient supply. The influence of the anthropogenic impact is so great, that no relation between the hill slope and the body of organic matter could be proved (Fig. 4).

Low pH-values are typical for old soils as a result of intense weathering. The measured pH-value of 5.3 and the content of organic matter with about 5% concurred with

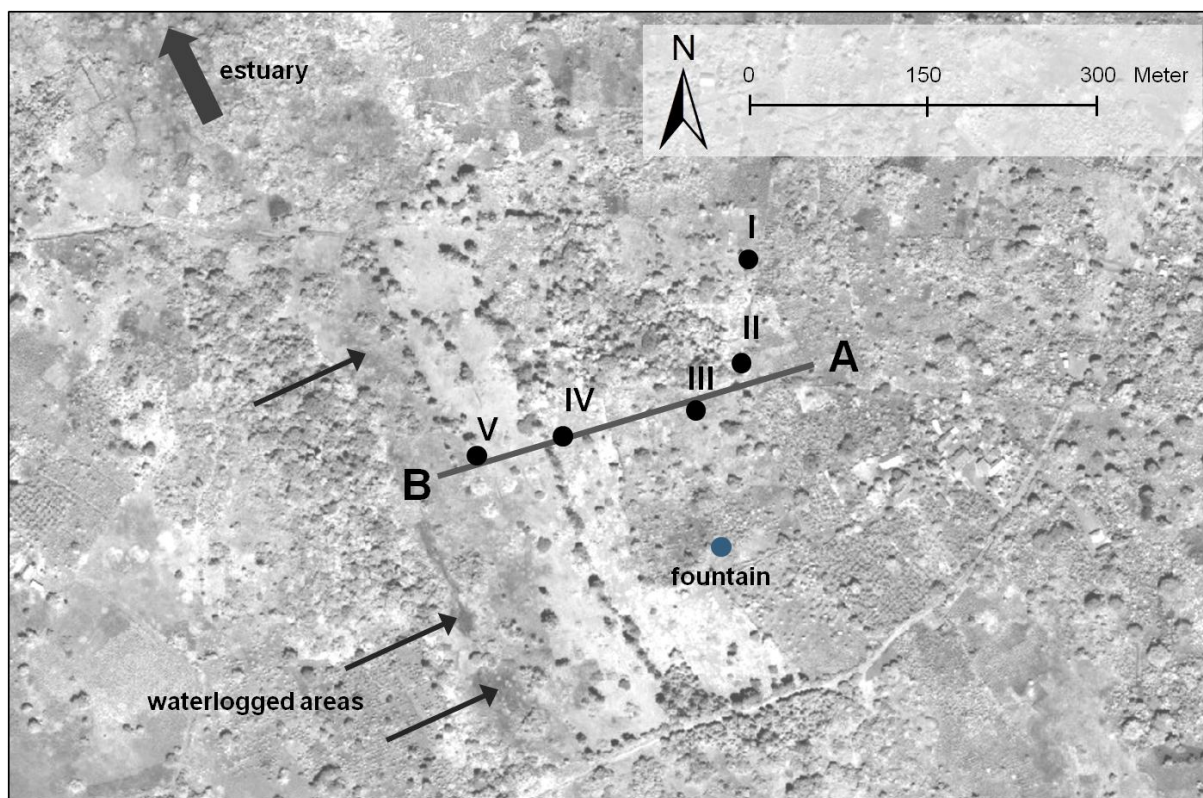


Figure 2. Study sites and transect of the catena with positions of soil profiles and the well construction. The arrows show the expanse of water (small arrows) and the estuary direction into the Nabajjuzi-River (big arrow).

