Soil erosion history and past human land use in the North Pare Mountains. A geoarchaeological study of slope deposits in NE Tanzania.

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ABSTRACT

Landscapes are the legacy of past environmental processes. The understanding of current environmental problems such as land degradation is strongly enhanced when trajectories of past landscape development are taken into account. In the Pare Mountains of north-eastern Tanzania widespread exposure of subsoil and saprolite indicates large-scale land degradation, which was advanced in the mid-19th century when the first European travellers reported widespread deforestation. The present study explores the timing, causes and consequences of past soil erosion to assess whether the spread of agriculture, large-scale iron working, or agricultural intensification during the 19th-century caravan trade were the main drivers of present day land degradation.

Geoarchaeological investigations drawing on a multi-proxy approach including pedological investigations of slope deposits and palaeoecological analysis of swamp sediments, suggest that enhanced soil erosion and corresponding accumulation of slope deposits started about 2000 years ago, roughly contemporaneous with the arrival of new subsistence strategies like agriculture and the spread of iron working. Three distinct periods of soil erosion characterised by an increasing intensity of land use have been distinguished by macroscopic soil features and analytical measurements: Slow topsoil erosion from about 300 BC on, accelerated runoff-based erosion of subsoils since the 15th century and ongoing land degradation under intensive agricultural land use since the 19th century. Progressive land clearance and continuous soil erosion depleted topsoil and later subsoil resources progressively, but resulted in rapid changes of environmental processes when internal thresholds were crossed. Topsoil exhaustion in the 15th century caused a shift from slow aggregate-based to accelerated runoff-based erosion, whereas localised colluviation is identified as having dammed the Lomwe swamp in the 6th century.

This research highlights the importance of cumulative impacts of prolonged human land use, whether forest clearing or cultivation, for landscape development. Rather than abrupt climate change, the impact of slow but continuous anthropogenic degradation processes is critical when assessing long-term stability of environment systems or the sustainability of land use practices. The investigation of past soil erosion based on its corresponding terrestrial archives produces detailed, site-specific reconstructions of past environments and their dominant processes and allows conclusions about human land use practices and settlement history. This is particularly important where the archaeological record is restricted due to anthropogenic erosion of past land surfaces.

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AUTHOR´S DECLARATION

This dissertation is the result of the author's original work and includes nothing, which is the outcome of work done in collaboration, except where specifically indicated. It has not been previously submitted for any other qualification at this or any other institution.

Specifically, collaborative work is restricted to:

- Stable isotope measurement was undertaken in collaboration with Dr. Arnoud Boom, University of Leicester. Samples were prepared at York; measurement took place in Leicester.
- Optical stimulated luminescence dating was carried out by myself under the supervision of Dr. Mark Bateman, University of Sheffield. All samples were prepared and measured on my own.
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1 INTRODUCTION

The current, accelerated environmental changes have stimulated interest in palaeoclimatic and palaeoenvironmental research. Following the well known dictum 'The past is the key to the future' investigation of past environment dynamics has become an important tool for guiding policy making in uncertain decision situations such as climate change, droughts and land degradation. Particularly, past human-environment interactions have attracted the attention not only of the scientific community but also the fascination of the public and have gained interest from financial donor organisations as they convey the possibility that potential insights might turn out to be a key to dealing with present and future developments (SWETNAM et al. 1999; COSTANZA et al. 2007; CASELDINE & TURNEY 2010; VEGAS-VILARRÚBIA et al. 2011). In the last decades, with mankind shaping the earth in faster and more irreversible ways that were unimaginable a century ago, attention has been drawn to closer examination of the way former societies interacted, shaped and coped with their environment and its limitations. Along the same lines it is now recognised that many environments once assumed to be 'natural' have a long-standing history of human interference (GILLSON & WILLIS 2004; WILLIS et al. 2004; ELLIS 2011; WIDGREN in press) This has changed the way scholars perceive, manage and protect ecosystems today that are under the threat of severe human re-shaping.

The investigation of human-environment interactions is often described within the conflicting concepts of environmental determinism and independent cultural development. But, as cultural development can not be explained as if detached from the physical environment, most ecosystems have been shaped in one way or the other by anthropogenic influences. The reciprocal and iterative evolution of environments and its inhabitants demands that single environmental processes, most importantly contemporaneous changes such as land degradation, have to be investigated against the background of past human-environment interactions. Through the last decades a number of synthetic approaches like Environmental History and Historical Ecology have emerged, which emphasise historicity in environmental and ecologic research covering a wide range of disciplines from history, archaeology, and geography to palaeoecology and systems ecology (CRUMLEY 1994; BUTZER 2005; BALÉE 2006; CRUMLEY 2006; LANE 2010). Any environmental history though is specific to a restricted space and therefore is a co-product of the respective physical landscape. Thus, reconstruction of the history and development of particular landscapes is an essential step toward understanding broader environmental histories. On different spatial scales, geoarchaeological work, located at the intersection of archaeology, pedology and geomorphology, has proven a suitable tool for the reconstruction of environmental histories on a wider, landscape-scale basis even, and particularly when, historical knowledge is lacking (ZOLITSCHKA et al. 2003; BUTZER 2005, 2008; DOTTERWEICH 2008; FRENCH et al. 2009; FRENCH 2010).

For example, the well-studied environmental history of Europe and the Mediterranean has shown that landscape change has been closely related to the transformation stages of past societies. Formation of colluvial slope deposits took place during the Neolithic, Bronze and Iron Ages, Roman times, the Middle Ages and the deposition of floodplain sediments marks the onset of intensive mining activities in Middle Europe (e.g. LANG & HÖNSCHEIDT 1999; BORK 2003; BORK & LANG 2003; LANG 2003; SCHMITT et al. 2003; DREIBRODT et al. 2010a; FUCHS et al. 2010), the British Isles (EVANS 1990; FRENCH et al. 2005) and the Mediterranean (FRENCH & WHITELAW 1999; AYALA & FRENCH 2005; FUCHS 2007). Although climate dynamics such as the Roman climatic optimum, the Migration Period Pessimum, the Medieval Warm Period and the Little Ice Age have strongly influenced the development of European societies, lasting landscape transformation of the late Holocene have generally been the direct result of human land use (c.f. ZOLITSCHKA et al. 2003; DREIBRODT et al. 2010b).

Unlike Europe, the Mediterranean, and the Middle East, written historic information is lacking for most of pre-colonial Africa up to the 19th century, especially in eastern Africa. The reconstruction of cultural and environmental changes before the 19th century is thus primarily based on the interpretation of archaeological, pedological, and palaeoecological findings and only in rare cases on the interpretation of oral traditions (for example see WEBSTER (1979) for the oral histories of the Interlacustrine kingdoms). The reconstruction of late Holocene environmental development in Africa thus is confronted by the lack of detailed historic information dating the rise and fall of pre-colonial African societies, which hampers the correlation of environmental changes with societal transformations and complicates or even impedes to discern between causes and effects. Over the course of the last few decades a number of studies based on palaeoenvironmental research have attempted to establish environmental histories and to link distinct socioeconomic and cultural phases with environmental and climatic change. Investigating a wide range of sediment archives research in Ethiopia (ESHETU & HÖGBERG 2000; ESHETU 2002; DARBYSHIRE et al. 2003; NYSSEN et al. 2004; GEBRU et al. 2009; SULAS 2010), West Africa (NGOMANDA et al. 2009b; LE DRÉZEN et al. ; LESPEZ et al. 2011), Central Africa (BRNCIC et al. 2007; RUNGE 2008; NGOMANDA et al. 2009a), and the Great Lakes area (ROBERTSHAW & TAYLOR 2000; TAYLOR et al. 2000; KERSTING 2010) has shown that both climate dynamics and human land use have shaped the late Holocene environments of Africa.

The 20th-century environmental history of Africa has been widely perceived as a time of land degradation and desertification as a consequence of resource over-exploitation and unsustainable human land use against the background of a rapidly increasing population (CLEAVER & SCHREIBER 1994; PIMENTEL et al. 1995; BURESH et al. 1997; DRECHSEL et al. 2001; SANCHEZ 2002). Confronted with the apparently fragile ecological equilibrium and the dynamics of semi-arid environments, colonial policies early on have promoted soil conservation plans and the creation of national parks to protect the 'natural environment' from the grasp of land degradation. Like received wisdom, narratives of desertification and land degradation have become 'common knowledge' to both donors and receivers of financial aid to such an extent that the local circumstances of land degradation often are overshadowed by easy to accept explanations - the apparent 'lie of the land' (LEACH & MEARNS 1996). The received wisdom of land degradation mechanisms has since been challenged by thorough interdisciplinary research on environmental histories in long-term perspective (see particularly studies compiled by FAIRHEAD & LEACH (1999), LEACH & MEARNS (1996) and GILLSON et al. (2003) but also LANE (2010) and BROCKINGTON (2002)). Particularly the inclusion of historicity and long-term developments in the evaluation of human-environment interactions – like the use of time-series of aerial photographs as well as interdisciplinary research including ecological and socioeconomic and historic research – has shifted the focus of interpretation from linear histories of resource overexploitation and land degradation to the dynamics of human-environment interactions on time scales from decades, centuries and millennia (GILLSON & DUFFIN 2007; GILLSON & HOFFMAN 2007). In essence, this means that to understand the current state of the environment and to develop adequate conservation or land use policies, it is necessary to consider past trajectories of landscape dynamics and take into account the historicity of the local environments, which have developed out of site-specific, long-term human-environmental interactions.

This approach of 'landscape historical ecology' has been recently specified and put forward by LANE (2010) and applied in the Historical Ecology of East African Landscapes (HEEAL) project investigating human-environment interactions in north-eastern Tanzania, of which the present study forms a part. The overall project focuses on the impact of the 19th-century caravan trade on local subsistence practices and settlement patterns (BIGINAGWA 2009) and its consequences for agricultural intensification in Pare (STUMP 2010). VON HELLERMANN (2010) investigates the 20th-century environmental history in South Pare, whereas COUTU (2011) studies changing patterns of elephant distribution during the last centuries.

The present thesis investigates the landscape development set against the background of the early arrival of sedentary agriculturalists, intensive iron smelting activities and agricultural intensification during the last millennia, and current land degradation and conservation policies. The study applies a pedological-geoarchaeological approach and examines terrestrial sediment archives focusing particularly on slope deposits and valley fills in the North Pare Mountains.

As with many of the other densely settled mountain areas of Tanzania, the North Pare Mountains have experienced over the last century the implementation of various soil and water conservation schemes to protect and enhance agricultural production and stop land degradation, especially enhanced soil erosion. Soil conservation measures started with afforestation programs in colonial times (SHERIDAN 2001) and have culminated in the rehabilitation of irrigation systems and terraces by national and international organizations (TIP, TFIP GTZ,) during the last decades (WARDELL 1991).

Deforestation and land degradation in North Pare, however, seem not restricted to the 20th century but preceded the establishment of colonial rule. For the Eastern Arc Mountains and particularly the Pare Mountains the assumption of pre-colonial anthropogenic deforestation and consequent land degradation is based on the historical accounts of the early European travellers VON DER DECKEN (1869), MEYER (1890), and BAUMANN (1891), who reported widespread open landscapes, bare hills and few trees in the late 19th century. In their accounts, many of the early travellers remark on the fertile, lush green valley sides of the Pare Mountains in direct contrast to the hot and dusty lowlands and comment on terraces and irrigation channels. Yet they also describe a deforested mountain region, which in the middle of the 19th century was widely covered by ferns and low bushland - a description suspiciously reminiscent of secondary vegetation. Whereas the earliest account of VON DER DECKEN (1869) lacks useful descriptions of the vegetation in Pare, HANS MEYER (1890) reports bare summits and widespread areas of 'man-high thickets of bracken ferns' while bushes and shrubs are rare and trees are completely absent[1] and combines his observations with the interpretation:

> 'The different population densities bring about that only the outer mountain ranges and the uninhabited north-western [part] is covered by forest or bushland, whereas middle, south and east Ugweno - except where it hasn't been deforested for agricultural purposes and now is covered with fields and except of the mountain tops – is only covered by small bushes or it is totally treeless, that means it is covered with ferns and grasses'[2]

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[1] e.g. Guamalla hill: 'The path winds through man-high thickets of bracken ferns; bushes and shrubs are rare, trees are lacking. … and climbed .... over rocks and ferns to the round, bare summits of the Guamalla hill'. [original: 'Der Pfad windet sich durch mannshohes Dickicht von Adlerfarnen; Busch und Strauch sind selten, Baumwuchs fehlt ganz. ... und kletterte .... über Fels und Farn zu dem runden, kahlen Gipfel des Gamuallaberges (2000m) hinauf' (MEYER 1890:185)]

[2] 'Die verschiedene Bevölkerungsdichte bringt es mit sich, daß nur die äußeren Randberge und der ganze menschenleere Nordwesten mit Wald oder Buschwald bewachsen sind, dagegen Mittel-, Süd- und Ostugueno da,

In a similar way, BAUMANN (1891:200) discusses the altitudinal zonation of the Pare mountains and suggests that the mid-altitudinal cultivation zone 'originally must have been entirely forested, as can be deduced from scattered groups of trees, but now forms an extended area of cultivated land'[3]. In the 20th century, low bushes and ferns were a characteristic vegetation of strongly eroded slopes and hill tops exposing subsoil and saprolite. Many of these degraded areas have been afforested since the early 20th century and have turned into eucalyptus plantations as inferred from old aerial photographs. Although no direct description of land degradation or soil erosion processes was made by the early travellers, bare hills and the ubiquitous occurrence of bracken fern together with early 20th-century observations suggest that the Pare environment had been entirely deforested and probably strongly degraded at the mid-19th century.

The widespread deforestation in Pare can be causally explained by several circumstances: the climatically-favoured mountain location as a spatially confined focus point for agricultural settlement, the iron-rich basement rocks as an easily available resource for iron smelting, and finally agricultural intensification as response to an external economic stimulus during the 19th-century caravan trade. Agriculture as a new subsistence strategy and the knowledge of iron smelting have been introduced contemporaneously around the begin of the Common Era (PHILLIPSON 2005). Following the assumptions of traditional degradation narratives, the demand of cleared land for agriculture and the impact of fuelwood extraction for iron smelting is supposed to have had a strong, albeit probably slow impact on the extent and the quality of the Pare forests resulting in a steady decline of the original forest cover (HAMILTON 1989a; SCHMIDT 1989; NEWMARK 1998). Iron working was widely practiced in Pare and the Wagweno were widely known for their high quality iron (VON DER DECKEN 1869; MEYER 1890; BAUMANN 1891) and also had a well established trading network with the Massai from the lowlands and the Chagga from Mount Kilimanjaro (KIMAMBO 1969). Archaeological evidence of intensive iron smelting has been recorded on numerous locations on the Pare footslopes as well as within the uplands (SOPER 1967b), although the fuel demands and intensity of their technology have yet to be assessed in detail. From the magnitude of the ivory and slave trade and from historic analogues, many scholars believe that the Pare economy experienced a boom during the 19th-century caravan trade (KIMAMBO 1969; SHERIDAN 2002; HÅKANSSON 2008; HÅKANSSON et al. 2008; STUMP 2010). Stimulated by the food demand of passing caravans, agricultural land use might have intensified and extended. Investment of labour in landesque capital such as terraces and irrigation systems became worthwhile as the area and possibly the fertility of the available cultivated land declined. However, given the general lack of well-dated archaeological evidences for the advent of agriculture, the extent and age of iron smelting, and the establishment of irrigation systems and terraces, it remains unclear if the open landscape encountered by the early travellers was the result of an agricultural intensification stimulated by the 19th-century caravan trade or if the lack of forests has been part of the Pare

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wo es nicht durch „Kulturenbrand“ entholzt und mit Feldern überzogen ist, bis auf die Bergkuppen entweder nur niedrigen Busch trägt oder ganz buschlos, das heißt, gras- und farnbewachsen ist.' (MEYER 1890:194).

[3] 'Above of these extends the cultivation zone, which originally must have been entirely forested, as can be deduced from scattered groups of trees, but now forms an extended area of cultivated land. Above this, one encounters a zone covered by short, luscious grasses, ferns and heather, which extends over the highest ridges of Mid- and North Pare.' [Original: ‚Ueber diesen dehnt sich die eigentliche Culturregion aus, welche, ursprünglich wohl ganz bewaldet, wie aus den vereinzelten dichten Baumgruppen noch zu schließen ist, nun ein ausgedehntes bebautes Gebiet bildet. Ober dieser erreicht man eine mit niedrigem, saftigem Grase, mit Farnkräutern und Ericas bewachsene Zone, die in Mittel- und Nord-Pare die höchsten Kämme bedeckt.' (BAUMANN 1891:200).

landscape for a much longer time - perhaps caused by initial human occupation or the spread of farming and afterwards maintained by intensive iron smelting. There is however a third possibility as GILLSON et al. (2003), critical of the conventional narratives of environmental degradation due to human land use, point out. What if the mid-altitudes of the Pare Mountains never supported the nowadays assumed potential natural vegetation cover of mature (sub-) montane forest? Confronted with this question GILLSON and co-workers (2003) propose that:

> 'Only archaeological investigation of the soil profiles of several sacred forests, radiocarbon dating of charcoal from precolonial iron-smelting sites and analysis of fossil pollen can conclusively document how and when the vegetation of North Pare, Mkomazi and Tsavo changed.'

It is the principal aim of this piece of research to establish an environmental history of North Pare, aimed at answering the question of anthropogenic vegetation change, the influence of climatic drivers and to reconstruct past landscape development and shed light on the trajectory of environment change which has ultimately led to the present state of partial land degradation.

Palaeoclimate and palaeoecological analysis are commonplace in East Africa. The investigation of past climates based on lake levels (for overviews see NICHOLSON & FLOHN 1980; GASSE 2000; GASSE 2006; GASSE et al. 2008) and the reconstruction of past vegetation patterns by pollen analysis (for overviews see HAMILTON 1982; JOLLY et al. 1997; KIAGE & LIU 2006) have a long tradition in the lake and swamp rich areas of East Africa. On the other hand, the reconstruction of landscape development and the investigation of terrestrial archives of environmental change such as soils, slope deposits, alluvial fans and fluvial sediments have so far been disregarded by most research in East Africa. Thorough pedological work on slope deposits is restricted to Kondoa (PAYTON & SHISHIRA 1994; SHISHIRA & PAYTON 1996; ERIKSSON et al. 2000) and Mindu Mountains (SØRENSEN 2001) in Tanzania, Butare in Rwanda (KERSTING 2010) and work by (RUNGE 2001a, 2008) in the Eastern Congo. Farther north, around the ancient town of Aksum in Ethiopia, geoarchaeological work involving soil micromophology has focused directly on human-environmental interactions showing stability during prolonged phases of intensive land use as well as rapid degradation during the last few centuries (BUTZER 1981; FRENCH et al. 2009; SULAS et al. 2009). In contrast to established climate and vegetation models, the aspect of landscape development in East Africa has not yet been comprehensively addressed.

Hypotheses about landscape change in North Pare so far have been based on conclusions drawn from archaeological, ethnological and (palaeo-) ecological research. Whereas the limited archaeological evidence suggest sedentary occupation on the lower slopes of the Eastern Arc Mountains since at least 2000 BP (SOPER 1967b), the land use history of the mountain areas, particularly of the undulating uplands but also of the high altitude grasslands, remains unknown. Oral histories summarised and collected by KIMAMBO (1969) and ethnographic work by CONTE (1999) suggest that the use of highland grasslands as pastures was common even before the advent of agriculture. Recent palaeoecological work has focused on the long-term history of the Eastern Arc Mountains studying swamp cores from the South Pare (FINCH & MARCHANT 2010), Usambara (MUMBI 2009) as well as the Udzungwa (MUMBI et al. 2008) and the Uluguru Mountains (FINCH et al. 2009) in order to establish a Holocene vegetation history of the montane forest zone. Palaeoecological investigations commonly involve a high-resolution study of one or better several lake and swamp cores. Well dated, with a reasonable number of radiocarbon dates, these allow the assessment of past hydrological and vegetation changes with a high temporal resolution. However, due to the restricted occurrence of lake and swamp deposits and a research bias towards high-altitude locations only limited information about vegetation dynamics in mid-altitudes and lowlands can be extracted. Whereas the palaeoecological work gives valuable insights in the long-term stability of high-altitude vegetation of the Eastern Arc Mountains, knowledge of late Holocene land use history remains inconclusive. Although the pollen records show that fire has shaped these ecosystems and that open grasslands have persisted through the Holocene (FINCH & MARCHANT 2010, in prep.) few evidence for human occupation or land use (animal husbandry, forest clearing or agriculture) has been obtained.

All approaches so far – whether archaeological, palaeoecological or ethnohistorical – attempt to answer questions about land use, land use change and landscape development on the basis of inferred evidence. The pedological-geoarchaeological approach of the present study in contrast, investigates the terrestrial sediment record, in particular, colluvial sediments on hill slopes, valley fills, and soil development along slope transects, to obtain direct information about past human land use on a landscape scale. As the correlated sediments of upslope soil erosion, slope deposits are directly related to landscape dynamics and provide information on surface processes and vegetation cover, thus allowing the assessment of past human land use activities on the grounds of their immediate environmental impact. The thesis integrates the evidence from three study areas into a landscape-scale model of environmental change in North Pare and closes the gap between the regional long-term vegetation history and site-specific historical accounts of land use and finally discusses the timing and causes of morphological change in the context of regional climate dynamics and agricultural practices.

1.1 Aims and Objectives

The principal aim of the present study is to establish a history of past soil erosion and reconstruct the shaping of the present North Pare landscape. The soil erosion history is then compared with the occupation history of the area inferred from oral accounts and archaeological research and with published reconstructions of palaeoclimate in order to disentangle human-environment interactions and the impact of climate dynamics on landscape development. The research has been conducted in an explorative approach and is based on several research questions rather than overt, formulated hypotheses, the aims of which can be summarised as

1. to establish the general framework of landscape development,
2. reconstruct vegetation dynamics,
3. to explore the origins of soil erosion and land degradation,
4. to evaluate the impact of early sedentary land use and iron smelting,
5. and the consequences of the 19th-century caravan trade on landscape and vegetation patterns.

Ultimately, the reconstruction of past landscape development will allow the evaluation of land degradation processes suggested by the reports of the 19th-century travellers and the present state of the North Pare landscape, and ties in to the broader questions about the environmental history of north-eastern Tanzania.

Terrestrial archives in North Pare suitable to answer the questions raised are most importantly hillslope deposits, ubiquitous in the small valleys. Three different study sites were investigated in detail – Lomwe, Mrongo and Usumbwe – and allow a comprehensive overview of Holocene slope processes in the agriculturally important, mid-altitudinal upland of North Pare (chapter 6.4). Three distinct phases of colluviation are distinguished across the study areas and are explained as cumulative soil erosion phases, initially transporting topsoil material and after its exhaustion land degradation and subsoil erosion. The explanatory power of the sedimentary record is enhanced by a soil transect study across the eroded source areas of the respective sediment traps. Eroded soils under agricultural land use and on differing topographic position are contrasted with soils under mature forest from remaining forest fragments at Kwa Kirumbi and and Kwa Chegho (chapters 6.2 & 6.3). The comparison of eroded and non-eroded soils allows a qualitative estimate of the amount of material lost since the onset of soil erosion (chapter 9.2). The terrestrial record is complemented by palaeoecological analysis of a buried swamp deposit at Lomwe (chapter 9.5). From its location in the mid-altitudinal agricultural zone the pollen record is expected to differ from previous studies in montane forest locations and to reflect strongly the onset of human land use and anthropogenic vegetation change.

The research is based on a multi-proxy approach. Fundamental is the field description of the slope deposits, which enables the identification of benchmark features for soil erosion processes and concludes in a generalised stratigraphy (chapter 8). The model of slope deposit formation is confirmed by magnetic susceptibility properties and basic geochemical parameters (chapter 7). To assess past vegetation cover, three different lines of evidence - pollen, phytolith and stable carbon isotope analysis - are integrated. Direct palaeoecological evidence from the swamp core is contrasted with indirect evidence from stable carbon isotope analysis of soil organic matter of the slope deposits (chapter 8.5). The chronology of soil erosion and slope deposit formation is based on radiocarbon dating of ubiquitous macroscopic charcoal fragments but is compared to independent deposition ages obtained from optical-stimulated luminescence dating (chapter 7.8).

1.2 Thesis structure

The thesis is structured into an introductory part summarising the physical environment of the Eastern Arc Mountains and particularly the North Pare mountains (chapter 2). The following chapter 3 highlights important research questions on soil erosion, hillslope deposit formation and landscape development in East Africa, discusses methodological caveats and presents important case studies from Tanzania. This is followed by an outline of the archaeological and historical information available for northeastern Tanzania in general and the Pare Mountains in particular (chapter 4). Methods are presented in chapter 5. Chapter 6 presents an overview of the three study areas and summarises the stratigraphy of the respective slope deposits, whereas detailed descriptions of each profile are given in Appendix B. A comparison of eroded agricultural and non-eroded forest soils follows leading to a quantitative estimate of soil erosion and land degradation. The analytical results are presented following a thematic structure (chapter 7), and are subsequently discussed in terms of stratigraphic correlation and their interpretational value for palaeo-environmental processes (chapter 8) before each of the slope transects is interpreted independently (chapter 9). Finally, the evidence is discussed in the light of the regional palaeoclimatic and archaeological paradigms (chapter 10). The thesis concludes with an evaluation of the research approach and the applied methods and closes with perspectives on future research questions.

2 PHYSICAL ENVIRONMENT

2.1 Physiography

The Pare Mountains are part of the Eastern Arc Mountains - a crescent shaped chain of thirteen crystalline mountain blocks in eastern Tanzania (LOVETT 1989). These tectonically uplifted blocks of Precambrian basement contrast with the much younger and higher volcanic mountains such as Kilimanjaro, Mt. Kenya and the Ruwenzoris. From north to south the thirteen Eastern Arc Mountain blocks are Taita, North Pare, South Pare, Usambara, Nguu, Nguru, Ulugruru, Ukaguru, Malundwe, Rubeho, Udzungwa, and Mahenge (Fig. 1).

2.1.1 Tectonic evolution of north-eastern Tanzania

North-eastern Tanzania is characterised by three distinct geological units. Old Precambrian basement is exposed on the peneplains of the Massai Steppe, the Mkomazi and Tsavo plains and in the uplifted blocks of the Pare - Usambara Mountain range (SAGGERSON 1972). Karoo sediments are preserved to the east and are overlain by progressively younger Mesozoic to Quaternary sediments near the coast. Rifting and associated volcanic activity have shaped the north-western part. The basement of the Eastern Arc Mountains forms part of the Precambrian Mozambique Belt, which extends along the coast from Mozambique to Ethiopia. During the Mozambiquian orogeny, crystalline rocks and sediments were subjected to metamorphic alteration and the present suite of metamorphic rocks - granulitic gneisses, hornblende-pyroxene granulites (from sandstone, shale), as well as marbles and graphitic schists (metamorphosed shale) – developed. In the Pare Mountains, radiometric dating suggests that the high-grade metamorphosis took place about 655 - 617 Ma ago (BAUERNHOFER et al. 2008b). Uplifting during the Karoo (290 - 180 Ma BP) and again since the Miocene, exposed the once deeply buried strata and formed the Eastern Arc Mountains. During the early Mesozoic, terrestrial Karoo sediments covered wide areas of East Africa. Whereas in the interior, Karoo deposits were eroded during uplift and faulting, they were preserved along the coast due to trough positions and subsequently covered by Jurassic and Cretaceous marine sediments (GRIFFITHS 1993). The break up of the Gondwana continent (180 - 120 Ma) and the drifting away of South America, Antarctica and Madagascar led to a restructuring of the remaining African continent. Rift faulting created range and basin structures and initial block faulting and probably saw the development of predecessors of the Eastern Arc Mountains (GRIFFITHS 1993).

Since then, repeated cycles of uplift and erosion have shaped different erosion surfaces, which characterise East African landscapes today. Inselbergs of harder and more resistant parent material rise over etchplains, bearing traces of older planation surfaces and repeated cycles of peneplanation. The Late Cretaceous - Early Tertiary African surface is represented in the Massai Steppe west of the Pare Mountains and its counterpart the Serengeti Plains west of the Rift Valley. The Central Tanzanian plateau on the other hand is presumed to be an etchplain of younger age (GRIFFITHS 1993).

The East African Rift system is the most important geomorphological feature of the present East African topography and shaped not only the regional climate pattern but also controls vegetation and more settlement patterns. The East African Rift extends from the Afar triple-junction to the Zambesi river in Mozambique and forms part of the large Afro-Arabian Rift system extending further north through the Levant to Turkey. The rifting originated as a consequence of uplifting due to two lithospheric bulges; the Afar and the East African Dome caused by stationary mantle plumes

(EBINGER et al. 1989). The rift valley diverts into two main branches: the Western Rift from Uganda to Northern Tanzania and the Gregory Rift running from Ethiopia through Kenya and Tanzania. In Northern Tanzania, the eastern branch splits further up into the Eyasi, Natron and Pangani rifts. Whereas rifting and volcanism in the northern part of the rift started as long as 30 Ma years ago, faulting in Tanzania did not commence until the late Miocene.

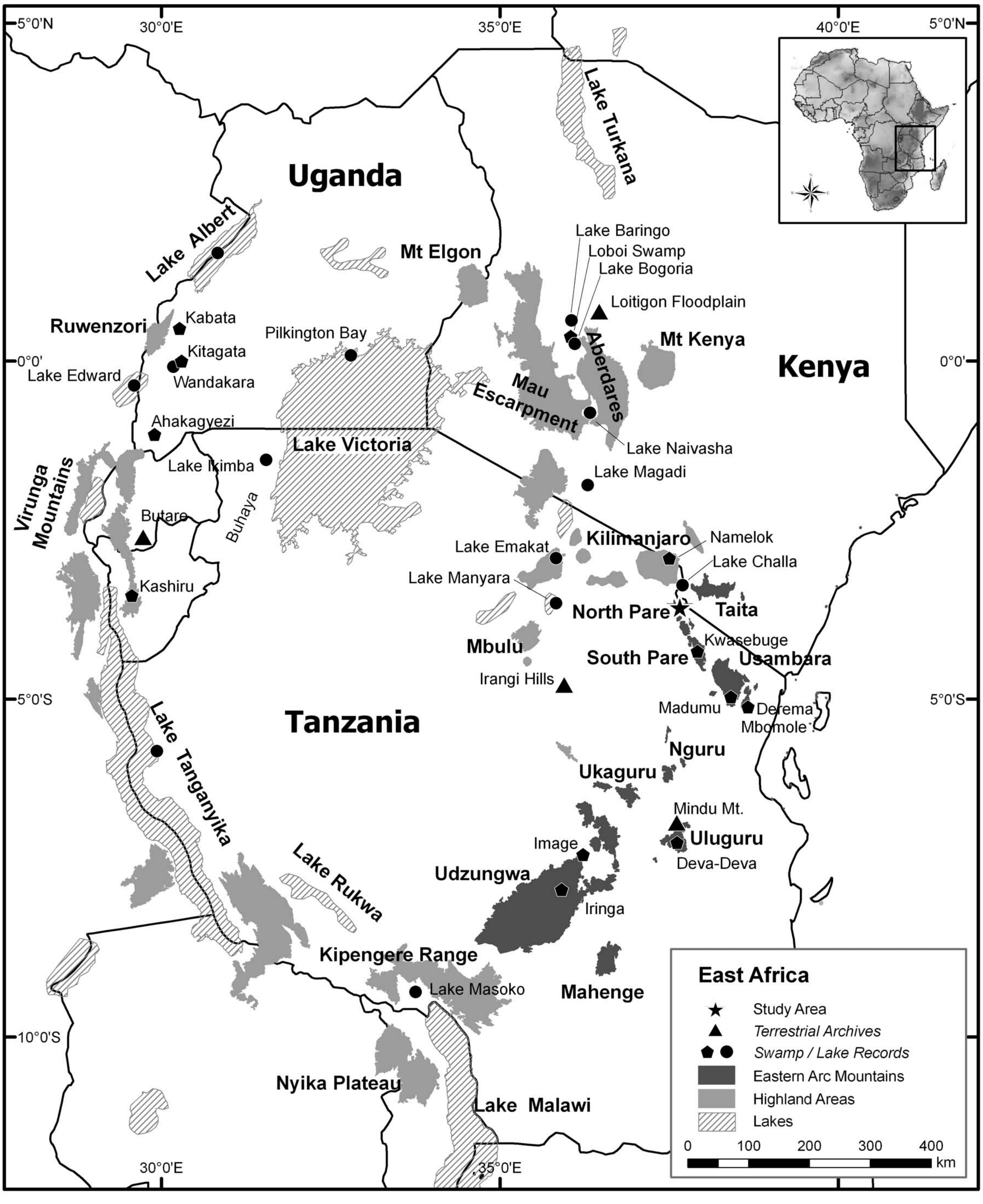

Fig. 1: The Eastern Arc Mountains and other highland areas of East Africa. Symbols indicate the location of important environmental archives mentioned in the text.

2.1.2 The Pare – Usambara horst structure

The uplift of the Eastern Arc Mountain blocks started during the early Mesozoic, but their present shape was only obtained during the final stages of the East African Rift development from about 7 Ma until about 1.2 Ma ago (GRIFFITHS 1993) when extensional faulting of the Pangani graben caused the final uplift of the Pare and Usambara mountain range (LE GALL et al. 2008). The late faulting of the Pangani rift is linked to the onset of volcanic activity of Mount Kilimanjaro around 1 Ma ago (DOWNIE & WILKINSON 1972; LE GALL et al. 2008) and interrupted a former drainage system resulting in the formation of the shallow and poorly drained Lake Jipe (Fig. 3).

The Pangani graben is bordered by the North Pare horst to the east and the Lelatema Mountains to the west. Farther south, the western escarpment develops gradually into a basement flexural warp of the Massai craton and the Pangani basin becomes an asymmetrical half-graben structure (Fig. 2). The vertical displacement of the tilted blocks along the main fault increases southwards from >1000m in the older North Pare Mountains, 1500m in South Pare and >1500 in the younger Usambara Mountains (LE GALL et al. 2008). The five fault blocks of North, Middle, and South Pare and North and East

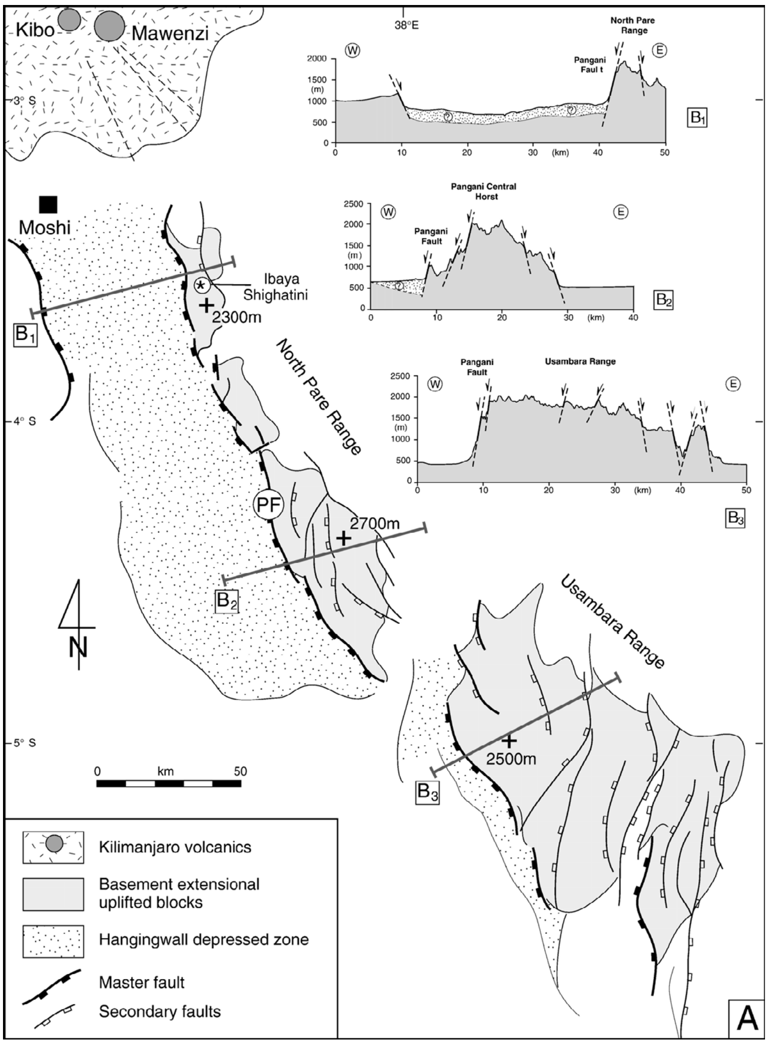

Fig. 2: The Pangani extensional fault range. Structural overview of the asymmetrical Pare-Usambara horst and Pangani half-graben structure. Cross sections of the North Pare (B1), South Pare (B2) and Usambara (B3) mountain ranges (vertical exaggeration x6, Map from LE GALL et al. 2008).

Usambara are asymmetrical horst structures with steep escarpments to the west and a slightly more gentle dip slope to the east. The main fault dips with angles >60° to the west. Recurrent secondary fault lines predominantly in NNW direction characterise the present topography of the mountain range and determined the drainage system such as the Kivisini-Pangaro fault and the Usangi valley in North Pare and the staggered Chome escarpment in South Pare. In addition, east–west oriented wrench faulting caused important topographic breaks such as the Lembeni and Ngulu faults (BAGNALL 1960; BAUERNHOFER et al. 2008b).

2.1.3 Geology of the North Pare Mountains

The North Pare Mountains consist of high-grade metamorphic rocks of an undifferentiated granulite–gneiss complex. The granulites belong to the Usagaran System and are markedly foliated (BAGNALL 1960). The rapid variation of often thin layers of different rock types across the strike does not allow differentiation on a map scale. Even within an outcrop, variation of bedrock is surprisingly high. Overall, BAGNALL (1960, 1962) distinguishes four main metamorphic complexes:

1. Granulites and granulitic gneisses: dominant rocks are pyroxene granulites showing a gneissic structure and often with a minor component of iron ore. Further common rocks are quartz-feldspar granulites and intercalated layers of hornblende granulites and calc-silicate granulites.
2. Associated with granulites and similar in terms of metamorphoses are amphibolites, quartzites, graphitic and biotitic schists and gneisses and meta-calcareous rocks like crystalline limestones and marbles, the latter found on the foothills of the western scarp.
3. Pegmatites occur throughout the area with iron ore as one of their minor components.
4. Migmatites, mainly found at the shear zone of the main fault along the western scarp.

The plains to the east around Lake Jipe and the west (Lake Nyumba ya Mungu, Fig. 3) are covered by a thin layer of Neogene and Quarternary sediments mainly derived from the Pare Mountains as well as dispersed tuffaceous material derived from the eruptions of Mount Kilimanjaro (BAGNALL 1960). Lacustrine sediments in the northern part of the Pangani fault trough indicate a Late Tertiary lake establishment. In 1965, the Nyumba ya Mungu reservoir was established by taking advantage of an exposed gneiss barrier, which might have been part of a former lake basin (DENNY 1978).

2.1.4 Geomorphology

2.1.4.1 North Pare Mountains

The North Pare Mountains rise abruptly from the surrounding lowland plains of the Pangani graben to the west and the Mkomazi/Lake Jipe plains to the east. From the foothills at about 800m a.s.l. the western escarpment rises steeply to about 1600m a.s.l. where more gentle slopes allow cultivation before the final ascend to the forested peaks of Kindoroko (2112m a.s.l.) and Kamwalla (1920 a.s.l.). The high uptilted western mountain ridge contrasts with a plateau-like upland in the central part, and a less pronounced eastern ridge with the Mochame (1600m a.s.l.) and Ngofe (1800m a.s.l.) hills. The Pare upland at intermediate altitudes between 1200m and 1400m a.s.l. is the main settlement and cultivation zone of North Pare and comprises the softly undulating central upland of Mruma, Msangeni and Ugweno as well as the prominent Usangi valley in the south.

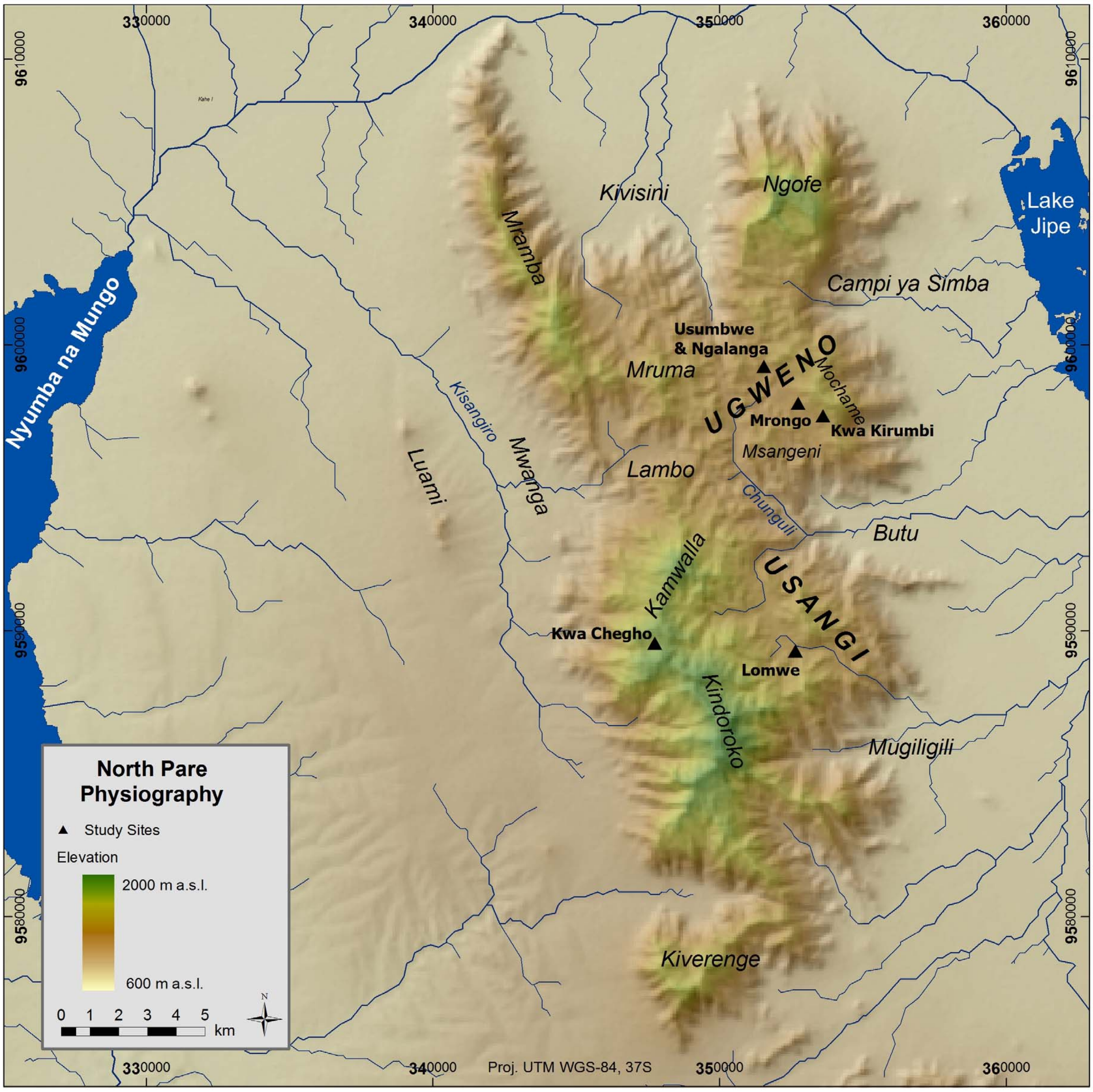

Fig. 3: Physiography of North Pare. Elevation, main mountain ranges, settlement areas and study sites. Digital elevation model based on CGIAR-CSI SRTM, 90m, 2007. Projection UTM-WGS 84, 37S.

The uniform morphology and elevation of the central North Pare upland suggests preservation of an old planation surface by down-faulting within the uplifted mountain block.. Similar down-faulted blocks preserving Cretaceous - Tertiary etchplain surfaces have been reported from the Usambara and South Pare mountains, where residual bauxite deposits have been investigated (MUTAKYAHWA et al. 2003). At North Pare 'plateau ferralitic red earths' are reported by BAGNALL (1962) but the geomorphological and pedological features of an old etchplain have been strongly modified by subsequent denudation. An inherited, ancient landform is supported by morphological evidence of a relictic drainage system oriented along the predominant northwest-southeast fault lines and characterised by interconnected valleys of zero slope. Neither formed nor maintained under the present morphologic and climatic conditions, these valleys are currently reshaped by two different and opposing processes.

During tectonic uplift, the original drainage pattern was disrupted and small streams now occupy oversised and often hanging valleys. Small catchment areas and a low elevation gradient of the streams within the upland plateau result in a low transport capacity. Consequently, entrainment of sediments is reduced and aggradation has resulted in the accumulation of valley deposits. Local seepage has led to the development of valley bottom swamps (e.g. Lomwe and Ngagheni swamp in the Usangi valley and Masumbeni swamp in Ugweno) and shallow interflues within former valley bottoms are frequently observed.

On the other hand, uplift stimulated down-cutting of the few well-watered streams running along zones of structural weakness in predominantly northwest-southeast direction. The deeply incised perennial Chunguli River and the northwards draining streams Molo/Kivisini and Shimbomu have captured most of Ugweno's streams and drain large parts of the upland All other independent watercourses run along almost flat, hanging valleys and pour down the steep slopes of the escarpment.

The pattern of undulating hills and swampy, infilled valley bottoms broadly resembles the geomorphology of the 'bas-fonds de regions humides' (RAUNET 1985) or more specifically the *marais* of the rolling hill country of Rwanda (GRUNERT et al. 2004; KERSTING 2010). Despite their small size, particular location and a much more intensive erosion regime, the undulating plateau-like upland preserved in central North Pare can be considered as bas-fond or 'tropical valley bottoms' *sensu* RAUNET (1985) reflecting the 'elementary drainage system' of 'ferralitised' planation surfaces.

2.1.4.2 Footslopes and pediments

The lower slopes of the Pare Mountains are broken up by step faults resulting in a discontinuous chain of lower foothills. Their footslopes gradually merge into pediments. Along the northern and eastern flanks, the footslope pediments are interconnected and extend into the four structural conditioned tectonic creeks of Kivisini, Kambi ya Simba, Butu and Mugiligil/Muvraini. The pediments are homogeneous and dip gently down to the Lake Jipe depression, a former river valley blocked by the development of Mount Kilimanjaro. Although streams flow year-round in the Pare highlands, they run dry along the slope and water only reaches the plains during the rainy season. Where the seasonal rivers seep away the accumulation of alluvial clay leads to the formation of dark clay soils. The shallow depressions are called *mbugas* (Kiswahili) and are more commonly known as dambos. These seasonally waterlogged, small channelless valleys are generally associated with granitic or metamorphic bedrock of the gently undulating plains of the post-African planation surfaces (MÄCKEL 1974; ACRES et al. 1985; RAUNET 1985).

The western foothills present a different situation. Here low, parallel ridges separate shallow, sediment-filled depressions. Soil erosion on the interfluves has exposed the weathered bedrock and recent gully erosion in the shallow valleys has created a network of gullies and up to 3m deep ravines. The seasonal streams are captured by the Kisangiro channel running north along the dominant step fault separating the small Luami hill from the North Pare mountain block. Between 2 and 10m of alluvial and colluvial deposits show that the Kisangiro depression has acted as an efficient trap for sediments transported by streams from the mountain block and the eroded footslopes of North Pare.

2.2 Climate

East African climate is one of the most complex meteorological systems on the African continent due to the interaction of three air masses leading to two distinct convergence zones. This large-scale pattern is modified by regional conditions including topography and large lakes resulting in a mosaic of local climates. The most conspicuous aspect of the present day East African climate is its azonal aridity, which has prompted many climatological investigations (FLOHN 1964; NICHOLSON & FLOHN 1980; NICHOLSON 2000; HASTENRATH 2001; HASTENRATH & LAMB 2004; HASTENRATH 2007).

2.2.1 East African climate patterns

Three main air masses control the East African climate: the south-western monsoon (boreal summer), the north-western monsoon (boreal winter) and the Congo Air with westerly flow (Fig. 4). The Congo Air originates from the high-pressure cell over the southern Atlantic and is the moisture source for the tropical forests of the central African lowlands. Thermally unstable it brings convective and orographic rains to the north-western part of East Africa. The elevated highlands of the Western Rift in Rwanda, Burundi, Uganda receive the bulk of this precipitation and act as a barrier for the Central Rift and the eastern lowland areas (NICHOLSON 1996).

The air masses of the north-western monsoon are predominantly dry as they originate from the high-pressure cells over the dry deserts of northeast Africa and Arabia. The south-western monsoon brings moist air masses from the high over the southwest Indian Ocean, but does not result in a pronounced rainy season during boreal summer. Both of the monsoon systems are thermally and dynamically stable (FLOHN 1964; HAMILTON 1982; NICHOLSON 1996). The stability of these air masses results from flow divergence and related subsidence as a consequence of a) increasing meridian area at the Equator; b) near parallel air flow along the East African coast and consequent friction stress and flow divergence along the land sea boundary; c) flow diversion to the Ethiopian trough in boreal summer; and d) subsidence due to cooling over cold upwelling bottom waters along the Kenyan and Somali coasts induced by the equatorial westerlies. The resulting thermal stability and general subsidence of air masses prevent rainfall during the summer and winter monsoon periods. Consequently, rainfall in most of East Africa is restricted to the transition period between the two monsoon phases when maximum solar insolation during the overhead passage of the sun promotes convectional rainfall. The interplay between the north-south migration of the Intertropical Convergence Zone (ITCZ) and the monsoons leads to a bimodal precipitation pattern with "Long Rains" (*Masika* in Kiswahili) occurring in boreal spring (April/May) and "Short Rains" (*Vule*) in November/December.

The "Long Rains" are more reliable and abundant, whereas the "Short Rains" are highly variable and sensitive to circulation anomalies, which have been responsible for heavy rainfalls resulting in disastrous 20th-century floods in e.g. 1961, 1994, and 1997 (NICHOLSON 2000; HASTENRATH 2007). Anomalous high precipitation events like the extreme event of 1961 are believed to influence lake levels for several subsequent years (HASTENRATH 2007). The intensity of the East African "Short Rains" are tightly correlated with the velocity of the equatorial westerlies, which establish ephemerally during the monsoonal transition phases as part of the equatorial zonal circulation cell (Walker circulation) over the Indian Ocean (Fig. 5) (HASTENRATH 2007). A stronger circulation cell leads to upwelling, lower sea surface temperatures, and subsiding airflow over the western Indian Ocean and hence dry conditions over most of East Africa, whereas the Indonesian region experiences rainfall. The establishment of equatorial westerlies is subdued in years of a strong southwest monsoon. A weaker circulation cell results in higher sea surface temperatures, enhancement of the tropical low pressure trough and hence strong convective rainfall.

This vertical circulation cell over the Indian Ocean is part of the global Walker circulation and therefore shows strong teleconnections to the El Niño - Southern Oscillation phenomenon (ENSO) as the pressure differences over the Pacific Ocean are transmitted through strengthening and weakening of the equatorial zonal circulation cells. During the 20th century, high precipitation and therefore higher lake levels in East Africa are correlated with strong tradewinds and weak equatorial westerlies. Thus, precipitation in East Africa tends to increase in ENSO years (weak Walker circulation) and is suppressed in the following La Niña years and follows cycles of about 5 - 6 years - similar to the ENSO phenomenon (NICHOLSON 1996). An independent Indian Ocean Dipole was proposed by SAJI et al. (1999). Parting from the catastrophic rains of 1961 in East Africa he analysed sea surface temperatures variation in the west and east Indian Ocean and suggested an independent Indian Ocean seesaw controlling South Asian and East African climate and precipitation patterns during weak or absent El Niño events (SAJI et al. 1999; YAMAGATA et al. 2003).

The local and regional climate patterns in East Africa are spatially complex due to diverse topographies, mountain ranges and the great lake bodies modifying the regional precipitation pattern. The large water bodies of the great Rift Lakes act as effective buffers and create a regional microclimate by recycling immense amounts of water. Rainfall maxima are generally associated with highland areas and mountains as a result of orographic precipitation, whereas regions in the rain shadow of mountain ranges are comparably dry. This leads to a heterogeneous precipitation and vegetation distribution and explains the exceptional dry conditions of the Tanzanian interior as well as the local variation in rainfall on the foothills of the Pare Mountains. The combination of fluctuating general circulation parameters and regional and local modifications result in the general precipitation patterns in East Africa being highly variable in space and time (NICHOLSON 1996).

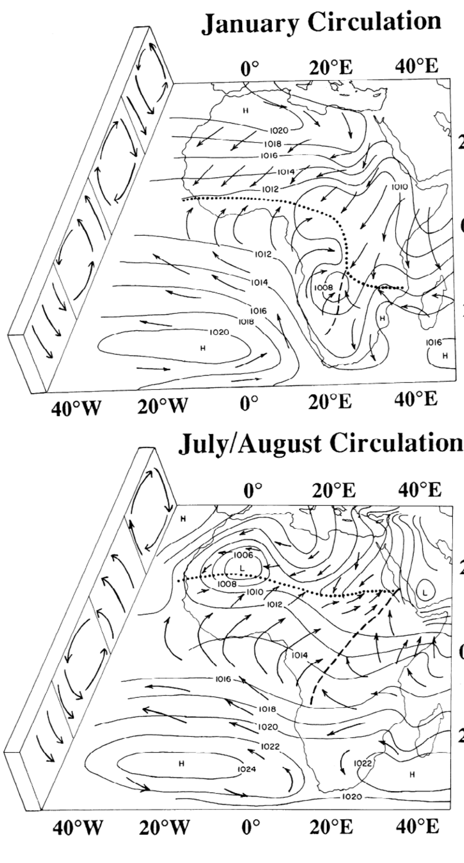

Fig. 4: Overview of the general circulation patterns over Africa. Dominant winds, pressure and important convergence zones are outlined: ITCZ (dotted) and Congo Air boundary (dashed) (from NICHOLSON 1996)

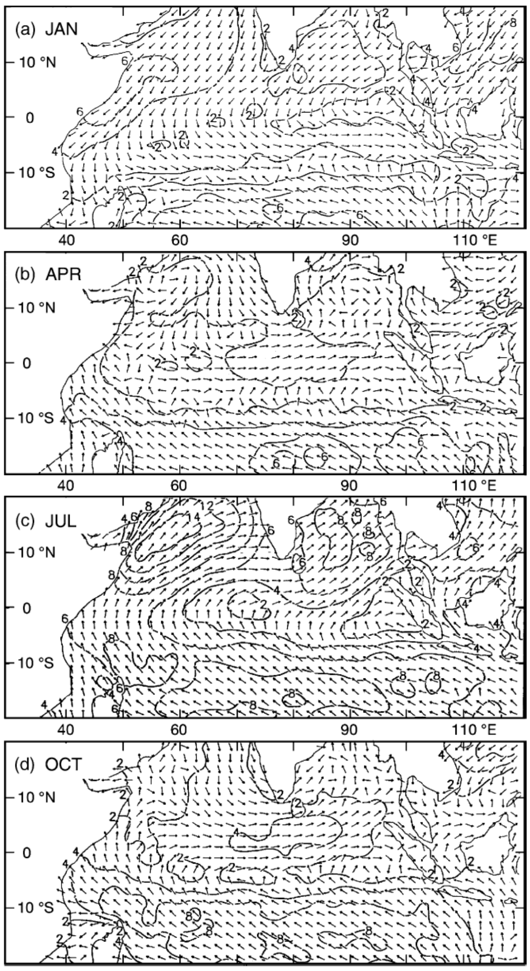

Fig. 5: Surface wind field over the Indian Ocean a) January, b) April, c) July and d) October. Taken from (from HASTENRATH 2007)

2.2.2 Precipitation records of North Pare

The climate of North Pare has been classified as a C_{wa} climate following the Köppen climate classification (KOTTEK et al. 2006). It is a warm temperate climate (T_{min} -3 - +18°C) (C) with dry winter (w) and maximum temperatures > 22°C (a). Annual rainfall varies with altitude and averages between 1100 and 1300mm in the mid-elevation highlands of North Pare (Fig. 6). The lowland plains receive much less rainfall and are hot (T_{annual} > +18°C, h) climates of arid steppes (BS climate). Mean annual precipitation of the stations at Voi and Same range between 500 and 600mm whereas the Pare foothills receive slightly higher rainfall amounts. The bimodal rainfall pattern is pronounced with similar amounts of rainfall during the short and long rains. Inter-annual rainfall variation is slightly higher for the short rains than for the long rains. Coefficient of variation of the short rains is 51% for the highland stations and 60% and 82% for Voi and Mwanga, respectively. Higher variability of the short rains is a pattern observed in East Africa in general, although MCWILLIAM & PACKER (1999) mentions higher variability of Late Rains observed for the Mkomazi reserve, east of the Pare Mountains. Evapotranspiration is estimated to similar amounts of 1450mm for the Mkomazi reserve (MCWILLIAM & PACKER 1999) and 1550mm for Amani (910m a.s.l.) in the Usambara mountains (HAMILTON 1989c). The resulting annual water balance (P/ET_{pot} ratios 0.5 - 1) indicate subhumid conditions for the mid-altitude Pare highland, whereas the mountain peaks are humid due to lower temperatures and higher precipitation. Further, occult or horizontal precipitation by dew and fog drip is of importance in the upper montane forest environments (HAMILTON 1989c). The reduction of montane forest cover and hence reduction of additional occult precipitation might have contributed significantly to the decreasing water budget of Kilimanjaro (HEMP 2005, 2009).

The local microclimate of different Pare slopes is strongly influenced by rain shadow locations, which is important to understand the local vegetation distribution. The local climate variability and the altitudinal variation of rainfall and temperature control the present distribution of taxa and vegetation zones on the Eastern Arc.

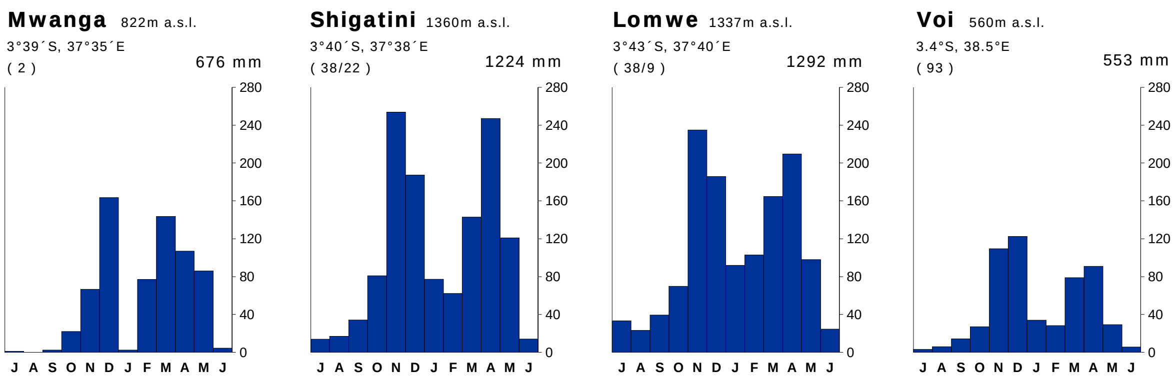

Fig. 6: Annual precipitation distributions for selected North Pare weather stations along an east-west transect. Lowland precipitation is shown by Voi, (Taveta, Kenya) and Mwanga. Lomwe and Shigatini are representative for the mid-altitude highland plateau of North Pare. Note the short observation span at Mwanga (1993-95), and incomplete annual records for Shigatini (1949-89) and Lomwe (1952-89). Data sources: Records for Shigatini, Lomwe and Mwanga were collected by Michael Sheridan from school archives and from TFAP Mwanga and are shown with his kind permission. Data for Voi was obtained from GHCN-monthly 2 (http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly).

2.3 **Vegetation**

2.3.1 Eastern Arc Mountains as a biodiversity hotspot

The Eastern Arc Mountains are well known for their ecological diversity and are classed as a so called "biodiversity hotspot" (MITTERMEIER et al. 1998; MYERS et al. 2000). A high proportion of endemic species compared not only to the young volcanic mountains of Mt Kilimanjaro and Mt Kenya, but on a world-wide scale are the reasons for the importance of this centre of endemism (LOVETT 1989; LOVETT 1998; BURGESS et al. 2007). From the number of possible explanations brought forward to explain the exceptionally high rates of endemism in the Eastern Arc Mountains, the two most important focus on high rates of speciation or reduced rates of extinction (BURGESS et al. 2007). To date, several studies have confirmed elevated *in situ* speciation rates for several plant and vertebrate populations, but the principal argument is based on the assumption that ecological stability has fostered the persistence of forest species in the Eastern Arc Mountains (LOVETT 1989, 1993a, b; BURGESS et al. 2007). Despite the fact that until to date there is no environmental evidence for long-term stability of the Eastern Arc Mountain environment, indirect evidence suggests persistent habitat conditions over long time spans. High numbers of genetically ancient taxa, the presence of taxonomic 'primitive' groups and the comparably low rates of endemism on the neighbouring volcanic mountains are the most important phylogenetic evidence for ecological stability (BURGESS et al. 2007).

The postulation of ecological long-term stability of the Eastern Arc Mountain forest environments emerges from the special circumstances of their phytogeographical and geological history but also relies on the assumption of climatic stability. Advection of moist air by the Indian Ocean Monsoon has been proposed to have been a constant and secure humidity supply for the elevated mountain environments and to have buffered the moist forests of the Eastern Arc Mountains during aridity phases (LOVETT 1993a; BURGESS et al. 2007; MARCHANT et al. 2007). The constant rainfall supply and the possibility of vertical movement during cold and warm periods facilitated the forest environment to persist in the mountain refugia. Recent palaeoecological studies have shown that the Eastern Arc Mountains indeed acted as refugia for montane forest taxa during the most recent aridity period of the Last Glacial Maximum, when western, central and east African forests contracted (MUMBI et al. 2008; FINCH et al. 2009).

A close phytogeographic relationship between the flora of the Usambaras and the highlands of West Africa backs the theory of a former connection between the mountain islands of East and West Africa and an late Cretaceous or early Palaeogene ancient pan-African forest (IVERSEN 1991). The separation is probably linked to the development of the East African rift system which also caused the uplift of the modern Eastern Arc Mountain blocks (GRIFFITHS 1993). At this time the Indian Ocean Monsoon must have been in place and it is assumed that the monsoon system prevailed even during the Quaternary climate fluctuations providing a constant moisture source for the Eastern Arc forest environments (LOVETT 1993a; BURGESS et al. 2007). Temporary links with the central African forests and expansion of lowland forest in East Africa during wet periods of the Quaternary discussed and proposed by MOREAU (1933) and LOVETT (1993a), however, warrant further research.

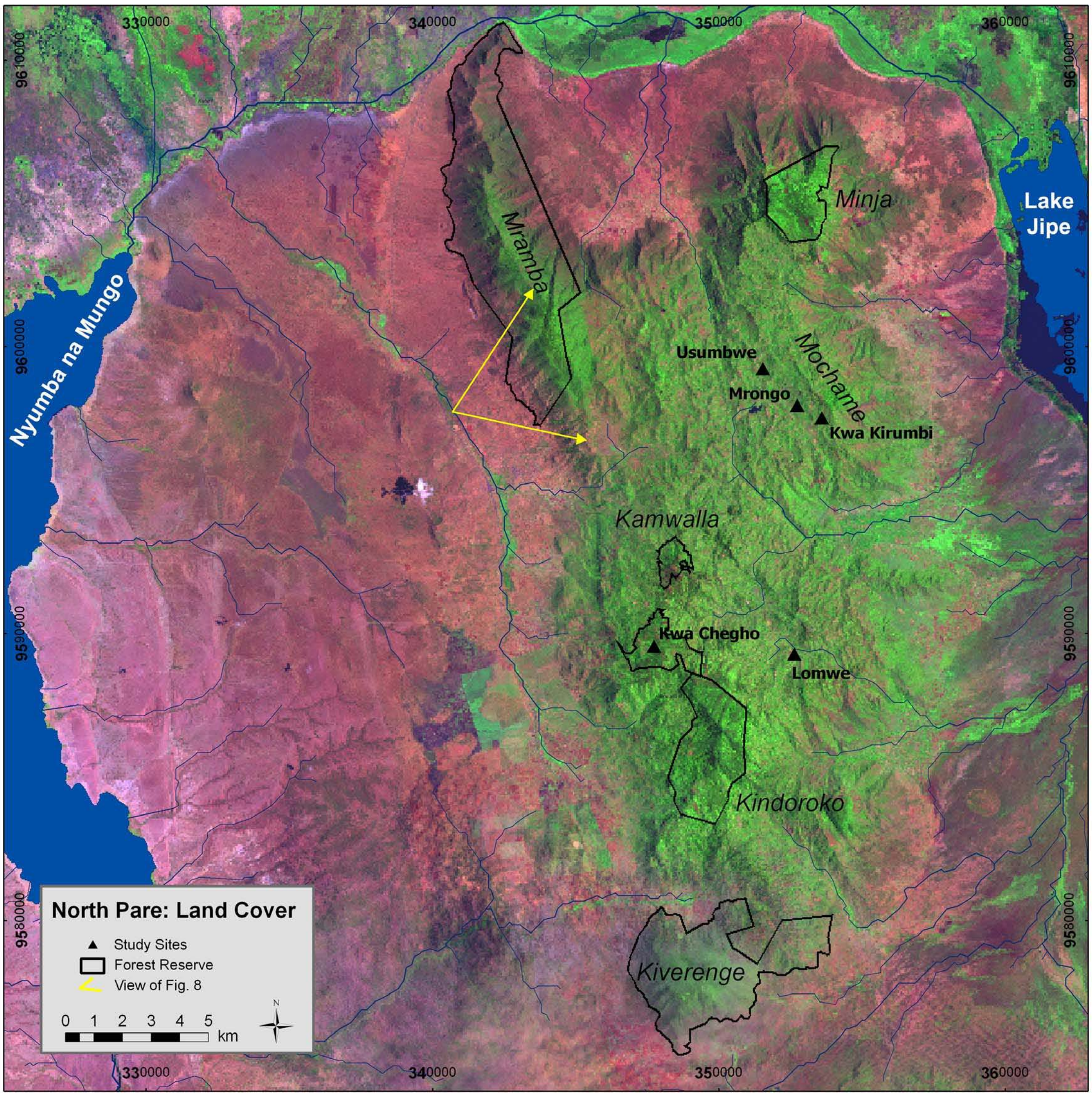

Fig. 7: Vegetation cover and forest reserves of North Pare. False colour Landsat ETM satellite image (03.04.2001, Bands 5/2/4). Green colours indicate dense vegetation cover; shades of red reflect degrees of soil exposure. Projection UTM-WGS 84, 37S.

Fig. 8: Forest remnants on the Mramba Ridge and secondary vegetation along the North Pare foothills. The sharp transition between submontane forest on the ridge and secondary vegetation on the slope is probably fire induced.

2.3.2 Flora of the North Pare Mountains

North Pare is one of the floristically most impoverished of the thirteen Eastern Arc Mountains (BURGESS et al. 2007; HALL et al. 2009). The low diversity is probably the result of the small size of the remaining indigenous forest fragments. Of the 454 km² of the mountain block only about 25-27 km² are still covered by forest (BURGESS et al. 2007). Five government forest reserves Mramba (3355 ha), Minja (520 ha), Kindoroko (885 ha), Kamwalla (293 ha) and Kiverenge (2155 ha) totalling about 72 km² (LOVETT & PÓCS 1993) and between 276 and 285 traditionally protected forests or sacred sites with a total between 370 and 391 ha have been reported (Tab. 1, Fig. 7). Within the agricultural mid-altitudinal zone traditionally protected forest fragments are the only remaining forests and play a crucial role as stepping stones and corridors for the preservation of biodiversity (MWIHOMEKE et al. 1998; YLHÄISI 2004; EAMCEF 2009).

The Eastern Arc Mountains have been subject to botanic research for more than a century and vegetation studies have been published since the early colonial period (c.f. ENGLER 1910; GREENWAY 1973; LIND & MORRISON 1974; WHITE 1983; IVERSEN 1991). Information about North Pare vegetation is primarily based on two reports, WARDELL (1991) and LOVETT & PÓCS (1993), commissioned by the Tanzanian Forest Division and non-government organisation, during the process of gazetting forest reserves in North Pare. Although no clear vegetation belts have been observed in the Usambara Mountains (LOVETT 1996; LOVETT 1998) in contrast to other tropical mountain areas (GENTRY 1988; HEMP 2006a), the floristic descriptions are conveniently divided into lowland, submontane and montane forest communities (IVERSEN 1991; LOVETT 1993b; LOVETT & PÓCS 1993; HAMILTON 1998).

Generally, the vegetation type of the north-east Tanzania lowland plains falls within the *Acacia-Commiphora* deciduous bushland and thickets (WHITE 1983) or deciduous woodland and deciduous bushland (GREENWAY 1973). The eastern plains between North Pare and Lake Jipe are part of the savannah formation covering the Tsavo National Park in Kenya and the Mkomazi Game Reserve and are described in detail by COE et al. (1999). Following the descriptions of lowland savannah vegetation (c.f. GREENWAY 1973; LIND & MORRISON 1974; WHITE 1983; LOVETT & PÓCS 1993; COE et al. 1999) the most common taxa are *Acacia*, *Commiphora*, *Grewia*, *Dobera*, *Euphorbia*, *Lannea*, *Salvadora persica*, *Terminalia*, shrubs like *Capparis*, *Combretum* as well as herbs of the Amaranthaceae family (e.g. *Sericocomopsis*), and Malvaceae (e.g. *Sida cuneifolia*) *Sansevieria* as well as grasses (e.g. *Sporobolus*, *Eragrostis*, *Aristida*, *Panicum*, *Chloris*, *Cynodon*).

The uncultivated lower and mid-slopes of the escarpments are covered by secondary, semi-deciduous open woodland and with grass undergrowth, which is extensively used for grazing and firewood collection. This generally secondary bush- and woodland vegetation is likely maintained by frequent fires. Sharp fire scars are readily seen such as at the boundary to mature lower montane forest on the top of the Mramba ridge (Fig. 8). Only locally deciduous dry forests dominated by *Commiphora*, *Grewia*, *Combretum* and *Terminalia* and *Ziziphus* remain (HEMP, personal communication, 2011)*(LOVETT & PÓCS 1993)*. On steep slopes between 1200 – 1400m a.s.l., the woodland is replaced by treeless grassland of unknown origin.

Smooth relief, moderate temperatures and rainfall offer suitable conditions for crop cultivation in the altitudinal range between 1300m and 1700m. This agriculture and settlement zone covers the entire mid-altitude Pare plateau. Today, undisturbed mid- and low-altitude forests are rare and only few descriptions of submontane and lower montane forests exist in the literature. An early account from

GILCHRIST (1952) is cited in LIND & MORRISON (1974) and describes a low altitude forests at elevations around 1200m with about 1200mm of rainfall in the Ulanga district probably on the foothills of the Udzungwa Mountains – an environment possibly comparable with North Pare Mountains. There, a mixed forest of deciduous as well as evergreen taxa is characterised by *Albizia* spp., *Antiarias usambarensis*, *Bombax schumannianum*, *Chlorophora excelsa*, *Newtonia paucijuga*, *Zanha africana*, *Diospyrus mespiliformis*, *Khaya nyasica*, *Pachystela* sp., *Terminalia kilimandscharica*, whereas at higher altitudes *Allanblackia stuhlmanii*, dominated associated with *Bersama*, *Celtis durandii*, *Cephalosphaera usambarensis*, *Tabenaemontana holstii*, *Macaranga kilimnandscharica*, *Parinari excelsa*, *Newtonia buchananii*. This account is important because Gilchrist reports widespread thickets of secondary shrubs and small trees composed of mainly *Agauria salicifolia*, *Albizia* spp., *Apodytes dimidiate*, *Catha edulis*, *Cussonia* spp., *Ilex mitis*, *Kiggeleria* spp., *Maesa lanceolata*, *Myrica salicifolia*, *Nuxia* spp., *Olea* spp., *Crassocephalum mannii*, *Trichocladus ellipticus*, *Vernonia* spp., *Tecomaria shirensis*. He also noted that the first species to invade the area if the secondary vegetation is cleared are semi-woody genera like *Hibiscus*, *Sparrmannia*, *Triumfetta* (Malvaceae) as well as *Maesa lanceolata*.

Today, montane forests only prevail on the summits of the North Pare Mountains, above the agricultural plateau at elevations ranging from 1600 – 2100m a.s.l. Only the large mountain top forests of Kindoroko, Mramba, Ngofe persisted without an explicit traditional protection status. Human interventions at these altitudes is assumed to have remained at a low level of intensity before the 20th century, when pressure on these mountain top woodlands increased as a result of rising demand for land due to population growth and entitlement problems (SHERIDAN 2001).

Following the forest reserve reports by WARDELL (1991) and LOVETT & PÓCS (1993) the most intact montane forests of North Pare, the Kindoroko forest is dominated by *Albizia* spp. and *Newtonia buchananii* accompanied by *Ficalhoa laurifolia*, *Macaranga kilimandscharica*, *Polyscias fulva* and *Syzygium guineense* subsp. *afromontanum* and the smaller trees *Maesa lanceolata*, *Tabernaemontana* sp.. Small patches of secondary heath dominated by *Erica arborea* are common in the Kindoroko as well as the Ngofe forest and are attributed to human impact (LOVETT & PÓCS 1993). The smaller and disturbed Kamwalla forests also harbour *Allophyllus* sp., *Bersama abyssinica*, *Ficus sur*, *Ochna holstii*, *Prunus africana*, *Xymalos monospora* as well as shrubs like *Clutia abyssinica*, *Dodonea viscosae*, *Solanum* sp.

	Number of forest fragments			
Forest Area [ha]	Ugweno	Usangi	Lembeni	North Pare
< 0.25	1	6	16	23
0.25 - <0.5	24	23	8	55
0.5 - <1	30	31	15	76
1 - <5	64	41	16	121
>5	6	2	2	10
Total N° [-]	125	103	57	285
Total Area [ha]	230	109	52	391

Tab. 1: Size distribution of forest fragments in North Pare. The analysis covered listed clan forests and local forests. Afforestation and government forest are not included. The table is based on unpublished data downloaded from http://www.easternarc.or.tz on 28.08.2009 (Compare also MWIHOMEKE et al. 1998 for a summary on traditionally protected forests in North Pare).

2.3.3 Forest fragments and Sacred Groves

Forest patches are scattered throughout the agricultural upland. Most of them are protected by tradition as Sacred Groves and have local religious importance for worship and ritual practices. The small and often disturbed forest fragments generally cover less than a hectare and even stands of a few trees are common (Tab. 1). Many of them are associated with *ndivas* (artificial and natural water sources) or exceptionally natural features such as large rock outcrops. Usually they serve as *mpungis* (burial places), where the skulls of the ancestors of the local lineage are buried and are important locations for sacrifice as well as fertility and rain making ceremonies. In addition to the spiritual aspect, they are used to demonstrate a clan's legitimate land tenure (SHERIDAN 2001:145). Larger forest patches are less frequent and often associated with *mshitu* – clan initiation forests, where young males are introduced into society. These forests are generally located on hilltops (approx. 1500-1600m a.s.l.), and are in the vicinity of settlement and agricultural areas. Having been places of cultural activities for centuries, the *mpungi* and to a lesser extent the larger *mshitu* have undergone a long history of human intervention. It is an open question, however, how far they have retained a potentially 'natural' vegetation composition.

Although no detailed vegetation survey could be carried out within the scope of this project, limited information about taxa present in these Sacred Groves could be gathered. The most important species of the small forest fragments characterised by mature trees at Kwa Kirumbi and Ngalanga are (local names in brackets) *Cordia africana* ('Mringaringa', Boraginaceae), *Albizia gummifera* ('Msanga', Fabaceae), as well as *Chlorophora excelsa* ('Mvule', Euphorbiaceae), *Croton macrostachys* ('Mfirifiri', Euphorbiaceae), and *Ficus* spp. ('Mkuyu', Euphorbiaceae). The local forest guardian Mr. Exaud Gurisha Msuya mentiones further trees using their Kipare names as follows: Mlulu, Mokeanyama, and Mringa/Mringwa/Mringanawo. Although the fragmentary information recorded is not enough for a thorough description, the evidence from these remaining forest patches points to a dense, evergreen (sub)montane forest vegetation with trees up to 20m high. Despite fragmentation and impoverishment, these small forest patches are likely to be remnants of the original submontane forest vegetation of the North Pare highland.

Despite limited precise information on floristic composition and the lack of studies on past forest dynamics in the mid-altitude Eastern Arc Mountains, it has been assumed that the highlands were covered by contiguous forest prior to human intervention (NEWMARK 1998; NEWMARK 2002; HALL et al. 2009). Although small and fragmented, the remaining forest patches of North Pare support this interpretation. The pollen record of a small wetland at Lomwe and stable carbon isotope composition of soil organic matter undertaken during this project may throw light on the question of past forest dynamics (chapter 9.5).

2.4 **Soils**

2.4.1 Soil types and pedogenetic processes

The distribution of soil types within Tanzanian territory is depicted on several general and nation wide soil maps (MORGAN 1961; SAMKI 1977; DE PAUW 1983; ISRIC et al. 2004). Whereas the colonial maps are based on early reconnaissance surveys and generalised field observations, the later FAO map (ISRIC et al. 2004) infers the distribution of soil types generally from geological background data and landscape position. As no detailed ground surveys have been carried out in the study area, the suggested soil types remain tentative. In the following, reference will be made to earlier soil studies mainly from Usambara before discussing the major soil forming processes and the respective reference soil groups for the Pare environments following the World Reference Base for Soil Resources (IUSS WORKING GROUP WRB 2007).

MILNE's (1935, 1937) descriptions of 'red earths' from West Usambara can be taken as representative for upland soils of the Eastern Arc Mountains and North Pare. His 'Usambara fasc of laterised red loams' or 'red earths' are found under original forest vegetation over crystalline basement rocks of mountain areas with high rainfall and moderately high temperatures. These soils are generally over 2m deep, freely drained, have a porous structure, show red-brown to yellow-brown colours, and are readily friable when both dry and wet (MILNE 1937). Iron oxides, most importantly the formation of red haematite (α-Fe_2O_3) under warm and dry climatic conditions in organic matter poor soils is responsible for the strong red colour (rubefication), and the common denomination of 'red earths'.

The organic carbon content of forest topsoils in the Usambaras varies between 2 - 6%, decreasing rapidly to <1% in the subsoils (HAMILTON 1989b). Above elevations about >1200m a.s.l. forest soils are characterised by a folic horizon, an organic layer of accumulated leaves partially decomposed, as mineralization is reduced due to lower temperatures (LUNDGREN 1980). At higher altitudes and on more humid slopes, organic matter rich Umbrisols do occur.

Under a tropical climate regime with high rainfall and moderate to high temperatures chemical weathering processes are advanced. Dissolution of primary minerals by hydrolysis, leaching of cations and incipient desilification have resulted in considerable acidification and topsoil pH values range between 4 – 5 (HAMILTON 1989b; MASUKI & BAKUTI 1994 in Sheridan 2001) but increase about 1 unit in the subsoil (LUNDGREN 1980). Continued percolation of rainwater results in desilification as silica is leached from the solum. The resulting shortage of silica and dominance of aluminium favours the formation of low activity clays like kaolinite, characterised by a low cation-exchange-capacity and a poor nutrient storage capacity as shown by a pilot study of North Pare soils (MASUKI & BAKUTI 1994 in SHERIDAN 2001).

Following LUNDGREN (1980), high altitude soils (~1450m a.s.l.) in West Usambara range from 'humic ferralitic soils' in wetter areas to 'humic ferrisols' and 'humic nitosols' in drier and cooler parts, the latter often under agricultural cultivation. Similarly, HAMILTON (1989b) classifies soils under lowland (250m a.s.l.) and submontane forest (~950m a.s.l.) on the Eastern Usambaras as Rhodic respective Orthic/Xanthic Ferralsols. Finally, the FAO soil map and SOTER database for Tanzania (ISRIC et al. 2004) reports for the upland areas of North and South Pare as well as Usambara a mosaic of mainly Humic Acrisols (25%), Ferric Lixisols (20%), Haplic Nitisols (15%), Rhodic Ferralsols (15%) and Eutric Leptosols (15%).

Although frequently described as 'ferralitic' no ferralsols have been reported from North Pare. Ferrallitisation is characterised by advanced leaching of base cations, prolonged desilification and in consequence the residual accumulation and relative enrichment of aluminium and iron oxides, and the neoformation of silica depleted low activity clays (IUSS WORKING GROUP WRB 2007). Under the present semi-humid conditions, soil formation in upland Pare does not lead to the advanced weathering stage of Ferralsols, which thus must be viewed as relict soils having developed under different environmental conditions. 'High level ferralitic red earths' (BAGNALL et al. 1963) are widespread in the Usambara Mountains and occur localised in South Pare (Shenghena), where uplifted palaeosurfaces of Cretaceous-Tertiary age are conserved (BAGNALL et al. 1963; MUTAKYAHWA et al. 2003). On these old weathered surfaces advanced ferrallitisation (relative and possibly also absolute enrichment of Al- and Fe– Oxides) has resulted in the development of local bauxite deposits, preserved in a morphological shelter location of down-faulted blocks (MUTAKYAHWA et al. 2003). In North Pare, the distribution of 'plateau ferralitic red earths' is locally restricted to small areas >1300m a.s.l. on the Kamwalla, Toni, Ngofe and Kindoroko mountains (BAGNALL 1962) but is not reported from the undulating plateau assumed to be the remnant of a former etchplain. Preservation of old surfaces in North Pare is incomplete and the conservation of relict ferralitic soils is hampered by steep terrain and the rejuvenation of soils by erosion. Hence, neither bauxite occurrence nor pronounced Ferralsols occur in North Pare.

Instead, Acrisols, Nitisols and Cambisols are reported for the slopes of the Pare upland and may have once formed natural toposequences with Ferralsols on the hills and Acrisols on the slopes. The predominant pedological process observed in Pare soils is the translocation of clay minerals from an elluvial topsoil horizon into the subsoil (lessivation/argilluviation) characteristic for Acrisols. The mobilisation of clays is favoured under a seasonally humid climate. Strong rains with electrolyte-poor water facilitate the dispersion of clay particles, whereas desiccation cracks caused by long dry periods facilitate the physical translocation of clay particles into the subsoil.

The literature review suggests a mosaic of Acrisols, Nitisols and locally Cambisols for forests of the Pare upland, whereas Eutric Leptosols or shallow Cambisols cover the steep slopes of the escarpment.

2.4.2 Agricultural soils

Except the steep slopes of the escarpment, most of the upland area of North Pare is under cultivation. The thick organic matter typically found under closed canopy forest cover decomposes rapidly after forest clearance and the humus content of agricultural topsoils is low (<1%). Most agricultural soils are truncated; the original topsoils have been eroded by soil and tillage erosion. Large areas are characterised by exhumed subsoil and widespread exposure of the underlying saprolite are a clear sign of advanced land degradation. A thorough comparison between eroded, agricultural soils and intact forest soils is given in chapter 6.2 & 6.3.

2.5 **Summary**

This chapter has provided an overview of the physical environment of the study area. Tectonic evolution of the Eastern Arc Mountains created ancient mountain environments, which benefit from the reliable advection of moisture from the Indian Ocean. The assumed long-term climatic stability of these semi-humid to humid highlands has been identified as promoting the exceptional biodiversity of the Eastern Arc montane forests. In North Pare, the gentle mid-altitudinal uplands of the uplifted mountain block offer favourable climatic conditions for agriculture and cultivation in a sheltered environment. The semi-humid climate and the iron rich bedrock geology of the Pare Mountains made this location highly suited to human occupation and enabled the spread of specialised subsistence strategies and technologies. Whereas the geology, climate, flora of the Eastern Arc Mountains have received considerable attention, the geomorphological development and its implications for the present condition of the soil resources are inadequately known. Also poorly understood is how the history of human settlement has shaped these resources. The following chapter discusses the importance of general surface processes like soil erosion and slope deposit formation for landscape development in East Africa, with particular reference to North Pare, while Chapter 4 offers an overview of the available evidence concerning the history and pattern of human settlement in the area.

3 SOIL EROSION AND CORRESPONDING TERRESTRIAL ARCHIVES

Like the two faces of a coin, erosion and deposition are intrinsically linked. In the following, a short overview of soil erosion and land degradation research in East Africa is presented to place this research in a broader context. A general discussion of models and concepts of slope deposit development follows. The chapter concludes with a short state of the art overview on terrestrial archives in East Africa in general and Tanzania in particular.

3.1 Landscape, soils and transformations

The term landscape combines geographic as well as cultural notions and is best described visually as the entity of impressions captured by 'a view out of the window'. A landscape is characterised by the occurrence of a typical set of characteristic patterns and structures so called landscape elements, which include topographic landforms, land cover, climatic characteristics, as well as cultural elements. Landscape thus is a patchwork of characteristic mosaics at different spatial scales and integrates physical elements, such as geomorphologic features (mountains, valleys, rock outcrops, pediments, superficial deposits), biotic features (forests, savannah, animals) as well as anthropogenic and cultural elements (terraces, paths, agricultural fields, houses, settlement structure).

From an ecological point of view, landscapes as mosaics of different ecosystems are characterised by fluxes, stores, and transformation of energy and matter between the different landscape compartments. There is a dynamic equilibrium between the different landscape elements maintained by internal reorganisation and transformation processes. Despite their dynamic and resilient character, changes in any of the landscape components or processes might trigger instability. The crossing of a threshold may trigger rapid, irreversible changes and the establishment of a different landscape complex (THOMAS 2001a). It is the sensitivity of a specific landscape to perturbations and its resilience, which controls landscape change and the transition from one stable state to the other.

Soil formation and development is controlled by a number of different parameters such as climate, organisms, relief, parent material and time (JENNY 1941). Early models of soil formation were static and implied that soil development under constant environmental factors will over long time periods lead towards a state of soil maturity (cf. GERRARD 1992). Later models go further and take processes as well as soil forming factors into account. SIMONSON (1978) distinguishes four major actors: additions, removals, translocations and transformations (e.g. addition of water, radiation, organic matter; losses of elements by leaching, water by evapotranspiration or drainage; translocations via clay elluviation, podsolization or nutrient cycling; transformations by weathering, humification or the formation of secondary minerals). These processes do no only act on the soil pedon scale, but are active on a landscape scale. Simonson´s model puts the single pedon into a dynamic spatial relationship with the surrounding soil complex to which it is intrinsically linked by translocations.

The abstract framework of soil formation and the linkage of soil development across different landscape positions by element removal and addition has been accurately described by MILNE (1935, 1936b). His classic catena approach illustrates the spatial differentiation of soil types along a slope gradient as a function of topography and drainage acting through differential translocation of soil material to create a characteristic sequence of soil types (Fig. 9).

Starting on an eroded hillock, the skeletal soil gradual turns into deeply weathered soil on the pediment. Soil erosion maintains shallow Leptosols on ridges and hill slopes (1, Fig. 9), whereas on the pediment mature soils (Lixisols/Luvisols) develop (2). Normal soil erosion during seasonal runoff events transports material slowly downhill. Differential transport takes place along the slope, small particles like clays being transported further than coarser silt and sand. Over time the lateral flux of material into the low lying deposition area results in the differentiation of sediments along the slope the which laterally grades from sand (4) to clay (7). These sediments become the parent material of soils at the respective slope positions. Developing on different parent material, Arenosols develop in the intermediate sandy areas (wash-belt) whereas Vertisol formation occurs in the centre of the depression (seepage belt). The deposition of alluvial clay soils characterises these depressions, locally called *mbuga* (Kiswaheli) or *dambo*.

The soil sequence along the catena is the direct result of material redistribution along the slope. Additionally, differentiation of soils occurs by translocation of chemical compounds such as leaching and consequent precipitation. Advection of dissolved iron or carbonates may result in the formation of calcretes or plinthite, where temporary seepage allows precipitation and oxidation of dissolved elements (3). Consequently, soil formation is not a locally restricted process of the single pedon, but involves pedological, and hydrological processes acting on a landscape scale and linking soils complexes with topography by surface processes such as erosion in turn controlled by vegetation, climate dynamics and land use practices.

3.2 **Hillslope deposits as terrestrial archives**

Surface material mobilised by erosion may be temporarily stored within slope hollows or depressions but finally accumulates in sediment traps at footslope positions and hillslope deposits build up. As corresponding sediments of soil erosion, these slope deposits are terrestrial archives containing not only the relocated slope material, but also information about the nature, the extent, and the timing of past surface processes and landscape dynamics. They have been investigated to determine the chronology and extent of past soil erosion phases and to infer and identify underlying drivers of land degradation such as human land use or climate change (PAYTON et al. 1992; BOTHA 1996; ERIKSSON et al. 2000; DOTTERWEICH et al. ; LANG 2003; FUCHS 2007; ROMMENS et al. 2007; FUCHS & LANG 2009; DREIBRODT et al. 2010b).

The main drivers of Holocene slope instability and erosion are climate dynamics, tectonic activity and human impact. Tectonic movements create the morphological relief conditions and elevation differences - the initial precondition for erosion and material redistribution in the landscape. The assignment of slope deposits to the tectonic trigger however is not unambiguous and generally restricted to active fault systems (FATTAHI et al. 2006; PORAT et al. 2009). Although tectonics are a well-known factor in landscape development, direct evidence for the tectonic causation of slope deposits is difficult to obtain, wherefore most researchers favour climatic or anthropogenic explanations. Nevertheless, tectonic activity is an important factor in the development of sediment traps and wetlands in the active East African rift valley environments and wetland of East Africa (e.g. Loboi Swamp, Kenya, ASHLEY et al. 2004).

Climate-vegetation dynamics are the most persistent and important factors acting upon the soil mantle and reshaping the landscape. Particularly, changing precipitation patterns and imbalances between water supply and the demand of the prevailing vegetation cover have been identified as triggers of soil erosion, slope instability and landscape change (THOMAS & THORP 1996). The time lag between climatic change and the delayed adjustment of the vegetation cover leaves the surfaces temporarily without adequate protection, facilitating erosion and removal of surface soil material until

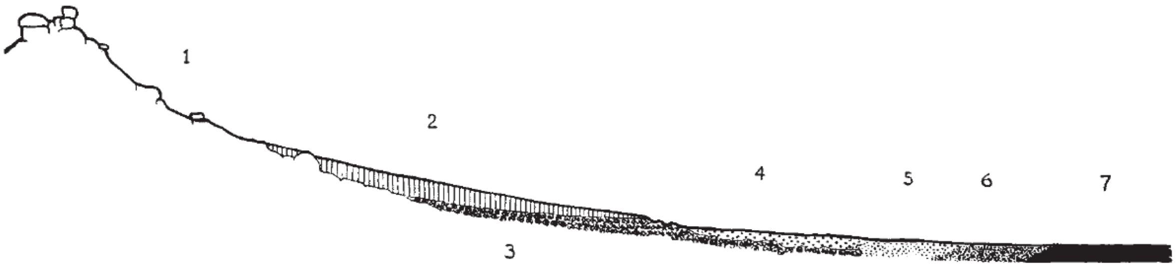

Fig. 9: Catenary succession of soil types along a toposequence according to depositional differentiation of texture along a footslope (from MILNE 1936b). 1. Shallow skeletal grey loam, 2. Red earths, 3. 4. Sand wash belt, 5 & 6 Silty to clayey sand, 7. Clay soil.

vegetation cover and soil mantle have readjusted to the new boundary conditions. In the same way but at different scales, seasonality, rainfall distribution and the magnitude of single precipitation events control soil erosion on shorter, annual time scales. Strong rains on non-vegetated soils after a long dry season will result in soil erosion while the annual water balance may remain constant. Depending on the initial conditions, higher absolute rainfall amounts as well as a shift in the annual precipitation distribution – maybe even coupled with decreasing total precipitation – will have similar effects on slope stability and promote enhanced material mobilisation and erosion. Although a result of comparatively rapid climatic change, scenarios of vegetation change span decades, centuries and millennia allowing time for the slow but continuous process of erosion. Only in particular cases have strong single precipitation events been identified to be responsible for the accumulation of slope deposits of regional occurrence in Central Europe (see BORK 2003; DREIBRODT 2005).

Globally, human land use has emerged as the most important single factor for soil erosion and slope deposit accumulation of the late Holocene. Anthropogenic disturbances of the natural vegetation cover, such as deforestation; land clearing and cultivation create an artificial imbalance between climatic conditions, vegetation and the soil mantle and hence anthropogenic soil erosion. Since the introduction of agriculture, accelerated soil erosion has been widely recognised in Europe by the presence of correlated slope deposits (ZOLITSCHKA et al. 2003; FUCHS 2007; DOTTERWEICH 2008; DREIBRODT et al. 2010a) but also in the Americas (FISHER et al. 2003; BOREJSZA et al. 2008; ARROYO-KALIN 2010), Asia (HUANG et al. 2006) and in Africa (KERSTING 2010). The identification and distinction of climatic and anthropogenic drivers of slope instability is generally based on the tentative temporal correlation between the deposition event and known climate dynamics and settlement phases. Yet, despite the presence of archaeological artefacts or charcoal, the causality often remains tentative as a direct proof of evidence for one or the other causation is rare.

By their nature, slope deposits are incomplete terrestrial archives, which record erosion events of different origins and different magnitude. Furthermore, most terrestrial deposits are only temporary sediment sinks and may be subject to further erosion. Despite these limitations - compared to more continuous records such as lake and swamp sediments – slope deposits represent direct evidence of the impact of slope processes and erosion on landscape development on a regional scale.

3.3 Soil erosion and land degradation

3.3.1 Erosion

Erosion (from Latin "erodere" which means literally "eating away") is the physical removal of soil material by different agents like water, wind, and gravity. The first stage of erosion is the detachment of soil particles from the surface, followed by entrainment and transport of material and finally deposition or sedimentation, when transport conditions cease. The term erosion applies in the first instance to local processes of surface wasting, whereas large-scale lowering of the relief is referred to as denudation.[4]

The most important erosive agent in mountain regions such as North Pare is water and the related processes of sheet, rill and gully erosion. Wind erosion has not been reported to be an important agent in contemporary East African environments. Deflation might be of considerable local importance in sparsely vegetated lowland plains, especially during dry periods without a permanent vegetation cover. Rapid mass movements like landslides, slumps, rockfall or mud flows are the most conspicuous signs of mass wasting and common in mountainous tropical areas (THOMAS 1994). The occurrence of rapid and large mass wasting events is restricted to predestined slopes with favouring geological bedding, subsurface water convergence and is generally triggered by high-magnitude storms (WESTERBERG & CHRISTIANSSON 1999). Although the amount of material relocated by rapid mass movements shows they are major geomorphic agents in landscape development they generally refer to single mass wasting event with a locally restricted distribution.

Small-scale erosional processes on the other hand show a uniform distribution and are more likely to provide information about regional environmental conditions. Slow gravitational processes like soil creep, for example, have strongly shaped the relief of the subhumid regions of Uganda during the early Holocene (MOEYERSONS 1988). These slow erosion processes comprise gravitational soil creep, precipitation induced splash creep and splash erosion, and by the action of flowing water laminar sheet wash. The laminar overland flow soon concentrates in concavities and results in linear erosion processes such as rill erosion eventually leading to the formation of ravines and gullies. Whereas mass wasting by laminar processes might proceed unnoticed, the rapid incision and spread of rills and gullies is the most visible hint of enhanced soil erosion. For agricultural fields in the Uluguru highlands KIMARO (2008) showed that rill erosion contributes about 70% to the total soil loss, whereas interrill erosion accounts for the remaining 30%.

The term 'soil erosion' was originally coined to describe erosion on cultivated land and is used to differentiate anthropogenically induced, accelerated forms of erosion (accelerated mobilisation, transport and deposition) from 'normal' background erosion. With the disappearance of 'virgin', anthropogenically uninfluenced environments, a distinction between normal or natural erosion and anthropogenic accelerated soil erosion has become unfeasible.

Soil erosion in the broader sense also includes tillage erosion. Tillage erosion is the mechanical transport of soil downslope by agricultural tools and gravity (LINDSTROM et al. 1992; VAN OOST et al. 2006). Similar to soil erosion by natural processes, translocation and loss of soil material is highest on convex slopes with high slope angles, whereas accumulation of tilled material occurs in concave

[4] The word pair is used with somehow different connotations in other languages, in the German usage for example erosion refers to linear mass wasting in rills or gullies and contrasts with denudation corresponding to laminar forms of erosion like sheet wash (AHNERT 1999)

hollows. The effects of tillage erosion become visible in a landscape dissected by pronounced field boundaries, which act as barriers and interrupt soil flux along the slope. Loss of material and truncation of soils occurs on the upper end of a field, whereas - given a physical barrier - tilled soil accumulates in colluvial deposits at the lower slope of the cultivated field. A soil bank grows and lynchets develop. Where field boundaries are physical barriers - like contour bands, or hedgerows - tillage results in the formation of progressive terraces (NYSSEN et al. 2000; VAN OOST et al. 2006; BÖRJESON 2007).

Soil and water conservation programs to fight soil erosion and land degradation have been widely promoted; their success however is often ambivalent and critically contested (cf. chapter 10.5). Whereas stories of success state that "rural society is now well on the way to control and reverse the degradation processes" such as the conclusion from an integrated soil conservation program at May Zegzeg in Ethiopia (NYSSEN ET AL. 2009), other scholars take a critical look on development programs concerning soil conservation and land degradation, particularly when the adopted measures are not fully accepted by the local communities (e.g. ÖSTBERG 1986; MBEGU 1996; OGLE 2001; LANE 2009).

3.3.2 Land degradation

Land degradation describes a variety of human-induced processes resulting in the decline of the capability of the land to produce goods and services. (BIOT et al. 1992; BIOT 1995; KINLUND 1996), soil erosion being the most visible and one of the most important processes (PIMENTEL et al. 1995; MONTGOMERY 2007). In general, the term is restricted to human-induced land degradation, the consequence of unsustainable land use such as ressource overexploitation, overgrazing or deforestation. Degradation goes along with a loss of biodiversity and vegetation change and finally results in the loss of soil fertility by processes such as the removal of fertile topsoil by water and wind erosion, the decline of water storage capacity, soil compactation, and siltation as well as chemical degradation such as salinization and the gradual loss of nutrients (DAHLBERG 1994).

Land degradation is a serious threat to agricultural productivity and the wellbeing of societies and has prompted the implementation of soil conservation schemes all over the world. Despite its serious implications, controversial debates exist on the local scale, questioning land degradation itself, the anthropogenic impact, and the causality chain of degradation for specific environments. The evaluation and analysis of land degradation, its severity, extent, and particularly the identification of the responsible causes and mechanisms are complicated by the complex interactions of environmental and climatic factors and the economic, socioeconomic and cultural framework (for examples see JONES 1996; BROCKINGTON & HOMEWOOD 2001; GILLSON et al. 2003; SHOWERS 2005).

Whereas traditional interpretation patterns have stressed the Malthusian theory of population growth triggering overexploitation, this simple explanatory model has been contested by the Boserupean theorem, that population growth stimulates agricultural intensification and the implementation of sophisticated and sustainable cultivation systems (cf. chapter 4.6.1). Similarly, poverty *per se* has been suspected to be a main driver of environmental degradation. However, a number of other important factors control the individual decisions of people such as the socioeconomic framework, land tenure, cultural standards, as well as the fluctuation of prices on the global market (KINLUND 1996).

Discerning human-induced land degradation from environmental dynamics is particularly difficult in semiarid environments, where agriculturally sustainable crop production and the carrying capacity of livestock fluctuate according to the spatial and temporal variability of the climatic conditions. It is in these environments, where ecosystems and in consequence human resource exploitation have to adapt constantly to oscillating water availability and related land cover changes. Distinction between trajectories of natural environmental change and anthropogenic land degradation is a difficult, often impossible task. One approach to bring light into the discussion of the causes of land degradation is to take into account the respective historic trajectories of landscape change (CHRISTIANSSON 1981; LANE 2009, 2010). Being the result of cumulative environmental changes in the past the present environment and the extent of anthropogenic forcing can only be understood when the overall direction of change as well as past responses to disturbance are known. Slope deposits, as archives of past soil erosion, offer the possibility to investigate past and present pulses of slope instability and contribute to the discussion of anthropogenic land degradation.