the values of Rueckers (2005) results in loamy topsoils of the Buganda Catena (cf. Fig. 4). Runoff near the surface is normally base-poor, while deeper soil layers show higher nutrient levels because of leachate enriched with ions. For the study area, there are a number of reasons which could lead to the acidic conditions. Low pH-values at the bottom of the valley could be caused by vegetation detracting ions from the soil water while organic acids are released by the roots (Bremer, 1995; Bremer, 2010). Covered by a humic fine root system including a distinct humification, the topsoil of the valley-bottom is enriched by organic acids, which are transported into the topsoil by infiltrating water (Fig. 3). More organic acids are accumulated by cow dung. Base-rich nutrients get absorbed by plants rapidly while leaving acid concentration behind (Kuntze et al., 1994; Eitel, 2006). In addition to that, the only input these soils receive is basic material from the depleted topsoil of the hill slope. External mineral input into the valley bottom can be excluded. In contrast to the summit soils, the valley soils are soaked with water throughout the year. As a result, there is no capillary rising moisture that bases could take along. In general, there is not much circulation in waterlogged soil. The only

distinct water movement is the fluxion to the Nabajjuzi-River, which once again causes a basic loss by leaching (Kuntze et al., 1994; Tardy, 1997; Blume et al., 2011).

Particle size distribution

Loamy soil was the common type in the study area. On old relief shields, a high rate of clay removal took place. Analysis of the soil samples revealed the low average clay content of 21.4%, but around 50% of sand (cf. Fig. 4). However, the values could have also been influenced and adulterated by high proportions of pseudosand within the soil samples and a conceivably insufficient treatment with hydrogen peroxide in the laboratory (Bremer, 1995; Howard and Taylor, 1999; Bremer and Sander, 2011). The amount of organic matter is mainly affected by agriculture, so that the relief primarily effects the pH-value and the allocation of clay (Ruecker, 2005). The mobilization of clay by flowing water was analyzed by measuring increasing amounts of clay from the hilltop (profile № I) to the valley bottom (profile № V). Surprisingly enough and exactly at the site where the highest rate of erosion was



Figure 3. Fine root system on the valley bottom site.

expected, profile № III as the middle stand at the steepest location (slope of 12°) on the hill slope showed the highest amount of clay with more than 30% (cf. Fig. 4). It is presumed that the clay minerals cemented as pseudosand are able to maintain their position (Bremer and Sander, 2011). Bremer (1971) also presumed that clay erosion mainly depends on chemical suspension and not on mechanical shift. The granulometry of profile № III could be explained by this theory and the analysis concurs perfectly with the study of Bremer and Sander (2011). They investigated the relationship between hill slope and grain size dispersion. Therefore, they discovered that relief with a slope gradient of more than 10° has a higher clay amount than flat hillsides. Also, Rohdenburg (1983) mentioned that slow water movement causes a selective washout of clay. If surface water does not reach high flow rates, it also does not reach high kinetic energy. But at plains along hillsides, water can accumulate after heavy rainfall. In that case, aggregates get into suspension and the solid clay particles can be removed easily, while silt and sand particles are left behind. On the contrary, the kinetic energy on a steep hill slope is high enough to shift even the (pseudo-) sand particles (Bremer and Sander, 2011; Gupta, 2011).

Furthermore, the grain size distribution of location № III could be explained by vegetation. Until 2010, the native plant cover was a closed forest. Eroded particles could be trapped by the thick growth. Finally, anthropogenic effects caused by agriculture, planation and infrastructure provision cannot be excluded.

Ferric trioxide and goethite

The color of tropic soils is normally caused by the two iron

minerals hematite (red) and goethite (yellow). While hematite usually generates under high temperatures and moisture, goethite is built by fast lateral water movement and air supply (Bremer, 1995). It is a fact that goethite, being a young element, does precipitate along chasms, pores and aggregates, as evident around the quartzite at profile № I (Fig. 4). However, the yellow color is not automatically metonymic with a young soil. Goethite also occurs by chemical conversion (Bremer, 1995).

Pattern of soil types within the Buganda-Catena

The studied soil profiles could be associated by the catena conception into a logical topographic sequence (Fig. 4).

Figure 5 (b) shows this catenary soil sequences chematically. For this work the already studied Buganda catena from Milne (1935) was used as a model and is also shown in figure 5 (a).