3.4 **Slope deposits**

The general term 'hillslope deposits' comprises a variety of deposits ranging from sediment blankets on slopes over slope wash and colluvial footslope deposits to talus in the case of coarse boulder-sized debris. Hillslope deposits are ubiquitous in all types of erosional landscapes, although their distinction might be difficult in the absence of clear discontinuities and due to their localised occurrence they are often omitted in pedological and geomorphological surveys (DANIELS 1992). Also named 'hillwash' or (CATT 1986), slope deposits are not necessarily wash sediments but cover sediments deposited by a wide range of transport processes. Mobilised by soil creep, sheet wash, rill erosion or tillage erosion, soil material is transported downslope by gravity or running water and accumulates at the base of slope, where declining slope angles reduce the transport capacity. According to transport distance and agent, sediments range from well-mixed deposits to runoff-sorted slope wash and sands. In mountain areas, deepest slope deposits are found at head slopes, whereas thinner sediment layers occur on linear and nose slopes (DANIELS 1992). The source area has experienced widespread erosion, although locally, concavities may have been infilled by slope sediments. On gentle terrain, slope deposits may grade into alluvium and fan deposits; where material transport is slow, cover layers of transported material may blanket the slopes. A special case in temperate, formerly periglacial regions are so called periglacial layers (ger. *Deckschichten*), formed by gelisolifluidal slope creep of the uppermost soil mantle blanketing extensive areas (see for example VÖLKEL 1995; FRÖHLICH et al. 2005).

Hillslope deposits are widely denominated 'colluvium'. The term 'colluvium' however is ill-defined and connotations differ between scientific communities (KLEBER 2006; FUCHS & LANG 2009)[5]. Usually it describes hillslope deposits resulting from spatially diffuse mass-wasting processes along slopes including gravity and unconcentrated runoff and is frequently used to distinguish between sediments deposited by non-channelised water flow and water lain alluvium, deposited within a confined stream channel (BOTHA et al. 1990a; THOMAS 1994; KLEBER 2006; FUCHS & LANG 2009).

Whereas 'colluvium' or 'hillslope deposit' are generally used to describe locally restricted deposit in the direct vicinity of the source area, the terms 'pedisediment' or 'colluvial apron' are applied to

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[5] In the German speaking academic community, 'Kolluvium' has a special connotation and is defined as a 'deposit created on slopes by running water due to humanly-induced soil erosion' (see KLEBER 2006 for discussion), directly implying anthropogenic causation. As direct evidence for anthropogenic causation is often difficult, this contentious differentiation is only of limited value and colluvium is used in general as the above descriptive term bearing in mind that slope deposits in Central Europe are either periglacial layers, or anthropogenic colluvium.

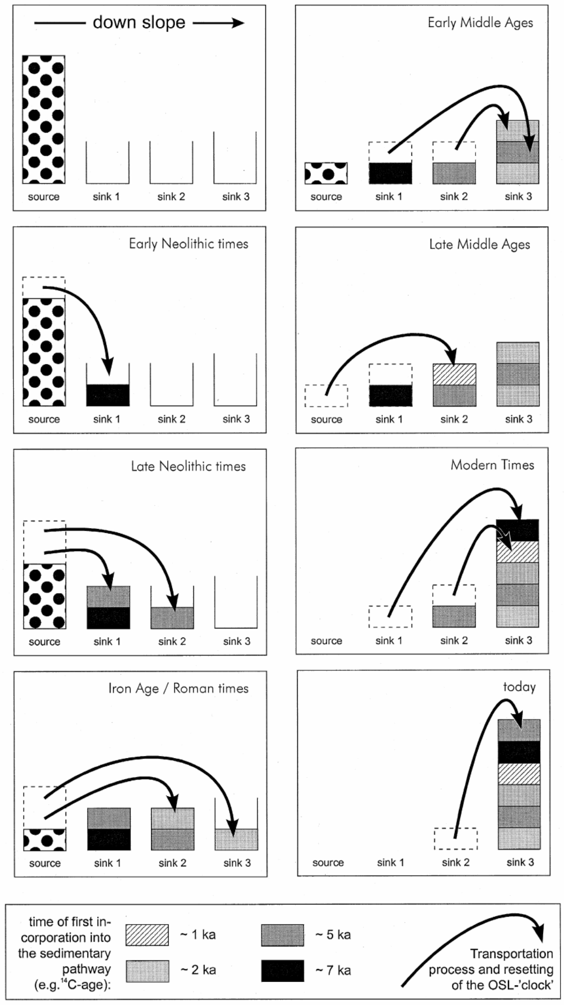


Fig. 10: Cascade model of colluvium formation with temporary storage of material in intermediate reservoirs along the slope. Of fundamental importance is that the sequence of deposition may differ from the sequence of erosion. Material eroded in early times might be stored on the slope and only later be redeposited to finally overlay recently eroded sediments (from LANG & HÖNSCHEIDT 1999).

extensive sediments blanketing pediments in many semiarid areas (THOMAS 1994), such as in South Africa (BOTHA et al. 1990a; BOTHA et al. 1990b; DE VILLIERS 1990; BOTHA 1996; CLARKE et al. 2003), Zambia (THOMAS 2001b), Central Africa (EMBRECHTS & DE DAPPER 1987; RUNGE 2001a, 2008) and Tanzania (SØRENSEN 2001). In South Africa for example, BOTHA (1996) describes pedisediments covering large areas of the Kwa-Zulu Natal region that it seems justified to describe them as formation. In particular, these types of large-scale 'pedisediments' show a high wash component and differential sorting of particle sizes is common (cf. Fig. 9).

In the present study the terms hillslope deposit and colluvium are used synonymously to describe well-mixed, heterogeneous sediments within small-sized upland valleys, deposited directly downslope of the source area. Transport processes comprise in the first instance unconcentrated runoff, gravity and tillage erosion. Due to these processes and the short transport distances, no sorting has taken place. Although the driver of erosion is most likely human land use, the denomination 'colluvium' as used here is not intended to restrict its possible causation solely to humanly-driven mechanisms.

3.4.1 Sediment Cascades

Sediment transport is a stepwise process and depending on erosion strength sediments are relocated along the slope, deposited in sediment traps or conveyed into the streams and transported out of the catchment. Transported material might be temporarily stored behind barriers or within buffers such as slope hollows, hillslope deposits, alluvial fans and floodplains or bedrock steps or may be prevented from mobilisation by a blanketing deposit (FRYIRS et al. 2007). Minor breaks in slope and small hollows or depressions represent sediment traps, which allow large amounts of eroded material to accumulate. Transport of material, temporarily stored within these intermediate sediment traps, is resumed either because continued erosion altered the slope morphology and protection due to a hollow position is no longer provided, or erosion pattern and strength changed as a result of altered climatic boundary conditions or human impacts.

The consequences of the discontinuous transport processes on the soil erosion record and the slope deposit development has been described by LANG & HÖNSCHEIDT (1999) as a cascade model of colluvium formation (Fig. 10). Considerable discrepancies between deposition ages obtained by OSL dating and radiocarbon dates of colluvial charcoal pointed to the deposition of reworked material. Therefore, the slope deposits are not only built up of material mobilised during different erosion phases, but most importantly, the sequence of deposition recorded in the sediment trap does not necessarily reflect the sequence of erosion. Material initially eroded in an early erosion stage might be temporarily stored in hollows along the slope, while material mobilised during later erosion events is transported and stored on the footslope. Subsequent remobilisation of the temporarily stored material will then lead to a partly inverted palaeorecord. On the other hand, a heavy runoff event may be strong enough to carry material through the system and so create a hiatus in the investigated sediment trap.

Incomplete sediment records, the possibility of deposit inversion, and dating problems related to the deposition processes are the main difficulties in the investigation of colluvial slope deposits (LANG & HÖNSCHEIDT 1999; FUCHS & LANG 2009). On the other hand, material stored in these sediment traps has only been transported over short distances and maintains most of its original characteristics. Additionally, the small source area enables identification of the transport processes and allows a qualitative guess about the possible causes triggering soil erosion phases (FUCHS & LANG 2009).

3.4.2 Erosion cycles and periodicity of landscape instability

As individual erosion events, landscape development is characterised by alternating phases of stability (*biostasy*) interrupted by instability phases (*rhexistasy*) (THOMAS 1994; THOMAS 2001a). Several studies, especially from semiarid areas with large-scale colluvial aprons, have shown repeated phases of colluviation interrupted by stability periods and soil formation (BUTLER 1959; BUTLER 1982; BOTHA et al. 1990a; THOMAS 1994; BOTHA 1996; ERIKSSON et al. 2000). In the same way as the transport of single particles is a stepwise process and mobilisation and deposition alternate as functions of erosion strength, the formation of slope deposits is controlled by long-term climate dynamics, modified by the prevailing vegetation cover and overprinted by tectonic activity pulses. When conditions are stable, climate, vegetation and landscape morphology reach an equilibrium state and soil development may proceed uninterrupted. Disruption of the equilibrium by external forces such as climatic change, tectonic activity or anthropogenic disturbance, forces the environmental system and its processes such as material redistribution to adjust to altered boundaries. A direct evidence of surface stability are buried palaeosoils, which mirror a prolonged time of soil development (RETALLACK 2001), whereas

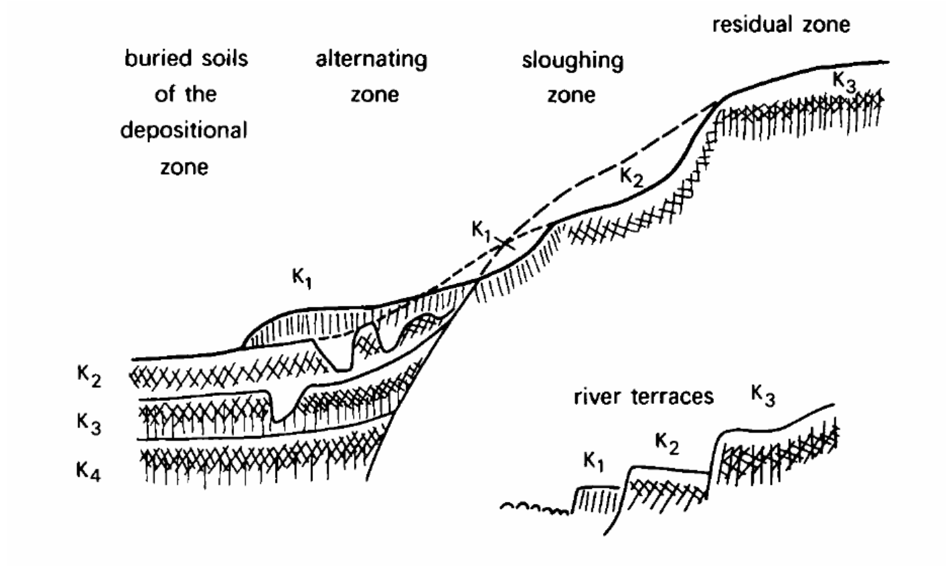


Fig. 11: κ-*cycle* concept of BUTLER (1959; 1982). Periods of land surface stability are characterised by soil formation, whereas repeated erosion phases create temporal ground surfaces. These may be destroyed or preserved during subsequent soil cycles

activity phases may destroy - or bury and preserve - parts of the former land surface. An instability period is thus represented as truncation unconformity, hiatus or by sediments of the corresponding erosion processes. To describe consecutive cycles of land surface creation by erosion and deposition and surface stability allowing soil development, BUTLER (1959) introduced the term soil cycles or with regard to the time component κ-*cycles* (*khronos*). Each κ-*cycle* covers an instability phase of groundsurface reshaping by destruction via erosion or creation by deposition and a consecutive stability phase of soil development (Fig. 11). According to the predominant transport processes, BUTLER (1959) distinguishes a sequence of landscape compartments: The residual zone, where a relict soils persists on a present groundsurface, the sloughing zone, characterised by material removal and the destruction of former groundsurface by erosion, the transportation zone, where erosion and deposition may alternate or take place simultaneously, and finally, the zone of accretion and accumulation, where the soils of former groundsurface are buried and preserved under colluvial material.

The κ-*cycle* concept is a useful model to describe strong, discontinuous erosion events and prolonged stability phases but the application of this concept becomes difficult when stability periods are too short for pronounced soil formation or when equilibrium phases are not synchronous on a regional scale. Ecosystems with slow but continuous erosion and the formation of accretionary soils as well as selective erosion processes may limit the application of the κ-*cycle* concept on a local scale (CATT 1986). Closely related to Butler's κ-*cycle* concept, are a number of later attempts to describe the three dimensional extent of buried soils. The terms 'geosol' (MORRISON 1978), 'pedoderm' (BREWER et al. 1970; WALKER et al. 1984; RETALLACK 1998) and 'groundsurface' (BUTLER 1959; BUTLER 1982) are often used synonymously although their original definitions differ slightly (cf. CATT 1986; BOTHA et al. 1990b). Whereas 'groundsurface' refers to sediments and soils of a specific time interval, 'geosol' and 'pedoderm' are generally used as soil stratigraphic units and commonly describe a whole soilscape with locally varying soil types. Despite the number of denominations CATT (1986) and RETALLACK (1998) admit that the careful use of the terms 'soil' and 'land surface' should be sufficient to describe buried soils and land surfaces together with their stratigraphic and catenary relationships.

The formation of extensive pedisediments is likely linked to the cyclicity of long-term climatic dynamics or sporadic tectonic activity. Although ice-, ocean- and lake-cores have allowed the reconstruction of African climate dynamics over much of the Quaternary (GASSE 2000; GASSE 2006; GASSE et al. 2008), the fragmentary terrestrial record and problematic dating control has so far hampered the establishment of a chronology of morphological change in the tropics (THOMAS & THORP 1995; THOMAS 2000).

Some insights can be gained from regional studies, however. For instance, a series of studies have investigated hillslope deposits on the South African Highveld in KwaZulu-Natal (BOTHA et al. 1990a; BOTHA et al. 1990b; BOTHA et al. 1994; BOTHA 1996; CLARKE et al. 2003; TOOTH et al. 2004; TEMME et al. 2008). Widespread slope deposits (the so called Matsocheni formation) cover waste areas of KwaZulu-Natal and is dissected by numerous gullies. A focus of the work undertaken by BOTHA (BOTHA et al. 1990a; BOTHA et al. 1994; BOTHA & FEDOROFF 1995) has been the stratigraphic subdivision of the Masotcheni formation with the add of intercalated palaeosols indicating stability phases and the deposition of distinct colluvial deposits. The slope deposits are homogeneous from a lithostratigraphic point of view and breaks in sedimentation are only seen by buried soils or stone lines representing marked stability phases. BOTHA (1990a; 1996) showed that the Highveld landscape has been formed by repeated cycles of erosion and stability. The age of these Late Pleistocene colluvial deposits range from 100 ka BP to the Holocene (CLARKE et al. 2003; TEMME et al. 2008). CLARKE et al. (2003) linked the colluviation and correspondent erosion to arid periods as reflected by the rainfall record of the Pretoria Salt Pan (PARTRIDGE et al. 1997), whereas formation of palaeosols took place during periods of higher precipitation and a denser vegetation cover. The most important erosion phases are dated to before 100 ka BP, around 55 ka BP, during the LGM around 22 ka BP and in the Holocene since 13 ka BP (CLARKE et al. 2003; TEMME et al. 2008).

3.5 Landscape change in Eastern Africa

Hillslope deposits have been investigated widely in Central Europe (DOTTERWEICH et al. 2002; BORK 2003; LANG 2003; ROMMENS et al. 2007; DOTTERWEICH 2008; FUCHS & LANG 2009; DREIBRODT et al. 2010b; DREIBRODT et al. 2010a) and the Mediterranean (BUTZER 2005; FUCHS 2007), where they generally are interpreted as evidence for human-induced erosion and landscape change. Elsewhere natural processes like climate dynamics have been identified as drivers of colluviation and human impact plays a secondary role (THOMAS 2001b; CLARKE et al. 2003; DE OLIVEIRA et al. 2008a; DE OLIVEIRA et al. 2008b; TEMME et al. 2008). In Africa, slope deposits have been subject to investigation since early geographical reconnaissance studies e.g. by MILNE (1936b, 1947), however due to the difficulty of accurate dating and the local variance of terrestrial archives, environmental and palaeoclimatic reconstruction so far have focused mainly on lake, swamp and ice core records.

Hillsope deposits investigated in the semi-humid to semi-arid highland areas of tropical East Africa date – with a few exceptions (RUNGE 2001a; SØRENSEN 2001; THOMAS 2001b) – to the Holocene and in the majority of studies anthropogenic causes are suggested (MÄCKEL 1992; ERIKSSON et al. 2000; KERSTING 2010). Valley infills and slope deposits of the Rwandan and Ugandan highlands are the best studied. Here, a rolling hill landscape has developed on an uplifted etchplain of the African surface, characterised by bas-fonds, tropical valley bottoms assumed to have resulted from dambo destruction by channel incision and valley widening (RAUNET 1985; KERSTING 2010). Hills of convex morphology (demi-orange) alter with bas-fonds, flat tropical valley bottoms, which act as sediment traps and only recently experience dissection by active gullying. Detailed research on slope forming processes, soil erosion, deep-seated slope creep and landslides has been carried out by MOEYERSONS (1991, 2001, 2003) on the Butare plateau in Rwanda. Creep lobes frequently overlie gravel layer of possibly LGM age suggestive of valley widening by incision and erosion (MOEYERSONS 2001). The creep lobes, led MOEYERSONS (2001) to propose that deep-seated long-term slope creep and slow earth flow processes during the wet early Holocene have maintained and accentuated the convex morphology of the Rwandan hill and valley country. The slow creep and flow was favoured by high soil moisture and low surface erosion and resulted in the narrowing and probably the local damming of valleys. Deep-seated slope creep ceased, when climate conditions became drier or more seasonal during the mid-Holocene (since ca. 5000 BP), and a more accentuated rainfall regime triggered soil erosion and the deposition of colluvial sediments in the valleys. Slow aggradation and hillwash deposition is recorded at Rwaza Hill throughout the late Holocene only interrupted by two stability phases characterised by peat growth around 3000 and 1800 BP (GRUNDERBEEK et al. 1984; MOEYERSONS 2001). At the Gaseke valley KERSTING (2010) describes ca 1500 year old colluvial valley fill over basal sands. Whereas the latter is assumed to relate to the strong seasonal climate during the mid-Holocene transition 3600 – 1800 BP, it is widely assumed, that the last phase of colluviation starting about 1800 - 1500 BP corresponds to the introduction of agro-pastoralist subsistence strategies and related forest clearing (GRUNDERBEEK et al. 1984; MOEYERSONS 2001; GRUNERT et al. 2004; KERSTING 2010).

Work on colluvial deposits in semi-arid northern Kenya was pioneered by MÄCKEL & WALTHER (1984) and MÄCKEL (1989, 1992). Several colluvial and fluvial sediment layers, buried soils and stone lines were dated. Within the region, radiocarbon ages from these sediments vary widely but are restricted (with few exceptions) to the Holocene. The dates fall into three broad clusters, the Early Holocene ~6,000 - 9,000 BP, between 3,000 - 4,000 BP and the last two millennia. In most areas a recent activity phase within the last millennium and probably linked to human land use is recorded (MÄCKEL 1989, 1992). Whereas during the early Holocene wet phase deep-seated slope creep and reduced soil erosion due to dense vegetation cover is assumed for the present day semi-humid Rwandan uplands, slope instability and the accumulation of slope wash deposits seem to have occurred at the same time in what is today semi-arid Northern Kenya. Thus, comparison of morphological and climatic change has to take into account the variability of regional climatic conditions and the respective vegetation cover.

On the volcanic mountains of Mt. Kenya and Mt. Kilimanjaro numerous buried soils are preserved and record past slope dynamics. On Mt. Kenya, palaeosols developed during interglacials and were buried during phases of slope activity and glacier advances. Besides buried soils dating to the mid-Quaternary glaciations, neoglacial advances are reported (MAHANEY & SLOWPOKE 1991; MAHANEY 1992). On Mt. Kilimanjaro, buried soils in the montane forest zone are interpreted to reflect shifts of vegetation belts and tree line fluctuations during the Late Pleistocene and the Holocene. Using n-alkanes and stable isotope analysis of soil organic matter ZECH (2006) has argued that during colder and wetter periods, the ericaceous vegetation belt extended and migrated down slope to altitudes as low as 2100m a.s.l. Topsoil formation and downslope expansion of ericaceous vegetation on the back of montane forest may have occurred around 7.2/7.6 ka cal BP as well as during the early Holocene wet period until about 10 ka cal BP. Furthermore, LGM and pre-LGM phases of tree line depression are reported from lower altitude soil profiles (ZECH 2006). Higher soil moisture due to lower temperatures or more precipitation is thought to be responsible for the development of these black, organic matter rich, ericaceous topsoils. However, burial of these topsoils by mineral material is not attributed to slope instability, instead inverted weathering profiles on the northern slopes of

Kilimanjaro are interpreted as having developed through a constant influx of Aeolian dust from exposed periglacial areas (ZECH et al. in press).

Research on lowland slope deposits in Tanzania developed out of the debates on soil erosion and land degradation and has been much more applied in character than most of the pedological and geomorphological work focusing mainly on the palaeoclimatic and palaeoecologic implications of colluvial deposits. Many regions of Tanzania such as Ugogo country (Dodoma District) and the Irangi hills (Kondoa District) in Central Tanzania, as well as the Pare Mountains - the research area of the present study - have been reported as severely degraded since their first visits by European travellers in the late 19th century (BURTON 1860; VON DER DECKEN 1869; STUHLMANN 1894). In Central Tanzania, soil erosion such as intensive sheet wash and rill erosion are widespread and the formation of deep gullies has converted former agricultural areas into badlands while eroding earlier slope deposits on the extensive hill pediments (CHRISTIANSSON 1981, 1986).

Soil erosion was recognised during the colonial era as a severe threat to the ecological and economic future of the affected areas, and the first soil conservations projects were implemented during the 1930s and 1940s (CHRISTIANSSON 1986). Whereas the severe consequences of soil erosion were realised early on and conservation measures were promoted soon afterwards, emphasise lay on reconnaissance and the theoretical understanding of slope processes. MILNE (1936a, b) discussed soil erosion and corresponding deposits as essential parts of geomorphological processes leading to substrate differentiation and the distribution of soil types along a toposequence, the so called catena. After independence in the 1970s, the early colonial soil conservation projects were followed up by the Tanzanian wide soil erosion research project DUSER (Dar-es-Salam/Uppsala Universities Soil Erosion Research Project) (RAPP 1972; RAPP et al. 1972a), which produced quantitative data on soil erosion processes at plot and landscape scales and "supported earlier qualitative judgements regarding land degradation" (CHRISTIANSSON 1992).

Research in the 1970s conducted by RAPP, TEMPLE and co-workers (RAPP et al. 1972b; TEMPLE 1972; TEMPLE & MURRAY-RUST 1972; TEMPLE & SUNDBORG 1972) focused on the process of soil erosion itself, the impact of differing agricultural techniques and soil conservation measures. Soil erosion was quantified on erosion plots or on catchment scale by reservoir sedimentation. Building on these earlier soil erosion studies CHRISTIANSEN (1981) investigated soil erosion and land degradation in Ugogo country around Dodoma. High soil erosion rates and strong land degradation to the extent of near desert like areas were observed and thus his study concludes with practical advice on soil conservation policies. Importantly, CHRISTIANSEN (1981) was one of the first researchers to draw from historical information on land use and Wagogo economy to explain past soil erosion and pre-20th-century gully formation. In particular, the local population concentration due to pressure from hostile neighbours and a high food and firewood demand during the heyday of the 19th-century caravan trade were identified as drivers of soil erosion and land degradation. The consideration of historicity in soil erosion research puts the observations of accelerated soil erosion and anthropogenic land degradation in context with concepts of long-term landscape and vegetation dynamics.

The results of the research project had influences on environmental protection politics in Central Tanzania. Between 1971 and 1979 a comprehensive soil and water conservation program - the HADO project (Hifadhi Ardhi Dodoma – Dodoma Region Soil Conservation Project) was established with special focus on the Irangi Hills of Kondoa. Again, scientific research on the exact and individual causes and circumstances of soil erosion only followed 20 years later. Building on former experiences and within the framework of conservation measures, the 'Man-Land Interrelations in Semi-arid

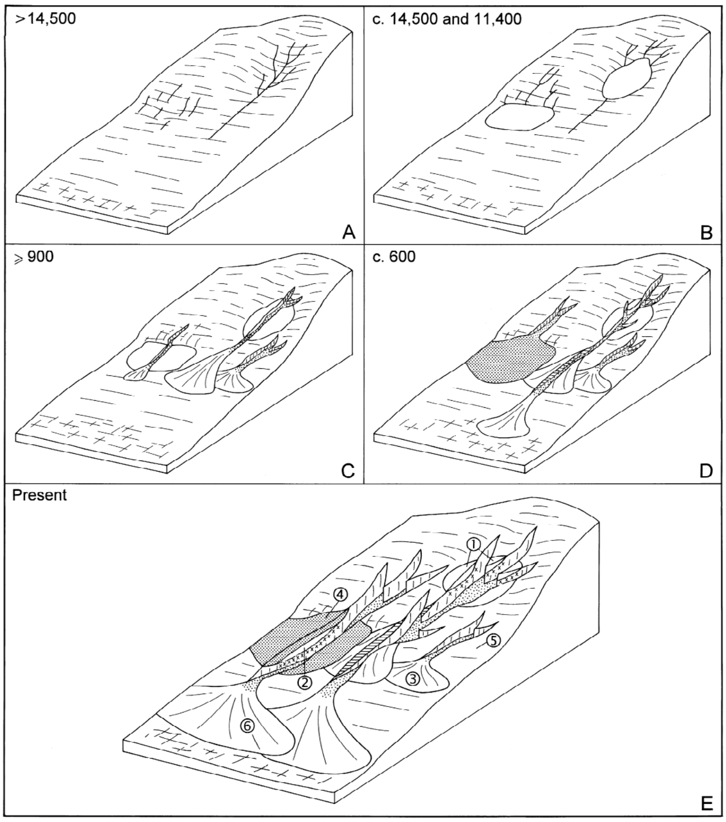


Fig. 12: Model of major phases of erosion and correlated colluvial and alluvial deposits in the Haubi Basin. 1- old colluvium, 2- old colluvium buried by red colluvium, 3- upper alluvial sand fan, 4- red colluvium, 5- shallow brownish colluvium (sandy wash deposit) blanketing the slopes, 6- lower alluvial sand fan (from ERIKSSON et al. 2000). See text for further explanations.

Tanzania' project was able to give a comprehensive overview of the causes and consequences of soil erosion and the intended and unintended effects of mitigation measurements (CHRISTIANSSON 1992; CHRISTIANSSON & KIKULA 1996).

Within this framework detailed research by PAYTON et al. (1992), PAYTON & SHISHIRA (1994), SHISHIRA & PAYTON (1996), and YANDA (2000) investigated past soil erosion and the nature of the correlated colluvial and alluvial sediments. The long-term history of soil erosion in the Irangi Hills and its possible causes have been studied intensively by ERIKSSON (1998, 1999), and ERIKSSON et al. (2000), and reviewed by LANE et al. (2001) and LANE (2009).

The research targeted colluvial and alluvial deposits in the Haubi Basin in order to date and quantify past soil erosion. As a result of a thorough soil reconnaissance study, Payton and co-workers were able to establish 'benchmark' soil catenas within the Haubi Basin reflecting the contemporaneous as well as pre-eroded toposequences and developed a relative chronology of the dominant erosion and sedimentation events (PAYTON et al. 1992; PAYTON & SHISHIRA 1994; SHISHIRA & PAYTON 1996). ERIKSSON et al. (2000) subsequently OSL dated the different colluvial units and developed a conceptual model of cyclical erosion phases (Fig. 12) in Central Tanzania.

A first weak erosion pulse occurred roughly contemporaneously with the dry-wet transition at the beginning of the Holocene (~14.5 - 11.4 ka) and resulted in the deposition of loamy sands in shallow depressions on the middle and lower footslopes. During the humid early Holocene, seasonal waterlogging in shallow depressions resulted in the eluviation of iron oxides, lateral transport and iron accumulation at lower positions of the landscape. After drainage, an Albic Arenosol developed over a hardened petroplinthic ironstone layer. The major period of erosion commenced before about 900 years BP, when incipient gully erosion resulted in the deposition of upper alluvial fan sediments. Accumulation of red colluvium with stratified quartz sands initiated about 600 years ago and suggests considerable transport by running water and reduced soil development as no B-horizon has developed. This late Holocene phase of soil erosion, which ultimately led to the extensive gullying observed today, has been linked to anthropogenic land use and the introduction of agriculture, domestic livestock and iron smelting (ERIKSSON et al. 2000). At present, all pediments are blanketed by a thin layer of recent brownish sandy wash deposit indicating the ongoing colluviation processes. Gully erosion on the other hand has resulted in deeply dissected badlands and the development of extensive alluvial fan deposits in the foreland.

The archaeological evidence has been investigated by LANE (2009), who discusses the possible causes of soil erosion beyond the general attribution to human impact. The archaeological survey revealed that most of the radiocarbon dated sites (16 out of 20) fall within the last millennium AD and only a few sites associated with iron smelting are recorded from the first half of the last millennium BC and around the begin of the Common Era (LANE 2009). The temporal correlation of the most recent erosion phases and settlement intensity strongly point to human land use as the main driver of soil erosion around 900 years ago. Lane stresses the need to take into account the interplay of different possible drivers of soil erosion such as climatic processes and anthropogenic development. During the most recent phase of soil erosion, severe gullying dissected the Irangi Hills and extensive lower sand fans developed. How far increasing population pressure and subsequent intensive human land use during phases of agricultural intensification stimulated by the 19th-century caravan trade, as discussed for Ugogo country and the Pare Mountains (CHRISTIANSSON 1981; BÖRJESON 2004; HÅKANSSON & WIDGREN 2007; HÅKANSSON 2008), contributed to intensify soil erosion in the Haubi area, remains unknown.

Finally, sediments of the Lake Haubi itself record soil erosion during the 20th century. Its conversion from a seasonal swamp to a lake around AD 1900 is attributed to the damming by alluvial sand fans – the direct result of gully erosion (ERIKSSON & CHRISTIANSSON 1997). Sedimentation rates of the accumulated lake sediments show a trend of increasing deposition reflecting advancing land degradation, whereas magnetic analysis seem to pick up alleviating periods of colonial soil conservation measures (ERIKSSON & SANDGREN 1999).

3.6 **Summary**

Hillslope deposits have been shown to be critical archives recording stability as well as periods of rapid landscape change. Directly linked to surface processes, most importantly soil erosion, hill slope deposits record long-term developments such as climatic transition but have emerged as particularly important when analysing the growing impact of human land use on the environment.

So far, several East African landscape studies agree that widespread enhancement of slope processes occurred during the Pleistocene - Holocene transition, when rapid climate shifts outpaced vegetation change. During the Holocene a number of locally distinct pulses of slope instability are recorded – most importantly disturbances related the mid-Holocene climatic transition. Evidence for slope instability increases during the last two millennia when anthropogenic land degradation becomes ubiquitous particularly during the last 1000 years. However, the patterns of slope dynamics vary regionally and point to a variable set of regional and local controls of slope processes. Despite the fast growing body of evidence for past climate dynamics and the establishment of palaeoclimate models, the reconstruction of past landscape dynamics in East Africa is still in its infancy. The fragmentary nature of the terrestrial records and the locally distinct trajectories of landscape development warrant further investigations on a local basis as developed in this thesis, before a large-scale model of regional landscape can be constructed. Before turning to the results of this work, however, a brief summary of what is known of the later Holocene settlement history of the study area and wider region is called for.

4 THE HUMAN ENVIRONMENT

In the late Holocene, human land use has become the main driver of vegetation and landscape transformation. This chapter presents an archaeological and historical overview on changing subsistence strategies and land use in East Africa and particularly in the Pare Mountains.

East Africa has a long history of hominin occupation and played and important role in the development of early modern humans (BARHAM & MITCHELL 2008). The morphological and ecological diversity of the East African Rift, its highlands, lakes and volcanoes is maintained and reshaped by recurrent tectonic activity and offered a diverse mosaic of environments and resources, which is thought to have facilitated and stimulated the human behaviour and development (BAILEY & KING 2011; BAILEY et al. 2011). On the other hand, there is much speculation about the impact of hominins, early modern humans and Stone Age hunter-gatherers on their environment and in particular the deliberate use of fire is discussed as having shaped vegetation patterns and landscape development not only on the African continent but also in view of the persistence and expansion of savannah landscapes (GOLDAMMER 1992; BIRD 1995; BOWMAN 2005; PAUSAS & KEELEY 2009). But only in the late Holocene can direct links between human land use, vegetation dynamics and landscape development be observed.

4.1 Early pastoralists and hunter-gatherers

An African particularity in the development of subsistence strategies is the adoption of domestic animals before the domestication of indigenous African crops (MARSHALL & HILDEBRAND 2002). Around 7000 – 6700 BP caprines (sheep/goat) had been introduced from the Near East, whereas the exact timing of the introduction or the autochthonos domestication of cattle is still disputed (BLENCH & MACDONALD 2000; MARSHALL & HILDEBRAND 2002; GIFFORD-GONZALEZ 2005). The origin for the domestication of indigenous cereals like pearl millet (*Pennisetum glaucum*) but also Sorghum (*Sorghum bicolor*), African rice (*Oryza glaberrima*), yam (*Dioscorea cayensis*), and cow pea (*Vigna unguiculata*) probably occurred around 4000 BP in the West African grasslands (MARSHALL & HILDEBRAND 2002; MANNING et al. 2011). Domestication of the most important East African crops finger millet (*Eleusine coracana*), ensete (*Ensete ventricosum*), and tef (*Eragrostis tef*) took place not before the beginning of first millennium AD (MARSHALL & HILDEBRAND 2002 and references herein).

Southward expansion of pastoralists into East Africa is generally assumed to have coincided with the end of the African Humid Period around 4.5 - 4 ka BP (DEMENOCAL et al. 2000a). Manifested by the final desiccation of the Sahara, the southward retreat of the ITCZ during the mid-Holocene also resulted in drier conditions in East Africa, where aridity has been deduced from falling lake levels and the increase in drought tolerant taxa (GASSE 2000; MARCHANT & HOOGHIEMSTRA 2004; KIAGE & LIU 2006). A spin-off from the southward shift of the forest/savannah ecotone and the establishment of extensive savannah rangelands was the retreat of the tsetse fly distribution limit, which facilitated the spread of pastoralism into the highlands of East Africa (BOWER 1991; SMITH 1992; GIFFORD-GONZALEZ 1998). Following RICHARDSON & RICHARDSON (1972) and NICHOLSON & FLOHN (1980) the modern circulation system of East Africa with a bimodal rainfall pattern established about 3,000 years ago. Two rainy seasons would have increased the productivity of the rangelands and in consequence milk production and reproduction of domestic herds, hence stimulating the development of specialised pastoralism in East Africa (MARSHALL 1990).

Faunal remains of domestic animals occur in the archaeological record since 3400 – 4500 BP in Northern Kenya but are rare in central Kenya and northern Tanzania until around 3,000 BP, when pastoralism became more widespread in parts of East Africa (KAREGA-MUNENE 2003). Several hypotheses have been put forward to explain the early presence of small numbers of domesticates from hunter-gatherer communities in southern Kenya and northern Tanzania and the time lag of about a millennium until an abrupt expansion of the pastoral way of life began (BOWER 1991; GIFFORD-GONZALEZ 1998; LANE 2004; DALE & ASHLEY 2010). The explanatory models can be seen as part of a "moving frontier" with sequential phases of contact and interaction between groups with different subsistence strategies (LANE 2004). The so called 'trickle-and-splash' model (BOWER 1991) suggests the presence of small groups of herders since the mid-forth millennium BP. But only around 3,000 BP a splash of southern Cushitic speaking pastoralists made its way into the Rift valley and northern Tanzania. A possible further explanation is offered on epizootiological grounds by GIFFORD-GONZALEZ (1998). Ecological factors like extended tsetse fly infested bush and woodland and highly contagious WD-MCF (Wildebeest derived - Malignant Catarrhal fever) might have been responsible for the delayed introduction of animal husbandry in East Africa. In particular, the distribution of the tsetse fly, the vector of *Trypanosoma* spp. causing sleeping sickness in animals and human beings, is often cited as responsible for the absence of animal husbandry in various regions of Africa. (ROGERS & RANDOLPH 1988; GIFFORD-GONZALEZ 1998). The Northeast African pastoralists entering East Africa were initially unaware of these threats to their livestock so successful immigration of pastoralists only became possible when the early herders had gained the veterinary knowledge to avoid wildebeest contacts and to circumvent tsetse infected shady bush and woodland. The threat, which trypanosomiasis poses to animal husbandry, has led to the widely repeated assumption among historians and archaeologists that early pastoralists were responsible for widespread burning and woodland clearing in order to create open spaces. (KJEKSHUS 1977; STEVERDING 2008).

The term Pastoral Neolithic was coined to refer to these new food-producing communities, which relied primarily on animal husbandry (cattle, sheep/goat), had knowledge of pottery but still used lithic industries and practiced complementing hunting and gathering (AMBROSE 1984; KAREGA-MUNENE 2003). From linguistic work EHRET (1998) suggests that the early pastoralists were speakers of a Southern Cushitic language and originated from southern Sudan and Ethiopia. They occupied open-air sites throughout the savannah rangelands of central Kenya and Northern Tanzania but did not yet penetrate into the bush and woodlands of central and southern Tanzania (PHILLIPSON 2005; BARHAM & MITCHELL 2008). These early pastoralists were heterogeneous groups and many different pottery traditions e.g. Nderit, Maringishu, Narosura, and Elmentaita (Remnant) developed contemporaneously (AMBROSE 1984).

The pastoralist newcomers spread into a region occupied since the early Holocene by hunter-gatherer communities characterised by their common use of the Eburran 5 lithic industries and who are assumed to belong to the Khoisan language family (AMBROSE 1984). Despite repeated postulations that foragers and pastoralists communities of the Later Stone Age may have practiced some sort of plant cultivation (PHILLIPSON 2005) no direct evidence has been found so far (KAREGA-MUNENE 2003). Pottery (Kansyore ware) however was known as early as the sixth millennium BC by hunter-fisher-gatherer communities around Lake Victoria (DALE & ASHLEY 2010). From site distribution and the resource use of the Okiek, a recent hunter-gatherer group in the Mau Escarpment, AMBROSE (1984) deduces that the Eburran communities favoured the lower fringes of the montane forests, which allowed access to forest resources (honey, animal traps) as well as to savannah environments (hunting). He concludes that distinct subsistence strategies exploiting different ecosystems allowed hunter-gatherers and pastoralists to coexist and even complement their resource use. Coexistence and interaction of hunter-gatherers, pastoralists and later farmer groups within the same region but specializing in the exploitation of resources of different ecological environments represents an important theme, and is of ongoing importance for the understanding of cultural cohabitation and conflict between farmers and pastoralists in many parts of Africa.

4.2 Farmers and smelters: The East African Iron Age

At the end of the first millennium BC, sedentary food-producing farmers entered the East African stage so far dominated by pastoralists and hunter-gatherers. In addition to the cultivation of plants, this new life-style is characterised by knowledge of iron working and by a new distinct pottery style known as Urewe ware (ASHLEY 2010). The origins and spread of African iron working is still poorly understood, but it becomes apparent that during the mid first millennium BC autochthonous iron production emerged at different regions across Africa – most importantly within the Nok culture in Nigeria, the Meroe in Southern Sudan, coastal Gabon and in the Interlacustrine Region of East Africa (CHILDS & HERBERT 2005). Linguistic research links the occurrence of 'dimple-based' Urewe ware with the establishment of Bantu speaking farming communities in the Great Lakes region. The antecedents of these early Bantu population, which probably practiced the cultivation of root crops like yams, must have migrated to the highlands of western East Africa from their assumed origin in Southern Cameroon and Gabon (EHRET 1998, 2001). Based on linguistic reconstructions SCHOENBRUN (1993a) proposes a patchwork like population pattern of root crop-based Bantu people amidst grain growing and stock raising Central Sudanic, alongside mixed farming practicing Eastern Sudanic and primarily pastoral Southern Cushitic groups. The diversity of subsistence strategies requiring different ecological environments allowed coexistence, exchange and amalgamation of technologies and languages. The combination of mixed agricultural techniques - including grain cultivation (sorghum, pearl and finger millet), planting of root crops (yams) and nitrogen fixing legumes (cowpea, Bambara groundnut) - and the raising and milking of cattle, combined with the new technological knowledge of iron working, resulted in a powerful toolkit, which facilitated the occupation of a variety of ecosystems and finally resulted in the rapid spread of Bantu-speaking groups over East and into South Africa (SCHOENBRUN 1993b). It is however worth noting, that the widely accepted assumption of farming is based on the occurrence of grinding stones and linguistic grounds. Archaebotanical research conducted so far has been hampered by the scarcity of botanical remains and has not yet confirmed the cultivation of crops in Early Iron Age contexts.

The first occurrence of the 'dimple-based' Urewe pottery style and iron smelting is dated to around 500 BC in the Buhaya region at Lake Victoria. Numerous iron smelting sites dating between AD 200 and AD 700 are reported throughout the Great Lakes Region (GRUNDERBEEK et al. 1984; SCHMIDT & CHILDS 1985; CLIST 1987; SCHMIDT 1997b, a). From here the knowledge of iron smelting and presumably farming spread together with the pottery style to the east and south and in the following centuries ceramic types ressembling Urewe ware are found all over East and Southeast Africa. The most important regional variety is Kwale ware (SOPER 1967a), which appears around AD 200 in the coastal regions of Kenya and Tanzania but is also found along the mountain ranges of Usambara and Pare (SOPER 1967b; ODNER 1971a; SOPER 1971a), on Kilimanjaro (ODNER 1971b), at Dakawa near the Nguru Hills (HÅLAND & MSUYA 2000), the Tsavo area (KIRIAMA 1987) and as far north as Mount Kenya.

Several scenarios of Bantu migration out of the Lake region into southeast Kenya and Northeast Tanzania have been proposed (cf. KIRIAMA 1993; PHILLIPSON 2005): A northern dispersal route via Mt Kenya and southwards along the coast, a southern route giving rise to the intermediate pottery style Lelesu ware in Sandaweland, Kondoa (SMOLLA 1957) and finally the direct migration from the interlacustrine highlands to Mt. Kilimanjaro and North Pare from where they further spread to Mt. Kenya and along the Eastern Arc Mountains (EHRET 1998). A general drawback of migration models based on purely linguistic grounds is that dispersal mechanisms of technologies like subsistence strategies, pottery styles, and iron smelting are not necessarily bound to the migration of linguistically constrained populations. EGGERT (2005) summarises the development and the ongoing discussion about the origin and dispersal of Bantu languages and critically accesses the often circular reasoning of linguists and archaeologists trying to confirm the prevailing paradigm. He concludes that the reconstruction of dispersal pathways based on linguistic theories should be regarded with caution as material evidence for the spread of common cultural traits is lacking in most areas. Instead of one great homogeneous Bantu expansion, it is more likely that diffusion and cross-cultural interaction between immigrants and local populations on different spatial and temporal scales has resulted in cultural change as well as language adoption and technology transfer. As WRIGLEY (1997) points out, voluntary as well as forced displacement of single people or small groups with the respective knowledge might also have been sufficient to initiate the emergence of similar cultural traits far away from the original centre of dispersal.

4.3 Integration of East Africa into the world trade system

Whereas farming communities spread in the interior, the Tanzanian coast established links with the Near Eastern and Indian world through the emergence of Indian Ocean trade networks. The earliest written references to the East African coast are found in the *Periplus maris Erythraei* written in the first century AD by an unknown author and translated by CASSON (1989; for alternative translations see among others WRIGLEY 1997) and the Geography of Ptolemy (second century AD). Later in the 10th century the Persian writer Al-Masudi confirms the integration of the East African coast into a wider regional network of exchange and trade with the Roman, Indian and even the Chinese worlds (FREEMAN-GRENVILLE 1962; CHAMI 1994). The most important trade goods mentioned in the *Periplus maris Erythraei* were "a great amount of ivory but inferior to that from Adulis; rhinoceros horn; best-quality tortoise shell after the Indian; a little nautilus shell" (or palm oil in other translations), whereas the Arabian traders supplied "axes; knives; small awls; numerous types of glass stone", the former presumably made of iron (CASSON 1989). Further export goods from the Azanian coast were ambergris (copal) from the Tanzanian coast (SUNSERI 2007), gold traded from Sofala (derived from the Zimbabwe plateau and Mozambique coast) and finally slaves (FREEMAN-GRENVILLE 1962; SHERIFF 1987). Archaeological evidence for this early trade is limited. Reports of Roman coins found on Zanzibar remain unconfirmed (FREEMAN-GRENVILLE 1962). The only archaeological evidence so far is from Mkukutu in the Rufiji delta, where CHAMI (1999) recovered Roman beads and pottery from an early iron-working context with pre-Kwale pottery dated to between 230 and 570 AD.

Along the coast, Kwale ware, the local pottery type of the Early Iron Age, is superseded around the 4th to 5th century AD by TIW (Triangular Incised Ware - also called Kitchen ware or Tana ware) (CHAMI 1994, 1995b). On the basis of a continuous pottery style development CHAMI (1994) proposes a local development of the TIW industry and related culture. On the other hand, the flowering of the Triangular Incised Wares on the Tanzanian coast coincides with the rise of the pre-Islamic Persian

Sassanid Empire. Blue-green glazed pottery and glass beads of Sassanid origin, the introduction of further metals, like copper and lead, and even a few sherds of Chinese porcelain are evidence of the growing importance of Indian Ocean trade and suggest Sassanid influence or control of the Indian Ocean trade (FREEMAN-GRENVILLE 1962; CHAMI 1994). The Indian Ocean trade stimulated the formation of hierarchical societies and the emergence of coastal states (SHERIFF 1987). By the 15th century the Swahili towns were flowering and the ruling merchant class lived in wealth and luxury. The upsurge of mercantile wealth since the 15th century at the coastal Swahili city-states of Kilwa, Pangani, Saadani/Bagamoyo, Malindi, and Lamu was strongly dependant on the external trade controlled by Arabian and Indian traders.

4.3.1 Ivory and Slaves

Ivory, slaves and spices were the three most important export commodities up to the 19th century (SHERIFF 1987). Ivory is highly valuable and represents one of the first and most constant export goods to the Indian, Arabian and Mediterranean world. Although the ivory boom in East Africa had a comparably late take off in the second half of the 19th century, the opening up of the East African hinterland occurred in less than half a century. Oral accounts of ivory trade in the interior date back to AD 1800 in Buganda, but it is only around AD 1811 when coastal merchants protruded into the hinterland and traded with 'tribes 15 days up the Pangani' (THORBAHN 1983). It took years until in 1824 the first known caravans departed into the interior. By the mid-19th century Arab merchants had established trade routes as far as Ujiji, and Unyamwezi and Kamba traders from the interior brought ivory directly to the coast (THORBAHN 1983 and references herein). Although the amount of ivory extracted from East Africa was small compared to West Africa and India (ALPERS 1975), Burton estimated that in the mid-19th century up to 100,000 elephants were killed annually (in THORBAHN 1983), which had a devastating effect on elephant population and societies (HÅKANSSON 2004).

Several reasons are put forward to explain the late and sudden East African ivory boom, including an increase in the ivory demand, declining supply from other source areas, the reorganization of the trade itself, and finally the organization of the ivory supply (THORBAHN 1983; SHERIFF 1987). THORBAHN (1983) analysed ivory prices and volumes in pre-colonial East Africa and concluded that ivory extraction involved not only the immediate hinterland of the coast but must have extended over large areas of the interior. From decreasing tusk size and fluctuating pattern of ivory supply at the Swahili coast he deduces that elephant populations were hunted to the rim of overexploitation at the dawn of the 19th century – event before the onset of the colonial ivory boom.

Trade of East African slaves to the Middle East has a long tradition. The famous Zanji rebellion (AD 869-883 AD) in former Persia is said to have been a revolt of Azanian slaves from East African and illustrates the widespread distribution of African slaves (FREEMAN-GRENVILLE 1962; SHERIFF 1987). European engagement in the East African slave trade commenced with the Portuguese in the early 16th century but intensified especially during the French dominated period between 1770 and 1822, when an estimate of about 1000 - 4000 slaves per year were exported from the East African coast (ALPERS 1975). British attempts to abolish the slave trade since AD 1807 resulted in a steady decline of the European slave trade and the diversion of slaves into agricultural production within Africa. The establishment of slave-based clove plantations on Zanzibar and Pemba and other areas of the coast such as around Pangani and Mombasa in the early 19th century was seen as a direct consequence of the decreasing European demand.

4.3.2 From exchange networks to caravan routes

Whereas trade with the outside world via the Indian Ocean has been studied in detail, information on exchange networks and long-distance trade in the hinterland is fragmented and based solely on the interpretation of archaeological evidence. In the last decades several archaeologists have set out to investigate the remains of market places, caravan stops and settlements along the caravan routes in order to investigate the changes early trade networks and later caravan trade had on the subsistence strategies and settlement patterns of local communities (THORBAHN 1983; WRIGHT 2005; ROCKEL 2006; BIGINAGWA 2009; WALZ 2010; WYNNE-JONES 2010). Interpretations of single findings of shell beads in archaeological contexts of the interior are ambiguous, as they do not reveal the means of transport. They may be the material remains of long-distance trade, but may also have arrived through interconnected local exchange networks, the latter without invoking organization and the far-distance movement of groups of people. In the case of ivory, THORBAHN (1983) disagrees with hypothesis of local exchange networks, through which the valuable commodity was passed on until reaching the coast. Instead he proposes trade networks between hunter-gatherers responsible for the ivory supply and pastoralist or agricultural groups, which occasionally organised trading parties directly to the coast or to middlemen as early as the 16th century.

In later periods, regional trade systems were established as a response to the high demand for ivory and slaves. Following earlier routes of exchange, groups of elephant and slave hunters (or traders) penetrated the interior to buy or capture ivory and human beings. Long-distance trade obviously relied on the knowledge of local guides, was constrained by water sources and the provision of food, and may have followed established tracks connecting inhabited areas and commercially interesting trading locations (WALZ 2010).

In the 19th-century caravans with up to 1,000 porters carried ivory to the coast although smaller caravans between 30 and 150 men were more common (KRAPF 1858; THORBAHN 1983; KOPONEN 1988a). Even these small caravans required provision, and it has therefore been assumed that the gathering and translocation of these quantities of people and products stimulated economic growth along the caravan routes (SHERIFF 1987; HÅKANSSON 1994, 2004). Places along the major caravan routes, where water and food were available became first resting places, then local market sites, and later developed into important market towns which attracted new settlers and became economic as well as political powers (ROCKEL 2006; WYNNE-JONES 2010). The food demand of the passing caravans offered farming communities the opportunity to sell surplus production and in return gain luxury products and status symbols. HÅKANSSON (2004; 2008) suggests that the opportunity to sell surplus was the economic incentive for farmers to intensify cultivation and the driving force behind agricultural intensification and the establishment of landesque capital in Pare but also in Usambara, Taita, Ugogo, and Kilimanjaro.

4.4 History of North Pare

4.4.1 Archaeological research

A first archaeological reconnaissance survey of north-east Tanzania was conducted during the 1970s within the Bantu-project of the British Institute in East Africa (SOPER 1967b, 1971a). Numerous archaeological sites - mostly associated with iron smelting - were recorded throughout North and South Pare as well as in the Usambara Mountains (Fig. 13). Although the concentration of site locations along the western and eastern foothills is certainly an artefact of survey trajectories and time constraints, the site distribution shows an intensive settlement history on the footslopes and a wide distribution within upland areas. WALZ (2010) mapped and excavated archaeological sites in the middle Pangani basin and along the Mkomazi corridor. His work revealed large numbers of sites ranging in date from the Early Stone Age to Modern times but shows increasing occupation during the last 1500 years. The evidence for a long history of human activity in semi-arid lowland areas - often declared as a 'settlement void' - challenges earlier assumptions that semi-arid lowland areas were rarely settled. The findings indicate a long history of 'coastwise' interactions and exchange of materials and finished goods and show evidence of early iron working. Strong socio-economic changes took place later during the 19th-century caravan trade as shown exemplarily at an 18th- to 19th-century settlement site and market place on the island of Ngombezi within the Pangani river (BIGINAGWA 2009).

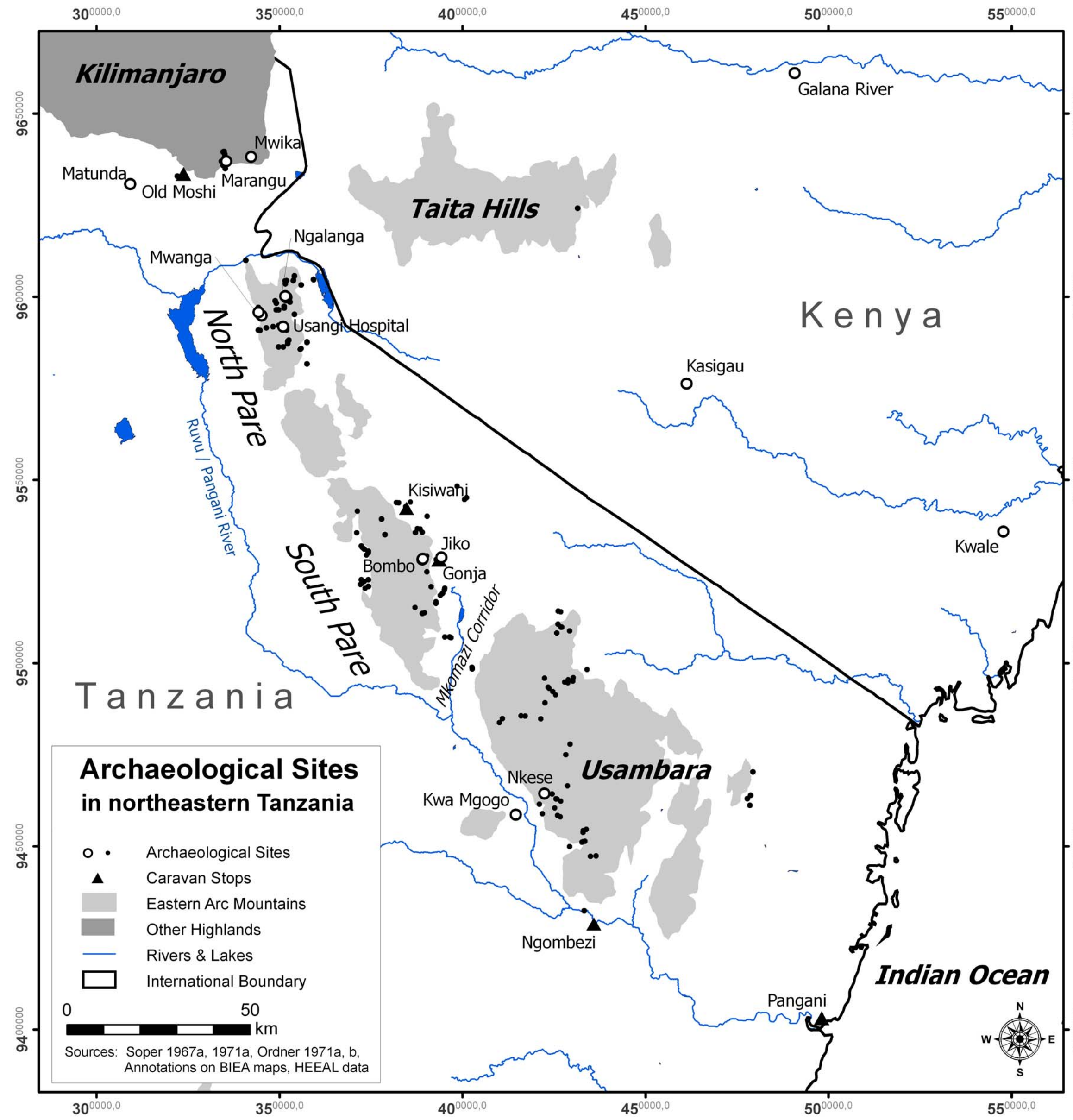


Fig. 13: Archaeological Sites in NE Tanzania. Location of archaeological sites of North Pare are based on ODNER (1971a), for Pare and Usambara on SOPER (1967b, 1971a), for Kilimanjaro on ODNER (1971b), Lower Pangani on BIGINAGWA (2009), Kasigau on KUSIMBA (2004) and on anonymous annotations on topographic maps of the British Institute in East Africa.

A closer look at the study area itself, the North Pare Mountains, shows that archaeological investigations are confined to early observations by FOSBROOKE (1954; 1957), ODNER's (1971a) excavation at Usangi hospital in North Pare, a short survey by CHAMI (1995a) and recent work in progress by STUMP (2010) (cf. Fig. 14). The earliest evidence of human occupation in Pare are unclassified flaked stones found at several upland and lowland sites (ODNER 1971a). These sites are located at the foothills of the mountains (Mwanga, Kwakoa), at Lake Jipe (Makuyuni) as well as within the upland basins (Usangi, Kivindu, Mruma) and ridges (Iria la Bora Mboji) and suggest that Stone Age hunter-gatherers dwelled in the montane forests of the Eastern Arc Mountains. References to former pygmy populations exist within the oral traditions not only in the Pare Mountains (KIMAMBO 1969), but also at Kilimanjaro (DUNDAS 1924), Mt. Kenya, in the Aberdares, and Cherangani (SUTTON 1966). In Pare they are remembered in oral histories as *Vimbiji* (Kipare) or *Sivira* (Kigweno). Whether or not these stone industries are remains of these 'small people' or of a second group of hunting-gathering people without houses remembered in Kipare as *Vasi* or *Wasi* (KIMAMBO 1969) remains speculation. Likewise, it is unclear if former non-Pare communities referred to within local histories as *Wandorobo* – and said to have been at least partly absorbed within the *Wambo* clan (KIMAMBO 1969) – included earlier Late Stone Age hunter-gathers, or whether they represent a different pre-Pare population using Eburran phase 5 technology.

References to an early occupation, possibly by agriculturalists, arises again from oral histories synthesised by KIMAMBO (1969). The so-called *Wagalla* were expelled from Pare by the first *Wapare* settlers, which ascribe their land rights to this early land conflict. The narratives tell, that the *Wagalla* lived on the eastern slope near Lake Jipe and iron smelting sites on the eastern slopes of Pare have been tentatively attributed to these pre-Wapare populations (FOSBROOKE 1957).

Early archaeological evidence is available for the bordering lowlands, especially the Tsavo area in Southern Kenya and the middle Pangani basin. In the Tsavo plains near the Galana River, Early, Middle and Late Stone Age lithic scatters are reported, and open-air sites buried under alluvial sediments of the Galana River show that Pastoral Neolithic groups grazed their cattle in the lowlands bordering the Pare Mountains (WRIGHT 2004). The remains include pottery of the Narosura tradition as well as domestic cattle bones and cowry shells and are dated between c. 3700 and c. 1400 ^{14}C BP (WRIGHT 2005). Although surprisingly early, the sites confirm pastoralist settlement in southern Kenya since the beginning of the Pastoral Neolithic.

Early Iron Age sites with evidence of iron smelting or Kwale ware are widespread in the Pare and Usambara Mountains, and Kwale ware - a variant of the dimple-based Urewe ware and characterised by its bevelled rim - is first recorded from the type site Kwale near Mombasa, where associated charcoal has been dated to between AD 80 and AD 600 (SOPER 1967a). Similar ages were obtained for Kwale ware recovered at Bombo Kaburi in South Pare dated by charcoal from a disturbance fill containing pottery to (SOPER 1967b). Despite some slag at the type site of Kwale and iron-smelting furnaces dating to the first centuries AD at Nkese, Usambara (SCHMIDT 1988), no direct evidence for early iron-working was recovered from the South Pare sites.

Around the 8th century AD, Triangular Incised Ware spreads along the Tanzanian coast (CHAMI 1995b). In the interior, a new local pottery tradition emerges slightly later. Maore ware, named after the first findings at Gonja Maore, South Pare, appears but does not substitute the traditional Kwale pottery, which continues in use. Maore ware has a graphitic surface and is either thick, crude and irregular or thin-walled and has a graphite surface (SOPER 1967b). Maore Group A ware recovered from a refuse mound at Gonja Maore and is dated by associated charcoal samples to between AD 700

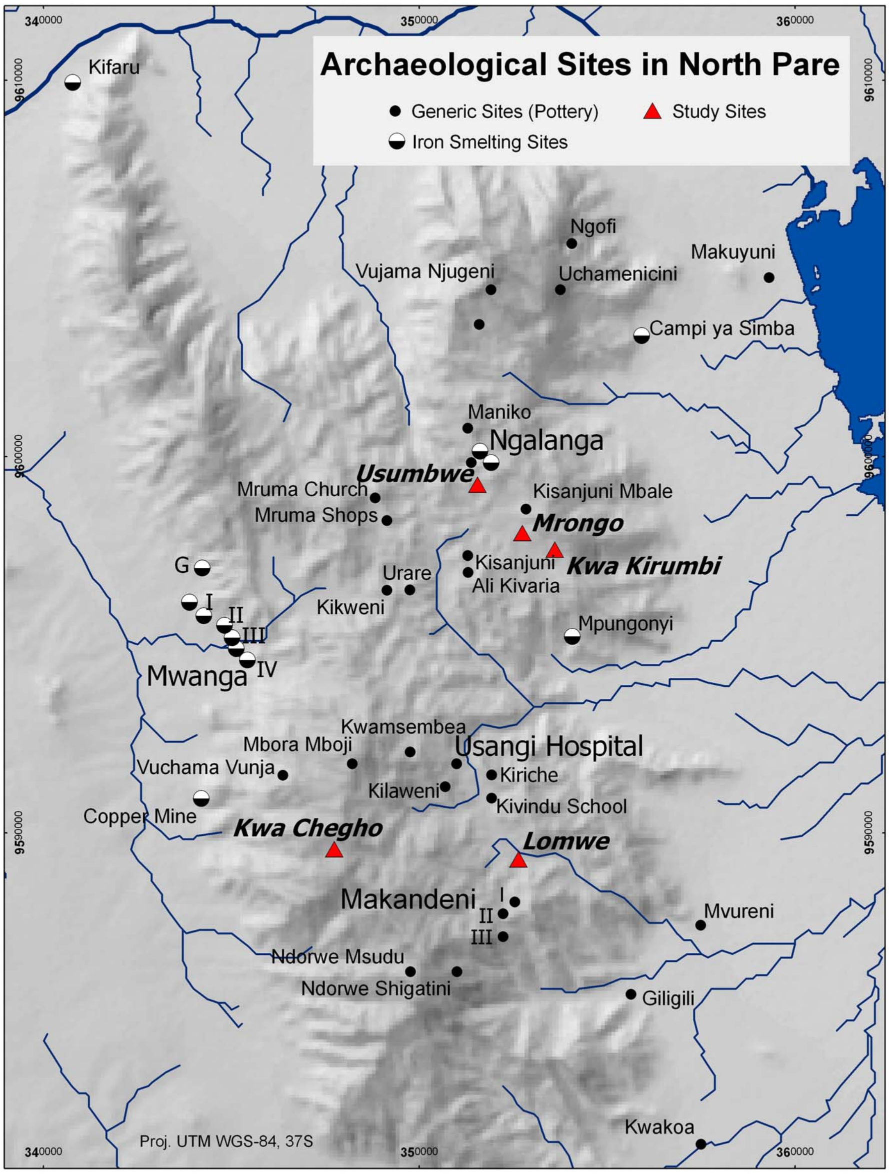


Fig. 14: Archaeological Sites in North Pare. The map shows archaeological sites identified by ODNER (1971a), CHAMI (1995a) and locations recorded during the HEEAL fieldwork.

and 1200. Similar dates were obtained for Maore Group B Ware from Bombo (SOPER 1967b) and Maore Group B and Triangular Incised Ware from site 209 (Gonja Maore) and Kwa Mgogo (WALZ 2010) (cf. Tab. 2). On Kilimanjaro, calibrated radiocarbon dates related to Maore ware and Maore related pottery styles (Kilimanjaro group C & D) span a wide range but do not contradict the distribution of Maore related pottery styles at the turn of the second millennium AD (ODNER 1971b). The subsistence of sedentary people at Gonja Maore (Group A & B) consisted mainly of wild animals, but they also had access to a few domestic animals (caprines and cattle), and probably cultivated some grains as inferred from the presence of grinding stones (SOPER 1967b). As at the Tsavo sites, the presence of seashell beads at Gonja Maore suggests early trade connections with coastal areas.

In North Pare, excavations at Usangi Hospital revealed a possible habitation site with a later burial and concurrent occurrence of Kwale and Maore ware throughout the excavated trench (ODNER 1971a). Two radiocarbon dates suggest that occupation took place between AD 690 – 1260 and AD 10 - 1160, which broadly corresponds to South Pare sites containing mixtures of Kwale and Maore ware. Counterintuitively, the deposits that produced these dates sandwiched a layer that produced a fourth millennium BC date and contained reworked stone flakes. ODNER (1971a) reasons that if the stone flakes are reworked Later Stone Age artefacts, an early occupation site might have been disturbed by the later settlement and the excavated deposits therefore also contained reworked charcoal fragments older than the pottery in question. Reconnaissance surveys undertaken by ODNER (1971a), CHAMI (1995a), and during the HEEAL project also attest to widespread occurrences of Later Iron Age pottery in the Pare highlands and include a stratified layer of wattle- and stake-impressed house daub and pottery recorded in the vicinity of Raa, Ugweno, during HEEAL surveys in 2010. A charcoal sample from a fine burnt layer immediately underlying this daub deposit dates to AD 1450 - 1650. The difficulty in locating further direct evidence of occupation sites might suggest that the settlement pattern of dispersed and perhaps relatively short-lived homesteads observed in the 19th century by BAUMANN (1891) may have been the norm throughout Pare history.

Numerous iron smelting sites are located on the lower foothills and the upper pediments of the Pare Mountains as well as within the mountain areas. At Mwanga IIIA, an iron smelting furnace associated with Maore group B pottery known from South Pare was dated to 780 – 1260 AD (ODNER 1971a). During HEEAL fieldwork smelting sites at Mwanga were revisited and the primary backfills of smelting furnaces dated to AD 1290 - 1440 at Mwanga C (probably Odner's Mwanga IIIA or IIIB) and AD 1040 - 1260 at Mwanga A (Odner's Mwanga I). So far, dating of furnaces suggests that iron smelting in Pare predominately dates to the early second millennium AD, and no evidence for earlier iron smelting in the first millennium AD such as at Kwale or Nkese has been recorded. Iron working, however, persisted throughout the second millennium as is attested by a pile of over 100 used ironworking tuyeres located in a mid-slope position at Mwanga G (AD 1440 – 1640) and an even later date of AD 1640 - 1730 (78.4% probability at 2σ) for a ditch fill associated with three iron-smithing hearths at Ngalanga in the Ugweno highlands.

4.4.2 Oral traditions of the Wapare

Oral traditions are an important source for the reconstruction of the Pare history. Isaria Kimambo recorded oral histories, traditional practices and clan histories throughout North and South Pare and synthesised a fairly consistent narrative of the history of the Wapare as told by the then current inhabitants. The following overview of the history of Pare encompassing the last five hundred years is based on his ethnohistorical work '*A political history of the Pare*' (KIMAMBO 1969) and further publications '*The Pare*' (KIMAMBO 1968), and '*Custodians of the Land*' (MADDOX et al. 1996).

According to these oral traditions, the ancestors of the *Wagweno* (inhabitants of *Ugweno*), the founder community of Pare, immigrated from Taita in Kenya. Oral traditions in Ugweno, North Pare, reach up to 22 generations back, however crosschecking the accounts of different clan lineages suggests that reliable information can only be extracted for the last sixteen generations. Assuming that an average generation lasts about 30 years, the *Wagweno* moved to Pare between 500 and 700 years ago. About 16 generations ago – around AD 1520 following KIMAMBO (1969) – the ruling *Washana* clan of blacksmiths was ambushed and the *Wasuya* clan took power and established a complex political system. The timing and the arrival of the *Wagweno* in Pare, however, may be questioned - not only on the grounds of the historical accuracy of oral narratives but also by differing assessments of the longevity of KIMAMBO'S genealogy. WINTER (1992) suggests that generations may be as short as sixteen years, and hence that societal transformation and Wagweno hegemony may only date to the 18th century.

Tab. 2: Radiocarbon age of archaeological sites in NE Tanzania and the respective features including iron smelting furnaces and ceramic types Kwale, Maore, and Triangular incised wares. Dates are calibrated by OxCal 4 using the IntCal 09 calibration curve and are rounded to decades.

Site	Feature	Conv. Age ^{14}C yr BP	Cal. Age (95.4%) BC/AD	Source
Kwale				
Kwale	Kwale ware	1690 ±115	80 - 590 AD	SOPER 1967a
	Kwale ware	1680 ±115	80 - 610 AD	SOPER 1967a
Dakawa				
Dakawa	TIW / Tana ware	various	650 - 880 AD	HALAND & MSUYA 2000
Usambara				
Nkese	Furnace	1780 ±70	80 - 410 AD	SCHMIDT & CHAMI 1988
	Furnace	2020 ±100	360 BC - 220 AD	SCHMIDT & CHAMI 1988
	Furnace	1800 ±30	120 - 330 AD	SCHMIDT & CHAMI 1988
Kwa Mgogo	Maore Group B & TIW	-	947 ± 48 AD	WALZ 2010
Kwa Mgogo	TIW	-	782 ± 66 AD	WALZ 2010
South Pare				
Bombo Kaburi	Kwale ware	1730 ±115	50 - 570 AD	SOPER 1967b
Bombo	Maore Group B	1060 ±110	700 - 1210 AD	SOPER 1967b
Gonja Maore	Maore Group A	1080 ±115	680 - 1180 AD	SOPER 1967b
- site 209	Maore & Group B	-	1545 ± 63 AD	WALZ 2010
- site 209	Maore & TIW	-	1095 ± 43 AD	WALZ 2010
Chongweni Hill	Furnace, Maore Group B	-	1095 ± 43 AD	WALZ 2010
North Pare				
Usangi Hospital	Kwale & Maore	1030 ±130	690 - 1260 AD	ODNER 1971a
	Kwale & Maore	1430 ±270	10 - 1160 AD	ODNER 1971a
	Stone flakes	5180 ±135	4330 - 3700 BC	ODNER 1971a
Mwanga IIIA	Smelting site, Maore Group B	990 ±105	780 - 1260 AD	ODNER 1971a
Mwanga C (IIIA)	Furnace	560 ± 45	1290 - 1440 AD	STUMP pers. comm.
Mwanga A (I)	Furnace	862 ± 40	1040 - 1260 AD	STUMP pers. comm.
Mwanga G	Tuyere pile	366 ± 45	1440 - 1640 AD	STUMP pers. comm.
Ngalanga Ditch	Iron working site	194 ± 45	1640 - 1960 AD	STUMP pers. comm.
Ngalanga house	House doub	323 ± 45	1450 - 1650 AD	STUMP pers. comm.
Ndiva Llame	Water reservoir	98 ± 30	1680 - 1940 AD	STUMP pers. comm.
Kilimanjaro				
Old Moshi II	Kili. Group C (Maore?)	2200 ±430	1380 BC - 640 AD	ODNER 1971b
Mwika IV	Kwale & Maore	1700 ±330	490 BC - 1020 AD	ODNER 1971b
Matunda	Kili. Group D	510 ±190	1040 - 1960 AD	ODNER 1971b
Marangu College	Kili. Group C & D ?	725 ±180	890 - 1620 AD	ODNER 1971b

A hierarchical society evolved with the ruler from the *Wasuya* clan being assisted by several councils of elders and a new administration consisting in several ministers (*wanjama*) responsible for state affairs, agriculture, initiation rituals and tribute. A key point of the reforms was the introduction of a prolonged (over 6 months) initiation ceremony organised by each clan though supervised by the *Wasuya* clan. A key reason for the initiation ceremony was probably the identity forming process that was a means to incorporate the frequent immigrants and to maintain aligned citizens. The new political system was strongly hierarchical and probably cemented labour divisions between clans, which had been in force long before. Economically, the most important clans remained the *Washana* (blacksmiths), who obtained their pig iron from the *Wafinanga* clan of iron smelters. A further clan is said to have provided charcoal, whereas rituals and celebrations were in the hands of the *Wamare* clan. The strong division of labour, specialization and the hierarchical political organisation with a strong emphasis on kinship and lineage facilitated the emergence of a tribute system and distinguish the Ugweno chiefdom from other societies in North and South Pare.

Throughout the following centuries, several waves of migration to and from Pare are said to have occurred. Similar to the initial immigration of the Ugweno themselves, many but not all of the migrations are reported to be related to famines. The melting pot of Pare assimilated migrants acquainted with farming from Taita, South Pare, Usambara, Nguru, and Kilimanjaro as well as Kamba. An exception was the pastoralist Wambugu clan which probably was forced to evade the pressure of Maasai groups and finally settled in the mountain areas of Usambara and Pare (KIMAMBO 1969; CONTE 1999). The newcomers were allowed to settle in still uninhabited areas and the availability of arable land underlines the lack of any population pressure far into the 19th century, when groups from Kilimanjaro displaced during the Orombe wars found refuge in the northernmost part of North Pare (SHERIDAN 2001).

From his review, Kimambo reasons that long-distance trade passed nearly unnoticed prior to 1860 and North Pare had remained a fairly peaceful place in the first part of the 19th century. When von der Decken arrived in North Pare in 1862, he was impressed by flowering maize and banana fields in the lowlands, and by prospering iron production on the eastern foothills of the mountains. On the other hand, passing of strangers and caravan food supply was less common in North Pare than in the previously visited South Pare as a gun shot, the common 'call for food' signal of the caravans in South Pare, was ignored. Unfamiliar and suspicious of foreigners or aware of the looming changes their presence announced, the Pare people looked at the caravan with distrust and feared that the intruders had disturbed the peacefulness (*mphorere*) of their land (VON DER DECKEN 1869).

During the heyday of the 19th-century caravan trade (1850 to 1880), no historical accounts are available. When Baumann passed through Pare thirty years later in 1890, things had changed. Beside dispersed homesteads, BAUMANN (1890) encountered two with stockade fortified settlements erected at Mashewa (Lomwe area, chief Maguera) and Kiritche (Usangi area, chief Kengia and Naguvu). The diffusion of firearms by Swahili traders and the possibility of acquiring wealth outside the traditional system of dependency and lineage weakened the traditional political and economic power structures. Tensions between two, only recently immigrated clans - the Wasangi and Wambaga - about initiation ceremonies and political influence grew and resulted in violent confrontations and finally the eviction of the Usangi leaders. Violence increased during repeated clashes. Clan chiefs but also independent gangs of young men took advantage of the power vacuum and uncontrolled robbery and slave raiding started. The Pare communities, debilitated by clan rivalries, turned into easy prey for cattle and slave raids of Maasai and Wachagga raiding parties. The shift of the economic focus from subsistence agriculture and cattle herding to ivory and later slave trade is best reflected by the establishment of new markets by Kengia, the victorious Wambaga chief. Particularly the establishment of a slave market attracted the long-distances caravan trade. The situation worsened when in the years between 1870 and 1880 several epidemics devastated Pare and cholera and smallpox took their death toll (KOPONEN 1988b). At the end of the century between the years 1887 and 1892 a strong famine remembered as the *Mnyime* famine hit Pare. Triggered by a probably benignant climatic drought, the devastating famine was the result of the collapse of the political and economic system debilitated by epidemics and warfare exacerbated by the long-distance (slave) trade (KIMAMBO 1969; KOPONEN 1988b; KIMAMBO 1996; SHERIDAN 2001). Thus, the late 19th century is remembered in Pare as *kibonda*: a time of heightened mortality, insecurity and violence (KIMAMBO 1969; SHERIDAN 2001). The incorporation of Pare into the world system by long-distance trade effectively destroyed within a few years a functioning political and economical system based on tradition, kinship, and interdependency.

4.4.3 Colonial Rule and Independence

During German and British colonial rule, the political and economic situation stabilised, but the repeated reorganisation of political leadership further corroded traditional channels of power and organisation. Population began to rise from about 10,000 habitants in North Pare in 1900 to over 100,000 in 1990. Pare, which previous had received immigrants, experienced for the first time male out-migration (SHERIDAN 2001). The decline of local and traditional resource management during colonial administration and the strong influence of central government influence and the lack of management by the new government lead to an open-access situation and consequent resource abuse. Formerly protected areas near water sources and swampy valley bottoms were turned into farmland. Similarly, the corrosion of traditional beliefes and power structures resulted in the encroachment of sacred forests (*mshitu, mpungi*) and communal forest reserves (SHERIDAN 2000, 2004).

4.5 **Production, land use and culture**

4.5.1 Social organisation & Agriculture

The social organisation and the recent political history of North Pare are discussed in depth by KIMAMBO (1968, 1969, 1991) and SHERIDAN (2000, 2001, 2004). In the 19th century, Pare was a hierarchical society with a strong emphasis on kinship and lineage relationships. Nucleated villages were uncommon in Pare, and the settlement pattern was dominated by dispersed farmsteads located in the direct vicinity of the agricultural fields. Although nowadays a predominantly agricultural society, economic wealth and political influence were measured in cattle and oral traditions suggest a long tradition of herding – in the lowlands as well as the uplands. As among the Massai, cattle were the symbol of status and essential to gain respect and influence.

Collected manure is used to fertilise fields, especially the banana groves, located strategically below the cattle stables. Cattle were stall-fed since the late 19th century (VON DER DECKEN 1869) although observations by BAUMANN (1890) suggest that formerly cattle herds were grazing in the empty upland meadows and had been strongly reduced during warfare and political instability at the end of the 19th century and especially by Massai and Wachagga raids (MEYER 1890). Old cattle tracks (*iria*) leading down from the escarpment to the plain, the cattle based Pare calendar, and oral accounts (KIMAMBO 1969; SHERIDAN 2001) show that animal husbandry was far more important in the early 19th century and has declined since the early visits of von der Decken, Baumann and Meyer.

The main crops cultivated in Pare today are maize, banana, plantain, beans, sugar cane, cassava, yams, and several root-crops, as well as few vegetables. Cash crops are nearly absent in the North Pare uplands. Coffee was introduced in colonial times but has never played a similarly important role as on Mt. Kilimajaro. Only a few coffee plantations remain today. Sisal plantations on the other hand are common along the foothills.

Bananas and plantains are an important staple. There is considerable debate about the time and place these major south-east Asian food plants were introduced to Africa (NEUMANN & HILDEBRAND 2009). Linguistic research between the Great Lakes led to the conclusion that cultivation of banana took place in the later part of the first millennium AD (SCHOENBRUN 1993b). Based on phytolith analysis, early dispersion dates around 2,500 BP in Cameroon (MBIDA MINDZIE et al. 2006) and Uganda (LEJJU et al. 2006) have been proposed. Due to the problematic identification of *Musa* phytoliths the broad time frame of introduction still remains unknown (NEUMANN & HILDEBRAND

2009). Nevertheless, banana and plantains played a crucial role in the occupation and cultivation of the submontane forest zone of many of the 'islands of agriculture' in many parts of Africa.

Whereas bananas are grown in permanent often manured plots, other crops undergo crop rotation and short fallow periods betweeen 3 – 5 years (BAUMANN 1891; KOTZ 1922). The traditional cereals sorghum and millet and root crops like yams were replaced by introduced maize and beans. Already in 1861 VON DER DECKEN (1869) had been offered New World crops such as beans, maize, and pumpkins and thirty years later, BAUMANN (1890) and MEYER (1890) describe markets where rice, *Hirse* (sorghum/millet), cassava (*mhogo*), sugar cane, yams, butter and honey were offered. On Kilimanjaro finger millet is known to have been a major pre-colonial crop, but only MEYER (1890) reports *Hirse* (sorghum/millet) from North Pare and BAUMANN (1890) even describes sorghum as very rare. Maize on the other hand was widespread in Pare during the middle of the 19th century, but was not widely cultivated on Kilimanjaro (TAGSETH 2008). The observations of apparent regional differences in food crops might be caused by either incomplete traveller accounts biased by seasonal crop variation but also could reflect different ways of food adoption.

4.5.2 Landesque Capital

Terraces and irrigation furrows are characteristic features of the Pare Mountains. The investment of labour in the construction of landesque capital like irrigation systems and terraces as well as labour intensive tasks like manuring and stall feeding are generally taken as evidence of an intensive agricultural production system aimed to increase agricultural yields (HÅKANSSON 2008; STUMP 2010).

The most apparent landesque capital in Pare is terraces. Different types of terraces can be observed in North and South Pare ranging from simple trash lines (*misingi*) to elaborate stone-lined terraces (*mafinga*) built of fieldstones (SHERIDAN 2001). Although there is no doubt that terraces were constructed by the Pare in the 19th century (BAUMANN 1890:228), the absolute dating of these features turned out quite difficult as most of the present features are either recent or rebuilt. With the incentive of irrigation rehabilitation, development organization (TIP, TFAP, GTZ) have convinced local farmers to construct new and rehabilitate old terraces with explicit aim of reducing soil erosion on the steep cultivated slopes. In consequence, a growing number of new terraces have been established during the last 20 years.

Irrigation systems in North Pare are widespread, but are far from being spatially comprehensive. The distribution of hill furrows is restricted to catchments of sufficient size and elevation to offer reliable water sources such as uphill springs, swamps or permanent streams. Irrigation features are reported from the slope of the high mountains Ngofe, Kindoroko and Kamwalla, where water is available from springs and streams and along the escarpment edge, where water can easily be diverted from streams. On the undulating central Pare upland at Msangeni, Ngweni, and Mruma, however, irrigation is nearly absent. Water reservoirs (*ndiva* in Kipare/Chasu) play a crucial role for both agricultural as well as domestic water supply and irrigation was deeply imbedded in spiritual notions of fertility and gender as well as socioeconomic power structures of land tenure and clientage (SHERIDAN 2001, 2002).

During the 20th century traditional concepts of communal labour and kinship based authority eroded, and out-migration of the male labour force and general economic diversification threatened Pare agriculture and culture. Irrigation features deteriorated until the last decades, when development agencies started to revive upland and lowland irrigation systems in combination with the promotion of soil conservation methods, particularly the (re-)construction of terraces.

In Pare, irrigation is not (and probably never has been) crucial for agricultural production, but allows a secure second growing period, thus playing an important role by enhancing yields. The reasons for the investment of labour in landesque capital to increase yields beyond the necessary is discussed in the following chapter focusing on the establishment of locally restricted islands of intensive agricultural in East Africa.

4.6 Islands of intensive agriculture

Outstanding features of 'landesque capital' such as terraces and irrigation features have early on drawn the attention of European travellers, agronomists, economists as well as historians and archaeologists. The occurrence of these clusters of organised systems of intensive agriculture, distributed unevenly over East Africa has prompted many attempts to explain agricultural intensification in an African context (WIDGREN & SUTTON 2004). Known as "islands of intensive agriculture" they are situated in or closely to ecologically favoured mountain environments, which due to altitude, a temperate climate and enhanced orographic rainfall act as 'water towers' and provide seasonal or perennial water supplies. KOPONEN (1988b) distinguishes between grain-based cultivation in areas of moderate to low rainfall such as plateaus and lowlands, and predominantly banana-based cultivation in well-watered isolated mountain areas.

Grain-based rain-fed agriculture is widely distributed in semiarid lowland plains (e.g. Il Chamus (ANDERSON 1989), Engaruka at the footslope of the Ngorongoro crater highlands (SUTTON 1984; STUMP 2006; WESTERBERG et al. 2010) as well as intermediate highland areas with moderate rainfall like the Mbulu highlands (BÖRJESON 2004, 2007), the Iraqw agriculture in the Irangi Hills (KANGALAWE et al. 2008) and the Pokot and Marakwet in the northern Cherangani Highlands (DAVIES 2008). Specialised agricultural systems based primarily on perennial banana cultivation are found in most of the ecologically favoured mountain areas like Usambara (FEIERMAN 1990), Pare (KIMAMBO 1996; SHERIDAN 2001, 2002; HÅKANSSON 2008), Taita (FLEURET 1985), and Kilimanjaro (TAGSETH 2008). Here the establishment of irrigation systems is an optional investment to secure and increase high returns of seasonal, rain-fed cultivation.

All of the mentioned agricultural centres stand out by the deliberate investment in labour and landesque capital in order to increase or secure yields per unit land (BOSERUP 1965; HÅKANSSON 1989). To achieve higher returns three types of investment are observed:

- labour intensification: weeding, manuring, ridging.
- capital intensification: construction of landesque capital: by means of labour investment long-lasting features such as irrigation reservoirs, dams, and furrows, terraces are established or new land is cleared. Value and returns from the land are increased.
- change in technology: new varieties of crops, ploughing, land use change e.g. agroforestry, shorter fallow periods.

Most options require the availability of labour to be invested in recurrent tasks such as weeding, manuring and ridging as well as one-off labour for construction work, where labour or capital is invested to create long-lasting features to improve and enhance the productivity of the given land e.g. via irrigation, terracing or conversion of unused to cultivated land.

4.6.1 Land degradation as driver of intensive agriculture?

Incentives for labour intensification are strongly debated and several socioeconomic models have been proposed to explain the increased labour investment. (BÖRJESON 2004; WIDGREN & SUTTON 2004; HÅKANSSON & WIDGREN 2007; STUMP 2010). In general terms, agricultural intensification to boost production can be interpreted as a response to food shortage - either due to external factors like climatic fluctuations and recurrent famines or internal changes such as population growth - or the need for surplus production to fulfil the demand of tribute for either social or ritual reasons.

The classical Malthusian explanation (MALTHUS 1809) of population growth and declining yields as a consequence of soil exhaustion and land degradation has been contested by BOSERUP (1965) who suggests that population pressure stimulates inventions and agricultural intensification and hence allows for cycles of population growth. A local variant of the Boserup model, the siege situation, has been suggested for communities unable to expand due to confinement by surrounding hostile enemies or a restricted area of arable land, both leading to the need for local enhancement of food production.

In the East African context and especially in the case of North Pare, land shortage or overpopulation pressure as a driving force to increase yields is unlikely as population densities in the 19th century are assumed to have been very low. (SHERIDAN 2002; DAVIES 2008; HÅKANSSON 2008; HÅKANSSON et al. 2008; STUMP & TAGSETH 2009). Oral traditions collected by KIMAMBO (1969) repeatedly mention migration waves to and from North Pare and the warm welcome for the newly arriving settlers suggests strongly that land was abundant (KIMAMBO 1991; SHERIDAN 2001). BÖRJESON (2007) proposed a different explanatory model, where the creation of landesque capital may have preceded population growth. Based on his work in the Mbulu highlands, Böjerson describes the unintentional creation of terraces by annual tilling along fixed field borders. This process of incremental accumulation of landesque capital results in terraces, however without additional labour investment nor intention nor organisation. In the same vein STUMP (2010) cautions that many assumed deliberate investments for future benefits might be simply necessary for present cultivation and therefore do not represent intentional agricultural intensification. The unintentional creation of landesque capital in turn induces a positive feedback, increases returns, attracts settlers and stimulates population growth and indirectly the growth of local and regional exchange networks.

For North Pare, two further models are particularly important. The first builds on the intrinsic socioeconomic situation of North Pare, the second tries to put the intensification of local cultivation practices into a global context of trade. Against the notion of the incremental and possibly unintentional nature of the creation of landesque capital SHERIDAN (2002) proposes active investment. He reckons that in an immigration country like Pare without shortage of land, the investment in landesque capital like irrigation furrows would attract new settlers. The immigrants would establish a patron - client relation with the irrigation builders, thereby increasing the labour force, tributes and social approval of the founder family of the irrigation system. Following SHERIDAN (2002), the investment in landesque capital and the later returns from dependent farmers would have emerged as an alternative to livestock clientage, which was increasingly threatened by cattle raids during the turmoil of the late 19th century.

In generally however, agricultural intensification in 19th-century East Africa is discussed as having been stimulated by the caravan trade and the incorporation into the economic world system (HÅKANSSON & WIDGREN 2007; LANE 2010). Regions along the caravan routes such as Ugogo (CHRISTIANSSON 1981), Mbulu (BÖRJESON 2004), Pare (KIMAMBO 1969), and Il Chamus

(ANDERSON 1989) experienced an agricultural boom during the second half of the 19th century, when the caravan trade was at its apogee. It seems reasonable to assume that increasing food demand by passing caravans and ivory hunters in the mid-19th century stimulated food production and made labour investment worthwhile.

So far, however, the debates among historians and archaeologists lack firm evidence of the antiquity of the landesque capital. Whereas the rise and fall of recent agricultural centres such as Il Chamus (ANDERSON 1989) can be traced historically, the origin of intensive agriculture and landesque capital in areas with older traditions has been difficult to assess (for example STUMP 2006; WESTERBERG et al. 2010). On Kilimanjaro irrigations systems were well established around 1840 and following oral accounts and indirect genealogical dating TAGSETH (2008) infers that hill furrow irrigation existed since at least the 17th century and certainly before the arrival of the Marangu and Kilema tribes from Ukamba. In the Usambaras, irrigation systems are said to pre-date the establishment of the Kilindi kingdom in the 18th century (FEIERMAN 1990: 65). In North Pare, the age of establishment of hill furrows and water reservoirs is only vaguely remembered and the present inhabitants do not attest a very old antiquity to these features for which 19th-century dates are given (STUMP, pers. comm.).

Intriguing though is the fact that the known construction of irrigation systems and terraces in the 19th century falls together with the observation of widespread land degradation by the early European travellers, which could have triggered the agricultural intensification. Lacking written accounts it is left to archaeological and environmental investigations to study the ways soil erosion, land degradation and the establishment of landesque capital might have been linked. While archaeological investigations are in process, the present study of slope deposits and past erosion focuses on the question of when and if accelerated soil erosion turned into irreversible land degradation and if this could have been a crucial step triggering the intensification of agriculture in North Pare.

5 Methods

5.1 Transect and soil profile placement

Present day agricultural soils and corresponding slope deposits were investigated in three study areas. At each location a soil transect from the hilltop to the valley bottom was established. Each catena covers accretion, transportation and sloughing zone and soil profiles were recorded on the valley bottom, the colluvial footslope, the transportational lower and middle slope and within the erosion zone of the mid-slope and upper slopes.

Selection of slopes for the establishment of soil transects was determined by minimizing the influence of recent human landscaping especially earthworks such as terracing for house construction and road building. Slope morphology determined the approximate location of the slope catena and the soil profiles. Preference was given to concave swale positions. Head slopes more likely to contain a complete sediment record were preferred over nose slopes prone to erosion. For the final location of individual soil profiles preferences of the land owners had to be taken into account.

5.2 Soil description and sampling

Soil pits (0.9 x 1.4m) were excavated to depths between 50cm (paralithic contact) on mid-slopes and maximal 5m at the valley bottom. If bedrock or saprolite were not encountered within the excavated pit, augering ensured recovery and description of deeper sediment deposits.

Soil profiles were described following the guidelines outlined in the World Reference Base for Soil Resources (IUSS Working Group WRB 2007) and the Soil Taxonomy (Soil Survey Staff 2003) and complemented when necessary following the Bodenkundliche Kartieranleitung (AG Boden 1994). Soil description comprised characteristics of horizon boundary, stone content and shape, soil density and humus estimations, and root quantity estimation. Texture, soil structure, biological activity and the occurrence and characteristics of mottles and concretions were recorded (cf. Tab. 3 for soil parameters recorded in the field). Potsherds were collected where encountered and charcoal samples were taken, if suitable amounts could be recovered.

Soil samples were taken from outlined soil horizons and stratigraphic layers, generally every 10cm, and stored in plastic bags. The spacing of auger samples was discontinuous, according to amount and quality of the recovered sample. Recovery was hampered and partly incomplete in saturated sediments below the water table due to sample loss. All samples were initially air-dried in Tanzania. After arrival in York they were oven-dried at about 40°C. Sample aggregates were gently broken down by a mortar to pass a 2mm sieve (Schlichting et al. 1995; Sheppard & Addison 2007).

5.3 Soil colour, pH, and bulk density

Munsell colours are reported for air-dry and moist soil aggregates. pH was determined in the laboratory in a 1:1 water-to-soil ratio. Distilled water was chosen over an electrolyte solution to reflect an electrolyte poor environment of strongly weathered soils (Schachtschabel et al. 1998). Bulk density was determined by measuring the oven-dry weight of samples obtained from sampling rings with a known volume. Further analyses were conducted on the fine earth fraction.

5.4 **Geographical Information System (GIS)**

Free available spatial GIS data was obtained from a range of sources (selection presented in Tab. 4). ArcGIS 9, as the most common GIS program was employed to display and transform the data. Base projection is the UTM WGS84 datum. A hydrological stream network and watersheds were derived from the hydrologically conditioned, pre-processed HydroSHEDS DEM. Panchromatic Spot 5 satellite images were obtained via the OASIS project. Aerial photographs were obtained from the Rhodes House collection, Oxford, with permission of the Director of Surveys and Mapping Division, Tanzania. They were georeferenced to the 5m high resolution Spot 5 image of North Pare (Path 141, Track 357, 31.10.2005).

5.5 **Organic carbon and stable carbon isotope analysis**

Stable carbon isotope analysis was carried out for selected samples only. A subsample of fine earth was dried over night at 105°C and ground with a ball-mill for 3 min at 25 rpm. Between 3 and 50 mg oven-dry samples were weighed into silver capsules. Judging from visible estimation of the carbon content, weights were adjusted to contain similar amounts of carbon (ELLERT & ROCK 2007). Inorganic carbon was eliminated by small-scale acidification following the procedures outlined by ELLERT & ROCK (2007). Up to 50µl of concentrated HCl was added to the samples in silver capsules using a micropipette. After removal of inorganic carbon by acidification and in the absence of geological sources of elemental carbon (e.g. coal, graphite) the remaining carbon fraction comprises organic and charcoal carbon and is referred to as (total) organic carbon (C_{org}).

Organic carbon and $\delta^{13}C$ were measured in a continuous flow isotope ratio mass spectrometer GC-IRMS (Gas Chromatograph – Isotope Ratio Mass Spectrometer) after combustion at 1000°C in a SerCon ANCA-GSL (Automated Nitrogen Carbon Analysis for Gas Solids and Liquids). Samples were measured in triplicates and standard deviations are provided. Overall precision calculated as the average of the standard deviations of triplicates was <0.2‰ for stable isotope and <0.15% for carbon analysis. For several single samples exceptionally large standard deviations were observed, which are ascribed to sample heterogeneity and/or sample loss during acidification. $\delta^{13}C$ values are reported in the standard delta notation (EHLERINGER & RUNDEL 1989):

$$\delta^{13}C_{sample} = \left(\frac{R_{sample}}{R_{s\tan dard}} - 1 \right) \times 1000$$

R_{sample} and $R_{standard}$ refer, respectively, to the molar isotope ratio of the sample and standard e.g. $^{13}C_{sample}/^{12}C_{sample}$. $\delta^{13}C_{sample}$ is the isotope ratio difference between the sample and the PeeDee Belemite (PDB) standard normalised by the standard and commonly reported in parts per thousand [‰]. Sample preparation was done at York; measurement was conducted in collaboration with Dr. Arnoud Boom, Department of Geography, University of Leicester.

Tab. 3: Parameters of soil description recorded in the field. Estimation classes from FAO (2006)

Category	Parameter	Unit	Classes	Reference
Boundary	Distinctness	-	abrupt, clear, gradual, diffuse	FAO, 2006
	Topography	-	smooth, wavy, irregular, broken	FAO, 2006
Rock fragments	Abundance	[%]	Estimation to nearest 5%	FAO, 2006
	Size	mm	2-6, 6-20, 20-60, 60-200, 200-600, >600 mm	FAO, 2006
	Shape	-	flat, angular, subrounded, rounded	FAO, 2006
	Weathering stage	-	fresh, weathered, strongly weathered	FAO, 2006
Humus	-	1-6	Estimation based on humous content and colour	AG Boden, 1994
Colour	-	-	Munsell Soil Color Chart	Munsell, 2000
Soil Structure	Type	-	blocky, subblocky, granular, prismatic, single grain, massive, coherent, rock structure, stratified	FAO, 2006
	Grade	-	weak, moderate, strong	FAO, 2006
Texture	-	-	FAO texture triangle	FAO, 2006
Bulk Density	-	1-5	Estimation based on penetration by knife	AG Boden, 1994
Root Abundance	Fine Roots (<2mm)	n dm^{-2}	none, present, 1-10, 10-20, 20-50, 50+	FAO, 2006
	Coarse Roots (>2mm)	n dm^{-2}	none, present, 1-2, 2-5, 5-20, 20+	modified
Carbonates	Abundance	-	10% HCl-test: non-calcareous, audible effervescence, visible effervescence, foam of bubbles, thick foam	FAO, 2006
pH	-	pH	Hanna HI 98139	-
EC		dS/m	Hanna HI 98139	-
Mottles & Redox Features	Type	-	Redox-Features, Weathering/Oxidation Features	FAO, 2006
	Abundance	%	0, 0-2, 2-5, 5-15, 15-40, >40	FAO, 2006
	Size	mm	<2, 2-6, 6-20, >20 mm	FAO, 2006
	Boundaries	-	sharp, clear, diffuse	FAO, 2006
	Contrast	-	faint, distinct, prominent	FAO, 2006
	Colour	-	Description	-
Concretions / Cementations	Type	-	Redox-Features, Weathering/Oxidation Features	FAO, 2006
	Abundance	%	0, 0-2, 2-5, 5-15, 15-40, >40	FAO, 2006
	Location	-	aggregates, outer aggregates	-
	Colour	-	Description	-
Coats / Films	Type	-	Clay illuviation	-
	Location	-	Description	-
Cracks / Channels	Frequency	n dm^{-1}	Estimation	-
	Depth	cm	Estimation	-
	Width	cm	Estimation	-
Biological Activity	-	-	Description	-
Observations	-	-	Description	-

Tab. 4: Sources of remote sensing data, aerial photographs, satellite images, thematic maps, DEM, and GIS data.

Name	Date	Type	Provider	Source
Maps		Scale		
Topographic Maps (various)	1957-68	1:50.000		War Office and Air Ministry. Directorate of Overseas Surveys, etc.
Geological Maps (various)	1963-75	1:125.000		Geological Survey of Tanganyika
Remote Sensing				
Aerial Photographs 1953/54/57	1953, 1954, 1957	Scanned Image	Rhodes House	Director of Surveys and Mapping Division, Tanzania
Aerial Photographs 1983/84	1983, 1984	Scanned Image	Ministry of Lands	Director of Surveys and Mapping Division, Tanzania
Spot Satellite Images	2002, 2005, 2007	res: 5 & 10m	OASIS	Panchromatic Spot 4 & 5 satellite images
Landsat MSS, TM, ETM Satellite Images	1957, 1987, 2001	res: 30, 60m	GLCF	NASA Landsat Program, 2003
Digital Elevation Models				
SRTM DEM, hydrologically conditioned	2007	res: 3'', (90m)	HydroSHEDS	HydroSHEDS, conditioned elevation for hydrological analysis
SRTM DEM, preprocessed CGIRAR v4	2007	res: 3'', (90m)	CGIAR	CGIAR-CSI SRTM dataset
DEM derived				
Stream Network for NE Tanzania	2009	Shapefile	-	HydroShed derived Stream Network for NE Tanzania
Stream Network for North Pare	2009	Shapefile	-	HydroShed derived Stream Network for North Pare
North Pare Basins/Watersheds	2009	Shapefile	-	HydroShed derived Basins of North Pare
Pangani Watershed	2009	Shapefile	-	HydroShed derived Watershed of the Pangani Basin
GIS Data				
Administration boundaries - Tanzania	1998	Shapefile	ILRI	International Livestock Research Institute (ILRI)
Administration boundaries - Kenya	1998	Shapefile	ILRI	International Livestock Research Institute (ILRI)
Forest Areas - Tanzania	-	Shapefile	ILRI	International Livestock Research Institute (ILRI)
Protected Areas		Shapefile	UNEP/IUCN	World Database of Protected Areas (WDPA)
SOTER		Shapefile		SOil and TERrain Digital Database
Archaeological Sites	2009	Shapefile	BIEA	Map Annotation on BIEA maps (presumably Soper)
Fieldwork GPS points	2009	Shapefile	Fieldwork	Study Sites

5.6 **Particle Size Analysis**

A combined sieving and pipette method as outlined by SCHLICHTING (1995) and KROETSCH AND WANG (2007) was applied. An oven-dry subsample of about 20g fine earth (<2mm) was pretreated with 30% hydrogen peroxide (H_2O_2) in to remove organic matter. The reaction was accelerated by gentle heating in a water bath. Dispersion of fine aggregates and clay minerals was achieved by shaking overnight in a solution of sodium metaphosphate and sodium carbonate (SCHLICHTING et al. 1995; KROETSCH & WANG 2007). Sand fractions were separated from the fines by wet sieving trough stacked sieves. The remaining silt and clay fraction was quantitatively transferred into 1l cylinders agitated with a plunger for about four minutes and left to settle down. At temperature dependant time intervals, small aliquots of suspended fines were extracted using a pipette (GUTACHTERAUSSCHUSS FORSTLICHE ANALYTIK 2005). The fractions were oven dried and weighed. After correction for the amount of dispersion agent and sample loss, the proportional amount of the silt and clay fractions were calculated.