The sequence of the Buganda-Catena starts on the top of the hills with dark grey skeletal soils of the bedrocks (Milne, 1936b). In the study area of the Masaka-District, this unit is missing because the hills do not reach high altitudes. Also, profile № I is neglected because it is a spotty location which does not depend on the relief position. Quartz dykes are responsible for the hilly landscape and could also be reached in the middle of the hill slope or even at the bottom of the valley. Thus the sampled catena starts with red earth, the second unit of the Buganda-Catena (Fig. 5).

The Ferralsol of soil profile № II represents a characteristic

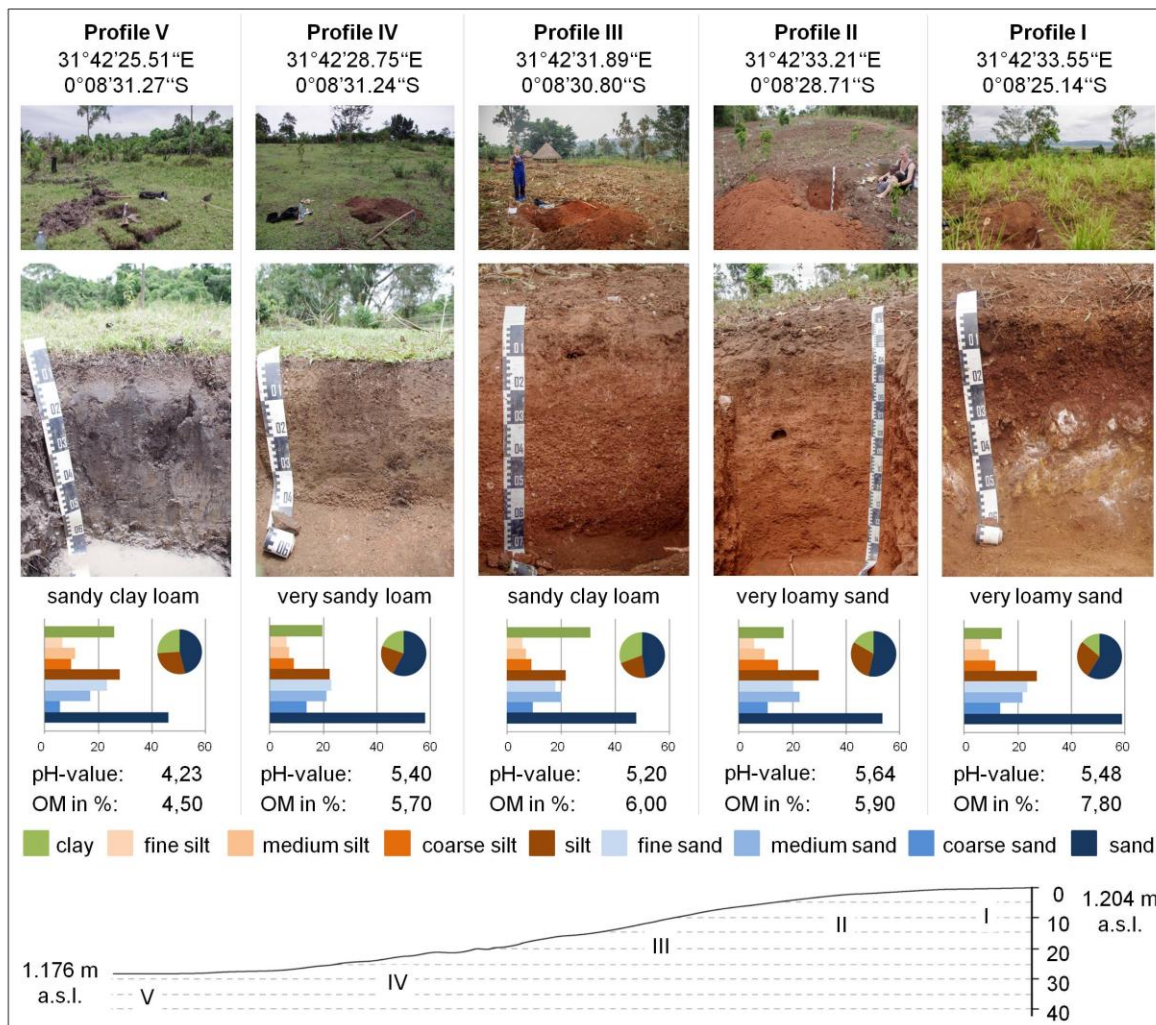


Figure 4. Summary figure of the results with profile numbering, location, profile, laboratory results and the position on the cross section of the hill slope.

soil type of the humid tropics with an average depth of four to six meters (Bremer, 2010). Acrisols and Nitisols as similar soil types are also common at the landscape of Buganda, but according to the WRB-Reference-Base they can be excluded within the investigated soil sequence.

The third unit of the Buganda-Catena after Milne (1936b) is a red earth with a clinker-like horizon. It is certainly meant as a Plinthosol with a petroplinthic horizon, as though it was found at the foot of the hill (soil profile № IV). According to Chesworth (2008) and Zech (2002), the formation of plinthite is associated with the level of gently sloping areas with fluctuating groundwater. Bottomlands similar to those at the investigated soil site are a favored locale. The ferric iron and clay-rich material in this soil have been hardened to hardpans or irregular aggregates

on repeated cycles of wetting and drying due to the variations of the groundwater level at this site. In the transition between Ferralsols and petroplinthic Plinthosols, there are such soils that are characterized by a firm plinthic horizon. Depending on the thickness of this layer, these soil types are named Plinthosols or plinthic Ferralsols (IUSS Working Group WRB, 2014). Profile № III owned a more than 15cm thick iron enriched and hardened horizon with many quartz grains, thus called a Plinthosol with plinthic horizon.

The last sequence of the Buganda-Catena is an alluvial soil type. The soil development at this site is strongly influenced by groundwater and depositional material. Thus, the soil of profile № V is annually water logged and shows a reddish color pattern, which is a typical feature of Gleysols. At this soil site, the accumulation of fine soil