Upland samples show pH values <6 and therefore absence of carbonates could be safely assumed. Iron oxides and iron coatings are common in tropical soils. Removal of iron oxides by sodium hydrosulphite treatment was not pursued, however. The results therefore are biased towards larger particle sizes. Given the predominance of clays the overestimation of particle size may not affect classification but may obscure clay translocation.

5.7 **Magnetic susceptibility parameters**

Magnetic susceptibility (χ_{lf}) was measured on a Bartington MS2B Dual Frequency Magnetic Susceptibility System at the University of York. Air dry subsamples of bulk soil were transferred to 10cm² cylindrical bottles and measured for magnetic susceptibility in a constant applied magnetic field (DEARING 1994). The obtained volume magnetic susceptibility κ [-] was transformed to mass specific susceptibility χ_{lf} [$m^3\ kg^{-3}$] by accounting for the known bulk density of weighted 10cm² samples. To obtain the coefficient of frequency dependency ($\chi_{fd\%}$) magnetic susceptibility was measured at two different frequencies 4.65 kHz (χ_{hf}) and 0.465 kHz (χ_{lf}) of the external magnetic field (DEARING 1994). The susceptibility reduction at higher frequencies is expressed as percentage frequency dependent susceptibility $\chi_{fd\%} = (\chi_{lf} - \chi_{hf})/\chi_{lf}$ x 100.

5.8 ^{14}C **AMS radiocarbon dating**

Charcoal and humin fraction of soil samples were dated by measuring the decay of unstable ^{14}C at the Waikato Radiocarbon Dating Laboratory, New Zealand and at the Centro di Datazione e Diagnostica (CEDAD) at the Dipartimento di Ingegneria dell'Innovazione, Università del Salento, Italy. Samples for radiocarbon dating were cleaned, oven dried at 105°C, weighed and submitted wrapped in aluminium foil. Laboratory pre-treatment for charcoal and soil samples included mechanical cleaning of visual contaminates like obvious recent roots and a chemical pre-treatment by acid-base-acid (ABA) wash to remove carbonates and chemical contaminants. Treatment of soil samples and bulk peat samples by acid-base-acid separated the insoluble and generally older humin fraction from the mobile humic and fulvic acids (HIGHAM 2002).

Conventional radiocarbon dates are reported as ^{14}C years BP and are calibrated using the OxCal online radiocarbon date calibration program at http://c14.arch.ox.ac.uk (RAMSEY 1995). Calibration is based on the international radiocarbon curve IntCal 09 (REIMER et al. 2009). Calibrated dates are rounded to decades and are reported as years BP, ka BP, or years BC/AD.

5.9 **Optical-stimulated luminescence dating**

5.9.1 Sampling and sample preparation

Samples for OSL dating were taken using black plastic gutter pipes and wrapping the samples in light-proof plastic bags (BATEMAN & ARMITAGE, pers. communication). Sample preparation was done according to the standard sample preparation protocol of the SCIDAR laboratory, University of Sheffield (BOULTER & BATEMAN 2008). Pure quartz samples were obtained under subdued red light using a series of cleaning steps involving the removal of carbonates, organic matter and finally separation of the coarse sand fraction 90-250µm. Quartz was extracted by heavy liquid separation using sodium polytungstate (density 2.7 g cm^{-3}) from either the 90-180 or the 125-180 µm size fractions. Quartz samples were than etched for one hour with 40% HF to remove the alpha radiation affected outer layer of the quartz grains (10µm) and to eliminate potential feldspar contamination. The purity of quartz grains was checked by stimulation of a subsample with infrared light and recording of an infrared stimulated luminescence signal.

5.9.2 SAR protocol and dose recovery preheat test

A single aliquot regenerative (SAR) dose protocol (MURRAY & WINTLE 2000, 2003) was applied to determine the equivalent Dose (D_E). Subsequently growth curves were established measuring five regeneration points including a zero dose to monitor recuperation of charge and a recycling point, which was used to check the sensitivity correction procedure (WINTLE & MURRAY 2006). For each sample between 24 and 35 single aliquots were measured. Aliquots with a recycling ratio outside 1 ± 0.1 were discarded. Samples were mounted on 9.8mm aluminium discs and measured by an upgraded TL-DA-12 luminescence reader (Risø National Laboratory, Roskilde, Denmark). A 150 W Halogen lamp filtered by a Schott GG-420+ SWP interference filter provided optical stimulation. Quantification of luminescence was done by a Thorn EMI 9235QA photomultiplier tube preceded by a 5mm Hoya-340 filter. A $^{90}Sr/^{90}Y$ β-source (0.061 Gy s^{-1}) provided irradiation. Detailed descriptions of the SAR protocol, recovery preheat tests and data analyses are given in the Appendix D.1.

5.10 **Loss-on-ignition**

Sequential loss-on-ignition (BALL 1964; DEAN 1974) is a cost effective standard method to estimate organic and inorganic carbon content of a soil or sediment sample (HEIRI et al. 2001; BENGTSSON & ENELL 2003; SANTISTEBAN et al. 2004). In the present study it was envisaged that loss-on-ignition (LOI) could be applied as a rough and fast estimation of the organic matter content of colluvial deposits.

Loss-on-ignition protocols differ significantly between laboratories; therefore a standardised methodology proposed by HEIRI et al. (2001) was adopted. The amount of organic matter was determined by weight loss after ignition at 550°C. Samples and empty crucibles were oven dried at 105°C overnight and cooled down in a desiccator. Crucibles were weighed and about 3g of soil was added. Samples were placed in a muffle furnace, gradually heated and ignited for 4h at 550°C. Hot crucibles were placed in a desiccator using tongs and weighed when cooled to room temperature to obtain the weight percent organic matter.

5.11 **Charcoal analysis by nitric-acid-digestion**

The quantification of charcoal followed the nitric acid digestion method proposed by WINKLER (1985) and modified by VERARDO (1997) and KURTH et al. (2006). Quantification of carbon was determined by element analysis (LAIRD & CAMPBELL 2000) to obtain absolute amounts of nitric-acid-resistant carbon (NARC). To digest the organic matter, between 0.5-3g of ground oven dry sample was transferred to Kjedahl test tubes. Concentrated nitric acid was added in steps to a total amount of about 20ml. After the initial reaction has slowed down the tubes were placed in a heating block and left to digest for 2 hours at 75°C (LAIRD & CAMPBELL 2000). The samples were then quantitatively transferred to centrifuge tubes, centrifuged and washed three times with deionised water until supernatant run clear. The residua were dried overnight at 105°C, cooled down in a desiccator and weighted to obtain sample weight after digestion. After homogenisation, a subsample was measured for elemental carbon content by a Vario CN-element analyzer, at the Environmental Department, University of York. The initial amount of nitric-acid-resistant-carbon is calculated taking into account the weight loss during digestion. Nitric-acid-resistant carbon was determined for samples from the Lomwe Swamp core and the soil profile Lomwe 10.

5.12 **Pollen analysis**

Along the 438cm long core, 45 subsamples were prepared and pollen types were identified by Veronica Muiruri at the Palynology and Palaeobotany Laboratory, National Museum of Kenya, Nairobi. Pollen preparation followed the standard pollen concentration method as outlined by (FÆGRI & IVERSEN 1989). Pollen grains were counted and identified on one slide per sample using a Leitz microscope at x400 magnification.

5.12.1 Pollen sum

Pollen data is presented as relative proportions of a pollen sum (BIRKS & BIRKS 1980; FÆGRI & IVERSEN 1989) based on arboreal and non-arboreal plant taxa including Poaceae. These taxa are expected to be derived predominantly from non-local vegetation, although vegetation of the basin bottom might have contributed during drier periods. Swamp taxa, aquatics, spores and taxa, which are likely to be dispersed unevenly and aberrantly due to the close vicinity of the pollen producing plants or to their particular dispersion mechanism, are excluded from the pollen sum to avoid distortion of the pollen diagram (FÆGRI & IVERSEN 1989). At Lomwe, the local swamp vegetation is represented by Cyperaceae, Liliaceae, *Ludwigia*, *Hydrocotyle,* and *Typha*, and omitted from the pollen sum. Monolete (reniform) and trilete spores and entomophilious Asclepiadaceae are excluded from the pollen sum.

Taxa excluded from the pollen sum are reported as percentages of the pollen sum plus themselves (BIRKS & BIRKS 1980; FÆGRI & IVERSEN 1989). No attempt was made to calculate separate pollen sums for local (basin bottom or slope vegetation) and non-local (regional) pollen types as proposed by MARCHANT & TAYLOR (2000), as the segregation of a possible dry basin bottom vegetation can not be based on objective criteria.

5.12.2 Pollen diagram

Pollen diagrams were constructed using C2 (JUGGINS 2007). According to their published ecological affinities (COETZEE 1967; GREENWAY 1973; LIND & MORRISON 1974; WHITE 1983; LOVETT 1993b; LOVETT & PÓCS 1993; MARCHANT 1997; MARCHANT & TAYLOR 2000; DHARANI 2002; LOVETT et al. 2006a) taxa were grouped into broad ecological classes:

- arboreal taxa typical for montane and submontane forest of the Eastern Arc Mountains,
- arboreal taxa common in semi-arid bushland and woodland possibly derived from the lower slopes and foothills of the Pare Mountains as well as by long-distance dispersal from the lowland plains of Tsavo and Mkomazi,
- arboreal, non-native, introduced forest taxa
- non-arboreal taxa of shrubs and herbs, loosely grouped according to their :
  - affinity to montane forests,
  - reported occurrence in woodlands, clearings, and glades and
  - possible association with anthropogenic disturbance or cultivation
- wetland taxa, including Cyperaceae, and insect pollinated Asclepiadaceae.
- spores.

To facilitate presentation, pollen types with low abundances are excluded from the pollen diagram (GORDON & BIRKS 1972). Only taxa with a maximum percentage of more than 2% and occurring in more than one sample are presented (29 out of 72 taxa). Pollen types only occurring within one slide (i.e. one depth) cannot confidently be used as palaeoecological indicators for past environments. Additionally, a lack of representativeness due to low absolute pollen counts and strong domination by single species led to the exclusion of the seven lowermost samples below 360cm depth.

5.12.3 Numerical analysis: Zonation and ordination of pollen data

Numerical methods offer a consistent and reproducible way of analysing stratigraphic change without the use of *a priori* information about the process involved in its formation and therefore reduce the bias introduced by subjective zonation (BIRKS 1986). To facilitate presentation and interpretation of the data, pollen zones of similar and uniform pollen assemblages were delimited by numerical zonation. The pollen zones suggested by depth-constrained cluster analysis were then independently confirmed by a non-constrained ordination method (GORDON & BIRKS 1972; BIRKS 1986).

Pollen zones of the Lomwe Swamp were identified by using the CONISS - Constrained Incremental Sums of Squares cluster analysis (GRIMM 1987) - a hierarchical and agglomerative procedure implemented in the psimpoll program (BENNETT 2009). Before calculation of the dissimilarity matrix, proportions were recalculated and a square root transformation down-weighted abundant and up-weighted less common taxa in order to reduce the influence of outliers (BIRKS 1986; GRIMM 1987; 2009). In combination with the applied dissimilarity matrix of squared Euclidean distances (also minimum variance or Ward method), the square root transformation results in the chord distance of Edwards and Cavalli Sforza (PRENTICE 1986; GRIMM 1987). The zonation algorithm minimizes the within-zone dispersion (sum of squares) or the mean within-zone dispersion (variance) of the clusters to be formed (GRIMM 1987). In a palaeoecological context, zonation has to be stratigraphically constrained and grouping of samples is limited to adjacent samples in the direct stratigraphic vicinity.

As a non-constrained ordination method, principal component analysis (PCA) was carried out using PCOrd (MCCUNE & MEFFORD 1999). A linear relationship of species abundance and principal factors suggested PCA over detrended correspondence analysis (DCA) more suitable for unimodal species distribution. PCA ordinates samples in a more dimensional space and axis are chosen so as to minimise the sum of squared distances from the points to the axis (PRENTICE 1980; PRENTICE 1986). The cross product matrix was calculated via a correlation matrix, which transforms the original data to be centred and standardised to unit standard deviation. This approach assures that all species are treated as equally important (GREIG-SMITH 1983). The 'arch'-effect, a common problem of ordination methods when the data set shows a gradual species turnover was not observed (PRENTICE 1986; JONGMAN et al. 1987).

For coherence, data preparation for statistical analysis followed the same criteria as for the pollen diagram. In addition, local wetland taxa and spores were excluded as zonation of the non-local pollen is aspired.

5.13 **Phytolith analysis**

Phytoliths were extracted and classified for 40 samples from the Lomwe swamp core by Veronica Muiruri at the Palynology and Palaeobotany Laboratory, National Museum of Kenya, Nairobi. Phytoliths extraction followed standard procedures outlined by (PIPERNO 2006). In brief, about 10-20g of sediment is shaken overnight for 24h in a dispergent agent (EDTA/Calgon) to deflocculate clay minerals and organic components. The sand fraction was segregated by wet sieving through a 250µm sieve and clays were separated by repeated gravity sedimentation. Organic matter destruction was done by cooking in concentrated nitric acid spiked with a small amount of potassium chlorate ($KClO_3$). Phytoliths have a specific gravity of 1.5 - 2.3gcm^{-3} and are separated from the mineral fraction (quartz 2.65gcm^{-3}) by heavy liquid separation. The density of the heavy liquid (zinc bromid or sodium polytungstate) is adjusted to 2.3gcm^{-3} and phytoliths floating on the surface are extracted washed and dried in Acetone/Ethanol and mounted on microscope slides using benzyl benzoate.

5.13.1 Phytolith classification

Phytolith types were identified and named according to the ICPN classification (MADELLA et al. 2005). Phytoliths were grouped following the classifications discussed by MULHOLLAND & RAPP (1992), PIPERNO (2006), BREMOND et al. (2008), and NEUMANN et al. (2009) and important categories are summarised in Tab. 5.

- Hair cell and hair base phytoliths are commonly produced in grasses but also by eudicots, where they occur predominantly in seeds, fruits, and leaves. Typical families include Asteraceae, Boraginaceae, Cucurbitaceae, Dilleniaceae, Moraceae, Ulmaceae, and Urticaceae.
- Globular spheres with a variety of decorations are produced in a wide range of arboreal and herbaceous monocots and eudicots but have not been isolated from grasses and therefore are indicative of forested landscapes. Spheres of monocts and eudicots tend to vary in sizes, whereas globular echinate spheres are diagnostic for palms.
- Sclerenchyma phytoliths are almost completely restricted to trees and shrubs and therefore a good indicator of forest or wooded vegetation.
- Silica bodies or short cell phytoliths are characteristic for grasses. Grass (leaf) phytoliths occur in a wide range of shapes. Generic grass phytoliths include long cells, parallepipedal and cuneiform

bulliform cells, stomatal and interstomatal cells of leaves, trichomes and hairs, and are produced in varying amounts with little use for identification (PIPERNO 2006). Short cell grass phytoliths - silica bodies *sensu strictu* (MULHOLLAND & RAPP 1992) – are derived from specialised silica accumulating cells of the Poaceae family and have a certain diagnostic value on subfamily level.

Grass phytoliths were grouped following published classification keys and plates (TWISS et al. 1969; TWISS 1992; FERNANDEZ HONAINE et al. 2006; PIPERNO 2006) and directly assigned to a corresponding Poaceae subfamily (Tab. 5). This direct assignment process of phytolith types to specific subfamilies has obscured the classification approach, as the original geometric forms of the grass short cell phytoliths are not recorded. Thus, interpretation of the data is considerably limited and complicated as comparison with other studies based on the original data is not possible.

Tab. 5: Phytolith categories. a) Type, common subcategories and possible anatomic origin are given for the main phytolith types following (MULHOLLAND & RAPP 1992; PIPERNO 2006; BREMOND et al. 2008; NEUMANN et al. 2009). b) Grass short cell phytolith types (silica bodies).

a)	Type	Subcategories	Origin
Poaceae	silica bodies	rondel, trapeziform, bilobate, polaylobate, saddle, cross	silica accumulating cells of grasses
	bulliform cell	cuneiform, parallepipedal, rounded	long cells (epidermis of grasses)
	elongate cells	smooth, sinuated, lobate, echinate etc.	
Ligneous Eucots	sclerenchyma	rods, cylindrical cells, rectangles, squares, large blocky	sclerenchyma, sclereids, fibres, xylem cells
	spherical bodies	globular psilate, decorated, facetted, echinate	woody & herbaceous plants
Non-diagnostic	trichomes & Hair cells		trichomes, hair base cells, prickles, edge spines, papillae
	stomatal complex		stomatal complex
	tabular	tabular, rectangular, thin	epidermal groundmass cells
	rectangles and squares	large, blocky, 3D, parallepipedal	

b) Type	Subcategories	Subfamily
Rondel	-	Pooideae, Bambusoideae
Trapeziform short cell	-	Pooideae
Trapeziform sinuate	-	Pooideae (Chloridoideae, Panicoideae)
Bilobate	panicoid,	Panicoideae,
	chloridoid,	Chloroideae
	erhartioid,	Erhartioideae
	stipa type (pooid)	Pooideae,
	aristoide,	Aristoideae
	-	Bambusoideae
Polylobate	crenate	Pooideae
Saddle	squat, plateau, tall	Chloroideae
Cross	-	Panicoideae, Bambusoideae

6 ARCHIVES OF SOIL EROSION IN NORTH PARE

Three lines of evidence are used to reconstruct landscape development and past soil erosion in North Pare. Soil surveys of selected slopes allowed the qualitative assessment of the overall degree of soil erosion across North Pare based on the comparison of the present soil resources of agricultural lands with soils of the remaining forest fragments and highland forests (chapter 6.2 & 6.3). The main research on slope deposits of three different valley basins at Lomwe, Mrongo, and Usumbwe (Fig. 15, chapter 6.4) provided more detailed and chronological information on past slope processes. The terrestrial soil erosion record is complemented by the palaeoecological analysis of a valley swamp at Lomwe with insights into the late Holocene vegetation dynamics of an anthropogenic landscape (chapter 6.5).

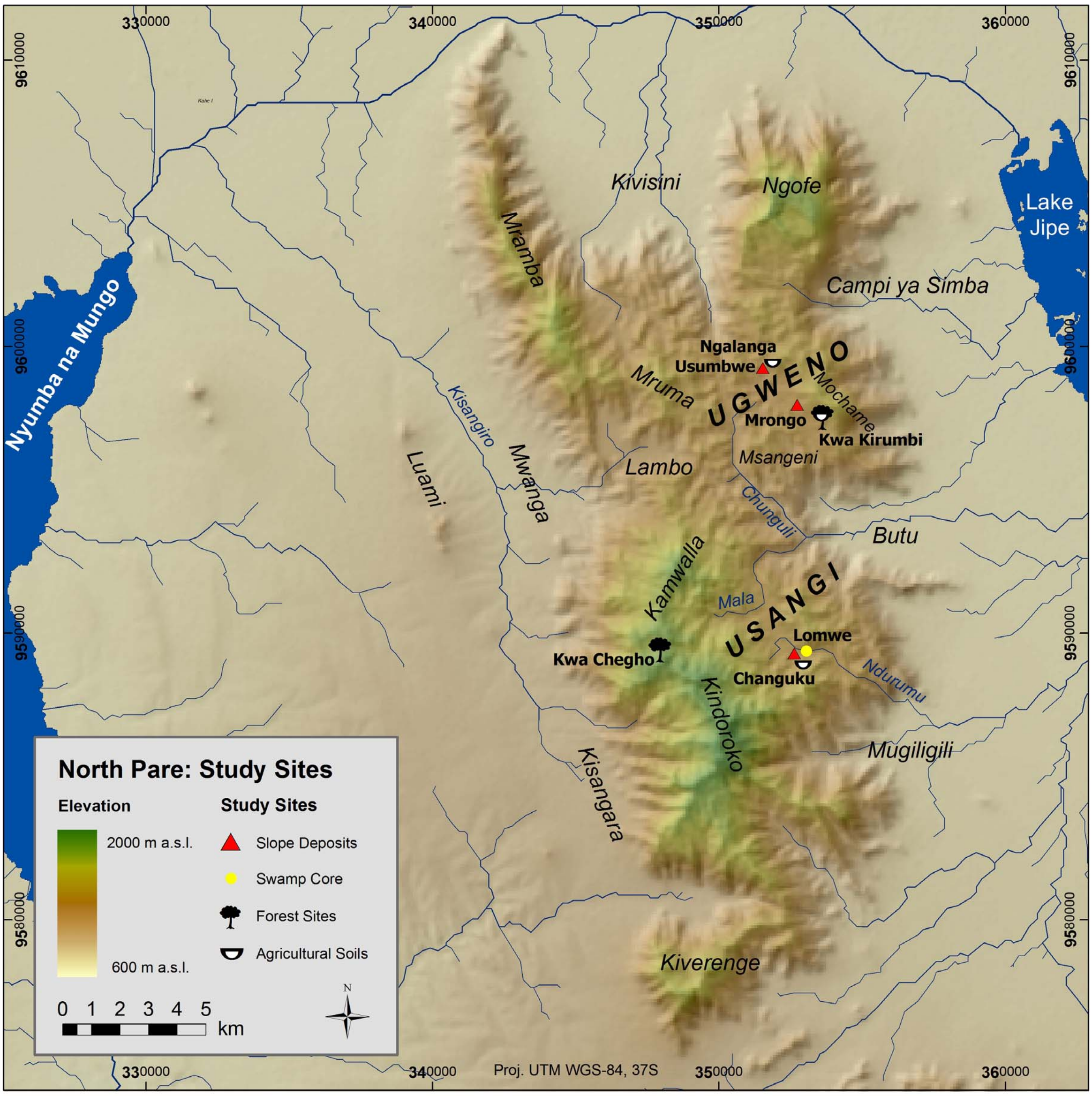


Fig. 15: Study areas in the North Pare Mountains. Slope deposits are studied at Lomwe, Mrongo and Usumbwe (red triangles). The Lomwe swamp core (yellow circle), and soil surveys at forest sites Kwa Chegho and Kwa Kirumbi (tree) and at agricultural slopes (half circle) are indicated.

6.1 Study areas

The present study focuses on the anthropogenic aspect of landscape development. The study sites were thus deliberately placed in areas shaped by agricultural land use and were distributed to cover a large (Lomwe), medium (Mrongo) and a small (Usumbwe) valley basin within the undulating upland plateau between 1200 and 1400m a.s.l.

The core settlement areas of the Pare chiefdoms Ugweno (Mrongo and Usumbwe) and Usangi (Lomwe) have been important cultural and political centres during the last 400 years (KIMAMBO 1969) and were chosen for geoarchaeological investigations of past human land use. Oral traditions collected by KIMAMBO (1969) emphasise the cultural and potentially archaeological (CHAMI 1995a) importance of Ugweno (Fig. 16). Two sites were investigated in Ugweno, the heartland of the Pare settlement: Mrongo, in the Masumbeni valley and Usumbwe, downslope of the prominent Ngalanga hill. The Ngalanga hill is the mythical origin of the Washana clan (Iron smelter) and thought to be one of the first settlement foci of the Pare occupation (KIMAMBO 1969). Locally informed archaeological surveys of the HEEAL project revealed a number of former iron smelting sites in the Ngalanga area.

Following the oral histories collected by Kimambo, immigrants from South Pare settled much later in the flat Usangi valley suggesting a slightly different settlement history of the southern and northern areas of North Pare (KIMAMBO 1969). Slope deposits were investigated at Lomwe, a small extension of the southernmost part of the Usangi valley, after a survey revealed a buried peat layer under a now partly dry valley bottom. The survey was extended along the Changuku hill to study recent soils on agricultural fields. Additionally, a core was extracted from the small Lomwe swamp and subjected to palaeoecological investigations.

In both Ugweno and Usangi, landesque capital is present. Irrigation reservoirs (*ndivas*), furrows (*msingi*) and also terraces are widespread in the Usangi valley but also occur frequently along the eastern escarpment in the Ugweno region. On the grounds of a known settlement history and anthropogenic landscape transformations (KIMAMBO 1969; SHERIDAN 2001) the areas of Ugweno and Usangi were given preference over the Mruma and Lambo basins in the north-eastern part of the Mountain range, which appear to have been less important as settlement centres (but see FOSBROOKE 1954 for archaeological evidence of market activities at Mruma).

6.2 Agricultural soils and eroded lands

Most of the Pare upland is under cultivation and densely settled. The intensity of cultivation varies and a mosaic of agricultural land use types can be observed. Perennial banana groves located generally near or downslope of homesteads and often irrigated, alternate with annually cultivated maize fields, small horticultural plots or perennial grasses providing cow fodder. Terracing and irrigation are common, particularly in the Usangi area. Evidence of soil erosion can be observed widely, particularly subsoil and saprolite exposure indicating advanced land degradation. Soil erosion varies considerably between fields according to the local land use history and the geomorphological landscape position.

To obtain a general overview about soil types and erosion stages of soils under different land use types, exemplary soil profiles were established on slopes above the study areas Usumbwe/Ngalanga and Lomwe. In each study area, a set of soils were selected representing the dominant land use and soil type. These were, in the first instance, well-managed banana groves (Kwa Kirumbi 6, Ngalanga 2) and agricultural fields on eroded slopes (Kwa Kirumbi 5, Ngalanga 3, Makongweni, Changuku 1, Changuku 2, Fig. 15).

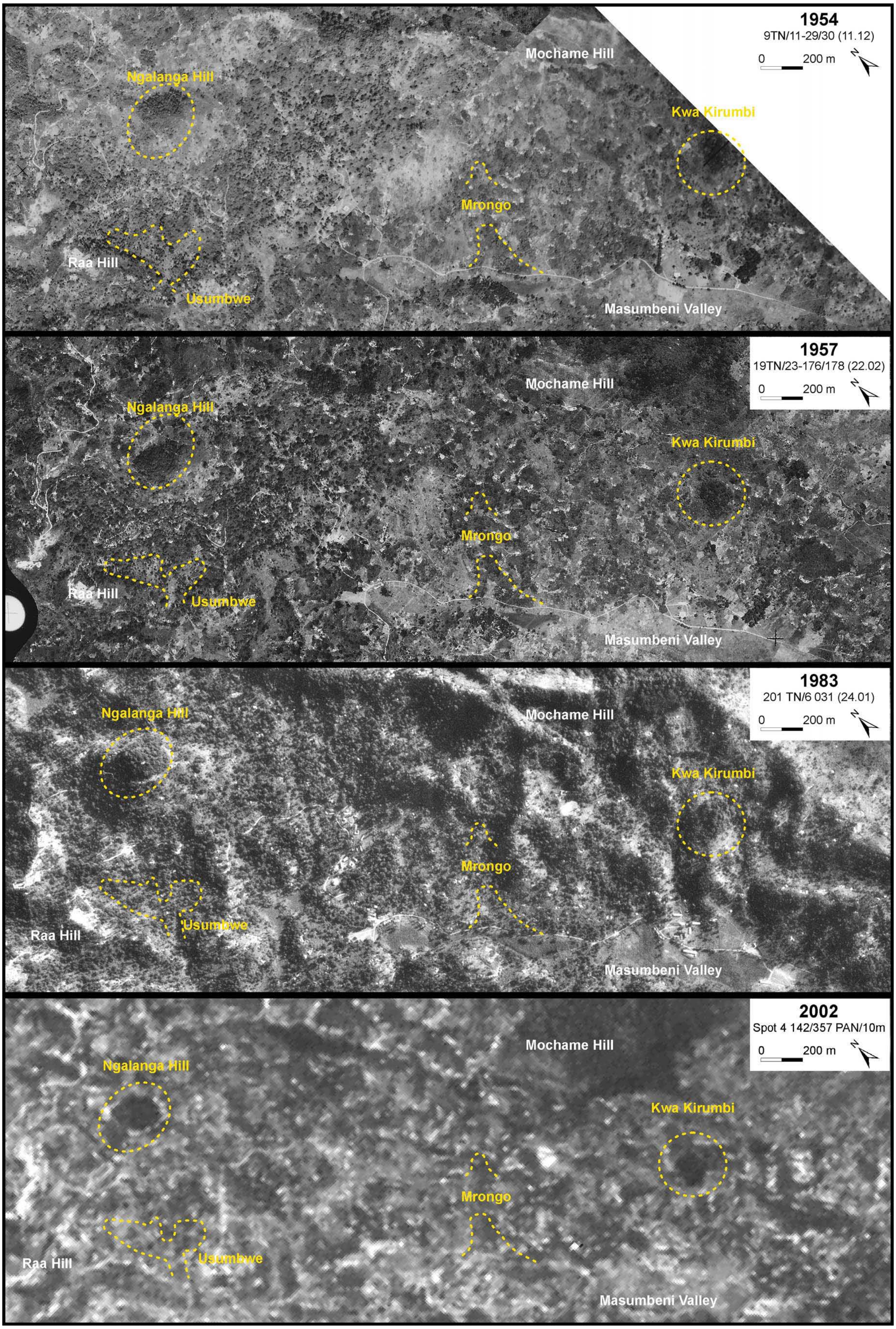


Fig. 16: Multitemporal aerial photograph comparison at Ugweno. Study areas Mrongo (slope deposits) and Kwa Kirumbi (soils of a forest fragment) along the Masumbeni valley and Usumbwe (slope deposit) and Ngalanga and Raa Hill (both eroded agricultural soils) are outlined.

Although from different locations within North Pare, they present a comprehensive overview of soil types and degradation stages in the study area. The severity of soil erosion varies and only a general, qualitative picture can be presented here. A quantitative analysis of land degradation stages is not within the scope of this study.

6.2.1 Ngalanga (Usumbwe)

Soil profiles were established along the western slope of the Ngalanga hill (Fig. 16, Fig. 17), high above the slope deposits of the Usumbwe valley bottom. The profiles provide a landscape-scale picture of the environmental impact of iron-smelting and soil erosion on the Ngalanga hill. Just outside the sacred forest of Ngalanga (~1ha across the top of the hill), the profile **Ngalanga 1 (forest edge)** was recorded, as access to the forest itself could not be obtained (for detailed soil profiles see Appendix B.4.). After forest clearing, typical features of a forest soil, such as an organic layer and an organic matter rich topsoil, have been eroded away. Despite considerable recent disturbance and erosion, the profile shows preservation of deep (about ~2m thick) subsoil over strongly weathered saprolite and gives some insights to the characteristics of the soil within the adjacent forest. Most remarkable is the deep red upper subsoil horizon. Below 65cm, the former rock structure is readily discernable from aligned unweathered rocks. The relatively thin soil profile compared with the forest soils of Kwa Kirumbi (chapter 9.2) suggests that not only the topsoil but also parts of the subsoil have been eroded.

A few hundred metres downslope, the **Ngalanga 2 (banana grove)** profile was established in a banana plantation, about 20m below a house platform. The profile on the steep slope is shallow and shows a complex history. A dark topsoil developed in colluvial material overlying a truncated subsoil (B/C horizon). The original red subsoil has been eroded away and only pockets are left within the B/C horizon. The exposed saprolite reflects the original rock structure and shows two different rock types according to the original metamorphic bedrock. Following severe erosion and the truncation of the original soil profile, about 40cm of colluvial material eroded from further upslope has accumulated and allowed the development of humus rich topsoil. The development of comparatively deep topsoil on this steep slope after the removal of the original soil shows that soil degradation can be reversed by agricultural practices, in this case by re-establishing a dense vegetation cover including shade trees and by reduced tillage. However, the contribution of colluvial material is the predominant factor at this site.

On an open ridge, the effect of different land use types on soil erosion and land degradation is exemplarily shown. The profile **Ngalanga 3 (eroded ridge)** straddles two neighbouring fields of different land use. The northern field is under permanent grass vegetation for fodder, whereas the southern one is tilled and used for annual crops (e.g. maize). Since the establishment of the maize field, sheet and rill erosion have resulted in the removal of about 25cm of soil in comparison to the adjacent grass plot with a dense perennial ground cover. Removal of fines by running water has favoured the formation of a stone pavement. Whereas the grass field shows the residual accumulation of about 10% gravel, stone cover on the surface of the maize field increases to about 30%. Additionally, erosion within the tilled maize field is severe (5 - 10cm deep rills). According to the observed severe soil erosion on the ridge, the soil profile is very shallow. A few centimetres thick, slightly humic cultivation horizon (Ap 1) overlies an also tillage-affected Ap 2. A transitional B/C horizon follows from 30 to 100^{+}cm. The original soil has been entirely eroded away and only the lowermost transitional horizon remains. The direct comparison of two different land use practices shows the devastating effects of repeated tillage on steep slopes but demonstrates, on the other hand, how erosion on degraded plots can be reduced while producing fodder.

Profiles **Ngalanga 4 & 5** show strong colluvial deposits and are discussed together with the slope deposits in chapter 6.4.2.

6.2.2 Makongweni: Strongly eroded Eucalyptus coppice

Planted *Eucalyptus* forests are common on slopes and hilltops all over North Pare and especially in the Ugweno hills. Contrary to the initial assumption of a closed forest offering protection against soil erosion, these *Eucalyptus* coppices frequently occur on strongly eroded slopes or hilltops. The coincidence of *Eucalyptus* forests and strongly degraded slopes has given rise to the question as to whether the slopes were eroded before the planting of *Eucalyptus* or if the *Eucalyptus* itself is responsible for accelerated erosion. On a hilltop (cf. Fig. 16 & Fig. 17) overlooking the adjacent Usumbwe valley several exposures where investigated in an attempt to answer this question.

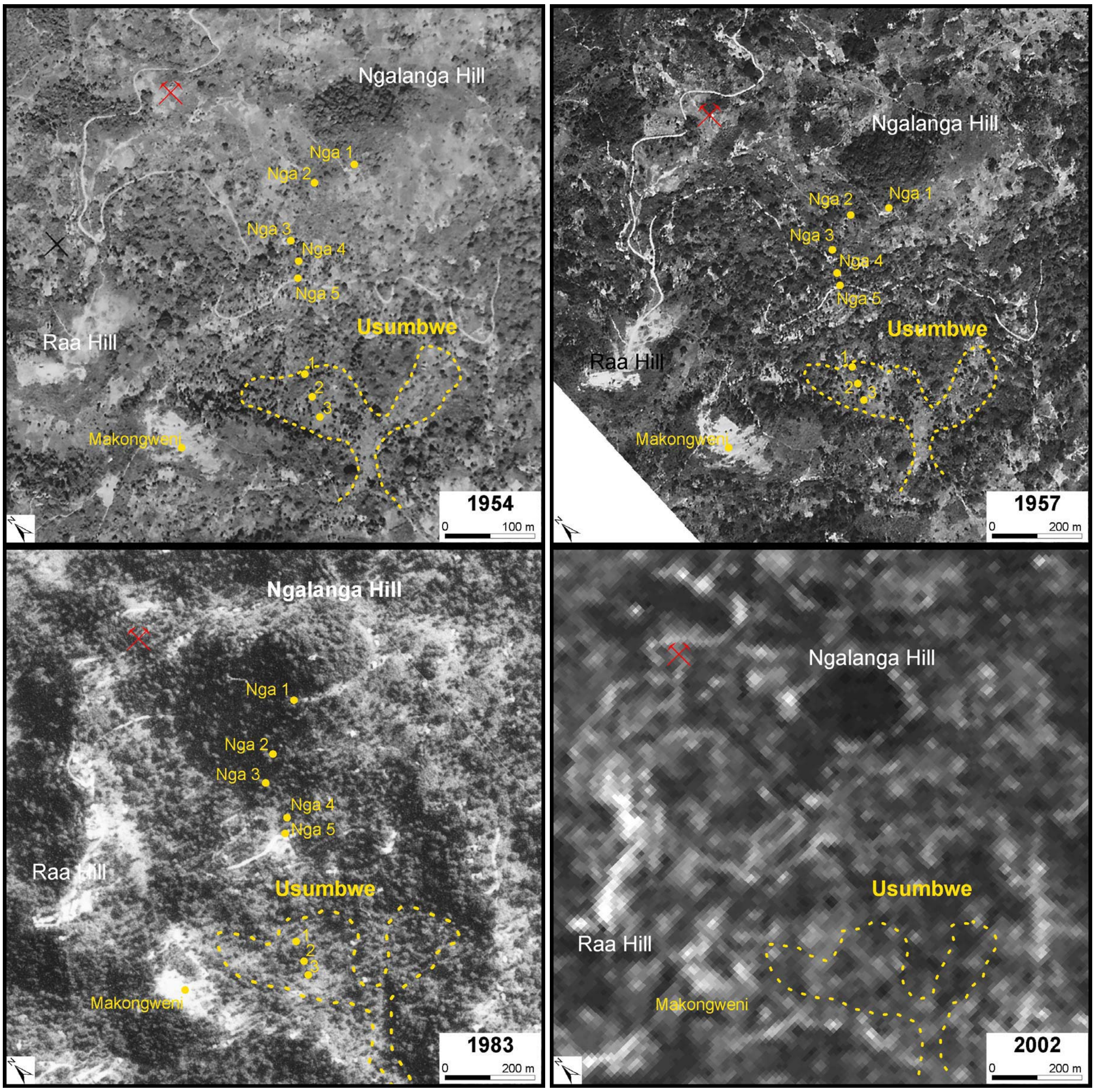


Fig. 17: Multitemporal aerial photograph comparison at Usumbwe/Ngalanga. Outlines of the Usumbwe valley (dotted yellow line) are plotted. Soil profiles: 1 – Usumbwe 1, 2 – Usumbwe 2, 3 – Usumbwe 3; Nga – Ngalanga; red cross: iron smelting site investigated by STUMP (pers. comm.). Sources: Aerial photographs: 9TN/11-29 (11.12.1954), 19TN/23-178 (22.02.1957), 201TN/6-031 (24.01.1983), Satellite Image: Spot 4, 143-357 PAN, 10m (10.09.2002)

Within the *Eucalyptus* forests, undergrowth is generally missing and thickets of bushes and ferns occur only at the forest margins and roadsides. The age of the plantation is estimated to about 60 years, which roughly agrees with information from local informants and coincides with a period when tree planting was promoted by the colonial authorities in North Pare (SHERIDAN 2001).

Small pedestals and the general absence of root exposure suggest however, that the soils had been truncated before the establishment of *Eucalyptus* plantations. Severe erosion has stripped off the soil and trees have grow literally on the exhumed, very compact and hard saprolite. Erosion of fine material has led to the residual accumulation of gravel and a strong stone pavement (50-90% surface gravel) has developed on the surface. Biological crusts contribute further to the stabilization of the surface. Litter accumulates in denser and in drift protected areas of the forest. However, no initial stage of humus formation is observed, probably because of the extremely dry environment, the lack of connectivity between litter layer and soil, and ongoing drift and wash on the sealed soil surface.

6.2.3 Changuku (Lomwe)

The Changuku toposequence encompasses heavily degraded soils of the Changuku ridge above the Lomwe study site (Fig. 18). Open agricultural fields on the ridge have been severely eroded and most plots lie in fallow. On the exposed subsoils maize plants are stunned and agricultural yields are low. Farmers frequently have switched to cassava cultivation, which is a productive crop, undemanding in terms of soil fertility. On the eroded Changuku ridge, the soil profiles **Changuku 1 (Cresta)** and **Changuku 2 (Ridge)** were established. Both profiles are truncated. The topsoil and most of the subsoil have been stripped off and only a shallow tillage horizon covers the transitional B/C horizon characterised by the preserved rock structure. With regard to the fragmented remains of the B-horizon, the soils may be classed as truncated Cambisols (for detailed soil profiles see Appendix B.1.).

On the steep, terraced slope below the ridge grasses are grown for fodder production. The profile **Changuku 3 (terrace)** shows an aggradational terrace soil developed within a colluvium, deposited over a truncated subsoil. A sharp boundary marked by a centimetre thin band of reddish brown (2.5YR 4/4) clay marks the boundary between the 90cm deep colluvial deposit and the underlying saprolite - strongly weathered fine quartz gravel. In contrast to the majority of profiles located over metamorphic gneiss, this profile developed over the outcrop of a quartz vein. The change of the parent material is well reflected in the magnetic susceptibility measurements (cf. chapter 8.4). The two profiles **Changuku 5** and **Changuku 6** were established on the steep lower slope stabilised today by a dense vegetation cover of grasses, herbs, and shrubs under open *Eucalyptus* cover. Both profiles have been truncated and the recent topsoil develops in colluvial material transported along the slope. At Changuku 5, continuous gneiss bedrock is blanketed by only about 40cm of colluvium. Changuku 6, similarly to Changuku 3, is located over a quartz vein crossing the gneiss bedrock and therefore composed of two distinct parent materials. The colluvial blanket provides water storage, rooting depth, and a fertile, though shallow substrate which allows bushes, shrubs, herbs and grasses to form a mosaic of undergrowth vegetation competing efficiently with the deep rooted *Eucalyptus*. The dense undergrowth vegetation of this *Eucalyptus* plantation contrasts with the sterile surface of the Makongweni *Eucalyptus* forest.

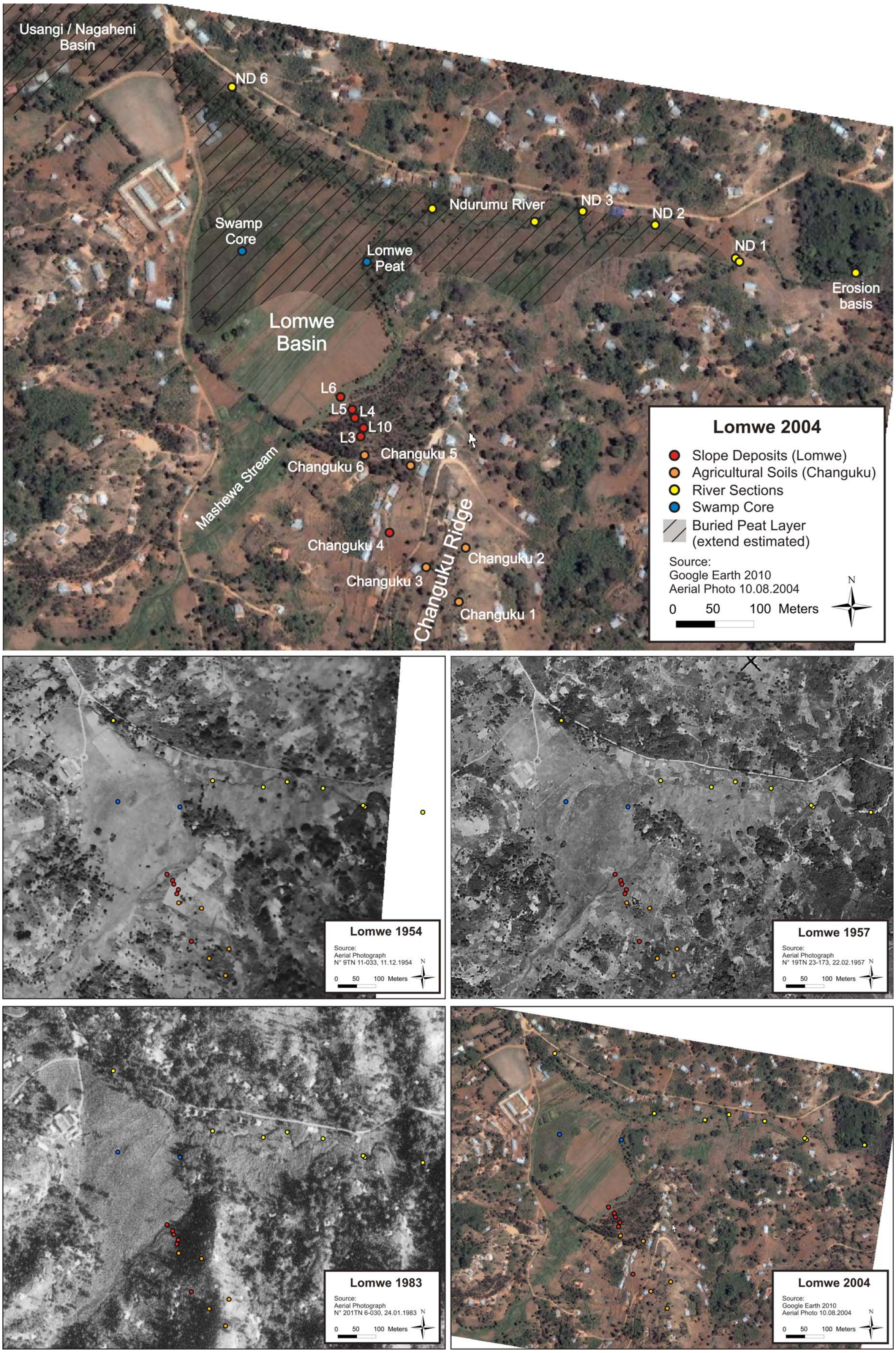


Fig. 18: Multitemporal aerial photograph comparison at Lomwe. Soil profiles and swamp core are plotted above aerial photographs from 1954, 1957, 1983, and Google Earth aerial photographs of 2004. Shaded area indicates the likely extent of the buried peat layer. L3 – 10: Lomwe slope deposits.

6.2.4 Kwa Kirumbi: Agricultural soils

A mosaic of agricultural land use can be found in the direct vicinity of the Kwa Kirumbi forest - well managed terraced banana groves with shade trees and irrigation channels as well as strongly eroded maize and cassava fields on unterraced slopes (Fig. 16). The soil **Kwa Kirumbi 6 (banana grove)** represents a stabilised slope, where terracing, manure application and the constant vegetation cover of a banana plantation effectively reduced the erosion hazard, although accumulation of surface gravel and incipient sheet and rill erosion were recorded. At **Kwa Kirumbi 5 (eroded slope)** in contrast, severe rill erosion has cut up to 10cm deep channels into the bare soil surface sealed by puddle erosion and only a sparse fallow vegetation of cow grass (*Miscanthus* spp.) grows here (for detailed soil profiles see Appendix B.6.).

Hoeing, the local method of tillage, has led to the creation of a 'plough' or better tillage horizon of varying depth. Accumulation of organic material on the ground is only observed within shaded areas and in fields where tillage is reduced, such as shaded banana groves. The bright soil colours indicate a generally low amount of organic matter within the soil. Whereas the well managed banana grove has a dark brown (7.5YR 3/3; moist) topsoil, the cultivation horizon of the eroded slope is much brighter (yellowish red 5YR 4/6, moist) and can only be recognised by a slightly granular soil structure and the apparent incorporation of colluvic material during tillage. Soil depths were estimated following auger survey. Impenetrable saprolite was encountered at 215cm depth at Kwa Kirumbi 6 and within only 105cm at the eroded site. Frequent rock outcrops in the vicinity of Kwa Kirumbi 5 further suggest an advanced thinning of the soil layer.

6.3 Forest soils and Sacred Groves

Forest soils were investigated at two sites: Kwa Chegho and Kwa Kirumbi. The Kwa Chegho Mountain is a closed, but disturbed forest environment at about 1800 m a.s.l. on the western slopes of the mountain block. Within the elevation range of the main zone of settlement and agriculture between 1200 - 1500m a.s.l. only a few contiguous forest patches with a size sufficient to retain the original vegetation and soil characteristics remain. Due to their importance as sacred groves, access to and research on these is restricted. Fortunately, access was negotiated for Kwa Kirumbi forest, a small forest remnant on the border between Mbore and Malekano village in Masumbeni/Ugweno, which allowed the establishment of several soil profiles in a surviving section of intact mid-altitude forest.

6.3.1 Kwa Chegho forest

Kwa Chegho mountain is located on the central North Pare mountain ridge between the summits of Kamwalla (1920m a.s.l.) and Kindoroko (2112m a.s.l.). Early aerial photographs taken in 1954 and 1957 show, that the Kwa Chegho and Kamwalla mountains had been almost entirely deforested in the first part of the 20th century (Fig. 19). In 1954, only scattered remnants of natural forest remained, mainly as small belts around the Chegho swamp margin, along streams and on a few ridges. Most of the slopes and hilltops were either bare or covered by low vegetation. A network of paths indicates intensive use of the area, which must have gone beyond the initial clearance, firewood collection and probably included grazing of animals. Three years later in 1957, regrowth of secondary vegetation is observed. During the following decades, forests recovered and by 1983 succession stages of secondary forest cover most slopes. Over time, canopies of forest fragments grew together, gaps closed and forest established itself again as the dominant vegetation type. Reforestation was supported by the

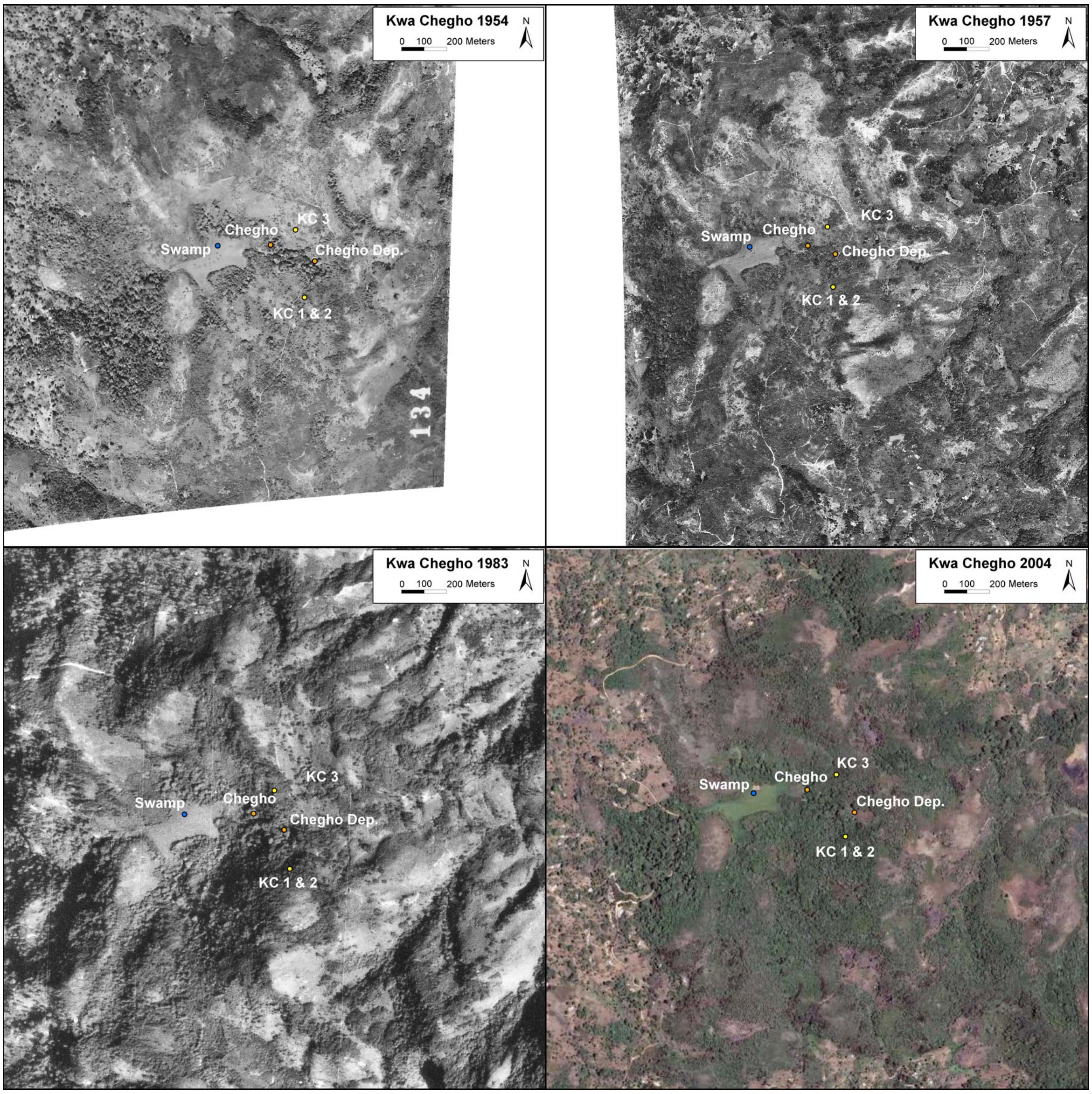


Fig. 19: Multitemporal aerial photograph comparison of Kwa Chegho forest. Forest profiles Kwa Chegho (KC) 1, 2 & 3 and the site of the Chegho slope deposits are indicated.

widespread and organised planting of *Eucalyptus* initiated by the British colonial authorities (KIMAMBO 1991; SHERIDAN 2001). Today the mountain tops are covered by a mosaic of secondary forest fragments, clearings, *Eucalyptus* coppices as well as fallow and a few agricultural plots (Fig. 20). These ‘forests’ are extensively used for browsing cattle, beekeeping, timber extraction and charcoal production.

The aerial photographic evidence does not indicate widespread agricultural activities (e.g. clear field boundaries or houses). However, abandoned fields, houses and irrigation intakes show at least intermittent occupation of the mountain areas within the last century. During the last forty years, several new clearings indicate re-establishment of agricultural plots. Currently, expansion of agricultural land into the secondary forest is observed as the present inhabitants move into higher, hitherto unoccupied and formerly reforested areas. Despite having been devoid of forest for some time prior to AD 1954, the recently established fields still maintain humus rich topsoils and thick organic layers, vestiges of a former montane forest cover. Soil conditions at Kwa Chegho vary widely due to a mosaic of different deforestation, erosion and reforestation histories. Many slopes around the Chegho swamp are strongly eroded, devoid of topsoils and paths are incising into the saprolite. Other areas still maintain apparently intact forest soils.

6.3.1.1 Kwa Chegho 1 & 2: Soils under mature forest

The eastern slopes of Kwa Chegho Mountain are dominated by secondary, indigenous forest, though several patches of planted *Eucalyptus* indicating former clearings can be distinguished. Since the 1950s the forest has recovered and mature trees form now a closed forest cover. Two soil profiles have been recorded within a mature forest patch, with old-grown trees but probably disturbed by 19^{th}/ 20^{th} century deforestation. The profiles Kwa Chegho 1 & 2 were located about 5m metres apart on a representative mid-slope at about 1800m a.s.l. (Fig. 19), ca. 400m higher than the Kwa Kirumbi forest (see Appendix B.8 for detailed soil profiles).

The forest soils may be addressed as Folic Umbrisols. An up to 30cm thick folic layer rests over a thin topsoil. The mineral soil shows a high organic carbon content in the upper 80cm (>2% C_{org}). A low pH (<5) allows the assumption of a low base saturation and the tentatively interpretation as an umbric horizon. Soil texture is clay. In contrast to the soils on the Pare upland, no clay coatings were observed in the field. The profile Kwa Chegho 2 is shallow and developed over a large boulder of unweathered rock at ca. 80cm depth, whereas the profile Kwa Chegho 1 extends to about 2m depth and shows a discontinuous dark layer at a depth of 90 – 144cm. The layer was prominent on the up-slope wall, faded out on the sidewalls and was not discernable on the lower side of the pit. The discontinuous nature of the organic matter enriched layer suggests disturbance processes within the forest, such as treefalls and local soil movement. However, fire and possibly anthropogenic disturbance have to be considered as charcoal fragments are found in the topsoil at Kwa Chegho 2 and up to depths of 140cm at Kwa Chegho 1.

6.3.1.2 Kwa Chegho 3: Secondary forest

The northern ridge of the Kwa Chegho Mountain had been entirely cleared in the 1950s, when *Eucalyptus* reforestation started (Fig. 19). Since then, the hill has been used for timber extraction, firewood collection and widespread charcoal production. Today, intermediate secondary forest is intermingled with open bushland and *Eucalyptus* coppices. Locally, severe soil erosion has exposed the saprolite. Elsewhere, the forest soils with thick organic matter layers are well conserved.

Soil profile Kwa Chegho 3 was established under open, small (5-10m high) secondary forest vegetation with grass and shrub undergrowth. The stony and shallow profile points to truncation and erosion. About 50cm of gravel rich subsoil material overlies a B/C-horizon with abundant weathered rock fragments. However, topsoil development and the ca. 20cm thick organic layer indicate that the slope has subsequently stabilised and soil formation has resumed.

6.3.2 Kwa Kirumbi Sacred Grove

Kwa Kirumbi forest was formerly a sacred grove of the Mshana clan. Some time ago, the forest was taken over by the Msuya clan, and has nowadays a less ridged protection status than other clan forests. The forest patch (1400 ma.s.l.) on a west-facing slope of the Mochame hill extends over about a hectare and covers two parallel ridges separated by a small dry head slope depression. The forest patch is rectangular and has clear cut boundaries at all sides and is dominated by mature up to $20m^{+}$ high canopy trees (Fig. 21). The under-storey comprises bushes and shrubs but few herbs and no grasses cover the ground. Lianas are frequent and characterise the canopy, especially at the forest margins.

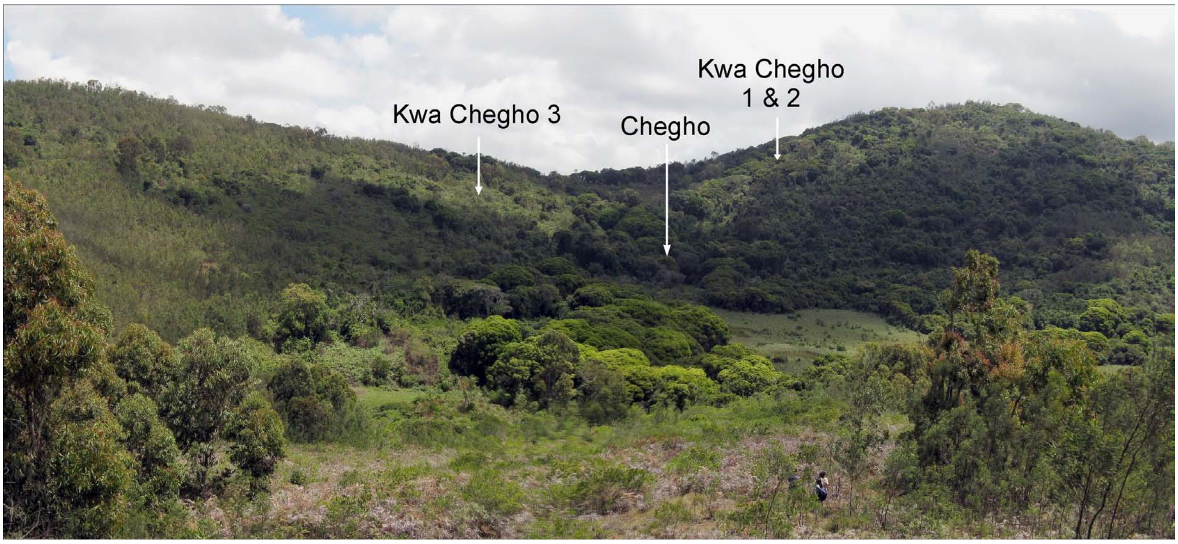


Fig. 20: Kwa Chegho Mountain and swamp. Eucalyptus plantations and secondary forest cover the northern summit, whereas the southern peak has maintained patches of mature indigenous forest. Clearings overgrown by bushes and ferns (foreground) are common and widespread. Arrows indicate the study sites Kwa Chegho 1 & 2 within mature but disturbed forest, Kwa Chegho 3 within secondary forest vegetation, and the slope deposit Chegho 2.

Fig. 21: Kwa Kirumbi forest. Note the clear cut forest boundary, the patchy and open canopy formed by widely spaced well established trees.

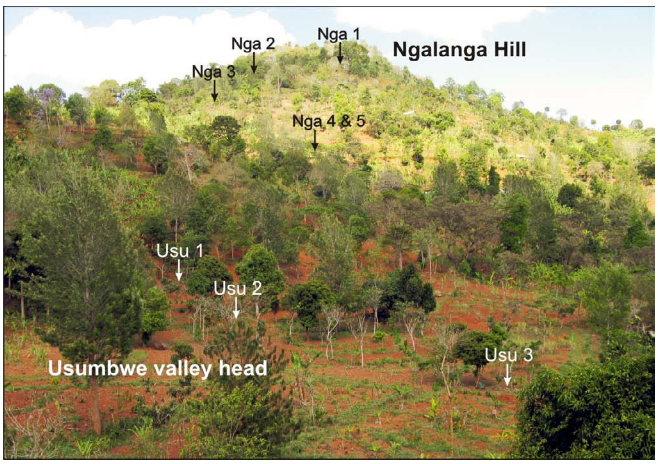


Fig. 22: Overview of the Usumbwe valley head below the Ngalanga hill. Agricultural soil profiles (Ngalanga 1 -3) and the Usumbwe slope deposits (Usumbwe 1 – 3, Ngalanga 4 & 5) are indicated.

Despite its protection as a communal forest, Kwa Kirumbi forest is strongly encroached upon by local farmers. Occasional firewood extraction and reports of organised extraction of organic soil layers for manure purposes (Ahadi Msuya 2010, pers. comm.), as well as numerous canopy gaps and evidence of selective logging are indicators of heavy pressure on the forest ecology. The evidence from the established forest soil profiles confirms a complex history of disturbance and intervention.

6.3.2.1 Kwa Kirumbi 1 - 4: Soils of forest fragments

Four soil profiles were recorded within Kwa Kirumbi forest (Fig. 23). Two soil pits were excavated on a west facing ridge; on top of the crest (Kwa Kirumbi 1) and on the upper slope (Kwa Kirumbi 2). Two further profiles were established via auger survey at the bottom of the adjacent head slope depression (Kwa Kirumbi 4) and on the corresponding steep slope (Kwa Kirumbi 3).

The most distinctive feature of the investigated forest soils is the prominent organic layer composed of litter and partly decomposed organic material held together by a very dense root mat. The thickness of the organic layer varies between 5 and 30cm. Bioturbation and decomposition however have ensured the incorporation of enough mineralogenic material so as to prevent its classification as a folic horizon at most locations. The dark, organic carbon rich topsoils can be classified as umbric mineral horizons (>1% C_{org}, >50cm) if the low pH (<4.5) of the mineral soil is accepted to indicate a low base saturation (for detailed soil profiles and analytical results see Appendix B.7). Elevated pH values between 5 and 6 measured for the organic layer reflects the base pump effect and the release of basic cations during humus decomposition.

The depth of the studied soil profiles generally exceeds 2m. The intensive dark red colours (5 - 2.5YR) of the subsoils are indicative of rubification. Below approximately 1.5m depth, subsoil development is less pronounced and gradually bright yellowish and whitish colours indicated increasing amounts of unweathered soil material. At the transition to the saprolite, unweathered rock fragments become more frequent, the clay content decreases and pH increases slightly. The soil texture throughout the topsoil and subsoils is clay (>40% clay). A texture change to clay loam is only recorded at about 100cm depth in the comparatively shallow profile on the ridge (Kwa Kirumbi 1). Clay coatings were observed in the subsoil (50 - 120cm) of Kwa Kirumbi 1 & 2, however the lack of an increase in clay content prevents the delimitation of an argillic Bt horizon (cf. chapter 5.6). Despite the corroboration of clay illuviation, the soils are tentatively classified as Acrisols. Alternatively, the soils might belong to the Nitisols reference group, although no nutty aggregates have been observed.

Soil profile Kwa Kirumbi 2 (upper slope) reveals that disturbance is a common feature within this sacred grove. A buried Ah horizon was identified between 35 and 55cm depth. The buried topsoil is overlain by mineral soil and a recent organic horizon. A high number of potsherds (20 fragments) as well as charcoal fragments were recovered from the buried topsoil and the colluvial overburden. Occurrence of potsherds is also recorded from the topsoil of Kwa Kirumbi 1 (forest ridge); although here no charcoal was recovered.

Disturbance and even soil movement is also suggested by a preliminary auger survey of the small head slope depression at Kwa Kirumbi 4. About 3m of homogeneous colluvial material with frequent occurrence of charcoal rest over a distinctly brighter material. Together with charcoal fragments up to a depth of 125cm at the steep forested slope of Kwa Kirumbi 3 this suggests reworking and incorporation of charcoal during material movem/ent along the slope and a deep colluvial deposit in the valley bottom.

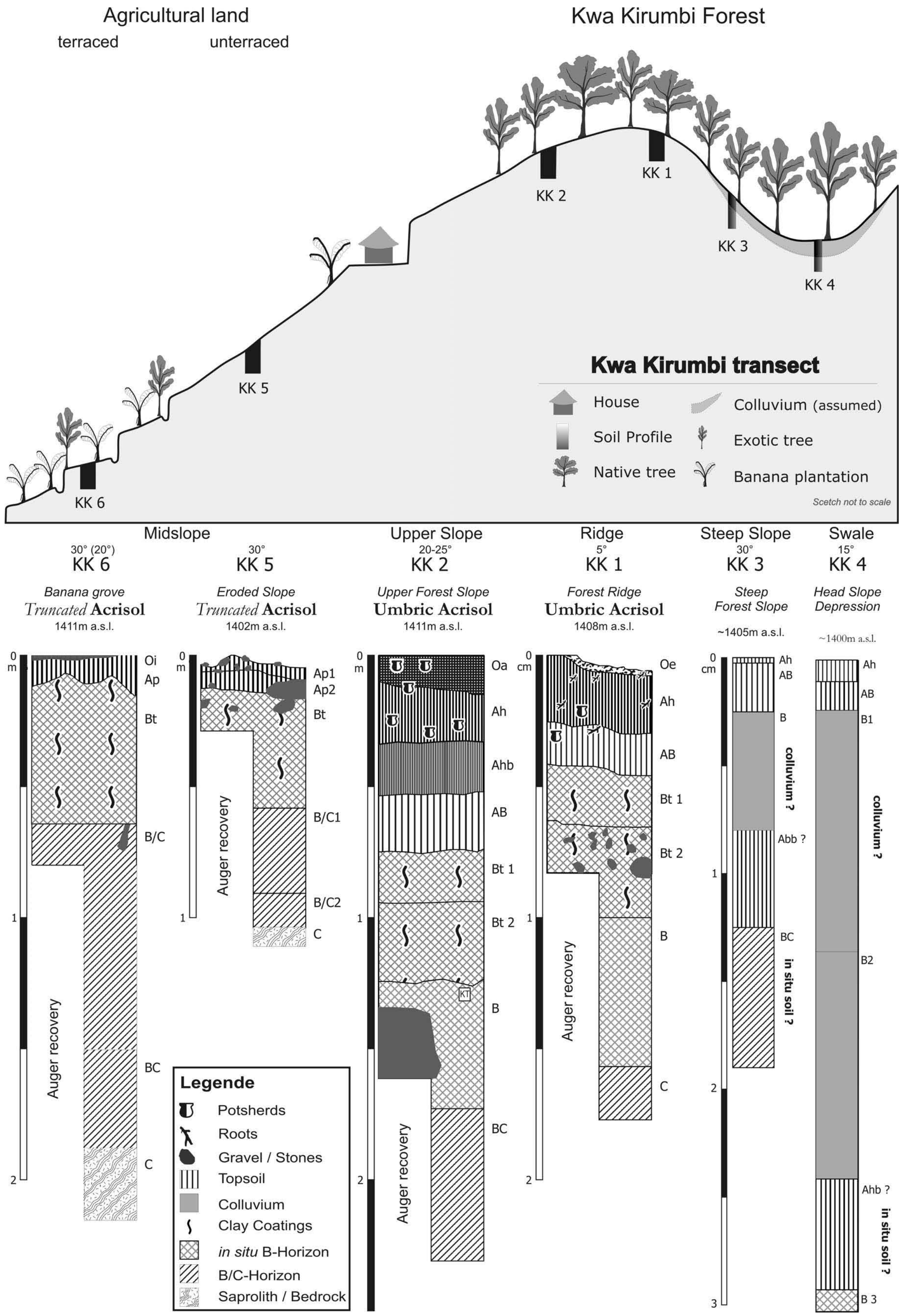


Fig. 23: Pedological landscape transect of the Kwa Kirumbi forest area

6.4 **Slope Deposits: The terrestrial record**

This chapter provides an overview of the three study areas Mrongo, Usumbwe and Lomwe, their most recent land use history and a short introduction to the stratigraphy of their colluvial deposits. Analytical results are presented in detail and context in chapter 7. As a representative example, profile Mrongo 10 is presented here, whereas detailed descriptions of the stratigraphy and the analytical results of each profile can be found in the Appendix B.

6.4.1 Mrongo

6.4.1.1 Mrongo creek

At the heart of Ugweno, the elongated Msumbeni valley stretches from Kifula village in the north to Minja High School in the south (Fig. 16). The area is densely populated and cultivated. The western slopes of the valley descend straight into the valley swamp and only valley bottom sediments are likely to be preserved. The eastern slopes of the Mochame Mountain (~ 1600 a.sl.) are longer, more gentle and seasonal streams have created a number of small creeks. The Mrongo creek was chosen as study site due to a reduced housing density and a gentle footslope suggesting accumulation of slope deposits (Fig. 24). The slopes retreat about 200m from the main valley to form the small creek of the seasonal Mrongo stream. Incised in a small channel on the slope, the stream spreads out on the valley bottom forming localised sand fans.

Aerial photographs of the Mrongo area taken in 1954 and 1957 show that only one small fragment of forest had remained into the 20th century (Fig. 25). Particular during the first part of the 20th century, open fields and relative few trees characterised the Ugweno landscape. Only within the last 40 years, large-scale tree planting has created a mosaic of agricultural and wooded land, which dominates the impression of the Pare landscape today. Banana groves are represented by homogeneous areas of intermediate grey, widespread on the 1954 and 1957 aerial photographs, as banana leaves create a homogeneous dark reflection signal. High reflection and bright grey colours mirror bare soil, tillaged fields or fallow vegetation with low ground cover. Compared with the bare ridge to the north and slopes higher upper the mountain the Mrongo catchment has maintained a relatively high vegetation cover, mainly because of the banana plantation, which persisted in place throughout the 20th century. (cf. Fig. 16).

The creek is intensively cultivated and well-managed agroforestry plots have been established. Banana (*Musa* spp.), coffee (*Coffea* sp.), taro (*Colocasia esculenta*, cocoyam) and pepper are grown under dispersed shade trees and accompanied by beans and maize as seasonal crops. The soil is covered by a discontinuous organic layer (Oi-horizon) of plant remains (litter, most importantly banana leaves), which are partly incorporated into the plough horizon by hoeing.

6.4.1.2 Slope deposits

At the Mrongo creek (Fig. 24, Fig. 27) between 4.5m (Mrongo 4) and 7.5m (Mrongo 3) of colluvial deposits bury a former stable ground surface (unit I) characterised by dark buried topsoils, about 10cm thick, which developed over about 2m of subsoil before auger survey indicates saprolite.

Three different phases of slope deposit formation have been identified. The lower half of the deposit (unit II) is made up of brown (7.5YR 5/4, dry) to reddish brown (5YR 4/4, moist) clay with few weathered gravel, occasional occurrence of dark, organic matter rich aggregates, clay coatings, and the presence of charcoal.

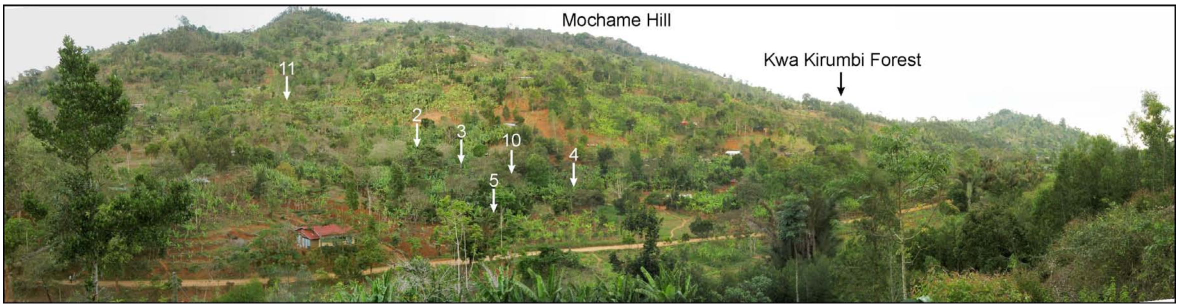


Fig. 24: Panorama view of the Mrongo creek and the Masumbeni valley. Location of the Mrongo profiles are indicated by respective numbers. Note the distribution of banana plantations and trees compared to the mid-20th century aerial photographs. Photograph taken in 10/2008.

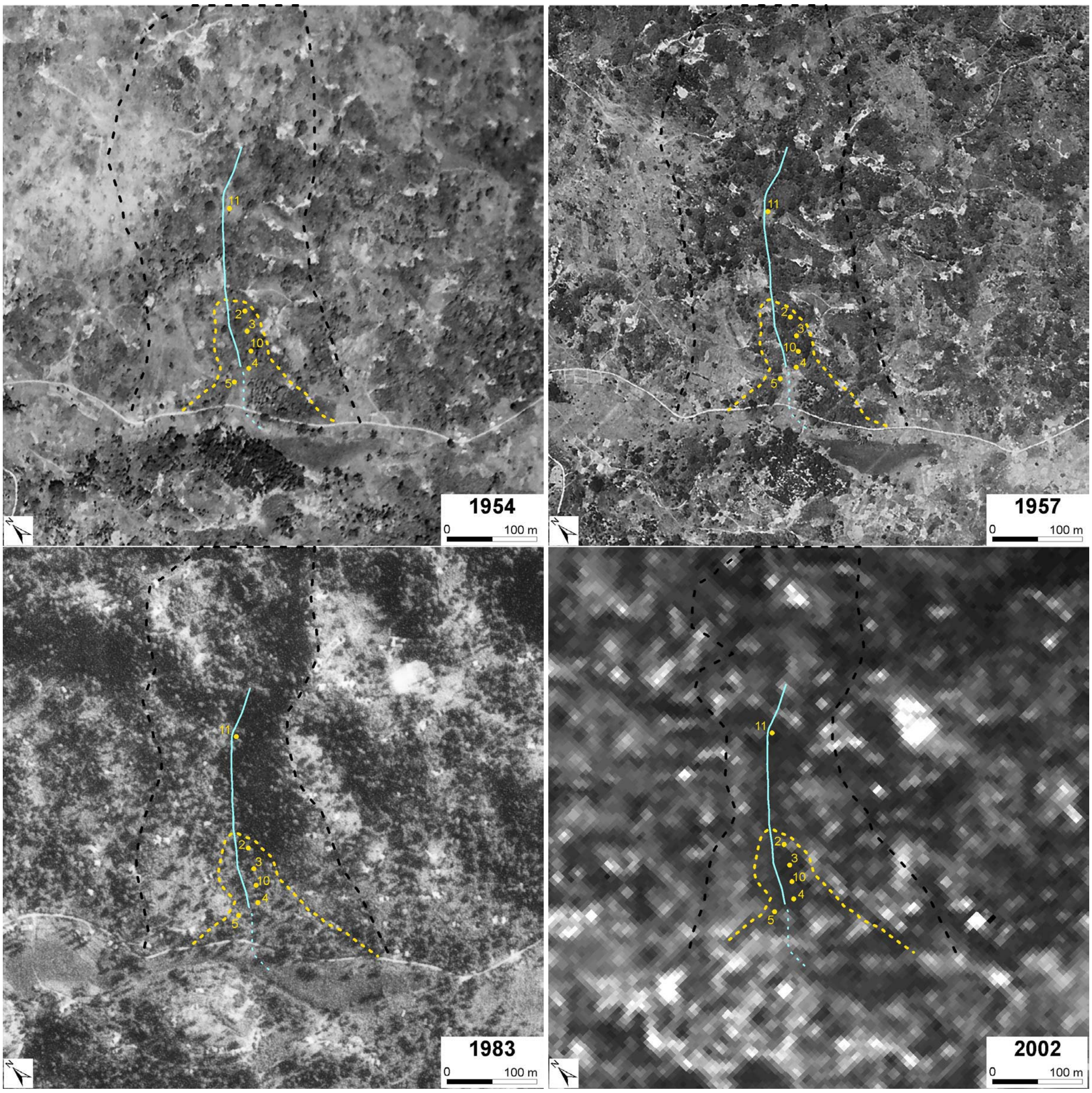


Fig. 25: Multitemporal aerial photograph comparison at Mrongo. Outlines of the Mrongo catchment (black dotted line) and the small creek (dotted yellow line) are given. Soil profiles are numbered: 2 - Mrongo 2, 3 – Mrongo 3, 10 – Mrongo 10, 4 – Mrongo 4, 5 – Mrongo 5, 11 – Mrongo 11. The distinct stream channel along the slope (blue) and its indistinct runoff pathway with sandy wash deposits at the valley bottom (blue dotted line) are marked. Sources: Aerial photographs: 9TN/11-29 (11.12.1954), 19TN/23-176 (22.02.1957), 201TN/6-031 (24.01.1983), Satellite Image: Spot 4, 143-357 PAN, 10m (10.09.2002)

Between 410 - 210cm and 150cm depth dispersed sandy spots are common, as well as well developed, between 10 and 100cm long and up to 5cm thick sand lenses indicating slope wash as characteristic erosion (unit III). Charcoal and clay coatings are present throughout. Potsherds are recorded in the buried topsoil (Mrongo 4) and in both the lower deposit and the slope wash sequence. Towards the valley bottom sand lenses merge into sand layers. Mrongo 5 was too shallow to reveal the buried soil. Instead, an infilled channel from a predecessor of the seasonal Mrongo stream and alternating, decimetre thick, sandy wash layers are recorded. The uppermost 1.5 meters (unit IV) are characterised by a red (2.5YR 4/6, moist) to reddish brown (5YR 6/6, dry) clay loam, the absence of sand lenses, and a contemporaneous slightly organic matter enriched plough horizon. On the lower slope (Mrongo 2) the buried topsoil was disturbed or partly eroded during the initial erosion phase. Similarly to other profiles on the lower slope, no sand lenses are recorded. A particularity of Mrongo 2 is the occurrence of a number of stones in a restricted depth interval between 190 and 240cm depth imbedded in the homogeneous clay of the lower slope deposit.

In a head slope depression on the mid-slope of the Mochame hill, the profile Mrongo 11 shows over three meters of slope deposits characterised by several events of stone and gravel deposition.

6.4.1.3 Mrongo 10: Exemplary profile description

This profile is located inside the banana grove on the lower footslope (6°) at Mrongo. A 20 - 40cm deep tillage horizon has developed with high organic matter content (2.3% C_{org}, cf. Fig. 26). The litter originates predominantly from C_3 plants, e.g. shadow trees and banana, which is reflected in a low $\delta^{13}C$ (-22.8‰). The surface near colluvium (unit IV) is a reddish yellow (5YR 6/6, moist) crumbly clay.

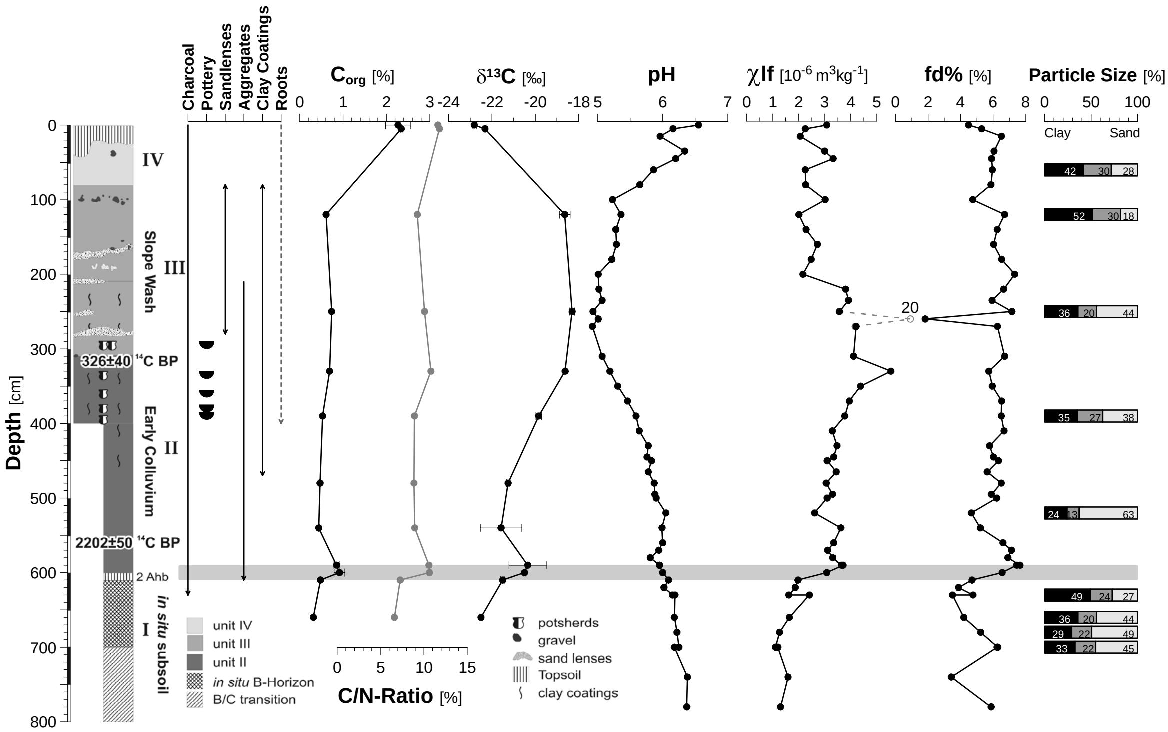


Fig. 26: Mrongo 10: Stratigraphy and analytical results. Four stratigraphic layers can be distinguished: I – *in situ* soil development, II – early colluvial slope deposit, III – sand wash and sand lens formation, IV – late colluvial slope deposit.

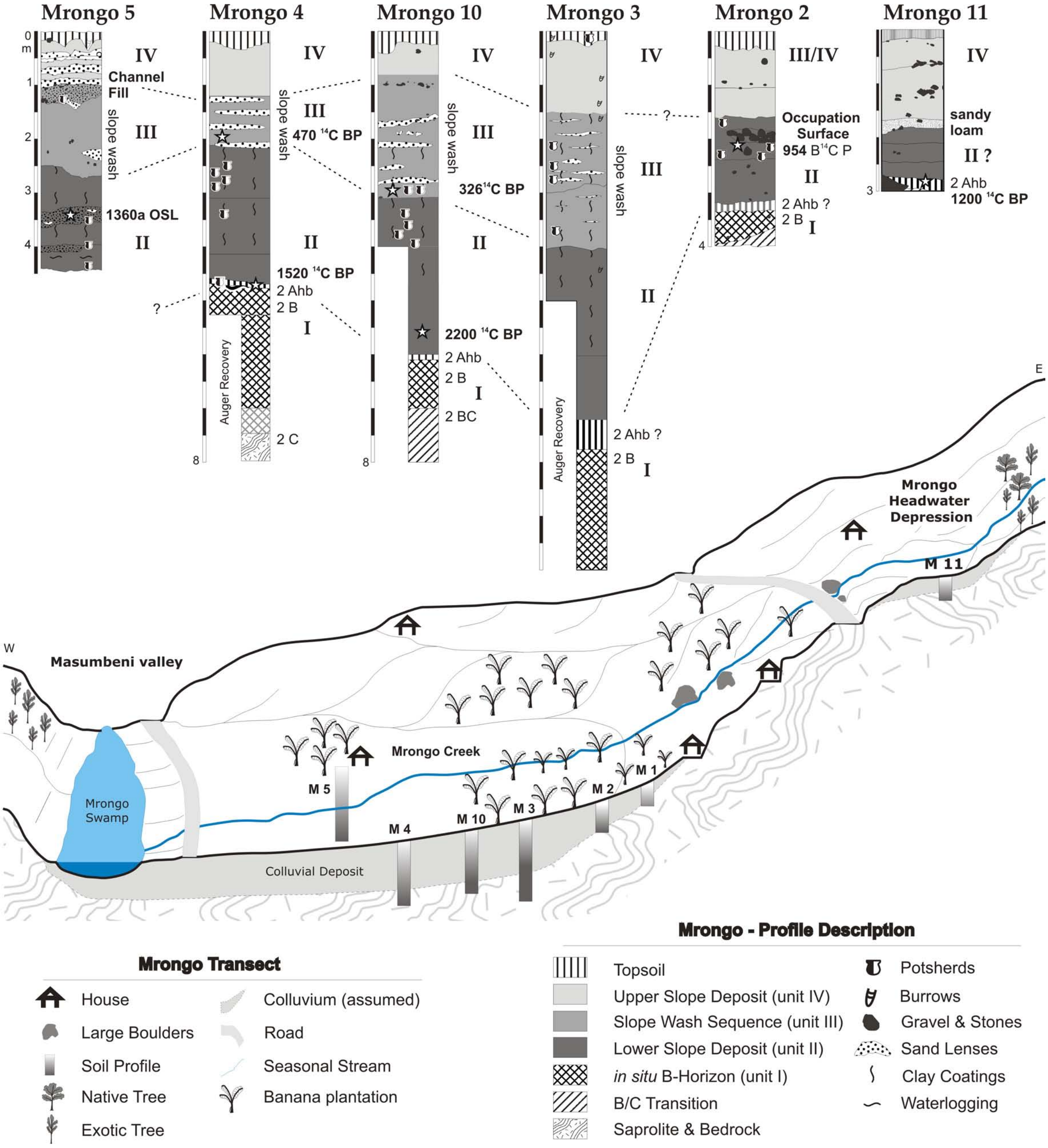


Fig. 27: Mrongo transect and stratigraphic overview. The E – W transect of the Mrongo creek, shows the location of soil profiles and the generalised stratigraphy of the slope deposits. Four distinct phases of landscape formation are distinguished: *In situ* soil development (unit I), early colluviation and deposition of eroded topsoil (unit II), runoff-based erosion and sand lens formation (unit III), and a upper slope deposit characterised by the deposition of eroded subsoil material (unit IV).

Between 100 and 280cm depth (unit III), dispersed sand lenses occur. The most prominent and contiguous sand lenses along the profile wall are recorded at 160-180cm, 210cm, and 240-280cm depth and distinctly visible due to black iron rich sand. Below 310cm, no sandlenses are observed and the deposit turns reddish brown to brown (5-7.5YR 5/4, moist). Clay coatings and firm, dark, organic matter rich aggregates as well as aggregates of bright subsoil material are characteristic features. Charcoal is present throughout the deposit while occurrence of potsherds is only reported between 300 and 400cm depth.

Description of sediments below 4m depth is based on auger samples. Below 580cm, the deposit turns darker and at 600 - 610cm depth a thin but distinct layer of brown (7.5YR 4/2, moist) clay with clear boundaries is interpreted as a buried topsoil horizon and supported by a slightly higher organic carbon content of 0.9% C_{org} compared to values of around ~0.5% for the slope deposit and the *in situ* subsoil. The latter is strongly compacted, and characterised by a coarser texture (sandy clay loam), probably related to disintegrating rock fragments. Unweathered mica and strongly weathered and oxidised rock fragments indicate saprolite below 700cm depth.

Magnetic susceptibility (χ_{lf}) of the *in situ* subsoil is low ($<2x10^{-6} m^3 kg^{-1}$), but increases to intermediate high values ($3 - 5x10^{-6} m^3 kg^{-1}$) in the buried topsoil and the overlying lower colluvium. Peak values are recorded for iron rich sand lenses and a general decline is noted in the upper most meters (unit IV). Frequency dependent magnetic susceptibility ($\chi_{fd\%}$) oscillates around 6% throughout the slope deposit but shows increased variability and slightly lower percentages for the original soil. Low $\delta^{13}C$ values around -22.8‰ in the topsoil reflect the present banana vegetation but are replaced by high $\delta^{13}C$ values and probably a higher contribution of C_4-plants (-18.3‰, -19.8‰) in unit III. Below 4m depth, $\delta^{13}C$ of the early slope deposit (unit II) decreases steadily to values between -20.5‰ and -21.5‰ in the buried topsoil and even lower $\delta^{13}C$ of -22.5 of the subsoil. pH values show a distinct pattern. High pH of 6.5 within the contemporaneous topsoil contrasts sharply with intermediate values of pH 5 between 100 and 300cm depth. Beneath, the pH of the colluvial deposit increases steadily until it stabilises at pH 6 - 6.4 in the *in situ* subsoil.

6.4.2 Usumbwe

6.4.2.1 Usumbwe valley head and Ngalanga hill

The Ngalanga hill, caped by a small sacred forest, is a distinct landmark in the heart of Ugweno and a culturally important place of Wapare history. Here the Wasuya clan took over the political power from the Washana clan (blacksmiths) by killing all male Washana during an initiation ritual in their sacred forest (*msitu*) on Ngalang hill. This event marked the rise of the Ugweno state and their hegemony in North Pare (KIMAMBO 1968, 1969). As homeland of the Washana clan, Ngalanga hill is a known area of iron smelting (Abasi Msangi, pers. comm.). ODNER (1971a) and recent surveys of the HEEAL project confirmed widespread iron working in the Ngalanga area.

Aerial photographs show that the Ngalanga Hill was bare during the mid-20th century (Fig. 17). The upper slopes were intensively cultivated and only a few trees had been left standing. Trees were more frequent on the lower slopes and in the valley bottoms. The Ngalanga sacred forest itself had been strongly encroached on, but has recovered since the 1950s. In general, tree cover increased during the last century. Areas barren and deployed of vegetation in the first part of the 20th century such as the Raa hill (cf. Makongweni, chapter 6.2.2) are nowadays afforested and covered by *Eucalyptus* coppices.

Banana groves, or fallow dominate the steep (20 - 30°) lower slopes of the Usumbwe valley head, whereas the gentle footslopes are terraced and under maize cultivation. Locally, contour trenches are established to reduce runoff and soil erosion. The valley is dry and only during heavy rainfall events does runoff concentrate and ephemeral channels develop. Cultivated soils were surveyed on the slopes of the Ngalanga hill (chapter 6.2.1). Slope deposits were investigated in a head slope depression on the mid-slope (Ngalanga 4 & 5) and in the Usumbwe valley head at the foot of the Ngalanga hill (Fig. 22, for detailed profile descriptions see Appendix B.5).

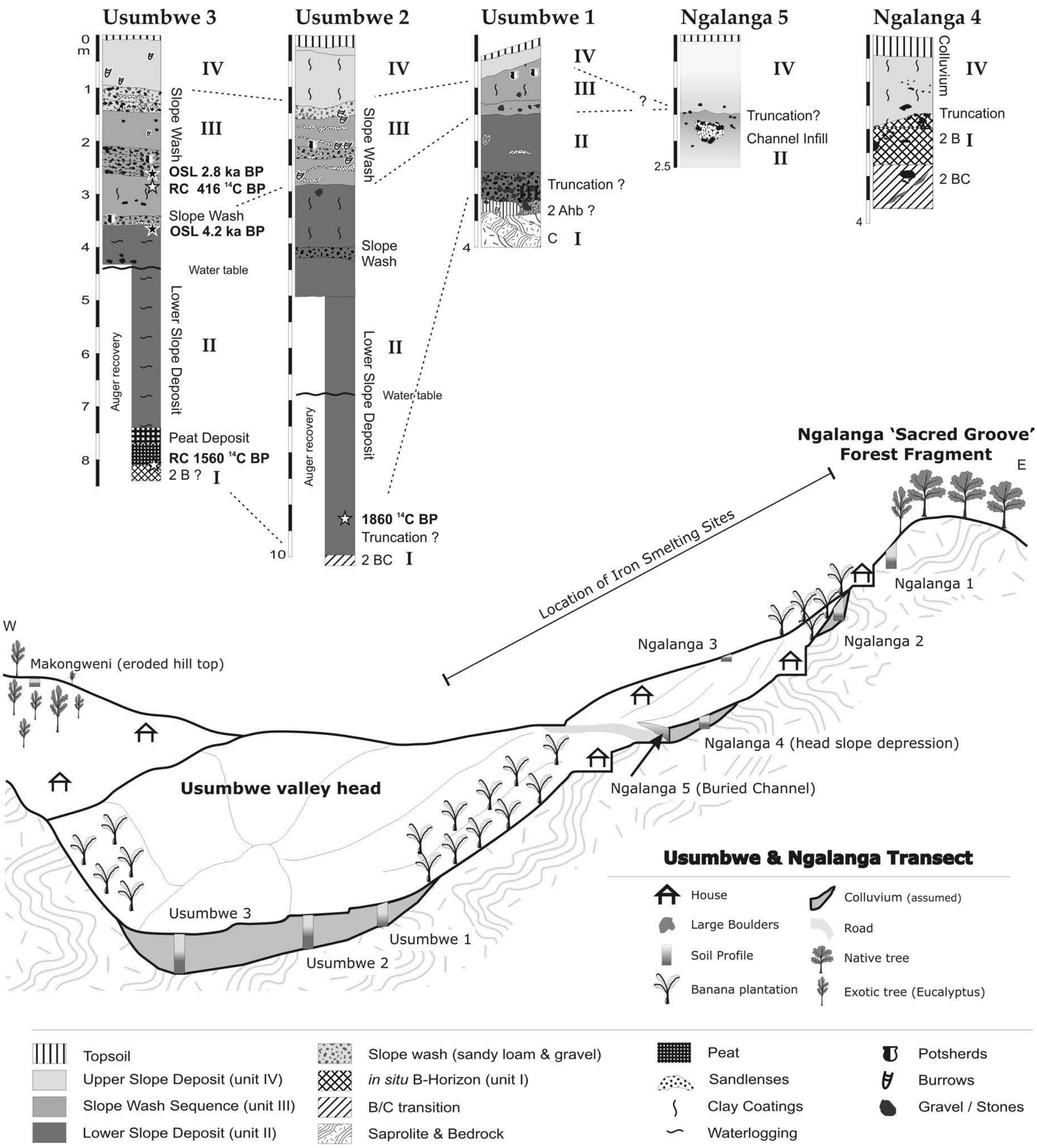


Fig. 28: Usumbwe and Ngalanga transect and stratigraphic overview. The E – W transect of the Ngalanga hill and the Usumbwe valley head shows the location of soil profiles and the generalised stratigraphy of the slope deposits. Four distinct phases of landscape formation can be distinguished: *In situ* soil and peat development (unit I), early colluviation and deposition of eroded topsoil (unit II), runoff-based erosion and sand lens formation (unit III), and a upper slope deposit characterised by the deposition of eroded subsoil material (unit IV).

6.4.2.2 Slope deposits

At Usumbwe, four distinct phases of surface development can be distinguished (Fig. 28). A buried surface is not preserved and original soils have apparently been truncated at Usumbwe 1 & 2, where no distinct buried topsoils have been recorded. A discontinuity is observed at Usumbwe 1, where a probably relocated gravel rich (15%) material between 265 and 310cm depth has possibly reworked former topsoil material and now rests directly over weathered bedrock. At Usumbwe 2, truncation is inferred from abrupt material changes, notably the increase of gravel content and the generally reddish yellow (5YR 4/5 and brighter) of the subsoil horizons. A former valley swamp is preserved in the valley bottom at Usumbwe 3, where about half a metre of organic matter rich peat is buried in 8m depth.

The colluvial deposits can be divided into three distinct depositional units. A lower colluvium (unit II) and an upper colluvium (unit IV) differ in colour, degree of compaction, and are separated by a sequence of slope wash events (unit III) recorded as sand lenses and sandy layers with gravel occurrence. Occurrence of sand lenses is only sporadic at Usumbwe 1 on the lower slope, whereas sequences of decimetre thick layers are common at the valley bottom. Potsherds are recorded predominantly in this layer, whereas charcoal is present throughout the deposits. Colluvial deposits were also recorded in a small head slope depression at Ngalanga 4. Here, about 150cm of colluvial deposits rest over a truncated soil, whereas a few metres downslope at a road cut an infilled stream channel incised in a colluvial deposits reflecting a phase of enhanced runoff erosion (Ngalanga 5).

6.4.3 Lomwe

6.4.3.1 Lomwe basin and Changuku ridge

The relief of the southern part of North Pare is dominated by the large Usangi basin. A small, separate basin in the south is named after the Lomwe Secondary School (Fig. 18), where ODNER (1971a) found traces of an 'Iron Age' habitation site. Likewise, several archaeological sites have been recorded by ODNER (1971a) and SOPER (1967b) on the Makandani ridge (Fig. 14). The only archaeological excavation so for undertaken in North Pare was by ODNER (1971a) at the Usangi Hospital site dated to the first millennium AD, at the northern end of the Usangi valley.

The Changuku ridge overlooking the Lomwe basin has been significantly transformed by agricultural land use, and by house and road construction. Abandoned terraces are vestiges of former agricultural land use and oral accounts of habitants confirm that the footslope of the Changuku ridge was used by the Lomwe School for vegetable production in the first part of the 20th century. Aerial photographs taken in 1954 and 1957 freshly tilled, large, contiguous fields on the lower and middle slopes stretching from the valley bottom up to the Changuku Hill. The ridge itself was a patchwork of small agricultural and fallow plots. Three years later in 1957, the slope was still under cultivation. In 1983, the large single field had been divided up and trees had been planted along field boundaries. Organised planting of *Eucalyptus* must have occurred shortly afterwards and more recently, a road and houses for teachers have been built on the midslope. Today open *Eucalyptus* woodland with a thick undergrowth of shrub, herbs, and grasses characterises the slope. Accumulation of slope deposit was studied at the footslope of the Changuku hill (Lomwe 3, 10, 4, 5, 6) and on the mid-slope of the Changuku hill (Changuku 4). Further eroded, agricultural soils on the Changuku ridge were recorded (chapter 6.2.3).

6.4.3.2 Slope deposits

At the Changuku footslope up to 5m of slope deposit accumulation is recorded (Fig. 29, for detailed stratigraphic descriptions see Appendix B.2). The deposits overlay a former land surface characterised by a buried organic matter rich topsoil. Buried topsoil horizons were recorded in four (Lomwe 3, 10, 4, & 5) out of five soil profiles at Lomwe. From a stratigraphic point of view, their location and depth suggest that they belong to the same buried landsurface, located in about 2.3m depth in the upper and about 5m depth in the lower part of the slope. At the two uppermost profiles Lomwe 3 & 10 the buried topsoil horizon is exposed within the excavated soil pits (205 - 230cm and 230 - 260cm depth, respectively). The buried horizon is characterised by a very dark brown (7.5YR

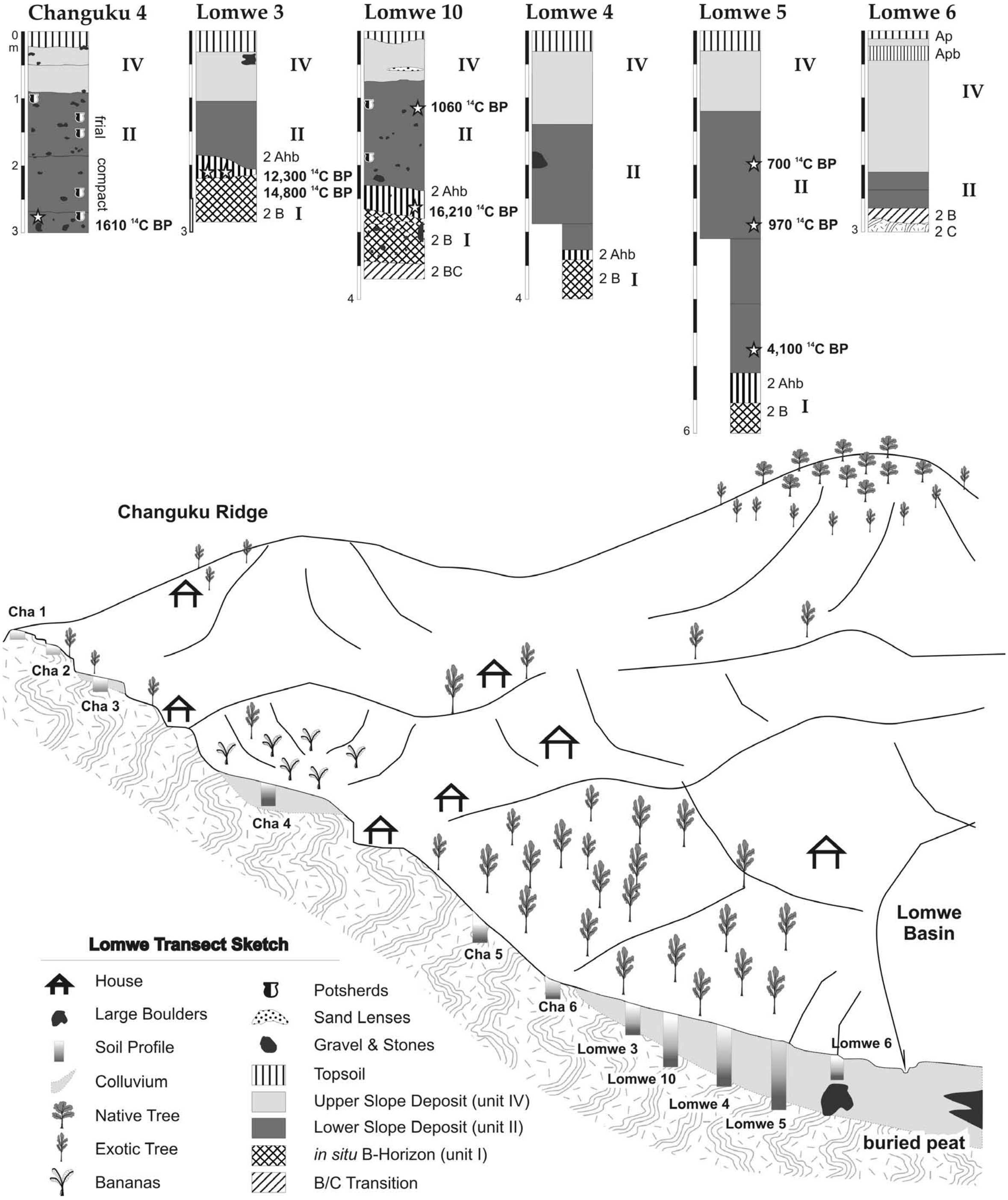


Fig. 29: Lomwe and Changuku transect and stratigraphic overview. The N – S transect of the Changuku ridge, shows the location of soil profiles and the generalised stratigraphy of the slope deposits. Three phases of landscape formation are distinguished: *In situ* soil development prior to the LGM (unit I), undifferentiated late Pleistocene and late Holocene colluviation and deposition of eroded topsoil (unit II), and a upper slope deposit characterised by the deposition of eroded subsoil material (unit IV).

2.5/3 and 5YR 3/2; moist), organic matter rich (2.4% and 2.2% C_{org}) material with a very low bulk density easily to excavate. The soft, dark horizons show a clear and smooth boundary to the underlying subsoil. Bioturbation can readily be seen by channels (Ø 0.5-1cm wide, up to 10cm long) of reddish subsoil material extending into the dark buried topsoils.

At the uppermost profile Lomwe 3 (15°) the soft, organic matter rich layer, thins out towards the slope indicating partial truncation and the upper end of the preserved surface. Whereas the subsoil is characterised by a high stone content (many 30% gravel and stones) at Lomwe 3, a transition horizon (ABb) at Lomwe 10 grades into a red (2.5YR 4/5, moist) subsoil horizon with many (20%) coarse gravel and a very high bulk density. Clay coatings were observed within the original subsoil. At Lomwe 4 & 5 samples of dark reddish brown (7.5YR and 5YR 2.5/2, moist), organic matter rich (1.9% and 2.4%, respectively) soil layers in a depth exceeding 3m were only obtained via auger survey. The dark layers rest consistently above a lighter coloured horizons characterised by higher gravel content, interpreted as *in situ* subsoil.

The slope deposits burying the former land surface can be separated into a lower, earlier deposit characterised by a low bulk density, dark colours and the presence of different types of aggregates and an upper, later colluvium with a high bulk density and reddish colours and sand admixture. Most pronounced are the characteristics of the slope deposits immediately overlying the buried topsoils at Lomwe 3 and Lomwe 10. At both profiles the former topsoils are buried by about 1 to 1.5m of reddish brown (5YR 4/4, moist), soft and crumbly soil material, with a low to moderate bulk density (for details see Tab. 11). This early slope deposit is readily recognised as such by its soft character and the heterogeneity of its materials: a variety of different weathered rock types, the occurrence of dark, organic matter rich aggregates as well as distinct aggregates of reddish material, common occurrence of charcoal and occasional occurrence of potsherds. In the lower part of this layer distinguishable aggregates of buried topsoil material are mixed into the deposit. No clay coatings are observed in this lower slope deposit.

The upper 1 - 1.5m of deposits at all Lomwe profiles are bright reddish in colour and much denser than the underlying lower colluvium. Gravel content tends to be lower (<5%) and organic matter rich aggregates are not found. At Lomwe 3 and 10 these are distinct, homogeneous red (2.5YR 4/6 – 5/7; moist) clays with a high bulk density. Sand lenses are recorded from between 50cm and 75cm depth at Lomwe 10.

Upper and lower deposits are much more homogeneous at Lomwe 4 and Lomwe 5. The transitions are gradual in colour, density and gravel content and boundaries are diffuse. Though less distinct, colour and bulk density differences as well as the presence of clay coatings are recorded. No buried soil or surface is recorded at the lowermost profile (Lomwe 6), where 3m of deposits rest over bedrock or a large boulder, impeding further excavation. Bulk densities are high throughout this profile and comparable to the upper deposition unit. In the light of much deeper deposits a few metres upslope and only a thin weathering zone between the deposit and the weathered rock it is likely that a large boulder translocated during a strong (tectonic?) instability event was buried here.

6.5 **Lomwe Swamp: The palaeoecological record**

Under the sediments of the Lomwe basin, an organic matter rich peat layer was discovered, indicating that strong and rapid environmental changes have taken place in the past (Fig. 18). The small permanent wetland in the northeastern part of the Lomwe basin offered the possibility to extract an undisturbed swamp core for stratigraphic and palaeoecological analysis.

6.5.1 Study Site: Lomwe Basin

The Usangi basin is the result of NW-SE oriented faulting, having resulted in an elongated and oversised basin ideal for capturing sediments. Infilled with sediments, swamps have developed on the flat basin bottom. The drainage pattern is tectonically controlled and water of the extensive former

Ngagheni swamp ('Ngaghe' grass - Cyperus rotundus - is reported to have formerly grown in the swampy valley bottom of the Usangi basin SHERIDAN 2001) in the Usangi valley drains both north via the Mala to the Chunguli river and south via the Ndurumu stream. The Ngagheni swamp was drained in the 20th century and since has become important for horticulture cultivation (SHERIDAN 2001).

The Lomwe basin is separated from the main Usangi valley by a small hillock, allowing a certain hydrological independence from the main basin as discussed below. The Lomwe basin was drained by the school in the first part of the 20th century and is nowadays intensively cultivated. Only a small wetland remained in the north-eastern part of the Lomwe basin. The original Mashewa stream is strongly reduced due to water management and drainage by a number of parallel furrows. The former stream channel on the southern edge of the basin is nowadays partly abandoned. Only during episodic flooding is the channel reactivated, acting as the main drainage. Especially, rains during the 1948 El Niño events are said to have flooded the entire basin, impeded passage, and destroyed homesteads (Mwalimu Shana 2008, pers. comm.). Aerial photographs from 1954 (Fig. 18) show that the current wetland was well established; the 1957 photograph suggests an indistinct alluvial fan and waterlogging at backswamp positions.

Bedrock outcrops determine the local erosion basis and control absolute incision of the Ndurumu stream and hence drainage of the Ngagheni basin (Fig. 18). Deeply incised into the sediments of the Ngagheni basin (up to 3m) the Ndurumu stream passes the Lomwe basin, where its cross section shows a two stepped profile. The stream probably incised during a recent erosion phase into an older, wider and less defined channel.

Outcrops of organic matter rich peat are exposed along the Ndurumu stream and along drainage furrows, where they are buried under one to three metres of colluvial and alluvial hillwash sediments (Fig. 30). The buried peat extends into the main Ngagheni basin, where it phases out. Downstream, the first occurrence is recorded over an *in situ* rock outcrop (ND1) shortly before the stream drops down the mountain. Here, the 10cm thin peat layer is buried under about 2-3m of sediments. Along the Ndurumu stream, occasional occurrence of coarse fluvial sediments e.g. sands (ND 2) and gravel (ND 3) is reported. Exposures along drainage furrows show varying thickness of the peat layer (between 30 and 100cm) and a thinning out towards the middle of the Lomwe basin.

6.5.2 Stratigraphy of the Lomwe Basin

The Lomwe basin sediments were recorded at three sites: The Lomwe swamp core, the peat profile and the Ndurumu 6 river cut. Dried, partly decomposed peat is exposed at a stream bank at Ndurumu 6, whereas drainage channels have exposed a fresh peat section in the eastern part of the basin (Peat Profile). Here a soil profile was established and peat samples were obtained to a depth of 4m using an Edelman auger. Finally, a 438cm long core was extracted from the Lomwe swamp using a half tube Russian peat corer. Sediment description followed the classification of unconsolidated sediments proposed by TROELS-SMITH (1955) and was complimented by a modern classification approach put forward by SCHNURRENBERGER et al. (2003).

6.5.2.1 Swamp Core

The stratigraphy of the swamp core is representative for the stratigraphy of the Lomwe basin. At the base of the core organic matter free, coarse clayey sand with a minor fine gravel component impeded further core recovery (421-438cm, cf. Fig. 31). This basal sand is overlain by a grey (2.5Y 6/1) organic matter free sandy clay with slightly increasing organic matter content between 365 and 343cm depth.

Two wood fragments at 343cm mark the abrupt start of peat development. One of the fragments dates the onset of peat development between AD 460 and AD 650 (1489±30 ^{14}C years BP). The lower part of the peat stratum is a dark black (10YR 2/1) herbaceous peat (*detritus herbosus*) characterised by a high component of woody material (*detritus lignosus*) and only a minor component of occasional clay inwash. A distinct 14cm thick clay band (291 - 305cm) separates an earlier woody peat from a later herbaceous peat. The organic fraction of this upper part of the peat layer is dominated by herbaceous material, especially reed and *Cyperus* remains, although wood fragments occur. The upper part of the sequence is characterised by five further distinct bands of grey clay inwash interrupting the continuous peat growth. These bands are between 2 and 5cm thick and have very low organic matter content.

The high numbers of clay bands indicate the increasing importance of flooding events and fine material inwash in the upper part. In total the peat layer is about 124cm thick (224 – 343cm) and is overlain by about 150cm of a stiff clay loam with a fine to medium gravel component. Macroscopic charcoal and discernable mica minerals are common. The sediment resembles soil material and is probably derived from eroded material deposited during alluviation and inundation events or by slow colluvial processes. The upper part (76 – 112cm) of the alluvial clay loam shows a transitional character and grades into the recent swamp deposit (20 – 76cm). The contemporary unconsolidated swamp deposit is composed of herbaceous material, mainly sedges and varying levels of standing water.

6.5.2.2 Peat Profile

Auger samples from the peat profile corroborate the stratigraphy of the swamp core (Fig. 32. Nearby, a deeply incised drainage furrow offered lateral observation of the characteristics of the buried peat. Beds of pure organic material are intercalated with fine laminated clay. These clay beds show thicknesses in the order of centimetres and extend horizontally between half a metre to a few metres. The intercalation of peat beds and clay lenses and layers create localised stratigraphies, which represent small-scale sedimentation patterns and are not representative of the peat development as such (cf. Fig. 30). The prominent inwash events observed in the Lomwe core are therefore local events and the small-scale stratigraphy cannot be seen as representative for the basin as a whole. The frequency and abundance of clay lenses is visually observed in both swamp core and auger samples and is corroborated by generally lower LOI results (Fig. 32) from the peat profile. Although the observed

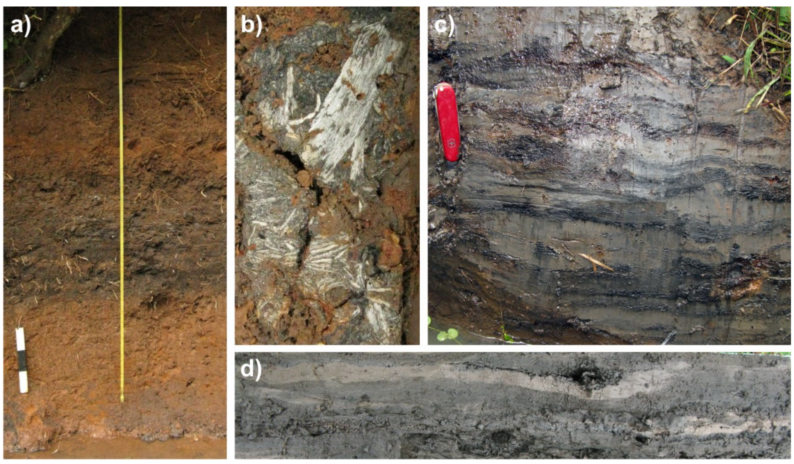


Fig. 30: Exposure of a buried peat layer at Lomwe. a) Exposure and b) preserved leaf imprint at the Ndurumu stream (ND 6). c) & d) Alternating deposition of organics and clay in the upper part of the organic matter rich deposit exposed along a drainage furrow adjacent to the Lomwe Peat profile.

small inwash events are unlikely linked across the basin, the increase in the proportion of mineral material suggests that the frequency and extent of flooding increased during the later part of the peat growth.

The peat itself is built up of well-preserved organic remains e.g. leaves, stalks, and shows internal horizontal lamination (Fig. 30). At exposures, the organic remains are subject to rapid degradation. Similarly to the evidence from the swamp core, the peat layer rests upon a grey clay loam with decreasing and very low organic matter content (C_{org} <0.6%, 285 - 360cm). No sandy bottom deposit as in the swamp core was observed at the end of recovery at 4m depth.

Peat development was interrupted by frequent flooding and clay inwash in the upper part of the peat and was finally superseded by colluvial/alluvial deposition characterised by coarse loamy material and frequent occurrence of small gravel in the upper 1.5m. The final burial of the peat by clay loam appears to have been a basin wide event, although its timing might have differed between parts of the basin.

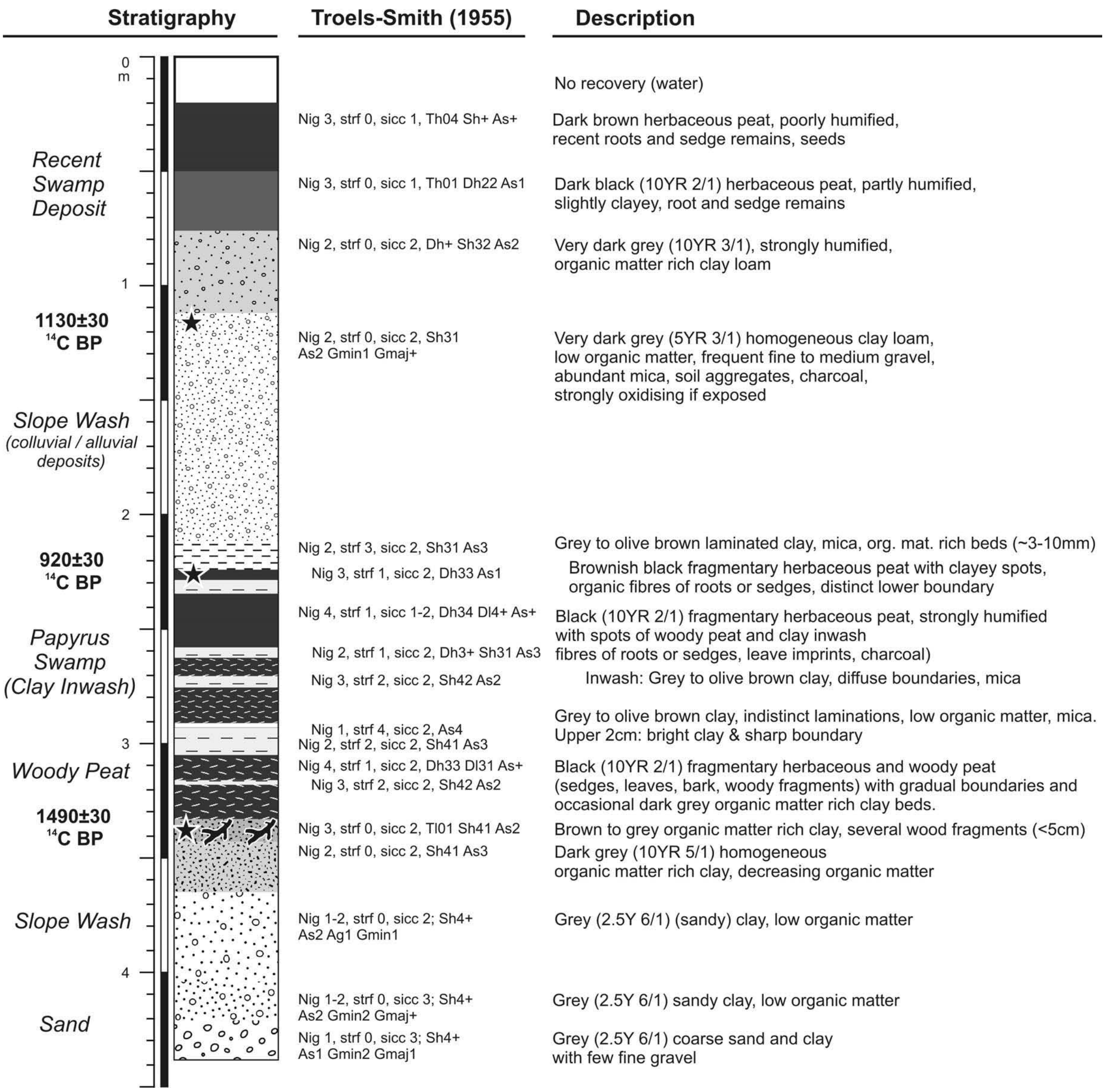


Fig. 31: Stratigraphy of the Lomwe Swamp Core. Stratigraphic description follow the system proposed by TROELS-SMITH (1955) but is given also in plain English following the suggestions of SCHNURRENBERGER et al. (2003). Note the age reversal of uncalibrated radiocarbon dates.

6.5.3 Organic carbon, stable carbon isotopes and charcoal proxies

Analytical determination of the organic carbon content (Fig. 32) confirms the above-discussed stratigraphy. Organic carbon values of the sandy bottom sediments are low (<0.3% C_{org}) and intermediate for the colluvial layer (2.5 - 6%), whereas the recent wetland and the buried peat show organic carbon contents of up to 40%. Stable carbon isotope composition suggests C_3 dominance of the bottom sediments ($\delta^{13}C$ <-23‰) and the recent sedge dominated swamp ($\delta^{13}C$ <-26.5‰). High $\delta^{13}C$ of the peat layers however, suggests C_4-vegetation, probably a *Cyperus* dominate reed swamp. High $\delta^{13}C$ values (>-17‰) of the buried peat and the beginning of the recent wetland however imply a considerable contribution from C_4-plants.

The charcoal proxy nitric-acid-resistant carbon (NARC) closely mirrors the distribution of organic carbon in the Lomwe swamp and shows maximum values for the buried peat and the recent wetland (Fig. 32). Average NARC percentages vary between 1 and 4% but are extremely low in the basal sediments (<0.2%).

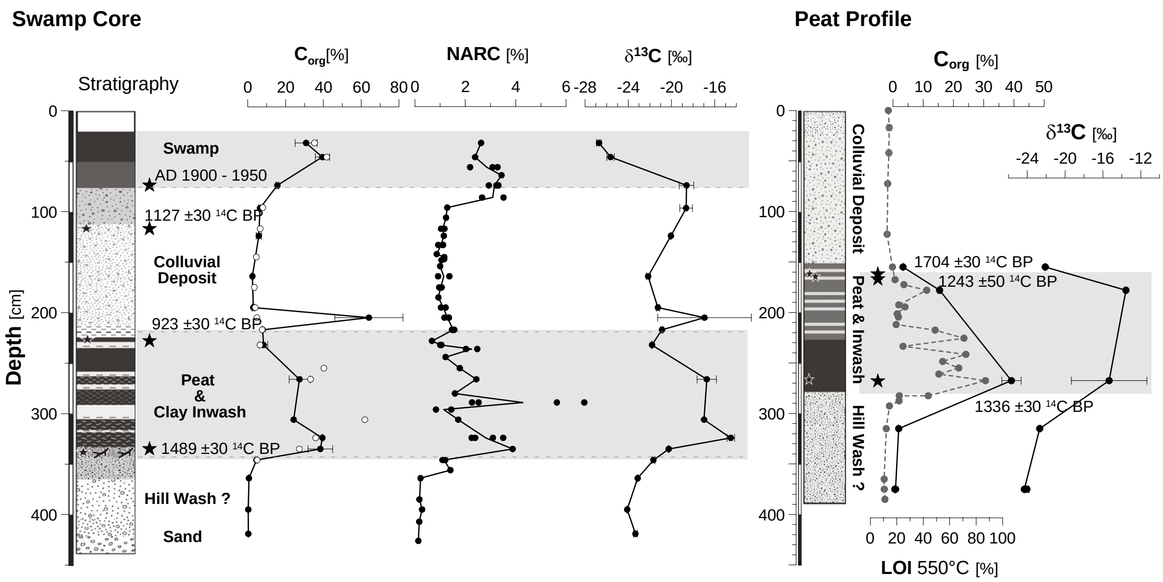


Fig. 32: Stratigraphy and analytical results of the Lomwe Swamp sediments. Organic carbon (C_{org}), stable carbon isotope ($\delta^{13}C$), loss-on-ignition (LOI) and nitric-acid-resistant carbon (NARC) of selected samples from the Lomwe Swamp and Lomwe Peat profiles. NARC is interpreted as a proxy for charcoal quantity closely reflects the amount of organic carbon. Single samples and average curve are plotted. Organic carbon (C_{org}) has been measured twice. Black circles and bold line represents average C_{org} of three replicates during isotope analysis. Open circles are single measurements during NARC analysis. High variation of organic matter content is reflected by the high-resolution LOI measurements of the Peat Profile. Note the reversal of uncalibrated radiocarbon dates at the transition from the peat to the colluvial/ alluvial overburdens at both sites. Recovery of exotic Cuppresus pollen indicates the start of the 19th century.

7 ANALYTICAL RESULTS

This chapter presents the analytical results of slope deposit grouped by method to draw the attention to overall trends and allow comparison between profiles and sites. For a summary of analytical results in the context of the respective profile, the reader is referred to Appendix B.

7.1 Organic carbon content

Organic carbon content and organic carbon isotope composition were measured for selected samples. **Forest topsoils** at Kwa Kirumbi and Kwa Chegho show high organic carbon contents between 3% and 5% C_{org}, which decreases in the subsoil to constant values below 1% (Fig. 33). The organic layers recorded at Kwa Chegho qualify as folic horizons (criteria: C_{org} >20%), whereas lower amounts of C_{org} at Kwa Kirumbi indicate faster decomposition at lower altitudes. At Kwa Kirumbi 2 a distinct, dark, buried topsoil is observed, which is reflected in a continuously high (>3%) organic carbon content over the upper 50cm. Similarly, elevated C_{org} values over the entire profile at Kwa Chegho 2 might be explained by soil disturbance. C/N-ratios widen with depth and mirror the decomposition stage of organic matter. Narrower C/N-ratios reflect the fresh nitrogen rich organic matter recently incorporated into the surface, whereas organic material of the subsoil is strongly decomposed, N-depleted and more resistant to degradation.

Organic carbon content of **slope deposits** is generally low and varies around 0.7% at Mrongo and Usumbwe and slightly higher at Lomwe (Fig. 34). Topsoils stand out with average C_{org} values of 1.5±0.2% at Lomwe and 2.8±0.7% at Mrongo (cf. Tab. 10). Similarly, buried topsoils are organic carbon enriched, although C_{org} varies between study sites. At Lomwe, organic carbon contents of buried topsoils (average 2±0.4%) even exceed C_{org} values of the respective current topsoils. At Mrongo on the other hand, accumulation of organic carbon on buried surfaces is less pronounced (average 0.9±0.1%), but still discernable. High organic carbon amounts are observed for the buried peat layer at Usumbwe 3, whereas the erosion surface at 950cm depth inferred for Usumbwe 2 lacks any indications of organic matter accumulation.

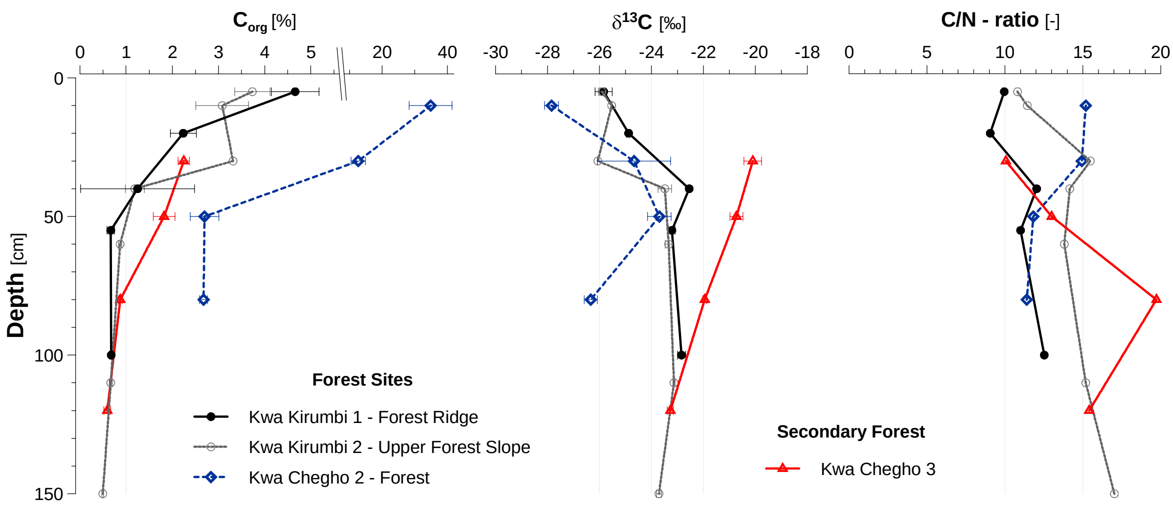


Fig. 33: Organic carbon content, carbon isotope composition, and C/N-ratios of forest sites at Kwa Chegho and Kwa Kirumbi.

7.2 Stable carbon isotope composition

The carbon isotope compositions of Kwa Kirumbi and Kwa Chegho **forest soils** show a common pattern (Fig. 33). $\delta^{13}C$ values of the organic layer and the topsoil are low at both Kwa Kirumbi (-26‰) and Kwa Chegho (-28‰), in accordance with the current C_3-forest vegetation. In the subsoil, $\delta^{13}C$ values increase to about -23‰ and stabilise. The depth of the observed shift in the $\delta^{13}C$ values coincides with the stabilisation of C_{org} at values <1% in the subsoil. Contrary to the closed forest sites, stable carbon isotope composition of the topsoil at Kwa Chegho 3 is high (-20.1‰) and reflects the current open secondary forest with grass undergrowth and hence contribution of C_4-plants.

Patterns of stable carbon isotope composition of **slope deposits** are similar at Mrongo and Lomwe (Fig. 35): low $\delta^{13}C$ values of the current topsoil, high ratios within the colluvial deposit and intermediate to low values for the *in situ* subsoils. Current topsoils have distinctly lower $\delta^{13}C$ values than the bulk of the colluvial deposit. Topsoil $\delta^{13}C$ at Mrongo 2, 3 & 10 plots between -22.8‰ and -25.0‰ reflecting the dominant C_3-vegetation of the present banana grove and its shade trees. An exception is Mrongo 4. Here the topsoil shows high $\delta^{13}C$ values of -18.0‰ indicative for contributions from C_4-plants according to its location in a maize field. At Lomwe, consistent topsoil $\delta^{13}C$ values of about -21.5‰ arise from the open *Eucalyptus* plantation with shrub and grass undergrowth.

Within the uppermost metre, carbon isotope ratios increase at both sites and maximum $\delta^{13}C$ values between -20‰ and -18‰ are observed in 1 to 3m depth. Below, the carbon isotope ratio decreases slightly but steadily and $\delta^{13}C$ values of *in situ* soils do not exceed -20‰ and frequently drop to -23‰ in the buried subsoils. $\delta^{13}C$ variation between profiles increases in the buried subsoils. At Lomwe, the observed pattern is most pronounced at the uppermost soil profiles Lomwe 3 & 10. The colluvial deposits show comparable high carbon isotope ratios (> -20‰) whereas the buried late Pleistocene soils are characterised by low $\delta^{13}C$ < -22‰ - in the subsoil even around -24‰.

Contrarily to the observations at Mrongo and Lomwe, the buried surface at Usumbwe 2 shows a tendency of increasing $\delta^{13}C$ values in the *in situ* soils. The variation of the stable carbon isotope composition at Usumbwe 3 on the other hand is most likely the result of a mixture of organic material in the buried peat and thus cannot be compared to the terrestrial environments discussed above.

7.3 Loss-on-ignition

The reliability of weight loss-on-ignition at 550°C as an organic carbon proxy was assessed by comparison with organic carbon values from element analysis (cf. Appendix D.2). LOI ranges from 5% to 16%. For samples with zero organic carbon content, a background weight loss between 4 and 8% was obtained. Correlation between LOI and organic carbon differs between profiles and study areas.

It is well known that LOI overestimates the amount of organic matter. Release of structural water from clay minerals and sesquioxides are the most important sources of weight loss, particular in samples with a high clay content (DEAN 1974; HOWARD & HOWARD 1990; SANTISTEBAN et al. 2004; DE VOS et al. 2005). Inorganic and elemental carbon as well as incomplete ashing are further sources of bias. Due to these well-known methodological problems, organic matter estimation based on loss-on-ignition has to be interpreted carefully. Despite moderate correlation between LOI and organic carbon (r^2~0.5, cf. Appendix D.2, Fig. B) the inherent fluctuations of LOI exceed the range of organic carbon variation between the bulk of the deposits and buried topsoils (differences between 0.1 – 0.4% C_{org}). LOI does not reflect the slightly increased organic carbon content at Mrongo, although the strong C_{org} enriched soils at Lomwe (~3%) were detected. Being unable to pick up the small but important organic matter accumulation of prominent and crucial soil features such as buried topsoils, weight loss-on-ignition was discarded as an adequate method to accurately describe small organic matter variations in the studied slope deposits.

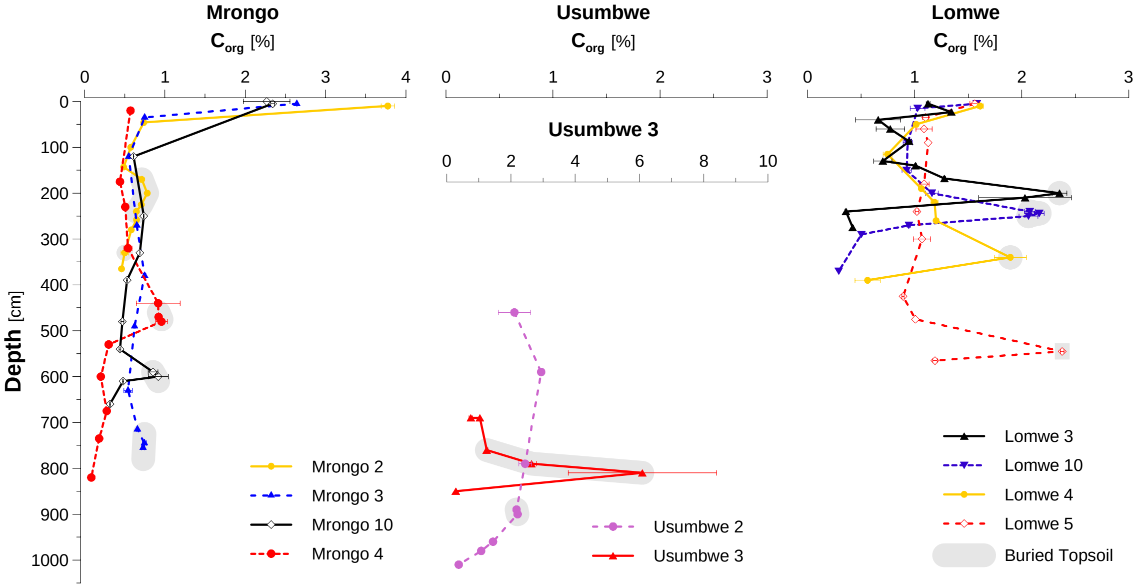


Fig. 34: Organic carbon content of slope deposits. To allow stratigraphic comparison between profiles of different depth, buried topsoils and inferred former surfaces (grey shaded areas) are indicated separately for each profile. Note the change of scale for the different study sites.

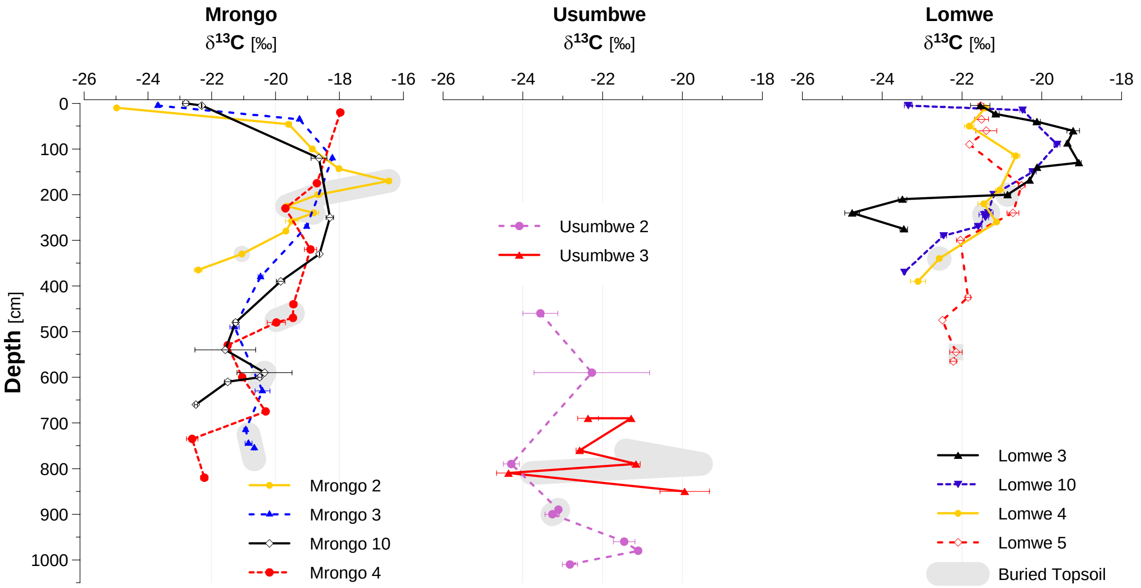


Fig. 35: Stable carbon isotope composition of hillslope deposits at Mrongo, Usumbwe and Lomwe. To allow stratigraphic comparison between profiles of different depth, buried topsoils and inferred former surfaces (grey shaded areas) are indicated separately for each profile. Standard deviation of three replicates is plotted.

7.4 pH

Forest soils show elevated pH values in topsoil and organic layer and low pH in the subsoil (Fig. 36). At Kwa Kirumbi, topsoil and organic layer pH values range between 5 and 6.5; at Kwa Chegho the topsoil pH increase is less pronounced. Values decline in the subsoil and vary between pH 4 and 4.5 at Kwa Kirumbi and slightly higher between pH 4.5 and 5 at Kwa Chegho. A slight increase is noticed in several profiles within the transitional B/C horizons, where weathered rock material becomes frequent. The elevated pH in the organic layer and topsoil can be explained by litter fall, the input of fresh organic matter and hence a constant supply of basic cations. This base-pump mechanism counteracts the effects of leaching, cation removal, and acidification reflected by depressed pH of subsoil horizons.

Agricultural soils show a higher pH (>5) than forest soils and an increased variability between profiles and sites (Fig. 36). Generally, higher pH values of eroded soils under agricultural use can be ascribed to the rejuvenation of the soils by erosion and the removal of leached material of former top- and subsoils. The exposed subsoil or even B/C-transition horizons are less acidic and have a higher pH. Nevertheless, elevated pH values of the topsoil reflect incipient organic matter accumulation or the admixture of base-rich topsoil material by disturbance. Exceptional high topsoil pH of 6.5 at Ngalanga 2 (banana grove) might not only be the result of *in situ* organic matter accumulation and decomposition under dense banana vegetation, but also due to the colluvial overburden and probably manure and waste application below a habitation site. The exceptional low pH of the severely eroded Makongweni profile might be related to distinct bedrock material or acidification under Eucalyptus forest.

pH profiles of **colluvial slope deposits** show a characteristic s-shaped pattern (Fig. 37). The uppermost metre of the slope deposits shows elevated pH (pH > 6). Below, pH declines to about pH 5 in 1 – 3m depth. This pH depression generally coincides with the occurrence of layers of hillwash deposits characterised by gravel and sand lens occurrence. In the lower slope deposit, pH values increase again and pH of buried *in situ* soils generally exceeds pH 6. Deviations from the general pH pattern are observed at Usumbwe and Lomwe. At Usumbwe 3, pH drops to a minimum pH of 3.6 between 7 and 8m depth due to strong organic acids of the buried, organic matter rich peat. At Lomwe, pH profiles do not show the distinct pattern observed at Mrongo and Usumbwe. pH values remain fairly constant and do not show any distinct change with depth. *In situ* soils and colluvial overburden show homogeneous pH values.

7.5 Magnetic Susceptibility

Magnetic susceptibility (χ_{lf}) of forest soils, agricultural soils, and slope deposits range from 0.05 to 10.7 $x10^{-6}$ m^3kg^{-1} and shows significant differences between sites. Low values between 0.05 and 2.7 $x10^{-6}$ m^3kg^{-1} are observed at the forest site Kwa Kirumbi, whereas at Kwa Chegho χ_{lf} is higher and ranges from 2.2 to 10.7 $x10^{-6}$ m^3kg^{-1}. Agricultural and eroded soils show intermediate magnetic susceptibility values that differ between study sites. Low χ_{lf} values <4.1 $x10^{-6}$ m^3kg^{-1}, are common in the Ugweno area (Ngalanga, Usumbwe, Makongweni), while slightly higher values <6.5 $x10^{-6}$ m^3kg^{-1} prevail at Changuku/Lomwe. Slope deposits show intermediate values and range between 0.5 and 7 $x10^{-6}$ m^3kg^{-1} at Mrongo and Usumbwe, whereas higher χ_{lf} values at Lomwe frequently reach up to 10 $x10^{-6}$ m^3kg^{-1}.

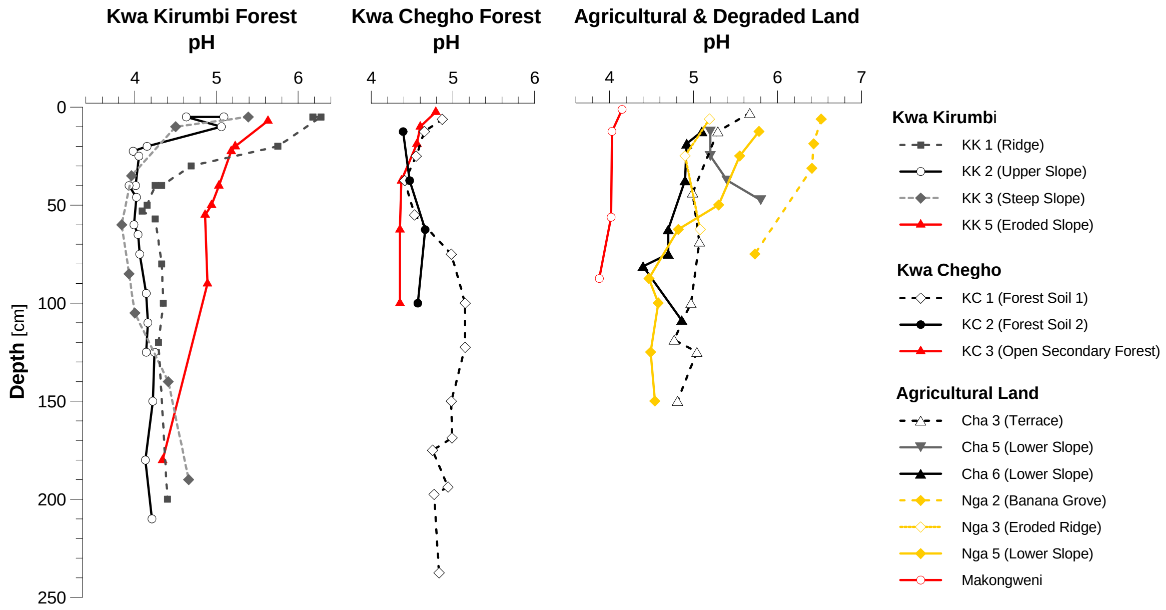


Fig. 36: Soil pH (H_2O) of selected profiles under forest and agricultural land use. Forest soils show elevated pH values in the topsoil due to base-pump effects and low pH due to leaching and acidification. Generally, higher pH values of cultivated and strongly eroded soils mirror soil truncation and exposure of less leached subsoil horizons.

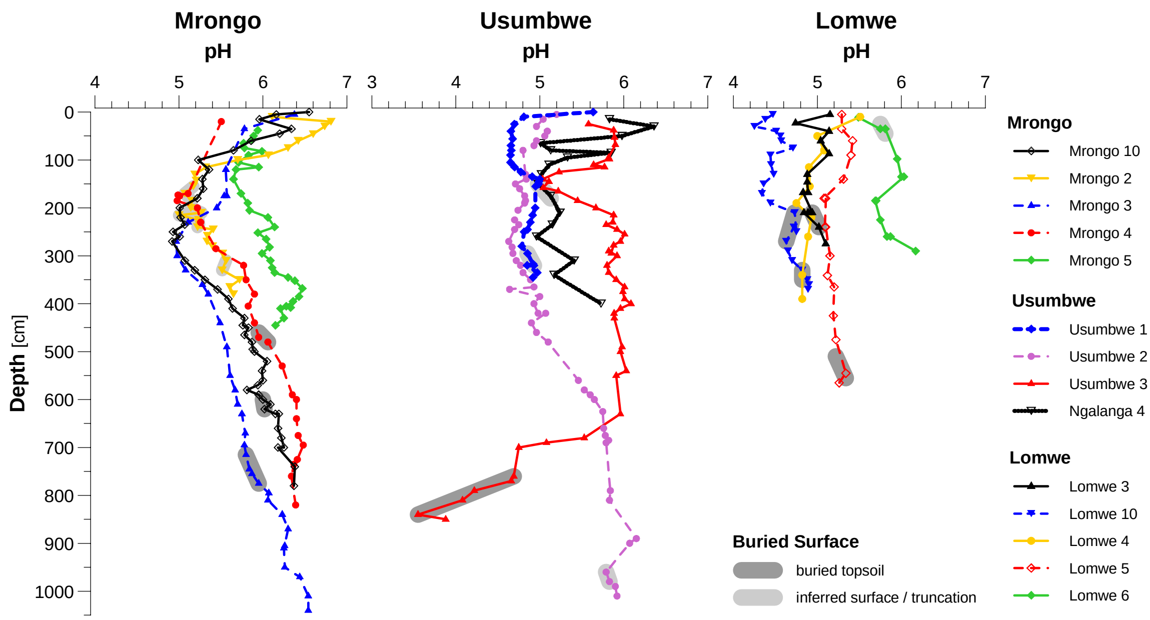


Fig. 37: Soil pH [H_2O] of slope deposits at Mrongo, Usumbwe and Lomwe. The depth of stratigraphic breaks differs between profiles. To allow stratigraphic comparison between profiles of different depth, buried topsoils (dark shaded areas) and inferred former surfaces (light shaded areas) are indicated separately for each profile.

Despite a high variability, two different patterns of magnetic susceptibility parameters are observed. *In situ* soils show enhanced magnetic susceptibility of topsoils and disturbed soil layers, whereas slope deposits show maxima of magnetic susceptibility in the lower and central part (unit II & III).

7.5.1 Forest and Agricultural soils

The pattern of enhanced magnetic susceptibility of topsoils is best observed at forest soils of Kwa Kirumbi - despite very low absolute χ_{lf} values (Fig. 38). Susceptibility is slightly elevated in the topsoil and upper subsoil (1 - 2 x10^{-6} m^3kg^{-1}) but decreases in the lower subsoil and the B/C-transition horizon. At Kwa Chegho 1, χ_{lf} is high and variable but drops sharply at the BC-transition. Similarly, χ_{lf} decreases in the truncated subsoil of Kwa Chegho 3. Absolute magnetic susceptibility of agricultural soils differs strongly between sites, but generally lack variation with depth. An exception is Changuku 3 (terrace), where the high χ_{lf} of the colluvial overburden contrasts sharply with low values in the truncated C-horizon.

Frequency dependent magnetic susceptibility ($\chi_{fd\%}$) ranges from low percentages <1% to high values up to 12% (Fig. 38). Again, forest soils of Kwa Kirumbi show a distinctive pattern of topsoil enhancement: elevated $\chi_{fd\%}$ (4 - 8%) for topsoils, colluvial deposits and upper subsoils but very low $\chi_{fd\%}$ (<2%) in the lower subsoil and B/C-transition horizons. At Kwa Chegho, this pattern is reflected by the partly eroded profile Kwa Chegho 3 (open secondary forest), whereas the closed forest profiles Kwa Chegho 1 & 2 show high and homogeneous $\chi_{fd\%}$ (6 - 8%). No clear pattern is observed on agricultural sites, where $\chi_{fd\%}$ is strongly site-specific. Exceptional high values (8 - 11%) are shown at Makongweni.

7.5.2 Slope Deposits

Magnetic susceptibility values (χ_{lf}) of topsoils of slope deposits are uniform within sites but differ between study areas. At Mrongo and Usumbwe, they vary between 2.1 and 3.2 x10^{-6} m^3kg^{-1}, but are consistently higher at Lomwe, where values range from 4.3 to 5.2 x10^{-6} m^3kg^{-1}. A consistent pattern of magnetic susceptibility is observed at the two Ugweno sites Mrongo and Usumbwe. Low magnetic susceptibility (<3 x10^{-6} m^3kg^{-1}) in the topsoil and the upper part of the slope deposits increases to intermediate magnetic susceptibility values ranging from 4 to 6 x10^{-6} m^3kg^{-1} below 50 - 250cm depth in the central part of the deposits. The shift from intermediate to low χ_{lf} in the upper part of the profiles coincides well with the occurrence of sand lenses (cf. chapter 8.3). The black iron sands are dominated by primary ferrimagnetic iron minerals characterised by exceptionally high χ_{lf} values between 10 and 24 x10^{-6} m^3kg^{-1} and a very low frequency dependent susceptibility. A second shift takes place at the former ground surfaces. χ_{lf} drops sharply and values of <2 x10^{-6} m^3kg^{-1} characterise the *in situ* subsoils.

Frequency dependent susceptibility values ($\chi_{fd\%}$) oscillate around 6 - 7% (Mrongo) and 8 - 9% (Usumbwe), ranging from minima around ~2% recorded in the buried subsoils to maxima around ~12% in the colluvial deposits at Usumbwe. Generally, highest variability as well as lowest frequency dependency ratios are observed for the buried subsoils. Exceptions are upper footslope profiles (Mrongo 2 & 3) where $\chi_{fd\%}$ values increase. $\chi_{fd\%}$ values of the buried topsoils and the slope deposits are high but fluctuate in a site-specific range. Only within the uppermost metres of the deposits, frequency dependency tends to decline slightly compared to the previous levels.

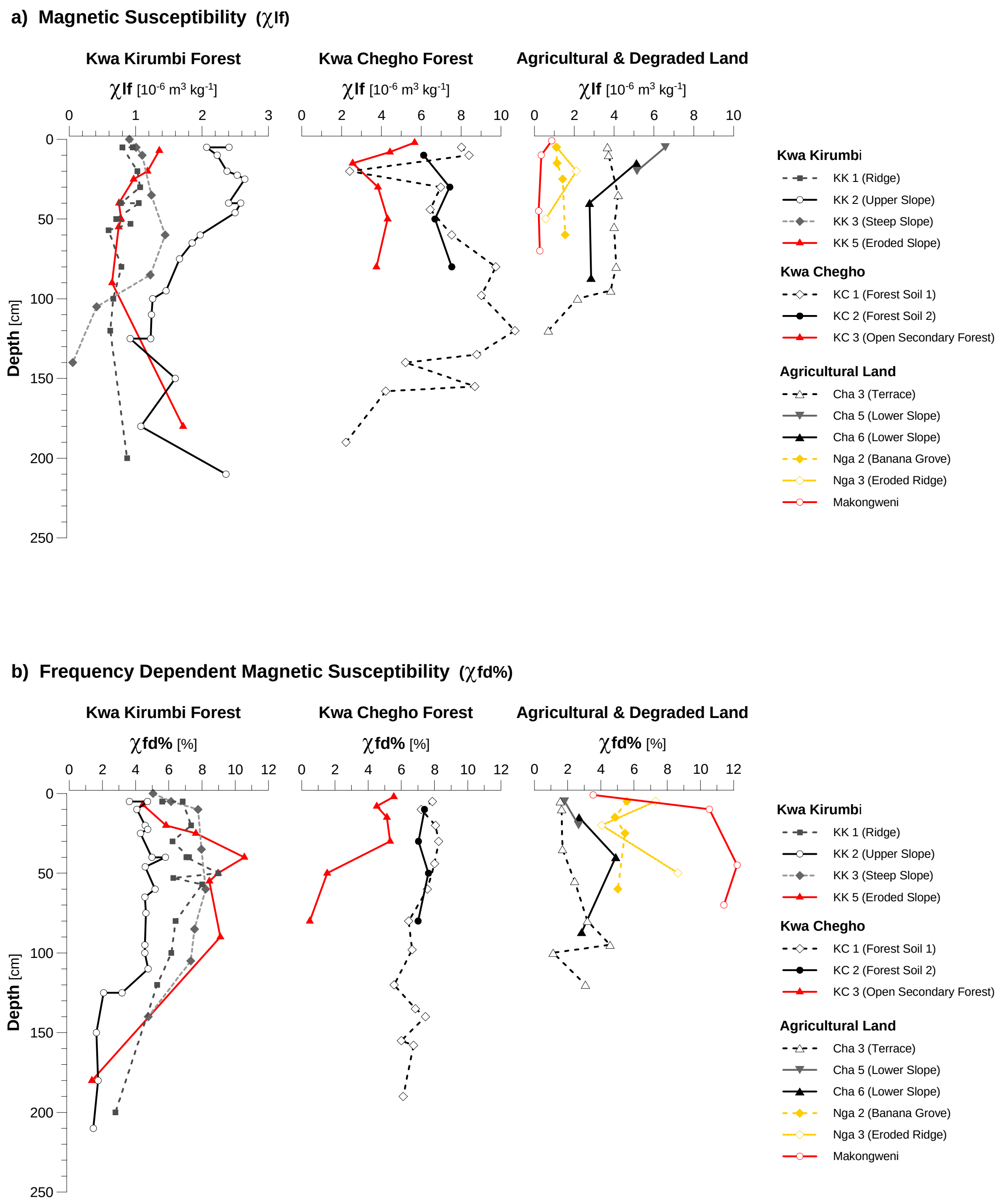


Fig. 38: Magnetic susceptibility parameters of selected profiles under forest and agriculture land use. a) Low frequency magnetic susceptibility (χ_{lf}). Differences of χ_{lf} values between study areas are related to variations of parent material. High χ_{lf} values indicate abundant ferrimagnetic minerals like magnetite or maghaemite. Note the change of scale for χ_{lf} of the Kwa Kirumbi profiles. b) Frequency dependent magnetic susceptibility ($\chi_{fd\%}$). $\chi_{fd\%}$ is a rough proxy for the relative contribution of secondary magnetic minerals formed during pedogenesis or fire.

At Lomwe, the observed pattern differs slightly. As observed at Mrongo and Usumbwe the two upper footslope profiles Lomwe 3 & 10 show a strong and abrupt decrease of magnetic susceptibility in the uppermost deposits. Contrary to this pattern, the lower footslope profiles Lomwe 4, 5 & 6 show steady decline from maximum χ_{lf} values in the buried topsoil to intermediate χlf values at the present surface. Similarly, frequency dependency at Lomwe peaks in the buried topsoil (9-10%), while declining steadily throughout the colluvial deposit to low $\chi_{fd\%}$ of 2.8 - 3.8% near the recent surface.

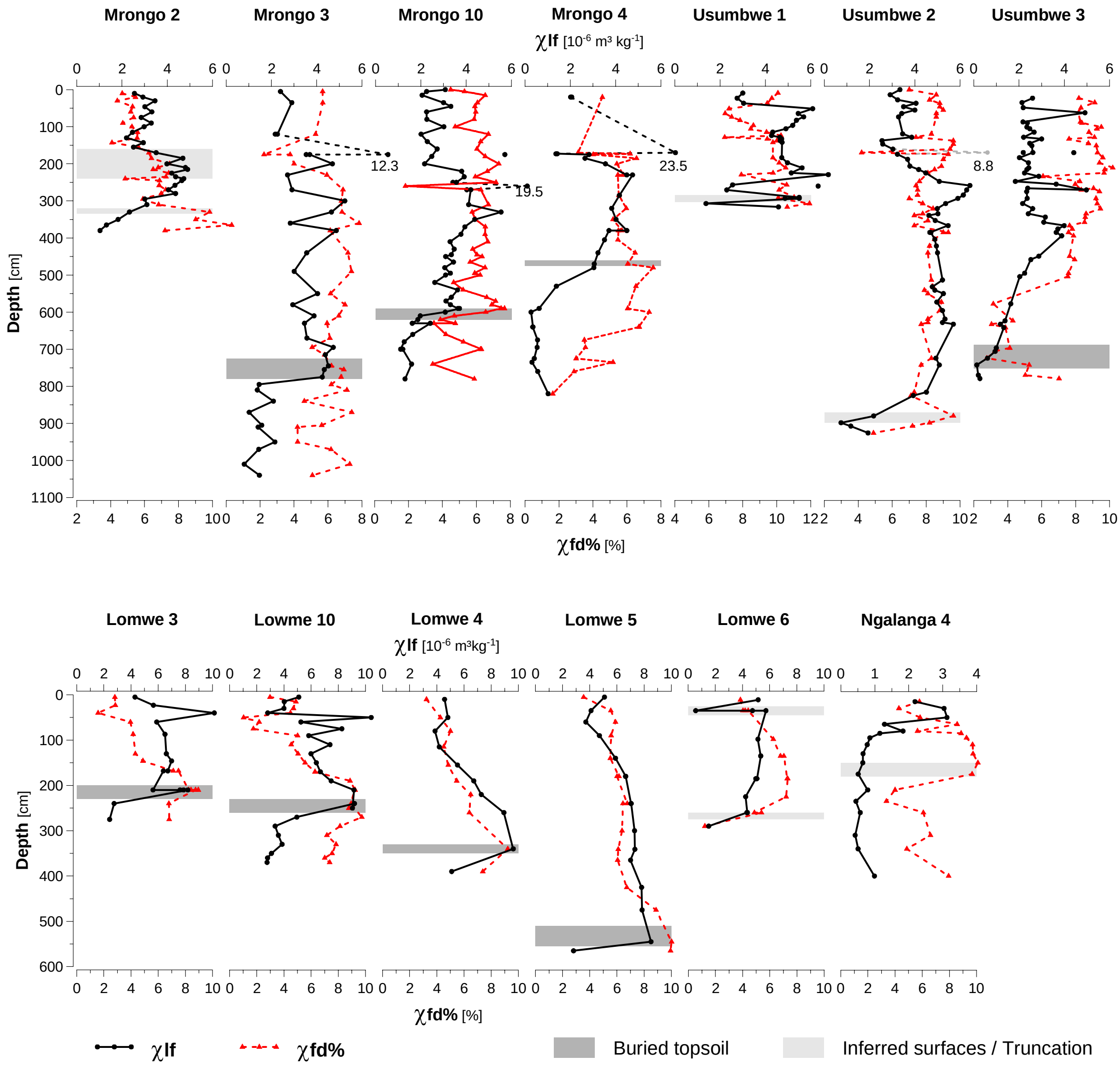


Fig. 39. Magnetic susceptibility parameters of slope deposits. Magnetic susceptibility (χ_{lf}, black) and frequency dependent magnetic susceptibility ($\chi_{fd\%}$, red) for slope deposits at Mrongo, Usumbwe and Lomwe. Since profile depth varies, buried topsoils are marked by dark, grey bars; possible former ground surfaces are indicated by light grey bars.

7.6 Particle Size

Clays and clay loams dominate the soil texture of the Pare uplands (Fig. 40). Clay and sand dominate while silt only occurs in low amounts between 10% and 30%. Clay content varies between about 30% and 60%, sand between 20% and 60%. Variations between adjacent samples are higher for slope deposits than for the more homogeneous samples of the Kwa Kirumbi forest. Clay content does not show any consistent or well-defined trend such as clay enrichment with depth. Although increasing clay content with depth is observed for the slope deposits at Mrongo 2 and at Lomwe 10, the majority of the profiles (Mrongo 4 & 10, Kwa Kirumbi 1 & 2) do not show clay enrichment with depth. Buried topsoils tend to have a higher proportion of fine particles than their subsoil and overlying deposits. Despite the frequent observation of clay coatings, particle size analysis was not able to confirm clay translocation for either forest soils at Kwa Kirumbi or for the slope deposits.

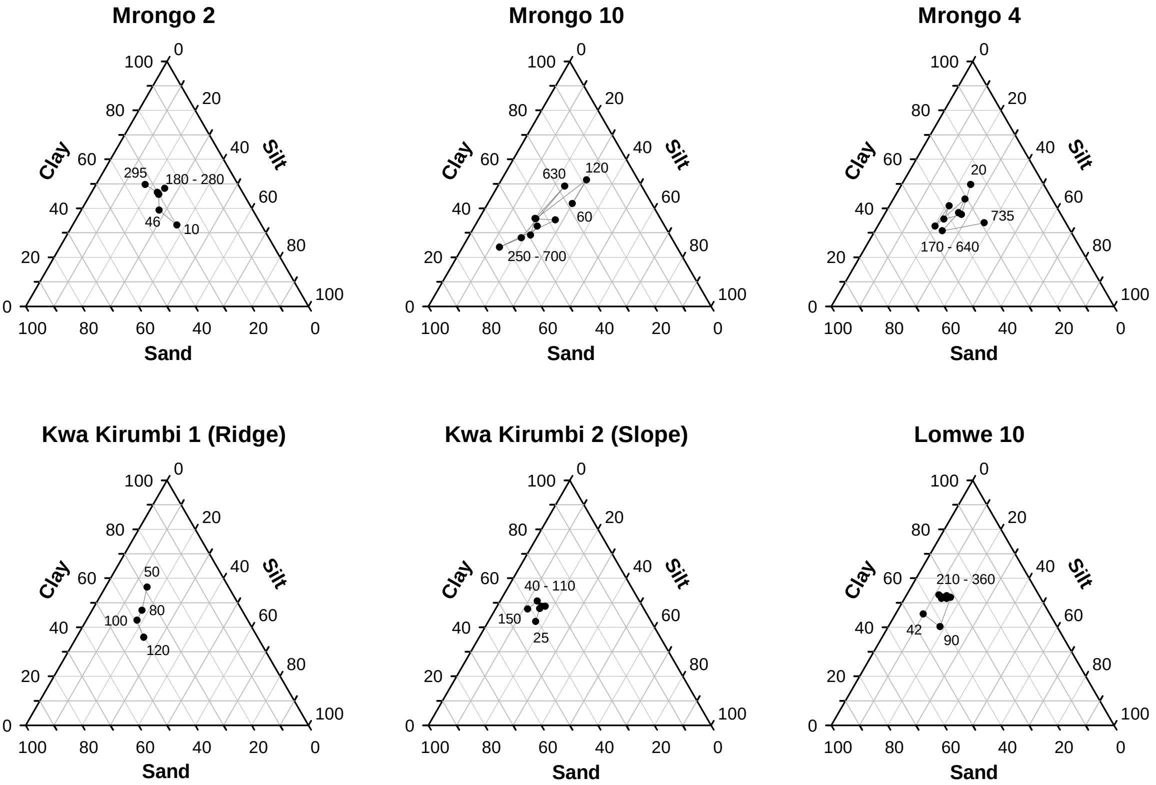


Fig. 40: Particle size ternary diagram for selected soil profiles. Numbers indicate sample depths.

7.7 Radiocarbon Dating

The landscape reconstruction of North Pare is based on 23 radiocarbon dates (Tab. 6). Due to its frequent occurrence, charcoal was the main sample type, complemented by a radiocarbon date of soil organic matter at Lomwe 3. Bulk peat was dated at the Lomwe swamp as separation of charcoal and plant organics from peat samples was unfeasible.

Charcoal fragments are likely to be reworked, rendering radiocarbon dates maximum ages for the deposition of the respective colluvial layer. Despite high biological activity of termites and frequent occurrence of animal holes and channels, no stratigraphic disturbances by bioturbation or age inversion were observed. This does not rule out that charcoal fragments have moved within the soil on a spatially more confined depth scale; e.g. within decimetres. The presented dates are therefore only rough estimates of the deposition age. Charcoal from buried topsoils is assumed to represent burial age and onset of soil erosion. Where no charcoal was found in the buried topsoil, the lowermost charcoal fragment gives a minimum age for soil burial (Lomwe 5, Usumbwe 2).

Onset of frequent sand lens deposition is dated at three sites and falls into the $14^{th}/15^{th}$ century (between AD 1340 – 1470, OxCal boundary model, 68% - confidence interval) but not later than the mid-15^{th} century (AD 1445 – 1481, boundary from OxCal combination of dates, 68% - confidence interval).

Tab. 6: ^{14}C AMS radiocarbon dates from North Pare. Sample type, depth, and dated features are reported. Calibration is based on the OxCal 4 program using the IntCal 09 calibration curve. Calibrated dates are rounded to decades.

Laboratory N°	Sample Code	Depth [cm]	Feature	Sample	Convent. Age ^{14}C years BP	Calibrated Age (95.4%) cal BP	BC/AD	$\delta^{13}C$ [‰]
WK-25772	Mrongo 2	220	placed stones	charcoal	954 ± 30	930 - 790	1020 - 1160 AD	-25.7 ± 0.2
LTL-5148 A	Mrongo 4	200	sand lenses	charcoal	472 ± 40	630 - 460	1320 - 1490 AD	-24.5 ± 0.5
WK-25723	Mrongo 4	470	buried topsoil	charcoal	1521 ± 30	1520 - 1340	430 - 610 AD	-25.0 ± 0.2
LTL-5150 A	Mrongo 10	300	sand lenses	charcoal	326 ± 40	490 - 300	1460 - 1650 AD	-19.6 ± 0.5
LTL-5149 A	Mrongo 10	560	buried topsoil	charcoal	2202 ± 50	2340 - 2060	400 - 110 BC	-25.3 ± 0.5
LTL-5151A	Mrongo 11	300	slope deposit	charcoal	1197 ± 50	1270 - 980	680 - 970 AD	-35.2 ± 0.3
WK-25727	Usumbwe 2	910	slope deposit	charcoal	1864 ± 30	1880 - 1720	70 - 230 AD	-22.8 ± 0.2
LTL-5152 A	Usumbwe 3	285	sand lenses	charcoal	416 ± 45	540 - 310	1410 - 1640 AD	25.4 ± 0.5
LTL-5143 A	Usumbwe 3	812	peat layer	charcoal	1558 ± 45	1540 - 1350	410 - 600 AD	-26.5 ± 0.5
WK-24690	Lomwe 3	~210	buried topsoil	bulk	12,299 ± 64	14,890 - 13,950	12,940 - 12,000 BC	-20.2 ± 0.2
WK-24689	Lomwe 3	210	buried topsoil	charcoal	14,812 ± 73	18,510 - 17,680	16.560 - 15,730 BC	-25.0 ± 0.2
LTL-5145 A	Lomwe 10	115	deposit change	charcoal	1060 ± 45	1070 - 830	880 - 1120 AD	-26.4 ± 0.5
LTL-5146 A	Lomwe 10	300	buried topsoil	charcoal	16,210 ± 85	19,570 - 18,930	17,620 - 16,980 BC	-24.0 ± 0.5
WK-24691	Lomwe 5	198	slope deposit	charcoal	697 ± 30	560 - 690	1260 - 1390 AD	-23.6 ± 0.2
WK-24693	Lomwe 5	289	slope deposit	charcoal	968 ± 30	940 - 790	1010 - 1160 AD	-24.8 ± 0.2
WK-24692	Lomwe 5	475	slope deposit	charcoal	4105 ± 30	4820 - 4450	2870 - 2500 BC	-23.7 ± 0.2
LTL-5147 A	Changuku 4	285	slope deposit	charcoal	1609 ± 50	1690 - 1380	260 - 570 AD	-26.1 ± 0.4
WK-24687	Lomwe Peat	162	up. boundary	bulk	1704 ± 30	1540 - 1700	250 - 410 AD	-17.0 ± 0.2
LTL-5144 A	Lomwe Peat	167	up. boundary	charcoal	1243 ± 50	1060 - 1290	660 - 890 AD	-12.9 ± 0.5
WK-24688	Lomwe Peat	268	low. boundary	bulk	1336 ± 30	1180 - 1310	640 - 770 AD	-14.8 ± 0.2
WK-25725	Lomwe Swamp	117	recent peat	bulk	1127 ± 30	960 - 1170	780 - 990 AD	-20.9 ± 0.2
WK-25726	Lomwe Swamp	228	up. boundary	bulk	923 ± 30	760 - 930	1020 - 1190 AD	(small spl.)
WK-25724	Lomwe Swamp	335	low. boundary	wood	1489 ± 30	1490 - 1300	460 - 650 AD	-26.0 ± 0.2

7.8 Optically-stimulated luminescence dating

OSL ages were obtained for Mrongo 5 (345cm) and Usumbwe 3 (365cm & 260cm). Absolute ages were calculated from the radiogenic and cosmic dose rates and the respective equivalent dose (Tab. 7). Determination of the respective equivalent dose was by probability mean for Gaussian-like probability distributions or following the strongest component of a multi-component distribution extracted using the finite mixture model (GALBRAITH & LASLETT 1993).

The equivalent dose distribution from Mrongo 5 (345cm) is positively skewed and shows a low tail - a typical distribution for a sample with a low number of aliquots containing partly bleached quartz grains (Fig. 41). Most aliquots were sufficiently bleached during transport to build up a coherent luminescence signal. After the exclusion of outliers a single Gaussian-like distribution is obtained and the mean of the probability function can be assumed to accurately reflect the bleaching event and hence deposition age. The OSL age of 1360±80 before 2009 translates to AD 649±80 years and dates the first occurrence of sandy wash sediments, about 2m below the buried channel. The early OSL date for a single sand wash event in the valley bottom at Mrongo 5 is plausible and does not oppose the assumption that widespread runoff-based erosion, channel incision, and the development of sand fans at Mrongo 5 occurred much later - contemporaneous with the occurrence of dispersed sand lenses at other Mrongo profiles radiocarbon dated to the early 15th century.

Equivalent doses of the colluvial deposits at Usumbwe 3 (260cm 365cm) are very heterogeneous. The equivalent dose distribution shows a wide spread and no clear tailing off suggesting the mixture of aliquots with a wide range of ages (Fig. 41). Following the finite mixture model both samples show three possible bleaching events of similar ages (cf. Appendix D.1, Tab C), which suggests a common bleaching and deposition history of the two samples. However, the youngest probability peak (c. 2 Gy) is weak and older equivalent doses dominate. A small number of aliquots with a low equivalent dose would be expected from bioturbation, resulting in the admixture of a low amount of recently bleached quartz into older material (BATEMAN et al. 2003). On the other hand, a high tail is observed, which suggests the presence of a high amount of insufficiently bleached quartz grains and hence a general lack of resetting the geomorphological clock (WALLINGA 2002; FUCHS & WAGNER 2003). Additionally, there is strong independent evidence that both samples are insufficiently bleached. Radiocarbon dates obtained from the same profile have yielded ages of 416±45 ^{14}C BP at 285cm and 1558±45 ^{14}C BP at 812cm. Pedo- and bioturbation on such a spatial scale is unlikely, especially as the charcoal dates are backed up by further radiocarbon ages for the same features in other soil profiles.

In summary, the Usumbwe samples show no distinct peak but a wide range of equivalent doses suggesting a considerable lack of light exposure and insufficient bleaching during the latest and final mobilisation step. Both OSL assays were rejected as they are not only suspected of partial bleaching but are also not in accordance with the general time frame of slope deposit accumulation based on consistent multiple radiocarbon dates from Usumbwe and Mrongo soil profiles.

Tab. 7: OSL dates from North Pare. Dates are given in calendar years prior to analysis in AD 2009. Equivalent dose determination are by probability mean (Prob) and finite mixture model (FMM, GALBRAITH & LASLETT 1993). The probability of the two most important peaks of multi-component distribution curves at Usumbwe 3 is calculated corresponding to the finite mixture model.

Lab Code	Site	Depth [cm]	Moisture [%]	Age [a]	Equivalent Dose [Gy]	Method	Prob. [%]	Dose Rate [µGy/ka]	Alpha Rate [µGy/ka]	Beta Rate [µGy/ka]	Gamma Rate [µGy/ka]	Cosmic Rate [µGy/ka]
Shfd09056	Mrongo 5	345	16.3	**1,360 ± 80**	2.25 ± 0.05	Prob.	n.a.	1651 ± 92	11.2 ± 3.2	1008 ± 86	486 ± 31	146 ± 7
Shfd09058	Usumbwe 3	365	31.1	**4,170 ± 240**	4.21 ± 0.14	FMM	**55**	1010 ± 46	24.6 ± 7.1	365 ± 33	478 ± 31	143 ± 7
				6,610 ± 520	6.68 ± 0.42	FMM	**20**					
Shfd09059	Usumbwe 3	260	21.4	**2,800 ± 250**	2.77 ± 0.22	FMM	**39**	989 ± 45	28.6 ± 8.3	351 ± 31	447 ± 29	163 ± 8
				4,580 ± 310	4.53 ± 0.22	FMM	**47**					

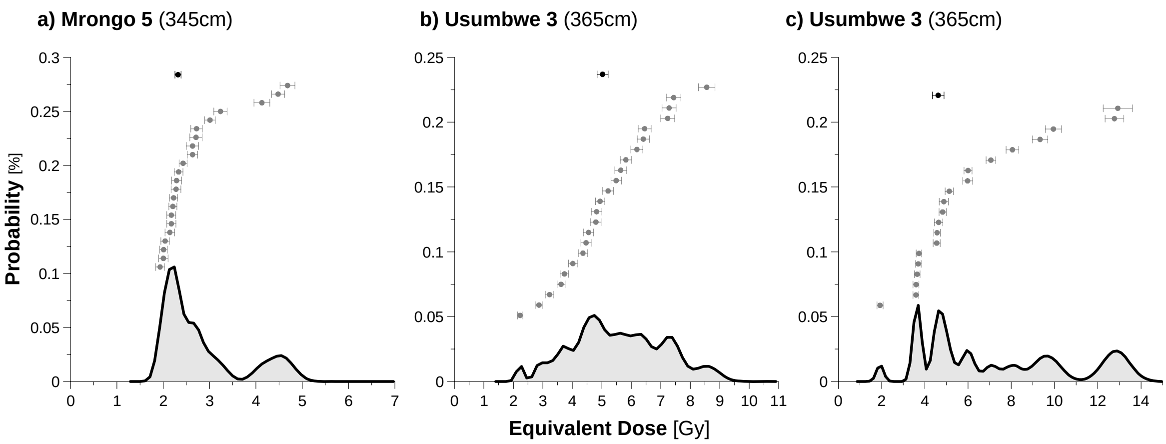


Fig. 41: Single aliquot equivalent dose measurements and probability distribution of OSL samples. Probability distribution curves (shaded area) of single aliquot measurements (grey dots) before exclusion of outliers within the 25th and 75th percentiles are plotted. Mean probability (black dots) is given. Whereas Mrongo 5 (345cm) shows a near Gaussian distribution, a multi-component distribution must be assumed for the wide spread observed for the two Usumbwe 3 samples.

7.9 **Pollen record**

Total counts vary considerably between 2 to 1981 grains per slide; terrestrial pollen varies between nil and 1449 per slide. A total of 72 different morphotypes were identified in the Lomwe Swamp Core, including 65 terrestrial pollen types, 6 wetland taxa, monolete (reniform) and trilete spores (Tab. 8 & Appendix C). Only 29 taxa are displayed in the pollen diagram (Fig. 42) and subjected to statistical analysis, whereas rare taxa (18 taxa only occurred in one depth interval and 38 taxa show maximum abundance proportions <2%) were excluded.

The terrestrial pollen sum shows high variation particularly within the buried peat below 220cm. Low total counts together with exceptionally high numbers of Asclepiadaceae and spores are responsible for low pollen sums and a high artificial variation. Single spikes of *Dobera*, *Cleome*, *Eucalyptus*/*Syzygium*, and *Cuppresus*/*Juniperus* are probably the result of uneven pollen deposition such as the inclusion of an entire inflorescence or catkins.

During the pollen identification process, several morphotypes had to be reclassified. Morphotypes initially counted as Urticaceae-type pollen were finally classed as *Acalpyha*. *Tribulus*-type pollen were re-classed and are now recorded as *Ilex* (similar ecology), likewise *Tremma* as *Celtis* (similar ecology). Pollen identified initially as *Maesa* were re-classed and is shown as *Dobera*. Due to their importance as ecological indicators and as stratigraphic time markers, two further pollen morphotypes *Eucalyptus*/*Syzygium* and *Cupressus*/*Juniperus* are discussed in detail in chapter 8.9.1.3.

7.9.1 Zonation and Ordination

Three major pollen zones can be separated on the bases of the two independent ordination methods - depth-constrained cluster analysis and unconstrained principal component analysis. Boundaries of the obtained pollen zones coincide with the stratigraphic delimitation of recent wetland (PZ III), hillwash deposit (PZ II) and buried peat layer (PZ I). Pollen samples from the first two zones fall into well-defined groups in both the cluster analysis (Fig. 42) and the PCA ordination (Fig. 43). The lowermost cluster (PZ I) on the other hand does not form a homogeneous cluster.

For the upper two pollen zones, sub zones are identified by both cluster analysis and PCA. Subzones (IIIa & IIIb) are characterised by distinct pollen assemblages and coincide with the stratigraphic boundaries between transition and the final establishment of the recent wetland. Similarly, two subzones (IIa & IIb) are distinguished within PZ II, albeit on a low dissimilarity level. The buried peat below 220cm (PZ I) shows a high between-sample variability, mirrored by high dispersion values of group joints in the dendrogram and a wide spread in the ordination plot. Whereas outliers are readily distinguished in the ordination plot, single samples distort the depth-constrained cluster analysis and may result in the splitting of an otherwise homogeneous cluster in two zones (e.g. sample 295cm, clay inwash). Forced inclusion of one distinct sample in a homogeneous cluster results in a dispersion increase and the loss of variance between originally heterogeneous clusters. Despite the exclusion of rare taxa, depth-constrained cluster analysis turned out to be an inadequate method to analyse the highly variable floral composition of the buried peat sequence. Final delimitation of pollen zones is based on comparison of both ordination results. This semi-objective approach was preferred over the non-critical adoption of significance values derived from a broken-stick model for the cluster analysis as proposed by BENNETT (1996).

Tab. 8: Pollen and non-pollen palynomorph types identified at the Lomwe swamp. Taxa are grouped according to their life forms and ecological affinities. Wetland taxa and spores are excluded from the pollen sum. Dominant life forms: T=tree, S = shrub, H = herb. Rare taxa (maximum abundances of less than 2% of the pollen sum or occuring only in a single sample) are excluded from statistical analysis and presentation in the pollen diagram.

Arboreal Pollen	Non-arboreal P. (Shrubs & Herbs)	Excluded from the Pollen Sum
Montane Forest	*Montane forest*	*Wetland*
Hagenia (Rosaceae), T	*Acalypha* (Euphorbiaceae) / Urticaceae, S	Cyperaceae, G
Ilex (Aquifoliaceae), T	Rubiaceae, S	*Typhae* (Typhaceae), H
Myrica (Myricaceae), T	*Asystasia* (Acanthaceae), S, rare	Liliaceae, H
Podocarpus (Podocarpaceae), T	*Acanthaceae* type (Acanthaceae), S, rare	*Ludwigia* (Onagraceae), H
Tapura (Dichapetalaceae), T	*Ericaceae* (Ericaceae), S, rare	*Hydrocotyle* (Araliaceae), H, rare
Nuxia (Loganiaceae), T, rare	*Polygala* (Polygalaceae), H, rare	Asclepidaceae, H
Schefflera (Araliaceae), T, rare	*Impatiens* (Balsaminaceae), H, rare	
Alchornea (Euphorbiaceae), T, rare		*Spores*
Macaranga (Euphorbiaceae), T, rare	*Woodland*	Trilete Spores (Pteridophyta), S
Apodytes (Icacinaceae), T, rare	*Aloe* (Aloaceae), S	Monolete Spores (Pteridophyta), S
Rapanea (Myrsinaceae), T, rare	*Capparis* (Capparidaceae), S	
Olea (Oleaceae), T, rare	*Euphorbia* (Euphorbiaceae), S	*Indetermined*
Lasianthus (Rubiaceae), T, rare	*Rhus* (Anacardiaceae), S, rare	Unknown
Canthium (Rubiaceae), T, rare	*Cissampelos* (Menispermaceae), S, rare	Indeterminable
Allophyllus (Sapindaceae), T, rare	*Commicarpus* (Nyctagynaceae), S, rare	
Polyscias (Araliaceae), T, rare	*Sansevieria* (Ruscaceae), S, rare	
Phoenix (Arecaceae), T, rare	*Solanum* (Solanaceae), S, rare	
Introduced Species	*Woodland, glades and clearings*	
Cupressus/Juniperus (Cupressaceae), T	Asteraceae, H	
Eucalyptus/Syzygium (Myrtaceae), T	Malvaceae, S	
Pinus (Pinaceae), T, rare	Lamiaceae, H	
	Justicia (Acanthaceae), H	
Semi-deciduous Woodland	*Phyllanthus* (Euphorbiaceae), H	
Acacia (Fabaceae), T	Amaranthaceae / Chenopodiaceae, H	
Dobera /Maesa (Salvadora./Primula.), T	Poaceae, G	
Tarrenna (Rubiaceae), T		
Terminalia (Combretaceae), T	*Anthropogenic Indicators*	
Commiphora (Burseraceae), T	*Rumex* (Polygonaceae), H	
Grewia (Tiliaceae), T, rare	*Commelina* (Commelinaceae), H	
Celtis (Ulmaceae), T, rare	*Zea mays* (Poaceae), H	
Croton (Euphorbiaceae), T, rare		
Lannea (Annacardiacea), T, rare	*Unclassified*	
Euclea (Ebenaceae), T, rare	*Cleome* (Capparidaceae), H	
Tarchonanthus (Asteraceae), T, rare	Fabaceae, H, rare	
Combretum (Combretaceae), T, rare	*Indigofera* (Fabaceae), H, rare	
Tamarindus (Fabaceae), T, rare	*Asparagus* (Asparagaceae), H, rare	
Ficus (Moraceae), T, rare	Apiaceae, H, rare	

The most important result of the ordination exercise is that pollen assemblage zones of non-local pollen coincide with the stratigraphic units of the swamp core. This agreement of pollen zone and stratigraphic units challenges the *a priori* classification of local and non-local taxa and questions the source area of the pollen grains. The fact that the pollen history parallels the hydrological development of the small Lomwe basin strongly suggests that pollen sources of many non-arboreal pollen types are - at least partly - local. Although wetland taxa like Cyperaceae, *Ludwigia*, Liliaceae, *Typha* and spores were excluded from the analysis, many shrubs and bush taxa common in dry woodland but also in glades and clearings dominate the pollen record between 222cm and 90cm (e.g. Amaranthaceae/Chenopodiacea, Malvaceae, Lamiaceae, and *Justicia*) and probably were growing locally on the open, seasonal dry basin bottom.

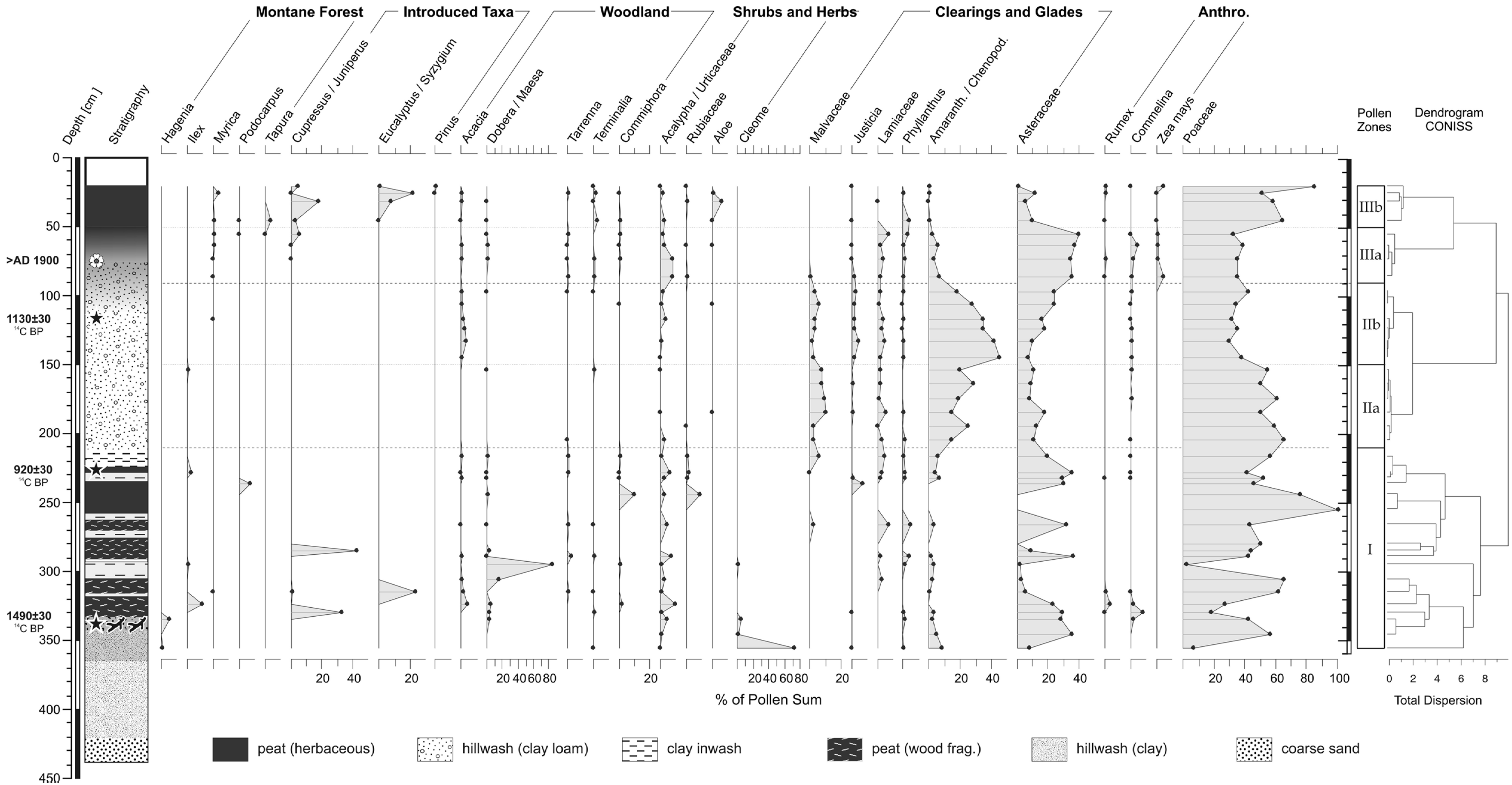


Fig. 42: Lomwe Swamp Pollen Diagram. Arboreal and non-arboreal pollen. Pollen types with maximum percentages >2% and occurrence in more than one sample are included in the analysis. Seven samples of the lower part (>360cm) are excluded due to low pollen counts. Pollen zones correspond to clusters derived from a dendrogram of CONISS cluster analysis.

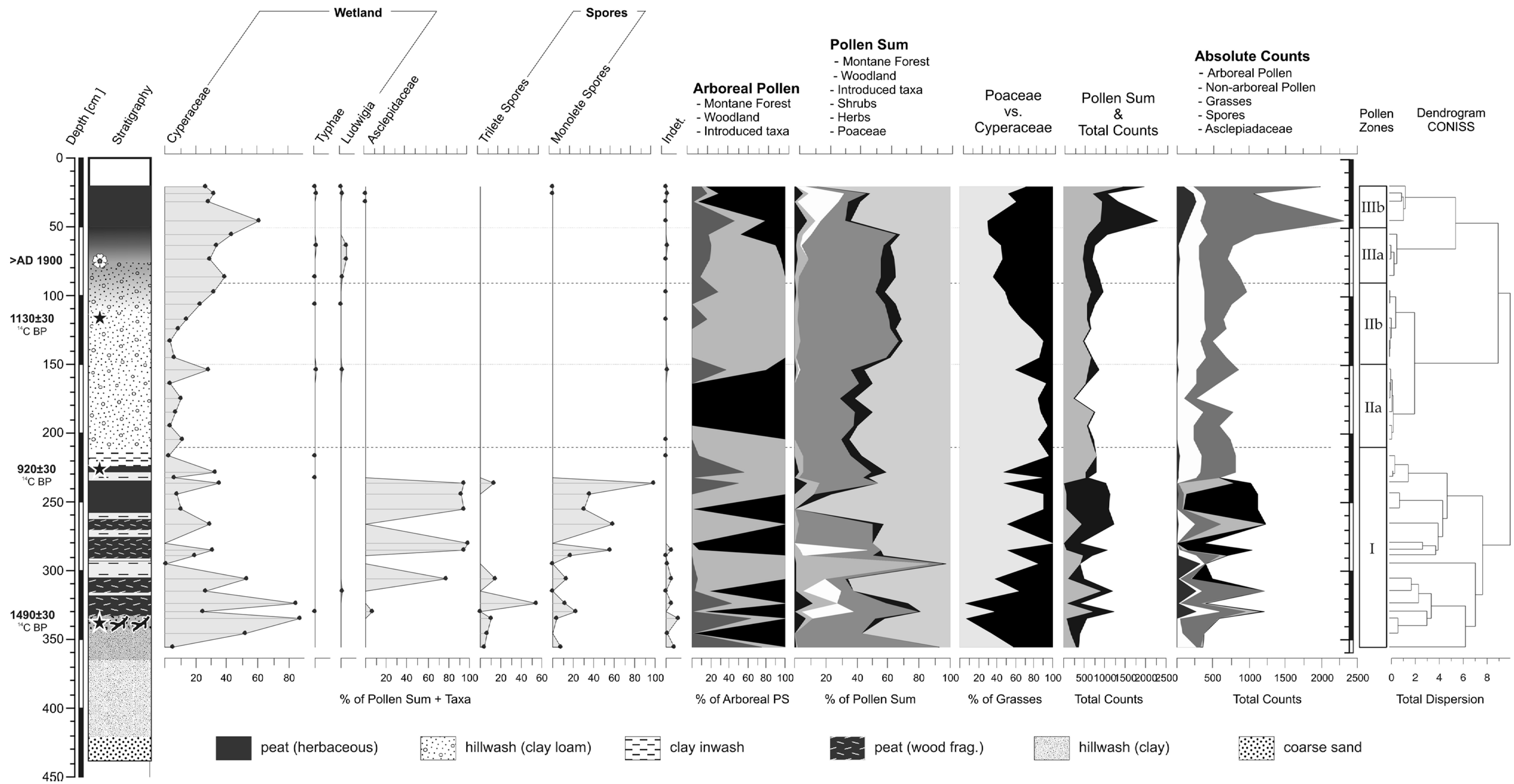


Fig. 42 continued: Lomwe Swamp Pollen Diagram. Wetland taxa and summary diagrams. Pollen types with maximum percentages >2% and occurrence in more than one sample are included in the analysis. Seven samples of the lower part (>360cm) are excluded due to low pollen counts. Pollen zones correspond to clusters derived from a dendrogram of CONISS cluster analysis

7.9.2 Pollen zones

7.9.2.1 Pollen zone I: Buried Peat

The lowermost pollen zone (>210cm) encompasses the buried peat layer and is characterised by highly fluctuating taxa. Arboreal taxa with woodland affinity like *Acacia*, *Tarrenna* and *Terminalia* occur frequently, but only *Dobera/Maesa* is present throughout the zone. Several spikes of *Dobera/Maesa*, Cupressaceae and *Eucalyptus/Syzygium* distort the pollen diagram and suggest an uneven spatial distribution of pollen such as the deposition of catkins by native species growing in the immediate vicinity of the swamp.

The shrubby *Acalypha*/Urticaceae group is present throughout the zone albeit with low percentages (<10%) – similarly Amaranthaceae/Chenopodiaceae and *Phyllanthus*. Asteraceae percentages are highly variable but reach up to 50%, especially in the lower part of the zone. Poaceae and Cyperaceae are abundant but fluctuate strongly and show opposing trends in the upper and lower part of the zone. Whereas Cyperaceae dominates the earlier part of the buried peat, Poaceae fluctuates between 15% and 60% but stabilises above 45% in the upper part. Based on the abundance of wetland taxa - Cyperaceae, Asclepiadaceae and spores - the pollen assemblage can be subdivided in a lower and upper peat layer. The lower part (360 - 292cm) is characterised by the occurrence of trilete spores, the presence of few reniform spores (<20%) and the occasional occurrence of Asclepiadaceae and abundant Cyperaceae. High absolute counts of Asclepiadaceae and reniform spores and little Cyperaceae pollen in the upper part (292 – 210cm) suggest a change in wetland vegetation. Additionally, the earliest peat development between 300 and 340cm shows a high number of rare taxa and a comparable high diversity. The extremely high absolute numbers of Asclepiadaceae indirectly results in a small pollen sum, increases variability and favours distortion.

7.9.2.2 Pollen Zone II: Colluvial and alluvial hillwash

Pollen zone II extends from 210cm to 90cm and coincides with the stratigraphic unit of alluvial and colluvial hillwash. Absence of arboreal taxa and dominance of non-arboreal shrubs and herbs typical for semi-deciduous woodland, glades, and clearings characterise PZ II. Dominant families are Amaranthaceae/Chenopodiaceae (15% to 45%) and Malvaceae (up to 10%). Abundance of Asteraceae is low compared to PZ I but rises steadily from about 10% to 30% towards the top of the zone. Further typical taxa that characterise this zone are Lamiaceae, *Justicia*, and *Commelina*. Montane forest undergrowth shrubs and herbs are rare and even the omnipresent *Acalypha/Urticaceae* group is only intermittently present with comparatively low amounts of pollen.

The few arboreal taxa recorded occur towards the upper and lower boundary, whereas tree pollen is absent in the middle part of in pollen zone II. Montane forest taxa are virtually absent in the entire zone with the exception of the occasional occurrence of *Ilex*. Woodland taxa are slightly better represented with *Dobera/Maesa*, *Tarenna*, *Commiphora*, *Celtis* and *Grewia* occurring towards the boundaries and comparatively high abundances of *Acacia* (1-4%) forming a distinct section in the upper part (97 – 150cm) of the zone.

PZ II can be subdivided in two subzones (IIa and IIb). Arboreal taxa disappear entirely between 150 and 200cm in the lower subzone IIa. They return in the upper subzone IIb with *Acacia* and *Grewia* being constantly present and *Acacia* experiencing maximum percentages. The subzone boundary at 150cm depth shows small but distinct changes in pollen abundances, like a decrease in Malvaceae and an abrupt increase of Amaranthaceae/Chenopodiaceae pollen, which subsequently declines steadily.

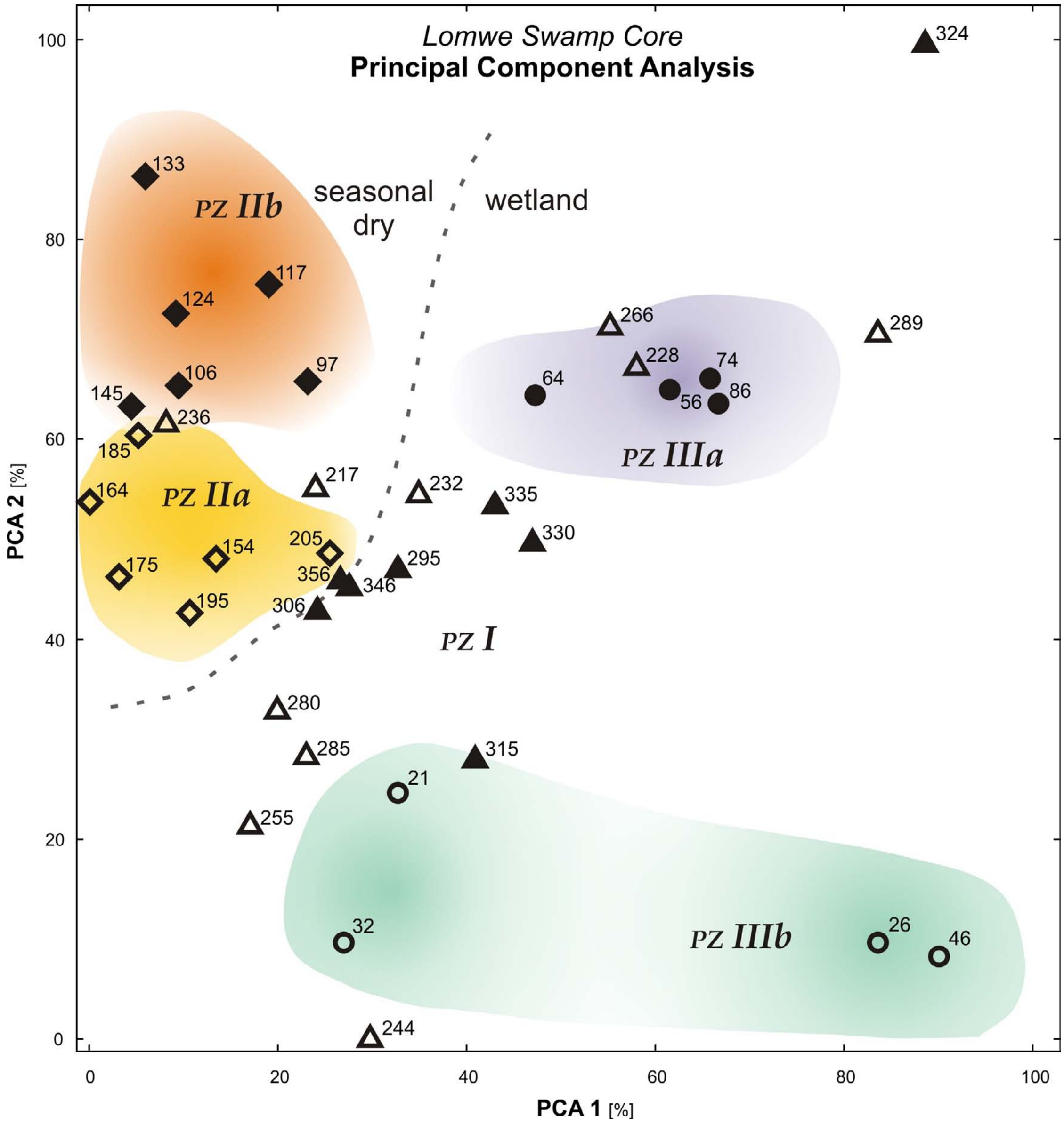


Fig. 43: Principal Component Analysis of the Lomwe Swamp Core. Ordination along the first and second component separates four distinct groups within the upper 220cm, corresponding to the pollen zones IIa, IIb, IIIa, IIIb obtained by the cluster analysis. Inherent heterogeneity is high in the lower pollen zones I. Distinct groups identified by both analyses are colour coded. Taxa with abundances below 5% and samples with less than 80 total counts were excluded from analysis (20 species, 38 samples).

Poaceae proportions are high in the lower part (50 - 60%) but experiences a sustained decrease to about 35% in subzone IIb, while contemporaneously Cyperaceae increases steadily from generally low values (<10%) to about 30% at the upper boundary of zone II. The increase in Cyperaceae pollen is certainly related to the stratigraphic evidence indicating a transitional character and the onset of wetter conditions and the slow establishment of the recent swamp.

7.9.2.3 Pollen Zone III: contemporaneous wetland

A distinct shift in the pollen assemblage at 90cm depth resulted in the delimitation of PZ III. Most taxa characteristic for zone II experience a strong decline or disappear. The formerly dominant Amaranthaceae/Chenopodiaceae drops strongly and stabilises at low values of <10%. Malvaceae characteristic for PZ II disappears completely; *Justicia* declines slightly. In contrast, abundance of

Asteraceae pollen, which was depressed during zone II, increases, and peaks at 35-40%. Arboreal taxa re-establish and woodland vegetation dominates, represented by *Acacia*, *Grewia*, *Celtis*, *Terminalia*, *Commiphora*, as well as *Tarrenna* and *Dobera/Maesa*. Montane forest taxa reappear but only *Myrica* is present throughout the zone, whereas *Nuxia*, *Podocarpus* and *Tapura*, *Olea* and *Lasianthus* only occur in the upper most samples. *Acalypha*/Urticaceae recovers and is represented with proportions of up to 10%. Most conspicuous however, is the first occurrence of exotic taxa like *Zea mays*, and shortly after *Cupressus*. The occurrence of maize is accompanied by ruderal vegetation indicators like *Rumex* and *Commelina*.

PZ III comprises two distinct subzones separated clearly by both numerical analyses. The lowermost zone IIIa (90 – 51cm) corresponds to the stratigraphic transition from the alluvium to the recent fen deposit, and mirrors the changes related to the reestablishment of a wetland. Wetter conditions are reflected by the occurrence of *Ludwigia*, *Typha* and *Liliaceae* and most notably by the sustained high proportions of Cyperaceae (>30%). The lower boundary of the zone is defined by the sustained absence of the Malvaceae family, the strong decrease of Amaranthaceae/Chenopodiaceae, elevated Asteraceae percentages and the appearance of *Zea mays*.

The upper zone IIIb (20 - 51cm) comprises the recent swamp deposit and can be taken as representative for modern pollen deposition on the Lomwe Swamp. In contrast to IIIa, arboreal pollen composition is dominated by high abundances of exotic tree pollen derived from the genera *Eucalyptus*, *Cupressus* and *Pinus* reflecting the recent afforestation with fast growing exotic timber taxa. In addition to *Myrica*, *Nuxia* and occasionally *Podocarpus* and *Tapura*, a considerable number of rare taxa like *Rapanea*, *Allophylus* and *Apdoytes*, *Schefflera*, *Canthium* occur sporadically in this zone and the overall diversity increased. Due to the high numbers of exotic tree pollen counts, the proportional importance of woodland taxa decreases from >70% to <10%. The woodland genera *Terminalia* and *Acacia* are still and steadily present and are accompanied by the occasional occurrence of *Dobera/Maesa*, Commiphora, *Tarenna*, *Grewia*, *Celtis*, *Croton*, *Lannea*, and *Euclea*. Owing to the strong abundance of exotic tree genera, arboreal pollen dominated over non-arboreal pollen for the first time since pollen zone Ia. Despite their proportional decrease, *Acalypha* pollen is still continuously present. Rubiaceae and *Euphorbia* as well as *Aloe* occur frequently.

The most distinct changes between subzone IIIa and IIIb is the complete disappearance of taxa dominating PZ II. Asteraceae pollen, which has dominated the non-arboreal record so far and peaked in zone IIIa (30-40%), is strongly reduced to about less than 10%. Amaranthaceae/Chenopodiaceae which experience its most remarkable decrease in zone III decline further but are present at low levels of <1%. Similarly, Lamiaceae, *Justicia* and *Phyllanthus* decrease and are only occasionally present. Low *Zea mays* pollen influx (<1%) indicates continuous maize cultivation, however only in the uppermost sample does maize represent more than 4% of the pollen sum. After sustained low levels throughout zone II and IIIa, Poaceae increases from around 40% to 60%, whereas Cyperaceae remains high around 30% indicating continuous wetland and swamp conditions of local basin bottom. *Phoenix* pollen is present and most likely to be derived from a local *Phoenix* palm.