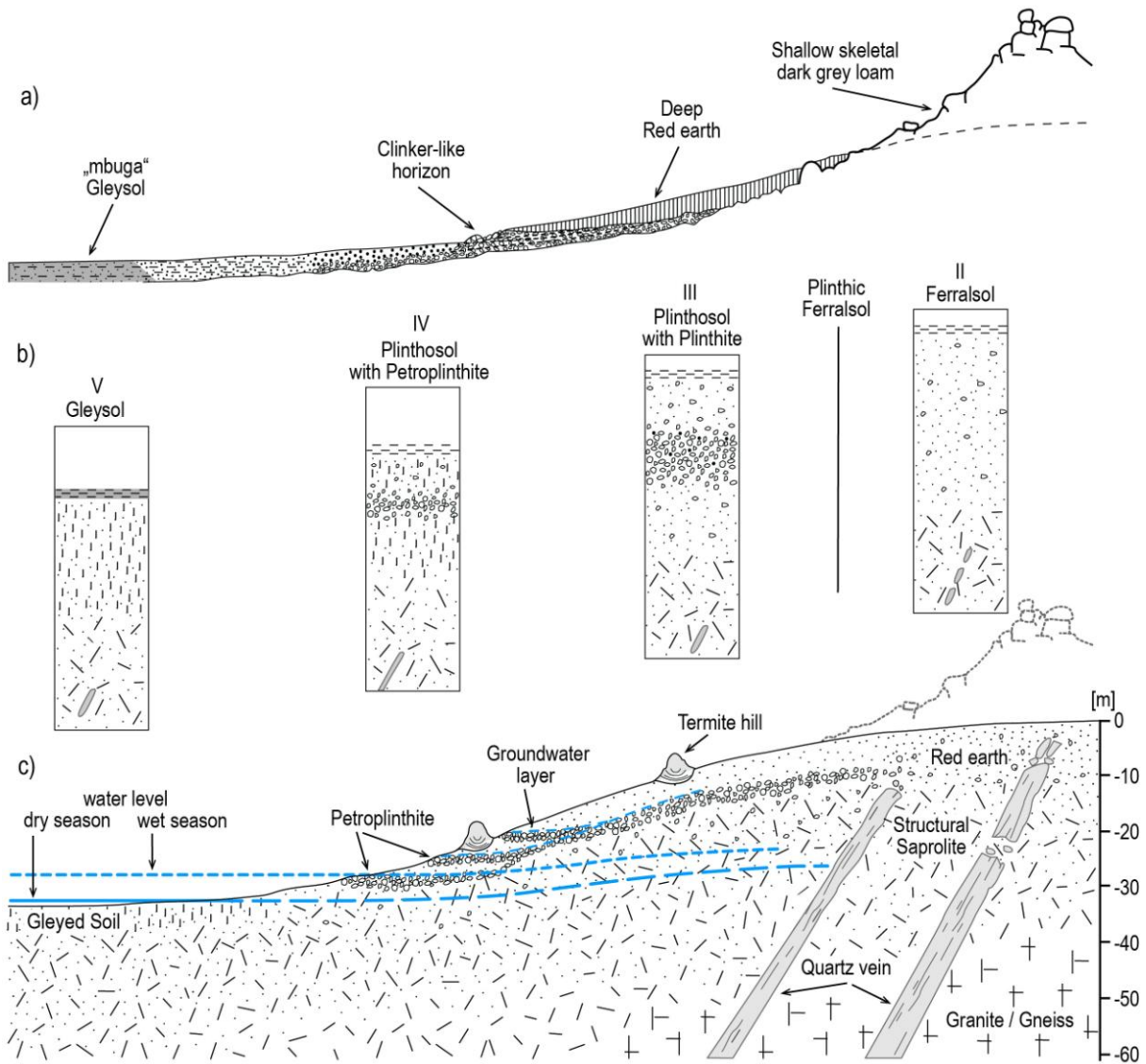


Figure 5. Schematic representation of the tropical Buganda-Catena: a) shows the Buganda-Catena described by Milne (1936b), b) shows the analyzed soil profiles of the fieldwork and c) shows the result of the supposed hill structure based on the soil-sequence-study.

material has been proven (Fig. 4).

DISCUSSION

On December 2014, an almost 40 meter deep water well was dug for the drinking water supply for the native population. The position of the well shaft was within the line of transect of the studied catena and offered the possibility to explore its geological subsoil. Surprisingly, there was no transition between the soil and the underlying saprolith recognizable that fits the view of Pallister (1956) and Radwanski (1960) according to which an essential differ-

ence is just noticeable at a very deep level. So it is hard to name a quantitative number for the soil thickness (Fig. 6 left). The soil layer arises from the saprolith with similar compound and can just be defined by disturbances in the soil structure caused by flora and fauna— mainly by termites (Ahnert, 2003; Bremer and Sander, 2006; Bremer, 2010). Water started to soak out of pores at a depth of 25-30 meters concurring with the water level of the Nabajuzi-River. To save water availability during dry periods, the well was further dug to a depth of 40 meters. At this depth, the compound changed profoundly. The color was yellowish and the material consisted of grained



Figure 6. Well digging into the saprolith (left) and its overburden of a depth about 35 meters (right). Just at this depth the overburden started to contain dark colored minerals as shown in the red circle.

fragmental pieces containing, for the first time, dark colored mineral residues (Fig. 6). In strong weathered tropic soils, this phenomenon currently does not occur in the top layer (Weischet, 1977). But there were still no rocks from the basement and the saprolith was still workable, so that its thickness was assumed to be more than 50 meters. In the tropics, weathering layers of 30 meters and more are common (Wirthmann, 1987; Ruecker, 2005). Incidentally the water well provides the position of profile № 1 on a quartz dyke can be seen as an exceptional location. The quartz veins can reach up to the hilltop but do not have to show any transition to the saprolith. Right next to profile № 1, the occurrence of a Ferralsol with a thickness of several meters is quite possible.

This knowledge enables the reconstruction of the morphology of the Bugandan landscape (Fig. 5). On the bedrock lies a huge saprolith-layer. This layer is formed as hills because of the quartz dykes. The dykes stabilize the hill-formation, which shows that the typical hill formation is caused by quartz dykes. These quartz belts and their outcrops can reach up into the pedosphere and there change into stonelines by weathering. Because of the high amount of quartz grains and the interaction between interflow and termites, a development of plinthite horizons in a depth of 1 to 1.5 meter is possible (Eitel, 2006; Thomas, 2011). Because of the seasonal flooding, the soil at the foot slope undergoes a change between wetness and dryness and transforms to Petroplinthit (Schlichting and Sommer, 1997; Ahnert, 2003; Zech, 2002). Because of these irreversible concretions, soil water gets dammed and new seasonal water levels are reached, where it dries and wets repeatedly again. With time, a steplike structure made of Petroplinthite covers the foot slope (Fig. 7 bottom right). This kind of laterite formation is typical for tropical climates with varying wet seasons and is

caused by the lateral transport of Fe^{2+} (Mohr et al., 1972; Dos Anjos et al., 1995; Thomas, 2011).

Moist conditions throughout the whole year lead to reductive soil formation, a grey color, and wetland vegetation at the valley bottom. In this position, stonelines are mostly dispersed and consequently rare (Emmerich, 1997).

CONCLUSION

The five analyzed soil profiles could be linked in a logical sequence with the use of the catena-conception. The soils in the target area are strongly influenced by the local topography. It was possible to prove a pedogenetic connection between the single hill segments: hill top, middle slope, and foot slope despite their different topographical positions. There is a highly developed lateral water movement, which causes a translocation of fine particles. The ground water level leads to reductive soil development at the valley bottom. Seasonal fluctuations and capillary rise of soil water leads to an irreversible concretion at the foot slope. Furthermore, the influence of the soil water movement leads mainly to a specific soil-sequence at the study site. Therefore, the importance of the relief as one of the soil-forming factors is proven by the catena-conception.

Apart from these local findings, it can be concluded that the traditional catenary conception is still an appropriate method in soil science to derive the spatial distribution of soils mainly based on geomorphological and topographical parameters. The concept facilitates the description of complex soil map units with regularly repeating soil-topography relationships (Brown, 2006). This enables simple soil mapping on difficult terrain and allows deductions from aerial views and remote sensing data.



Figure 7. An outcrop of petroplinthite in the study area (left, top right) and steps formed by concretion in layers (bottom right).

Thus, the seemingly outdated approach of Milne (1935) can help even today to close gaps in regional and local soil mapping as well as studies on soil erosion (Ruecker et al., 2008; Luliro et al., 2013). So the old-fashioned approach of Milne is still a useful tool in pedogeomorphology, soil science and soil-landscape modeling.