7.10 **Phytolith record**

Phytolith types were dominated by generic and grass short cell phytoliths (Tab. 9). Generic grass phytoliths are tabular rectangular (blocky rectangular), cuneiform bulliform cells (Fan shaped) and parallelepipedal bulliform cells (bulliforms). Further, trichomes and hair root cells as well as cells from the stomatal complex are recorded. Undiagnostic types are elongate entire and elongate polylobate (elongate wavy) cells. Globular cells (spherical bodies) associated with woody vegetation are not recorded in the swamp core and their absence together with the lack of other indicators of woody vegetation (sclerenchyma cells, tracheids or vessel elements) is a strong indicator for an open grass vegetation of the Lomwe basin and catchment during the entire span of the record. Finally two diagnostic phytolith types were recorded known to occur in specific higher plant taxa such as opaque perforated platelets (burnt leave sheets) diagnostic for Asteraceae and phytoliths diagnostic for the *Cyperus* genus (PIPERNO 2006).

Phytolith counts of the 40 samples of the Lomwe Swamp core range from nil (295cm) to 759 (56cm) counts. Very low absolute numbers of phytoliths (<130counts) and almost absence of grass short cells phytoliths are recorded for the basal sediments and the lower peat (<260cm depth) (Fig. 44 cf. Appendix C). Above 260cm, generic grass phytoliths dominate the sediment record.

The grass short cells record is dominated by Pooideae but the presence and absence of other grass subfamilies allows the distinction of four phases, which can be broadly linked to the sediment stratigraphy and the distinguished pollen zones. The basal sands and clays are characterised by low numbers of Pooideae phytoliths and the absence of other subfamilies. With the onset of peat growth the subfamilies Panicoideae and Chloridoideae appear although low absolute numbers result in high fluctuating percentages. During the later part of the peat development, phytolith numbers increase and Chloroideae is replaced by Bambusoideae. The period of colluvial hillwash deposition at Lomwe is characterised by the steady presence of Pooideae, Panicoideae and Bambusoideae. Only after the establishment of the recent wetland, panicoid phytoliths disappear and the record is dominated again by Pooideae, albeit accompanied by low numbers of Bambusoideae.

Tab. 9: Phytolith morphotypes identified in the Lomwe Swamp. Naming followed the IPCN proposal for Phytolith classification (MADELLA et al. 2005). Typical phytolith types for Poaceae subfamilies are reported according to the respective literature (MULHOLLAND & RAPP 1992; PIPERNO 2006; BREMOND et al. 2008; NEUMANN et al. 2009).

	IPCN	Working Name	Occcurence
Diagnostic	opaque peforated platelets	Burnt leave sheets	Asteraceae
		Cyperus phytoliths	Cyperus spp.
	tracheids	Arboreal phytolith	woody plant
Non-diagnostic	trichomes hair cells stomatal cells	trichomes hair cells stomatal cells	generic phytoliths with no indicator value
Generic grass phytoliths	tabular rectangular	blocky rectangular	non – diagnostic
	elongate sinuate elongate smooth	elongate wavy elongate entire	long cells of grass epidermis
	bulliform cuneiform bulliform parallelepipedal	fan shaped bulliforms	bulliform grass cells
Grass short cell phytoliths	rondells, bilobate stipa type,	-	Pooideae (C_3)
	saddles, bilobate chloridoid,	-	Chloridoideae (C_4)
	crosses, panicoid bilobates, panicoid,	-	Panicoideae (C_3 / C_4)
	bilobates, aristidoid	-	Aristoideae
	rondels, saddles, crosses, bilobate bambusoid	-	Bambusoideae (C_3)
	genus specific phytolith	-	Pharoideae
	Short dumbbells	-	-

7.10.1 Interpretation

Of the short cell phytoliths, Pooideae are present throughout the record. The Pooideae subfamily is of temperate grasses and its distribution is restricted to high altitudes in the tropics (TWISS 1992). Phytolith studies focusing on grasses in East Africa record pooid phytoliths (rondel type) for afromontane vegetation types (30-60%) as well as for mid-altitude semi-desert (5-20%) and edaphic grasslands (15-40%) of the Somalian – Massai phytogeographic zone (BARBONI et al. 1999; BARBONI et al. 2007). The Lomwe catchment receives discharge from the Kindoroko, Kwa Chegho and Kamwalla ridge, where nowadays open clearings overgrown by grasses and secondary vegetation are common. Studies along an elevation gradient on Mt Kenya have shown that Pooideae only occur in significant amounts above an altitude of 3000m a.s.l. (BREMOND et al. 2008) and more generally only above 2300m a.s.l. (TIESZEN et al. 1979). Given the low altitude of the North Pare Mountains (<2100m a.s.l.) the constant Pooideae influx cannot be explained by alluvial input of phytoltihs from small high-altitude grassland patches. The introduction of temperate fodder grasses or cereals could have led to high Pooideae in the uppermost deposits. However, no introduced, temperate cereals or grasses are grown in the Pare Mountains today. The hydrological conditions of the basin bottom might be the most plausible cause for the high presence of pooid grasses. Good water availability and a temperate climate offer locally suitable ecological conditions for Pooideae grasses.

Other possible explanations involve the data itself and question the unambiguous classification of rondels and pooid bilobates as Pooideae. Possible other subfamilies producing similar silica bodies are Chloridoideae (BARBONI et al. 1999) and Bambusoideae (BREMOND et al. 2008). High values of pooid phytoliths are reported from the Middle Awash valley in Ethiopia (BARBONI et al. 1999). As at Lomwe, altitude, local vegetation, and semi-arid conditions exclude the presence of Pooideae. The presence of Pooideae type phytoliths is discussed as an artefact of *Sporobolus* (Chloridoideae) producing similar silica bodies or by the fluvial influx from upland areas. BREMOND et al. (2008) investigated phytolith assemblages along altitudinal gradients on several East African Mountains (Mt. Kenya, Mt. Rungwe, Masoko) and cautions against the straightforward interpretation of climatic and or vegetation composition indices along altitudinal gradients because of observed disagreement of phytolith and botanical indices. Particullarly, the production of Pooideae type phytoliths by Bambusoideae results in deviation from the observed botanical reality (BREMOND et al. 2008). Due to the phytolith classification process of this study, it is not possible to examine further any of these explanations.

Panicoid grasses are tropical tall grasses following both the C_3 and C_4 photosynthetic pathway and including maize, sorghum, and sugarcane. Grasses of this subfamily are present during the period of peat accumulation and in the beginning hillwash deposition. Despite widespread maize cultivation in the catchment today, no maize phytoliths are found indicating that the current inwash of sediments is low - although influx of allochthonous Bambusoideae is reported. The phytolith record of panicoid grasses might reflect the influx of phytoliths from natural undergrowth grasses in clearings and glades or is linked to local genera of seasonal wetlands (e.g. *Themeda triandra*, *Setaria* spp., *Hyparrhenia* spp.) or swamps (e.g. *Loudetia phragmitoides*, *Miscanthus violaceus*). The absence of Panicaceae in the recent swamp deposits then reflects either the progressive disappearance of natural glades or the dominance of Cyperaceae, which despite their recent and past abundance in the swamp are only recorded from a single sample.

Most striking is the restriction of bambusoid phytoliths to the period of colluvial hillwash deposition. This can be explained either by Bambusoideae species colonizing the seasonally inundated basin bottom or by allochthonous phytolith influx linked to the redeposition of eroded soil material.

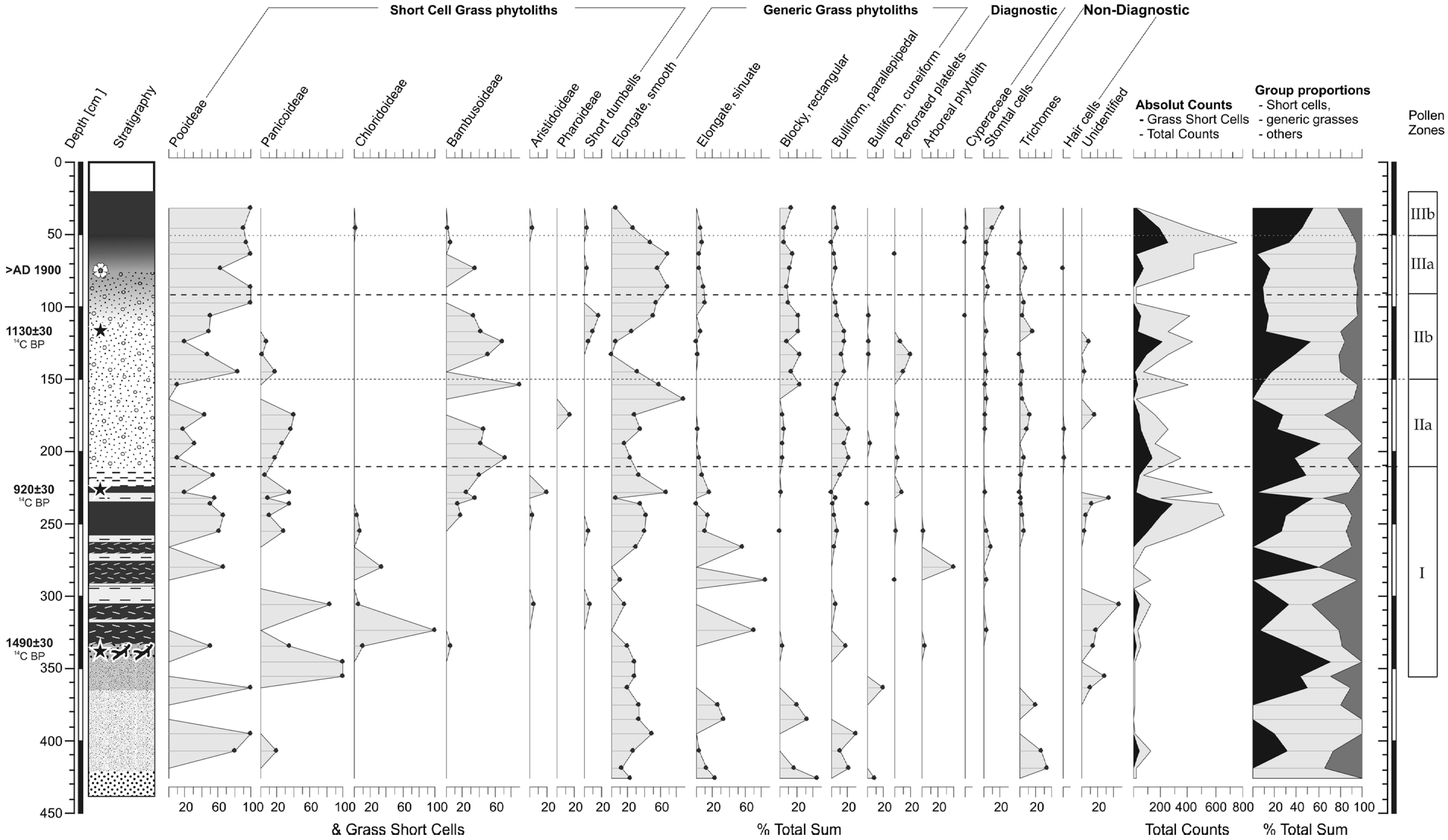


Fig. 44: Lomwe Swamp Phytolith diagram. Abundance of Poacease subfamilies is given as percentages of grass short cell phytoliths. Other phytoliths types are shown as percentages of the total phytolith sum. Stratigraphy and pollen zones are shown for comparison.

Most likely is that phytoliths of herbaceous, forest-dwelling Bambusoideae (PIPERNO 2006) have been derived with eroded forest soils of the catchment slopes and been redeposited together with hillwash sediments. Herbaceous Bambusoideae are the most likely source for the bambusoid phytoliths as the well-known woody bamboo, *Arundinaria alpina* has not been reported on the Pare and Usambara Mountains albeit being present in the southern Eastern Arc Mountains, on Mt. Meru, and on a few spots on Kilimanjaro (LOVETT 1994; GRIMSHAW 1999; HEMP 2006b). The occurrence of Bambusoideae on the catchment slopes would be a strong evidence for an open forest environment with either natural glades or anthropogenic clearings, favouring grass growth in an open forest setting.

The presence of Chloridoideae during the formation of the buried swamp is somehow puzzling as the Chloridoideae subfamily is characteristic for semi-arid grasslands (TWISS 1992). In his phytolith study along an altitudinal gradient on Mt Kenya BREMOND et al. (2008) found that unambiguous identification of the chloridoid saddle type is not possible if Bambusoideae and Arundinoideae are present – both also saddle producers. Therefore, it cannot be ruled out that the counted Chloridoideae saddles are at least partly derived from Bambusoideae, which would extend their occurrence into the period of peat accumulation and result in a constant presence of Bambusoideae in the record. Otherwise, Chloridoideae grasses in the catchment would suggest drier conditions and a local expansion of short grass vegetation – maybe within anthropogenic clearances. The possibility that Chloridoideae phytoliths are derived from the cultivation of the indigenous cereal genera *Eragrostis tef* (teff) and *Eleusine coracana* (finger millet) on the slopes should be viewed with caution as no maize phytoliths have been recognised despite current widespread maize cultivation.

The interpretation of the Lomwe phytolith record is hampered by three main difficulties: methodological shortcomings considering the classification of Poaceae subfamilies, the difficulty of discerning between (probably temporally varying) autochthonous and allochthonous phytolith sources, and the tempered climate of the montane environment, where silica bodies from both C_3 and C_4 subfamilies are likely to occur. Given these complications, the only pattern, which can be interpreted confidently, is the rise and fall of Bambusoideae. The occurrence of Bambusoideae represents the influx of allochthonous phytoliths and reflects increased levels of disturbance, the presence of secondary vegetation in anthropogenic clearings and hence a general, widespread opening up of the montane forests in the Mashewa catchment.

8 STRATIGRAPHY AND CHARACTERISTIC FEATURES OF HILLSLOPE DEPOSITS

A stratigraphic framework of slope deposit accumulation is constructed based on the correlation of characteristic sediment features between profiles and sites. The division of slope deposits into stratigraphic units is based on benchmark criteria, that allow the distinction of *in situ* subsoils and buried topsoils (unit I), as well as different phases of colluvial deposition (units II, III, IV). The most important benchmark characteristics are topsoil development, sand lenses, redeposited soil aggregates, colour changes, and charcoal occurrence. Magnetic susceptibility parameters support the division and facilitate stratigraphic correlation between profiles and sites. Further, stable carbon isotope composition gives insights into the vegetation and forest history of Pare.

8.1 Buried soils and erosion surfaces

Former ground surfaces are recognised as either unconformities due to truncation or by the preservation of a former surface soil. Accretionary soil development on the other hand results in over-thickened and poorly developed soil horizons difficult to identify (CATT 1986; RETALLACK 2001). All three types of former surfaces are recorded in the slope deposits of North Pare.

Distinctive dark buried topsoil horizons were recorded at Mrongo 3, 10, & 4 and Lomwe 3, 10, 4, & 5, but not at Mrongo 2 & 5, Usumbwe 1 & 2, and Lomwe 6, where slope deposits apparently overlie B/C-transition horizons (Fig. 45). The dark layers are about c. 10 - 15cm thin at Mrongo but slightly thicker at Lomwe, show clear-cut boundaries and are readily distinguishable in the field by their dark appearance (generally hue 7.5YR, value <3, chroma <2) suggesting an elevated organic matter content. Buried soils at Lomwe are dark, frail, and organic matter rich (2.0%±0.4 C_{org}, Tab. 10). Average organic carbon content of dark buried topsoils at Mrongo is much lower (0.9%±0.1) and analytically hardly discernable from the background organic matter content of the slope deposits (0.6%±0.1). The higher organic carbon content at Lomwe confirms the field observation of a thicker, more frail and organic matter rich layer at Lomwe and thinner, less developed and more compacted horizon at Mrongo. The differences between the two buried surfaces are not only of diagenetic nature and due to stronger compaction below deeper deposits at Mrongo, but are likely to reflect an originally strongly organic matter enriched soil, possibly even a buried organic layer at Lomwe. This difference is supported by considerable different age of the two buried surfaces. Whereas the buried topsoils at Lomwe date to the LGM, the burial of the land surface at Mrongo and Usumbwe must have occurred between 400 BC and AD 610 (^{14}C dates of charcoal fragments from buried topsoils, cf. Tab. 6).

The buried land surfaces are not observed at all profiles. A large boulder put an end to excavation at Lomwe 6 and no signs of a former stable surface were recorded. Mrongo 5 was too shallow (4.4m) to reach the bottom of the colluvial deposits. At Usumbwe 2, slope deposits merge at 910cm (charcoal recovery) into a B/C-transition horizon characterised by common, strongly weathered gravel around 9.7m. No distinct boundary between slope deposits and *in situ* subsoil material was observed. Profiles on the upper footslope (Mrongo 2 & Usumbwe 1) show diffuse, dark grey boundary layers between colluvial material and subsoil or B/C-transition horizons. These layers are often characterised by mottles and dark staining of blackish to dark greyish colours (Fig. 45). The dark staining may have originated from originally higher organic carbon content, however, no C_{org} increase has been detected (Fig. 34). Alternatively, redoximorphic processes in a probably seasonally waterlogged stratum over more compact bedrock may have promoted dark staining by finely dispersed iron and manganese oxides creating an overall dark impression of the horizon. Similar, oxidative mottling was recorded at several profiles proximate to the capillary fringe of the water table. At both profiles, the dark stained strata are discontinuous and restricted to the downslope wall of the soil pit. A similar situation is shown at Lomwe 3, where the organic matter rich horizon thins out towards the upslope. At Usumbwe 1, the dark stained layer rests directly on top of a truncated B/C-horizon and is buried by a gravel rich deposit indicating subsequent mass movement with gravel translocation. Shallow subsoils and poor preservation or even lack of topsoils suggest that all three profiles on upper footslope positions have been partly eroded and truncated prior to the accumulation of slope deposits. Slope deposit accumulation at Mrongo and Usumbwe thus shows a spatial-temporal development. During the initial erosion phase (since the early centuries BC), when accumulation of colluvial material started on the footslope (Mrongo 10, 400 – 110 BC; Usumbwe 2, AD 70 - 230), erosion and truncation took place at lower slope positions. Only later, the lower slopes were covered in sediments, and only between AD 410 – 610 did accumulation of sediments extend into the valley bottom (Mrongo 4, AD 430 – 610; Usumbwe 3, AD 410 - 600).

At Mrongo 2 a dark layer (160 - 240cm) with slightly elevated C_{org} and low $\delta^{13}C$ values (Tab. 10, lowest $\delta^{13}C$ -16.5‰ at 170cm) is noteworthy because of numerous placed boulders (20 - 60cm) in one corner of the soil pit (cf. Appendix B.3). The spatially restricted occurrence strongly suggest placement of boulders in a non-random manner by deliberate human action. Deposition by colluvial mass movement can be ruled out, as a natural process would not result in the concentrated accumulation of boulders in such a restricted way and the occurrence of boulders in slope deposit is very rare. Together with potsherds and charcoal fragments (dated to AD 1020 – 1160, 220cm) the placed boulders suggest recurrent human activity over a prolonged period. Due to accretionary soil development and continuous deposition, no distinct topsoil horizon developed on this former surface.

8.2 Colluvial features as benchmark criteria for slope deposits

The investigation of colluvial slope deposits has revealed a common set of characteristic features, which in conjunction, are used as benchmark criteria to identify stratigraphic breaks in slope deposits and to distinguish colluvial material from *in situ* developed soils. The main criteria observed are:

- sand lenses (cf. separate chapter 8.3)
- charcoal occurrence throughout the slope deposit,
- presence of gravel from a wide range of different rock types,
- firm, dark coloured aggregates,
- bright reddish soil aggregates,
- soil colour differences between upper and lower slope deposits,
- bulk density changes,
- presence of potsherds.

Charcoal was recovered throughout all slope deposits, but not from *in situ* subsoils. The charcoal fragments are macroscopic, between 1 and 10mm long. Translocation of charcoal particles within the soil profile is an often discussed issue (see THÉRY-PARISOT et al. 2010). However, the high abundance of macroscopic charcoal throughout the deposits does not suggest translocation of charcoal. More likely is the incorporation of charcoal particles during the transport of surface material. Taken in conjunction with other evidence, occurrence of macroscopic charcoal fragments is a tentative criterion for the colluvial nature of the deposits.

Tab. 10: Average C_{org} and $\delta^{13}C$ of stratigraphic units and dark soil aggregates. Average soil matrix values of stratigraphic units (*in situ* subsoil, buried topsoil, slope deposit unit II, III and IV, and topsoil) are calculated across profiles of the same catena. Firm, dark aggregates frequently recovered from colluvial slope deposits at Usumbwe and Mrongo are organic matter enriched compared to the respective soil matrix. Single values are averages of three replicates.

	Mrongo			Lomwe		
Soil Matrix	C_{org} [%]	$\delta^{13}C$ [‰]	n	C_{org} [%]	$\delta^{13}C$ [‰]	n
Topsoils	2,76 ± 0,70	-23,45 ± 1,17	4	1,47 ± 0,23	-21,96 ± 0,93	4
Colluvium (Unit IV)	0,61 ± 0,11	-18,65 ± 0,68	6	0,98 ± 0,21	-20,78 ± 0,91	10
Colluvium (Unit III)	0,64 ± 0,12	-19,03 ± 0,85	5			
Colluvium (Unit II)	0,56 ± 0,08	-20,28 ± 1,08	9	1,04 ± 0,15	-20,82 ± 0,98	14
Buried topsoils (Uni I)	0,86 ± 0,09	-20,18 ± 0,57	7	2,02 ± 0,37	-21,94 ± 0,84	8
Buried subsoils	0,31 ± 0,14	-21,69 ± 0,80	9	0,43 ± 0,11	-23,44 ± 0,84	5
Mrongo 4 (320cm)	0,54 ± 0,05	-18,91 ± 0,19	1			
Dark aggregates						
Mrongo 4 (320cm)	1,06 ± 0,03	-21,25 ± 0,05	1			
Usumbwe 2 (90cm)	0,80 ± 0,03	-19,29 ± 0,13	1			
Usumbwe 3 (365cm)	2,35 ± 0,18	-20,25 ± 0,07	1			
Placed Boulders						
Mrongo 2 (170-240cm)	0,71 ± 0,06	-18,39 ± 1,36	4			

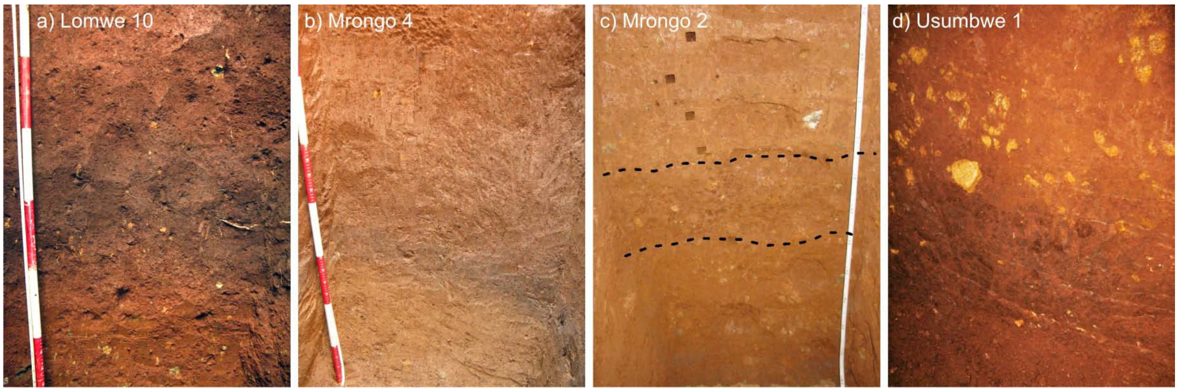


Fig. 45: Buried topsoils and possible truncation surfaces. Dark organic matter rich buried topsoils. a) late Pleistocene soil at Lomwe 10 and b) Holocene soil at Mrongo 4. Erosion surfaces or partly truncated, buried soils characterised by black staining at c) Mrongo 2 and d) Usumbwe 1. All layers show signs of bioturbation by animal and root channels, best seen at Usumbwe 1.

Fig. 46: Reworked soil aggregates. Examples of dark greyish brown, organic matter enriched aggregates in distinctly brighter soil matrix.

Gravel sized rock fragments span a wide range of weathering stages from fresh and firm to strongly weathered and rotten. The rock debris derive from a variety of metamorphic bedrock types - mainly gneisses, schists, quartzites and amphibolites - with distinct weathering colours ranging from yellowish-whitish to dark red, often dark stained as a result of iron and manganese weathering crusts. The recovery of distinct rock types indicates a mixture of material derived from a variety of bedrock types. The wide range of rock types reflects the inhomogeneity of the geological substrate across the catchment slopes and thus is indicative for the colluvial nature of the deposit.

Strong and firm **soil aggregates** have been observed in all of the soil profiles at Mrongo and Usumbwe (Fig. 46). They are prominent, imperfectly rounded, and when broken up show either a dark greyish brown coloured inner material or bright reddish colours compared to the surrounding soil matrix. Both are distinct from similarly coloured, strongly weathered rock fragments. If broken up, decomposed rocks show a sandy texture, whereas soil aggregates have a clay or clay loam texture. Dark aggregates predominantly occur in the lower part of the colluvial deposits, bright ones are less frequent and less striking and cannot be assigned to a single depth interval. Quantification of organic carbon shows that dark aggregates have a higher C_{org} content than the soil matrix (Tab. 10, aggregate Mrongo 4, 320cm). Although no direct comparisons are possible for the Usumbwe aggregates, C_{org} of both exceeds the average C_{org} content of the slope deposits; organic carbon of the Usumbwe 3 aggregate (365cm) even exceeds recent topsoil values. Carbon isotope composition of the dark aggregates from lower depths (Mrongo 4, 320cm & Usumbwe 3, 365cm) is ^{13}C depleted in comparison with the soil matrix (Tab. 10).

In conclusion, the dark greyish-brown, organic matter enriched aggregates are interpreted as representing former topsoil aggregates. Based on colour, C_{org}, and $\delta^{13}C$ values, the original soil could have been akin to the buried topsoils. Higher organic matter content and a higher contribution from C_3-plants suggest an environment more shaded than during the build up of the slope deposit. Bright reddish aggregates in contrast are probably derived from soils stripped of their topsoil to expose bright reddish subsoil material. Both types of soil aggregates have been mobilised and relocated by gentle mass movement processes such as soil creep or tillage erosion, which facilitated the down slope transport of entire, unbroken aggregates. They were preserved an organic matter depleted matrix of disturbed and reworked soil material either derived from less gentle erosion processes or resulted from soil working and bioturbation. Post-depositional disturbance, however, must have been low and selective or burial might have been comparatively fast as soil working, bioturbation, and soil formation did not result in the destruction of these particular aggregates. The possibility that the dark grey aggregates might be related to animal burrows or faeces was discarded as the occurrence is dispersed and not related to vestiges of animal channels.

Visual determination of **soil colour** using the Munsell colour chart is, despite the caveats of light conditions and subjectivity, an effective way to differentiate material changes, predominantly organic matter accumulation and the degree of rubification. Strong and abrupt soil colour changes are recorded for Lomwe, where colour and bulk density changes allow the delimitation of an uppermost and a lowermost deposition unit (Unit II & IV). The upper metres show a (yellowish) red (2.5-5YR 4/6 moist) to yellowish red (5YR 5/6, dry) soil colour, which differs markedly from the dark (reddish) brown (5-7.5YR 3/4 moist) to strong/red brown (5-7.5YR 4/5, dry) lower deposit. Comparable colour changes, but less distinct and much more gradual are observed for the more homogeneous Mrongo and Usumbwe deposits. Here the uppermost metres are red (2.5YR 4/6, moist) to reddish yellow (5YR 6/6, dry), while the lowermost metres show a reddish brown (5YR 4/4, moist) to brown (7.5YR 5-

Tab. 11: Bulk density changes of slope deposits at Lomwe. Low bulk density of buried topsoils and lower colluvial deposits contrast with a high packing density of *in situ* soils and upper slope deposits. Lomwe 6 comprises only the uppermost deposition unit IV. Bulk density therefore is high and homogenenous.

Stratigraphic unit		Lomwe 3		Lomwe 10		Lomwe 4		Lomwe 6	
		Depth [cm]	Bulk Density [g ccm^{-1}]	Depth [cm]	Bulk Density [g ccm^{-1}]	Depth [cm]	Bulk Density [g ccm^{-1}]	Depth [cm]	Bulk Density [g ccm^{-1}]
Upper Colluvium (red)	IV		-	42	1,47	10	1,42	11	1,44
					-	50	1,34	35	1,43
						80	1,36	35	1,46
						115	1,47	98	1,29
Lower Colluvium (brown)	II	168	1,18	100	1,27	155	1,31	135	1,41
			-	138	1,29	190	1,29	185	1,50
				200	1,15	220	1,28	260	1,43
					-	260	1,13	290	1,46
Buried Topsoil	I	210	1,21	244	1,15		-		-
		210	0,98						
***in situ* subsoil**		-	-	300	1,51		-		-

6/4) colour. At the latter sites, the gradual colour transition is accompanied by occurrence of sand lenses (8.3).

Bulk density changes have been determined for compacted upper and frail lower deposits at Lomwe (Tab. 11). Bulk density changes are most prominent at Lomwe 3 & 10, where the palaeosol is buried by frail and friable, dark reddish brown material with a low packing density (unit II). The following deposit is yellowish red, compacted, dense and hard to excavate (unit IV). Similar, but less pronounced bulk density changes of the more homogeneous and in general more compact deposits at Mrongo and Usumbwe are based on field observation.

Pottery fragments have been recovered from most slope deposits. Potsherd frequency was highest before and after the onset of sand lens occurrence and colour change (unit II/III) and again in the topsoil. However, no estimation of potsherd abundance is feasible for auger recovery below excavation depth. The pottery fragments cannot be unequivocally assigned to one of the known pottery traditions of Kwale, Maore or local variants because of their small size and the general lack of characteristic features (Davies, pers. comm.). Only one potsherd found at Mrongo 4 (Fig. 47) shows horizontal decorative bands of oblique comb-stamped bands found on dimple-based Kwale ware (SOPER 1971b).

Non-parallel incisions found on a number of potsherds could reassemble Type A Maore ware (Fig. 47) but the decoration type is also reported to be recent (SOPER 1967b). ODNER (1971a) reports out-turned rims and decoration by bundles of grass stalks (possibly leaving the pattern observed in Fig. 47) as common recent decoration practices. Further characteristics of the recovered pottery fragments are out-turned rims, which differ from in-turned rims typical for Kwale ware as outlined by SOPER (1967a).

Occurrence of potsherds in soils and deposits is strong evidence for prolonged human activity, even if the fragments are reworked as supported by their highly abraded nature. Potsherds, either reworked or *in situ*, indicate human settlement or depositional practices on-site or immediately upslope. Although translocation of potsherds down profile (as with charcoal) is technically possible, the size and amount of pottery fragments in the investigated deposits suggest concurrent human presence and are interpreted as a strong indicator of human land use.

The observed pedological features characterise different sections of the slope deposits and are used to outline three phases of soil erosion in Pare. Although ambiguous on their own, in conjunction the discussed benchmark criteria allow the distinction of different sedimentary units. Generally, we can distinguish *in situ* subsoil, buried topsoils, and a lower and an upper slope deposit. The bright red, moderately rubified *in situ* subsoil is compact and shows a homogeneous rock assemblage (unit I). Where a distinct buried topsoil is lacking, the lower colluvial deposit can be distinguished from the *in situ* subsoil by the presence of a variety of rock fragments, charcoal occurrence, and potsherds. The occurrence of firm, dark soil aggregates suggests the deposition of former topsoil material and a gentle, aggregate-based mass transport such as during tillage erosion or forest clearing events. Generally, the lower deposit (unit II) is frail and has a low bulk density such as expected when topsoil material with a high pore volume is relocated. The redeposited material retained its dark (reddish) brown matrix colour inherited from the original, rubified, organic matter rich topsoil material, although its present organic carbon content is indistinguishable from subsoils and upper colluvial deposits.

The uppermost deposit on the other hand, is characterised by the lack of dark aggregates and a compact and dense nature, which suggests a runoff-based erosion process (unit IV). Disintegration of aggregates before and during transport resulted in the deposition of single particles, the lack of micro- and mesopores and hence a high packing density. The bright (yellowish) red colours suggest redeposition of subsoil material implying the widespread exhaustion of the topsoils resource and exposure of subsoils on the slope.

The stratigraphic differentiation based on the discussed benchmark features is corroborated by magnetic susceptibility parameters and is in accordance with the inferred environmental conditions during sand lenses formation. The environmental implications are discussed in chapter 8.5.

8.3 Sand lenses: indicators of slope wash processes

The most prominent benchmark feature of the investigated slope deposits at Mrongo and Usumbwe are sand lenses. The spatial restricted occurrence of sand lenses led to the delimitation of depositional unit III. Sand accumulation is observed as diffuse spots or as distinct lenses with clear boundaries extending generally about 10-15cm but exceptionally up to 1.5m along the pit walls (Fig. 48). Sand lenses often consist of black iron sand, which enhances visual distinctness and results in exceptionally high magnetic susceptibility peaks. They are spatially restricted and only occasionally can they be traced along more than one pit wall. Exceptions are the valley bottom profiles Mrongo 4 & 5 and Usumbwe 3, where sand lenses have merged into sandy layers indicating widespread deposition of coarse textured material such as in small fans at the end of ephemeral erosion rills. At Mrongo 5, coarse textured gravel and sand layers intercalated with clay loam colluvium have been deposited after the infill of a stream channel and stream avulsion.

Sand lenses are observed in all Mrongo and Usumbwe profiles with the exception of the two uppermost profiles Mrongo 1 & 2. At Lomwe, only small sand lenses in the upper 50cm of profile Lomwe 10 were observed. Generally, sand lenses occur dispersed in the mid-section of deposits between 100 and 300cm depth (Tab. 12). The beginning of the main phase of hillwash was dated based on charcoal fragments at three different profiles (Mrongo 10, 300cm, AD 1460 – 1650; Mrongo 4, 200cm, AD 1320 – 1490; Usumbwe 3, 285cm, AD 1410 – 1640) and must have started before the mid-15th century, probably around AD 1400 (AD 1340 - 1470, OxCal boundary model). At Mrongo 5 and Usumbwe 2 & 3, an earlier, separate hillwash event is recorded at depths of about 4m and 3.5m, respectively (cf. Appendix B.3 & B.5). Optical stimulated luminescence dates of the main phase at

Tab. 12: Deposition rates and stratigraphic divisions based on benchmark features. Depth intervals [cm], calibrated radiocarbon and OSL dates (Mrongo 5) of important stratigraphic divisions at Mrongo and Usumbwe inferred from buried surfaces, sand lenses, and reworked aggregates. Deposition rates are derived from the calibrated average radiocarbon age of charcoal fragments. The estimated timing of sand lens cessation is calculated based on average radiocarbon dates and estimated deposition rates.

Type	Mrongo 2	Mrongo 3	Mrongo 10	Mrongo 4	Mrongo 5	Usumbwe 1	Usumbwe 2	Usumbwe 3
Cessation of sand lenses (*unit IV*)	-	-	***~ AD 1880***	***~ AD 1635***	-	-	-	***~ AD 1885***
sand lenses (*unit III*)	- -	155 - 350 -	80 - 280 **AD 1460-1650**	125 - 212 **AD 1320-1490**	0 - 375 **AD 650±80**	230 **-**	120 - 300 **-**	95 - 280 / 370 **AD 1410-1640**
Potsherds	100 - 320	210 - 390	280 - 400	270 - 470	138/ 360 - 460	70-80	210	170 - 355
reworked aggregates	160 - ~300	~200 - 410+	210 - 610	~280 - 420+	135 - 400 ?	-	288 - 670	95 - 420+
stable surface (*unit I*)	placed stones 160 – 240 **AD 1120-1160** surface ? 320 - 335 **-**	buried topsoil 725 - 780 **-**	buried topsoil 600 - 610 **400 - 110 BC**	buried topsoil 460 – 475 **AD 430 - 610**	- - **-**	surface ? 310 – 330 **-**	surface ? 910 - 970 ? **AD 70 - 230**	peat layer 750-820 **AD 410 - 600**

Deposition rates		Average Rate	Mrongo 10	Mrongo 4	Usumbwe 2	Usumbwe 3
	overall deposition rate	**0.40** ±0.13cm/a	**0.26** cm/a	**0.32** cm/a	**0.51** cm/a	**0.52** cm/a
	since 15th century	**0.58** ±0.21cm/a	**0.62** cm/a	**0.35** cm/a	-	**0.76** cm/a
	up to the 15th century	**0.29** ±0.09cm/a	**0.18** cm/a	**0.29** cm/a	**0.27** cm/a	**0.40** cm/a

Fig. 47: Pottery fragments from Mrongo. a) Potsherd recovered from the buried topsoil at Mrongo (430cm) reassembles the oblique comb-stamped bands found on Kwale ware (Soper 1971b). b) Potsherd from Mrongo 1 (topsoil) shows a pattern of non-parallel striae, common on recent pottery from the area. c) Potsherds from Mrongo 3 (250cm) and d) Mrongo 10 (380cm).

Fig. 48: Sand lens occurrence and formation processes. Sand lenses observed at a) Usumbwe 3, b) Usumbwe 2, c) Mrongo 10 and d) Mrongo 4. e) Recent sand lens formation at Mrongo. Sand is deposited in small erosion rills at the end of heavy rains. Preservation of sand lenses only occurs if they are not disturbed by bioturbation or tilling. f) Banana plantation after tillage.

Usumbwe 3 (260cm, 2.800±250 a) and the early hillwash layers at Mrongo 5 (345cm, 1360±80 a) and Usumbwe 3 (365cm, 4170±240 a) produced consistently older ages than proposed by radiocarbon dating of charcoal fragments (see chapter 7.8 for discussion).

A modern analogue of sand lens and sand layer formation was observed during rainfall events in January 2010 (Fig. 48). Within the dense and shaded banana grove no ground covering undergrowth has developed. Nevertheless, patchy cultivation of beans, taro, tubers, and at sunny spots maize, as well as weeding and tillage are observed. The soil surface is bare of vegetation but partly decomposed organic matter (mainly banana leaves) has accumulated and forms a patchy soil cover. During rain events sheet wash within the banana grove - but also overland flow originating further upslope - gathers and concentrates in depressions and creates temporary, up to 10cm deep, rills. Differential transport of fine and coarse particles along the slope results in sorting and the irregular deposition of sand and fine gravel in depressions and ephemeral rills. A combination of diffuse sheet wash and localised rill erosion is responsible for the development of spatially confined sand lenses and sand layers, which are thus evidence of former runoff-based erosion processes.

Today, topsoil disturbances caused primarily by tillage but also by bioturbation (termites, ants) suffice to destroy the evidence of sand lenses. Despite current observation of the sand lens formation process, no sand lenses are preserved in the upper 0.5 – 1.5m of the deposits. Soil reworking by hoeing and weeding appears to effectively erase the evidence of particle separation. The lack of sand lens preservation under present agricultural land use and different crop types (maize at Usumbwe, banana at Mrongo) prompts the question under which environmental conditions (deposition regime, vegetation type, and cultivation practices) sand lenses were able to persist (see chapter 8.7).

8.4 **Magnetic stratigraphy**

Magnetic susceptibility patterns of slope deposits, forest soils, and disturbed agricultural soils are explained by magnetic enhancement of topsoil horizons and relocation of material by erosion. A consistent magnetic stratigraphy of slope deposits is established based on magnetic susceptibility variations reflecting major changes in the erosion and deposition regime.

8.4.1 Soil magnetism

Magnetic properties of soil and sediments are useful tools to investigate iron dynamics and their driving forces from which a variety of environmental processes such as soil development, fires and the deposition of allochthonous material can be inferred. Application of environmental magnetism include stratigraphic correlation of sediments, the reconstruction of palaeoenvironmental conditions (for overviews see THOMPSON & OLDFIELD 1986; EVANS & HELLER 2003), sediment provenance studies tracing soil erosion (e.g. DEARING et al. 1986; THOMPSON & OLDFIELD 1986; SMITH et al. 1990) and catchment degradation histories (in Africa see ERIKSSON & SANDGREN 1999; FOSTER et al. 2007) as well as the deposition of industrial fly ash from fossil fuel combustion. In situ magnetic enhancement is attributed to the neoformation of fine grained ferrimagnetic minerals (OLDFIELD 2007) and several processes have been proposed including the oxidation of ironoxides to maghaemite at high temperatures during fires, bacterial magnetite formation, dehydration of lepidocrocite to maghaemite in waterlogged soils, bacterial mediated precipitation of magnetite during reduction-oxidation, and wetting/drying cycles under normal pedogenetic conditions. (MULLINS 1977; THOMPSON & OLDFIELD 1986; EVANS & HELLER 2003).

Basic magnetic parameters are magnetic susceptibility (χ_{lf}) and frequency dependent magnetic susceptibility ($\chi_{fd\%}$). Magnetic susceptibility is controlled by the type, amount, size, and shape of magnetic minerals and varies over several orders of magnitude allowing distinction between different mineral types and their amount (THOMPSON & OLDFIELD 1986; DEARING 1994). Frequency dependency, on the other hand, is a rough means to estimate mineral grain size distribution of the dominant magnetic minerals. Neoformation of secondary magnetic minerals during weathering, pedogenesis and fire results in the first instance in the production of small mineral grains, predominantly superparamagnetic or single domain minerals with a high magnetic susceptibility (DEARING 1994). In contrast, primary minerals consist of larger multidomain grains with a lower susceptibility. With higher frequencies of the applied magnetic field, superparamagnetic grains start to behave like single domain grains and overall susceptibility decreases. Frequency dependent susceptibility is a rough measure of the amount of small, superparamagnetic mineral grains generally associated with the neoformation of secondary minerals.

Based on two basic magnetic parameters, the present study identified primary and secondary ferrimagnetic minerals (magnetite and maghaemite) as the dominant iron species and interpretations are based on the amount of magnetic susceptibility (χ_{lf}) whereas distinction between primary (unweathered rocks) and secondary sources (pedogenesis, fires, allochthonous material) relies on the frequency dependency ($\chi_{fd\%}$).

8.4.2 Type and source of magnetic minerals

Soils and deposits of North Pare show high absolute values of magnetic susceptibility (2 - 11 x10^{-6} m^3kg^{-1}) indicative for the presence of ferrimagnetic minerals such as magnetite (Fe_3O_4), maghaemite (γ-Fe_2O_3) and titanomaghaemite characterised by high χ_{lf} between 200 - 1000 x10^{-6} m^3kg^{-1} (DEARING 1994). Small amounts of these dominant iron oxides suffice to cause the high magnetic susceptibility. The red colour of the investigated soils (Hue 2.5 - 5YR) points to a high amount of secondary oxides - predominantly hematite (α-Fe_2O_3) and goethite (α-FeOOH). These are canted antiferromagnetic iron oxides formed during pedogenesis and have χ_{lf} values about 2 - 3 orders less (0.3-2 x10^{-6} m^3kg^{-1}) than ferrimagnetic minerals (DEARING 1994). Despite their abundance, antiferromagnetic minerals contribute only marginally to the high bulk susceptibility measured in Pare.

The high absolute values of soil magnetic susceptibility measured in North Pare exceed the range commonly discussed for pedogenetic enhancement in temperate regions (generally <1 x10^{-6} m^3kg^{-1}). Higher χ_{lf} values up to 10 x10^{-6} m^3kg^{-1} however, are reported from volcanic bedrock (MAHER 1986) and ultrabasic bedrock geology (DEARING 1994) but also from soils developed over phyllites and sandstone (HENDRICKX et al. 2005) in Ghana. Even higher χ_{lf} is generally associated with fly ash or restricted to burned topsoil horizons (MAHER 1986; DEARING 1994).

The generally high background susceptibility of the North Pare soils is probably the result of the (ultra-) mafic bedrock geology (BAUERNHOFER et al. 2008a). Ferrimagnetic, primary magnetite minerals are common in metamorphic basement rocks and particularly in the granulites and gneisses of the Pare Mountain range. Being an accessory element of the pyroxene and hornblende granulites and quartzites of North Pare (BAGNALL 1962), resistant magnetite grains are released by weathering and are ubiquitous in Pare soils. Mobilised, magnetite grains become differentially enriched in the bedload of streams. Beside locally restricted occurrence of gangue ore, these black magnetite iron bearing sands have been the main ore supply for the famous Pare iron industry during the past two millennia (VON DER DECKEN 1869; MEYER 1890; KIMAMBO 1969).

8.4.3 Pedogenetic enhancement and source variation

Magnetic topsoil enhancement is recorded for forests soils at Kwa Kirumbi. The increase of magnetic susceptibility between subsoil and topsoil indicates a higher concentration of ferrimagnetic minerals, whereas the rising frequency dependency suggests that formation of small grained, secondary, and hence pedogenetic iron minerals is responsible for the χ_{lf} increase (cf. Fig. 38). The magnetic trend observed at Kwa Kirumbi reflects the classical processes of topsoil enhancement by slow oxidation after bacterial mediated fermentation as proposed by several authors (LE BORGNE 1960; MULLINS 1977; DEARING et al. 1986). High absolute χ_{lf} of eroded agricultural soils but also of forest soils at Kwa Chegho imply strong magnetic enhancement by magnetite or maghemite formation. Frequent and repeated surface fire events and rapid, high temperature oxidation of ubiquitous ironoxides hematite and goethite to magnetite or maghemite are the most likely process to explain the high χ_{lf} measured. (THOMPSON & OLDFIELD 1986; EVANS & HELLER 2003)

Most of the investigated soils have experienced disturbance, often accompanied by deposition of reworked, eroded material from upslope. Eroded material is transported along the slope and becomes temporarily part of the topsoil. It is then magnetically enhanced by biologically mediated fermentation, fire, or by mixture and incorporation of enhanced topsoil material. The abrupt change of magnetic parameters is pronounced at erosion surfaces, where colluvial overburden rest directly on the truncated subsoil (e.g. Changuku 3, terrace). Less distinct colluvial deposits and disturbance events at Changuku 5 & 6 and Ngalanga 2 &5 and Kwa Chegho 1 & 2 might be responsible for the generally high χ_{lf} and $\chi_{fd\%}$ values, without the development of distinct depth trends. The high $\chi_{fd\%}$ observed for the strongly eroded soil at Makongweni remains problematic, as it suggests pedogenetic formation of secondary minerals, which contrasts with the initial weathering stage of the sampled C- horizon.

Magnetic enhancement is site-specific and the absolute values of magnetic susceptibility differ strongly between study sites. Susceptibility at Kwa Chegho and Lomwe varies between 2-8 $x10^{-6}$ m^3kg^{-1}; at Kwa Kirumbi and Ngalanga χ_{lf} never exceeds 3 $x10^{-6}$ m^3kg^{-1}. Similarly, absolute χ_{lf} differences are observed between slope deposits at Usumbwe and Lomwe. The absolute χ_{lf} differences may be attributed to different bedrock geology controlling abundance, size and shape of ferrimagnetic minerals.

Set against a background of high concentrations of primary, ferrimagnetic minerals, distinction of pedogenetic enhanced magnetic properties becomes increasingly sophisticated (DEARING et al. 1986). In the study area, it is not possible to infer unequivocally topsoil development, subsoil extent, or soil - bedrock transition from absolute magnetic susceptibility parameters. Instead, relative susceptibility changes between *in situ* soils and the overlying colluvial deposits are used to delimit stratigraphically the extent and nature of slope deposits.

8.4.4 Magnetic stratigraphy of slope deposits

The colluvial slope deposits at Mrongo, Usumbwe, and Lomwe share a distinct magnetic susceptibility pattern, which is superimposed on the absolute susceptibility differences between the study areas. The interpretation of this pattern draws on the discussed observation that disturbed soils and reworked material is generally magnetically enhanced compared to *in situ* subsoil horizons.

At **Mrongo** and **Usumbwe** low magnetic susceptibility of *in situ* subsoils (unit I) contrasts with a rapid χ_{lf} increase in the buried topsoil and a plateau of high susceptibility in the lower colluvial deposit (unit II). Only in the uppermost deposit, χ_{lf} decreases again to intermediate values. This pattern of magnetic susceptibility reflects the stratigraphic subdivisions established through field observations in previous chapters and sheds light into a complex deposition history (cf. generalised diagram Fig. 49).

Low magnetic susceptibility and frequency dependency values (χ_{lf} generally not exceeding $2 \times 10^{-6}\,m^3kg^{-1}$) are observed for subsoil horizons, where susceptibility is controlled by primary minerals. The coupled increase of both magnetic parameters in buried topsoils and colluvial deposits points to pedogenetic enhancement as the dominant driving force. High χ_{lf} values are indicative of the presence of ferrimagnetic minerals (magnetite or maghemite), whereas intermediate to high frequency dependency suggests the neoformation of secondary, fine grained, superparamagnetic minerals. Thus, the magnetic enhancement of the buried topsoils is likely the result of soil development and pedogenetic and microbial mediated magnetic enhancement in the presence of soil organic matter (MULLINS 1977; THOMPSON & OLDFIELD 1986; EVANS & HELLER 2003). Similar, if not more important, is the frequent occurrence of fires, as evidenced by the abundance of charcoal fragments, which further promotes the formation of ferrimagnetic minerals throughout the deposits.

Soil erosion on the valley slopes resulted initially in the relocation of enhanced topsoil material. The eroded topsoil material was temporarily stored along the slope and remained a prolonged time within the biologically active surface layer, giving time for magnetic enhancement and formation of secondary iron minerals by pedogenetic processes, microbial activity, and recurrent surface fires. Mixing of eroded material from different sources (whether topsoils and subsoils material or material from distinct bedrock geology) may have caused fluctuations of the magnetic properties.

Magnetic susceptibility declines in the uppermost deposits and stabilises on an intermediate level, whereas $\chi_{fd\%}$ remains high indicating that magnetic grain size classes and hence contribution of secondary, pedogenetic minerals is not affected by the decreasing concentration of ferrimagnetic minerals. Despite reduced χ_{lf} values, pedogenesis or fires are still the dominant factors controlling susceptibility, although the absolute magnitude of enhancement is reduced. The observed χ_{lf} decrease is therefore interpreted to reflect the deposition of weakly magnetic subsoil material. This is in accordance to the observed shift to brighter (yellowish) red soil colours and a compact soil structure of the uppermost deposits (chapter 8.2). The magnetic parameters thus support and strengthen the field observation that after centuries of soil erosion on the slope, topsoils had been eroded away and the proportion of eroded subsoil material increased significantly.

The magnetic susceptibility pattern of the **Lomwe** profiles differs from the Mrongo/Usumbwe sites. Instead of a rapid shift, χ_{lf} and $\chi_{fd\%}$ decrease in tandem from the buried topsoils towards the surface. The steady decrease of both parameters reflects a continuous reduction of the absolute amount of ferrimagnetic minerals at the same time as frequency dependency and hence the proportion of secondary minerals declines. The coupled decline of both parameters indicates that at Lomwe pedogenetic enhancement has declined continuously since erosion began and that erosion of topsoil and later subsoil material has been a steady and continuous process.

8.4.5 Sand lenses

Exceptionally high χ_{lf} peaks reflect the occurrence of dark iron rich sand lenses (Mrongo 3, 10, & 4) with a high concentrations of ferrimagnetic minerals - probably primary, ilmenitic magnetite (ILES

2011). The χ_{lf} peaks are matched by sharp drops of $\chi_{fd\%}$ confirming dominance of primary minerals characterized by large multidomain grains and hence a low frequency dependency. Further changes in the concentrations of primary, ferrimagnetic minerals are reflected by paired excursions of high χ_{lf} and depressed $\chi_{fd\%}$ values observed at several sites (e.g. Usumbwe 1, Lomwe 3 & 10). Less pronounced, systematically opposing trends of both parameters are characteristic for the fluctuations observed within most profiles. These opposing trends reflect variations of primary mineral concentrations superimposed on the high magnetic susceptibility caused by secondary iron oxides.

8.4.6 Waterlogging

Seasonal or permanent waterlogged conditions below the groundwater table promote a reducing environment. Anaerobic conditions lead to the reduction of Fe^{3+} and the dissolution of iron(hydro)oxides. Soluble Fe^{2+} is not magnetic and might be leached resulting in a permanent depletion of iron minerals. As small particles are more susceptible to dissolution than larger grains, reductive conditions favour the dissolution of fine grained, superparamagnetic, secondary iron hydroxides, thus obliterating selectively the evidence of pedogenetic magnetic enhancement (THOMPSON & OLDFIELD 1986).

Decreasing magnetic susceptibility coincides with evidence of seasonal waterlogging at Mrongo 4 (mottles at 500cm, water table at 720cm, Nov. 2009). At Usumbwe 3, χ_{lf} and frequency dependency both decline below the watertable (450cm, Dec. 2009), although minimum values (~0.3 10^{-6} m^3kg^{-1}) are attributed to the buried organic layer. Contrastingly, the dry season water table at Usumbwe 2 (690cm, Dec. 2009) is not accompanied by any change in magnetic properties. At the fringe of the water table secondary formation of iron(hydr)oxides such as lepidocrocite or ferrihydrite is expected. These, however, are paramagnetic, have a low χ_{lf}, and remain undetected in the presence of ferrimagnetic minerals.

At mid-footslope positions (Mrongo 3 & Usumbwe 2) overall variability increases in the buried *in situ* soils possibly related to seasonal waterlogging. At upper footslope positions (Mrongo 2 & Usumbwe 1) increasing frequency dependency of dry profile bottoms to values of >10% might be related to the observation of active weathering along the B/C-transition, as indicated by oxidation crusts around weathered rock fragments. If this is the case, it remains unclear why this trend is not reflected in the overall magnetic susceptibility, which in contrast shows decreasing values.

8.4.7 Summary

he magnetic stratigraphy based on two basic susceptibility parameters supports the interpretation of magnetically enhanced topsoil eroded and deposited during an early erosion stage and subsequent deposition of less enhanced subsoil reflecting widespread soil erosion and land degradation on the catchment slopes (Fig. 49). However, both primary magnetite derived from the local parent material, and secondary iron oxides from pedogenetic enhancement, contribute to the observed susceptibility patterns. The high background χ_{lf} values of the magnetite rich Pare geology requires the measurement of further magnetic parameters (e.g. ARM, IRM) to discern unambiguously between the two sources. The identification of different colluvial deposits by susceptibility changes, however, remains unaffected by the exact process of magnetic differentiation.

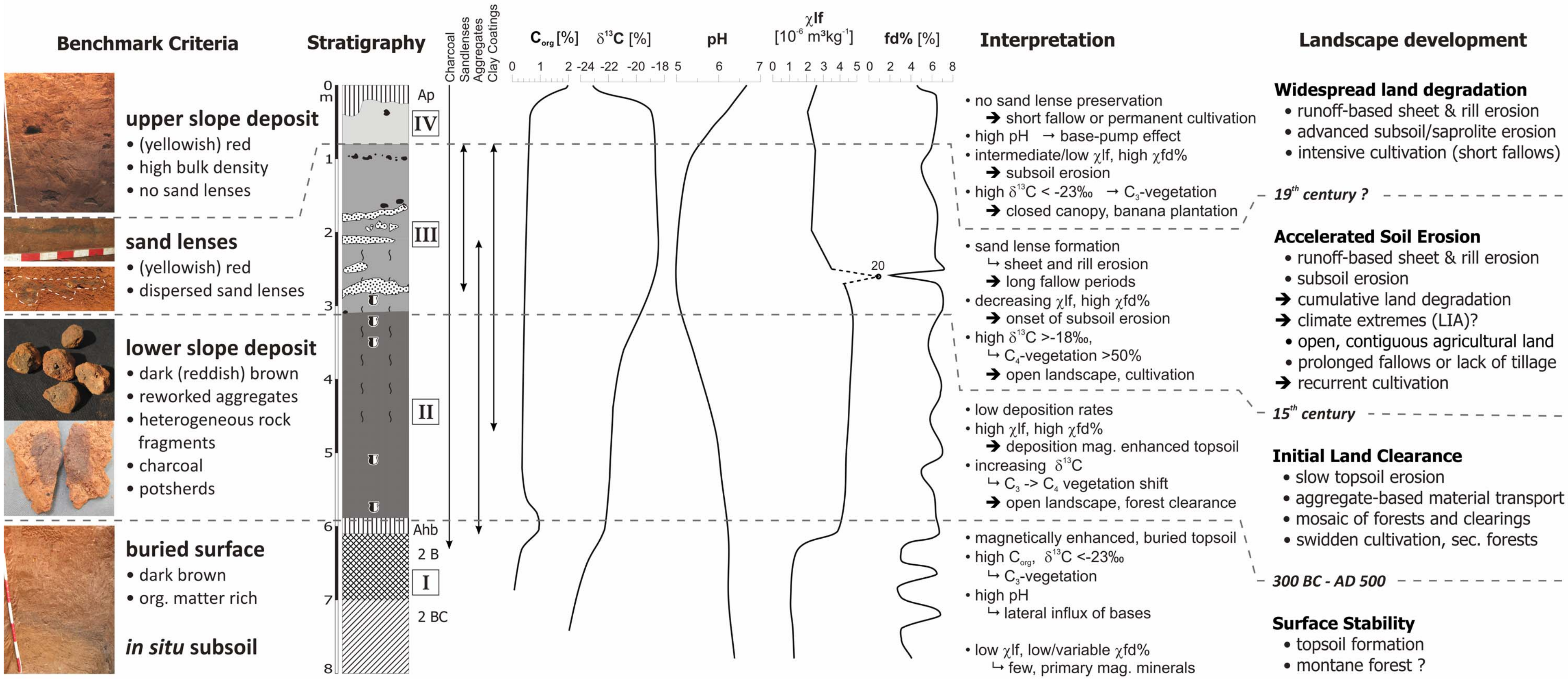


Fig. 49: Overview of stratigraphy and colluvial processes in Pare. Stratigraphic deposition units, benchmark features, and analytical results are complemented by an interpretation of colluvial processes and a generalised model of landscape development. For detailed explanation see chapter 8.

8.5 **Vegetation change: Evidence from stable carbon isotopes.**

The history of vegetation change in upland Pare is based on three lines of evidence: comparison of multitemporal aerial photographs of the 20th century, organic carbon and stable carbon isotope composition of slope deposits, and palaeoecological pollen and phytolith analysis of the Lomwe Swamp core. This chapter focuses on changes in the stable carbon isotope composition of terrestrial archives, whereas the palaeoecological findings are discussed in chapter 9.5.

8.5.1 Stable carbon isotopes and vegetation change

The stable carbon isotope composition of plants differs according to their photosynthetic pathway (FARQUHAR et al. 1989; RUNDEL et al. 1989; SAGE & MONSON 1999). Commonly, C_3, C_4 and CAM plants with a distinct range of $\delta^{13}C$ values are differentiated. Due to their efficient carbon fixation mechanism, C_4 plants ($\delta^{13}C$: -13 - -10) are more tolerant to water-stress and dominate in dry environments particularly tropical grasslands, whereas C_3 plants ($\delta^{13}C$: -32 - -23) are mainly trees and grasses of temperate or high-altitude locations (RUNDEL et al. 1989; SAGE & MONSON 1999). In palaeopedological studies, stable carbon isotope compositions have been widely used to infer vegetation change in East African environments (SCHWARTZ et al. 1986; AMBROSE & SIKES 1991; SCHWARTZ et al. 1996; ESHETU & HÖGBERG 2000; RUNGE 2001b; ESHETU 2002; DRIESE et al. 2004; GILLSON et al. 2004; ZECH 2006; TERWILLIGER et al. 2008; GEBRU et al. 2009).

$\delta^{13}C$ variation of single species varies according to the isotope fractionation processes controlled by local humidity and temperature conditions as well as canopy effects (BOUTTON et al. 1998; CERLING 1999). Bulk $\delta^{13}C$ of soil organic matter in C_3-environments range from -35 to -28‰ in mesic, closed canopy environments and up to -23‰, where dominated by xeric C_3-plants (CERLING 1999). Higher $\delta^{13}C$ values between -23‰ and -10‰ indicate varying contributions from C_4 plants (Fig. 50).

In the present study, $\delta^{13}C$ values of slope deposits vary in a narrow range between -18‰ and -25‰ and isotope composition changes result from both variations in the humidity and temperature conditions of the C_3-environment and the admixture of C_4 plants. Consequently, small $\delta^{13}C$ variations are not to be interpreted as indicators of vegetation change and it is not possible to infer the exact type of vegetation from carbon isotope composition. It is however reasonable to assume that lower $\delta^{13}C$ values indicate a generally more forested landscape, whereas a higher contribution of C_4 biomass points to open vegetation or an agricultural landscape.

8.5.2 Forest soils

The Kwa Chegho and Kwa Kirumbi forests harbour mature, although disturbed, montane forests. Stable carbon isotope signatures of recent forest soils at both sites reflect the extant C_3-forest vegetation (<-25‰), whereas open secondary forest shows elevated $\delta^{13}C$ (-20.1‰, Kwa Chegho 3) reflecting a mixed vegetation of C_4-grasses and C_3-trees and shrubs. All investigated forest profiles show increasing $\delta^{13}C$ values in the subsoil levelling out at about -23‰ (Fig. 33). Material translocations and possibly anthropogenic disturbance are recorded as negative $\delta^{13}C$ deviations of the buried soils at 80cm at Kwa Chegho 2 and between 28 – 45cm at Kwa Kirumbi 2 but do not alter the observation of a general $\delta^{13}C$ increase in the subsoil.

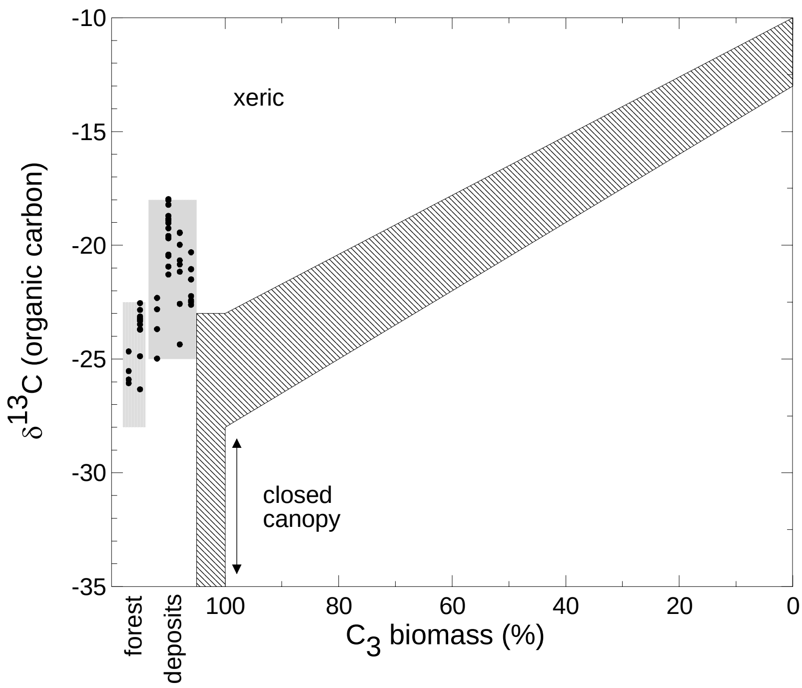


Fig. 50: C_3-C_4 mixing diagram. Relative biomass contribution of C_3 and C_4 plants inferred from $\delta^{13}C$ values. C_3 endmembers are -23‰ for xeric and -28‰ for mesic environments. C_4 endmembers are -10‰ and -13‰ (modified after CERLING 1999). $\delta^{13}C$ ranges of forest soils (left: topsoil, right: subsoil) and slope deposits (left to right: topsoil, colluvium, buried topsoil and *in situ* subsoil) at Mrongo are shown.

The tendency to higher $\delta^{13}C$ values in the subsoil can be explained by either past vegetation change or as the artefact of isotopic fractionation during decomposition. In the first case, the $\delta^{13}C$ shift reflects a change of the predominant photosynthetic pathway: The contemporaneous C_3-environment of a closed forest replaced a former open woodland or dry forest with contributions from C_4-plants. An alternative explanation for elevated subsoil $\delta^{13}C$ values is isotope fractionation during soil organic matter decomposition (BALESDENT & MARIOTTI 1996; WYNN 2007). With depth and hence age of the organic matter $\delta^{13}C$ values are known to increase between 1.5‰ and possible up to 4 to 6‰ (BALESDENT et al. 1993; BALESDENT & MARIOTTI 1996; WYNN 2007). The observed isotopic shift over time has been attributed to three processes: Historical changes in atmospheric carbon isotope composition and carbon concentration since industrialisation, differential decay of biochemical fractions with differing $\delta^{13}C$ values, and isotopic fractionation by decomposing organisms (MELILLO et al. 1989; BALESDENT & MARIOTTI 1996; BOUTTON 1996; WYNN 2007). The most important process regarding the increase of $\delta^{13}C$ with depth is the isotopic enrichment of ^{13}C by fractionation during microbial respiration or fermentation. During microbial decomposition, the lighter ^{12}C is preferentially respirated, whereas ^{13}C is incorporated into the biomass. The more the original soil carbon content has been reduced, the more important is the process of $\delta^{13}C$ enrichment, which can be modelled by a Rayleigh distillation function (WYNN 2007). In East Africa, a similar trend of increasing $\delta^{13}C$ with depth was observed in subsoils of an Ultisol under ancient forest vegetation in the Kagamega forest, Kenya, considered to be a 'living remnant' of Pleistocene forests (KRULL et al. 2002). A distinct ^{13}C enrichment of about +4‰ to +6‰ was reported by KRULL et al. (2002) and WYNN (2007), whereas the average $\delta^{13}C$ shift between topsoil and subsoil at Pare is only moderate (~ +2.5‰).

Isotope fractionation during organic matter decomposition could explain the observed trend to higher $\delta^{13}C$ values in modern steady state forest subsoils, without the need to speculate about former vegetation change. In the absence of further corroborating evidence of Holocene montane forest decline and subsequent recovery, the observed $\delta^{13}C$ shift within the overlap of the C_3 and C_4-domains is interpreted as the result of isotopic fractionation.

8.5.3 Slope deposits

A common pattern is observed for colluvial slope deposits at Mrongo and Lomwe. Albeit not equally pronounced at every profile, two major vegetation shifts during the built-up of the slope deposits can be identified. Low $\delta^{13}C$ values of the buried soils (<-22‰) followed by an increase throughout the colluvial deposits indicate a growing contribution from C_4-vegetation. In the topsoil, an abrupt return to low $\delta^{13}C$ values reflects the contemporary dominance of C_3-vegetation.

Buried, in situ **soils** show low to intermediate $\delta^{13}C$ values in the same range as the aforementioned forest subsoils (Fig. 35). Considering carbon isotope fractionation by decomposition, the intermediate subsoil $\delta^{13}C$ values might be derived from an initially even lower carbon isotope ratio thus indicating a possible far higher contribution of C_3-plants than the present isotope composition suggests. Isotope fractionation might explain the high $\delta^{13}C$ of subsoil horizons of both forest and buried soils, and does not question the assumption of prehistoric montane forest cover in upland Pare.

Similarly to the differences in organic carbon content (chapter 8.1), $\delta^{13}C$ values of *in situ* subsoils at Lomwe (-22.5 - -24.8‰) show a higher contribution of C_3-plants than at Mrongo (-21.5‰ to -22.6‰) suggesting a more humid forest environment at the end of the LGM than during the late Holocene.

The stable carbon isotope composition of buried topsoils differs from the isotope signature of contemporaneous dry forests and savannah woodland (~-19‰, Tab. 13) and hence rules out the former expansion of woodland environments into mid-altitude Pare. On the other hand, $\delta^{13}C$ values of buried topsoils show a higher contribution of C_4-plants than expected from current montane forest environments. Isotopic fractionation is offered to explain this discrepancy, although not all evidence support the ^{13}C enrichment with time and depth. The buried soils of the slope deposits do not show the depth pattern expected from the isotope fractionation model and discussed above for forest soils. Instead, $\delta^{13}C$ of buried topsoils general exceeds $\delta^{13}C$ of buried subsoils (Fig. 35). Of course, the higher $^{13}C/^{12}C$-ratios of buried topsoils could be the consequence of admixture of C_4-plant material by disturbance or perhaps partial truncation during the burial process or be related to bioturbation during the accretion of the slope deposit.

Both explanatory approaches have considerable caveats. While the possibility of isotopic fractionation does not categorically rule out a former drier environment, the isotopic evidence for a prolonged mid to late Holocene dry period (before or around 2000 BP) is not convincing (see chapter 10.4). Given the possibility of an alternative explanation by isotope fractionation, the postulation of drastic reduction of forest cover about 2,000 years ago and subsequent reestablishment of a humid montane forest in Pare is not justified. For now, it is reasonable to adhere to the conservative assumption of a closed montane forest environment having prevailed throughout the Holocene.

Stable carbon isotope composition of the **colluvial slope deposits** show increasing $\delta^{13}C$ from bottom to top reflecting a slow change from a C_3 dominated vegetation to a mixed C_3/C_4 environment. $\delta^{13}C$ values of the uppermost metres are high (> -20‰) at all sites and suggest a

Tab. 13: Organic carbon, δ13C and C/N-ratios for selected topsoil and plant samples. Standard deviations are given for the average of the respective categories if calculated from distinct soil profiles. For single samples laboratory variation of three replicates are reported.

Site	Layer	C_{org} [%]	$\delta^{13}C$ [‰]	C/N-ratio [-]	n	Altitude
Upland Forest Sites						
Kwa Chegho 2	organic layer	34.9 ± 6.6	-27.8 ± 0.3	15.2 n/a	1	1790m a.s.l.
Kwa Chegho 2	topsoil	12.7 ± 2.2	-24.7 ± 1.4	14.9 n/a	1	1790m a.s.l.
Kwa Kirumbi	topsoil	3.4 ± 1.0	-25.5 ± 0.5	10.3 ± 1.0	4	1400m a.s.l.
Secondary Forest (Kwa Chegho 3)	topsoil	2.2 ± 0.1	-20.1 ± 0.3	10.1 n/a	1	1790m a.s.l.
Upland Cultivated Sites						
Banana Grove (Mrongo)	topsoil	2.8 ± 0.7	-23.4 ± 1.2	10.3 ± 1.9	4	1320m a.s.l.
Open Eucalyptus & undergrowth (Lomwe)	topsoil	1.5 ± 0.2	-22.0 ± 0.9	12.3 ± 4.1	4	1350m a.s.l.
Bushland (Ngalanga-Mochame ridge)	topsoil	1.8 ± 0.3	-23.6 ± 0.8	10.1 n/a	1	1400m a.s.l.
Maize field (Mrongo 4)	topsoil	0.6 ± 0.0	-18.0 ± 0.0	7.6 n/a	1	1320m a.s.l.
Lowland						
Degraded Bushland (Mandaka)	topsoil	0.6 ± 0.1	-18.7 ± 0.5	10.3 ± 0.5	3	815m a.s.l.
Dry Forest (Lambo)	topsoil	1.0 ± 0.1	-18.9 ± 0.3	8.7 n/a	1	1000m a.s.l.
Swamp						
Cyperus Papyrus (Mrongo)	dry stalk	32.3 ± 8.8	-14.9 ± 0.1	29.7 n/a	1	1300m a.s.l.
Swamp Grass (Mrongo)	dry stalk	35.0 ± 10.5	-14.3 ± 0.1	24.6 n/a	1	1300m a.s.l.
Swamp Surface (Mrongo)	clay	1.8 ± 0.3	-22.6 ± 0.6	7.1 n/a	1	1300m a.s.l.

significant biomass contribution of over c. 50% from C_4-plants. As isotopic change started with the onset of colluviation the $\delta^{13}C$ of soil organic matter is a compound signal. However, local vegetation can be assumed to dominate over the contribution from reworked organic matter as shown by the recent $\delta^{13}C$ shift of the topsoil.

The increasing contribution from C_4-plants may reflect the spread of grasses, weeds, and the introduction of cereal cultivation following the opening up of the original C_3 forest vegetation by the first sedentary agriculturalists. Maximum proportions of C_4-plants ($\delta^{13}C$ between -19‰ and -18‰) are observed after the onset of sand lens occurrence in the 15th century, whereas the highest single $\delta^{13}C$ values (-16.5‰) is associated with placed boulders and human activity at Mrongo 2 (11th century AD). The isotope signatures are similar to C_4 dominated environments in North Pare such as contemporaneous agricultural fields (Mrongo 4), dry forest vegetation at mid-altitudes (Lambo) and open, degraded bushland with dispersed trees at the Pare footslopes (Mandaka, Tab. 13).

It is possible that the $\delta^{13}C$ shift reflects not only open vegetation but is the direct consequence of cultivation of indigenous African cereals. Indigenous East African cereals, like sorghum (*Sorghubicolour*, Andropogoneae) and several millet species such as finger millet (*Eleusine coracana,* Chloridoideae), common millet (*Panicum milliaceum,* Paniceae) and pearl millet (*Pennisetum glaucum,* Paniceae) as well as tef (*Ergrostis tef,* Chloridoideae), follow the C_4 photsynthetic pathway (BROWN 1999; VAN DER MERWE & TSCHAUNER 1999). Cultivation is always accompanied by the spread by weeds, known to have a high proportion of C_4 plants (BROWN 1999). Even within extensive agricultural systems relying predominantly on tubers, grasses and weeds are present and the overall $^{13}C/^{12}C$-ratio will increase.

Changes of soil $\delta^{13}C$ are often used as markers for the introduction of exotic C_4 crops such as maize. In East Africa, banana and sugar cane from Asia and maize from the Americas are the most important introduced crops. Sugar cane and maize are important C_4-plants, widely cultivated in Pare today. Plantations of sugar cane were observed frequently in North Pare in 1861/1862 during the visits of VON DER DECKEN (1869), when maize was available at several market places in Pare. Due to the widespread presence indigenous C_4 grasses and cereals, their introduction did not have a strong impact on the $\delta^{13}C$ signature of the soil.

Banana and plantains are C_3 plants. Cultivated in plantations or agroforestry systems, a closed canopy and the subduction of C_4-plants allows their distinction from annual cereal cropping systems by low $\delta^{13}C$ values of the soil organic matter. The $\delta^{13}C$ record from the investigated sites does not show any evidence for past banana plantations. On the contrary, a rapid shift to more negative $\delta^{13}C$ values in the topsoils indicates the very recent establishment of the Mrongo banana grove.

Topsoil $\delta^{13}C$ values at Mrongo and Lomwe are low and increase rapidly within the uppermost 30cm. The isotopic shift to C_3 dominated vegetation occurs within the upper 10 – 30cm and is interpreted as a recent change in vegetation cover and land use. Most accentuated at Mrongo, low topsoil $\delta^{13}C$ (-22.8, -23.7‰ and -25.0‰, respectively) reflects the present C_3 vegetation of a banana grove dominated by bananas, shade trees, and shade tolerant undergrowth. This recent vegetation change is however spatially restricted to the banana plantation. Beyond this, at Mrongo 4, no isotopic change is observed and topsoil $\delta^{13}C$ (-18‰) reflects the present cultivation of C_4 plants like maize and sugar cane. Aerial photographs taken in the years 1954, 1957, and 1983 show that the banana plantation had been established in its present boundaries before 1954. Involving only the uppermost 30cm, the $\delta^{13}C$ shift suggests that the banana grove has not been a persistent landscape feature and probably does not predate the mid-19th century. At Lomwe, high topsoil $\delta^{13}C$ values are similarly related to recent land use changes. Here, *Eucalyptus* afforestation during the 20th century resulted in the decrease of the topsoil $\delta^{13}C$.

8.5.4 Summary

Stable carbon isotope composition of buried soils does not allow the unambiguous assignment of a vegetation type. Although a forest environment is likely to have prevailed when the first settlers arrived in Pare, no distinction between humid montane or drier submontane forests can be made. It is reasonable to assume that initial land clearing was responsible for both the onset of colluviation and the concurrent spread of C_4-vegetation. Cultivation of C_4 sorghum and millet varieties probably has contributed to higher $^{13}C/^{12}C$-ratios, but the opening of the landscape alone and the spread of grasses and weeds with a high proportion of C_4 plants would have been sufficient to cause the slow shift of the stable carbon isotope composition. Highest $\delta^{13}C$ values are recorded for the period following the onset of sand lenses occurrence in the 14th/15th century suggesting the end of the initial land clearing phase and an increased intensity of agricultural land use.

8.6 From hillwash processes to a history of land use and erosion

Several processes might be responsible for the onset of runoff-generated erosion in the 14th/15th century as deduced from the onset of sand lense occurrence: the cumulative effects of progressive forest clearance and land degradation; a change of the agricultural land use practices; social, cultural and population transformations; - or climate dynamics, particularly precipitation changes. In the following, environmental conditions associated with sand lens formation and preservation are discussed emphasizing particularly the impact of land use practices and progressive forest clearance. The possible impacts of regional factors such as climate dynamics or cultural transformations on runoff-based erosion are reviewed in chapter 10.4.5.

8.6.1 Drivers of enhanced slope wash and sand lens formation

The formation of wash layers and sand lenses occurs today during moderate to strong rainfall events in a seasonal climate. Higher rainfall *per se* does not necessarily lead to higher rainfall erosivity. Rather than the amount, it is the intensity and distribution of rainfall events and particularly a seasonal rainfall regime with strong, single rainfall events will increase precipitation erosivity and promote runoff production and sand lens formation. During the late Holocene, Pare has been under the influence of a seasonal climate; however, the intensity might have changed over time. The reconstruction of past precipitation distribution is a difficult task and past climate variability on a yearly basis has been subject to many speculations. Particular during the Little Ice Age, roughly contemporaneous with the period of sand lens occurrence, climatic variability in East Africa increased and several drought periods interrupted a generally intermediate humid climate. Fluctuating climatic conditions and pronounced seasonal precipitation during drought periods might have contributed and triggered short-lived surface runoff events, sheet wash and rill erosion (see chapter 10.4.5).

At the same time, however, the internal development of the Pare environment had reached a threshold. When sand lens formation started in the 15th century, the slopes of Pare had experienced about 1500 years of soil erosion. The cumulative effects of several hundred years of slow but progressive soil erosion on the slopes had resulted in the loss of topsoils and the exhumation of subsoils as indicated by decreasing magnetic susceptibility and changing colour of slope deposits. In the 14th/15th century, soils on the slopes had been truncated and for the first time the effects of prolonged erosion and land degradation came to the fore.

Whereas the eroded topsoils had been well structured, frail, pore rich, stabilised by high amounts of organic matter as well as loosened by a biological activity, the now exposed subsoils have a low pore volume and only initial soil structure. Not only was soil fertility of the exposed subsoils lower, but also infiltration capacity was considerable reduced thus increasing runoff production.

On the slope scale, progressive forest clearance has resulted in the expansion of the cultivated area. Larger, contiguous fields and probably shorter fallow periods (as discussed below) provided increasingly larger areas for runoff production. Expansion of agricultural fields and cleared, disturbed land resulted in longer overall slope length; less possibility of intermediate water and sediment storage such as within patches of dense forest vegetation; and in consequence a rising amount of surface runoff. Increasing areas of runoff production combined with a reduced infiltration capacity must have resulted in a general higher overland flow and triggered sheet wash, runoff concentration and finally rill erosion. As a trigger for sand lens formation, we identify a combination of progressive soil erosion since the beginning of farming about 2000 years ago and a seasonal precipitation pattern providing strong rainfall events.

8.6.2 Land use practices and the preservation of sand lenses

Agricultural land use interferes directly with ecosystem processes and controls soil erodibility, infiltration capacity and hence runoff-production and erosion processes.

Preservation of sand lenses (unit III) in agricultural environments requires special circumstances and land use practices. On the field scale, tillage practices, crop types and planting techniques like monocultures or mixed agroforestry systems as well as the location of field boundaries, paths and homesteads play an important role in controlling runoff-generation and deposition and hence the formation and preservation of sand lenses. Particularly, changing agricultural techniques, tillage practices or the introduction of new species would have affected the preservation of sand lenses.

The introduction of banana is strongly controversial and the timing and dispersal of banana in Africa are subject to discussion. Earliest claims for banana during the 4th millennium BC in Uganda (LEJJU et al. 2006) and the first millennia BC in Cameroon (MBIDA MINDZIE et al. 2006) are strongly questioned (NEUMANN & HILDEBRAND 2009) although generally an early introduction probably as soon as the first millennia AD is accepted (SCHOENBRUN 1993b). Banana plantations create a shadowed and protected environment generally assumed to reduce rainfall erosivity by retarding raindrop impact. Field observations at Mrongo however have shown that severe sheet and rill erosion takes place in a banana grove agroforestry system, despite reduction of rainfall erosivity under a closed canopy and reduction of soil erodibility by soil conservation measures like mulching and intercropping (Fig. 48 & Fig: 51). Banana propagation does not require tillage but involves the establishment of about 0.5m deep soil pits for planting cuttings and shoots - even on steep slopes (Fig: 51). Over time, this propagation technique effectively mobilises and relocates the entire slope topsoil, and contributes to accelerated downslope movement of soil material on a large scale. Besides traditional tillage for annual crops, excavation of banana pits on slopes emerges as an important process for the translocation of entire soil aggregates. In deposition areas, banana might not entirely erase the evidence of sand lens formation as only small parts of the field are turned over and the spoil might protect lenses from being disturbed. Stable carbon isotope composition of topsoils under banana plantation is distinctively ^{13}C depleted and show low $\delta^{13}C$ around -23.5‰ (cf. Tab. 10). Sand lens occurrence in colluvial deposits is, however, accompanied by high $\delta^{13}C$ up to about -18‰ (cf. Fig. 35) suggesting a considerable contribution of C_4-plants, and thus does not support the possibility of a farming system based on closed banana plantations.

Within the last centuries, maize has become the main staple of east African diets and land use practices have adapted accordingly. Tillage practices for the indigenous cereals millet, sorghum, and the later introduced maize are based on tillage (hoeing) and leave the soil exposed, bare, and susceptible to erosion. Conversely, mixing of topsoil material during tillage effectively impedes sand lens preservation despite current sand lens formation, as shown by their absence in the upper decimetres of the slope deposits. Consequently, cereal and maize cultivation stimulate erosion on the slopes but effectively erase the evidence of rill erosion and sand sedimentation at depositional fooslope positions.

While preservation of sand lenses in sedimentary unit III excludes permanent cereal cultivation, banana plantation is ruled out based on the stable carbon isotope composition of soil organic matter. Further, on the grounds of high $\delta^{13}C$ values, recovery of forest vegetation can be excluded. To allow sand lens formation, soil erosion on the catchment slopes must be severe, while accretionary conditions must have prevailed in the deposition areas in order to bury and preserve the deposition features. Thus, sand lens occurrence indicates low land use intensity on-site – most likely temporary cessation of cultivation, regrowth of open secondary vegetation characterised by a high contribution of C_4-plants, probably grasses and weeds. This does not necessary imply a reduction of land use intensity compared to the former stratigraphic unit II, but rather suggests decade-long fallow periods to allow burial and preservation of dispersed sand lenses. If fallow periods were long enough, dispersed sand lenses are likely to survive soil working during cultivation phases.

Recurrent but extensive cereal and tuber cultivation with intermediate decade-long fallow periods could even reflect a more intensive form of agriculture compared to earlier forms of swidden agriculture. Swidden agriculture and slash and burn practices with long fallows can be assumed to have

Fig: 51: Important present day soil erosion processes. Contour trenches on steep slopes help visualise the magnitude of sediment transport during runoff events under dense banana plantation: a) recently excavated trench at Usumbwe and b) half year old infilled trench above Mrongo 2. Tillage erosion associated with banana transplanting: c) banana pit and related spoil material on a 25° steep slope, d) cut and fill feature resulting from banana planting, exposed in the contour trench shown in a).

prevailed during the early centuries of agriculture, when occasional forest clearance in a sparsely populated landscape was followed by 'fallows' long enough for forest to re-establish. The slow change of the stable carbon isotope composition in the lower most colluvium supports the notion that the retreat of forest was a slow process until the 15th century when low $\delta^{13}C$ values indicate that secondary vegetation grown during fallows did not develop into mature forests anymore. Thus, in the 15th century, a shifting cultivation regime with rotating fallows long enough to allow preservation of deposition features but short enough to prevent the establishment of a closed secondary forest is proposed.

Definitions of farming practices and terminologies differ widely and the terms shifting cultivation, swidden cultivation, and slash-and-burn are often used synonymously to describe 'any continuing agricultural system in which impermanent clearings are cropped for shorter periods in years than they are fallowed' (CONKLIN 1961; see also GREENLAND ; RAINTREE & WARNER 1986). Whereas swidden cultivation and slash-and-burn generally are used to refer to land reclamation, shifting cultivation implies a broader meaning. However, terminologies do not allow differentiation between initial forest clearance or recurrent cultivation, sedentary or temporary settlement or the intensity of the land use (cf. chitemene systems). In particularly the length of fallow requires differentiation in, for example, long (forest), intermediate (bush) and short (grass) fallow (BOSERUP 1965). More intensive, often permanent, farming practices such as ley farming (animal husbandry and manure input during fallow periods) and crop rotation complicate the picture. To differentiate between the lengths of the fallow period and hence cultivation intensity, the present study applies the broader term shifting cultivation to describe recurrent farming of the same field with fallow periods of different length. Less intensive cultivation practices are referred to here as swidden agriculture and characterised by land reclamation by slash-and-burn; the abandonment of fields after cultivation for very long 'fallows', thereby allowing forest to re-establish; and perhaps also the shifting of settlements.

Cessation of sand lens preservation (unit IV) was not directly dated as calibration of single, subrecent radiocarbon dates since AD 1700 produces broad and ambiguous age ranges. Rough age estimation is obtained assuming constant deposition since the dated onset of sand lens formation. Cessation of sand lenses falls between AD 1780 (Mrongo 4) and AD 1900 (Mrongo 10, Usumbwe 3, cf. Tab. 12), a period of considerable economic and political change in East Africa.

Currently, sheet wash and rill erosion are observed in open maize fields and under dense banana plantations and it must be assumed that the sand lens formation processes has continued uninterrupted since the 15th century. Sand lenses, however, are not recorded within the upper metres of the deposits suggesting that preservation has been effectively subdued during the last centuries.

No strong climatic shift has been observed that would explain a temporary cessation of hillwash during the 20th century and a very recent resumption of a seasonal precipitation regime (NICHOLSON 2000; HASTENRATH 2001). Instead, as noted above, soil working is the most likely driver of sand lens destruction. Today, hoeing for cereals, maize, and beans and the occasional digging of banana pits effectively prevents sand lens preservation and as such, the lack of sand lenses within the upper deposits is indicative for permanent cultivation or a significant reduction in fallow periods. The current permanent cultivation of the comparably fertile slope deposits thus represents a further intensification of agricultural land use compared to the previous period, when prolonged decadal-long fallows must have prevailed. Annual tillage (or very short fallow periods of a few years only) might be a response to increased population pressure, declining soil fertility of the slope soils or to other incentives of agricultural intensification discussed further in chapter 4.6 & 10.4.6.

In summary, runoff-based erosion and the formation of sand lenses are the consequence of progressive and cumulative soil erosion during fifteen centuries of extensive swidden farming practices of a perhaps semi-sedentary population. Around the 15th century, the intensity of land use increased probably because of societal transformations, population growth or due to fertility decline of eroded soils. Recurrent cultivation of fields may have resulted in regular - albeit initially decade long - fallow periods preventing forest re-establishment but allowing sand lens preservation. Intensification of agricultural land use following societal transformations triggered by the 19th-century caravan trade or population growth in the 20th century is likely to have led to a further reduction of fallow periods and thus the destruction of sand lenses.

8.7 Post depositional translocation processes within slope deposits

8.7.1 Base cation enrichment

pH profiles of forest soils reflect current soil development: elevated topsoil pH due to base pump effects, leaching and acidification in the subsoil, and intermediate pH values near the weathering front. After truncation of agricultural soils, slightly weathered B/C-material with a generally higher pH becomes exposed. Locally, addition of reworked material might contribute to an elevated pH.

Post-depositional leaching processes as well as differing pH values inherited from the colluvial parent material are likely to be responsible for the pH pattern of slope deposits. Analogous to forest soils, pH of the uppermost slope deposits is elevated due to biogeochemical cycling and the steady influx of basic cations by decomposition of above ground biomass. Near surface leaching in the upper metres of the slope deposits causes a lowering of the pH, whereas correlated accumulation of bases takes place in the lower part of the colluvium and within the buried soils. In addition to vertical influx, lateral influx of dissolved elements from higher landscape positions contributed to the elevated pH of slope deposits. Basic cations leached from the subsoil of slope soils percolate within the groundwater and may be retained in the valley bottom. Post-depositional base enrichment via groundwater flow is likely to be a major cause of high pH values >6 observed in the lowermost deposits/buried soils. Lateral influx is supported by a spatial trend to higher overall pH values for valley bottom locations (Mrongo 5, Usumbwe 3, Lomwe 6) compared to footslope profiles within the slope transects.

In addition to dissolved element transport, re-deposition of eroded slope material might also have contributed to the observed pH pattern in slope deposits. During early erosion stages, deposition of topsoil material with a comparatively high pH was later replaced by partly leached subsoil material with a lower pH. Recently slightly weathered subsoil and B/C-material is mobilised. The concurrent occurrence of sand lenses and low pH values might be a temporal coincidence or may be a consequence of enhanced leaching due to improved drainage in sandy material.

8.7.2 Clay illuviation

Clay coatings are observed in colluvial deposits and soils of forests and eroded agricultural slopes. Although their presence may indicate the initial formation of clay enriched, argic illuviation horizons, absolute clay enrichment was not confirmed by particle size analysis. Clay contents of subsoil horizons at Kwa Kirumbi do not suggest clay translocation and enrichment, but rather clay formation during pedogenesis in the most weathered upper decimetres of the soil. The failure to detect clay enrichment by particle size analysis might be attributed to the presence of clay bound to ironoxides, not destroyed during pre-treatment. Thus, further research may be required.

Particle size variation between adjacent samples is higher in colluvial deposits than *in situ* soils. The particle size variations of the colluvial deposits demonstrate that particle size composition is controlled, in the first instance by the delivery of material with varying particle size fractions and not by post-depositional pedogenetic processes. Deposition of sorted sediments during runoff events and their subsequent incorporation into the soil matrix contribute to the observed particle size variability.

The frequent and abundant occurrence of clay coatings in the slope deposits is indirect evidence for the disturbance process 'erosion'. Colluvial deposit are likely to favour clay translocation. Erosion leads to dispersion and mobilisation of clay minerals. When the runoff water infiltrates on the footslope, clay particles not sedimented on the surface are dragged into pores and are translocated within the infiltrating water stream. This transportation process possesses a much higher energy compared to clay translocation within the profile itself, and hence clay illuviation becomes much more effective. Preconditions, however, are favourable physical soil conditions – particularly open macropores and the absence of surface sealing. Soil disturbances, such as soil and tillage erosion and bioturbation by termites and ants, clear the path for disaggregated soil material to erode and disperse, and provide the corresponding macropores through which water infiltrates and clay illuviation can take place.

The lack of particle size differentiation in the slope deposits is attributed to the particular setting. In contrast to conventional clay translocation, the main source of the transported clay minerals is not an elluvial horizon but appears to be the fine fraction of eroded and transported material. This circumvents clay depletion of the uppermost deposit. As infiltration depth shifts during the built-up of the deposit no distinct clay enriched horizon develops. Further, particle size variation suggests that the heterogeneous texture of the colluvium outweighs post-depositional changes of the clay content.

8.8 **Nitric-acid-resistant-carbon: Charcoal or resistant organic matter?**

Nitric-acid-resistant carbon (NARC) is a widely used, though disputed, charcoal proxy (WINKLER 1985; LAIRD & CAMPBELL 2000; KURTH et al. 2006). The NARC content of the Lomwe swamp core closely mirrors the distribution of total organic carbon and shows maxima for the buried and the recent peat (Fig. 32). The close relationship between nitric-acid-resistant and total organic carbon questions the efficacy of the nitric acid digestion method to discern between charcoal and highly recalcitrant organic matter. The stratigraphic coincidence suggests that either the digestion agent fails to effectively remove the recalcitrant highly resistant organic fractions of the peat or that the standard combination of time, temperature and amount of nitric acid is inadequate to completely digest the high amount of organic matter of the peat layer. If nitric acid digestion of organic matter is incomplete, the amount of recovered carbon may depend on the initial amount of digestible material and represents a methodological shortcoming. A taphonomic explanation of the concurrent maxima of NARC and organic carbon could be differential sedimentation favouring charcoal deposition in wetlands compared to terrestrial deposition environments. Only if these possibilities are excluded can the charcoal proxy be interpreted in terms of palaeofire frequency. Still, the high 'charcoal' occurrence during peat development is more likely to reflect local swamp fires instead of a regional palaeofire signal. Given these uncertainties, the origin of the nitric-acid-resistant carbon in the Lomwe swamp core can not be determined satisfactory.

A similar conclusion can be drawn from NARC quantification of the Lomwe 10 soil profile (cf. Appendix Fig. D.3). Again, elevated NARC values coincide with high organic carbon values in the buried topsoil. The slope deposits themselves show a constant background 'charcoal' content. These observations suggest in the first place accumulation of residual charcoal – or recalcitrant organic matter - on the former ground surface but do not elucidate the fire history.

These preliminary analyses caution against the interpretation of the NARC content in terms of a charcoal proxy for past fire frequency as the ability of the method to discern charcoal and recalcitrant organic matter is questioned. Extension of the trial run to further soil profiles was not justified and interpretation of NARC as a palaeofire proxy was abandoned.

In East Africa several charcoal records are based on the nitric-acid-digestion method of Winkler (FINCH et al. 2009; MUMBI 2009; FINCH & MARCHANT 2010; RUCINA et al. 2010). Similar to the present study, the nitric-acid-resistant carbon content is often closely linked to changes in sediment stratigraphy (HOWELL 2009; RUCINA et al. 2009; FINCH & MARCHANT in prep.). In several cases however the NARC increase could be confirmed independently by microscopic charcoal count (MARCHANT 1997; RUCINA et al. 2009). The present study cautions against the interpretation of NARC as a direct charcoal proxy, as a methodological bias must be considered when NARC correlates with total organic matter. Instead of using chemical methods, measuring carbon along a continuum depending on strength and type of the oxidant, other characteristics of charcoal such as colour (charcoal count, reflection analysis) or chemical signature (biomarker analysis) are recommended which might give an independent and more reliable picture of charcoal occurrence.

8.9 **Chronology of the Lomwe swamp core**

8.9.1 Exotic taxa as stratigraphic markers

Stratigraphic markers enable the indirect dating of a sequence by being unambiguously related to a known event in time. A number of different stratigraphic markers have been used to support the dating of sedimentary sequences such as the occurrence of tephra (PYLE 1999), algal blooms (VERSCHUREN et al. 2000) or the first occurrence of non-native species (FINCH & MARCHANT 2010, in prep.). At Lomwe, pollen types of two introduced species – *Zea mays* and *Cupressus* – are potential stratigraphic markers dating, respectively, the arrival of the new world crop maize and later the impact of colonial afforestation measures.

8.9.1.1 Maize

The earliest occurrence of *Zea mays* pollen (86cm depth) coincides with the establishment of the recent wetland and predates by about 12cm the occurrence of the exotic tree genera *Cupressus* at 74cm, *Eucalyptus* at 46cm, and finally *Pinus* at 26cm depth.

The spread of maize through Africa has been subject to discussion as the fragmentary historical record only offers broad bracketing dates (GOODWIN 1953; JEFFREYS 1963; MIRACLE 1963, 1965; MCCANN 2001). Its initial introduction to West Africa by the Portuguese cannot be fixed to an exact date, but must have happened between 1502 and 1550. Since then, maize has been adopted widely by many local African populations as it offers higher yields and matures faster than native cereals such as sorghum and millet and allowed the expansion of the agricultural frontier into subhumid and humid forest environments, until then reserved for the banana (MCCANN 2001).

In East Africa, maize is thought to have arrived with Portuguese traders, who in the 16th century established trading posts along the Swahili coast. The earliest accounts are from Madagascar, where a priest was growing *milho zaburro* in 1561 and it is assumed to have arrived in Mozambique by 1570 (MIRACLE 1965). WHITE (1949) reports that maize was established on Pemba and Zanzibar in 1643, were it was grown to provide the Portuguese garrison at Mombasa with food. The spread of maize into the interior remains obscure, as written accounts only exist for the Swahili coast. Historical accounts start only in 1848, when the missionary Krapf (1858) reports maize as a major staple of the Wakamba in Kenya. In 1861, VON DER DECKEN (1869) reports maize from markets in Pare and MCCANN (2001) discusses maize as one of the staples of the mid-nineteenth century Swahili caravan trade. The earliest palaeoecological records place maize at Lake Naivasha around AD 1690 (LAMB et al. 2003) and at Kwasebuge swamp in the South Pare Mountains around AD 1700 (FINCH & MARCHANT in prep.) and suggest a rapid spread of the New World crop in the East African interior.

The direct stratigraphic proximity of *Zea mays* and *Cupressus* pollen suggests only a minor time lag between the introduction of maize and the first plantation of *Cupressus* and limits the use of maize pollen as a stratigraphic time marker indicating a post AD 1643 date. Maize cultivation in pre-colonial Pare as suggested by the Kwasebuge pollen record might have been relatively restricted and therefore it might not be recorded in the Lomwe swamp. Invisibility of maize pollen, despite the presence of the plant, is a common problem as *Zea mays* is known to be a poorly dispersed pollen type. Transport distances are particular short due to the large size (>80µm) and mass of the pollen grains. Effective pollen dispersal has been shown to be limited to about 60m, at which point the concentration of pollen grains has dropped to less than 1% (RAYNOR et al. 1972; BANNERT & STAMP 2007).

Considering the poor pollen dispersion, the historical fact of maize cultivation in the mid-19th century, and palaeoecological evidence from South Pare, early maize cultivation is likely to have taken place on a small scale in North Pare but probably was not as important as it became in later times. Therefore, it is proposed here that maize pollen remained undetected in the Lomwe pollen record until maize cultivation expanded rapidly during the 19th century.

8.9.1.2 Introduced tree species

Apart from food crops, there is no evidence that Portuguese traders introduced other exotic species to the East African shores. The first exotic trees in Tanzania are reported from the Bagamoyo Mission, founded in 1869 (SCHABEL 1990). In 1893, the German colonial government established an experimental station in Dar es Salaam and as early as 1895 when seeds were distributed to private planters and government stations for testing. A few years later in 1902 the Biological-Agricultural

Station at Amani in Wilhelmstal/Lushoto in the Usambara Mountains was established and large scale seed testing of indigenous and exotic trees commenced (SCHABEL 1990). Most important exotic tree species are *Cupressus*, *Eucalyptus*, *Grevillea*, and *Pinus*. In North Pare exotic tree species might have been introduced shortly after AD 1900, however only in the 1950s did tree planting became popular when schools and the Mass Literacy Scheme in 1952 were responsible for the planting of over half a million trees in North Pare (SHERIDAN 2001). As stratigraphic marker, *Cupressus* and *Eucalyptus* pollen point to sometime between AD 1900 and 1950.

8.9.1.3 Classification of *Cupressus/Juniperus* and *Eucalyptus/Syzygium* pollen

Straightforward interpretation of *Cupressus* and *Eucalyptus* pollen as stratigraphic markers is however problematic as both resemble similar native pollen types and therefore cannot be unambiguously assigned to a sole genus. However, close examination allows separation of exotic and native taxa based on circumstantial evidence.

The first morphotype is of the Myrtaceae family and classified as either *Syzygium* or *Eucalyptus*. *Syzygium* is an indigenous tree genus, which occurs frequently at riverine locations, at lake and swamp margins, as well as within upper and dry montane forests (LOVETT et al. 2006b). Introduced *Eucalyptus* is of high economic importance and ubiquitous in North Pare where it is planted in extended plantations as well as scattered throughout farmed and forested areas. The most recent swamp deposits are expected to reflect the widespread distribution and the dominance of this exotic timber genus. The pollen morphotypes of *Syzygium* and *Eucalyptus* are very similar and distinction between them is not always possible (Marchant, Muiruri & Rucina 2010, pers. comm.). In the pollen record of Lomwe Swamp, *Eucalyptus/Syzygium* pollen occurs in high numbers in the upper 50cm and in a single spike at 315cm depth. The high occurrence of this pollen type in the upper part of the swamp deposit is confidently interpreted as *Eucalyptus* as minor contribution from native *Syzygium* can be discounted.