REFERENCES

- Ahnert F (2003). Einführung in die Geomorphologie. 3rd edn. UTB, Stuttgart.
- BakamaNume B (2010). A Contemporary Geography of Uganda. Mkuki na Nyota Publ., Dar es Salaam.
- Baker SJK (1956). Buganda: A Geographical Appraisal. RGS 22: 171-179.
- Beck L, Höfer H, Martius C, Römbke J, Verhaag M (1997). Bodenbiologie tropischer Regenwälder. Geogr. Rundsch. 49(1): 24-31.
- Birkeland, PW (1999). Soils and Geomorphology. 3rd edn. Oxford Univ. Press, New York.
- Blume HP, Leinweber P, Stahr K (2011). Bodenkundliches Praktikum. 3rd edn. Spektrum Akad. Verl., Heidelberg.
- Bremer H (1971). Flüsse, Flächen- und Stufenbildung in den feuchten Tropen. Würzburger geographische Arbeiten 35, Würzburg.
- Bremer H (1995). Boden und Relief in den Tropen: Grundvorstellungen und Datenbank. Relief, Boden, Paläoklima 11. Borntraeger, Berlin.
- Bremer H (1999). Die Tropen. Geographische Synthese einer fremden Welt im Umbruch. Borntraeger, Stuttgart.
- Bremer H, Sander H (2006). Data base supported regolith-analysis, geomorphologie processes and morphogenesis in the humid tropics. Z. Geomorphol. Suppl. 142: 319-333.
- Bremer H (2004). Water movement, landform and soil structures in the humid tropics. Z. Geomorphol., Suppl. 136: 135-162.
- Bremer H (2010). Geoecology in the tropics with a database on micromorphology and geomorphology. Z. Geomorphol. Suppl. 54(1). Borntraeger, Stuttgart.
- Bremer H, Sander H (2011). Clays – a tool for tropical geomorphology. Z. Geomorphol. 55(1): 95-107.
- BRG (Bundesanstalt für Geowissenschaften und Rohstoffe) (2005). Bodenkundliche Kartieranleitung KA5. 5th edn. Schweizbart, Stuttgart.
- Chesworth, W. (Ed.) (2008). Encyclopedia of Soil Science. Springer, Dordrecht.
- Dos Anjos LHC, Franzmeier DP, Schulze DG (1995). Formation of soils with plinthite on a toposequence in Maranhão State, Brazil. Geoderma 64: 257-279.
- Drechsel P, Stache N (1997). Ökologischer Landbau in der ländlichen Entwicklung Ruandas. Geogr. Rundsch 49 (1): 32-38.