The second morphotype is of the Cupressaceae family suggesting either *Juniperus* or *Cupressus*. *Juniperus*, a widespread dry montane forest genus occurring between 1500 – 2200m a.s.l. (HAMILTON 1981; LOVETT 1993b), has a high economic value and is a preferred timber for building and construction. *Cupressus* is not native to East Africa and was introduced during early colonial times. Nowadays *Cupressus* is widespread throughout Pare, but unlikely *Eucalyptus, Cupressus* occurs as single trees or as a boundary marker and not in plantations. Pollen types of *Juniperus* and *Cupressus* are similar and differentiating them is difficult. Its pollen type occurs in high numbers in the upper 80cm as well as in three samples from the lower part of the profile (285, 315, 330cm). Today, *Juniperus* is absent from the agricultural mid-altitudes of Pare, which backs the interpretation of the large quantity of this pollen type in the uppermost metre as exotic *Cupressus*.

Single spikes of *Eucalyptus/Syzygium* and *Cupressus/Juniperus* pollen in the lower part of the profile cannot be related to introduced species due to a deposition age >1000 BP. Their occurrence in depths where exotic genera cannot be expected has to be interpreted as native *Syzygium* and *Juniperus*.

8.9.2 Radiocarbon date reversals and allochthonous material influx

Early wetland establishment and its subsequent burial at Lomwe are dated independently at two sites: the swamp core and at the peat profile. At both sites, radiocarbon dates relating to the burial of the peat layer and the hillwash deposit indicate date reversals (cf. Fig. 32 & Fig. 52). Early wetland formation started roughly around AD 600, whereas radiocarbon dates for the onset of accelerated hillwash deposition and peat burial are reversed and range between AD 200 and AD 1200. Due to contamination of bulk samples by old reworked carbon, only a maximum age of ~AD 1200 can be given for the burial of the peat. The following paragraphs discuss the causes and consequences of reversed dates and the reliability of the time interval given above for peat accumulation.

Dating of mixed materials is probably the main reason for the inconsistent chronology. With the exception of a recovered wood fragment (Lomwe, 335cm) and charcoal fragments (peat profile 167cm), radiocarbon dating had to rely on the total organic carbon fraction. A more reliable approach entailing dating of macrofossils (stalks and leaves) failed as the separation of charcoal and plant material was not successful. Bulk organic material comprises the entirety of organic matter fractions and includes carbon from a variety of sources most importantly plant material, soil organic matter, and charcoal, which might be locally derived or redeposited and reworked, and thus of mixed ages.

Two ways of contamination have to be considered. Contamination by young organic carbon resulting in age underestimation, and the incorporation of old carbon diluting the ^{14}C content and resulting in age overestimation (MATTHEWS 1985; OLSSON 1991; HIGHAM 2002). Sources of young carbon are incorporation of roots and contamination during pre-treatment and handling. Bioturbation may result in either age over- or underestimation. Incorporation of old reworked organic matter or charcoal is generally related to taphonomic processes such as the admixture of allochthonous material or artefacts and leads to age overestimation. Additionally, radiocarbon age of the recalcitrant humus fractions, stabilised within soil aggregates and clay-humus complexes, generally describes the mean residence time of organic carbon in the soil and thus result in a considerable age overestimation (MATTHEWS 1985). Charcoal on the other hand is strongly resistant to decay and accurately dates carbon fixation. Due to its low density, charcoal particles are more susceptible to erosion than soil organic matter and when exposed might be mobilised during normal rainfall events. The influx of old, decay resistant charcoal produced during past fires on the slopes may play an important role for the overestimation of the burial age.

For the start of peat accumulation, age underestimation due to post-depositional processes such as bioturbation, incorporation of roots, and contamination by modern carbon are thought to be minimal. The clear layering and the well-preserved organic remains of the peat deposit exclude strong bioturbation. Intact and recent roots were removed during pre-treatment. Contribution from decomposed roots is likely to be minimal due to the high water table and the absence of recent roots. Contamination by modern carbon during sampling and pre-treatment is negligible as great care was taken during the sampling process. Two radiocarbon dates from the swamp core (1489±30 ^{14}C BP, wood fragment) and the peat profile (1336±30 ^{14}C BP, total organics) are derived from two different materials and suggest a narrow time interval for the establishment of the former wetland. The inbuilt age of the small wood sample is estimated to be less than 20 years (about 2 cm thick fragments), whereas the sample from the peat profile (268cm) postdates the onset of changing hydrological conditions and peat growth by about 5cm. The onset of wetland conditions at Lomwe is estimated to fall between 1450 and 1350 BP, i.e. around AD 600 or the turn of the 7th century (Fig. 52).

The cessation of peat accumulation is dated by two samples from the peat profile showing reversed (162cm, 1704±30 ^{14}C BP, bulk) and inverted (167cm, 1243±50 ^{14}C BP, charcoal) dates compared to the agreed date for wetland establishment (Fig. 52). A more reasonable age for the burial by hillwash deposits is obtained from the swamp core (228cm, 923±30 ^{14}C BP, bulk), although at 117cm depth a reversed age for the recent establishment of the present wetland (1127±30 ^{14}C BP, bulk) was obtained.

The reversed radiocarbon ages from bulk and charcoal samples occur at the transition to the hillwash deposit and suggest basin wide influx of old carbon rather than local disturbance events or

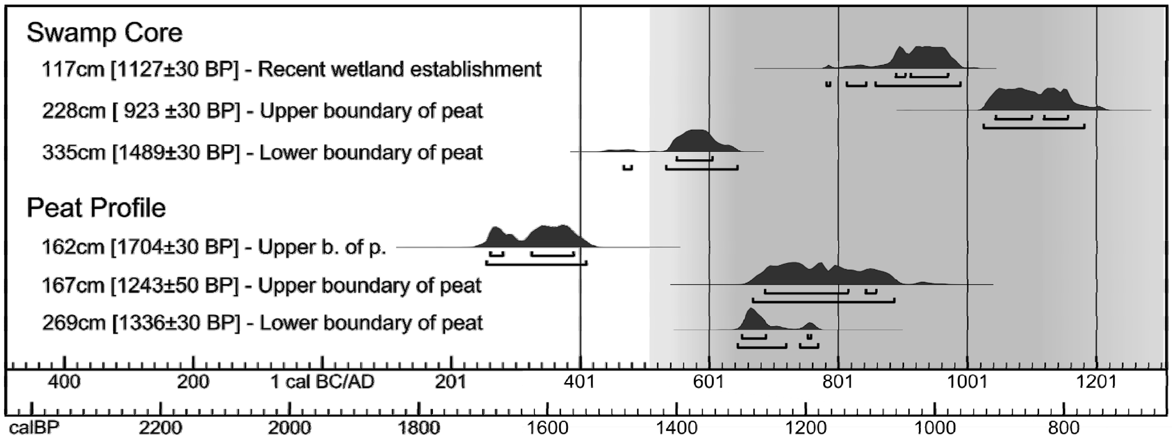


Fig. 52: Calibrated radiocarbon dates of the Lomwe swamp core and the peat profile. Age probability distributions and 68.2% and 95.2% confidence intervals are shown for each radiocarbon date (cf. Tab. 6). Note reversed dates for the upper boundary of the peat deposit and the onset of the recent wetland. Shaded area indicates the interval of peat growth from about AD 600 to after AD 1200.

sample contamination. The reversed radiocarbon ages of bulk organic carbon and charcoal establish a direct link between the extent of accelerated soil erosion in the Mashewa catchment and the burial of the Lomwe wetland by hillwash deposition.

Influx of allochthonous, old organic matter probably started early during peat development when flooding events deposited lenses of fine material throughout the basin. With the deposition of reworked, eroded soil, the contribution of old carbon is likely to have increased. The radiocarbon dates obtained for the cessation of peat accumulation are therefore interpreted as maximum ages and onset of hillwash deposition must have occurred after about AD 1200 (Fig. 52).

Despite repeated ^{14}C-dating of stratigraphic breaks from different sections, the influence of old carbon prevented the establishment of a reliable chronology for the Lomwe basin. The occurrence of *Cupressus* pollen as a stratigraphic marker of the 20th century at 74cm depth indicates that even without the bias from old carbon the establishment of an independent radiocarbon chronology of the recent wetland would have been difficult. Calibration of ^{14}C-dates of the last three centuries is hampered by variations in the atmospheric ^{14}C concentration and a ^{14}C plateau in the 19th century (CHARMAN & GARNETT 2004). Without external constraints, calibrated ages are ambiguous and might span up to 300 years. ^{210}Pb and ^{137}Cs activity profiles have been widely used to date recent lake and, with some caveats, swamp sediments (APPLEBY & OLDFIELDZ 1983; ERIKSSON & CHRISTIANSSON 1997; VERSCHUREN 1999, 2001; BESSEMS et al. 2008). However, the maximum age of ^{210}Pb and ^{137}Cs radionuclide dating is about 150 years and while its application could have independently confirmed the late 19th- early 20th-century age of recent wetland establishment, no additional information on the sedimentary history or for the introduction of maize would have been obtained. Given the discussed shortcomings due to the influx of old carbon and the limitations of alternative dating methods, the obtained chronology is the best approximation for the reconstruction of the environmental history of Lomwe. Peat development took place between the 6th and at least the 12th century probably the 15th century, when colluvial and alluvial deposition of hillwash sediments started. Recent wetland formation probably began in the late 19th or even the early 20th century.

9 LANDSCAPE DEVELOPMENT IN NORTH PARE

9.1 Forest soils

Soil profiles established in the Kwa Chegho and Kwa Kirumbi forests have shown that disturbance has been an essential part of the forest history. Although no direct evidence for the causes and processes of disturbance can be presented yet, several lines of evidence warrant further discussion.

9.1.1 Kwa Chegho

Tentatively classified as Folic Umbrisols, the **Kwa Chegho forest** soils represent soil development under high-altitude montane forests at Kwa Chegho, Kwamwalla, Kindoroko and Ngofe. Despite an intact topsoil and a thick organic layer, subsoil disturbances are recorded by frequent occurrence of charcoal and past soil movement. The disturbance is linked to widespread deforestation during the first part of the 20th century as shown by a strongly fragmented forest cover on aerial photographs from 1953. Since then, indigenous forest has recovered, supported by widespread planting of exotic trees, and a closed canopy forest reestablished. Today, only patches of fully-grown *Eucalyptus* are evidence of former widespread encroachment. On the other hand, selective logging, widespread charcoal production, firewood collection, and grazing are contemporaneous disturbance factors. Early 20th century deforestation observed at Kwa Chegho weakens the representative character of the investigated soils but at the same time emphasises the ubiquitous nature of disturbance within North Pare's high-altitude forests.

9.1.2 Kwa Kirumbi

The **Kwa Kirumbi** forest profiles show soil disturbances even within the protected area of a former sacred grove. The occurrence of abundant potsherds accompanied by charcoal and even soil movement corroborates repeated human activity and probably a long history as places of ritual activities as suggested by SHERIDAN (2001) and KIMAMBO (1969). However, the frequent occurrence of potsherds has to be put into perspective. Considering the small area of the forest fragments and the limited area suitable for ceremonial activities such as gentle slopes and flat ridges, the recovery of sacrificial remains might not be representative for the entire forest fragment. Deep slope deposits in the small valley head depression (Kwa Kirumbi 3 & 4) on the other hand warrant further research into the forest history.

9.1.3 Complex history of forest soils

The investigated profiles show that forest soils in the Pare Mountains have a complex history. They are often polygenetic and are likely to have experienced aggradation as well as erosion phases. Mass movements and fires are widespread within the forested environments (see YLHÄISI 2004 for recent forest fires). The presence of colluvial deposits and the widespread recovery of significant amounts of charcoal were unexpected and warrant further investigation.

Whether of natural or anthropogenic origin, fires have been part of this forest ecosystem for a considerable span of time and the widespread occurrence of charcoal at both forest sites raises questions about the long-term history of disturbance in mountain forests, forest fragments and protected sacred groves. Disturbance events like fire, mass movements, and anthropogenic impacts on varying scales have shaped the ecology of the small Kwa Kirumbi forest fragments as well as the Kwa Chegho forest. The impact on its forest ecology is not readily discernable from an initial glimpse, and changes in species composition await further research. However, the forest relicts preserved as sacred groves are the only means of obtaining a broad picture of the potential natural vegetation cover of the otherwise deforested agricultural upland zone.

The soils found within these forest patches are representative examples of present forest soils in an elevation zone, now more widely shaped by settlement and agriculture. Although they narrate a history of disturbance and human activities and show evidence of colluvial mass movement, the soils under protective forest cover have not been affected by intensive human land use within living memory. True, these soils are disturbed and may not be exactly representative of undisturbed forest soils (assuming these still exist anywhere) but they are substantially deeper and more humic than agricultural soils on similar slopes. Despite the discussed shortcomings, the Kwa Kirumbi and Kwa Chegho forest soils can be taken as representative baseline soils to which soils under recent and past agriculture can be compared, thus allowing the qualitative assessment of soil degradation due to forest clearance and agriculture. In consequence, the differences between forest and agricultural soils have to be thought of as a minimum level of change.

9.2 Qualitative assessment of soil erosion

The degree of soil erosion was qualitatively assessed by comparison of soil development depth between forest and agricultural soils. Depth of soil development was calculated as depth of the B/C-transition. In cases of colluvial overburden, the deposit was subtracted to obtain soil depth after erosion (instances of colluvial overburden are shown *above* the zero line in Fig. 53). The depth of the B/C-transition is given by either the alignment of rocks reflecting former rock structure or by the recovery of abundant saprolitic material in soil auger samples, both accompanied by a prominent brightening of soil colour (value >4/6 and chroma >6/7, moist/dry). Although the presence of weathered rocks and structural alignment of saprolitic rocks may vary depending on the bedrock chemistry, depth of weathering is a readily available criterion to evaluate the depth of soil development and to qualitatively assess soil loss by comparing soil depths of forested and eroded environments. Distinction between subsoil, B/C-transition and the original saprolite (C-horizon) is particularly difficult where horizon boundaries are inferred from auger samples.

In general, agricultural soils are severely eroded and have lost their original topsoil and most of their subsoil. Often, incipient topsoils have developed within a mixture of *in situ* and transported colluvial material. The majority of agricultural fields are characterised by bright surface soil colours indicating a lack of soil development and rubification, as well as by the presence of unweathered rock fragments. Often saprolite is exposed at the surface. Although exact delimitation of soil depth is difficult as the B/C-transition horizon is characterised by gradual transitions from the B-horizon to the saprolite, soil development in most agricultural soils does not exceed 30cm. An exception is Ngalanga 1 in direct vicinity to the Ngalanga forest, which only recently has experienced erosion and still maintains a comparably deep subsoil. Within the upper 30cm of the profile, all studied agricultural profiles preserve weathered saprolitic rocks aligned along the original rock structure. These rocks are generally strongly weathered, disintegrate under moderate pressure and grade with depth into continuous saprolite. Aggregate formation and rubification indicated by red (2.5YR – 5YR) material shows soil development between *in situ* rocks and within cracks of the decomposing saprolite.

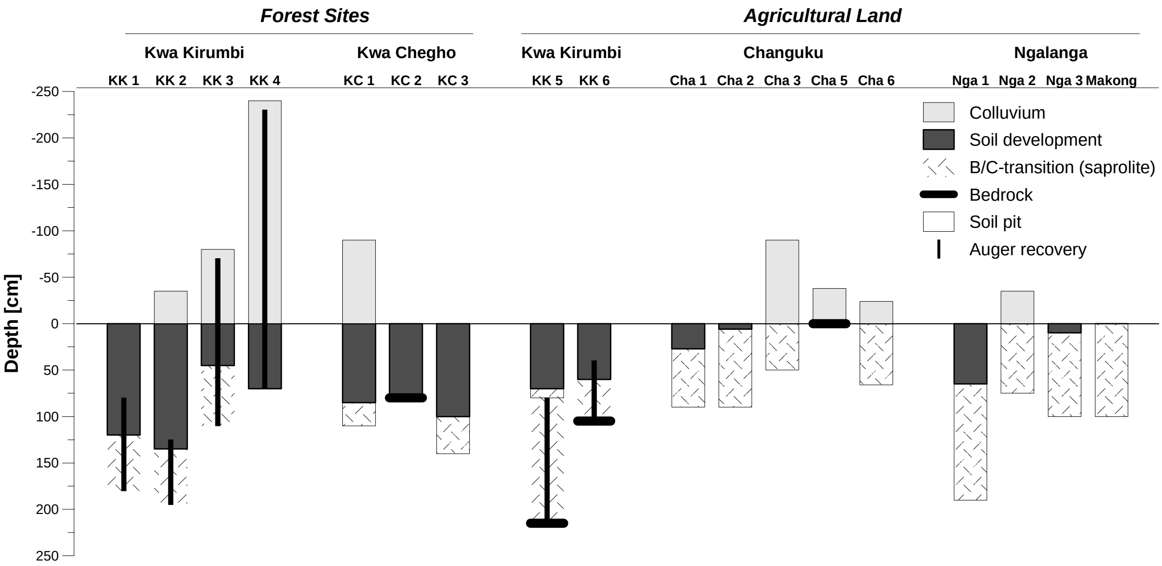


Fig. 53: Comparison of soil development depth under forest and agricultural land. Addition of material, e.g. colluvial deposits are plotted above the imaginary former groundsurface (baseline). Forest soils show soil development in depths between 80 and 140cm, whereas soils under agricultural land use are strongly eroded and depths of soil development are less than 30cm (with exception of the Kwa Kirumbi profiles and Ngalanga 1). The depth of soil development is inferred from the B/C-transition horizon indicated by a) the preservation of former rock structure within the weathered saprolite, b) the recovery of abundant saprolitic material in soil auger samples, and c) distinct brightness of soil colour (value >4/6 and chroma >6/7, moist/dry). Colluvial deposits are inferred from prominent truncation boundaries and colluvial benchmark criteria.

Soil profiles of all forest soils were evaluated with the exception of slope deposits Kwa Kirumbi 3 & 4, where neither the surface of the *in situ* soil nor subsoil horizons could be accurately distinguished. Reliable depth is obtained from Kwa Kirumbi 2, where B/C-material was recovered from a depth of about 170cm. Excluding 35cm of colluvial overburden, the soil depth is estimated to be about ~135cm. Soil depth is probably underestimated on ridge locations such as Kwa Kirumbi 1. Here, auger samples indicate saprolite at 160cm depth, whereas aligned rocks and high gravel content in the lower part of the soil pit suggest a depth of 55cm. Between 100 and 160cm only a limited amount of saprolitic gravel is recovered and the presence of clay coatings indicates soil formation at the bottom of the pit at 100cm. An arbitrary depth of 120cm is therefore assumed to represent the average depth of soil development. At Kwa Chegho 1, many pieces of weathered gravel were recovered from about 175cm depth, however no *in situ* rock structure was observed. Taking into account 90cm of probably colluvial material, a soil depth of about 85cm soil is calculated. A similar soil depth of 80cm is obtained from Kwa Kirumbi 2 resting over hard, continuous bedrock. The last profile considered shows a soil depth of 100cm under secondary forest at Kwa Chegho. In summary, profiles suggest an average soil depth of forest soils in North Pare to range between 80 and 140cm.

Compared to agricultural profiles with a soil depth of about 30cm, we can conclude, that about 100cm of soil has been eroded from most agricultural soils in North Pare. This does not take into account subsequent deposition of relocated material on the same slope section, as observed at Changuku 3 or Ngalanga 2, and even more significantly within the colluvial deposits accumulated in slope depressions.

9.3 Ugweno: A history of anthropogenic soil erosion

The slope deposits investigated at Mrongo and Usumbwe in the Ugweno district can be divided into four depositional units corresponding to distinct periods of landscape change (cf. Fig. 27 & Fig. 28). Stratigraphic descriptions, laboratory analysis and benchmark features like sand lenses and reworked soil aggregates make it possible to differentiate distinct erosion and deposition processes and infer an environmental history of Pare.

9.3.1 Unit I: Mid-Holocene stable land surface and forest environment

The lowermost stratigraphic unit comprises *in situ* soils, now buried below several metres of colluvial slope deposits. The original soils developed over saprolite and are characterised by a high content of rock fragments and bright yellowish and reddish colours indicating only incipient rubification as expected in swale positions. The *in situ* soil have intermediate to high pH values interpreted as secondary accumulation of base cations by vertical and lateral soil water advection. Low magnetic susceptibility indicates a low amount of ferrimagnetic minerals and predominantly secondary pedogenetic minerals according to a high but variable frequency dependency.

A former land surface is reconstructed based on several buried topsoils. The dark coloured horizons show a slightly elevated organic carbon content and enhanced magnetic susceptibility. The absence of distinct, buried topsoils at upper footslope positions (Mrongo 2, Usumbwe 1) and the lack of a distinct boundary between *in situ* and colluvial material at Usumbwe 2 suggests partial truncation of the former land surface at lower slope positions probably during the initial phase of erosion. Stable carbon isotope ratios of buried topsoils and particularly subsoils indicate the predominance of C_3-vegetation. Taking into account the effects of isotopic fractionation during microbial soil organic matter decomposition (chapter 8.5) closed canopy montane forest vegetation is assumed.

9.3.2 Unit II: Initial, anthropogenic soil erosion (since ~200 BC)

Concurrent accumulation of homogeneous slope deposits at Mrongo and Usumbwe marks the onset of regional land clearance and soil erosion. Burial of the mid-Holocene surface started at mid-footslope positions, around 400 – 110 BC (2340 - 2060 BP) at Mrongo 10 and 70 - 230 AD (1880 – 1720 BP) at Usumbwe 2. In the course of the following centuries deposit accumulation extended into the valley bottoms and between 410 and 610 AD (1340 -1540 BP) the lower footslopes at Mrongo 4 and Usumbwe 3 were buried. Despite the spatial and temporal trend on the footslope, land clearance extended rapidly into higher altitudes and accumulation of sediments in head slope depressions at Mrongo 11 and Changuku 4 was in progress during the mid-first millennium AD (deposits older than AD 680 – 970 and AD 260 – 570, respectively).

Gravel of distinct rock types, reworked soil aggregates and the presence of charcoal and potsherds characterises the lower slope deposit. Occurrence of potsherds and abundant charcoal point to land clearance by sedentary agriculturalists as the cause of soil erosion. Initial forest clearing probably was fragmentary and took place over centuries. Glades, agricultural fields, and secondary vegetation created a mosaic of different vegetation and land use types. Soil erosion was retarded within this patchwork of forests, secondary vegetation and agricultural fields, and initially only surface material was mobilised. Topsoils on steep slopes are readily displaced during forest clearance and disturbance by tillage, whereas erosion by running water was still reduced due to a good infiltration capacity and small fields.

Magnetic susceptibility remains high throughout unit II indicating the deposition of magnetically enhanced topsoil material, which remained long enough within the biologically active zone to become magnetically enhanced. pH of the lower deposit is high, probably due to the deposition of base rich topsoil material and lateral advection of bases.

The vegetation composition begins to change. Contribution of C_4-vegetation increases slowly but steadily and is attributed to the spread of C_4-grasses and weeds in agricultural fields and clearings. More importantly, the slight shift might reflect the cultivation of indigenous African cereals like sorghum and millet, typically following C_4-photosynthetic pathways. As the $\delta^{13}C$ shift is slow and gradual, regrowth of secondary forest on cleared land such as under a regime of swidden agriculture is proposed. Alternatively, mixed cultivation involving banana might have been practiced.

9.3.3 Unit III: Accelerated runoff-based soil erosion & sand lens formation (14th/15th to 19th century)

Soil erosion accelerated concurrently with the occurrence of sand lenses and layers. Three charcoal fragments (Mrongo 4 & 10, Usumbwe 3) date the onset of sand lens formation between AD 1340 and AD 1470. Average deposition rates double from ~0.3cm/a in the early phase of soil erosion (unit II) to 0.6cm/a since the 14th/15th century (unit III and IV, cf. Tab. 12). The widespread occurrence of both sand lenses and sand layers since the 14th/15th century indicates a drastic change of the erosion and deposition processes. Formerly, soil erosion had been dominated by slow mass movement, soil creep, and particularly tillage erosion characterised by the displacement of entire aggregates. Now, runoff-based transport such as sheet wash and localised rill erosion has become an important part of soil movement. Sand lenses formed only in the restricted range of middle and lower footslope positions. Due to comparable steep (~10°) slopes, sand lenses are absent at the upper footslope profiles (Mrongo 2, Usumbwe 1). At valley bottom locations, the dispersed sand lenses of middle footslope positions merge into distinct sand layers (<3°, Mrongo 4 & 5, Usumbwe 3). Here, concentrated runoff is no longer confined to rills and spreads out depositing small sand fans at the end of ephemeral or seasonal rills.

Evidence of concentrated runoff is observed at the mid-slope of the Ngalanga hill (Ngalanga 4 & 5, Fig. 54, Appendix, B.4). Buried under slope deposits, a former stream channel is exposed on a road cut and suggests an early phase of severe land degradation dominated by linear runoff erosion and channel formation. Although undated, the incision of the seasonal channel into deposits on the mid-slope of Ngalanga hill is likely to be linked to the onset of sand layer deposition in the valley bottom at Usumbwe 3.

Similarly, an infilled and buried channel at the valley bottom at Mrongo 5 (Fig. 27 & Fig. 54, Appendix B.3) provides evidence for increased runoff and landscape instability. Although undated, the stratigraphic position of the buried channel (1.4m depth) correlates with the 14th/15th century occurrence of sand lenses at other Mrongo profiles. The channel has been filled by medium to coarse gravel, stones and boulders, which excludes human water management likely to have resulted in slippage of soil material from the channel walls. Single, strong rainfall events, able to rapidly mobilise gravel and stones, must have been responsible for the exceptional stream load. Channel abandonment might have been the consequence of channel avulsion, but overlying sand layers, also observed at Mrongo 4 and Usumbwe 3, indicate subsequent deposition in a fan-like environment and rather suggest the temporary absence of a permanent channel until incision and establishment of the present day channel.

The earliest occurrence of sandy material at Mrongo 5, about 2m below the buried channel, was dated by OSL to AD 649±80 (1360±80 a). This early sand wash deposit might relate to a short-lived early phase of runoff-based erosion. Apparent overestimation of deposition ages due to insufficient bleached sand grains as shown for Usumbwe 3 put this early wash event into context and the reported deposition age has to be interpreted as a maximum age.

The residual sand lenses are rich in primary magnetite, and stand out by their extremely high magnetic susceptibility values. At the same time as the variability of magnetic susceptibility increases and sand lenses provoke peak χ_{lf}, overall bulk susceptibility starts to decrease. The reduced magnetic enhancement is interpreted as an increased contribution of weakly magnetic, eroded subsoil material replacing enhanced topsoil material. Besides progressive forest clearance, the widespread exposure of truncated subsoils on the slopes might have been the critical trigger for the onset of runoff-based erosion. Potentially important is the reduced infiltration capacity of the exposed subsoils, which have a generally lower pore volume, a higher bulk density, and a higher tendency to surface sealing compared to biologically active topsoils with a well-developed soil structure. Consequently, runoff increases and concentrated overland flow triggers sheet wash and rill erosion. At the same time as subsoil erosion becomes evident, erosion accelerates, slope wash is noticed, and vegetation cover becomes dominated by C_4-vegetation suggesting recurrent cultivation, possibly of C_4-cereals like sorghum and millet. While accelerated erosion points to increased land use intensity and advanced land clearance on the slopes, the preservation of sand lenses requires long periods of fallow and undisturbed sediment deposition on the footslopes (cf. chapter 8.6). Compared to the previous centuries of swidden agriculture, land use may well have intensified. An extensive shifting cultivation regime with decade long fallows would allow the regrowth of open, secondary vegetation with a high contribution of C_4 grasses and weeds while at the same time facilitating preservation of deposition features.

9.3.4 Unit IV: Land use intensification and prolonged soil degradation (since 19th century)

The uppermost deposit is characterised by bright (yellowish) red colours and a generally high bulk density. Measurement of magnetic susceptibility shows intermediate magnetic enhancement corresponding to the eroded, weakly enhanced subsoil material. Following the slow relocation of topsoil material during the early phases (unit II), subsoil material and probably even saprolite is eroded in the later erosion stages (unit III, IV) representing advanced stages of land degradation.

With the exception of the sand layers and local sand fans described at the valley bottom profiles Mrongo 5 and Usumbwe 3, no sand lenses are recorded in the uppermost metre. On the other hand, field observations at Mrongo have shown that sand lens formation currently takes place during strong rainfall events. Sheet wash and rill erosion is still an important factor of present day soil erosion but the corresponding sand lenses are not preserved. Cultivation of annual crops like maize and beans within the banana grove are part of the present agroforestry system at Mrongo and tillage (hoeing) seems to effectively erase recently formed sand lenses from the upper centimetres. Increased tillage frequency since the 19th century might be a consequence of more intensive agricultural land use such as intensive forms of cultivation with permanent plots or short fallow periods of only one to two years, as was common practice in late 19th century Pare (KOTZ 1922).

In this context, colluviation on formerly eroded slopes and the burial of truncated subsoil such as on the Ngalanga mid-slope (Ngalanga 4 & 5), at Ngalanga 2, or at Changuku 3 offer useful insights into temporal slope dynamics. Following a phase of runoff erosion and channel formation, local

Fig. 54: Buried and infilled stream channels at Mrongo and Ngalanga/Usumbwe. a) Buried channel incised in truncated subsoil on the mid-slope of the Ngalanga hill. b) & c) Buried channel in valley bottom deposits at Mrongo 5, overlain by decimetre thick sand layers after channel avulsion or abandonment. d) Present, intermittent Mrongo stream

stabilization of the slope took place. Colluvial deposits, found today on previously eroded slopes, record a subsequent shift from erosion to a deposition environment. Soil erosion, however, continued on a large-scale further upslope and on the ridges, providing the material now stored on mid-slope depressions. The spatial mosaic of erosion and localised deposition observed today on the slopes is dynamic in time and space and is controlled by past trajectories of land use including agricultural intensification and soil conservation measures.

Overall, deposition rates and hence erosion on the slopes increased since the widespread removal of topsoils in the 15th century, and recent observations of sheet wash and rill erosion confirm the ongoing importance of runoff-based erosion despite local implementation of soil conservation measures. Exposure of truncated and infertile subsoils on the slopes is the legacy of two millennia of soil erosion resulting from unsustainable land use practices.

9.4 Lomwe: Holocene landscape development

Slope deposits at Lomwe revealed a buried late Pleistocene land surface but two distinct deposition phases. Late Holocene sediments overlying the late Pleistocene topsoil suggest a prolonged hiatus, probably an undetected erosion event prior to anthropogenic colluviation.

9.4.1 Unit IP: Late Glacial land surface and forest environment

Buried organic matter rich horizons at Lomwe are evidence for a stable land surface during the Last Glacial Maximum. Radiocarbon dates of charcoal and soil organic matter span a period of about 6000 years suggesting a prolonged phase of morphological stability during the later part of the glacial dry period. Charcoal fragments dated to 18.5 - 17.7 ka BP at Lomwe 3 and 19.5 - 18.0 ka BP at Lomwe 10 show that fire events occurred during the LGM. On the other hand, the humin fraction of soil organic matter at Lomwe 3 suggest soil burial several thousand years later (14.9 - 13.9 ka BP).

Generally, radiocarbon dates of soil organic matter are younger than the age of initial soil development but older than the burial event (MATTHEWS 1985; CATT 1986; WANG et al. 1996). During soil development, mixing and incorporation of fresh organic matter rejuvenates the apparent soil age and thus it is only possible to obtain a minimum age for the beginning of soil formation

(SCHARPENSEEL & SCHIFFMANN 1977; WANG et al. 1996). Whereas the most labile organic matter fractions are readily decomposed, stable organic carbon compounds accumulate and their proportion increases with time. Burial of a soil ideally cuts off the incorporation of further organic material; however the age of burial might be overestimated by as much as the apparent mean residence time of soil organic matter (WANG et al. 1996). Decomposition after burial as well as admixture of young carbon derived from roots or percolating organic acids might further influence the ^{14}C content of the soil carbon (MATTHEWS 1985; CATT 1986). Despite the discussed caveats, buried topsoil horizons with high organic carbon content are assumed to be far from a steady state and are generally understood to allow reliable dating of the burial age (GEYH 2005). At Lomwe 3, the possibility and the magnitude of an inherited apparent steady stage age of recalcitrant organic matter cannot be assessed with any certainty but is likely to exceed contamination by young carbon as the buried horizon shows clear-cut boundaries, and the contribution from roots and percolation of humic acids is reduced by pre-treatment – thus a maximum age of soil burial is assumed.

Charcoal fragments, in the first instance at least, date fire events during the LGM when temperature depression and aridity were at their maximum in East Africa (GASSE et al. 2008). Whereas inbuilt ages of the burned wood are negligible when compared to the time span concerned, reworking and temporal storage of charcoal fragments before burial is a serious source of overestimation of the real burial age. Considering that radiocarbon dates differ by material and hence event dated (fire vs. incorporation of soil organic matter), soil burial around 14 ka BP is assumed.

High organic carbon contents between 1.9% and 2.4% C_{org} indicate strong accumulation of organic matter typical for a cool and moist montane forest environment and retarded decomposition. The comparatively low stable carbon isotope ratios of the organic matter ($\delta^{13}C$: -22.5‰ to -24.8‰) are similar to $\delta^{13}C$ values observed for subsoils of present forest soils. Taking into account isotope fractionation during decomposition (cf. chapter 8.5) topsoil $\delta^{13}C$ at the time of burial is likely to have reflected a closed canopy C_3 montane forest environment, similar to the Kwa Chegho forest. The stable morphological conditions under closed forest however, did not exclude occasional forest fires. Probably around 14 ka BP, this former surface soil was sealed by a rapid natural erosion event, possibly triggered by rapid climatic change at the end of the LGM.

9.4.2 Unit II: Early and late Holocene landscape instability –

The LGM soil is overlain by a distinctly dark (reddish) brown lower slope deposit with a low bulk density interpreted to represent an early phase of slow topsoil erosion in a sheltered environment, probably during early land clearance phases.

Radiocarbon dates obtained from Lomwe 5 at 475cm (2,870 – 2,500 BC), 289cm (AD 1010 – 1160) and 198cm (AD 1260 - 1390) suggest that most of the lower slope deposit has accumulated during the last two millennia. The slope deposit at Lomwe 10 dates almost entirely to the last two millennia as inferred from a potsherd (age <2000 BP) in 210cm depth - about 40cm above the buried soil - and a radiocarbon date of 880 – 1120 AD at 115cm depth. A first millennium AD date for the onset of anthropogenic soil erosion at Lomwe is also supported by the recovery of potsherds in deposits dating to 260 – 570 AD (285cm) at the small head slope depression Changuku 4 (cf. Appendix B.2).

As most of the deposit has accumulated during the last two millennia, the initial deposit burying the late Pleistocene soil turns out to be very shallow comprising less than half a metre at both Lomwe 5 and Lomwe 10. Rapid and deep burial was necessary to preserve the 15cm thick organic matter rich

LGM topsoil, prevented its mineralization, and conserved the distinct horizon boundaries. Material of unknown but sufficient depth to cut off disturbance of the buried horizons was deposited and a new stable surface developed. The lack of this postulated late Pleistocene to early Holocene land surface is best explained by a hiatus. Subsequent erosion, most likely linked to the onset of anthropogenic land clearance, removed - at least partially - the blanketing cover, before accumulation of the present, potsherd bearing, anthropogenic colluvium began. The mid-Holocene charcoal from Lomwe 5 must then be interpreted as reworked during later erosion processes.

This scenario postulates the deposition of similar material during two temporally wide spaced and causally distinct erosion events: erosion triggered by climatic change at the end of the LGM and anthropogenically induced soil erosion of the past millennia. On the other hand, an erosional hiatus is supported by the upslope thinning of the buried topsoil at Lomwe 3, which together with similar evidence from Usumbwe 1 and Mrongo 2 suggests that the anthropogenic build-up of sediments was preceded by initial erosion on lower slope positions. Based on the available data, the exact circumstance of early slope deposit formation at Lomwe can not be deciphered yet.

The close occurrence of potsherds and mid-Holocene charcoal above a late Pleistocene surface suggest that an early overburden has been partly eroded during the initial phase of anthropogenic soil erosion. The major part of the present slope deposits built up during the last two millennia.

9.4.3 Unit III/IV: Accelerated soil erosion and land degradation

The uppermost deposits at Lomwe are characterised by bright (yellowish) red colours and a high bulk density. The pronounced colour and density changes allow clear distinction between the early phase of topsoil translocation (unit II) and this later phase of subsoil erosion. The presence of sand lenses recorded at Lomwe 10 and inferred from peak χ_{lf} at Lomwe 3 indicate that the change of source material was accompanied by a changing erosion pattern, although not as pronounced as at Mrongo and Usumbwe.

Contrary to the pronounced material changes, analytical results do not corroborate two distinct deposition units as observed at Mrongo and Usumbwe. Instead, continuously decreasing magnetic susceptibility parameters suggest a gradual transition from topsoil erosion in the lower deposit to subsoil erosion in the upper deposit, the latter showing similar magnetic susceptibility values as the eroded subsoils at Changuku. Likewise, stable carbon isotope composition gradual increases from the buried surface to the upper colluvium (Fig. 35) reflecting an increasing contribution of C_4-plants interpreted as an opening up of the former forest cover and the progressive spread of cultivation and fallow land.

The upper colluvial deposit is undated but, assuming constant deposition rates, charcoal samples from the upper part of the lower deposit (Lomwe 10, 115cm, AD 880 – 1120 & Lomwe 5, 198cm, AD 1260 – 1390) allow extrapolation of the start of the final phase of soil erosion at Lomwe into the late 16^{th} century. The establishment of *Eucalyptus* and the development of a dense ground cover since AD 1957 are reflected in an abrupt shift of topsoil $\delta^{13}C$. Topsoil development suggests that soil erosion might have diminished as the steep lower slope above the catena stabilised.

The reconstruction of the colluviation history at Lomwe is complicated by disturbance and possibly repeated truncation events. A postulated erosional hiatus prior to the deposition of anthropogenic colluvium is necessary to explain the observed chronology. Although analytical measurements do not pick up either the proposed hiatus or the distinct boundary between the two colluvial layers shown by material changes, the general trends of δ^{13}C and magnetic parameters are in accordance with the processes discussed in detail for Mrongo and Usumbwe. Initial erosion of topsoil material was replaced in the upper deposit by erosion of subsoil material estimated to have started in the 16th century – slightly but in accordance with the onset of runoff-based subsoil erosion and sand lens formation at Mrongo. Despite the Pleistocene age of the buried soil, the Lomwe deposits record anthropogenic erosion since the first centuries AD, and their stratigraphy reflects the trajectory of land degradation observed for soils on the Changuku ridge.

9.5 Lomwe Swamp: Vegetation and environmental history

The composition of the pollen diagram of the mid-altitude Lomwe Swamp resembles lowland pollen records such as Namelok in Amboseli (RUCINA et al. 2010), the Kanderi and Ziwani swamps in Tsavo (GILLSON 2004, 2006) and the Lake Challa record (RUCINA et al.) but differs markedly from montane forest environments of the Uluguru (FINCH et al. 2009), Udzungwa (MUMBI et al. 2008) and South Pare Mountains (FINCH & MARCHANT in prep.). Even swamp records from comparable altitudes in the Usambara Mountains (Derema, Mbomole and Madumu swamps, ~950m a.s.l., MUMBI 2009) show higher contribution of montane forest taxa than observed at Lomwe.

The pollen record of the Lomwe swamp is characterised by strong fluctuations and a general lack of taxa constancy (cf. Appendix C). Only four families (Asteraceae, Amaranthaceae/Chenopodiaceae, Poaceae, and Cyperaceae) - but no genus or specie - are present over the entire pollen record. The arboreal pollen record is especially fragmentary, and montane forest elements are infrequent and rare.

Non-arboreal pollen dominates the pollen record. In addition to Asteraceae and Amaranthaceae/Chenopodiaceae, shrubs like *Acalypha*, *Justicia,* and of the Malvaceae family as well as herbs like Lamiaceae and *Phyllanthus* occur. Following HAMILTON (1982), most of the taxa dominating the Lomwe pollen record are known to occur on disturbed land (*Justicia*, *Lamiaceae*, *Rumex*, Asteraceae, *Grewia*, Chenopodiaceae*,* Malvaceae). The fragmentary occurrence of taxa, the general absence of tree pollen, and the dominance of taxa typical for secondary vegetation usually interpreted as disturbance indicators, suggest that the entire record reflects a strongly disturbed environment. Thus the pollen record is interpreted as representing the temporal and spatial mosaic of secondary vegetation and cultivated land in an agricultural landscape after forest clearance.

9.5.1 … before the 6th century

Only limited evidence is available for the period prior to the establishment of the early swamp environment. Very low pollen counts, low phytoliths counts, and low organic matter levels characterise both the clay and the sterile sandy bottom sediment. The absence of diatoms precludes the possibility of a former lake bed as proposed by ODNER (1971a). The rapid transition from coarse sand, over sandy clay to clay questions the interpretation that this is an *in situ* soil profile with weathered sterile subsoil grading into a sandy saprolite and rather suggests sorting and hence alluvial sediments. The distinct sandy bottom sediments - also recovered from below an organic layer at Usumbwe 3 - suggest a phase of fluvial activity and sand deposition. Although rapid sedimentation would explain the low levels of pollen, phytoliths, and organic carbon, the fine texture of the overlying clay requires a slow deposition environment and probably corresponds to a former phase of colluviation and alluviation during terrestrial - but much better aerated - conditions than the latter hillwash deposit. The lack of a distinct topsoil development prior to the establishment of the early wetland might imply an erosional hiatus. The environmental conditions prior to the swamp establishment in the 6th century AD remain speculative because of inconsistent and fragmentary data and warrants further investigation (for further discussion of sandy bottom sediments and a possible erosional hiatus see chapter 10.3).

9.5.2 The early swamp environment (6th – 12th century, PZ I)

Wetland conditions established rapidly in the 6th to 7th century AD. The early phase of peat growth is characterised by a woody to herbaceous well-laminated peat deposit with occasional clay inwash. Recovery of wood fragments and *Cyperus* stalks, high $\delta^{13}C$ values and abundant Cyperaceae pollen suggest that the local swamp vegetation was a *Cyperus* dominated reed swamp with few arboreal species. *Cyperus* is one of the few wetland plants following the C_4-pathway (HILLAIRE-MARCEL et al. 1989; GICHUKI et al. 2001) and stands or floating mats of pure *Cyperus* are a common feature of lowland and mid-altitude swamps in East Africa (LIND & MORRISON 1974). A *Cyperus* sample from a pure stand at Mrongo/Ugweno shows high $\delta^{13}C$ values (Tab. 13). Elevated $\delta^{13}C$ values also suggest that the recent swamp started as a *Cyperus* wetland, which is supported by the local name – Ngagheni – for the Usangi basin (Ngaghe - Kipare for *Cyperus*). Preserved wood fragments suggest the local presence of shrubs or trees; however, the pollen record does not support the idea of a swamp forest, as pollen from possible swamp trees are rare.

Around 300cm a decline in Cyperaceae pollen and the high abundance of monolete spores and Asclepiadaceae pollen suggest a change to a more herbaceous peat characterised by members of the Asclepiadaceae family and ferns. Asclepiadaceae, the milkweed, is an entomophilous, insect-pollinated family comprising forbs, herbs and lianas of dry environments often succulent and with milky sap (AGNEW 1974). The general habitat of the family is arid and semi-arid grassland but they also occur in montane grasslands up to around 2700m a.s.l. and apparently show a preference for frequently burned areas (GOYDER 2009). Although not a wetland taxa, several species, especially of the genera *Asclepias*, *Pachycarpus* and *Tylophora*, are reported from seasonal flooded areas, on lake shores or grassy swamps (BULLOCK 1953; GOYDER 1998, 2009). Due to their unique pollination system Asclepiadaceae pollen is unlikely to be far-travelled and it must be assumed that the parent plant formed part of the very local swamp vegetation. Asclepiadaceae are also recorded in swamp deposits from the Udzungwa Mountains, where they occur mainly during wet phases of the Holocene and from Durumu, West Usambara (MUMBI et al. 2008), albeit in low abundances.

The regional arboreal vegetation signature is characterised by low and sporadic occurrence of montane forest genera. The most common genera *Hagenia*, *Ilex*, *Myrica*, and *Nuxia* are not exclusive montane forest taxa but are also reported from secondary vegetation after forest clearance (LIND & MORRISON, 1974 citing GILCHRIST, 1952). More abundant are semi-deciduous woodland taxa, like the dominant *Dobera/Maesa* group but also *Acacia*, *Tarrenna, Terminalia, Commiphora*, *Grewia*, and *Celtis* (GREENWAY 1973; LOVETT 1993b; KIAGE & LIU 2009).

The non-arboreal pollen record further emphasises the importance of open, probably semi-deciduous woodland in the early period. The genus *Acalypha* is represented by 30 species in East Africa mainly perennial shrubs, occasionally trees and herbs with a very high export ability (HAMILTON 1972; HAMILTON 1982). It is most common in moist lower montane forest environments, particularly in secondary vegetation (LIND & MORRISON 1974). Being a well dispersed pollen type the parent taxa might be found in the remaining forest fragments on the mountain tops or as undergrowth and within secondary vegetation within the catchment area.

The ecologically widespread Asteraceae family is the most abundant non-arboreal taxa in the record. Asteraceae pollen in lower montane and savannah settings are derived from undergrowth vegetation of open woodland and bushland. Continuous abundance of Asteraceae pollen (between 10% and 20%) is recorded for the Namelok swamp in Amboseli (RUCINA et al.) as well as swamps in Tsavo National Park (GILLSON 2004, 2006). The sustained occurrence of Asteraceae pollen throughout the Lomwe core suggests that the parent plants have been common in the catchment.

Members of the Amaranthaceae/Chenopodiaceae group are found in semi-arid environments as well as in seasonally flooded areas and are generally a dry indicator (KIAGE & LIU 2009; RUCINA et al. in prep.). Amaranthaceae/Chenopodiaceae pollen is common in *Acacia – Commiphora* bushland (WHITE 1983) and is reported to be abundant in the eastern plains of NE Tanzania (VOLLESEN et al. 1999). Similarly, *Phyllanthus* is known to be a dry indicator (KIAGE & LIU 2009).

The pollen assemblage of PZ I represents an open woodland with *Acalypha*, Asteraceae and Amaranthaceae/Chenopodiaceae and Poaceae undergrowth - similar to lowland savannah woodland or disturbed secondary vegetation. An open, shrub and herb dominated vegetation with semi-deciduous woodland, instead of the assumed submontane forest deduced from the present forest fragments, must have covered the mid-altitudes of North Pare since AD 600. In the absence of strong climatic controls, the lack of a closed canopy forest is attributed to widespread anthropogenic land clearance before the 6th century AD (cf. chapter 10.4).

9.5.3 Beyond the threshold: Widespread soil erosion since the 12th century (PZ II)

The beginning of PZ II coincides with the onset of mineral material deposition and reflects drastic environmental changes in the Lomwe watershed. Already in PZ I peat growth was frequently interrupted by the deposition of fine clay lenses pointing to frequent flooding events of the basin bottom. But only around AD 1200 was the former swamp abruptly buried by a mineral material facies. The general lack of organic matter accumulation reflects cessation of peat development and at least seasonal dry conditions. The deposited clay loam with fine to medium gravel points to a medium energy transport regime - distinctly different from the occasional formation of alluvial clay lenses.

Catastrophic flooding by one or several high-energy events, triggered by heavy rains and causing land or mudslides in the watershed, could explain the comparatively rapid shift from organic to mineral material and the good preservation stage of the organic matter. Deposits resulting from mudslides or avalanches are characterised by a chaotic mixture of fine and coarse sediments, including stones and large boulders. The deposition of homogeneous clay loam with a minor gravel component and the lack of greater than gravel-sized material do not support the assumption of a catastrophic single event. Instead, a combination of colluvial mobilisation along the Mashewa valley and subsequent short distance alluvial transport resulted in the accumulation of 1.5 – 2m thick sediments. A radial flow pattern suggesting a gentle alluvial fan can be observed on the 1957 aerial photograph (Fig. 18).

The shift from organic to mineral deposition and the transport of gravel-sized material implies a drastic change of the hydrological conditions and the runoff regime in the Mashewa catchment. Anthropogenic land use and land clearance in Pare has been shown to have provoked prolonged soil erosion since about 2000 years ago (chapter 9.3). During initial clearance phases, overland flow might only have occurred locally within small spots of cleared land and results in local redistribution of eroded material on the slopes and occasionally in a runoff-event leading to clay inwash in the basin. As deforestation continues, the exposure of bare soil offers readily available material for erosion. Clearings merge and contiguous open areas are established allowing the transport of eroded material into the streams and out of the catchment. The clearing of forest, the erosion of topsoils, and general agricultural land use, favour soil compaction and reduce the infiltration capacity of the soil. Increasing amounts of surface water leads to the concentration of overland flow and subsequent runoff-based erosion. The availability of soil material for erosion and the higher transport capacity of overland flow and stream discharge due to enhanced runoff, trigger soil erosion on the slope and the transport of eroded material into the basin.

It is this important catchment specific threshold of contiguous land being cleared and becoming susceptible to erosion, which has been crossed here. Runoff-based transport of eroded material now sets in and coarse mineral material is transported over short distances to sediment traps such as lakes and swamps. In this interpretation, the mineral deposits of the Lomwe swamp is the result of large–scale soil exposure in the catchment, which was in turn a consequence of progressive forest and woodland clearing. Human land use has passed a threshold, and triggered profound changes of the environmental processes, accelerating soil erosion and leading ultimately to land degradation (for climatic influence see chapter 10.4.4).

9.5.3.1 Open landscape of the past centuries

The pollen record parallels the changes of the core stratigraphy and supports the interpretation of clearing related vegetation change triggering soil erosion and deposition. Good preservation of pollen in PZ II indicates a high water table during most of this period and hence a probably only seasonally dry wetland. The predominantly terrestrial character of the Lomwe basin after AD 1200 is reflected in the pollen assemblage from the local basin vegetation. Low abundance of Cyperaceae indicates a reduced extent of the wetland and high numbers of local non-arboreal taxa (Amaranthaceae/ Chenopodiaceae, Malvaceae, Lamiaceae, and Justicia) support seasonally dry conditions. The dominant Amaranthaceae/Chenopodiaceae group generally indicates arid environments but also occurs frequently in seasonally inundated areas. Semi-woody genera of the Malvaceae (e.g. *Hibiscus*, *Sparrmania*, *Triumfetta*) are among the first to invade cleared areas of land in submontane and montane forest areas (LIND & MORRISON 1974 citing GILCHRIST 1952), but they are also widespread in savannah bushland and woodland and occur frequently in seasonally flooded areas (15 out of the 37 species of Malvaceae present in the Mkomazi reserve include seasonally inundated grasslands VOLLESEN et al. (1999)). The distinct record of PZ II suggests that dry land taxa like Amaranthaceae/Chenopodiaceae, tolerant of seasonally waterlogged soils, and the coloniser genera of the Malvaceae, accompanied by Lamiaceae and *Justicia* invaded the basin bottom shortly after the change in sedimentation took place.

In addition, both Malvaceae and Amaranthaceae/Chenopodiaceae are known to occur in recent clearings and are together with Asteraceae indicators of disturbance. Asteraceae, however, declines during PZ II. As Asteraceae are not specifically wetland plants, their occurrence is unlikely to be linked to wetland formation. Asteraceae occur in low numbers as undergrowth in the forest but are more characteristic as herbs and shrubs in woodland vegetation. Similar unexplained abundance changes of Asteraceae and Amaranthaceae/Chenopodiaceae in an antiphase manner were observed by RUCINA et al. (2010) in Amboseli. If the abundance of Asteraceae and Amaranthaceae/Chenopodiaceae is interpreted in terms of a regional pollen signal derived from the lowland savannah woodland, then the antiphase occurrence with Amaranthaceae might indicate that the latter not only occurred in the basin bottom (if at all), but is also derived from regional pollen fallout and therefore indicates a dry climatic phase, when Amaranthaceae dominated above Asteraceae.

Following this interpretation, the conspicuous timing at the onset of the alluvial deposition phase points to a strong drought event. Enhanced soil erosion and subsequent alluvial deposition then must be interpreted as being the result of strong seasonal runoff-events and erosion being facilitated by the opening of the vegetation cover due to aridity. This scenario does not exclude the importance of anthropogenic impact and is discussed in detail in chapter 10.4.2.

Remarkable is the total absence of arboreal – both montane and woodland - pollen during PZ IIa. Disappearance of tree taxa due to reduced precipitation is an unlikely scenario in the relatively moisture buffered mountain environment – instead it probably reflects the advanced clearing stages of the Lomwe catchment. Although the absence of arboreal pollen seems to strengthen the interpretation of advanced forest clearing, it needs to be noted that transported and redeposited soil is very likely to contain old, reworked tree pollen stored in the topsoil of the surrounding hills (MSAKY et al. 2005). The lack of reworked tree pollen is explained by early deforestation starting even before the establishment of the wetland in the 6th century AD. In this scenario, the initial forest topsoil has been eroded during early phases of cultivation and is probably stored in sinks on footslopes along the Mashewa stream. Material eroded and transported at this stage is either pollen poor subsoil or thoroughly reworked and pollen depleted topsoil material.

The absence of arboreal vegetation and the dominance of taxa typical for disturbed or secondary vegetation support the interpretation that forests were completely cleared by the 12th century. Contiguous, open, agricultural land facilitated increased runoff- generation. Soil erosion accelerated and crossed an environmental threshold triggering colluvial and alluvial deposition of hillwash sediments from the Mashewa catchment on the seasonally dry valley bottom. This new processes framework reflects the advanced stage of land degradation of the catchment in the 12th century.

9.5.4 The recent wetland (PZ III, ~19th to 20th century)

Wetland conditions return between 110 and 80cm depth. The recent swamp is restricted to the north-western corner of the basin and differs in several ways from the early basin wide wetland. The recent swamp formation is most likely the consequence of fan-like sedimentation of the Mashewa stream creating a backswamp position with reduced deposition in the northern part of the basin (Fig. 18). This swale position on its own promotes a higher water-table and waterlogging, and thus favourable conditions for the accumulation of organic matter and wetland development.

Decreasing sediment load or decreasing magnitude of runoff events would have contributed but are not crucial to explaining restricted deposition in the southern part and formation of a morphological depression in the northern part of the basin. Decreasing sediment load might be related to a slow down of the land degradation process as a consequence of soil conservation measures or exhaustion of the soil resources on the slopes. The decline in sediment load and wetland formation (since 110cm) predates possible effects of colonial soil conservation measures, which postdate the introduction of non-native tree species at 74cm depth. Indigenous terracing reported by early European travellers in the mid-19th century (VON DER DECKEN 1869; MEYER 1890; BAUMANN 1891) might have at least locally reduced soil erosion and sediment load, though it remains unclear whether terraces were constructed in the immediate area. On the other hand, progressive soil erosion over centuries has removed the top- and later subsoils of the Mashewa catchment and has exposed the underlying saprolite and bedrock. A reduction in sediment load might be the result of a declining supply of transportable source material directly reflecting the severe stage of land degradation and soil erosion in the catchment.

Wetter climatic conditions during the last ~150 years would have contributed to a rising water-table and facilitated the establishment of the wetland. From the occurrence of the time-stratigraphic marker *Cupressus,* the onset of swamp development can be placed in the late 19th century. Framed by two drought periods in the beginning and during the last two decades of the 19th century, the mid 19th century is assumed to have been comparatively wet, whereas the subsequent 20th century is characterised by a more balanced, intermediate climate (HASTENRATH 2001; NICHOLSON & YIN 2001). Although the establishment of the recent wetland might have been favoured by wetter conditions, precipitation variation alone cannot explain the timing of swamp establishment and the subsequent persistence of the wetland. Incremental development of the morphological swale location, probably facilitated by decreasing sediment load due to material depletion or soil conservation measures are the most likely factors for recent wetland establishment.

9.5.4.1 Contemporaneous vegetation

Pollen zone IIIa reflects the stratigraphic change from mineral to organic sediments. The steady increase of Cyperaceae culminates at 90cm and wetland genera *Ludwigia* and *Typha* indicate swamp vegetation. The establishment of the permanent swamp falls together with the first evidence of introduced *Zea mays* in the pollen record and the increase of ruderal vegetation like *Rumex* and *Commelina* – the first possible evidence for agriculture. The abrupt and complete disappearance of Malvaceae and the steady decline of Amaranthaceae/Chenopodiaceae (reflecting the increase in Cyperaceae) strongly support their interpretation as dominant basin bottom vegetation during the dry period. The final decline of the herb and shrub vegetation (Amaranthaceae/Chenopodiaceae, Lamiacae, and *Justicia* pollen disappear and Asteraceae decreases) and the increase in Poaceae in the uppermost samples might be related to a more intensive use of the dry basin bottom for cultivation and grazing during the late 20th century.

Arboreal taxa return in PZ III and show their highest diversity. Whereas woodland taxa such as *Acacia*, *Dobera/Maesa*, *Tarrenna*, *Terminalia*, *Commiphora*, are most likely far-travelled pollen from the Mkomazi and Tsavo plains, the rise of *Acalypha*, *Myrica* and *Nuxia* accord with recovery of secondary forests in the (sub)montane forest zone (cf. chapter 10.4.7). The rise in arboreal pollen is dominated by *Cupressus* and *Eucalyptus* reflecting their introduction by German foresters shortly after AD 1900 and afforestation and widespread planting of exotic trees in the mid-20th century (cf. chapter 8.9.1.2). Although present in the upper samples, *Pinus* plays a minor role in North Pare as can be judged from the low occurrence in the pollen record, which reflects the absence of pine plantations in North Pare.

9.5.4.2 Recent stream incision

Clear stratigraphies at stream banks show that the Ndurumu and Mashewa streams incised into the most recent sediments of the Lomwe basin. Several factors suggest that the incision of the Ndurumu stream might be another consequence of land use practices and prolonged land degradation.

Traditionally the moist basin bottoms were protected from cultivation and only during exceptionally dry periods did cultivation extend into the wetlands. As a consequence of declining traditional land use practices under colonial rule in the first part of the 20th century, parts of the swampy valley bottoms at Lomwe and Ngagheni were drained for cultivation (SHERIDAN 2001). The artificial drainage is likely to have had a positive feedback on the incision of streams, and was possibly even its sole cause.

In addition, removal of the topsoil cover and advanced subsoil erosion has reduced the infiltration and water retention capacity of the Mashewa catchment. With the decline of water retention capacity, runoff increases temporally, and the discharge regime becomes more seasonal A higher transport capacity during seasonal runoff events combined with a reduced sediment load, as discussed for the establishment of the small backswamp at Lomwe, would have promoted stream incision.

The incision caused the lowering of the watertable, allowed cultivation on the now permanently dry Lomwe basin bottom and probably reduced the extent of the remaining swamp, although no direct impact is discernable from the pollen record itself.

10 ENVIRONMENTAL HISTORY OF NORTH PARE

The environmental history of the three Pare catchments was reconstructed on the basis of sedimentological, palaeopedological and palaeoecological research. This synthesis presents a model of landscape development for North Pare (Fig. 55 & Fig. 57) emphasising the anthropogenic impact and the importance of slow but cumulative clearance and erosion processes for triggering rapid landscape changes. Vegetation changes are discussed in the context of regional climate dynamics; however, their importance controlling environmental change during the last 2000 years is questioned.

10.1 Late Pleistocene transition

The Last Glacial Maximum (LGM) in East Africa was dry and cold climate (BARKER & GASSE 2003; KIAGE & LIU 2006; GASSE et al. 2008). The hydrological balance of most East African lakes was negative and the shallow, eastern rift valley lakes Manyara (HOLDSHIP 1976), Magadi (ROBERTS et al. 1993), Naivasha (RICHARDSON 1966; RICHARDSON & DUSSINGER 1986), and Bogoria (TIERCELIN et al. 1981) dried out or experienced marked low stands. Severe drought is reported from Lake Victoria, which desiccated completely (TALBOT & LÆRDAL 2000; STAGER et al. 2002). Lake levels of the deep Western Rift Valley lakes Tanganyika (FELTON et al. 2007), Albert (BEUNING et al. 1997), and Turkana (OWEN et al. 1982) fell considerably. Dry and cold conditions between ~24 ka and ~14 ka BP were interrupted by short periods of wetter climate recorded by lake transgressions at Lake Victoria and Lake Albert. Pollen records confirm a dry and cold Last Glacial Maximum (JOLLY et al. 1997; KIAGE & LIU 2006). Expansion of grasslands are recorded at numerous sites for example at Lake Naivasha (MWORIA MAITIMA 1991) as well as in the Burundi highlands (BONNEFILLE & RIOLLET 1988). From the Kashiru swamp, Burundi, BONNEFILLE et al. (1990) reconstructed a temperature decrease of about 4.2°C and precipitation drop of 30% during the LGM.

The oldest terrestrial archive in North Pare is the Lomwe slope deposit (cf. Fig. 55). The organic matter rich buried topsoils evidence a prolonged phase of morphological stability during the heights of the LGM. Charcoal fragments from the buried soil record fire events during the glacial dry period (19.5 - 18.9 ka BP and 18.5 - 17.7 ka BP), but it is the radiocarbon date of soil organic matter (14.9 – 13.9 ka BP) that is interpreted to give a maximum age for slope instability leading to the burial of the late Pleistocene land surface (chapter 9.4.1).

A montane forest environment prevailed at Pare during dry glacial times. Thickness, organic matter content, and stable carbon isotope composition of the buried soil at Lomwe resemble humus rich, umbric forest soils under montane forest vegetation. Persistence of montane forest vegetation during the LGM is in accordance with palaeoecological studies at Dama swamp (2100m a.s.l.) in the Udzungwa (MUMBI et al. 2008) and Deva-Deva (2600m a.s.l.) in the Uluguru Mountains (FINCH et al. 2009). At both of these sites, vegetation composition of the investigated upper montane forests remained stable throughout the major climatic fluctuations of the LGM. The stability of upper montane forests of the Eastern Arc Mountains contrasts with distinct downward shifts of the subalpine, ericaceous belt inferred from buried topsoils between 2000 and 3000m a.s.l. on Mount Kilimanjaro (ZECH 2006). Here black organic matter rich palaeosols are interpreted as having developed under ericaceous vegetation, which extended downslope during cold and dry phases of the LGM, the Younger Dryas, and Holocene dry spells. A recent downward shift of the subalpine, ericaceous vegetation belt on Kilimanjaro has been attributed to increased fire frequency stimulated by decreasing precipitation in the course of global warming (HEMP 2005, 2009). Increasing fires during former dry phases might have played a similar role leading to the depression of vegetation belts on Kilimanjaro, whereas the impact of fire was probably buffered by smaller areas of subalpine heathlands on the lower and smaller Eastern Arc Mountains. Temperature-driven depression of altitudinal vegetation belts during the LGM (ZECH 2006) are likely to have stabilised montane forests at mid-altitudes between 1200 and 2000m a.s.l. in Pare, where climatic and ecological conditions remained stable despite the extreme dryness of the LGM and allowed a closed montane forest to prevail, albeit disturbed by occasional forest fires.

Slope instability around 14.9 - 13.9 ka BP at Lomwe coincides with the first phase of climatic amelioration and precipitation increase in East Africa. The transition from the LGM to the warm and humid climate of the early Holocene started around 15 – 14 ka BP (GASSE et al. 2008) and took place in several steps, interrupted by climatic drawbacks such as the Younger Dryas (12.8 – 11.5 ka BP). Lake levels at Lake Victoria (STAGER et al. 2002) and Lake Albert (BEUNING et al. 1997) rose between 15 – 14 ka BP and the White Nile flow reassumed (WILLIAMS et al. 2006). By about 10 ka BP, lake level high stands are reported from most of the eastern Rift Valley lakes (GASSE 2000; BARKER & GASSE 2003; GASSE et al. 2008).

The rapid climatic transition from dry and cold glacial conditions to the moist and warm climate had considerable impact on the mobilisation and transport of sediments. The time lag between climatic change, precipitation and temperature increase on the one hand, and the retarded reorganisation of the vegetation adjusting to the new environmental conditions on the other, are often stressed to explain erosion pulses, especially at the end of the LGM (THOMAS 1994; THOMAS & THORP 1995). Generally, the delayed re-establishment of closed (forest) vegetation results in a temporal disequilibrium of the climate – vegetation system producing enhanced runoff and leading to soil erosion as the land surface adjusts to the new external driving forces. Enhanced geomorphologic activity during the transition phase of rapid climatic change at the beginning of the Holocene is recorded in several terrestrial archives for example from Zambia (THOMAS 2001b), the Eastern Congo (RUNGE 2001a) and Central Tanzania (ERIKSSON et al. 2000). However, slope instability at this time was not spatially comprehensive as no enhanced slope deposit formation was observed at the long-term record from Mindu Mountains in Central Tanzania (SØRENSEN 2001).

In central Tanzania, the footslope of the semi-arid Irangi hills (Kondoa) are covered by several layers of extensive pedisediments, recording distinct phases of soil erosion (ERIKSSON et al. 2000). The earliest phase of erosion and hillwash deposition dates between 14.5 and 11.4 ka BP and is roughly contemporaneous with the inferred slope instability in Pare. Currently semi-arid, a strongly reduced vegetation cover can be assumed for the Irangi hills during the LGM offering little protection against erosive rainfall events during the transition to a wetter climate. For the semi-humid North Pare upland (1300m a.s.l.) on the other hand, montane forest vegetation has been proposed. Under a closed forest canopy, precipitation increase, although abrupt, is unlikely to have provoked enhanced soil erosion. Alternatively, increased precipitation and soil moisture could have resulted in local slope instability and mass wasting events such as slumping or landslides. The homogeneity of the deposits, however, excludes mass wasting processes as relief forming factors at Lomwe. Tectonic activity is a further possible cause of slope instability along the Pangani Graben. However, in the absence of any strong indications for earthquake induced mass movement, climate dynamics are the mostly likely trigger.

Although the exact mechanisms are not fully understood, climatic fluctuations during post-glacial warming and wetting stages are the most likely natural drivers of slope instability. Short-lived climatic fluctuations may have played a major role by temporarily opening up the forest cover or promoting fires and creating conditions suitable for erosion and the burial of former surface soils. The restriction of the LGM soils to only one of the three study areas puts late Pleistocene slope instability into perspective as localised disturbance cannot be conclusively ruled out.

10.2 **Early Holocene surface stability**

So far, no dated sediments of the early and mid-Holocene have been recovered in North Pare. The buried land surface at Mrongo and Usumbwe dates to around 2000 BP. Its buried soils are deep (2 to 3m), and have developed *in situ* over subsoils with increasing gravel content and weathered rock fragments. The overlying late Holocene deposits (4 – 9m) have smoothed the land surface and levelled a much more accentuated mid-Holocene mountain relief of narrow valley bottoms and steep slopes. The lack of early to mid-Holocene slope deposits is explained by either landscape stability under closed (forest) vegetation or by an erosional hiatus preceding the late Holocene accumulation phase.

During the moist and warm climatic optimum of the early Holocene, high lake level stands (GASSE 2000) and forest expansions are reported throughout East Africa (HAMILTON 1982; KIAGE & LIU 2006). Evergreen forest expanded around Lake Victoria (KENDALL 1969), and at Lake Naivasha an increase in tree pollen indicates downward expansion of montane forests in the Central Rift Valley (MWORIA MAITIMA 1991). A continuous history of montane forest vegetation is reported from the Eastern Arc Mountains. According to palaeoecological studies at Dama and Deva-Deva swamps, montane forests between 2000 and 2600m a.s.l. remained stable throughout the Glacial Maximum and the early Holocene (MUMBI et al. 2008; FINCH et al. 2009). Given widespread forest expansion during the warm and moist early Holocene, it is reasonable to assume a continuous montane forest environment in the North Pare upland.

In Rwanda, slope creep has been identified as the predominant geomorphological process of the early Holocene, where MOEYERSONS (2001) proposes that high water tables and increased soil moisture facilitated slope creep and slow flow of the deeply weathered surface mantle, and that large scale soil creep processes took place. Over time, the slope creep bulged into the valleys eventually narrowing and damming them. The slow early Holocene slope creep accentuated the characteristic convex slope forms of the Rwandan bas-fonds. In the comparable North Pare environment, no evidence for such widespread slope creep has been observed. Asymmetry of tectonically derived valley forms and partial infilling of the valley bottoms suffice to explain the occurrence of steep slopes in North Pare.

10.3 **Mid-Holocene aridity?**

Hydrological changes during the mid-Holocene might have affected the Pare highland. From about ~8 ka BP on precipitation and lake levels in East Africa declined during several drying steps (GASSE 2000; JUNG et al. 2004). The timing of these drying events varies regionally but appears to be triggered by abrupt and short lived droughts around 8.2, 5.2 and ~4 ka BP recorded by dust peaks in the Kilimanjaro ice cores (THOMPSON et al. 2002). The latest and most profound climatic change occurred around 4 ka BP, when declining northern summer insolation crossed a threshold and non-linear feedback processes led to the end of the African Humid Period, the onset of increasing aridity in northern Africa, and the desiccation of the Sahara desert (DEMENOCAL et al. 2000a; DEMENOCAL et al. 2000b). Throughout East Africa, lake levels declined (MARCHANT & HOOGHIEMSTRA 2004) and seismic stratigraphy of Lake Challa records three prolonged low stands with ponded sedimentation during the mi-Holocene (8–6.7, 5.9–4.7, and 3.6–3.0 ka BP; VERSCHUREN et al. 2009). Similarly, a strong dry phase is recorded around 3.8 BP at Lake Manyara (HOLDSHIP 1976). Lake levels declined in the Naivasha basin from 5 ka BP onward and the three present day lakes Nakuru, Elmentaita and Naivasha separated. The most severe dryness and desiccation of the Crescent Island Crater lake occurred after 3 ka BP (RICHARDSON & DUSSINGER 1986) but before c. 1865 - 1605 BP (VERSCHUREN 2001).

Mid-Holocene drought also affected vegetation cover in most of Central Africa and East Africa (MARCHANT & HOOGHIEMSTRA 2004), where decreasing precipitation, recurrent droughts and a shift to a more seasonal rainfall pattern since about 4 ka BP have been identified as causing the increase of drought tolerant taxa, the spread of semi-deciduous forests (TAYLOR 1993; TAYLOR & MARCHANT 1996), and the spread of swamp forests (TAYLOR 1990). Palaeoecological evidence for aridity, however, is limited in Kenya and Tanzania. Altitudinal shifts of the savannah – montane forest boundary are reported from the Mau escarpment in the Central rift valley in Kenya. AMBROSE (1986) observed a strong increase of stable carbon isotope composition (~7‰) in the subsoil of current forest soils between 2000 and 3000m a.s.l. Albeit relying on a single (and quite young) minimum age for soil formation (soil organic matter), AMBROSE (1986) proposes an altitudinal upwards migration of the savannah-forest boundary of about 300 to 500m during the mid-Holocene dry phase. Climatically induced forest retreat in Pare would have started on the escarpment and in dry habitats, with shallow slope and ridge locations being the first to open up and be exposed to erosion.

Whilst no slope deposits are recorded from the mid-Holocene, undated sands recorded below late Holocene peat deposits in valley bottom locations might be related to mid-Holocene material translocation (observed at Lomwe swamp, Mrongo swamp (data not presented) and at Usumbwe 3). These sterile sands (>50cm thick) represent the base of recovered sediments in the valley bottom. Sandy bottom sediments in upland valleys are also reported from bas-fonds in a similarly fossilised Tertiary landscape near Butare in southern Rwanda (GRUNERT et al. 2004; KERSTING 2010), while mid-Holocene erosion is inferred from buried soils at Kesubo floodplain, Kenya (DRIESE et al. 2004). KERSTING (2010) links the sandy bottom sediments to erosion during the mid-Holocene dry period. Strong seasonal precipitation events in an open landscape caused enhanced sheet wash processes on the slopes and the deposition of sands in the valley bottom. Near the study area, the sediments of Lake Challa show three distinct mid-Holocene lake level lowstands as well as occasional mass-wasting events (VERSCHUREN et al. 2009). Swamps of higher altitudes in the Eastern Arc Mountains (Dama, Deva-Deva, Kwasebuge) targeted for palaeoecological studies present continuous sedimentation histories as far back as the Pleistocene and do not show mid-Holocene slope instability (MUMBI et al. 2008; FINCH et al. 2009; FINCH et al. in prep.).

Additional evidence for an erosion period in Pare is inferred from stratigraphic inconsistencies of the slope deposits. Not only sands under late Holocene peats, but also truncation of the late Holocene surfaces (Mrongo 2, Usumbwe 1 & 2, and Lomwe 3) and particularly the thin late Pleistocene deposit at Lomwe, combined with the lack of a distinct deposition unit linked to the mid-Holocene charcoal fragment at Lomwe, all suggest an erosional hiatus directly preceding the accumulation of anthropogenic deposits (cf. chapter 9.4.2). Instead of being related to mid-Holocene erosion events, stratigraphic evidence suggests that truncation took place during the initial erosion pulse triggered by anthropogenic land clearance.

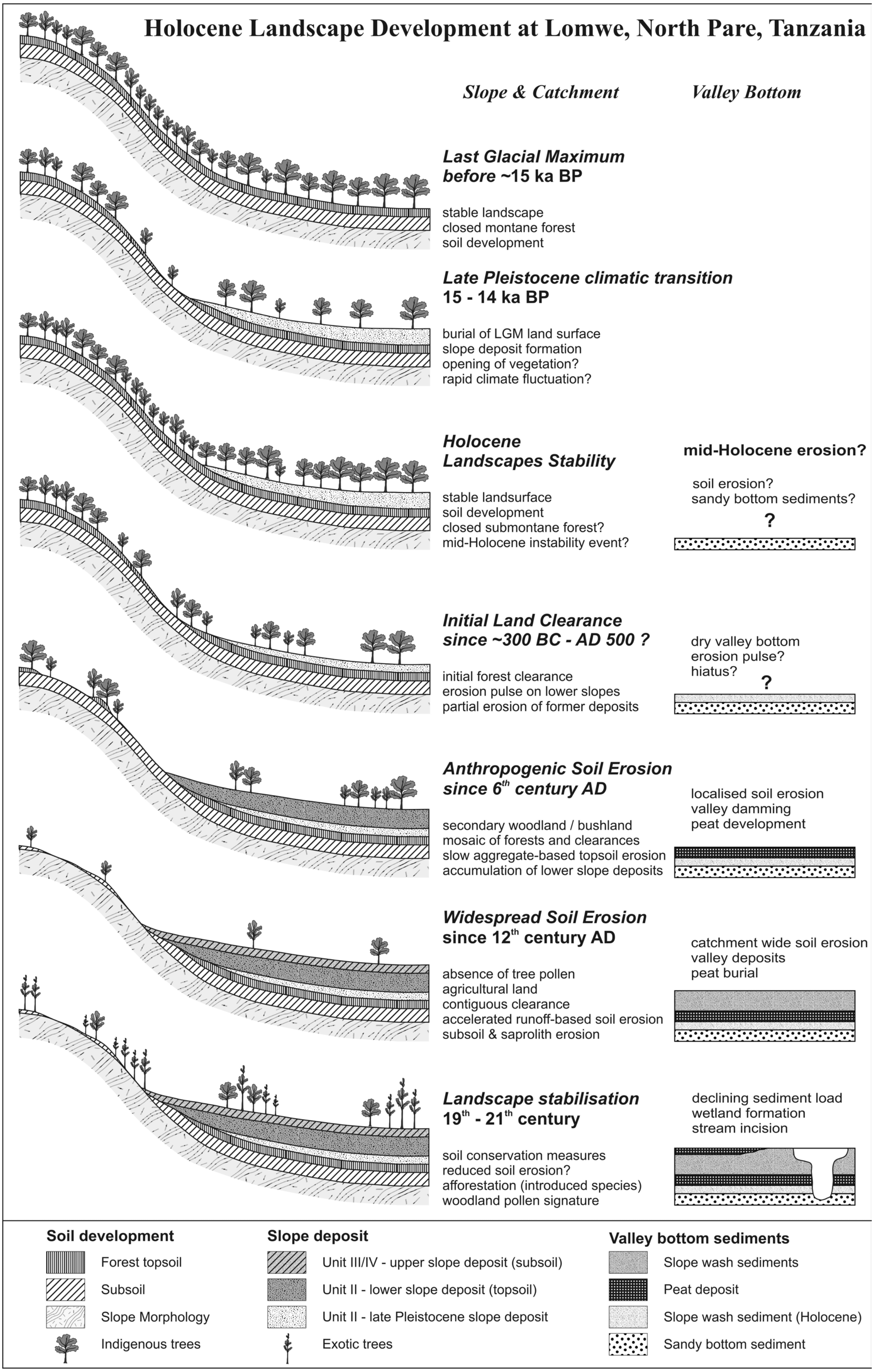


Fig. 55: Holocene landscape development at Lomwe, North Pare.

The present study can neither substantiate nor rule out soil erosion and accumulation of sandy bottom sediments during the mid-Holocene. The causation and age of the sandy bottom sediments as well as their subsequent partial entrainment warrants further investigation. The lack of dated mid-Holocene sediments and considering that more benign climatic conditions prevailed during the mid-Holocene than during the LGM, it is reasonable to assume that stable landscape conditions and a montane forest prevailed during the early and mid-Holocene in the mid-altitudes of North Pare.

10.4 Late Holocene, anthropogenic landscape development

The late Holocene has seen major environmental changes as well as socio-economic transformations. The reconstruction of landscape development in North Pare based on terrestrial archives at Usumbwe, Mrongo and Lomwe reveals four major stages of landscape change (Fig. 55 & Fig. 57): 1. Onset of soil erosion and accumulation of colluvial slope deposits since 300 BC - AD 500 concurrent with the occurrence of Early Iron Age (EIA) pottery; 2. Valley damming and wetland establishment between AD 600 and AD 1200; 3. Widespread forest clearing and catchment wide soil erosion since the 12th century; 4. A change to an erosion-deposition regime characterised by runoff-based erosion in the 15th century AD signalling increasingly severe land degradation as evidenced by subsoil erosion.

10.4.1 Early Iron Age settlers and onset of soil erosion (3th c. BC – 6th c. AD)

Hillwash and accumulation of corresponding slope deposits dating between 400 – 110 BC (Mrongo 10), AD 70 - 230 (Usumbwe 2), and AD 430 – 610 (Changuku 4) represent the most drastic environmental change recorded in the terrestrial archives over the last 20,000 years. The onset of enhanced and sustained soil erosion in Pare falls into a time of socio-economic and cultural change in East Africa. During the first millennium BC, food production in East Africa underwent a substantial transformation. After a prolonged standstill in Northern Kenya, herding began to spread into areas that now fall in Tanzania (BOWER 1991; GIFFORD-GONZALEZ 1998; KAREGA-MUNENE 2003). Only a few centuries later roughly around 500 BC agricultural food production and iron working emerged in the Great Lakes Region (CLIST 1987; SCHMIDT 1997b). The spread of agriculture and iron working in East Africa was formerly explained by migration of Bantu speaking populations from their assumed secondary dispersal centre within the Interlacustrine region, though this view has been modified more recently to stress a spread of ideas, technologies and languages rather than a migration of people per se (SCHOENBRUN 1993a; EHRET 2001; EGGERT 2005). Mainly based on linguistic research, these new subsistence strategies such as mixed farming and herding systems now appear to have developed as a consequence of cultural contact of different population groups, each with its own set of crops and technologies (SCHOENBRUN 1993a; LANE 2004). Although zooarchaeological and archaeobotanical data is limited (although see LANE et al. 2007), this change in subsistence practices is reflected in the material culture evidence through the recognition of distinct ceramic styles and manufacturing techniques associated with Early Iron Age agriculturalists such as Urewe ware from the Ugandan highlands and around Lake Victoria (KIRIAMA 1993; ASHLEY 2010).

In north-eastern Tanzania, the advent of agriculture is commonly inferred from the distribution of Kwale ware, a pottery type related to the interlacustrine Urewe ware (SOPER 1967a). Although such correlations between pottery types and particular subsistence techniques has been questioned for this area and period (PHILLIPSON 1977), occupation sites including Kwale ware and iron smelting sites dating to the early centuries AD are recorded in the Usambara Mountains (SCHMIDT 1988) and on the foothills of the South Pare mountains (SOPER 1967b). In the present study, Early Iron Age pottery was recovered from slope deposits dated to AD 430 – 610 (Mrongo 4) and 260 – 570 AD (Changuku 4). Potsherds and the accumulation of slope deposits confirm the presence of Early Iron Age populations and suggest agricultural land use in North Pare since 300 BC - 600 AD. The present work supports early occupation and settlement of forested mountain environments (SCHMIDT 1989) in contrast to earlier assumptions made by SOPER (1967b) and FOSBROOKE (1957) that Early Iron Age people settled predominantly on the footslopes and only later migrated to the highlands (see also AMBROSE 1984). Initially, forest clearing and farming in the upland probably concentrated on favourable and level terrain along the valley footslopes and depressions on the slopes. During this initial phase of occupation swidden agriculture may well prevailed. After slash-and-burn, disturbed forests and fallow fields had time to recover and develop into secondary forests. Forest recovery allowed topsoils to recuperate and soil erosion was intermittent and localised.

Iron tools enhanced the efficiency of slash-and-burn practices to create clearings for crop production, and fuel demand for iron working further increased the pressure on the forest resources. Whereas various taxa were used for fuel in the early years of iron smelting in the Buhaya region at Lake Victoria, later centuries witnessed a much more selective firewood extraction (SCHMIDT 1997a). Either way, the fuelwood demand contributed to forest clearance, removing locally the protective vegetation cover and exposing forest soils to erosion. The temporal coincidence between the onset of enhanced soil erosion and the advent of new ways of food production involving and depending on the transformation of the ecological environment strongly suggests a causal link.

A phase of inferred aridity in East Africa around 2000 years ago has been reported (Fig. 56), but this event is not thought to be the cause of prolonged soil erosion in Pare. Water levels of Rift Valley lakes fell at the same time as indications of anthropogenic land clearance and soil erosion appear in the pollen records. Most palaeoecological studies therefore emphasise the difficulty of distinguishing between anthropogenic and climatic induced vegetation change during the last three millennia. Low lake levels are indicted by high magnesium concentration in the sediments of Lake Edward (RUSSELL & JOHNSON 2005) and by ostracode distributions of Lake Tanganyika (ALIN & COHEN 2003). Lake Naivasha desiccated completely prior c. 1865 - 1605 BP (VERSCHUREN 2001) and BIT-indices are interpreted as indicting erosion around 2 - 1.6 ka BP at Lake Challa (VERSCHUREN et al. 2009). With the exception of Lake Naivasha, which apparently dried out completely (see RICHARDSON & DUSSINGER 1986 for a possibly older date of 3000 BP for lake desication), the drought period around 2000 BP was not exceptional compared with other much more abrupt and prolonged droughts during the Holocene. Specifically, none of the strong drought periods recorded by ponded sedimentation at Lake Challa (VERSCHUREN et al. 2009), analcime formation at Lake Manyara around 3.8 ka BP (HOLDSHIP 1976) or the dry spells of 8.3, 5.2 and ~4 ka BP recorded in the glaciers of Mount Kilimanjaro (THOMPSON et al. 2002) had severe environmental impacts on the Pare landscape and do not appear to have resulted in soil erosion or formation of slope deposits in the Pare uplands.

Sustained soil erosion in Pare continued despite subsequent climatic amelioration without cessation up to the present. Precipitation decline around 2000 BP is unlikely to have caused a strong enough reduction of vegetation to prompt and maintain high levels of soil erosion during the fluctuating climatic conditions of the following two millennia. Climatic fluctuations like the well-documented drought periods around the beginning of the Common Era, the Medieval Warm Period or the Little Ice Age are likely to have influenced and perhaps probably amplified - but not initially caused - slope instability and soil erosion. Instead of directly causing environmental change, droughts may have stimulated the human occupation of well-watered mountain environments. Additionally, climate-induced vegetation stress and the promotion of forest fires during arid conditions would have enhanced the efficiency of slash-and-burn practices for forest clearance. The advent of sedentary agriculturalists with their new suit of subsistence strategies remains the crucial factor to explain the distinct and long-lasting impact of late Holocene soil erosion on the Pare landscape.

During the first millennium BC, human presence becomes more and more apparent in the environmental archives, as people began to consciously exert changes to the East African environment. Discerning between human activity and climatic or ecological driving forces in pollen records from Africa is hampered by the absence of distinct pollen from domesticated indigenous crops and hence a reliance on indirect evidence from increasing pollen from weeds and secondary vegetation. Changes in the floristic composition have been picked up early in palaeoecological records from the Rukiga Highland in southern Uganda. Expansion of secondary vegetation at the expense of forest started around 2500 BP (TAYLOR 1990; TAYLOR et al. 1999), contemporaneous with the early dates for iron smelting in the broader region recorded by CLIST (1987). At Lake Masoko in southern Tanzania increased burning, the expansion of grasslands, and the presence of *Ricinus communis* pollen, is interpreted as forest clearance by humans from about AD 400 (VINCENS et al. 2003).

Whereas pollen-based studies seem to pick up likely anthropogenic changes in the vegetation cover, direct evidence for anthropogenic landscape change based on terrestrial archives is observed only several centuries later. Severe soil erosion as a result of land clearance, farming and iron smelting is inferred from the deposition of limonite nodules in Lake Ikimba around AD 450 - 500, and is accompanied by a decrease of arboreal pollen (LASESIKI 1983 in SCHMIDT 1997b). At Gaseke, in the Butare region of Rwanda, deep (up to 4 m), loamy valley deposits accumulated after about 1500 BP and overlie undated mid-Holocene sandy sediments. KERSTING (2010) suggests that the expansion of Bantu speaking farmers and concomitant change in subsistence practices prevented natural reforestation after the end of the mid-Holocene dry phase. Higher precipitation levels during the late Holocene and a reduced vegetation cover resulted in increased runoff and hence the deposition of loamy sediments in the valley bottoms. The rich archaeological record from the Interlacustrine region has shown Early Iron Age furnaces dating back to the middle of the first millennium BC (CLIST 1987; SCHMIDT 1997a). Compared to the early adoption of farming and iron working between the Great Lakes, landscape modification and soil erosion at Butare and Lake Ikimba commenced late. This can be explained as during early periods of settlement, occupation sites and anthropogenic impact are localised and dispersed. Similarly, terrestrial sediments are site-specific archives and only allow accurate reconstruction of such local environmental histories. Thus, a number of sites are required to establish a reliable and comprehensive regional chronology. The spatially and temporally limited significance of local swamp archives has been shown by the distinct timing of the imprint of human land use on three adjacent swamps in a small area of the Rukiga Highlands in Uganda (TAYLOR & MARCHANT 1996).

In North Pare the onset of soil erosion and inferred human agricultural land use spans several centuries between roughly 300 BC and AD 500. Based on three radiocarbon dates from two neighbouring catchments, the large age range shows the variability of deposition histories on a local scale. Given the wide temporal range of the dates, it is imprudent to select a fixed date for the beginning of significant anthropogenic landscape transformation. On the other hand, the progressively younger burial ages along the footslope at Mrongo and Usumbwe reflect the spatial dynamic of colluviation starting near the break of slope and advancing forward into the valley bottom (chapter

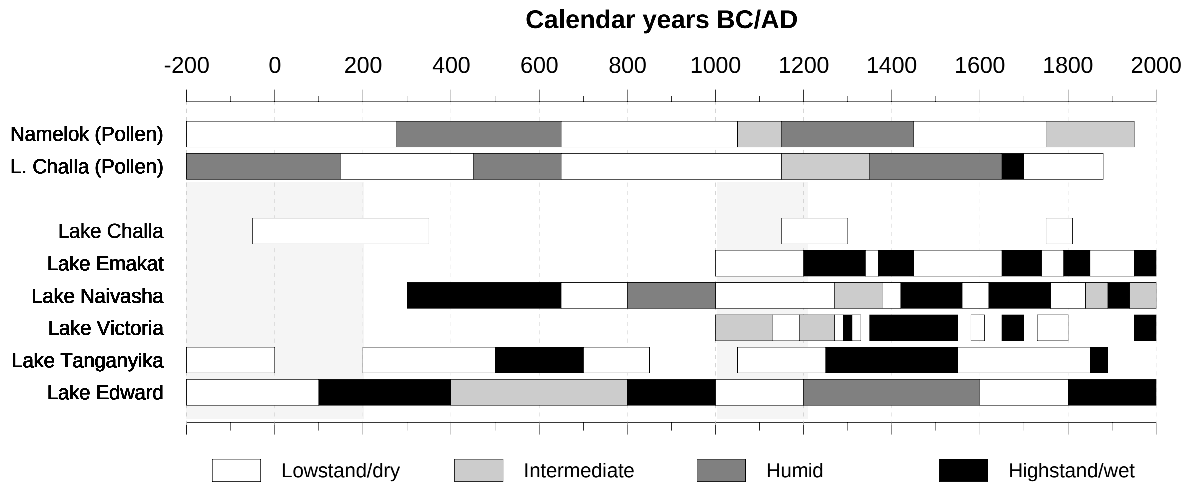


Fig. 56: Arid and humid periods in East Africa. Climate reconstructions of the late Holocene according to lake level stands from Lake Challa (VERSCHUREN et al. 2009), Lake Emakat (RYNER et al. 2007), Lake Naivasha (VERSCHUREN 2001), Lake Victoria (STAGER et al. 2005), Lake Tanganyika (ALIN & COHEN 2003), and Lake Edward (RUSSELL & JOHNSON 2005). Climate reconstruction based on pollen records are from Lake Challa (RUCINA et al.) and Namelok (Amboseli) (RUCINA et al. 2010). General accepted aridity periods around 0 BC/AD and the Mediaeval Warm Period are shaded in grey. Note the regional variability - particular regarding specific time intervals. For North Pare the most representative sites are Lake Challa, Namelok and Emakat (cf. Fig. 1). Records from Lake Naivasha, Victoria, Tanganyika, and Edward are general accepted reconstructions of East African palaeoclimate.

9.3.2). The wide range of initial burial dates, the slow horizontal deposition advance, and the later rapid vertical accumulation, all corroborate that soil erosion in the first centuries BC was slow or locally restricted, but later spread and gained momentum in the first millennium AD.

The oldest Early Iron Age sites with typical Kwale ware are Bombo Kaburi in South Pare (SOPER 1967b) and furnaces at Nkese, Usambara (SCHMIDT 1988) dating to the first centuries AD (cf. Tab. 2). In contrast to environmental studies of the Interlacustrine region (LASESKI 1983; KERSTING 2010), anthropogenic soil erosion in North Pare slightly predates the two earliest Kwale ware sites in north-eastern Tanzania and shows that landscape modification in Pare commenced immediately after the arrival of sedentary Early Iron Age farmers. The new technologies of farming and iron working seemingly had instantaneous and large-scale consequences for vegetation and landscape development.

10.4.2 Vegetation cover before and during the transition to agriculture

The mid-altitude uplands of North Pare and probably also the other Eastern Arc Mountains, experienced drastic landscape transformation after the introduction of farming and iron working. High altitude swamps in the Eastern Arc Mountains however do not show any strong evidence for anthropogenic disturbance of upper montane forests (MUMBI et al. 2008; FINCH et al. 2009), although MUMBI et al. (2008) observed an increase of coprophilous fungi at Dama swamp indicating the possible presence of domesticated animals during the past two millennia. Similarly, high-altitude grasslands of the Eastern Arc Mountains, have been shown to predate human advent and are not of secondary nature (FINCH & MARCHANT 2010).

Reconstruction of vegetation cover in the current study is based on the Lomwe swamp pollen record and on stable carbon isotope composition of buried soils. The swamp established around AD 600, thus pre-settlement vegetation composition cannot be reconstructed from the available pollen data. Generally, the first millennium AD is accepted to have been a relatively humid time (Fig. 56). Despite climatic conditions similar or wetter than today, the pollen record of the early phase of wetland establishment suggests semi-deciduous open woodland with sporadic occurrence of montane taxa, whereas present day forest fragments of the Pare plateau suggest humid lower montane forest vegetation. Three possible explanations are discussed to explain the under-representation of pollen from lower montane forests and the apparent absence of widespread humid forests in the first millennium AD.

First, the pollen signature of the submontane forests might be weak. Low pollen production or insufficient pollen dispersal can lead to a low pollen count of humid forest taxa. A literature review of published observations on pollen dispersal capacities (COETZEE 1967; HAMILTON 1972; HAMILTON 1982; MARCHANT & TAYLOR 1998) does not indicate any severe restriction on submontane forest taxa pollen production or dispersal in general. Consequently, the pollen signature probably accurately reflects the absence of submontane humid forest in the landscape surrounding the Lomwe swamp.

Second, the remaining forest fragments and sacred groves scattered throughout North Pare are not representative of the pre-farming vegetation cover of the mid-altitude upland. Humid lower montane forest was always restricted to sites with special ecological conditions or has even been created by human intention (GILLSON et al. 2003). Following this hypothesis, semi-deciduous woodland and thicket with floristic elements of the lowland savannah vegetation covered the North Pare upland during the first millennium AD. Dry woodland would have ascended the mountains, and humid forest was restricted to ecologically favoured refuges e.g. along streams. Thanks to cultural protection, these refugia of humid forest vegetation persisted until the present as sacred groves. However, present day forest fragments are scattered throughout North Pare on hilltops, slopes, and valley bottoms and are not restricted to particular humid environments. Dry woodlands as suggested might resemble vegetation found today on the comparatively arid Kiverenge hill and Mramba ridge dominated by taxa like *Acacia*, *Commiphora*, *Combretum*, *Dodonea*. But, even those two arid hilltops harbour a variety of dry forest taxa like *Olea capensis*, *Brachyleana huillensis*, *Albizia*, *Newtonia buchananii*, and *Podocarpus* (LOVETT & PÓCS 1993), which are absent from the impoverished pollen record of the first millennia AD. Finally, the intermediate to humid climate proposed for the first millennia AD (VERSCHUREN 2001; ALIN & COHEN 2003; RUSSELL et al. 2007; VERSCHUREN et al. 2009) does not support arguments for a dry woodland on the Pare plateau.

Thirdly, the lack of pollen reflecting a closed lower montane forest environment around AD 600 is the result of advanced anthropogenic transformation towards an open landscape. From terrestrial archives widespread forest clearance is inferred since the beginning of the Common Era. Following this scenario, the period of peat development at Lomwe swamp covers the post-clearance period, when submontane forest had been cleared substantially and open grass and bushland had begun to dominate. Scattered patches of secondary and remaining forest fragments prevailed and later obtained protection status as sacred groves. Such a fragmented landscape matches the pollen record: sporadic occurrence of typical montane forest taxa, but dominance of secondary vegetation and far-travelled woodland pollen from the plains. The latter probably encroaching upon the mountain slopes as a consequence of fires and favoured by changing microclimatic conditions following forest clearance.

Stable carbon isotope composition of buried topsoils at Mrongo show $\delta^{13}C$ values (-21 - -23‰) suggesting a mixed but C_3-plant dominated environment. Although stable carbon isotopes do not allow assignment of vegetation types, $\delta^{13}C$ reference values do allow exclusion of secondary bushland as well as semi-arid woodland and dry forests on the Pare slopes on the basis of their distinctly higher

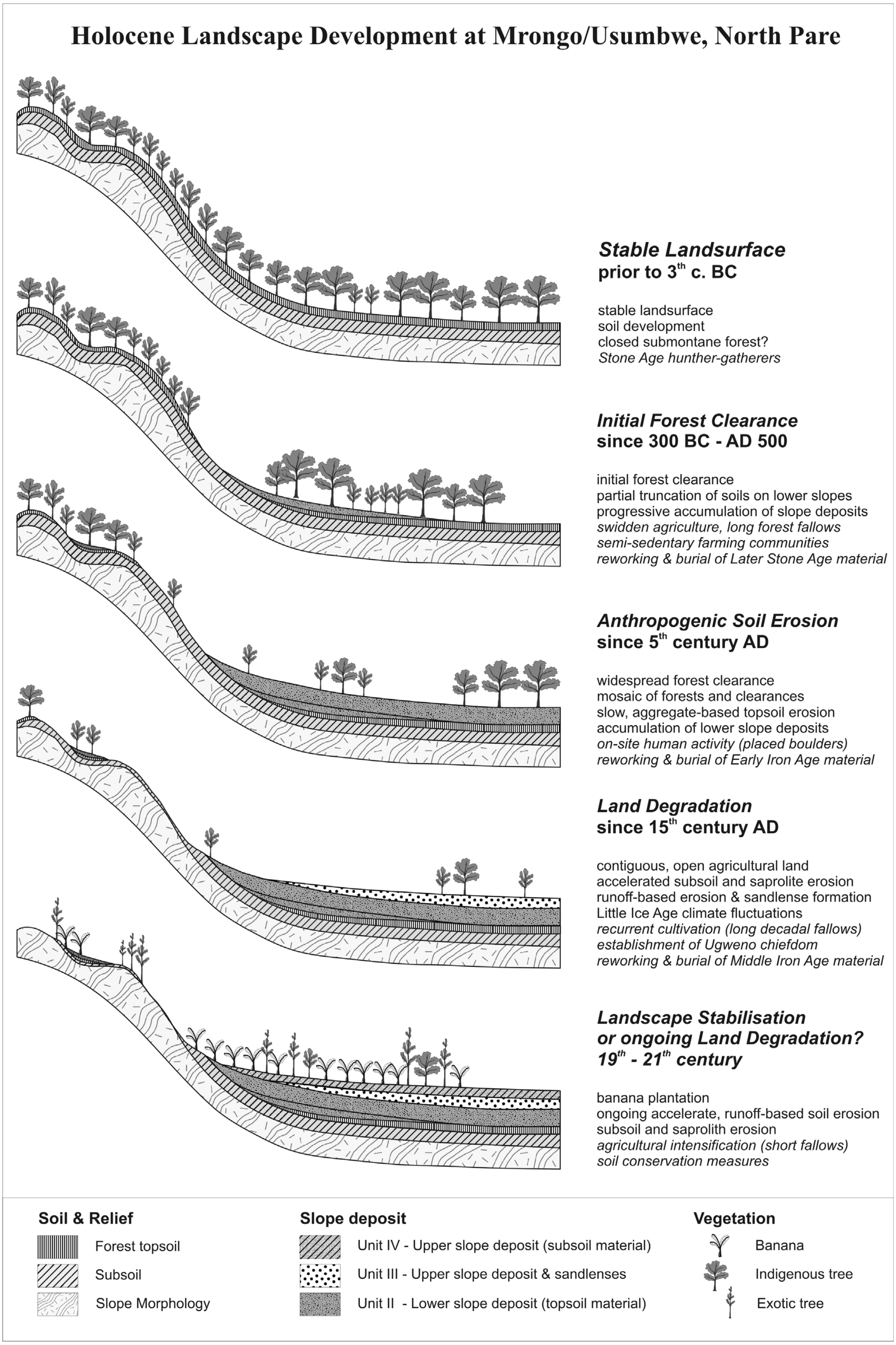


Fig. 57: Late Holocene landscape development at Mrongo and Usumbwe, North Pare.

$\delta^{13}C$ values (Tab. 13). Taking into account isotopic fractionation shown to occur in present day forest soils (chapter 8.5), it appears likely that the intermediate $\delta^{13}C$ values of buried subsoil at Mrongo are derived from a (sub-) montane forest akin to present day Kwa Kirumbi. The tentative suggestion from stable carbon isotope data needs to be viewed with caution and does not definitely prove the assumption of a dense pre-agriculture forest cover such as conveniently assumed by NEWMARK (1998; 2002) and HALL et al. (2009), and questioned by GILLSON et al. (2003). However, in conjunction with the Lomwe pollen record, the increasing stable carbon isotope composition of the slope deposits does indicate anthropogenic vegetation change in the first millennium AD and an opening up of a previous forest or woodland vegetation. At the time of swamp establishment, the original vegetation cover – probably a humid lower montane forest – has already been lost and was replaced by a mosaic of shifting agricultural fields and secondary forests of various succession stages dominated by woodland taxa, shrubs, and grasses as is reflected in both the pollen and the stable isotope record.