- Eitel B (2006). *Bodengeographie*. Westermann, Braunschweig.
- Emmerich KH (1997). Decksedimente in den Tropen. *Geogr. Rundsch.* 49(1): 18-23.
- ESG International ESG International Inc. (Canada), WS Atkins International (United Kingdom), Development Consultants International (DCI) Ltd. (Uganda), African Development and Economic Consultants (ADEC) Ltd. (Kenya) (2001). Uganda Bujagali Hydropower Project. Environmental assessment. Environmental impact statement. Project Report E464 (4).
- Farinan F, Jeje LK (1983). Humid tropical geomorphology: a study of the geomorphological process and landforms in warm humid climates. Longman, London, New York.
- Finck A (1963). *Tropische Böden. Einführung in die bodenkundlichen Grundlagen tropischer und subtropischer Landwirtschaft*. Parey, Hamburg.
- Fungo B, Grunwald S, Nkedi-Kizza P, Tenywa M M, Vanlauwe B (2011). Lunnyu soils in the Lake Victoria basin of Uganda: Link to toposequence and soil type. *Afr. J. Environ. Sci. Technol.* 5(1): 15-24.
- Gupta A (2011). *Tropical Geomorphology*. Cambridge Univ. Pr., Cambridge.
- Brown DJ (2006): A historical perspective on soil-landscape modeling. In: Grunwald S (ed), *Environmental Soil-Landscape Modeling. Geographic Information Technologies and Pedometrics*. Taylor and Francis Group. New York. Pp 61-105.
- Hartge KH, Hoern R (1992). *Die physikalische Untersuchung von Böden*. 3rd edn. Enke, Stuttgart.
- Höller E, Stranz D (1976). *Klima-Handbuch Afrika*. 2nd edn. Übersee-Verl. Hamburg.
- Howard KWF, Taylor RG (1999). Lithological evidence for the evolution of weathered mantels in Uganda by tectonically controlled cycles of deep weathering and stripping. *Catena* 35: 65-94.
- IUSS (International Union of Soil Science) Working Group WRB (World Reference Base) (2014). World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO (Food and Agriculture Organization of the United Nation), Rome.
- Jahnke H (2000). Landwirtschaftliche Entwicklung in den Sommerfeuchten Tropen. *Geogr. Rundsch.* 52(10): 40-47.
- Kalpagé FS (1974): *Tropical Soils. Classification, Fertility and Management*. Delhi Press. New Delhi.
- Krenkel E (1910). Zur Geologie des zentralen Ost-Afrika. *Geogr. Rundsch.* 1(5): 205-224.
- Kuntze H, Roeschmann G, Schwerdtfeger G (1994). *Bodenkunde*. 5th edn. Ulmer, Stuttgart.
- Luliro DL, Tenywa JS, Majaliwa JGM (2013). Adaption of RUSLE to Model Erosion Risk in a Watershed with Terrain Heterogeneity. *Int. J. Adv. Earth Sci. Engin.* 2(1): 93-107.
- Manshard W (1965). Kigezi (Südwest-Uganda). Die agrargeographische Struktur eines ostafrikanischen Berglandes. *Erdkunde* 19(3): 192-210.