10.4.3 Wetland establishment and peat growth (6 – 12th century)

Generally, explanations of wetland formation invoke precipitation shifts and result in the reconstruction of regional climate dynamics. At Lomwe, peat establishment around AD 600 takes place in a period of intermediate climatic conditions that is generally assumed to be comparatively humid but which also spans the dry phase of the Medieval Warm Period (cf. Fig. 56). A climatic explanation could be stressed when linking the onset of wetland establishment at Lomwe with a short wet period in the mid-first millennium AD inferred from the nearest palaeoecological records at Lake Challa (RUCINA et al. in prep.) and Namelok (RUCINA et al. 2010). However, comparable climatic conditions have occurred several times during the Holocene as well as within the last two millennia, but have not resulted in similar wetland deposits.

Instead of climatic causes, anthropogenic soil erosion and the damming of drainage channels by the accumulation of corresponding deposits in the valley bottom are proposed as possible drivers of wetland formation at Lomwe. Rapid colluviation at crucial key locations of the Ndurumu stream could have acted as a barrier, effectively damming the small valley. Increased sediment load contributed to stream aggradation, additionally favoured by low slope gradients and low transport capacity of the small streams on the Pare plateau, thus preventing incision and clearing away of debris. In consequence, the water table of the valley rose and the Lomwe and Usangi swamps established. Instead of invoking ambiguous climate records, local human-induced morphological change is proposed to explain the abrupt onset of peat development around AD 600 at Lomwe.

New or re-establishment of swamps in cultivated mountain areas has rarely been documented in East Africa as most palaeoecological work focuses on undisturbed, high altitude swamps or crater lakes likely to provide records over long time intervals. However, wetlands are a common feature of flat valley bottoms not only in the intensively cultivated plateau zone of the Pare and Usambara Mountains but also in the highlands of Uganda and Rwanda. The proposed mechanism of anthropogenic soil erosion triggering the establishment of swamps can be tested there. Possible further humanly-made swamps might be found in the agricultural zone of Usambara, where three small wetlands surrounded by fields and settlements were investigated by MUMBI (2009). Similar to the Lomwe core, radiocarbon date reversals complicate the deposition histories and may point to anthropogenic disturbance, particularly as the establishment of all three wetlands is likely to have occurred within the last 300 years during a period of intensive human landscape transformation.

Few palaeoecological studies in East Africa discuss the causes of initial wetland establishment or link the pollen record and sediment stratigraphy to address the soil erosion history of the catchment. Although anthropogenically influenced and disturbed archives might be difficult to interpret, sediment stratigraphy offers important insights in settlement and land use histories, particularly useful for geoarchaeological research.

10.4.4 Catchment wide soil erosion (since the 12th century)

Initially a shallow swamp with small trees and or bushes, the Lomwe wetland developed into a papyrus swamp as concordantly shown by plant remains and high $\delta^{13}C$ values indicating dominance of C_4 swamp plants like *Cyperus papyrus*. At the same time, deposition of clay lenses free of organic matter indicates increased periodic flooding. Although the exact chronology of the swamp deposits is hampered due to the admixture of old reworked carbon, rapid burial by eroded hillwash sediments occurred after AD 1200 and may even be linked to later slope deposition formation discussed in chapter 10.4.5). With the onset of mineral deposition, tree pollen vanishes completely, whilst disturbance indicators and taxa typical for open secondary bushland dominate the pollen record. This indicates that most of the catchment was cleared and forests were replaced by non-arboreal secondary vegetation or cultivated land. Both the pollen and the sediment record suggest catchment wide forest clearance as a precondition for the observed hydrological change and the shift in the erosion/deposition regime. Soil erosion is no longer restricted to a single slope or confined to temporary clearances within a mosaic of regrowing secondary forest such as assumed for the early phase of cultivation. Instead, fields and clearings have merged and the lack of vegetation boundaries along longer and contiguous slopes initiated a higher energy erosion regime with strong runoff events. The eroded soil material is no longer relocated locally on the slope or deposited on the footslope but transported into the receiving Mashewa stream and finally deposited in the Lomwe basin.

The anthropogenic land degradation outlined above was enhanced by climatic change at the beginning of the second millennia AD. Between AD 1000 and 1270 a prolonged lowstand is reported from Lake Naivasha (VERSCHUREN et al. 2000; VERSCHUREN 2001). Roughly contemporaneous with the Medieval Warm Period (MWP, AD 800 - 1200) of temperate regions, this drought period is also recorded as a lowstand at Lake Challa (VERSCHUREN et al. 2009) and Lake Emakat (RYNER et al. 2007). Low stands are also reported from Lakes Tanganyika (ALIN & COHEN 2003) and Edward (RUSSELL & JOHNSON 2005), although palaeoecological work suggests asynchronicity or even an opposing trend for the Ugandan highlands (ROBERTSHAW et al. 2005; SSEMMANDA et al. 2005). Although prolonged and regionally significant, the magnitude of approximately two hundred years of more arid conditions was not as pronounced as preceding mid-Holocene aridity phases e.g. around 2000 BP, when lake desiccation at Lake Naivasha has been observed.

In palaeoecological studies, the MWP has rarely been picked up - exceptions being the Amboseli basin and Lake Challa. At Namelok swamp a short period of abundant pollen from grasses and savannah taxa accompanies a decline in *Syzygium* (RUCINA et al. 2010), whereas at Lake Challa the exposed lake bed was invaded by Cyperaceae and Poaceae (RUCINA et al. in prep.). Although palaeoecological evidence from nearby sites support a dry MWP, climate fluctuations during the MWP alone cannot be held responsible for the observed strong vegetation change, particularly the total absence of arboreal taxa in a montane environment, and can explain neither the abrupt onset nor the prolonged deposition of mineral material at Lomwe. Prolonged aridity debilitates the resilience of ecosystems and thus the MWP may have facilitated and enhanced the effect of anthropogenic land degradation but did not cause environmental change at Lomwe. Against the background of a more arid climate, progressive anthropogenic forest clearance and opening up of the vegetation cover around AD 1200 pushed the ecological system of the Lomwe watershed beyond an ecosystem immanent threshold, and severe soil erosion and material discharge set in.

10.4.5 Accelerated and runoff-based soil erosion – the legacy of past land degradation? (15th to 19th century)

In the 15th century, processes of erosion and deposition on the Pare slopes changed. Thus far relocation of soil material occurred principally by tillage erosion, rainsplash and overland flow (cf. chapters 8.6 & 9.3.2). However, on the turn of the 14th to the 15th century (between AD 1340 and AD 1470) runoff-based erosion becomes important at the same time as deposition rates start to increase. Three factors are thought to control the changing erosion and deposition regime: magnitude and pattern of precipitation, changes in cultivation techniques and land use intensity, and crossing of ecological thresholds as a consequence of cumulative effects of land degradation arising from prolonged forest clearance and past soil erosion.

Accelerated and runoff-based erosion is inferred from sand lenses recorded in the slope deposits, indicating differential transport and deposition of coarse particles, typical for sheet wash and rill erosion. A precondition for sheet wash and rill erosion is runoff concentration, which is enhanced by strong precipitation and reduced infiltration. Strong but infrequent rainfall events under a seasonal rainfall regime favour runoff production, rill erosion, and hence sand lens formation. Infiltration capacity on the other hand depends on the cultivation technique, crop types, slope length, and roughness, but particularly on topsoil properties such as soil structure, bulk density, and abundance of macro pores.

In the study areas, centuries of slow soil erosion have reduced soil depth substantially. Frail porous topsoil material has been eroded away and subsoils are exposed and now subject to mobilisation as shown by decreasing magnetic susceptibility values of the correlated deposits. Infiltration capacity of exposed subsoil horizons is considerably reduced due to a high packing density, a compact soil structure, and a low pore volume of subsoils. Forest clearance and the establishment of large, contiguous fields facilitate runoff production by increasing source area, slope length, and by reducing the number of temporary sediment traps such as small forests fragments. Farming practices such as mulching, organic matter incorporation and the choice of crop types also influence infiltration capacity and runoff production. However, sand lenses and hence rill erosion have been observed on bare fields, on maize fields, and under dense banana plantations, suggesting other parameters are more decisive.

The combination of reduced infiltration capacity due to topsoil erosion and subsoil exposure, changing land use practices such as the establishment of larger contiguous fields and reduced fallow periods (cf. chapter 8.6), all play together resulting in enhanced soil erosion rates and runoff based material transport. After fifteen centuries of slow but progressive forest clearance and topsoil erosion, soil erosion crossed an environmental threshold and a new set of processes took over. Subsoil exposure and increased runoff are the first obvious consequences of irrevocable land degradation after centuries of unnoticed resource depletion.

Following oral accounts, the history of the present day Wagweno people commenced when the mythical founder migrated to Pare after being expelled for food theft from the Taita mountains (KIMAMBO 1969). Being oral traditions, these narratives need not be taken literally and certainly need not refer to wholesale migration of communities or clans but instead may reflect the creation of a cultural Wagweno identity. Nevertheless, explicit reference to food insecurity - as with many later migrations – may indicate migrations as a consequence of famine and possible climatic droughts (KIMAMBO 1969). Based on oral histories, KIMAMBO (1969) reports that major socioeconomic change in North Pare occurred about 16 generations ago and estimated this cultural transition to fall in the late 15th or early 16th century. Although WINTER (1992) has questioned Kimambo's chronology on the grounds that some Pare genealogies appear to treat male siblings as different generations, the rough temporal correspondence between the changing erosion regime and the emergence of a new organised and hierarchical society might be more than mere coincidence and warrants discussion. The shift in economic and political power and the establishment of Wasuya rule marked the emergence of a hierarchical society characterised by labour division, a strong kinship based organisation and a politically instrumentalised initiation ceremony. Strong labour division and a tribute system point to organised resource exploitation, and this could conceivably lead to an increasing pressure on the shifting cultivation cycle, reducing fallow periods and encouraging encroachment on forests and secondary vegetation.

If so, the reorganisation of society and land use practices might have had serious consequences on the Pare environment. While an intensification of land use is likely, long fallow periods must have prevailed on the studied footslopes to allow sand lenses to be buried and preserved (cf. chapter 8.6). However, long fallow periods up to several decades might still represent an intensification stage compared to previous periods of swidden agriculture, when fields were left open to be overgrown by secondary forests. Since the 15th century, recurrent cultivation of the same field but with long decadal fallow periods is proposed. This practice agrees with the sedimentological evidence of sand lens preservation and accelerated erosion and fits with concurrent cultural transformation proposed by historical research (KIMAMBO 1969).

The emergence of a stratified society and organised resource exploitation in the 15th/16th century as suggested by KIMAMBO (1969) could have triggered land use intensification and shorter fallow periods. In this context, it is noteworthy to emphasise the selective nature of the impact cultural transformation may have on the environment. The spread of TIW wares since 5th century AD along the coast (CHAMI 1994) and the later occurrence of Maore ware in the Pare Mountains has often been hypothesised to relate to cultural change (e.g. SOPER 1967b) but is not reflected in the environmental record of North Pare. The environmental history of Pare so far, however, does not depend on cultural change. Progressive land degradation on its own, as outlined above, is in itself sufficient to explain the observed change in the environmental process system and might even has caused the reduction of fallow periods due to decreasing soil fertility after topsoil removal.

Climate dynamics or the advent of new food crops such as banana are further external factors which might have triggered rill erosion, migration and socioeconomic change. In the Great Lakes Region of Uganda detailed oral accounts and genealogical information are available and narrate the rise and fall of the interlacustrine kingdoms (SCHOENBRUN 1998). Several palaeoecological studies have pointed out correlations between political changes, shifts in the subsistence practices and climate dynamics – with particular focus on recurrent droughts associated with the Little Ice Age (ROBERTSHAW & TAYLOR 2000; TAYLOR et al. 2000; TAYLOR & ROBERTSHAW 2001; ROBERTSHAW et al. 2005; LEJJU 2009).

During the Little Ice Age (LIA, AD 1550 – 1850) prolonged aridity has been reported from the interlacustrine highlands (TAYLOR et al. 2000; RUSSELL et al. 2007) at Lake Edward (RUSSELL & JOHNSON 2005; RUSSELL & JOHNSON 2007) and Lake Tangayika (ALIN & COHEN 2003; STAGER et al. 2009). An opposing climatic trend and generally wetter conditions are observed for the eastern part including Lake Victoria (STAGER et al. 2005) and Lake Naivasha. Most relevant for North Pare are regional palaeoclimatic reconstructions from Northern Tanzania and Southern Kenya. Lake level changes at Lake Naivasha (VERSCHUREN et al. 2000; VERSCHUREN 2001), Lake Emakat (RYNER et al. 2007) and Lake Challa (VERSCHUREN et al. 2009) suggest generally wetter conditions in north-eastern Tanzania after the marked dry period of the MWP. Lake levels rose after about AD 1200 but were frequently interrupted by short-lived, decadal drought events. At Lake Naivasha drought events are correlated with maxima of sunspot activity (VERSCHUREN et al. 2000): a pattern also shown by $\delta^{18}O$ signatures from the Kilimanjaro ice cap recording a generally colder climate (THOMPSON et al. 2002) or, if stable isotope discrimination is interpreted in terms of dilution, a more humid environment (GASSE 2002) interrupted by drought periods. Similarly, a prolonged dry period between AD 1450 and 1650 at Lake Emakat emphasises the importance of drought events during a period of generally enhanced humidity (RYNER et al. 2007). Variability of precipitation during the Little Ice Age was high not only along an east-west gradient (RUSSELL et al. 2007) but also on a regional scale. Decadal drought events were common even in the wetter eastern part, as the lowstand of Lake Emakat illustrates. Compression or southward movement of the ITCZ as a consequence of irradiation decline during the sunspot minima possibly coupled with ENSO variations have been proposed to explain the spatial variability of LIA climate dynamics (RUSSELL & JOHNSON 2007; RUSSELL et al. 2007; STAGER et al. 2009).

In Northern Tanzania drier conditions around AD 1400 suggested by declining lake levels at Lake Emakat have been interpreted as triggering the implementation and expansion of irrigated agriculture at nearby Engaruka (WESTERBERG et al. 2010). Engaruka on the footslopes of the Ngorongoro Crater highlands is well known for its large and extensive stream-fed irrigation features and maintained a considerable population in a semi-arid environment (STUMP 2006). For Pare, the varying lake level records and the contradictory pollen records from Namelok swamp (RUCINA et al. 2010) - indicating dry conditions - and Lake Challa (RUCINA et al.) - implying increased precipitation - suggest more locally variable climatic patterns, however. Rainfall after prolonged dry periods is likely to have a similar impact and may have accentuated a seasonal precipitation pattern, which has been identified as favouring runoff-based erosion and the formation of sand lenses. On the other hand, rill erosion and sand lens formation are observed under contemporary intermediate climatic conditions in fields with or without the protective vegetation cover of banana plantations. Therefore, it is unlikely that particular climatic conditions were the sole reason causing runoff production and hence rill erosion and sand lens formation during a restricted time period.

In conclusion, it would appear that widespread runoff-based erosion developed since the 15th century as a long-term consequence of prolonged soil erosion, topsoil removal and land degradation initiated by the expansion of agriculture in North Pare. The creation of a Wagweno identity and the related cultural and socioeconomic changes dated through genealogical sources to the 15th/16th century may have been accompanied by new farming practices and a shift from swidden agriculture and slash-and-burn practices towards a more intensified agricultural land use characterised by further agricultural expansion and recurrent cultivation of established fields. Nevertheless, long fallow periods of a decade or more must have prevailed for centuries to allow the preservation of sand lenses cited here as evidence of runoff-based erosion. Although the exact local climatic conditions are unknown, decadal droughts during the LIA with sporadic and seasonal rainfall events are likely to have contributed to generate runoff-based erosion under open secondary vegetation.

10.4.6 Possible impact of 19th-century agricultural intensification

It has been argued that the establishment of economic trade networks during the 19th-century caravan trade stimulated major socio-economic and political changes and promoted agricultural intensification in Pare (HÅKANSSON & WIDGREN 2007; HÅKANSSON 2008; HÅKANSSON et al. 2008). Landesque capital such as terraces and irrigation systems reported from 19th-century Pare (MEYER 1890; BAUMANN 1891) have been taken as material evidence for what is otherwise difficult to prove agricultural intensification (HÅKANSSON & WIDGREN 2007; HÅKANSSON 2008; STUMP 2010). However, several other mechanisms have been proposed to explain the creation of landesque capital and the application of soil conservation methods in Pare (SHERIDAN 2002; STUMP 2010), Mbulu (BÖRJESON 2004, 2007), and Engaruka (WESTERBERG et al. 2010), and the motives as well as the age of agricultural intensification in Pare remains inconclusive. At the onset of this research it was envisaged that the land use change brought about by this assumed agricultural intensification might have influenced the magnitude and type of soil erosion processes and thus would affect the sedimentary record of slope deposits.

Contrary to the expectations, colluvial deposits in all of the three study areas did not reveal any direct evidence for successful soil conservation measures and landesque capital in Pare. Further, the subrecent deposits corresponding to the period of interest could not be dated directly due to the inherent ambiguities of single radiocarbon dates from the last three centuries. Despite dating uncertainties and the lack of a strong change in the erosion and deposition processes, there is indirect evidence for land use intensification in the 19th century. Accelerated and runoff-based erosion started in the 15th century and sand lense formation continues until the present day. Although undated, the cessation of sand lens preservation is interpolated to have taken place between AD 1780 and AD 1900 and coincides roughly with the 19th-century caravan trade (Tab. 12). Cessation of sand lens preservation in slope deposits has been linked to destruction by regular soil working, reflecting a more permanent cultivation during the deposition of the uppermost slope deposits (chapter 8.6). This assumption agrees with observations by KOTZ (1922:146), who reports fallows of one to two years followed by a three to four year period of cultivation for the first decade of the 20th century. Such a reduction of fallow periods would have erased the imprint of runoff-erosion in the colluvium preserved by sand lenses since the 15th century. Building on KOTZ (1922) observations, intensification of agricultural practises must have taken place prior to the turn of the 20th century. Given the lack of a firm chronology, identification of a more specific time is not possible. Whether shorter fallows and the inferred step of agricultural intensification were related to the assumed economic boom stimulated by the caravan trade (HÅKANSSON 2008) or, in contrast, was initially a consequence of political commotion and population concentration in the late 19th century and later maintained by economic and political stability and subsequent population growth during the early colonial period, warrants further investigation.

10.4.7 20th-century land cover changes

Land use changes in the last century have been studied on various scales. Based on satellite images, aerial photographs and map evaluation, forest cover changes of the Eastern Arc Mountains (NEWMARK 1998; NEWMARK ; HALL et al. 2009), and more specific land use change in the Pare Mountains (YLHÄISI 2004) and Taita Hills (PELLIKKA et al. 2009) have been investigated. NEWMARK (1998; 2002) and recently HALL (2009) have made an attempt to estimate the total forest loss of the Eastern Arc Mountains since the beginning of anthropogenic forest clearance about 2000 years ago.

The prehistoric forest cover is arbitrarily assumed to have covered the mountains down to its base on the eastern, windward side and about 400m higher on the leeward side due to rain shadow effects. Estimates of forest loss range from 76% to 80% for the Eastern Arc Mountains (NEWMARK 1998; NEWMARK 2002). In North Pare, HALL et al. (2009) calculate forest loss to about 92% by AD 2000. Considering only indigenous forests, YLHÄISI (2004) concludes that only 4% (15 km^2) of the potential forest area (365 km^3) of the North Pare Mountain still holds closed primary forest. The high forest reduction in North Pare compared to other Eastern Arc Mountains is probably the combined result of its small size and the tectonic plateau setting, which facilitated cultivation and settlement and thus a high population density.

The study of HALL et al. (2009) shows that 89% of the estimated original indigenous forest in North Pare had been cleared before AD 1955 (75% for all Eastern Arc Mountains). In a similar way, aerial photographs from the 1950s (Fig. 25, Fig. 17, Fig. 18) support the picture outlined by historical accounts for the end of the 19th century (MEYER 1890; BAUMANN 1891): A general lack of forests, few dispersed trees within large areas of open cultivated land, or secondary vegetation in various succession stages from bare land, ferns and shrubs, to bushland and finally secondary forest. Most recent clearances had affected large areas of the Kamwalla and Kwa Chegho/Kirumwi mountains, where bare ground and shrub vegetation covered the mountain tops in the 1950s (Fig. 19). Timber demand for colonial infrastructure projects like the Dar-es-Salam – Moshi railway construction, as well as construction of missionary stations and private enterprises, prompted the establishment of logging companies in the Usambara mountains (SCHABEL 1990; CONTE 1999). Although in North Pare no logging concessions are known, similar incentives can be assumed for the early 20th-century deforestation.

The pollen record from Lomwe reflects a total lack of arboreal taxa after the 12th century and the general absence of trees and forests continues until the 19th century. Only within the last century did a diverse set of trees ranging from woodland to montane forest taxa emerge. Dominated by the exotic *Cupressus* and *Eucalyptus*, the return of arboreal taxa mirrors the successful colonial afforestation efforts. Conservation measures such as the gazetting of forest reserves started during German occupation, but widespread reforestation schemes were implemented only between 1935 and 1955 during British rule. Alone in 1951, over half a million trees were planted in North Pare (SHERIDAN 2001: 287). Declining deforestation rates in the late 20th century are observed at most Eastern Arc Mountains and are likely to arise out of the decreasing availability of forest resources but also must be attributed to successful conservation strategies. In North Pare, high initial deforestation rates of 25% between 1955 and 1975 declined to 3.7% between 1975 and 2000 (HALL et al. 2009). PELLIKKA et al. (2009) takes a contrary view studying forest cover change in the nearby Taita Hills, where total forest cover of selected areas declined only marginally (2%) between 1955 and 2004 but indigenous forest was reduced by up to 50%. The results of PELLIKKA et al. (2009) and HALL et al. (2009) show that strong conservation efforts and the reduction of the overall deforestation rates due to successful local reforestation measures mask the ongoing severe clearance of ecologically important indigenous forest.

In Pare, the planting of trees is a means to maintain tenure rights by low labour investment and tree planting (e.g. *Grevillea*, *Cupressus* or *Eucalyptus*) along field borders and as shade trees in agroforestry systems soon became popular. The seedlings planted throughout Pare in the 1950s changed the Pare vegetation cover: a mostly treeless landscape in AD 1890 as observed by MEYER (1890), BAUMANN (1891) and VON DER DECKEN (1869) is today characterised by small plantation forests on eroded hilltops and widespread scattered trees and tree clumps offering firewood and fodder.

As the most favoured reforestation taxa due to good timber quality and fast growth, *Eucalyptus* has been planted on many degraded areas all over Pare. Overgrown with ferns, areas of exposed saprolite were widespread in the early 20th century as Mronga Shimbiri Msangi from Manico recalls (informal interview, 2010). It is likely that these strongly degraded areas were targeted by colonial and postcolonial afforestation programs and have been converted into *Eucalyptus* plantations, since these in North Pare grow almost entirely on strongly eroded sites. The ecological value of exotic timber plantations is low and even negative impacts on soil ecology and hydrology have been suggested (SANGHA & JALOTA 2005; FAO 2011). Widely planted *Eucalyptus* and pine are strongly competitive taxa, and inhibit the establishment of diverse secondary undergrowth vegetation and retard topsoil formation, thus promoting further soil erosion and land degradation. Although *Eucalyptus* cannot be

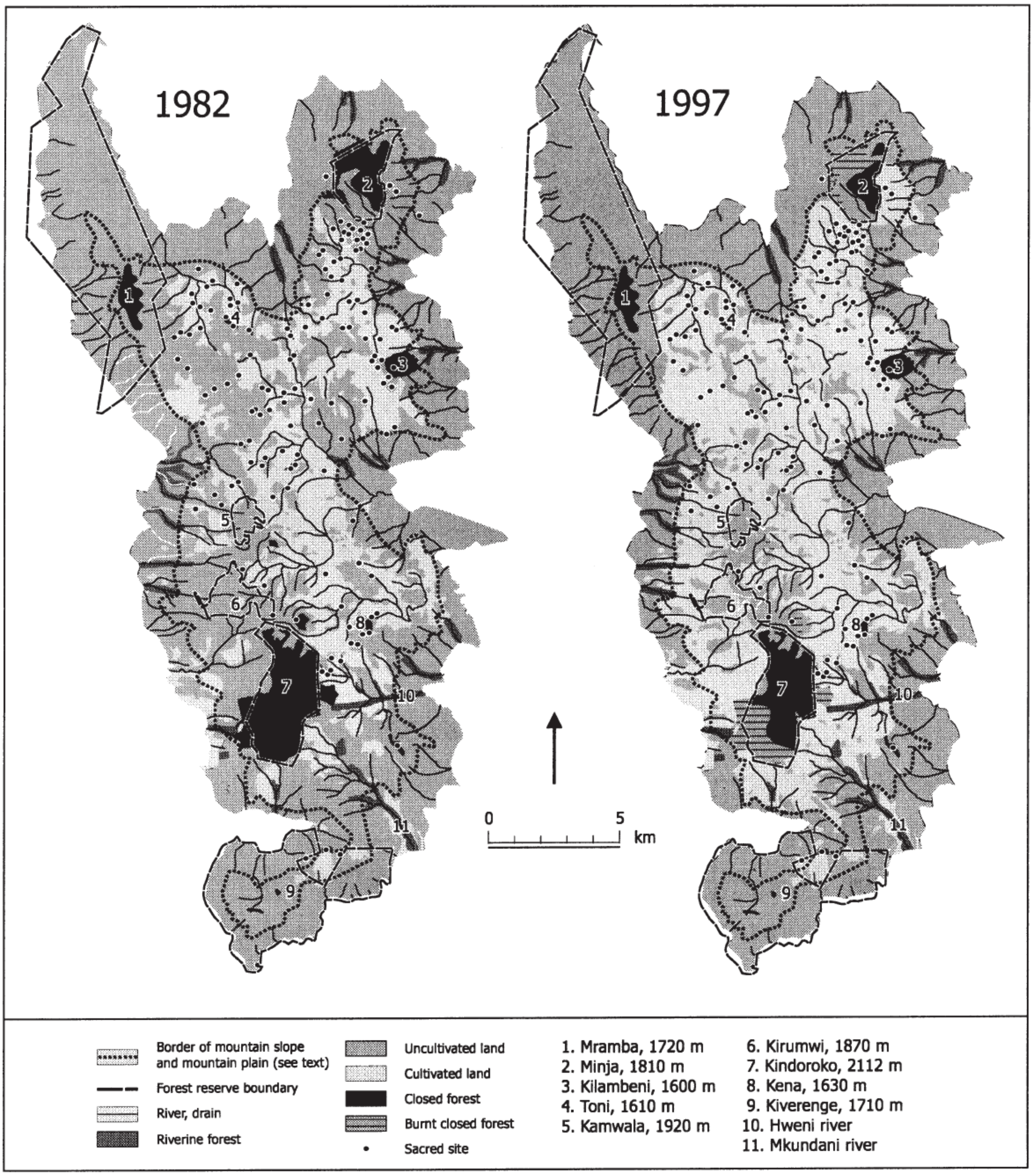


Fig. 58: Land cover from 1982 and 1997 in the North Pare Mountains (Source: YLHÄISI 2004).

blamed for the initial degradation, it currently fails to protect the soil surface and hinders topsoil formation by impeding undergrowth. Exceptions are observed in fertile areas such as on slope deposits at Lomwe or under mixed secondary forest vegetation at Kwa Chegho.

The rapidly increasing North Pare population during the 20th century (SHERIDAN 2002) created the demand for new agricultural land, construction timber, charcoal and firewood putting pressure on the forest resources. The clan and family based land tenure system also contributed to the fragmentation of farms and the expansion of the agricultural frontier. Between 1982 and 1997 the area of cultivated land increased by 68% from 73 km² to 123 km² (YLHÄISI 2004) but the expansion took place at the expense of 'uncultivated land' converted into agriculture (Fig. 58). This category includes open dry forests on the escarpment as well as swampy valley bottoms and riverine thickets, but the better part consisted of secondary bushland and woodland of various succession stages on former cultivated land.

The expansion of agricultural land into traditionally protected areas such as swamps, stream banks, sacred groves and high altitude indigenous forests was not only a consequence of increasing population pressure but accompanied the decline of traditional values and belief systems (SHERIDAN 2001, 2004). Colonial rule, post-independence governmental politics, and the Christian and Islamic missions questioned traditional sets of values and beliefs and undermined the authority of elders and clan leaders. Traditional environmental protection mechanisms such as the conservation of traditional forest reserves and restrictions on swamp and riverine cultivation have been eroded, whereas governmental and non-governmental efforts for protection are seen with distrust and lack legitimacy as they are often imposed without consideration of local needs and traditions (SHERIDAN 2001).

Today, land clearing and expansion of agricultural land takes place in highland areas >1600m a.s.l. At the same time, fallow land and encroachment of secondary vegetation is observed on many plots within the agriculturally favourable Pare upland. The Pare land tenure system of male partible inheritance, whereby land is divided equally between the sons, is responsible for the fragmentation of agricultural land into small uneconomic plots and stimulates the out-migration of young people unable to make a living from these small plots. While many agricultural plots lie fallow because of the migration of their owners, communal tasks like the running of irrigation systems become harder and economic efficiency declines further. The consequence of this artificial land shortage is the expansion of the agricultural frontier into the less populated lowland and highland areas fostering clearance of the remaining indigenous forests.

10.5 **Behind the paradigms: Does the land lie?**

Environmental narratives of land degradation and the often non-consensual implementation of soil, vegetation and biodiversity conservation measures have been a central part of African development policies in the last century. The apparent demise of agricultural land as stated by ecological assessments of land degradation in the context of rapid population growth and influenced by the American Dust Bowl experience and exceptional climatic famines in the Sahel prompted calls to action. The observation of widespread land degradation under traditional agricultural practices turned into a general concept and prevailed as received wisdom (REIJ et al. 1996; KONING & SMALING 2005; MUCHENA et al. 2005). During the 20th century degradation narratives have become commonplace in most of Africa and have shaped land development projects, influenced the establishment of conservation areas, and may even have replaced local and traditional histories of environmental change in order to attract funding (JONES 1996; LEACH & MEARNS 1996).

These narratives of ubiquitous land degradation - the so called 'lie of the land' (LEACH & MEARNS 1996) - were challenged by new, often historically oriented research bringing forward positive histories and portraying sustainable, indigenous land use and soil conservation practices, alongside traditional protection of forests, and human-made landscape domestication that increased productivity and even biodiversity (TIFFEN et al. 1994; LEACH & MEARNS 1996; FAIRHEAD & LEACH 1999). The polarization of views between the received wisdom of generalised land degradation on one hand and an also generalised critique of orthodox development strategies based on positive case studies of traditional land use on the other, has opened the discussion about the wider framework of land degradation and human-environment interactions including social (livelihood, vulnerability, culture), economic (prices, trade networks, subventions), political (tenure, poverty) as well as agricultural, climatic and environmental factors (KONING & SMALING 2005; MUCHENA et al. 2005). Most importantly however, historicity of landscapes was recognised as a crucial aspect of environmental work to understand the present state of ecological and agricultural systems (CHRISTIANSSON 1981; LANE 2010). Further, emphasis has been put upon the ubiquitous nature of human activity even in long-assumed 'virgin' environments (WILLIS et al. 2004). The integration of palaeoenvironmental work to understand long-term environmental developments has added a whole new dimension to the debate over land degradation, sustainable agricultural practices, and development strategies (MARCHANT et al. 2010). The investigation of landscapes as dynamic and historical systems yet again shows that trajectories of environmental change are local and site-specific and warrant careful investigation of the actual causes and processes responsible for present day conditions.

The investigation of colluvial deposits in Pare does not indicate that indigenous soil conservation measures such as terracing, irrigation and manure application did decelerate soil erosion. Deposits concurrent with both the post-15th-century Wagweno state and the assumed agricultural intensification during the 19th century are characterised by high deposition rates and subsoil erosion and indicate enhanced soil erosion and land degradation rather than effective soil conservation. The lack of preserved evidence from slope deposits, however, does not rule out that the construction of terraces, the establishment of the irrigation system, or manure application did take place and were attempts to maintain soil productivity. But, they were not successful enough to decelerate soil erosion on the particular slopes. Similarly, 20th-century afforestation and implementation of soil conservation measures as well as increased fallow periods due to out-migration is not (yet?) documented in the sedimentary record.

The fact that indigenous people have dwelled in the landscape for millennia and adapted their livelihood strategies according to their environment does not necessarily imply sustainable land use or the application of effective soil conservation practices. The present study shows that from at least the early first millennium AD, land use in Pare had long-term environmental consequences and thus, over this period, has not been sustainable. Although imperceivable in the beginning, the soil resource has been depleted slowly but steadily. Land degradation, however, only became apparent when ecological thresholds were trespassed and a new process system established. Two examples of process shifts have been presented: catchment wide forest clearance triggering the onset of mineral material deposition in the Lomwe swamp and area-wide exhaustion of the topsoil resource leading to subsequent runoff-based subsoil erosion.

Ecosystem resilience and non-linear behaviour near environmental thresholds are difficult to assess parameters of ecosystems, particularly when investigating dynamic systems and human-climate-environment interactions. Precipitation changes during the MWP or the LIA can be correlated with changes of the environmental record in Pare, although this study does not hold them responsible for the observed changes in the erosion regime. Rather than climatic changes, the protecting vegetation cover and the properties of the soil surface changed after clearance and topsoil erosion. Given the new boundary conditions, continuous land use under a constant climate may suffice to trigger landscape transformation. This conclusion differs from many other scholars who emphasise the dominance of climatic influence on environmental change, generally, because direct anthropogenic forcing cannot be corroborated.

Following the shift from one process framework to another, the impact of internal and external interventions may change although direction and magnitude remain the same. Consequently, evaluation of resource exploitation strategies has to take into account the respective historical, ecological and socio-economic framework. Thus, indigenous land use techniques common in pre-colonial times might not be viable options under different contemporaneous circumstances. Population growth, distinct socio-economic and cultural structures, but also different climatic and - as the present study shows - pedological conditions require the adaptation of livelihood strategies. Whereas swidden agriculture might have been an acceptable land use practices during the early centuries of farming, it set off unnoticed a history of soil erosion requiring agricultural adaptation, and possibly starting a cycle of agricultural intensification in Pare *sensu* BOSERUP (1965). Adaptations of land use and agricultural intensification have the potential to conserve the soil resources; however generally follow with a time lag. Thus, agricultural intensification itself is an indicator that former land use has become unsustainable under new boundary conditions. Today, establishment of drastic soil conservation measures such as terraces is the latest move and a best guess to stabilise the Pare environment in the long run (although soil fertility might decrease in the short term, being one of the reasons for reluctant acceptance by local farmers). Whether or not the currently proposed soil conservation practices will be more successful than former attempts is beyond present knowledge and only time will tell.

Blaming any single generation of farmers, agricultural officers or scholars for accelerated soil erosion or unsuccessful conservation measures will be misleading. Instead, the challenge today is to understand the development of the anthropogenic landscape, its past trajectories and critical turning points and confront the often complex histories of land degradation, with all the available knowledge of today - as generations before have attempted under their respective circumstances.

11 CONCLUSION

The present study set out to investigate the past soil erosion history of North Pare based on the colluvial record of slope deposits. Its aim was to elucidate the interactions of climate dynamics, anthropogenic land use, vegetation change, and to reconstruct environmental processes and landscape development particularly since the introduction of agriculture and iron smelting. The approach combined geoarchaeological, pedological, and palaeoecological techniques to establish a history of landscape change in North Pare and put historical accounts and present day narratives of land degradation into perspective.

In contrast to previous archaeological, historical, and palaeoecological studies in Pare, the applied landscape-based approach focuses on the characteristics and features of terrestrial archives to infer past surface processes and reconstruct Holocene landscape evolution. The investigation of slope deposits as corresponding archives of soil erosion directly linked to landscape processes is not only a new methodological approach in East Africa but also sheds light on the late Holocene landscape history in north-eastern Tanzania so far subject to speculation.

The identification of soil and surface processes draws on sedimentary and pedogenetic benchmark features primarily aggregates and sand lenses and was supported by magnetic susceptibility as criteria of subsoil and topsoil erosion, whilst stable carbon isotope composition was employed as a proxy for vegetation cover. Although in the first instance a history of soil erosion, the findings have strong implications for the temporal development of past vegetation cover and particularly land use. The correspondence of site-specific developments from three study sites confirms their regional significance and allows extrapolation of observed patterns and processes from the only suggestive data of single profiles to a generalised model of North Pare landscape development.

The most important finding is the confirmation of over 2000 years of land clearance, farming and probably iron working based on the sedimentary record, which supplements the more limited archaeological evidence for early occupation in Pare. Widespread burial of soils, the occurrence of potsherds, abundant charcoal, and subsequent uninterrupted soil erosion in North Pare corroborates the timing and hence the rapid spread of food producing subsistence strategies suggested by dispersed archaeological findings in north-eastern Tanzania. A pronounced shift from an early period of slow topsoil erosion to an accelerated and runoff-based erosion regime since the 15th century corresponds with the onset of both climatic fluctuations of the Little Ice Age and the extrapolated establishment of the Ugweno state in North Pare. This temporal coincidence opens the debate about timing and impact of human-climate-environment interactions prior to the 19th century, so far dominated by oral accounts and undated changes in pottery traditions.

Whereas the onset of land clearance in the course of expansion of farming and iron working has left a strong imprint in the terrestrial archives, there is only suggestive evidence for 19th-century agricultural intensification. Against the background of 2000 years of prolonged soil erosion, evidence for truncated subsoils and the lack of arboreal vegetation since the 15th century confirm the existence of a bare and treeless landscape as reported by 19th-century European travellers and observed on mid-20th-century aerial photos: a degraded environment that prompted subsequent colonial soil conservation and afforestation measures.

Finally, the lack of slope deposits dating to the early and mid-Holocene corroborates surface stability similar to findings from pedisediments in the Irangi Hills and the Mindu Mountains, and is in accordance with palaeoecological findings of vegetation stability in the Eastern Arc Mountains. Only rapid and strong climatic change during warming and wetting steps at the end of the late Pleistocene has left its imprint in the terrestrial record of Pare. The silence of the terrestrial record in Pare contrasts with active slope dynamics on neighbouring Kilimanjaro and fluctuating lake levels in most of East Africa during the Holocene.

The coincidence of shifting erosion processes and material change in the 15th century is interpreted as the result of an internal development: prolonged cumulative erosion leading to the exposure of subsoils and triggering a new set of erosion processes. This explanation draws the attention from the study of external changes (e.g. climate, tectonics and land use changes) to the consequences of prolonged and directed internal developments in a non-equilibrium system. It leads to a retrospective evaluation of the ecosystem resilience, particularly the ecosystem response to the directed long-term impact of farming, and examines the implications of such a rapid transition to a new process framework. In retrospective, it becomes possible to identify critical impacts or trends, which ultimately resulted in resource exhaustion and system change, but it also highlights, when possibilities of recovery where used or neglected.

Ecological thresholds play a crucial role in landscape development and in vegetation and climate dynamics. The identification of such a changeover from one state to another is, however, difficult. Both of the pivotal events presented here - damming of streams by excessive sediment supply in response to widespread land clearance at Lomwe and accelerated runoff-based soil erosion as a consequence of subsoil exposure at Mrongo and Usumbwe - are preceded by a prolonged state of apparent stability and a rapid transition to a new processes framework with a distinct environmental imprint. Once the environmental process framework has changed, the response to external and internal drivers is readjusted and the same external impact may cause different results. Despite the temporal coincidence with oral historical evidence for societal transformation and the climatic fluctuations of the Little Ice Age, the observed environmental changes in Pare since the 15th century are attributed here to prolonged anthropogenic land use; albeit that favourable climatic conditions or changes in the land use techniques might have contributed or enhanced the observed effects.

The emphasis on anthropogenic land use brought forward by the present study deviates from a wide range of palaeoecological and lake-level based climate reconstructions and may stimulate further discussion and investigation. It highlights the different responses of palaeoarchives depending on type, location, size, and investigation method. High-altitude locations far removed from early farming communities record human impact only after a time delay, as do large lake catchments, regardless of their physical proximity to the events in question. Small sediment traps in agricultural zones, in contrast, are likely to be dominated by anthropogenic instead of climatic influences and respond immediately and strongly to such local disturbance. Site selection and choice of investigation method for the respective research question thus warrants close consideration when tracing the impact of human land use.

An important aspect of past land use reconstruction is the tentative suggestion that characteristic features of slope deposits reflect increasing levels of land use intensity. Based on the interpretation of sand lens occurrence, this interpretation presents an indirect but consistent picture of intensifying land use. Slow erosion during land clearance in the early centuries of the first millennium is explained by extensive swidden agriculture and secondary forest regrowth. Since the 15th century, sand lens preservation and accelerated soil erosion in an open cultivated landscape suggest recurrent cultivation of the same field albeit with long decadal fallow periods. Finally, short fallows or permanent cultivation inferred from the suppression of sand lens preservation since the 19th/20th century reflect the most recent intensification stage.

For archaeological research, the reconstructed landscape development of Pare has important implications. The advanced erosion of slopes predicts a lack of archaeological sites in North Pare, particularly Early Iron Age sites. On the slopes, sites are likely to be eroded, their remains reworked, translocated and stored in the slope deposits. *In situ* sites might only be found at footslope positions or in slope depressions where colluvial deposits have buried and preserved the evidence; though in this latter circumstance they will be hard or impossible to locate by common surface survey techniques. Thus, the present distribution of reported archaeological sites does not reflect the original distribution but is biased by subsequent site destruction and erosion of the former surfaces.

Narratives of land degradation and environmental development find themselves discussed between two extremes: one that sees indigenous land use as adapted to the local environment through the maintenance and conservation of resources, whilst the other regards local land use as predisposed to resource depletion, either because individuals do not perceive the long-term dangers of such a strategy, or because it is imposed by circumstances (e.g. economics) beyond their control. The late Holocene environmental history of the North Pare Mountains presents a clear picture of long-term soil erosion over the past two millennia and enhanced land degradation during the last five hundred years. It demonstrates that indigenous land use practices are not necessarily sustainable or adapted to their environment and instead may have long-term consequence and lead to progressive land degradation. The environmental history of North Pare once more highlights that reconstructed environmental narratives are always site-specific and present conditions are the result of a local historical development that precludes generalisations of the underlying causes.

11.1 Caveats and methodological critique

Multi-proxy approaches comprehensively address different aspects of environmental records by combining a variety of analyses. The approach is robust and does not rely on a single parameter, which may or may not be suitable for the respective research question. On the other hand, the selected methods might not be able to answer the research questions straightforwardly and, as time and resources are limited, in depth investigations of complex questions related to a single method are not possible. Several of the questions left open by this study relate to such limitations and partly warrant further in depth analysis.

The assumption of an originally closed canopy, montane forest in upland Pare has been questioned strongly (GILLSON et al. 2003). The reconstruction presented here of pre-farming vegetation cover remains only tentative. It was not possible to unambiguously reconstruct vegetation prior to the onset of soil erosion as the pollen record did not extend beyond the 6th century AD. While stable carbon isotope composition of buried soils is in accordance with an expected subhumid C_3 vegetation cover, it does not confirm the assumption of a montane forest. To clarify the possible bias induced by the isotopic fractionation of soil organic matter and strengthen the evidence from stable carbon isotopes, reference soil profiles along an altitudinal and vegetation transect would be necessary, but were not possible during the current study due to time constraints.

The third approach to past vegetation composition, phytolith analysis, was envisaged to replace pollen analysis in the terrestrial archives. However, a difficult to interpret phytolith record from the swamp, and a preliminary phytolith analysis of colluvial deposits, both highlighted problems posed by the lack of an available reference collection, and by a high variation of phytolith types between swamp and terrestrial deposits. The apparent absence of grass phytoliths in the colluvial deposits complicate matters, and requires further research. Thus, phytolith analysis at Pare was abandoned within the scope of this study.

Magnetic susceptibility patterns became a key parameter to differentiate between topsoil and subsoil erosion and to highlight the onset of accelerated soil erosion and land degradation. Exceptionally high magnetic susceptibility values are explained by the base and iron-rich rocks of Pare. Further, pedogenetic enhancement is identified as the principal process responsible for magnetic differentiation of slope deposits. In this study, the differentiation between pedogenetic enhancement and primary magnetic minerals is based only on the magnetic susceptibility and frequency dependency. To identify the dominant iron species responsible for the observed susceptibility pattern and to differentiate between neoformation of magnetic minerals and the admixture of primary minerals from distinct geological sources, a combination of element assays of iron sand and bulk soil samples together with further magnetic analysis, particularly remanence ratios (e.g. IRM, SIRM, ARM), will be necessary.

The deposition chronology is based on radiometric and optically stimulated luminescence dating. Whereas radiocarbon dating of charcoal fragments provided a consistent time frame for the accumulation of slope deposits, OSL dating appeared to be biased by insufficiently bleached sediments. Taking into account both reworking of charcoal fragments and problems of insufficient bleaching in colluvial settings it is not possible to decide at the outset of a study which of both techniques will be reliable. Although two of the three OSL dates from the present study had to be rejected, adjustments of the technique (e.g. single grain analysis) may prove successful in similar environments.

Loss-on-ignition as organic matter proxy was abandoned during the laboratory work as it transpired that LOI was not capable of picking up small organic matter variations in the buried topsoils. Although a useful tool for a rough characterisation of organic matter rich sediments, it is not suitable for quantitative estimation of the organic matter content of carbon poor and clay rich sediments.

Charcoal estimation by nitric acid digestion recovered charcoal carbon qualitatively but correlation of nitric-acid-resistant carbon with total organic carbon hinted either at a methodical problem or the absence of an interpretable variation in both the swamp and one terrestrial deposit. As methodical uncertainties outweighed the anticipated interpretative value, the method was abandoned.

The course of this research not only demonstrated the limitations of some of the methods applied, but also identified several other methods that could benefit similar projects in the future. The interpretation of pedogenetic features of the slope deposits would have been greatly enhanced by micromophological analysis of the different deposition units. Micromorphological confirmation of the type and material of reworked aggregates, the extent and nature of sand lenses, as well as implications from fabric and structure for post-depositional soil formation could have increased the explanatory power of the pedological benchmark features. A preliminary suite of micromorphology samples were taken from several of the profiles discussed here in 2010 by the author in collaboration with Stump; the results from which are forthcoming.

The emerging land degradation narrative will benefit from a detailed soil fertility assay such as cation exchange capacity, base saturation, and aluminium concentration. Comparison of present-day eroded agricultural soils with the soils of forest fragments and different units of the slope deposits may confirm the assumed decline of soil fertility after erosion of topsoils. A soil fertility assessment will enhance the discussion of causes and mechanisms of agricultural intensification in Pare and may explain decreasing fallow times.

In a similar way, monitoring of current soil erosion would be a further step to quantify present day soil erosion. Instead of traditional plot based methods, ^{137}Cs measurements allow the calculation of soil erosion rates and can be used to indirectly date the last forty years of slope deposit accumulation. This more spatial approach would have allowed the two dimensional findings from the slope deposits to be extended to the catchment scale.

While several of the applied analytical techniques turned out to be unsuitable to answer the research questions in this specific environment, the range of techniques allowed the characterisation of slope deposit accumulation from different perspectives. It is this strength of the multiproxy approach to integrate evidence from different techniques, different archives and from different processes, which has allowed not only a reconstruction of landscape evolution but also a number of inferences to be drawn concerning vegetation and climate dynamics and land use techniques.

11.2 Directions for future research

The present research into the environmental history of Pare has identified several areas that warrant further research. The perspectives are restricted to addressing direct implications from this thesis.

The present study has identified a spatial bias of palaeoecological and palaeoenvironmental research. Especially semi-arid lowland areas and agriculturally transformed sub-humid mid-altitudes of mountainous regions have been neglected so far, largely because the focus of previous studies has been on long time series reconstructed from cores taken from medium to large lakes and high-altitude swamps. Thus, the history of lowland vegetation and lower montane forests is fragmentary. Particularly, the fluctuation of the forest-savannah boundary might be sensitive to environmental changes during the Holocene and is likely to have experienced the strongest anthropogenic transformation. Palaeoecological investigations of lowland settings, involving a comprehensive study of past and present phytolith distribution, will complement the high-altitude records particularly in view of an accurate climate history not biased towards exceptionally humid environments.

Detailed research is particularly missing for the agriculturally important mid-altitudes. Besides the vegetation and settlement history, the apparent late Holocene age of mid-altitudinal swamps in Pare has prompted the hypothesis of widespread valley damming as a consequence of anthropogenic soil erosion. Mid-altitudinal wetland establishment warrants further investigations focusing on possible damming as well as a possible palaeoecological reconstruction of pre-farming vegetation. Valley bottom sands on the other hand, have led to the postulation of a mid-Holocene erosion period. Targeted investigations of mid-Holocene sedimentary sequences will be necessary to shed light on the exact nature and timing of these erosion periods, which seem to be characterised by sediment clearing out and hiatus, rather than by the accumulation of slope deposits.

Having stressed the differential developments in lowland, mid-altitudes and highland areas, landscape development of the Pare foothills and surrounding lowlands awaits detailed investigation. Late Holocene sediments exposed in recent gullies along the foothills of Pare were described as part of the HEEAL fieldwork, however, and suggest that anthropogenic soil erosion was not restricted to the densely settled uplands of modern times. Although not reported upon here, erosion of the Pare foothills is likely to be associated with the high number of exposed iron smelting sites, and is subject to ongoing work by the author in collaboration with Stump, Iles and Lane. Investigation of terrestrial archives along the Pare foothills will include the dating of both the remaining archaeological remains and the timing of accelerated erosion. The comparison of the environmental history of lowland, upland and highland sites promises comprehensive insights into the spatial variation of Holocene climate dynamics and anthropogenic land use as drivers of soil erosion and landscape development.

The onset of soil erosion in Pare has been linked to the spread of farming and iron working in the last centuries BC. The impact of fuelwood demand by iron working communities is a controversial topic and several attempts for quantification have been made (e.g. SCHMIDT 1997a). In Pare, a high number of iron smelting sites are known, but only a few have been dated so far and do not yet give a comprehensive picture of the developments and changes over time. The assumption that iron working has played a crucial role for land clearance and subsequent soil erosion cannot yet be confirmed. So far, iron working sites in North Pare are restricted to the second millennium AD, and there is nothing but circumstantial evidence for the contribution of fuelwood extraction to deforestation. Further dating of iron working sites in upland and lowland Pare will indicate if iron working took place continuously or if periods of more intensive smelting and smithing occurred. However, the implications of the present work and the almost complete erosion of topsoils on the Pare slopes question the success of the proposed approach. Early Iron Age sites are likely to have been eroded away during the first millennium AD and it is therefore anticipated that only most recent archaeological sites will have remained *in situ* and can be dated accurately. The present study of slope dynamics and deposit formation has provided important background information for the likely state of preservation of Early Iron Age sites in North Pare and thus contributes to the design of archaeological survey strategies but may also explain a possible archaeological void in the first millennium AD. Known to be a centre of iron production, documenting the extent of past iron working in Pare still remains a challenging task.

This thesis has shown that farming and perhaps iron working had instantaneous and large-scale consequences for the development of the North Pare landscape. To allow such a generalised model of landscape development to be drawn, a spatially comprehensive approach must combine the evidence from a representative numbers of sites, each with its own local history and take into account the high local variability of not only slope processes but also climatic and anthropogenic drivers. The present study emphasises the importance of human landscape transformation in the late Holocene and cautions against interpretations of environmental records based only on external controls such as climate change. Instead, it draws attention to ecosystem resilience and the consequences of progressive internal developments and the importance of ecological thresholds for rapid environmental change.

The presented multi-proxy approach allowed detailed examination of specific deposition features from which slope processes and past land use practices were inferred, thus elucidating timing, causes, and consequences of past resource exploitation strategies. Pedological - geoarchaeological studies of landscape development provide important contextual details for historical, archaeological and ecological research and may even allow the retrospective evaluation of the sustainability of past land use practices.

APPENDIX

A Soil Data (On CD-ROM)

A.1 Analytical Data - Slope Deposits

A.2 Analytical Data – Forest and Cultivated Soil Profiles

B Soil and slope deposit descriptions

B.1 Changuku: Eroded soils under agricultural land use

Changuku 1 – *Cresta* — Truncated Cambisol

Coordinates: (UTM WGS 84)		
Easting:	352925	E 37°40'32.2"
Northing:	9588836	S 3°43'08.0"
Elevation:	1433m a.s.l.	
Pit depth:	90cm	
Colluvium:	none	

Relief	
Slope:	10°
Aspect:	NNE 30°
Slope Pos.:	ridge - crest
Slope Form:	convex – convex
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	gneiss, in situ
Outcrops:	none

Description: Severely eroded north facing ridge of the Changuku hill. The profile is located on top of the terraced ridge above the Changuku and Lomwe catenae. The gentle slope is strongly eroded. Soils are truncated and saprolite is exposed.

Vegetation: Extensive cultivation of *Zea mays* (mahindi) and *Manihot esculenta* (mahoge), within fallow land covered by abundant grasses and herbs, no trees.

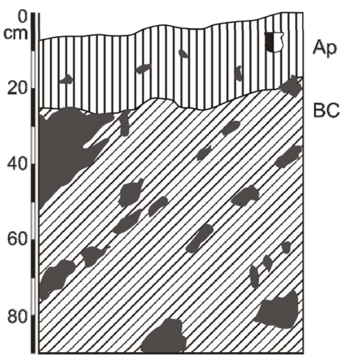
Soil Cover: 50% bare soil, 40% medium gravel, 10% grasses

Alterations: Terraces (spaced 15-25m, 50cm high terrace steps), cultivation.

Erosion Feat.: Bare soil and a strong stone pavement of 40% medium gravel indicate severe sheet erosion, which has led to the loss of the original top- and subsoil.

Archaeological Features: A single generic potsherd (rim) in the plough horizon is probably redeposited and therefore of no indicative value.

Soil Profile



Horizons	Description
Surface 0cm	Many (40%) medium weathered gravel
Ap 0 – 27cm	Brown (7.5YR 4/4, moist, strong brown (7.5YR 5/6) clay loam, Common (15%) medium weathered gravel, moderate to high density, weak granular to subangular blocky structure, common fine roots, no coarse roots, common animal holes, clear wavy boundary, one potsherd at 10cm depth.
B/C 27 – 90+cm	Yellowish red (5YR 5/6, moist; reddish yellow 7.5YR 6/6, dry) sandy clay, Many (30%) strongly weathered stones, moderate density, weak subangular blocky structure, few fine roots. Saproliteic structure of the strongly weathered whitish-yellowish Gneiss.

Changuku 2 – *Ridge* | Truncated Cambisol

Coordinates: (UTM WGS 84)

Easting:	352934	E 37°40'32.5"
Northing:	9588906	S 3°43'05.7"
Elevation:	1425m	
Pit depth:	90cm	
Colluvium:	none	

Relief

Slope:	15°
Aspect:	NNE 30°
Slope Pos.:	ridge – middle slope
Slope Form:	convex – convex
Microrelief:	terraced

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	saprolite, in situ
Outcrops:	none

Description: Severely eroded north facing ridge of the Changuku hill. The profile is located on a terraced upper slope on the ridge above the Changuku and Lomwe catenae. The soil is truncated and saprolite is exposed. The soil profile shows exemplary the complex bedrock stratigraphy of the metamorphic parent material. Intercalated narrow bands of gneiss with differing mineral composition and quartz veins lead to a complex weathering profiles. The parent material of the lower profile part (60+cm) weathers faster and weathering colours differ from the gneiss above.

Vegetation: Fallow, covered by abundant grasses and herbs, no trees. Extensive cultivation of *Zea mays* (mahindi) and *Manihot esculenta* (mahoge).

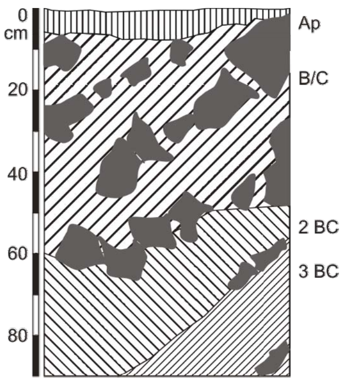
Soil Cover: 50% bare soil, 40% coarse gravel, 10% litter & grasses

Alterations: Terraces (spaced 15-25m, 50-100cm high terrace steps). Agriculture.

Erosion Feat.: Bare soil and a strong stone pavement of 40% coarse gravel indicate severe sheet and rill which has led to the loss of the original top- and subsoil.

Archaeological Features: None

Soil Profile



Horizons	Description
Surface 0cm	Many (40%) coarse weathered gravel
Ap 0 – 6cm	Brown (7.5YR 4.5/4, moist; very pale brown 10YR 7/4, dry), loam, very low humus content, many (25%) weathered stones, moderate to high density, weak subangular blocky structure, common fine roots, no coarse roots, clear wavy boundary.
B/C 6 – 60cm	Strong brown (7.5YR 4/6, moist; light brown 7.5YR 6/4, dry) silty clay loam, abundant (50%) strongly weathered stones, moderate to high density, weak subangular blocky structure, common fine roots, clay coatings in pores. Slowly weathering parent material, resulting in whitish to yellowish strongly weathered stones preserving the original rock structure.
2 BC 60 - 90+cm	Yellowish red (5YR 5/6, most; pink 5YR 7/4, dry) silty clay loam, few (5%) strongly weathered stones, moderate to high density, weak subangular blocky structure, very few fine roots, clay coatings in pores. Fast weathering parent material resulting in whitish to reddish colours, very few strongly weathered stones left.

Changuku 3 – *Terrace*

Truncated Cambisol (colluvic)

Coordinates: (UTM WGS 84)		
Easting:	352882	E 37°40'30.9"
Northing:	9588881	S 3°43'06.5"
Elevation:	1426m a.s.l.	
Pit depth:	140cm	
Colluvium:	95cm	

Relief	
Slope:	25-30°
Aspect:	NW 310°
Slope Pos.:	upper slope
Slope Form:	straight – convex
Microrelief:	terraced

Geology	
Geology:	quarz vein (local)
Parent Mat.:	colluvial material
Outcrops:	boulders, 3m distance

Description: Steep, terraced slope below the Changuku ridge. The soil develops on colluvium over a truncated subsoil. Spatial variability is shown by severe sheet and rill erosion in a in a maize field on the same terrace.

Vegetation: Fallow land. Grasses, herbs, eucalyptus on terrace steps, on the same terrace eucalyptus as well as maize is grown.

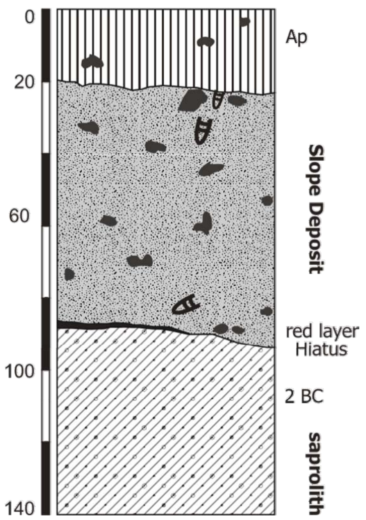
Soil Cover: 30% medium gravel,

Alterations: Terraces (spaced 10m)

Erosion Feat.: A stone pavement made up of 30% medium gravel indicates moderate sheet erosion..

Archaeology: none,

Soil Profile



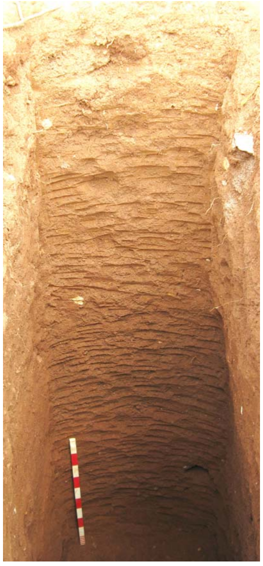
Horizons		Description
	Surface 0cm	30% medium gravel
Colluvium	**Ap** 0 – 25cm	Brown (7.5YR 4/3 moist; light brown 7.5YR 6/4, dry), clay loam, low humus content, common (10%) fine occasional up to coarse strongly weathered gravel, moderate density, weak granular to subangular blocky structure, common fine roots, clear wavy boundary.
Colluvium	**B** 25 – 90cm	Brown (7.5YR 4/3 moist; brown 7.5YR 5/4, dry), (sandy?) clay loam, many (30%) coarse strongly weathered gravel, high density, weak subangular blocky structure, few fine roots, common animal holes, gradual boundary.
Hiatus ?	**red layer** 94-96cm	Reddish brown (2.5YR 4/4 moist, red 2.5YR 5/6, dry) clay, abrupt broken boundary. Abrupt boundary and change of parent material suggests an erosive hiatus before colluvial deposition. Origin of red band unknown.
Truncated Soil	**2 BC** 90 – 140+cm	Yellowish red (5YR 5/6 moist; reddish yellow 7.5YR 7/6 dry) clay, **many (40%) fine fresh quartz gravel**, high density, weak subangular to angular blocky structure, no roots. Parent material: quartz vein

Changuku 4 - *Headwater Depression*

Coordinates: (UTM WGS 84)		
Easting:	352834	E 37°40'29.3"
Northing:	9588926	S 3°43'05.0"
Elevation:	1385m a.s.l.	
Pit depth:	300cm	
Colluvium:	300+ cm	

Relief	
Slope:	~10°
Aspect:	WNW 300°
Slope Pos.:	middle slope - depression
Slope Form:	concave – concave
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/as



Description:: Small terraced slope depression on the mid-slope of the Changuku hill about 15m below a road and above the steep lower slope of the Lomwe catena. The colluvial deposit exceeds 3m depth and shows a distinct stratigraphy although correlation with depositional units of the Lomwe catena remains only tentative. The first centuries AD are a minimum for the onset of slope deposit accumulation as no *in situ* soils was recorded. Potsherds and frequent charcoal occurrence are indicative of human presence.

Vegetation: Open banana (*Musa* sp.) vegetation and scattered *Manihot esculenta*, *Saccharum* sp.(sugar cane), *Zea mays* (mahindi), herbs.

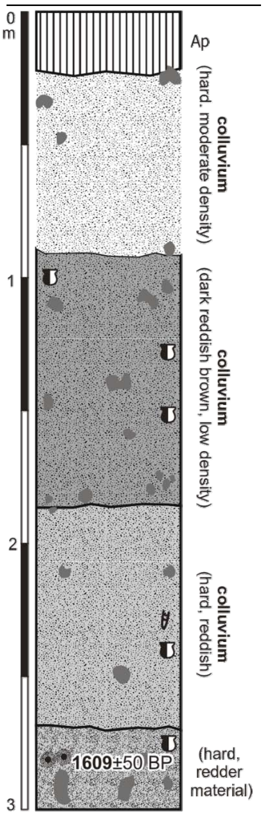
Soil Cover: 90% bare soil, 10% medium gravel

Alterations: Terracing (50-100cm high terrace steps), soil movement due to road and house construction upslope, a broken water pipe might have resulted in a slight moistening of the soil profile during sampling.

Erosion Feat.: Slight to moderate erosion is indicated by a slight surface stone pavement (10% medium gravel) indicating sheet erosion, incipient rill erosion (5cm deep rills, spaced 60cm apart) and surface sealing by puddle erosion.

Archaeology: Common decorated potsherds and charcoal fragments within the colluvial deposit (100 – 300+cm).

Soil Profile



Zones	Horizon	Description
III / IV d (hard deposit)	**Ap** 0 – 25cm	**Plough Horizon.** Dark brown (7.5YR 3/4, moist; brown 7.5YR 5/4, dry) clay, low humus content, few (5%) medium strongly weathered gravel, moderate to high density, weak subangular blocky structure, common fine roots, no coarse roots, charcoal present, animal holes, gradual boundary
	25 – 90cm	Reddish brown (5YR 4/3, moist; 5YR 5/4, dry) clay, few (5%) medium to coarse strongly weathered gravel, occasional stones, moderate density, weak subangular blocky structure, common fine roots, charcoal present, animal holes, gradual boundary
II c (soft deposit)	90 – 190cm	Dark reddish brown (5YR 3/3, moist; 5YR 4/4, dry) clay, low humus content, **common (15%) up to coarse strongly weathered gravel**, different rock types, **low density**, weak subangular blocky structure, few fine roots, clay coatings, charcoal present, animal holes, **clear boundary, organic matter rich aggregates, common potsherd fragments**.
II b (hard deposit)	190 – 265cm	**Dark reddish brown** (5YR 3/4, moist; 5YR 4/4, dry) clay, common (10%) up to medium strongly weathered gravel, **moderate density**, weak subangular blocky structure, no fine roots, clay coatings, gradual boundary. Animal holes, charcoal present, **common potsherd fragments**.
	Charcoal 275cm	Discontinuous accumulation of dispersed charcoal fragments (5%) on the left front wall and the back right wall; ca. 20-30cm wide, 5-10cm thick dispersed spots. No correlated change in other attributes of the colluvium recorded.
II a (hard, reddish)	265 – 300+cm	Reddish brown (5YR 4/4, moist; **yellowish red** 5YR 4/6, dry) clay, common (15%) up to coarse strongly weathered gravel**, high to very high density,** weak subangular blocky structure, no fine roots, clay coatings, charcoal present, **potsherds.** Radiocarbon Date: **1609±50 ^{14}C BP** (285cm, charcoal fragment)

Changuku 5 – *Lower Slope* | Truncated Cambisol (colluvic)

Coordinates: (UTM WGS 84)

Easting:	352862	E 37°40'30.2"
Northing:	9589013	S 3°43'02.2"
Elevation:	1427m a.s.l.	
Pit depth:	37cm	
Colluvium:	-	

Relief

Slope:	20-25°
Aspect:	NW 320°
Slope Pos.:	upper middle slope
Slope Form:	concave – straight
Microrelief:	Variable

Geology

Geology:	gneiss, weathered
Parent Mat.:	highly variable bedrock types:
Outcrops:	large boulders, 10m

Description: Steep slope directly above the Lomwe Catena and below a house platform. Transport zone for eroded material from the upper and middle slope. Principal source area for the colluvial slope deposits of Lomwe. The organic matter enriched topsoil has formed in colluvial material resting directly above the fresh bedrock surface implying the loss and erosion of the original top- and subsoil.

Vegetation: Eucalyptus plantation with an undergrowth of raspberries, grasses and herbs.

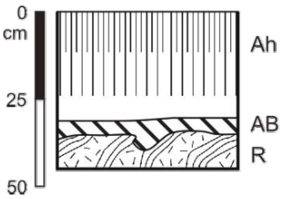
Soil Cover: 35% bare soil, 15% gravel, 50% litter

Alterations: Eucalyptus plantation, paths, house platforms upslope

Erosion Feat.: None

Archaeological Features: None

Soil Profile



Horizons		Description
Slope Deposit	**Ah** 0 – 32cm	Dark brown (7.5YR 3/4 moist; brown 7.5YR 5/4, dry) clay loam, moderate humus content, common (15%) weathered medium gravel, moderate granular to subangular blocky structure, moderate density, common fine and coarse roots, charcoal present, gradual boundary.
	AB 32 – 38cm	Dark brown (7.5YR 3/4 moist; strong brown 7.5YR 5/6, dry) clay loam, low humus content, many (30%) weathered medium gravel, weak subangular blocky structure, moderate density, common fine and coarse roots, abrupt, irregular boundary.
***in situ* bedrock**	**R** 38+cm	Bedrock. Hard, coherent gneiss.

Changuku 6 – *Lower Slope* — Truncated Cambisol

Coordinates: (UTM WGS 84)		
Easting:	352802	E 37°40'28.3"
Northing:	9589027	S 3°43'01.7"
Elevation:	1368m a.s.l.	
Pit depth:	90cm	
Colluvium:	-	

Relief	
Slope:	25-30°
Aspect:	WNW 304°
Slope Pos.:	middle slope
Slope Form:	concave – straight
Microrelief:	-

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	highly variable bedrock:
Outcrops:	large boulders, Ø 10m

Description: Steep slope directly above the Lomwe Catena. Transport zone for eroded material from the upper and middle slope. Principal source area for the colluvial sediments. A shallow organic matter enriched topsoil has formed in colluvial material. The original soil is lost and *in situ* subsoil material is only preserved in spaces between weathered saprolitic bedrock, extending in pockets to depths of over 90cm. Bedrock type varies on a decimetre scale (cf. photo above from northern and southern profile wall) and controls the highly variable subsoil characteristics (depth, structure, texture). The southern part of the profile developed over a local quartz vein and has a much redder colour.

Vegetation: Eucalyptus plantation with a undergrowth of raspberries, grasses and herbs.

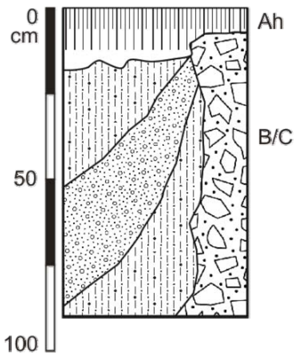
Soil Cover: 60% bare soil, 10% gravel, 30% litter

Alterations: Eucalyptus plantation, paths, house platforms upslope

Erosion Feat.: n.d.

Archaeological Features: None

Soil Profile



Horizons	Description
Ap 0 – 24cm	Dark brown (7.5YR 3/4 moist; brown 7.5YR 5/4, dry) clay loam, low humus content, abundant (40%) strongly weathered coarse gravel, weak subangular blocky structure, moderate density, common fine and coarse roots, gradual boundary. **Cullets.**
B1 (north) 24 – 46cm	Dark red (2.5YR 3/6 moist; yellowish red 5YR 5/6, dry) clay loam, low humus content, abundant (60%) strongly weathered coarse gravel, weak subangular blocky structure, moderate density, few fine roots, coarse roots present, diffuse irregular boundary.
BC 46 – 90+cm (north wall)	Red (2.5YR 4/6 moist; reddish yellow 5YR 6/6, dry) clay loam, abundant (75%) strongly weathered coarse gravel, , weak subangular blocky structure, moderate density, very few fine roots, coarse roots present.
B/C 24 – 90+cm (south wall)	Yellowish red (5YR 4/6 moist; yellowish red 5YR 5/6, dry) clay loam, low humus content, abundant (75%) weathered stones occasional boulders, weak subangular blocky structure, moderate density, few fine roots, coarse roots present.

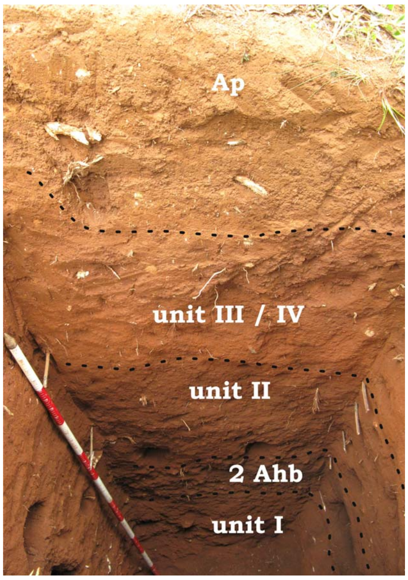
B.2 Lomwe: Slope deposit descriptions

Lomwe 3 – *Late Pleistocene topsoil*

Coordinates: (UTM WGS 84)	
Easting:	352807
Northing:	9589045
Elevation:	1341m a.s.l.
Pit depth:	285cm
Colluvium:	140+cm

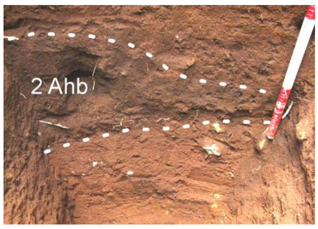
Relief	
Slope:	~15°
Aspect:	NNW 338°
Slope Pos.:	lower slope
Slope Form:	concave – concave
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a



Description: Uppermost colluvial soil profile recording a buried late Pleistocene topsoil in 2m depth. The soft very dark brown and organic matter rich buried forest soil is most prominent at the lower right corner of the soil pit and thins out towards the upper corners. The distinct topsoil horizon is buried by about a metre of dark reddish brown colluvial material of a similarly low bulk density (<1.2g ccm-1), which is overlain by a further metre of compact red material. A charcoal fragment from the buried dates to 14.812±73 ^{14}C BP, whereas soil organic.matter shows a younger radiocarbon age of 12.299±64 ^{14}C BP. The buried forest soil rests on a bright *in situ* subsoil horizons.

to cross a small terrace step. The construction of the terrace however did not lead to any visible alterations of the soil material



Vegetation: Eucalyptus with a thick undergrowth of ograsses and herbs.

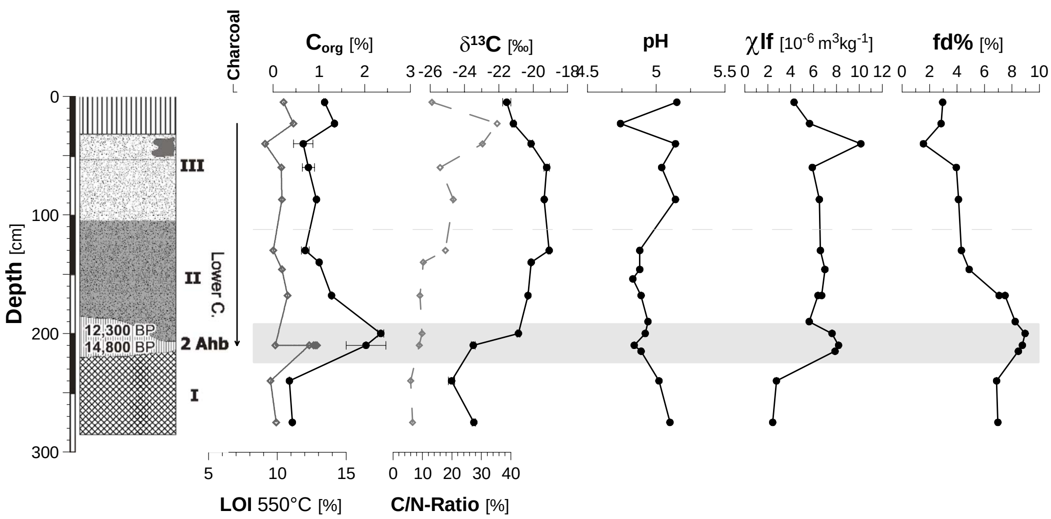
Soil Cover: n.d.

Alterations: Terracing, agriculture, paths

Erosion Feat.: n.d.

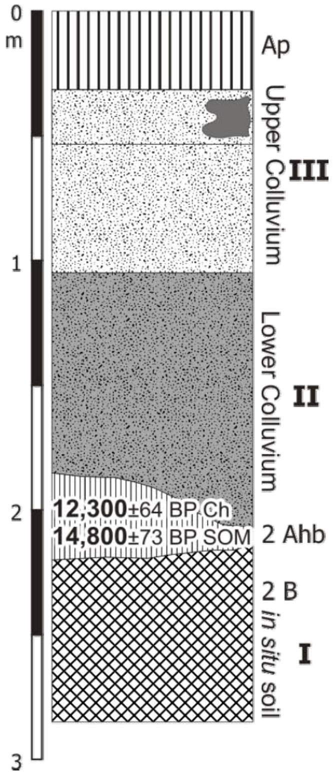
A. Features: None

Lomwe 3: Analysis Overview

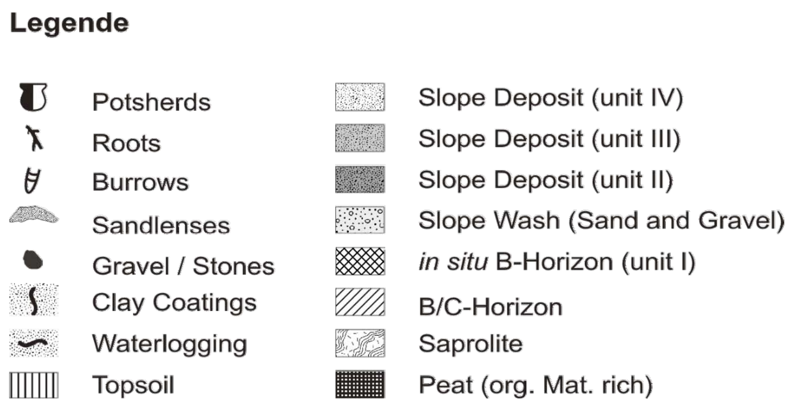


Lomwe 3 – *Late Pleistocene topsoil*

Soil Profile



Zones	Horizon	Description
	Ap 0 – 32cm	**Plough horizon.** Dark brown (7.5YR 3/4; strong brown 7.5YR 4/6, dry) clay loam, few (<5%) medium weathered gravel, moderate subangular to granular structure, moderate density, few fine roots, coarse roots present, termite activity, charcoal present, gradual smooth boundary
III / IV **Late colluvium**	32 - 53cm	Dark brown (7.5YR 3/4; strong brown 7.5YR 5/6, dry), clay loam, few (<5%) medium weathered gravel, one erratic boulder, weak subangular structure, moderate density, few fine roots, coarse roots present, termite activity, charcoal present, clear smooth boundary.
	53 - 105cm	**Red** (2.5YR 4.5/7; reddish brown 5YR 4/3, dry), clay loam, few (<5%) medium weathered gravel, weakly developed subangular blocky structure, moderate density, few fine roots, coarse roots present, termite activity, charcoal present, clear smooth boundary
II	105 - 185cm	**Dark reddish brown** (5YR 3/4; reddish brown 5YR 4/4, dry), clay loam, common (<10%) angular weathered medium gravel, weak subangular blocky structure, **low 1.18g ccm^{-1} density** (1.86cm)**,** few fine roots, coarse roots present, termite activity, charcoal present, clear smooth boundary.
Early colluvium	**BAhb** 185 - 220cm	Dark reddish brown (5YR 3/4; reddish brown 5YR 4/4, dry), loam, common (<15%) coarse angular weathered gravel, weakly developed subangular blocky structure, **very low packing density**, few fine roots, coarse roots present, charcoal present, clear broken boundary; **transition horizon** to and interfingering with Ahb horizon, present on all walls.
I **Buried topsoil**	**2 Ahb** 205 - 229cm	Very dark brown (7.5YR 2.5/3; dark reddish brown 5YR 3/3, dry), loam, common (<15%) coarse angular weathered gravel, weakly developed subangular blocky to granular structure, **very low (210cm: 0.98 & 1.21g ccm^{-1}) packing density**, few fine roots, coarse roots present, charcoal present, channels (Ø0.5-1cm) of bright subsoil material, clear broken boundaries, varying thickness between 10-30cm, thinning out on the side walls, not present on the upslope wall. **Radiocarbon Date: 14.812±73 ^{14}C BP** (210cm, charcoal), **Radiocarbon Date: 12.299±64 ^{14}C BP** (~210cm, soil organic matter)
***in situ* soil**	**2 B** 229 – 285+cm	Reddish brown (5YR 4/6; yellowish red 5YR 5/6, dry) clay loam, many (<30%) angular weathered stones, moderate blocky strucure, high density, very few fine roots, no charcoal.



Lomwe 10 - Late Pleistocene topsoil

Coordinates: (UTM WGS 84)		
Easting:	352797	E 37°40'28.1"
Northing:	9589051	S 43°00'09"
Elevation:	1340m a.s.l.	
Pit depth:	370cm	370cm
Colluvium:	230cm	230cm

Relief	
Slope:	14°
Aspect:	NW 320°
Slope Pos.:	lower slope
Slope Form:	concave - concave
Microrelief:	terraced

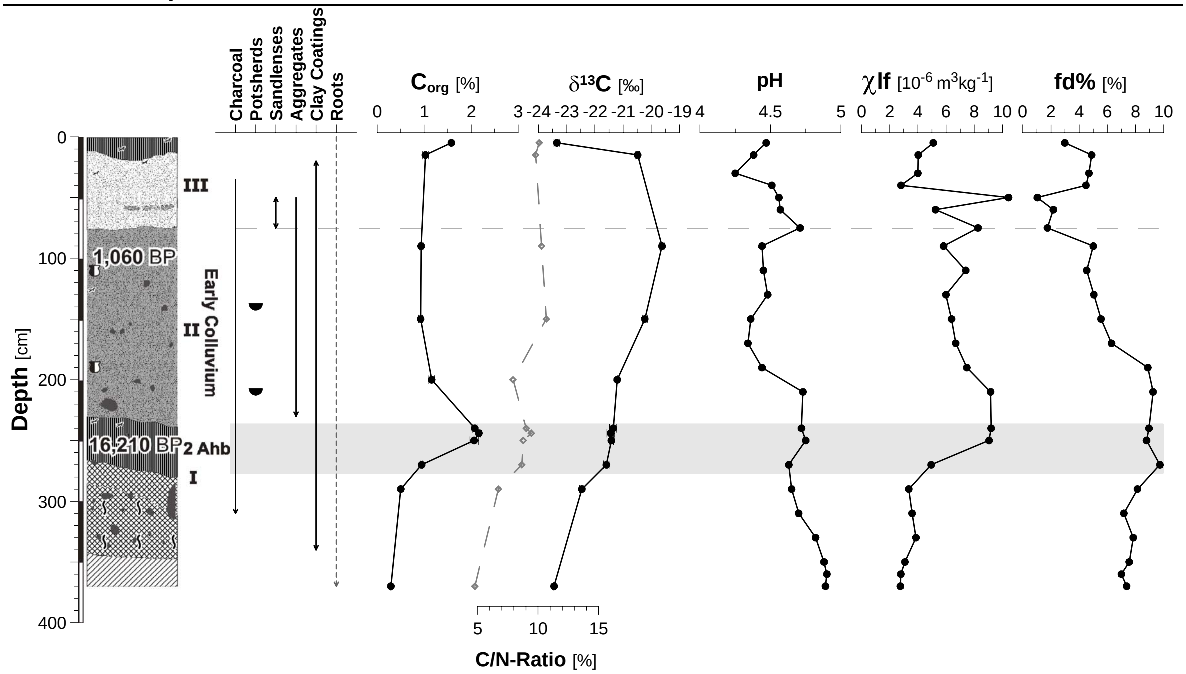
Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a

Description:

A late Pleistocene *in situ* soil is buried beneath 2.5m of slope deposits. The 30cm thick, dark, organic matter rich (2.2% Corg) buried topsoil is very frial and shows a low bulk density. Charcoal fragments from the buried soil date to 16,210±86 ^{14}C BP. The topsoil is buried by a dark reddish (5YR 3/3, moist) frial clay (75 – 230cm depth) with a low bulk density, easily to excavate. Organic matter rich aggregates as well as yellow clay aggregates are recorded. Two potsherds, the lower one about 50cm above the buried topsoil, the upper one at about 120cm depth indicate human presence during colluviation. A red clay (2.5YR 4/6, moist) with a high packing density represents the uppermost depositional unit. Between 50 and 75cm depth small, discontinuous sand lenses and generally higher gravel content indicate runoff-based erosion processes.

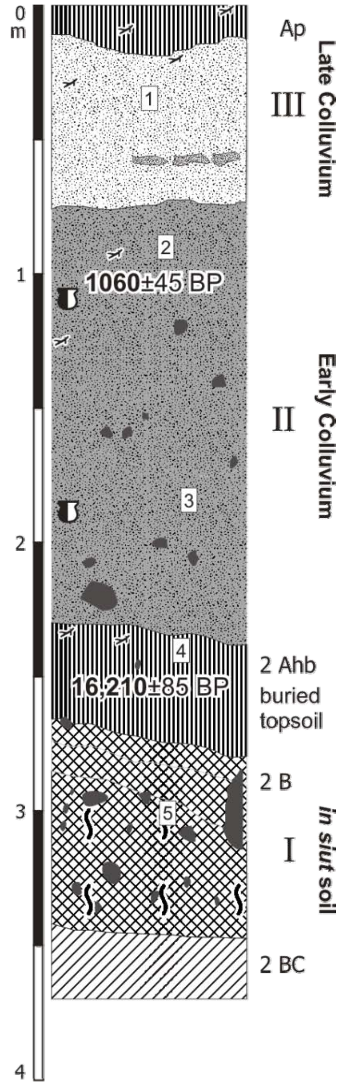
Vegetation:	Eucalyptus with a thick undergrowth of grasses and herbs.
Soil Cover:	none
Alterations:	Terracing, agriculture, paths
Erosion Feat.:	sheet wash
Archaeological Features:	none

Lomwe 10: Analysis Overview



Lomwe 10 - *Late Pleistocene topsoil*

Soil Profile



Zones	Horizon	Description
	Oi	Discontinuous litter layer
III / IV **Late Colluvium**	**Ap** 0 – 20cm	Reddish brown (5YR 4/3, moist; strong brown 7.5YR 5/6, dry) clay, Very few (1%) fine subrounded and angular weathered gravel, low density, moderate granular to subangular blocky structure, common fine roots and few coarse roots, charcoal present,, gradual wavy boundary
	20 – 50cm	Red (2.5YR 4/6 moist; reddish yellow 5YR 6/6, dry) clay, **few (5%)** fine occasional medium angular weathered and strongly weathered gravel, moderate to high density, weak subangular blocky structure, very few roots, clay coatings, charcoal present, clear irregular boundary
	50 – 75cm	Red (2.5YR 4/6 moist; reddish yellow 5YR 6/8, dry) clay, **many (20%) fine occasional medium angular weathered gravel**, **moderate to high densit**y, weak subangular blocky structure, very few roots, coarse roots present, charcoal present, **organic matter rich aggregates,** clear wavy boundary. Discontinuous, small (0.5-4cm thick) **sand lenses**,
II **Early Colluvium**	75 – 230cm	Dark reddish brown (5YR 3/3 moist; yellowish red 5YR 4//6, dry) clay, up to common (10%) fine occasional medium subrounded and angular weathered gravel, **low density**, moderate granular to subangular blocky structure, common fine roots, coarse roots present, **organic matter rich aggregates & reddish yellow clay aggregates, charcoal present**, big (50cm) empty animal burrow, clear wavy boundary, **Potsherds** (120cm & 180cm) Accumulation of fine gravel at lower boundary **Radiocarbon Date: 1060±45 ^{14}C BP** (115cm, charcoal)
I **Buried Topsoil**	**2 Ahb** 230 – 260cm	Dark reddish brown (5YR 3/2 moist, reddish brown 5YR 4/4, dry) clay, few (5%) fine occasional medium subrounded and angular weathered gravel, **low to moderate density**, moderate granular to subangular blocky structure, few fine roots very few coarse roots, charcoal present, gradual wavy boundary. Patchwork of yellowish red channels (subsoil material) due to bioturbation. Accumulation of fine gravel at lower boundary **Radiocarbon Date: 16,210±85 ^{14}C BP** (300cm, charcoal)16,210
	2 ABb 260 – 275cm	Dark reddish brown (5YR 3/3 moist; reddish brown 5YR 4/4; dry) clay, common (10%) medium angular strongly weathered gravel, **moderate density**, moderate subangular blocky structure, few fine roots, charcoal present, clay coatings, gradual wavy boundary. Gradually less organic matter.
***in situ* soil**	**2 B** 275 – 340cm	Reddish brown (2.5YR 3.5/4 moist; yellowish red 5YR 5/6, dry) clay, many (20%) medium angular strongly weathered gravel, one boulder, **high density**, moderate subangular to angular blocky structure, very few fine roots, clay coatings, no charcoal, gradual wavy boundary.
	2 BC 340 – 370cm	Red (2.5YR 4/6 moist; yellowish red (5YR 5/6; dry), many (20%) clay, coarse angular strongly weathered gravel, very high density, angular blocky structure, very few fine roots, no charcoal, black weathering crusts on gravel.

Lomwe 4 - *Late Pleistocene topsoil*

Coordinates: (UTM WGS 84)		
Easting:	352801	E 37°40'28.2"
Northing:	9589062	S 3°43'00.6"
Elevation:	1338m	
Pit depth:	280cm,	
Colluvium:	330cm	

Relief	
Slope:	~12°
Aspect:	NNW 340°
Slope Pos.:	lower slope
Slope Form:	concave – straight
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a

Description: The upper 1.5m of the Lomwe 4 profile are characterised by yellowish red (5YR 4/6, moist) clay with a high packing density and thepresence of clay coatings. Below a softer and darker (dark reddish brown 5YR 3/4, moist) deposit extends up to 330cm depth. A single big boulder (ø 80cm) is recorded at 2m depth. In a depth of 330 -350cm an organic matter rich layer (1.9% Corg) overlies a yellowish red clay loam and is interpreted as a buried topsoil. Charcoal is present throughout the profile. Magnetic susceptibility parameters are low in the subsoil sample and peaks in the buried topsoil. Throughout the slope deposit magnetic susceptibility and frequenc dependent susceptibility decrease steadily. Stable carbon isotope values on the contrast increase from bottom to about 1m depth, and show intermediate values at the recent surface.

Vegetation: Eucalyptus plantation with a raspberry undergrowth, grasses and herbs.

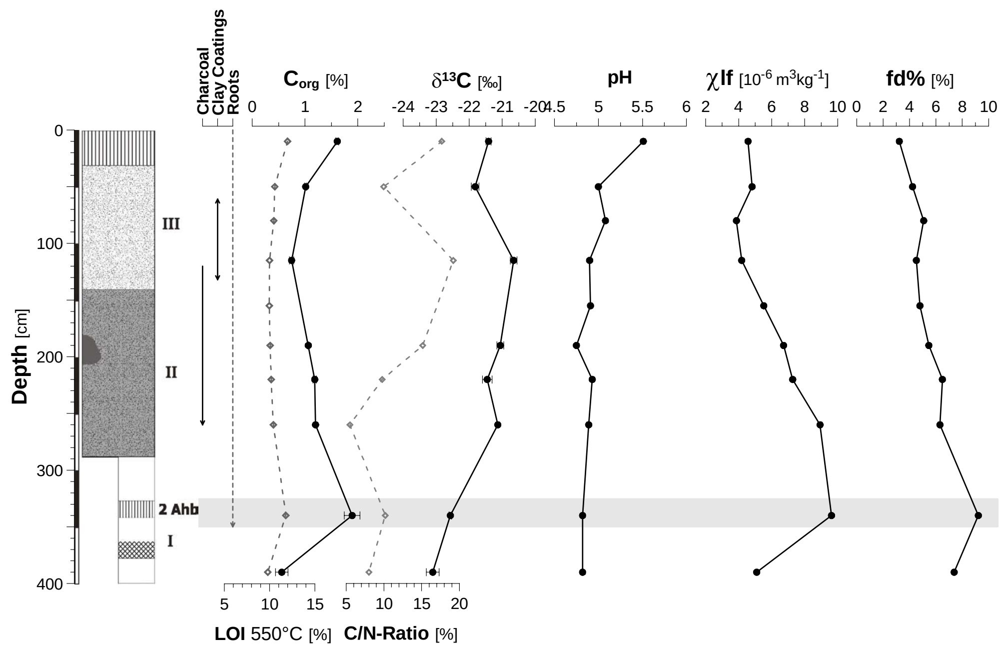
Soil Cover: 50% bare soil, 10% gravel, 40% litter and grasses

Alterations: Terracing, agriculture, paths

Erosion Feat.: n.d.

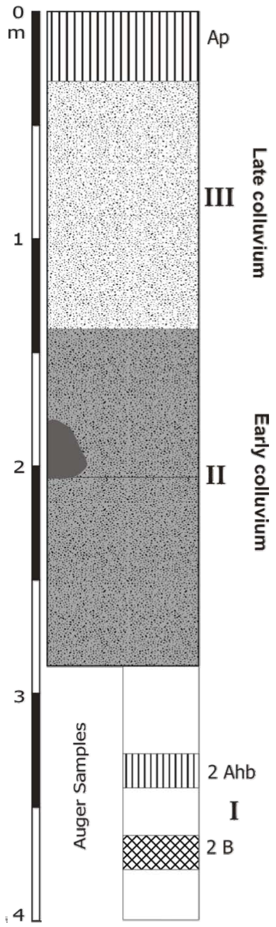
Archaeological Features: n.d.

Lomwe 4: Analysis Overview



Lomwe 4 - *Late Pleistocene topsoil*

Soil Profile



Zones	Horizon	Description
III / IV Upper Colluvium	**Ap** 0 – 36cm	**Plough horizon.** Dark brown (7.5YR 3/4, moist; brown 7.5YR 5/4, dry) clay loam, very few (<2%) angular weathered medium gravel, weak granular to subangular blocky structure, **high (1.42g ccm^{-1}** (10cm) **density**, fine and coarse roots present, dispersed charcoal, diffuse boundary.
	36 - 61cm	Yellowish red (5YR 4/6, moist; yellowish red 5YR 5/6, dry) clay loam, very few (<2%) angular weathered fine gravel, weak granular to subangular blocky structure, moderate (1.36g ccm^{-1} (80cm), 134 ccm^{-1} (450cm) bulk density fine and coarse roots present, dispersed charcoal, diffuse boundary.
	61 - 132cm	Yellowish red (5YR 4/6, moist; yellowish red 5YR 5/6, dry) clay loam, few (<5%) angular weathered coarse gravel, weak subangular blocky structure, **high (1.47g ccm^{-1}** (115cm) **bulk density** fine and coarse roots present, dispersed charcoal, clay coatings, diffuse boundary.
II Early Colluvium	132 - 200cm	Dark reddish brown (5YR 3/4, moist; strong brown 7.5YR 4.5/7, dry) clay loam, common (<10%) angular weathered coarse gravel, one erratic large boulder (Ø 80cm), weak subangular blocky structure, moderate (1.31g ccm^{-1} (155cm) 129 g ccm^{-1} (190cm) bulk density, fine and coarse roots present, dispersed charcoal, diffuse boundary.
	200 - 330cm	Dark brown (7.5YR 3/4, moist; strong brown 7.5YR 4/5, dry) clay loam, common (<20%) angular weathered fine to coarse gravel, weak subangular blocky structure, **low (1.13** (260cm) **& 1.28g ccm^{-1}** (220cm) **bulk density**, fine and coarse roots present, dispersed charcoal, diffuse boundary.
I Buried topsoil	**2 Ahb** 330 – 350cm	Dark reddish brown (5YR 2.5/2, moist; 5YR 3/4, dry) clay loam, very few (<2%) medium gravel, fine roots present, dispersed fine charcoal.
	2 B 370 – 420+cm	Yellowish red (5YR 4/6, moist; 5YR 4/5, dry) clay loam, common (<6%) coarse strongly weathered gravel, no fine roots, dispersed fine charcoal.

Lomwe 5

Coordinates: (UTM WGS 84)		
Easting:	352789	E 37°40'27.8"
Northing:	9589076	S 3°43'00.1"
Elevation:	1349m	
Pit depth:	300cm /	
Colluvium:	510cm	

Relief	
Slope:	~11°
Aspect:	NNW 340°
Slope Pos.:	lower footslope
Slope Form:	concave – concave
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	None
Water table:	

Description: The upper 120cm consist of a hard, yellowish red deposit with few gravel and a high packing density. A lower slope deposit can be distinguished by a dark brown (7.5YR 3/3) clay loam with a significant lower packing density, organic matter rich aggregates and a slightly increased gravel occurrence. An organic matter rich (2.4% C_{org}) layer was recovered from auger samples in depth between 510 and 555cm.

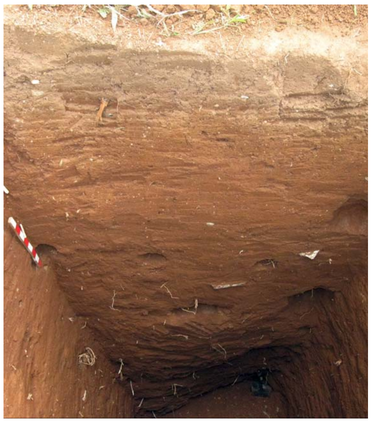
Vegetation: Eucalyptus with a thick undergrowth of raspberries, grasses and herbs.

Soil Cover: n.d.

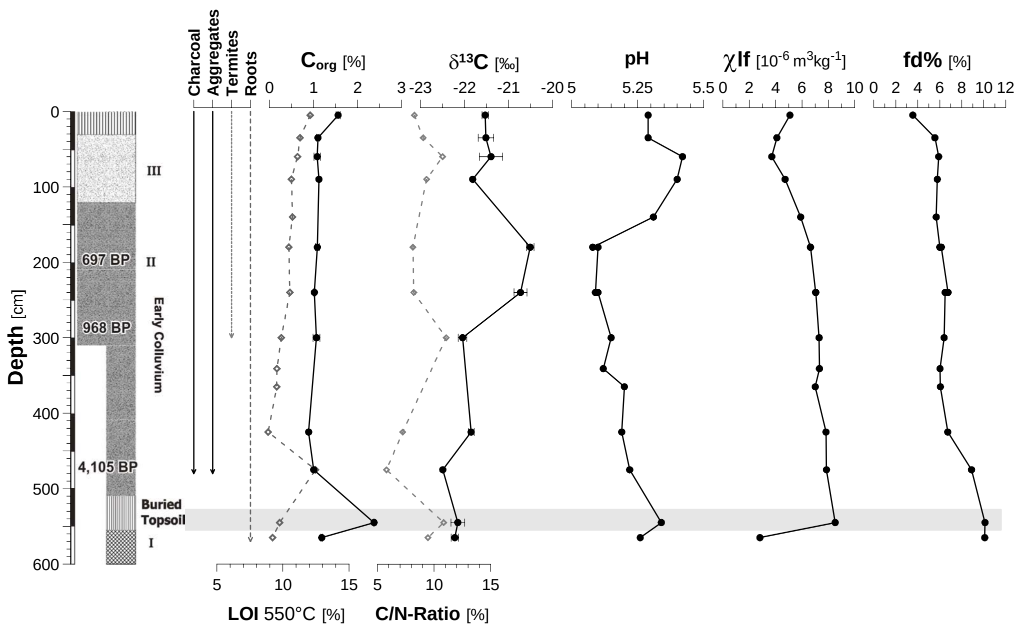
Alterations: Terracing, agriculture, paths

Erosion Feat.: n.d.

Archaeological Features: none

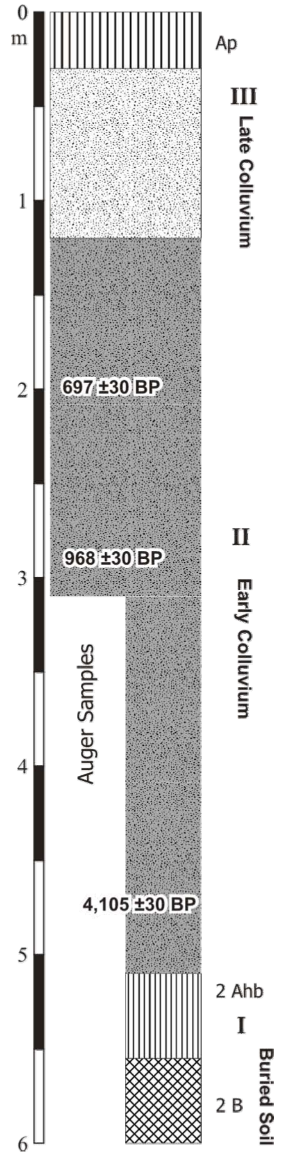


Lomwe 5: Analysis Overview

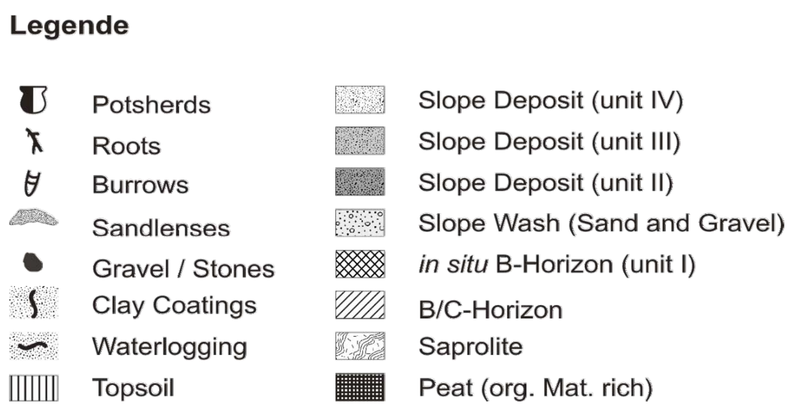


Lomwe 5

Soil Profile



Zones	Horizon	Description
III / IV	**Ap** 0 – 30cm	Dark brown (7.5YR 3/4 moist; brown 7.5YR 5/4, dry) clay loam, few (5%) weathered medium gravel, moderate granular to subangular blocky structure, medium density, fine and coarse roots present, charcoal present.
Late Colluvium	30 - 120cm	Yellowish red (5YR 3/4 moist; strong brown 7.5YR 5/6, dry) clay loam, **few (5%)** weathered medium occasional coarse gravel, weak subangular blocky structure, moderate density, fine and coarse roots present, charcoal present.
II **Early Colluvium**	120 – ~410cm	**Dark brown** (**7.5YR 3/3** moist; strong brown 7.5YR 4/6, dry) clay loam, **common (<15%)** angular weathered medium gravel, occasional coarse gravel and stones, weak subangular blocky structure, **low density**, fine and coarse roots present, termite holes, charcoal present. **Radiocarbon Date 697±30 ^{14}C BP** (198cm, charcoal) **Radiocarbon Date 986±30 ^{14}C BP** (289cm, charcoal)
	410 – 510cm	**Dark brown** (7.5YR 3/3 moist; brown 7.5YR 4/4, dry) clay loam, very few fine gravel, fine roots present, abundant charcoal. **Radiocarbon Date 4,105±30 ^{14}C BP** (475cm, charcoal)
I **Buried Topsoil**	**2 Ahb** 510 – 555cm	**Buried topsoil. Very dark brown** (7.5YR 2.5/2 moist, dark brown 7.5YR 3/3, dry) clay loam, few fine strongly weathered gravel, fine roots present, **no charcoal**.
***in situ* soil**	**2 B** 555 – 600+cm	Very dark brown (7.5YR 2.5/3 moist, brown 7.5YR 4/4, dry) clay loam, low humus content, many coarse strongly weathered gravel, fine roots present.