- McFarlane MJ (1991). Some sedimentary aspects of lateritic weathering profile development in the major bioclimatic zones of tropical Africa. *J. Afric. Earth Sci.* 12 (1/2): 267-282.
- Milne G (1935). Some suggested units for classification and mapping, particularly for East African soils. *Soil Res.* 4: 183-198.
- Milne G (1936a). A Provisional Soil Map of East Africa. East African Agricultural Research Station. Amani.
- Milne G (1936b). Normal Erosion as a Factor in Soil Profile Development. *Nature* 26: 548-549.
- Mohr EC, Van Baren FA, Van Schuylenborgh J (1972). *Tropical Soils. A comprehensive Study of their Genesis*. Mouton, The Hague.
- Ollier CD, Radwanski SA (1958). A Study of an East African Catena. *J. Soil Sci.* 10(2): 149-170.
- Pallister JW (1956). Slope development in Buganda. *Geogr. J.* 122(1): 80-87.
- Preuß J, Schmanke M (2006). Geomorphologische Relieffanalyse im äquatorialen Ostafrika. *Natur & Geist* 2: 22-28.
- Radwanski SA, Ollier CD (1959). A study of an east African catena. *J. Soil Sci.* 10(2): 149-170.
- Radwanski SA (1960). The soils and land use of Buganda. Department of Agriculture, Kampala.
- Rohdenburg H (1983). Beiträge zur allgemeinen Geomorphologie der Tropen und Subtropen. Geomorphodynamik und Vegetation. Klimazyklische Sedimentation. Panplain/Pediplain-Pediment-Terrassen-Treppen. *Catena* 10: 393-438.
- Ruecker GR (2005). Spatial variability of soils on national and hillslope scale in Uganda. Cuvillier, Göttingen.
- Ruecker GR, Park SJ, Brunner AC, Vlek PLG (2008). Assessment of soil redistribution on two contrasting hillslopes in Uganda using Caesium-137 modelling. *Erdkunde* 62(3): 259-272.
- Schlichting E, Sommer M (1997). Archetypes of catenas in respect to matter – a concept for structuring and grouping catenas. *Geoderma* 76: 1-33.
- Schlüter T (1997). *Geology of East Africa*. Borntraeger, Berlin.
- Tardy Y (1997). *Petrology of laterites and tropical soils*. Balkema, Rotterdam.
- Thomas MF (2011). *Geomorphology in the tropics. A study of weathering and denudation on low latitudes*. Wiley, Chichester.
- Weischet W (1977). *Die ökologische Benachteiligung der Tropen*. Teubner, Stuttgart.
- Westerhof AB (2014). Geology and geodynamic development of Uganda with explanation of the 1:1,000,000 Scale Geographical Map. GTK Special paper 55.
- Wirthmann A (1987). *Geomorphologie der Tropen*. Wiss. Buchges., Darmstadt.
- Young A (1976). *Tropical Soils and Soil Survey*. Cambridge Univ. Pr., Cambridge.
- Zech W (2002). *Böden der Welt*. Spektrum, Akad. Verl., Heidelberg.