Lomwe 6

Coordinates: (UTM WGS 84)		
Easting:	352786	S 3°42'59.8"
Northing:	9589086	E 37°40'27.7"
Elevation:	1343m	
Pit depth:	290cm	
Colluvium:	290cm	

Relief	
Slope:	~10°
Aspect:	NNW 340°
Slope Pos.:	footslope
Slope Form:	concave – concave
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	buried boulder
Water table:	

Description: The profile Lomwe 6 at the lower footslope of the Changuku slope, is located at a terrace step, separating the Lomwe valley bottom and the slope. The terraced slope was used by the Lomwe School as a vegetable garden during the first half of the 20th century, prior to afforestation with Eucalyptus.
A slightly darker layer recorded in 25 – 45cm depth is probably related to recent soil movement during the establishment of the terraces or due to disturbance related to clay extraction (several clay extraction pits have been recorded here). The slope deposit is homogeneous and rests over bedrock or a big boulder buried in 3m depth. Weathering of the boulder has created a thin weathering B/C horizon with strongly weathered gravel. No distinct buried surface or topsoil were recorded at Lowme 6. High bulk densities suggest that the deposit corresponds to the upper deposition unit IV.

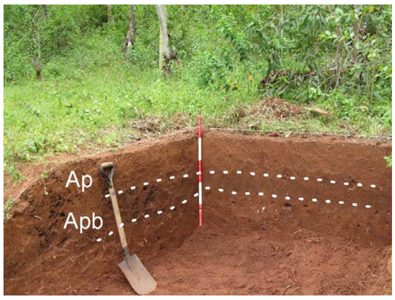
Vegetation: Eucalyptus plantation with a undergrowth of raspberries, grasses and herbs.

Soil Cover: n.d.

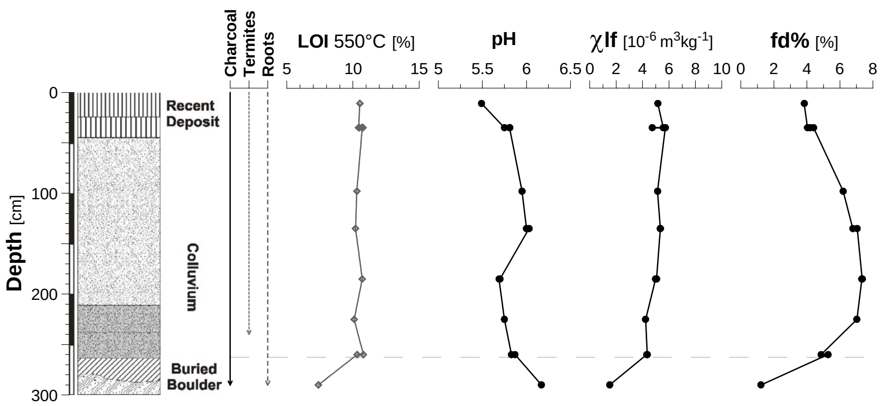
Alterations: Terracing, agriculture, paths

Erosion Feat.: n.d.

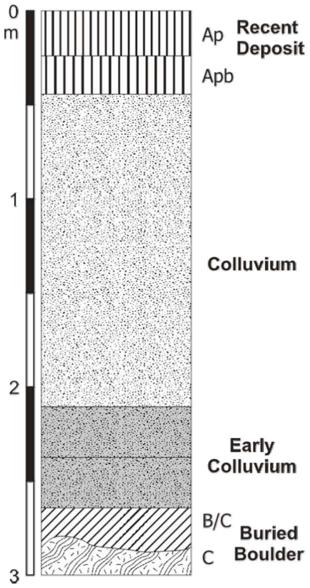
Archaeological Features: None



Lomwe 6: Analysis Overview



Lomwe 6



Zones	Horizon	Description
IV Recent Deposit	**Ap** 0 – 25cm	**Recent plough horizon.** Dark brown (7.5YR 3/4 , moist; brown, 7.5YR 5/4, dry) clay loam, low humus content, very few (2%) strongly weathered medium gravel, weak subangular blocky structure, fine roots present, clear smooth boundary.
	Apb 25 - 45cm	**Buried plough horizon.** Dark brown (7.5YR 3/4, moist; strong brown 7.5YR 4/6, dry) clay loam, moderate humus content, very few (1%) strongly weathered medium gravel, weak granular to subangular blocky structure, fine roots present, abundant charcoal, clear smooth boundary.
III	45 - 210cm	Dark brown (7.5YR 3/4, moist; strong brown 7.5YR 4/6, dry) clay ,common (10%) strongly weathered medium gravel, weak subangular blocky structure, fine roots present, very few charcoal, termite activity, diffuse boundary.
II Early Colluvium	210 – 240cm	Dark brown (7.5YR 3/4, moist; strong brown 7.5YR 5/6, dry) clay, common (<15%) angular strongly weathered coarse gravel, weak subangular blocky structure, fine roots present, dispersed charcoal, diffuse boundary.
	240 – 275cm	Brown (7.5YR 4/4, moist; reddish yellow 7.5YR 6/6, dry) clay, many (30%) strongly weathered coarse gravel, weak subangular blocky structure, fine roots present, few charcoal, **clear wavy boundary**.
Buried Boulder	**B/C** 275 – 290cm	Reddish yellow (7.5YR 6/8, moist & dry) clay in pockets within a dominant (<90%) strongly weathered gravel, moderate subangular blocky structure, fine roots present, common charcoal.
	C 290+cm	Strongly weathered saprolite. Interpreted as a large boulder redeposited from upslope.

Lomwe Peat

Haplic Gleysol (colluvic)

Coordinates: (UTM WGS 84)		
Easting:	352805	E 37°40'28.4
Northing:	9589279	S 3°42'53.5"
Elevation:	1341m	
Pit depth:	122cm	
Colluvium:	155cm	

Relief	
Slope:	none
Aspect:	none
Slope Pos.:	basin bottom
Slope Form:	straight
Microrelief:	flat, erosion gully

Geology	
Geology:	??
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	100cxm

Description: The buried peat layer crops out in a deeply incised drainage channel developing into a gully. The profile is located just above the outcrop. The subsoil shows a gleyic colour pattern with many reddish oxidation mottles within a reddish brown to grey matrix. At the fringe of the water table in about 1m depth a homogeneous grey matrix indicates continuous waterlogging and reductive conditions; although the oxidation mottles are still common. Here plant remains (leaves, stalks, etc.) are well preserved.

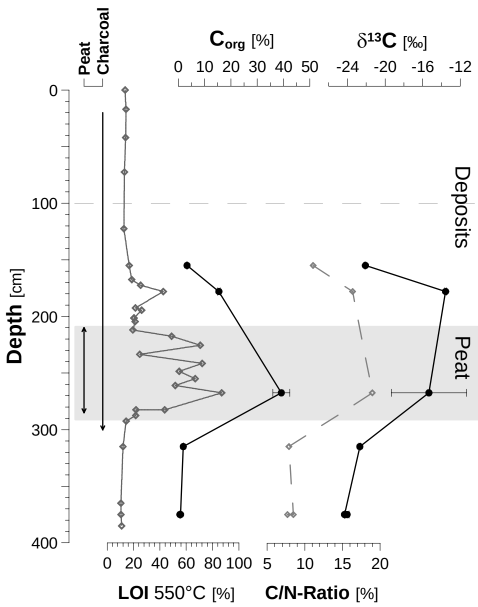
Vegetation: Grasses with Grevillea trees planted along the stream

Soil Cover: Grasses 100%

Alterations: Agriculture, former rice cultivation ?

Erosion Feat.: About 2m deep gully developed from a drainage channel.

Soil Profile



Zone	Horizon	Description
Colluvial Deposits	**Ap** 0 – 34cm	**Plough horizon.** Loam, very few (2%) strongly weathered medium gravel, weak subangular blocky structure, low density, frequent roots, abrupt boundary,
	Bl 1 34 – 95cm	Clay loam, common (10%) strongly weathered medium occasionally coarse gravel, weak subangular blocky structure, few roots. Many prominent reddish oxidation mottels within a reddish grey reductimorphic matrix, **gleyic colour pattern.**
	Bl 2 95 - 155cm	Clay loam, common (10%) strongly weathered medium occasionally coarse gravel, weak subangular blocky structure, very few roots. Common prominent reddish oxidation mottles within a grey reductimorphic matrix and common black plant remains. Preservation of leaves, stalks, and other plant remains, **gleyic colour pattern.**
Peat	**Peat & Inwash** 155 – 235cm	Discontinuous peat with frequent centimetre thick clay inwash, no pure peat accumulation. **^{14}C-Date: 1704±30 ^{14}C BP** (162cm)
	Peat 235 - 285cm	Black continuous peat layer with only small lenses of grey reduced clay and sandy clay inwash. Eventual woody peat (240-250cm). Gradual boundary. **^{14}C-Date: 1336±30 ^{14}C BP** (268cm)
Soil ? Coll. ?	285 – 360cm	Dark grey clay, occasional sandy clay. Dispersed organic matter, charcoal and plant remains occasionally bedded.
	360 -390+cm	Grey clay, no gravel. Colours getting brighter to the bottom.

B.3 Mrongo: Slope deposit descriptions

Mrongo 1 – *Lower Slope*

Coordinates: (UTM WGS 84)	
Easting:	E 37°40'28.0"
Northing:	S 3°38'09.9"
Elevation:	1350m a.s.l.
Pit depth:	200cm
Colluvium:	200cm+ ?
Relief	
Slope:	17°
Aspect:	WSW 250°
Slope Pos.:	upper footslope
Slope Form:	straight -. concave
Microrelief:	none
Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a

Description: Uppermost profile of the Mrongo catena located on the upper footslope within the transportation zone of colluvial sediments. Colluvial deposits of between 140cm and 200cm+ depth have accumulated here and are subject to severe erosion as observed by strong rill and sheet erosion during the rainy seasoin. Contour trenches have been established to reduce run off but are filled in rapidly by coarse sandy sediments (upper right).

Vegetation: Banana plantation (4-5m), dominated by banana (*Musa* sp.) with scattered shade trees (e.g. *Grevillea*), coffee (*Coffea sp.*), taro (*Colocasia esculenta*, cocoyam), and chilli pepper (*Capsicum* sp.).

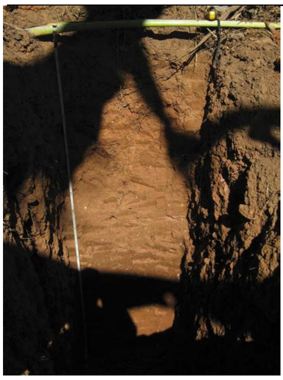
Soil Cover: 75% litter (mixture of litter and manure) 30% bare soil

Alterations: Animal husbandry, manure application, human waste.

Erosion Feat.: transportation zone, strong sheet and rill erosion during the rainy season

Archaeological Features: Potsherds in the topsoil.

Soil Profile



	Horizons	**Description**
Colluvium	**Ap** 0-38cm	Bright brown clay loam, few (5%) medium to coarse gravel, weak subangular blocky to granular structure, low bulk density, common roots, animal holes, charcoal present, clear wavy boundary. **Potsherd.**
	B1 38 – 80cm	Reddish brown clay loam, few (5%) medium to coarse gravel, weak subangular blocky structure, moderate bulk density, common roots, charcoal present, diffuse boundary.
	B2 80 – 140cm	Bright reddish brown clay loam, common (15%) medium to coarse gravel, weak subangular blocky structure, high bulk density, roots present, no charcoal present, clear boundary.
	B3 140 - 200cm	Reddish orange clay loam, few (5%) coarse gravel, weak subangular blocky structure, moderate bulk density, roots present, animal holes.

Mrongo 1: Analysis Overview

No laboratory analysis performed.

Mrongo 2 – *Placed Boulders*

Coordinates: (UTM WGS 84)

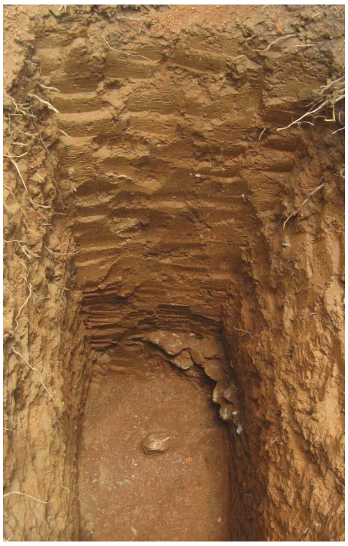
Easting:	352743
Northing:	9597968
Elevation:	1324m a.s.l.
Pit depth:	400cm
Colluvium:	320cm

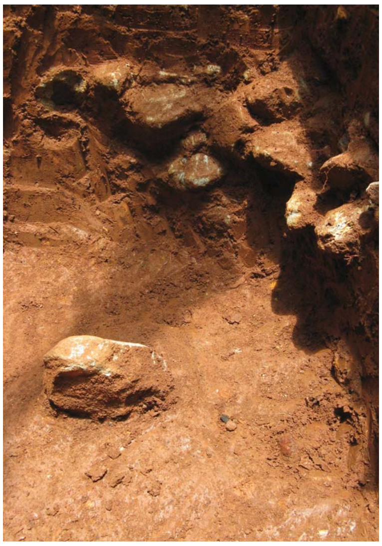
Relief

Slope:	11°
Aspect:	SW 235°
Slope Pos.:	foot slope
Slope Form:	concave-convex
Microrelief:	11°

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a





Description: The profile is located on the gentle upper footslope about 40m below a house platform and about 15m away and slightly higher than the dry channel of the small seasonal Mrongo stream. A homogeneous and reddish upper colluvium rest upon a distinctly darker deposit characterized by common occurrence of potsherds, reworked aggregates and a variety of weathered and unweathered rock types. At 200cm, placed stones and boulders in the north-eastern corner and potsherd occurrence indicate deliberate human activity. Below this 'occupation surface' dated to 954±30 ^{14}C BP, a further metre of colluvium buries a possibly truncated lower subsoil horizon. Seasonal water logging and intensive oxidative weathering have lead to incipient mottling and the occurrence of dark stained spots within the truncated *in situ* subsoil horizon.

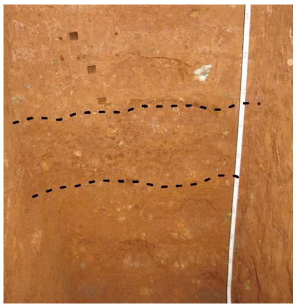
Vegetation: Banana plantation (4-5m), dominated by banana (*Musa* sp.) with scattered shade trees (e.g. *Grevillea*) and old grown indigenous trees. Extensive mixed agroforestry systems with dispersed coffee (*Coffea sp.*), taro (*Colocasia esculenta*, cocoyam), and chilli pepper (*Capsicum* sp.).

Soil Cover: 80% litter (mainly banana leaves) and manure are forming a thick (up to 5cm) matt of partly decomposed organic material, 20% bare soil.

Alterations: Agricultural activities, animal husbandry (chicken), manure application, household waste

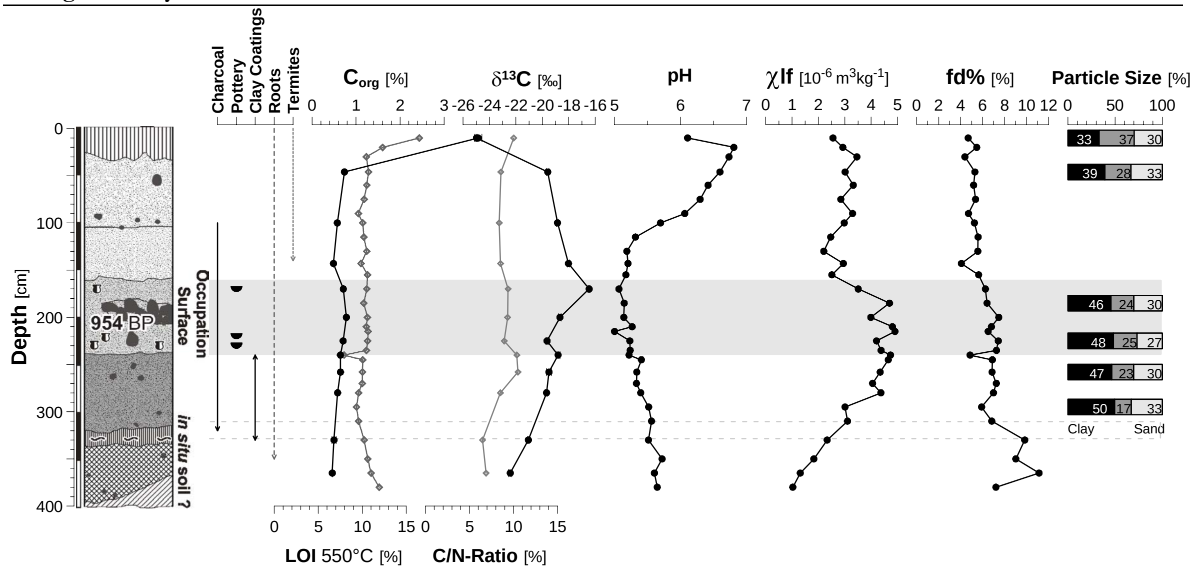
Erosion Feat.: Strong sheet and rill erosion during the rainy season, mats of partly decomposed litter and manure stabilize the soil surface.

Archaeological Features: Potsherds (170cm, 220cm, 2x 230cm), Placed stones (200-240cm).



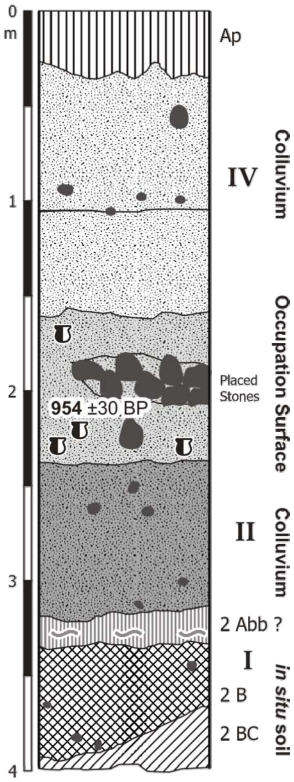
Dark stained, truncated soil horizon (2 Ahb ?)

Mrongo 2: Analysis Overview



Mrongo 2 – *Placed Boulders*

Soil Profile



	Horizons	Description
Late Colluvium	**Oi** +4 – 0cm	Litter (mainly banana leaves and litter manure) forming a thick organic matter matt
Late Colluvium	**Ap** 0 - 25cm	Reddish yellow (7.5YR 6/6,) clay loam, with few (<5%) fine <0.6cm) angular weathered gravel, moderate granular-subangular blocky structure, abundant fine and many coarse roots, voids from animal, termite and root activity, clear wavy boundary.
Late Colluvium	25 – 100cm	Reddish yellow (5YR 7/6 dry) clay loam with few (<5%) fine (<0.6cm) angular weathered gravel, occasionally stones, moderate subangular blocky structure, many roots, voids from animal, termite and root activity, gradual wavy boundary. **pH values >6.**
Late Colluvium	**Stones** 100 – 110cm	**common (<15%) coarse (<6cm) angular weathered gravel**
Late Colluvium	100 - 160cm	Reddish yellow (5YR 7/6 dry) clay loam with few (<5%) fine (<0.6cm) angular weathered gravel, weak subangular blocky structure, very few roots, voids from animal, termite and root activity, clear wavy boundary. **Low pH values <6.**
Occupation Surface	**Ahb 1** 160 – 180cm	**Yellowish red (5YR 5/6 dry)) weakly humous (<2%)** clay with few (<5%) fine (<0.6cm) angular weathered gravel, weak subangular blocky structure, **many fine roots, clear irregular boundary, Potsherd** (170cm)**.** Transition horizon mixed with overlaying colluvial material
Occupation Surface	**Placed Stones** 190 - 210cm	**Yellowish red (5YR 5/6 dry)) weakly humous (<2%)** clay with **abundant (<80%) angular fresh to weathered boulders (<30cm)**, weak subangular blocky structure, few roots, presence of charcoal.
Occupation Surface	**Ahb 2** 180 – 240cm	**Yellowish red (5YR 5/6 dry) weakly humous (<2%)** clay with **common (<15%) coarse (<6cm) angular fresh to weathered gravel**, weak subangular blocky structure, very few roots, abundant charcoal, firm **organic matter rich aggregates,** , clear boundaries. **Potsherds** (220cm, 230cm)**.** Radiocarbon Date: **954±30 ¹⁴C BP** (220cm, charcoal)**j**
Coll.	240 – 320cm	**Yellowish red (5YR 5/6 dry**) clay with **few (<5%)** angular **weathered stones (<10cm),** moderate subangular blocky structure, few roots, presence of charcoal, **few reddish and bright clay coatings in holes and cracks,** clear irregular boundary.
in situ soil	**2 ABb ?** 320 – 335cm	**Yellowish red (5YR 5/6 dry**) clay, with many (<30%) coarse (<6cm) angular weathered gravel, moderate subangular blocky structure, very few roots, clear wavy boundary. **Slightly mottled (dark spots), dark blackish (Fe/Mn ?) staining of matrix and gravel**
in situ soil	**2 B** 335 – 375cm	**Reddish yellow (5YR 6/8 dry**) clay loam with many (<20%) coarse (<6cm) angular weathered gravel, medium quartz gravel, fresh gneiss gravel, moderate subangular blocky structure, very few roots, gradual broken boundary.
in situ soil	**2 BC** 375+ cm	**Strong brown (7.5YR 5/8 dry**) clay loam with abundant (<50%) strongly weathered stones (<2cm) with black **(Fe/Mn ?) weathering crusts.**

Mrongo 3

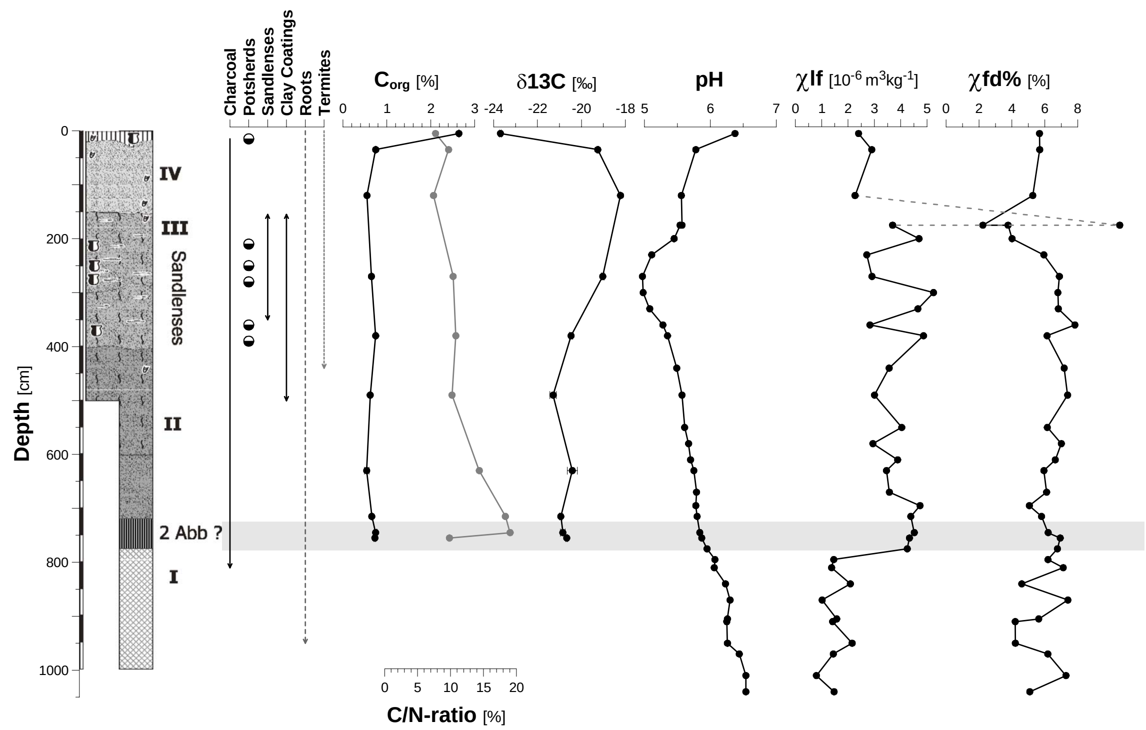
Coordinates: (UTM WGS 84)	
Easting:	352719
Northing:	9597929
Elevation:	1307m a.s.l.
Pit depth:	500cm
Colluvium:	1040cm

Relief	
Slope:	8°
Aspect:	SW 230°
Slope Pos.:	middle foot slope
Slope Form:	concave-straight
Microrelief:	smooth

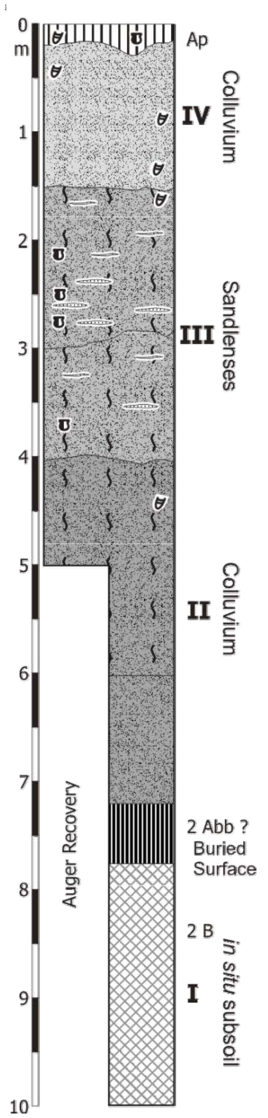
Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a

Description:	Mrongo 3 shows deep, homogeneous clay loam sediments throughout the excavated pit. Occurrence of sand lenses and a varying gravel content between 155-410cm are associated with potsherds occurence. Clay coatings are recorded below 155cm. Auger survey recovered a thin layer of slightly darker clay loam deposits around 750cm possibly corresponding to the remains of a former topsoil or an eroded landsurface. Below 780cm, the *in situ* subsoil is characterised by bright soil colours and strongly weathered gravel.
Vegetation:	Banana plantation (4-5m), dominated by banana (*Musa* sp.) with scattered shade trees (e.g. *Grevillea*) and old grown trees, coffee (*Coffea sp.*), taro (*Colocasia esculenta*, cocoyam), and chilli pepper (*Capsicum* sp.).
Soil Cover:	90% litter (mainly banana leaves) and manure are forming a thick (up to 5cm) matt of partly decomposed organic material, 10% bare soil.
Alterations:	Agricultural activities, animal husbandry (chicken), manure application, waste
Erosion Feat.:	Strong sheet and rill erosion & deposition during the rainy season, mats of partly decomposed litter and manure stabilize the soil surface.
Archaeological Features:	Potsherds (200-400cm)

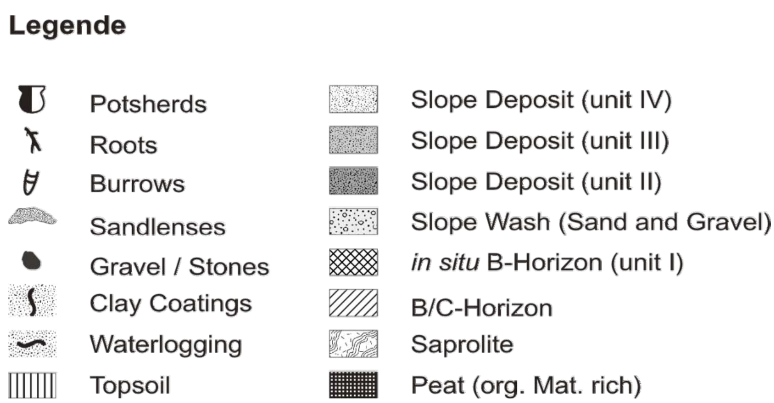
Mrongo 3: Analysis Overview



Mrongo 3



Horizons		Description
IV Colluvium	**Oi** +1 – 0cm	Litter composed of banana leaves forming a thick organic matter matt
	Ap 0 - 25cm	Light brown (7.5YR 6/4, dry) clay loam, weak subangular blocky structure, abundant (banana) roots, gradual wavy boundary, high termite activity (holes & channels), presence of charcoal, **Potsherd** (15cm).
	25 - 155cm	Red (2.5YR 4/6, moist; reddish yellow 5YR 6/7, dry), clay, common (<10%) weathered up to coarse gravel, weak subangular blocky structure, few fine and coarse roots, diffuse boundary, high termite activity (holes & channels).
III Slope Wash Sequence	**Sand lenses** 155 - ~300cm	**Red (2.5YR 4/6, moist**; reddish yellow 5YR 6/7, dry), sandy clay loam, indistinct layers of varying gravel content, alternating between **few (5%) to common (15%) dispersed medium to coarse strongly weathered gravel**, weak subangular blocky structure, few roots (banana), high termite activity (holes & channels), **charcoal** present, diffuse boundaries. **Clay coatings**, **common dispersed sand lenses** and **sandy spots,** often **iron-enriched sand**. **Potsherds** (210, 250, 280cm)
	Sand lenses ~ 300 - ~410cm	**Reddish brown (5YR 4/4, moist**; reddish yellow 7.5YR 6/6, dry), sandy clay loam, few (5%) medium strongly weathered gravel (variety of rock types), weak subangular blocky structure, few roots (banana), charcoal present, diffuse boundaries. **Clay coatings** brighter (redder) than matrix, **few dispersed sand lenses** and **sandy spots,** often **iron-enriched** sand (<350cm). **Potsherd** (360cm)
II Colluvium	410 - ~600cm	Reddish brown (5YR 4/4 moist, reddish yellow 7.5YR 7/6, dry) clay loam with few (<5%) **fresh and weathered** angular fine and occasionally coarse gravel, weak subangular blocky structure, very few roots, termite activity (filled and empty holes), **clay coatings.**
	~600 - ~725cm	Reddish brown (5YR 4/4 moist, **brown 7.5YR 5/4 dry**) clay loam with few (<5%) weathered up to medium gravel, very few roots.
I Stable Surface ?	**2 ABb ?** ~725 - ~780cm	**Dark reddish brown (5YR 3/3 moist**, brown 7.5YR 5/4 dry) sandy loam with very few (<2%) weathered medium gravel, weak subangular blocky structure, very few roots, **presence of charcoal**.
in situ subsoil ?	**2 B** ~780 – ~1000cm	**Yellowish red (5YR 4/5 moist,** Reddish yellow 7.5YR 6/6 dry) sandy loam partly with ground rotten rocks (saprolite), with few (<5%) weathered fine gravel (up to <0.6cm), **mica rich** rock at 900 - 970cm, very few roots.
	2 BC ~1000 - ~1050cm	**Yellowish red (5YR 4/6 moist**, Reddish yellow 7.5YR 7/6 dry) sandy loam with common (<15%) weathered angular medium gravel (up to <2cm), Mn & Fe staining, weathering crusts.



Mrongo 10 – *Buried Topsoil*

Coordinates: (UTM WGS 84)

Easting:	352709	E
Northing:	9597916	S 3°38'12.3"
Elevation:	1305m a.s.l.	
Pit depth:	400/740cm	
Colluvium:	600cm	

Relief

Slope:	6°
Aspect:	SSW 210°
Slope Pos.:	toe slope
Slope Form:	convex – convex
Microrelief:	smooth

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Water table:	n/a

Description: Located in a banana grove on the toe slope, the profile Mrongo 10 shows a treepart slope deposit over an *in situ* soil. A plough horizon has developed in reddish yellow crumbly clay of the upper colluvial deposit. Between 80 and 310cm depth a distinct deposit of coarse, sandy slope wash material is characterised by the occurrence of continuous and discontinuous sand lenses, distinctly visible by black iron rich sand.
Below 310cm the deposit turns reddish brown to brown (5-7.5YR 5/4, moist), clay coatings are observed and firm organic matter rich aggregates as well as aggregates of bright subsoil material are present. Several potsherds are recovered between 3 and 4m depth. Around 580cm the colluvium turns darker and at 600-610cm depth a thin but distinct layer of brown (7.5YR 4/2, moist) clay with clear boundaries suggests a buried topsoil horizon. Recovery of strongly weathered saprolitic rock fragments and unweathered mica suggests transition to the strongly weathered saprolite between 700 and 800cm depth.

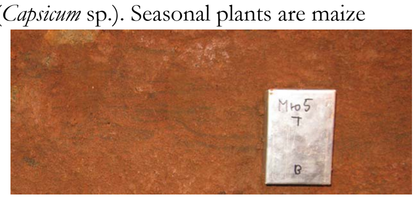
Vegetation: Banana plantation (4-5m), dominated by banana (*Musa* sp.) with scattered shade trees (e.g. *Grevillea*), coffee (*Coffea sp.*), taro (*Colocasia esculenta*, cocoyam), and chilli pepper (*Capsicum* sp.). Seasonal plants are maize (*Zea mays*) and ground covering beans.

Soil Cover: 90% litter, 10% bare soil

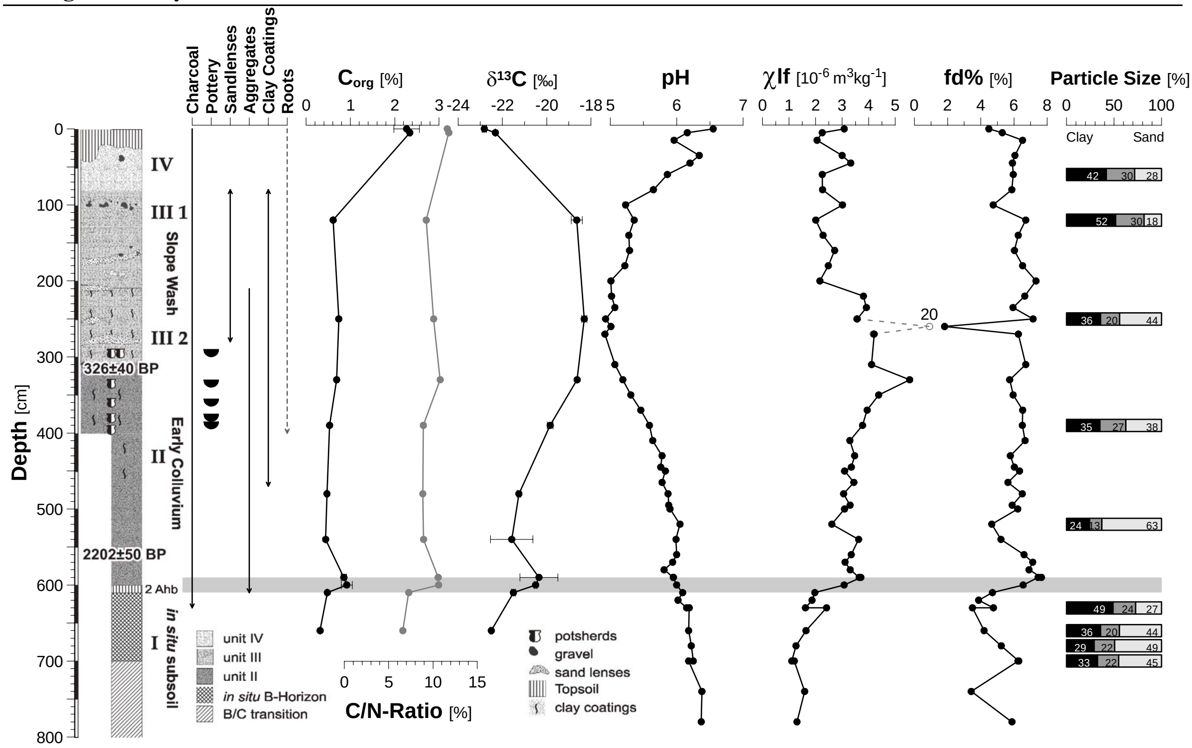
Alterations: animal husbandry (chicken), agriculture

Erosion Feat.: moderate sheet and rill erosion, hidden by continuous tillage.

Arch. Features : Potsherds (290, 335, 360, 380, 390cm)

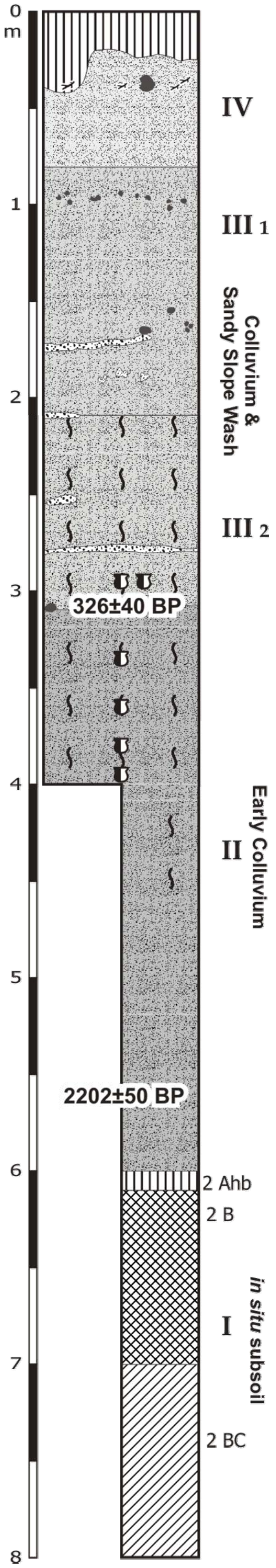


Mrongo 10: Analysis Overview



Mrongo 10 – *Buried Topsoil*

Soil Profile



Horizons		Description
IV Late Colluvium	**Oi** +0.5cm	Discontinuous (70-90%) litter layer (banana leaves, herbs, twigs etc), ephemeral slight to moderate rill erosion and local deposition of sand lenses.
	Ap 0 – 20 (40)cm	**Plough horizon.** Light brown (7.5YR 6/4; brown 7.5YR 4/4 moist) clay, very few (1%) fine weathered gravel, weak granular to subangular blocky structure, crumbly clay aggregates, low density, common fine roots and few coarse roots, common charcoal, clear wavy boundary.
	20 – 80cm	Reddish yellow (5YR 6/6; reddish brown 5YR 4/4 moist), clay, very few (1%) fine weathered gravel, occasional coarse gravel, weak subangular blocky structure, crumbly clay aggregates, medium density, few fine roots and very few coarse roots, common charcoal, gradual boundary.
	80 – 210cm	Reddish yellow (5YR 6/6; red 2.5YR 4/6 moist) clay, few (4%) medium weathered gravel, weak subangular blocky structure, crumbly clay aggregates, medium density, **clay coatings**, very few fine roots, few charcoal fragments. Small (<10cm) discontinuous sand lenses, rich in black iron sand, abrupt broken boundaries
III Slope Wash Sequence	**Sand lenses** 160 – 180cm	Contiguous sand lenses (<5cm thick), rich in black iron sand, common medium occasionally coarse fresh and weathered gravel, very few charcoal, abrupt broken boundaries.
	Sand lenses 210cm	Discontinuous sand lenses (<5cm thick), rich in black iron sand, common medium occasionally coarse fresh and weathered gravel, abrupt broken boundaries.
	210 – 310cm	Yellowish red (5YR 5/6; reddish brown 5YR 4/4 moist) clay loam, very few (2%) fine strongly weathered gravel, **different rock types, organic matter rich aggregates**, weak subangular blocky structure, medium density, **few clay coatings**, no roots, common charcoal, common, gradual boundary, **potsherds** at 280-300cm depth, Radiocarbon Date Charcoal fragment: **326±40 ^{14}C BP** (300cm)
	Sand lenses 240 – 280cm	Contiguous sand lenses (<15cm thick), rich in black iron sand, common medium occasionally coarse fresh and weathered gravel, few charcoal, abrupt broken boundaries.
II Early Colluvium	310 – 470cm	reddish brown (5YR 5/4; reddish brown 5YR 4/3 moist) clay, few (5%) fine fresh and weathered gravel, different rock types, **different rock types, organic matter rich aggregate,** moderate angular blocky structure, moderate density, **common clay coatings**, no roots, abundant charcoal, **common potsherds** (335, 360, 380, 390cm)
	470 - 550cm	brown (7.5YR 5/4; reddish brown 5YR 4/3 moist) clay, **different rock types, organic matter rich aggregate,** moderate density, charcoal present,
	550 - 580cm	brown (7.5YR 5/4; reddish brown 5YR 4/3 moist) clay, **different rock types, organic matter rich aggregate,** high density, charcoal present, Charcoal fragment: **2202±50 ^{14}C BP** (560cm)
	580 - 600cm	brown (7.5YR 4/3; dark reddish brown 5YR 3/3 moist) clay, **different rock types, organic matter rich aggregate,** high density, charcoal present,
I Buried Topsoil	**2 Ahb** 600- 610cm	brown (7.5YR 4/2; dark reddish brown 5YR 3/2 moist) clay, different rock types, organic matter rich aggregate, high density, **charcoal present**, **clear boundary.**
	2 B 610-700cm	strong brown (7.5YR 5/6; brown 7.5YR 4/4 moist) sandy clay loam, medium to coarse strongly weathered gravel, rotten rocks, **homogeneous**, high density, **charcoal above 630cm**.
in situ soil	**2 BC** 700-800cm	strong brown (7.5YR 5/6; brown 7.5YR 4/4 moist) clay loam common gravel, abundant mica, dark iron rich weathering crusts around gravels, clay bands, saprolitic rock structure
	2 C 800+	strong brown (7.5YR 5/6; brown 7.5YR 4/4 moist) Saprolite, no further penetration possible

Mrongo 4 – *Buried Topsoil*

Coordinates: (UTM WGS 84)

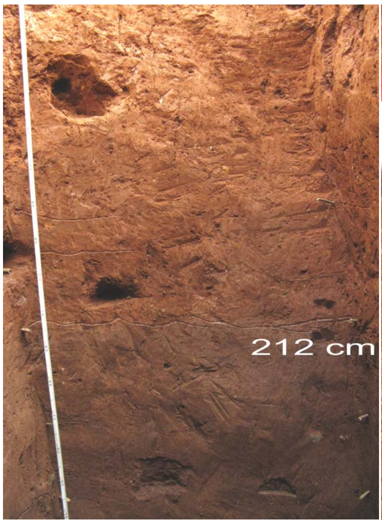
Easting:	352703
Northing:	9597896
Elevation:	1303m a.s.l.
Pit depth:	520cm
Colluvium:	830+ cm

Relief

Slope:	n/a
Aspect:	SW 235°
Slope Pos.:	valley bottom
Slope Form:	straight-concave
Microrelief:	terraced

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Water table:	725cm



Description: Mrongo 4 is located within the valley bottom. A red upper colluvium has been deposited atop a sequence of sand wash events sand wash events (125-212cm). In the upper part of the sand wash sequence, sandy layers are undifferentiated in the lower part alternating sandy clay loams and clay loams with frequent occurrence of large sand lenses and sandy spots are recorded (cf. image below). The homogeneous reddish brown deposit beneath 212cm shows clay coatings and the occurrence of firm organic matter rich aggregates. Four potsherds were recovered between 250 and 280cm. At 460 to 475cm depth a dark, buried topsoil, slightly enriched in organic matter contains potsherds and charcoal. The underlying *in situ* subsoil is affected by the fluctuating fringe of the water table and shows signs of incipient redoximorphic mottling.

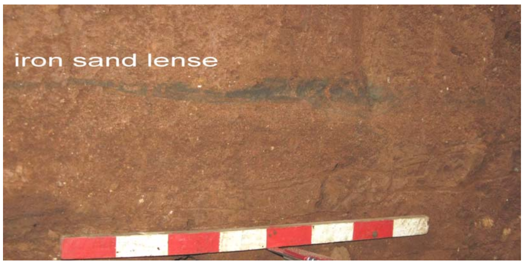
Vegetation: Recently ploughed field for maize cultivation

Soil Cover: bare soil

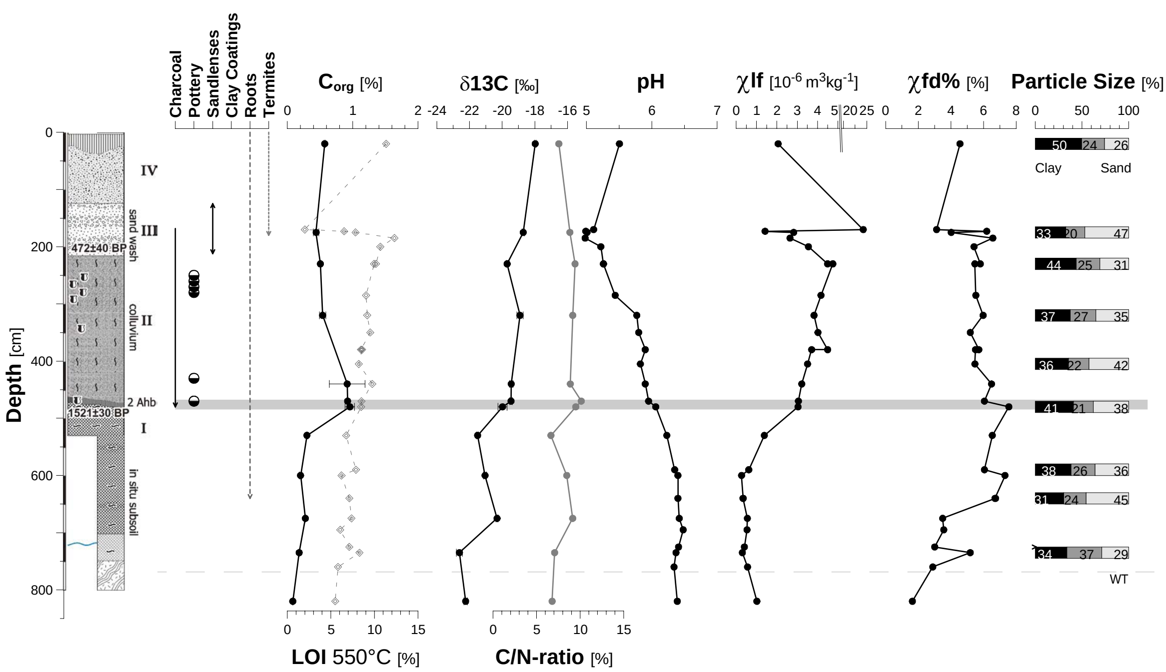
Alterations: Agricultural activities, animal husbandry, manure application, upper pit walls dried out,

Erosion Feat.: none

Archaeology: none

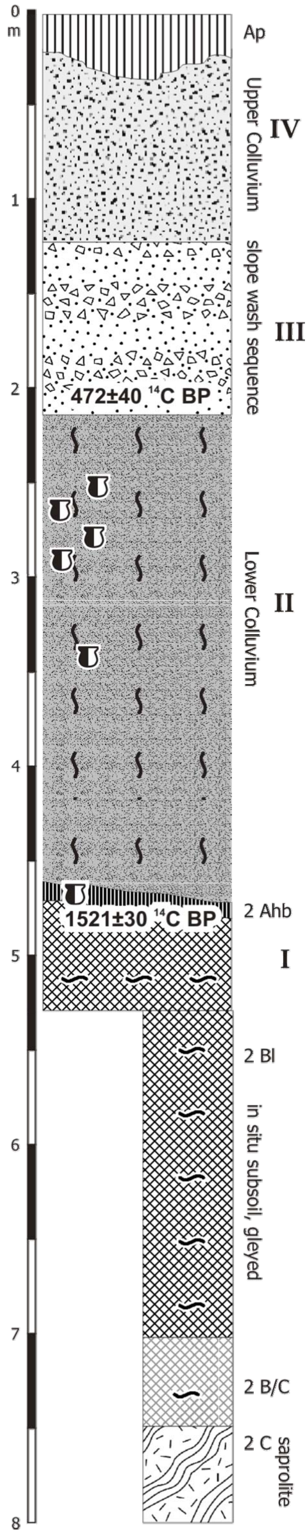


Mrongo 4: Analysis Overview



Mrongo 4 – Buried Topsoil

Soil Profile



Horizons		Description
IV Late Colluvium	**Ap** 0 - 35cm	**Plough horizon.** Red (2.5YR 4/6 moist, reddish yellow 5YR 6/6 dry) clay with very few (<2%) medium angular weathered gravel, weak subangular blocky structure, many roots, partly refilled voids from animal & termite activity, gradual boundary.
	35 – 125cm	Red (2.5YR 4/6 moist, reddish yellow 5YR 6/6 dry) clay with few (<2%) coarse (<6cm) angular weathered gravel, moderate granular-subangular blocky structure, few roots, partly refilled voids from animal & termite activity, gradual boundary. Dry.
III Slope Wash Sequence	**Sand lenses** 125 – 170cm	**Undifferentiated sequence of thin discontinuous layers** of **coarse sandy clay loams and clay loams**, diffuse broken boundaries. Continuous and **discontinuous sand lenses** (e,g, 170cm, photo) and **dispersed spots of black iron sands.** Generally: red (2.5YR 4/6 moist, reddish yellow 5YR 6/6, dry) clay loam few (<5%) fine to coarse (<6cm) weathered to strongly weathered gravel, moderate subangular blocky structure, high density, very few roots, partly refilled voids from animal & termite activity, charcoal present, organic matter rich aggregates present.
	Sand lenses 170 - 212cm	**Alternating, discontinuous about 10cm thick beds** of **sandy clay loams and clay loams,** clear broken boundaries. **Dispersed spots of black iron sands.** Generally: Red (2.5YR 4/6 moist, reddish yellow 5YR 6/6, dry) clay loam, with few (<5%) fine to medium (<2cm) weathered to strongly weathered gravel, moderate subangular blocky structure, high density, very few roots, charcoal present. **Abrupt wavy boundary and colour change.** Radiocarbon Date : Charcoal fragment **472±40 ^{14}C BP** (200cm)
II Early Colluvium	212 – 310cm	Reddish brown (5YR 4/4 moist, **light brown (7.5YR 6/4 dry**) clay with few (<5%) medium to coarse angular weathered gravel, weak subangular blocky structure, moderate to high density (230cm: 1.46g ccm^{-1}), very few roots, **few clay coatings**, **four potsherds** between 250 and 280cm**,** diffuse boundary
	310– 420cm	Reddish brown (5YR 4/3 moist, light brown 7.5YR 6/4 dry) clay loam with common (10%) coarse weathered gravel, occasionally stones, moderate subangular blocky structure, moderate density (380cm: 1.56g ccm^{-1}), **common reddish clay coatings**, presence of charcoal, **organic matter rich aggregates,** diffuse boundary.
Distinct, brown homogeneous layer	420 - 460	**Dark reddish brown** (5YR 3/3 moist, brown 7.5YR 5/4 dry) clay loam with **very few (<1%)** coarse angular weathered gravel, weak subangular blocky structure, low density, reddish clear fine prominent (oxidation) mottles, **reddish clay coatings,** clear smooth boundary.
I Buried Topsoil (Stable Surface)	**2 Ahb** 460 – 475cm	**Dark brown** (7.5YR 3/2 moist, brown 7.5YR 5/3 dry) clay loam with very few (<1%) coarse angular weathered gravel, weak subangular blocky structure, low density, **light brown clay coatings**, Mosaic of l**ight red (2.5YR 6-7/6-8) oxidation mottles, bright reddish brown animal channels within a dark matrix soil, presence of charcoal, 2 potsherds** 430 & 470cm, abrupt smooth boundary, Radiocarbon Date : Charcoal fragment **1521±30 ^{14}C BP** (470cm):
	2 B 475 – 530+cm	Reddish brown (5YR 4/4 moist, reddish yellow 7.5YR 6/6 dry) clay with very few (<2%) coarse angular weathered gravel, moderate subangular blocky structure, moderate density, **reddish yellow (5YR 6/6) clay coatings, indistinct mottling.**
***in situ* subsoil**	**2 Bl** ~530 – 700cm	Brown (7.5YR 4/4 moist, light yellowish brown 10YR 6/4 dry) clay loam (sandy) with **distinct weathering mottling / gleyic colour pattern** (pale reduction mottles (very pale brown 10YR 8/2) and spots of light red (2.5YR 6/8) oxidation mottles), common strongly weathered gravel, mica abundant.
	2 B/C 700 – 750m	Brown (7.5YR 5/4 moist, very pale brown 10YR 7/4 dry) clay loam (silty) with **weathering mottling** (oxidation colours), common strongly weathered gravel.
	720cm	Water table
Saprolite	**2 C** 750 – 820+cm	Brown (7.5YR 4/4 moist, reddish yellow 7.5YR 6/6 dry) mica rich sandy loam with greyish reduction mottles and blackish Mn – staining, weathering crusts, and black iron sand. **In situ weathering.**

Mrongo 5 – *Buried Channel*

Coordinates: (UTM WGS 84)

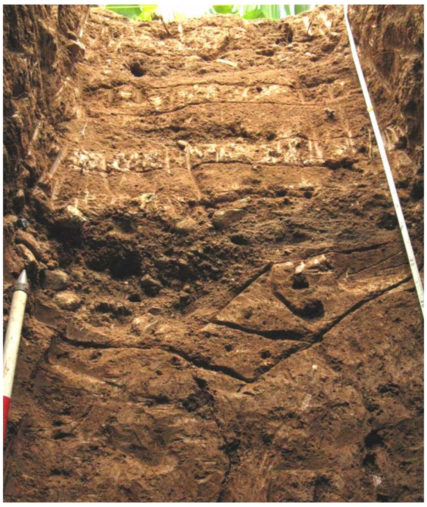
Easting:	352656	E 37° 40'24"
Northing:	95979121	S 3°38'12.4"
Elevation:	1294m a.s.l.	
Pit depth:	440cm	
Colluvium:	440cm	

Relief

Slope:	~3°
Aspect:	n.d.
Slope Pos.:	lower footslope
Slope Form:	straight
Microrelief:	settlement

Geology

Parent Mat.:	colluvial material
Outcrops:	none



Description: On the northern side of the seasonal Mrongo stream an open but yet unused latrine pit within a homestead was deepened and cleaned. The upper meter is characterised by alternating layers of fine textured clay loam and sandy loam and sands. Between 1 and 1.4m a channel was cut into the fine textured colluvium. The channel is filled with coarse gravel, stones and sand, observed at the front and right wall of the soil pit suggesting deposition of water transported sediments. The lower part of the profile is of predominantly colluvial origin. Between 150 and 375cm sand lenses and sandy spots occur evidencing sporadic slope wash and rill erosion events. The OSL deposition ages of the lowermost layer (330-375cm) with occurrence of dispersed sandy spots, e.g. indistinct sand lenses suggests early runoff events since abouot 1360±80 years ago. In general, the deposit is characterised by different types of strongly weathered rocks, transported bright reddish and dark, organic matter rich soil aggregates. Clay coatings are present. Below 375cm, the clay loam becomes slightly brighter and gravel content increases markedly, below 400cm incipient mottling is observed. Potsherds and charcoal in the lower part of the profile indicate human presence throughout the accumulation of the deposit. As the profile was shallow compared to the other profiles, no buried topsoil or former surface could be recorded.

Vegetation:
shade trees

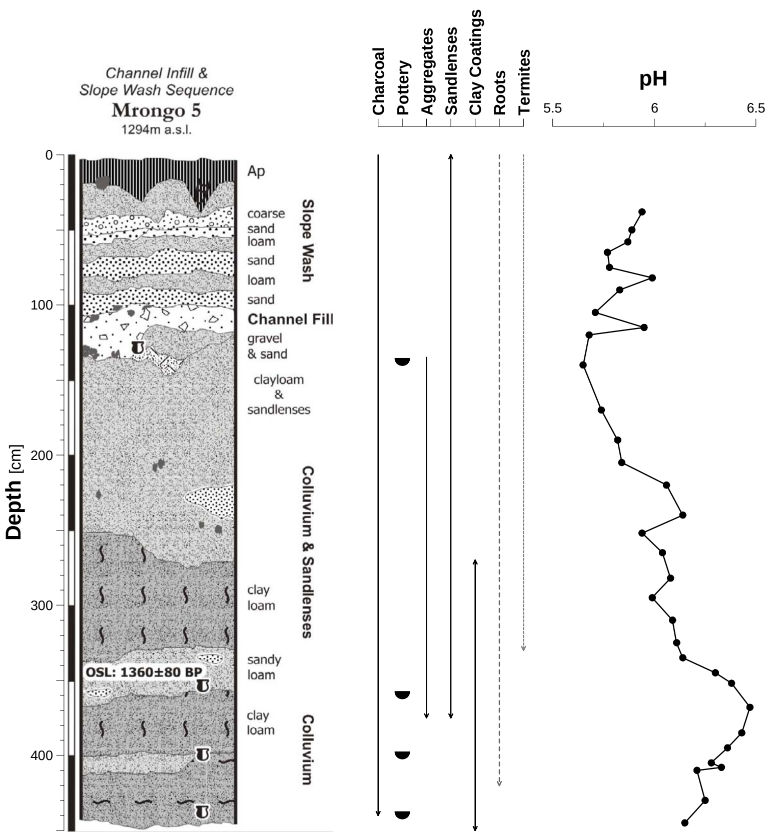
Soil Cover:
bare

Alterations:
Homestead disturbance, waste, animal husbandry, chicken,

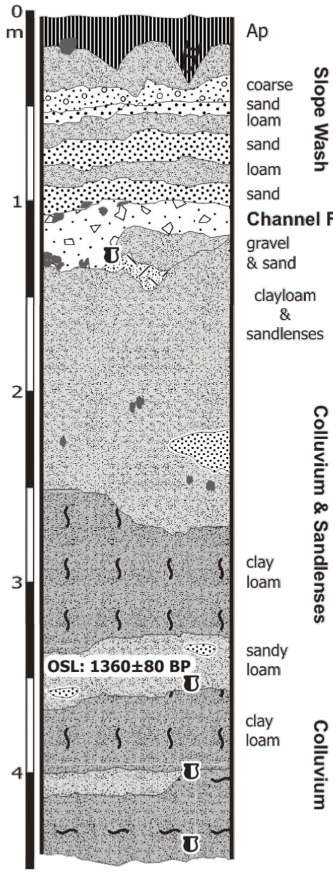
Erosion Feat.:
none

Archaeology:
modern waste (shoes, plastic) in the upper layer, potsherds (135, 360, 400, 440cm).

Mrongo 5: Analysis Overview

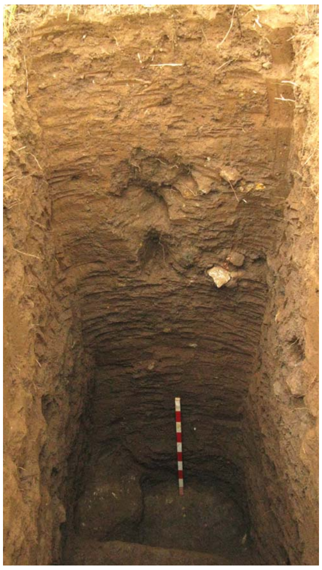


Mrongo 5 – *Buried Channel*

Soil Profile	Horizons		Description
			

Horizons		Description
III / IV Coarse, layered Slope Wash Deposit	**Ap** 0 – 30cm	**Recent plough horizon.** Light brown clay loam, common (10%) angular gravel, occasionally stones, subangular blocky structure, moderate density, fine and coarse roots present, termite holes, human waste (shoes, plastic), charcoal present, clear boundary.
	Sand & Gravel 30 – 44cm	Reddish coarse sand, many (40%) fine to coarse angular gravel, occasionally stones, single grain structure, moderate density, fine and coarse roots present, gradual boundary.
	Sand 44 – 52cm	Light brown loamy sand, few (2%) fine to coarse subrounded gravel, single grain structure, moderate density, fine and coarse roots present, termite holes, abrupt smooth boundary.
	Loam 52 – 62cm	Light brown clay loam, very few (1%) fine gravel, subangular blocky structure, moderate density, fine and coarse roots present, termite holes, abrupt smooth boundary.
	Sand 62 – 77cm	Reddish yellow loamy sand, **stratified**, few (5%) mostly fine but up to coarse gravel, single grain structure, moderate density, fine and coarse roots present, termite holes, abrupt smooth boundary.
	Loam 77 – 85cm	Light brown clay loam, very few (1%) fine gravel, subangular blocky structure, moderate density, fine and coarse roots present, abrupt smooth boundary.
	Sand 85 – 92cm	Reddish yellow loamy sand (iron sand rich), very few (1%) fine gravel, single grain structure, moderate density, fine and coarse roots present, clear wavy boundary.
III Channel Fill	**Gravel & Sand** 92 –135cm	Reddish yellow loamy sand, stratified (iron rich), (75%) fine to coarse angular and subrounded gravel and stones, single grain structure, low density, fine and coarse roots present, termite holes, abrupt irregular boundary.
	Sand & Loam 110 – 135cm	Reddish yellow sandy loam (iron sand rich), very few (1%) fine gravel, subangular blocky structure, moderate density, fine and coarse roots present, abrupt broken boundary. **Potsherd** (~138cm).
II 2 Colluvium & Sandy Slope Wash	**Sand lenses** 135 – 270cm	Reddish brown (5YR 4/4, moist; brown 7.5YR 5/4, dry) clay loam. **Sand lenses, sand and gravel accumulation (220-260cm, right wall)**. many **(25%) medium grave**l (different strongly weathered rock types), subangular blocky structure, high bulk density to very high density (1.44g ccm^{-1}, 220cm; 1.57 ccm^{-1}, 252cm), fine and coarse roots present, organic matter rich aggregates, gradual boundary.**,**
	270 – 330cm	Reddish brown (5YR 4/4, moist; brown 7.5YR 5/4, dry) clay loam, many **(15%) medium gravel** (different strongly weathered rock types), subangular blocky structure, high bulk density (1.53g ccm^{-1}, 282cm; 1.54 ccm^{-1}, 310cm; 1.47 ccm^{-1}, 325cm), fine and coarse roots present, termite holes, **few clay coatings**, diffuse boundary, organic matter rich aggregates.
	Sandy loam 330 – 375cm	Reddish brown (5YR 4/4, moist; brown 7.5YR 5/4, dry), **sandy loam, discontinuous sand lenses** (black iron rich sand), few (5%) coarse gravel (different strongly weathered rock types), subangular blocky structure, high bulk density (1.59g ccm^{-1}, 352cm; 1.48g ccm^{-1}, 345cm), few clay coatings, fine and coarse roots present, clear wavy boundary, organic matter rich aggregates, **Potsherd** (360cm). OSL Date: **1360±80 a** (345cm)
	375 – 400cm	Reddish brown (5YR 4/4, moist; brown 7.5YR 5/4, dry) **clay loam**, common (10%) gravel, subangular blocky structure, moderate density, fine roots present, few bright clay coatings, fine roots present, charcoal present, clear wavy boundary.
II 1 Colluvium	400 – 450cm	Yellowish red (5YR 4/6, moist; strong brown 7.5YR 5/6, dry) clay loam, **many (20-40%)** strongly weathered **gravel** and stones, subangular blocky structure, high density, fine roots present, **few clay coatings** (same colour as matrix)**, incipient mottling**, iron rich weathering crusts on gravel, clear wavy boundary. **Potsherd** (400cm, 440cm)

Mrongo 11 – *Headwater Depression*



Coordinates: (UTM WGS 84)		
Easting:	352884	E 37°40'31.3"
Northing:	9598172	S 3°38'04.0"
Elevation:	1380m a.s.l.	
Pit depth:	300cm	
Colluvium:	300+cm	

Relief	
Slope:	15°
Aspect:	W 270°
Slope Pos.:	footslope - depression
Slope Form:	concave – concave
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	2-3 boulders within 20m
Water table:	>300cm

Description: Small partly terraced head slope depression of the seasonal Mrongo stream, upslope of the Mrongo catena. The headwater depression is partly deforested and cultivated. At a road cut within the depression a dark grey horizon below 1-2m of deposits rests over boulders. The groundwater table was observed in 1½m depth at a waterhole near the road. The profile is located upslope within the depression 2m away from a seasonal about 20cm deep channel.

Three discontinuous lines of stones were recorded, the lowest one coinciding with a reddish layer of sandier material and a line of small tiny charcoal fragments. Large boulders mark the profile bottom. On top of these boulders the dark grey horizon observed at the road cut was recorded and is suspected to be part of a former ground surface dated to around 1197±50 ^{14}C yrs BP by a charcoal fragment from 3m depths.

In contrast to the Changuku head slope depression, where colluviation started in the first centuries AD, slope deposit accumulation at the Mochame mid-slope was delayed compared to the Mrongo footslope profiles.

Vegetation: Open agricultural field with scattered *Manihot esculenta*, *Saccharum* sp.(sugar cane), *Zea mays* (mahindi), cow grass, grasses and herbs.

Soil Cover: 75% bare soil, 15% medium gravel 10% litter

Alterations: Terracing, maize, cassava, sugar cane cultivation.

Erosion Feat.: Slight sheet erosion indicated by a surface stone pavement (15% medium gravel) and moderate rill erosion (5cm deep, 1m spaced).

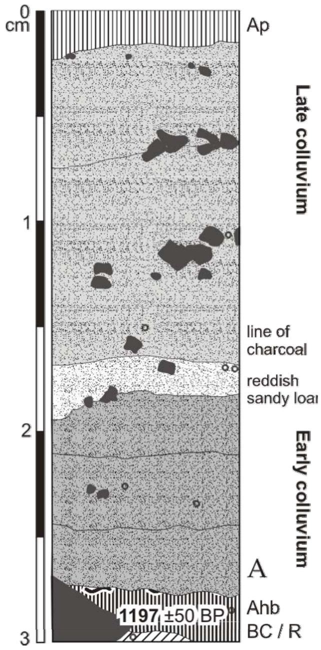
Archaeological Features: none

Mrongo 11: Analysis Overview

No laboratory analysis performed

Mrongo 11 – *Headwater Depression*

Soil Profile



Horizons		Description
	Surface	Common (20%) medium strongly weathered gravel.
IV	**Ap** 0 – 20cm	Very dark greyish brown (10YR 3/2, moist; yellowish brown 10YR 5/4, dry), clay loam, few (5%) strongly weathered medium gravel, weak subangular blocky structure, low density, common fine roots, charcoal present, termite activity, clear wavy boundary
upper deposits	20 – 70cm	Brown (7.5YR 4/4, moist; light brown 7.5YR 5.5/4, dry) clay loam, few (5%) strongly weathered medium gravel, weak subangular blocky structure, , low density, common fine roots, charcoal present, termite activity, gradual boundary.
	gravel 70cm	**Discontinuous line of stones** (fresh and weathered), mainly front, right & back wall, associated charcoal
slope deposit	70 – 165cm	Brown (7.5YR 4/3, moist, brown 7.5YR 5/4, dry), clay loam, common (5-10%) strongly weathered medium occasional coarse gravel, weak subangular to angular blocky structure, low density, common fine roots, termite activity, charcoal present, gradual boundary. **Indistinct hard identifiable sand lenses** (with black iron sand).
	120cm	**Discontinuous line of stones**, mainly right wall.
	165 / 190cm	**Discontinuous line of coarse gravel**, mainly right/back wall, **charcoal layer** (10cm long) at right/back wall
sand wash	**reddish sandy loam** 165 – 185cm	Reddish brown (5YR 4/4), comparably bright, **sandy clay**, common (20%) strongly weathered medium occasional coarse gravel, weak subangular to angular blocky structure, moderate density, common fine roots, charcoal present, diffuse boundary.
II **slope deposit**	185 – 278cm (210/245cm)	**Indistinct layers of different shades of reddish to greyish colours**. Generally: dark brown (7.5YR 3/2, moist; brown 7.5YR 5/3, dry), sandy clay loam to clay loam. common (20%) strongly weathered medium occasional coarse gravel, weak subangular to angular blocky structure, moderate density, common fine roots, charcoal present, diffuse boundary. **Discontinuous indistinct sand lenses present**.
I **Stable Surface**	**Ahb** 278 – 295cm	**Distinct discontinuous dark grey (organic matter rich?) seasonally waterlogged and discoloured layer extending all along the depression around/above boulders** Very dark grey (10YR 3/1, moist; dark greyish brown 10YR 4/2, dry), Colours reported in the field range from 'dark grey' (5YR 3/2 – dark reddish brown; mainly aggregates) to 'bright grey' (7.5YR 4/3 – brown, mainly pores). **clay,** common (20%) strongly weathered medium occasional coarse gravel, quartz & mica present, weak subangular to angular blocky structure, low density, common fine roots, charcoal present, wavy surface, abrupt broken boundary.
Weathering horizon	**BC** 295 – 315cm	**Discontinuous weathering layer between/near stones.** Dark yellowish brown (10YR 4/4, moist; light yellowish brown 10YR 6/4, dry) **sandy clay,** common (10%) strongly weathered medium occasional coarse gravel, quartz (fresh), other rocks strongly weathered, weak subangular to angular blocky structure, low density, common fine roots, charcoal common, abrupt broken boundary. Radiocarbon Date: **1197±50 ^{14}C BP** (300cm, charcoal)
Boulder	**R** 280 – 315+cm	Large, translocated boulder (75%, <200cm), locally common and exposed on the surface. The boulder at the bottom of the pit is not bedrock but probably the result of a mass movement.

B.4 Ngalanga: Eroded soil under agricultural land use

Ngalanga 1 – *Forest Edge* — Cambisol?

Coordinates: (UTM WGS 84)		
Easting:	351977	E 37°40'02.0"
Northing:	9599468	S 3°37'21.7"
Elevation:	1461m a.s.l.	
Pit depth:	~200cm	
Colluvium:	none	

Relief	
Slope:	n/a
Aspect:	S 360°
Slope Pos.:	upper shoulder
Slope Form:	convex-convex
Microrelief:	none

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	bedrock
Outcrops:	1x 10m Ø1m

Description: The profile was located at the edge of the Ngalanga sacred grove on top of the Ngalanga hill in a strongly disturbed area between a house platform and the forest. Despite the strong recent disturbance and erosion the profile shows the preservation of a deep subsoil ~2m over strongly weathered saprolite and points to what a potential forest subsoil on the Ngalanga hill looks like. Most striking are the dark red upper subsoil horizons. Comparison with the Ngalanga ridge and banana plantation profiles shows that these soils have potentially lost about >1m of their original soil.

Vegetation: Shrub and grass cover on the profile surface; indigenous and introduced tree species at the forest boundary.

Soil Cover: Bare soil (70%), litter (30%)

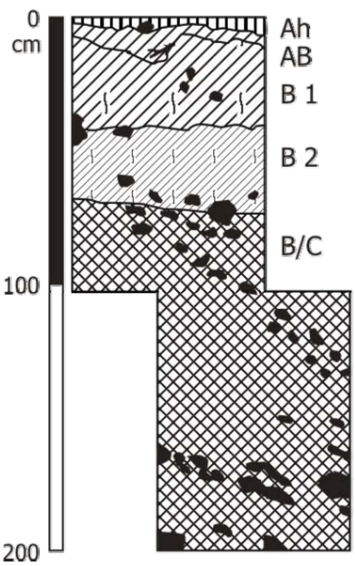
Alterations: Agriculture, animal husbandry, waste, erosion

Erosion Feat.: Sheet and rill erosion

Archaeological Features: none

Clay coatings in saprolite material

Soil Profile



In situ subsoil

Horizons	Description
Ah 0 – 2cm	Brown (7.5YR 4/3, moist, 7.5YR 5/4, dry) clay, charcoal present, clear boundary.
AB 2 – 10cm	Dark reddish brown (5YR 3/3, moist; reddish brown 5YR 4/4, dry), clay common (15%) fine to medium weathered gravel, moderate subangular blocky structure, high density, few fine roots, charcoal present, clear boundary.
B 1 10 – 40cm	Reddish brown (2.5YR 4/4, moist; red 2.5YR 4/6, dry), clay common (10%) fine to medium weathered gravel, weak moderate subangular blocky structure, low bulk density (1.26g ccm^{-1}, 35cm), few fine roots, clear boundary
B 2 40 – 65cm	Reddish brown (2.5YR 4/4, moist; red 2.5YR 5/8, dry), clay, common (15%) fine to medium weathered gravel, weak subangular blocky structure, low bulk density (1.12g ccm^{-1}, 50cm) high density, few fine roots, gradual bound.
B/C 65 – 190	Red (2.5YR 4/6, moist; red 2.5YR 5/8, dry), clay many (20%-30%) up to coarse strongly weathered gravel, subangular blocky structure, low to moderate bulk density (1.37g ccm^{-1}, 85cm; 1.34g ccm^{-1}, 130cm; 1.20g ccm^{-1}, 175cm), clay coatings in rocks structure. Preserved rock structure.

Ngalanga 2 – *Banana Grove* Cambisol (colluvic)

Coordinates: (UTM WGS 84)

Easting:	351868	E 37°39'58.5"
Northing:	9599431	S 3°37'22.9"
Elevation:	1389m a.s.l.	
Pit depth:	~100cm	
Colluvium:	35cm	

Relief

Slope:	25°
Aspect:	W 270°
Slope Pos.:	middle slope/ridge
Slope Form:	convex-convex
Microrelief:	none

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	bedrock & colluvium
Outcrops:	2x 10m Ø2m

Description: The profile was established on the steep upper slope of the Ngalanga hill in the banana plantation of a still practicing iron smith, about 20m below the house platform. The soil is characterized by dark topsoil developed in colluvial material and an eroded and truncated subsoil (2 B/C horizon). The original red subsoil is eroded and only pockets are left within the B/C horizons. The bedrock exposed in the soil pit shows varying rock types and the stratigraphic arrangement of the metamorphic bedrock. Subsequent deposition of material from upslope allowed the development of humus rich topsoil. The development of a comparative deep topsoil on this steep slope after the removal of the original soil shows that soil degradation can be reversed by agricultural practices e.g. a dense vegetation cover by dense oldgrown shade trees, reduced tillage.
The most important factor however is the addition of colluvial material, organic waste, and animal manure.

Vegetation: Banana plantation (4-5m), dominated by banana (*Musa* sp.) with scattered shade trees (introduced and indigenous), coffee (*Coffea* sp.), taro (*Colocasia esculenta*, cocoyam), maize (*Zea mays*), and beans as ground cover.

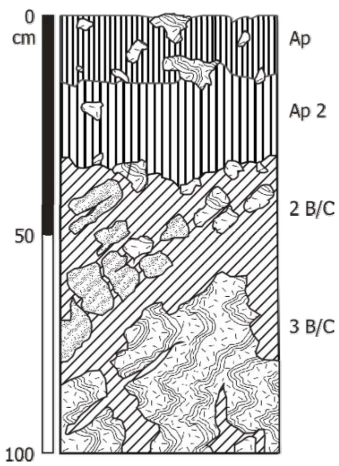
Soil Cover: Litter (30%), bare soil (40%), gravel (20%), grasses (10%)

Alterations: Agriculture, spoil of house platform, banana planting, animal husbandry, manure, waste

Erosion Feat.: Slight stone pavement

Archaeological Features: Plastic waste, tatters

Soil Profile



	Horizon	Description
	Surface	15% medium gravel, 5% coarse gravel
Colluvium	**Ap** 0 – 20cm	Dark brown (7.5YR 3.5/3, moist; yellowish brown 10YR 5/4, dry) clay loam, common (10%) strongly weathered stones, weak granular to subangular blocky structure, low density, frequent roots, gradual wavy boundary, plastic waste.
Colluvium	**Ap 2** 20-35cm	Brown (7.5YR 4/3, moist; brown 7.5YR 5/4, dry) clay loam, few (5%) strongly weathered medium gravel, weak subangular blocky to granular structure, moderate density, frequent roots, clear wavy boundary.
Truncated, in situ soil	**2 B/C** 35 – 60cm	Brown (7.5YR 4/3, moist; brown 7.5YR 4.5/4, dry), clay, abundant (60%) strongly weathered stones, weak subangular to angular blocky structure, high density, few roots, animal holes, clear irregular boundary. Bedrock is a greyish gneiss
Truncated, in situ soil	**3 B/C** 60 – 110cm	Reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6, dry), clay, abundant (80%) strongly weathered stones, weak subangular to angular blocky structure, high density, few roots. Bedrock is a yellowish-whitish weathering gneiss

Ngalanga 3 – *Eroded Ridge* Regosol

Coordinates: (UTM WGS 84)

Easting:	351779	E 37°39'55.6"
Northing:	9599451	S 3°37'22.3"
Elevation:	1388m a.s.l.	
Pit depth:	100m	
Colluvium:	none	

Relief

Slope:	25°
Aspect:	SW 220!
Slope Pos.:	ridge
Slope Form:	concave-concave
Microrelief:	terraced

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	bedrock
Outcrops:	none

Description: Located on a severely eroded ridge, the soil profile covers two neighbouring fields of different land use. The northern field is under permanent grass vegetation for animal fodder, whereas the southern one is ploughed and used for annual crops (e.g. maize). The soil profile is severely truncated and the subsoil – saprolite transition is exposed. In addition, erosion differences between the different land use types are observed Erosion within the tilled field is severe. Up to 6cm deep rills destroy the growing crop and a stone pavement has developed. The height difference of 25cm between the cultivated field and the grass vegetation indicates strong recent removal of surface material. The higher surface of the grass field on the other hand only shows minor gravel accumulation.

Vegetation: Grass field to the northern, a recently tilled field to the southern side of the pit.

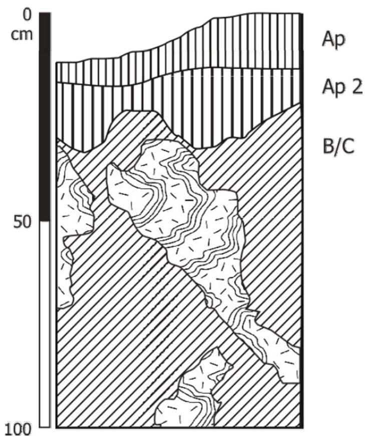
Soil Cover: North: 100% dense grasses: South: 100% bare soil

Alterations: agriculture

Erosion Feat.: Strong stone pavement and severe rill and sheet erosion within the ploughed field. Height difference about 25cm.

Archaeological Features: None

Soil Profile



Horizon	Description
Surface	North (grass field): common (10%) medium fresh and weathered gravel
Surface	South (maize field): many (30%) medium weathered and fresh gravel
Ap 1 0 – 10cm (0 – 2cm)	Reddish brown (5YR 4/4, moist, reddish yellow 5YR 6/6, dry) clay loam, common (10%) medium weathered gravel, weak subangular blocky structure, frequent roots, gradual wavy boundary. Charcoal present.
Ap 2 10 – 30cm (2 – 20cm)	Red (2.5YR 4/6, moist, yellowish red 5YR 5/6, dry) clay loam, many (20%) fine strongly weathered gravel, weak subangular blocky structure, few roots, clear wavy boundary
B/C 30 – 100+cm (20 – 70+cm)	Red (2.5YR 4/6, moist, reddish yellow 5YR 6/6, dry) clay loam, many (40%) fine strongly weathered stones, weak subangular blocky structure, few roots, animal holes

Makongweni – *Strongly eroded Eucalyptus coppice* Regosol

Coordinates: (UTM WGS 84)

Easting:
Northing:
Elevation:
Pit depth: 50cm
Colluvium: none

Relief

Slope: 5 – 30°
Aspect: variable
Slope Pos.: slopes, hilltops, ridges
Slope Form: variable
Microrelief: variable

Geology

Geology: gneiss, strongly
Parent Mat.: saprolite
Outcrops: none

Description: In North Pare, eucalyptus forests have been planted to rehabilitate strongly eroded and degraded land. Planted on degraded land in the mid 20th century the soils have not recovered since undergrowth development is inhibited by eucalyptus and no surface protecting vegetation cover could establish. Today, the former soil has been totally stripped off and saprolite is exposed. A strong stone pavement has developed finally reducing further erosion.
The degraded soils are probably inherited and are not caused by eucalyptus vegetation. However, eucalyptus inhibited surface stabilisation by preventing development of undergrowth and topsoil formation and thus is not a suitable specie for the recovery of strongly degraded lands.

Vegetation: Eucalyptus coppices, no undergrowth, locally thickets of bushes and ferns.

Soil Cover: none, in sheltered position up to 10cm of drifted litter

Alterations: strong erosion

Erosion Feat.: strong stone pavement up to 90%. Severe sheet erosion and subordinate rill erosion.

Archaeological Features: none

Soil Profile

Horizons	Description
(**Oi**) 0 – 5cm	Litter layer, undecomposed litter and twigs (locally present)
Surface	**Stone pavement**, 40 – 90% fine to coarse gravel, biological surface crusts
C 0 – 50+cm	Red (2.5YR 4/6, moist, reddish yellow 5YR 6/6, dry) **saprolite**, abundant (70%) coarse strongly weathered gravel, common roots.

Ngalanga 4 – *Head slope depression*

Coordinates: (UTM WGS 84)

Easting:	351726	E 37°39'53.9"
Northing:	9599378	S 3°37'24.6"
Elevation:	1348m a.s.l.	
Pit depth:	~280cm	
Colluvium:	-150cm	

Relief

Slope:	25-30°
Aspect:	SSW 200°
Slope Pos.:	head slope – depression
Slope Form:	concave-concave
Microrelief:	terraced

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	colluvium & bedrock
Outcrops:	none

Description: This profile was established about 10m upslope form the road cut (Ngalanga 5) in a steep head slope depression. The slope had been terraced and is extensively used by grass fodder cultivation. The soil profile crosses a terrace step shows recent disturbance by terracing as well as the postulated former ground surface indicated by the channel infill 10m down slope. An overthickened topsoil represents the recent terrace infill. Colluvial material extends up to 150cm depth and rests upon truncated subsoil. No clear indicators for a buried ground surface were recorded. Clay coatings on soil aggregates as well as within saprolitic material were observed.

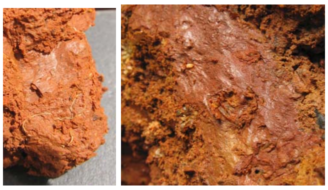
Vegetation: Fodder grasses and sugar cane

Soil Cover: Bare soil (85%), litter (15%), thick grasses

Alterations: Agriculture, terracing

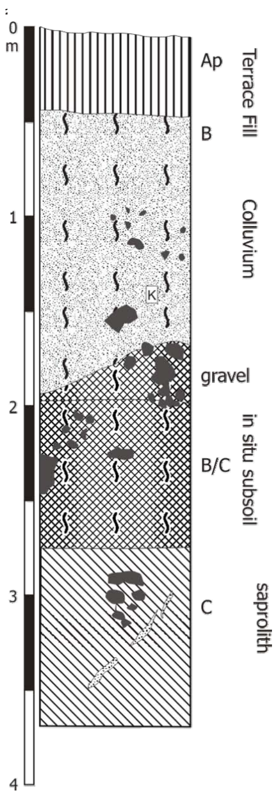
Erosion Feat.: Incipient stone pavement, terracing seems to effectively stop erosion.

Archaeolog. F.: None



Clay coatings

Soil Profile



Zones	Horizons	Description
	Surface	Common (10%) medium gravel
Terrace Fill	**Ap** 0 – 40cm	Recent terrace fill. Reddish brown (5YR 4/4, moist; 5YR 4/5, dry), few (3%) fine weathered gravel, moderate angular blocky structure, few roots, clear wavy bound.
Colluvium IV	40 – 135cm	**Reddish brown (2.5YR 4/5,** moist, 4YR 5/6, dry), clay, common (10%) medium weathered gravel, angular blocky structure, few roots, clay coatings, clear irregular boundary.
	135 – 150cm	**Reddish brown (2.5YR 4/4,** moist, 4YR 5/6, dry), clay, few (5%) fine weathered gravel, angular blocky structure, clay coatings gradual boundary.
Truncation Surface	**gravel** 150 – 180cm	**Red (2.5YR 5/7,** moist; yellowish red 5YR 5/7, dry) clay, common (15%) medium strongly weathered gravel, angular blocky structure, gradual boundary , gravel line stone l
***in situ* subsoil I**	**B/C** 180 – 280cm	Red (2.5YR 5/8, ,moist; reddish yellow 5YR 6/6, dry) clay, many (40%) fine strongly weathered stones, moderate angular blocky structure
	C 280 - 370cm	Red (2.5YR 5/8, ,moist; reddish yellow 5YR 6/6, dry) clay dominant (90%) strongly weathered stones, angular blocky structure, Preservation of original rock structure and alignment.

Ngalanga 5 – *Channel Infill*

Coordinates: (UTM WGS 84)		
Easting:	351716	E 37°39'53.6"
Northing:	9599368	S 3°37'25.0"
Elevation:	1352m a.s.l.	
Pit depth:	n.d.	
Colluvium:	~100cm ?	

Relief	
Slope:	25-30° (no data)
Aspect:	SSW 200°
Slope Pos.:	head slope – depression
Slope Form:	concave-concave
Microrelief:	road cut

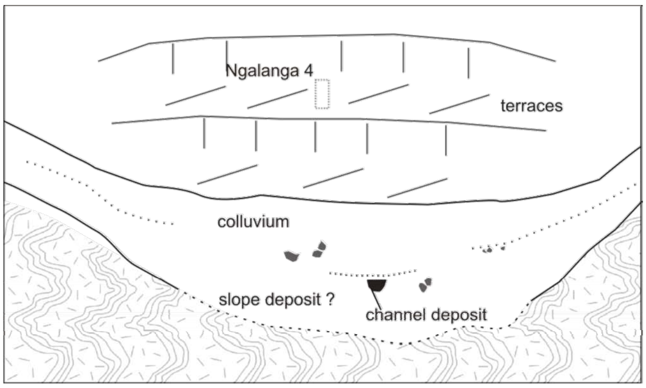
Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvium & subsoil
Outcrops:	none

Description: A road cut crossing the head slope depression at the mid-slope of the Ngalanga hill exposes a former channel infill. The coarse gravel and sandy loam of the channel infill differ distinctively from the surrounding colluvial sediment. However, no distinct land surface corresponding to runoff-based erosion and channel incision was distinguished. Occurrence of stones and boulders however might indicate a former surface. Channel incision on mid-slope position is suggestive for strong runoff-based erosion and is tentatively correlated with the depositional unit III recorded at the Ngalanga footslope at Usumbwe by the deposition of sand lenses and sand layers and dated to the 15th century.
No excavation was undertaken and hence the original ground surface was not recorded.

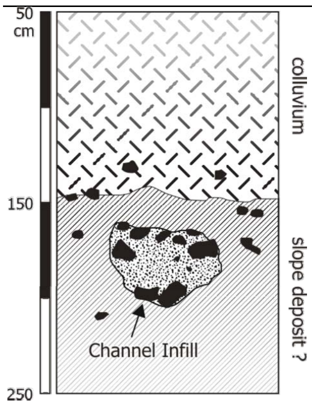
Alterations: road cut

Erosion Feat.: n.d.

Archaeology: None



Soil Profile



Zones	Horizons	Description
	Surface	
Colluvium	0 – 150cm	Reddish brown (5YR 3.5/3, dry) clay, many (30%) medium weathered gravel, abundant roots
Channel Infill	**Gravel and sandy clay** 170-210cm	Red to yellowish red (2.5YR – 5YR 5/6, dry) sandy clay, abundant (60%) fresh gravel (30% fine gravel, 10% medium gravel, 20% coarse gravel),
***in situ* subsoil or slope deposit?**	150+cm	Dark reddish brown (2.5YR 3/4, dry) clay, many (15%) fine fresh to weathered gravel.

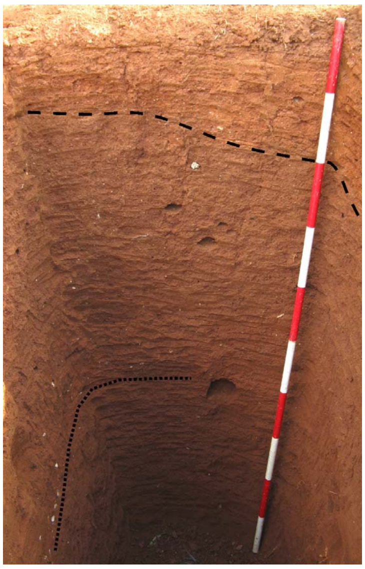
B.5 Usumbwe: Slope deposit decriptions

Usumbwe 1

Coordinates: (UTM WGS 84)	
Easting:	351570
Northing:	9599315
Elevation:	1304m a.s.l.
Pit depth:	400m
Colluvium:	260 –

Relief	
Slope:	11°
Aspect:	SW 235
Slope Pos.:	foot slope
Slope Form:	concave-convex
Microrelief:	terraced

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	n/a



Description: The profile is located on the upper footslope just below the break in slope. The relief is strongly modified by up to 1.5m high terraces and contour trenches to stop erosion. The profile shows four colluvial layers. A clear-cut boundary between the uppermost 40cm (unit IV) and an underlying colluvial layer, characterised by high magnetic susceptibility values and clay coatings is observed. At 140-150cm depth, an indistinct line of dispersed stones separates the upper colluvium (unit III) from a lower colluvium (unit II). A stone and gravel rich layer between 265 and 310cm is probably the result of creep processes over a truncated soil as fragments of a dark stained clay suggests a buried topsoil. The dark layer is not continuous and truncation has to be considered, as it overlays directly a stone and gravel rich B/C-horizon. The parent material is made up of narrow (20cm thick) bands of a variety of bedrock types distinguished by texture and their different weathering colours ranging from whitish-yellow to purple.

Vegetation: Recently tilled open maize field. Very few old grown indigenous shade trees, dispersed banana plants.

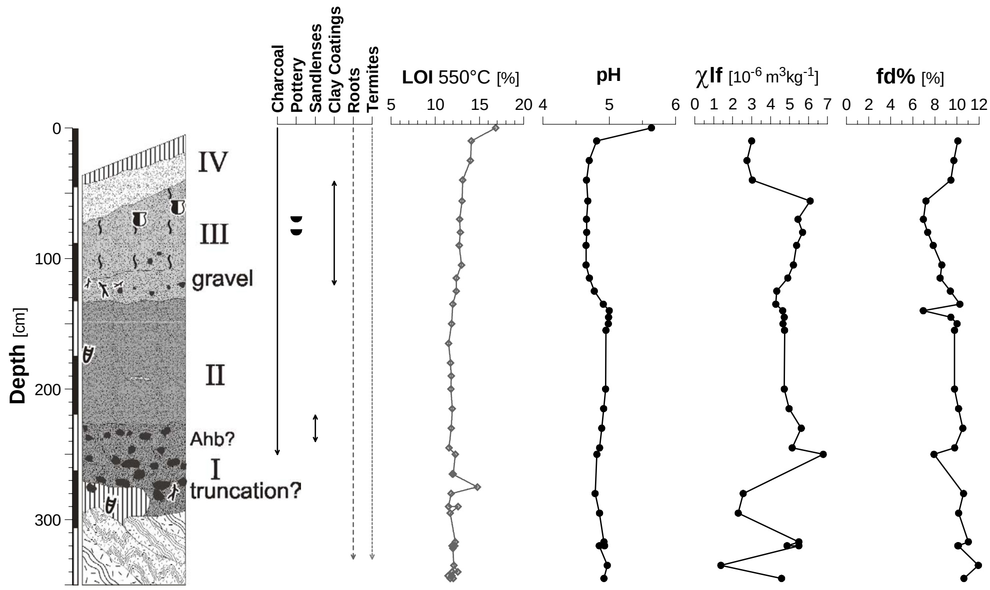
Soil Cover: bare soil

Alterations: Terracing with substantial soil movement, agriculture, manure application

Erosion Feat.: None observed as destroyed by tillage. Contour trenches are established within short distances indicating enhanced slope wash and the need for erosion control measures.

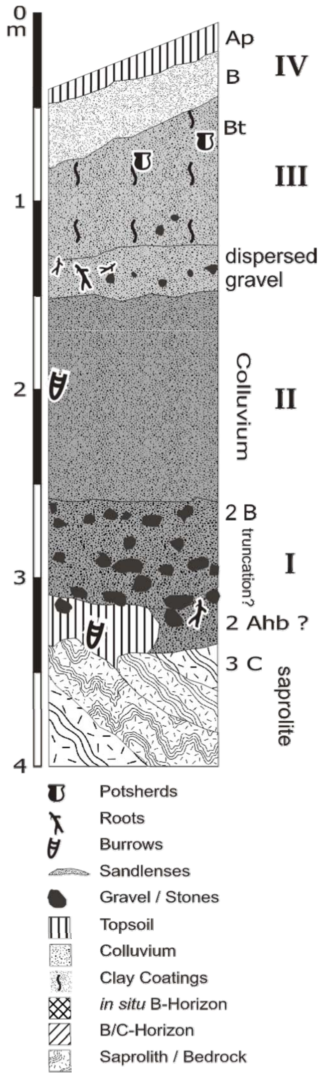
Archaeology: Potsherds (70 & 80cm depth)

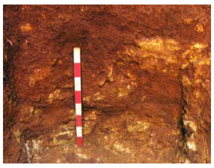
Usumbwe 1: Analysis Overview



Usumbwe 1

Soil Profile





Zones	Horizon	Description
IV Recent deposit ? Colluvium	**Ap** 0 - 15cm	**Plough horizon.** Reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6) clay, roots present, gradual boundary.
	15 – 41cm	**Dark red (2.5YR 3/6**, moist; red 2.5YR 5/6, dry) clay common (15%) weathered fine gravel, animal holes, roots present, **clear smooth boundary.**
III Upper Colluvium	41 – 120cm	**Reddish brown (2.5YR 4/4, moist; yellowish red 5YR 5/6, dry)**, common (10%) weathered fine gravel, animal holes, roots present, **clay coatings**, gradual boundary. Potsherds (70cm & 80cm)
	gravel 120 – 140cm	**Dispersed gravel, discontinuous stone line.** Many (20%) fresh fine and medium gravel, animal holes, roots present, diffuse boundaries
II Lower Colluvium	140 – 265cm	Reddish brown (2.5YR 4/4, moist; **red 2.5YR 5/6, dry**), few (5%) weathered fine gravel, animal holes, **sandlense (230cm)**, diffuse boundary.
Truncation ?	265 – 310cm	Dark red (2.5YR 3/6, moist; red 2.5YR 5/6, dry) clay, common (15%) strongly weathered coarse gravel and stones, roots present, gradual irregular boundary Front & right: 300 – 340cm; common (~20%) coarse gravel and stones Back & left: 265 – 310cm, many (30-40%) coarse gravel and stones
I buried topsoil ?	**2 Ahb ?** 310 – 330cm	**Dark reddish brown (2.5YR 3/3,** moist; reddish brown 2.5YR 4/4, dry) clay many (20%) stones, animal holes, roots present, clear broken boundary
	3 B/C 340 – 370cm	Red (2.5YR 4/6, moist; reddish yellow 5YR 6/8, dry) strongly weathered gneiss, abundant (80%) strongly weathered stones, gradual boundary.
Saprolite, truncated, *in situ*	**3 C** 370 – 385cm	Reddish yellow (5YR 4/5, moist; reddish yellow 5YR 6/6, dry) strongly weathered gneiss, many (20%) strongly weathered coarse gravel, clear boundary.
	4 C 385 – 400cm	Weak red (10R 4/3, moist; pale red 10R 7/3, dry) strongly weathered gneiss, abundant (75%) strongly weathered stones

Usumbwe 2

Coordinates: (UTM WGS 84)

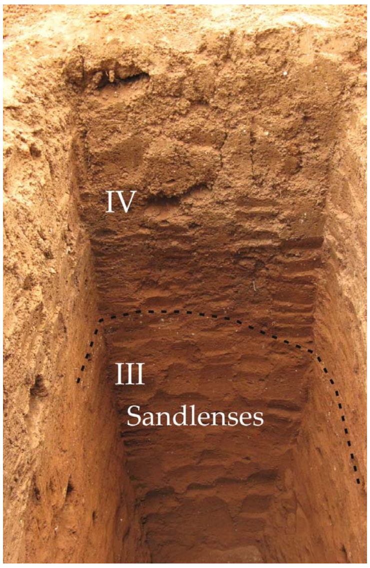
Easting:	351548
Northing:	9599268
Elevation:	1283m s.l.
Pit depth:	5 (10) m
Colluvium:	9.7m

Relief

Slope:	5°
Aspect:	WSW 242
Slope Pos.:	foot slope
Slope Form:	concave-straight
Microrelief:	terraced

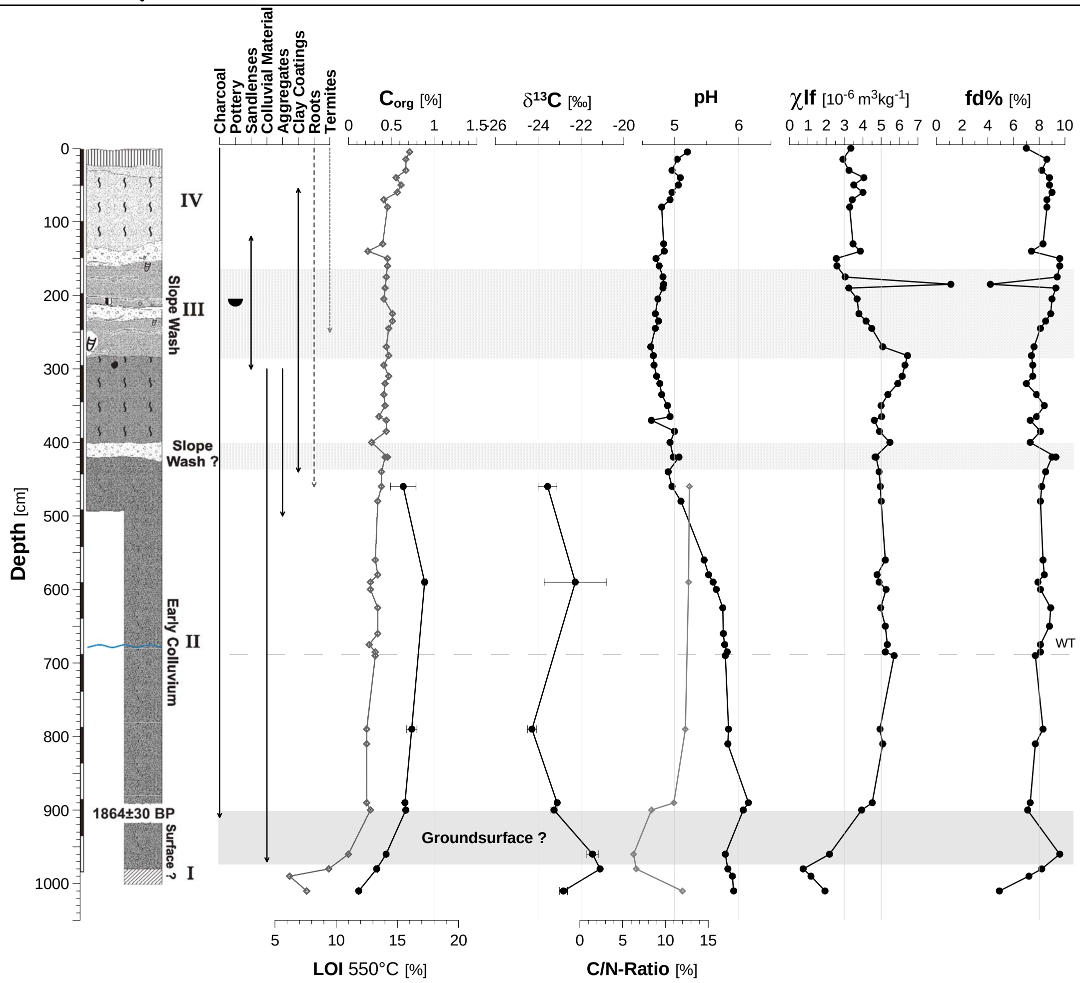
Geology

Geology:	gneiss
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	690cm



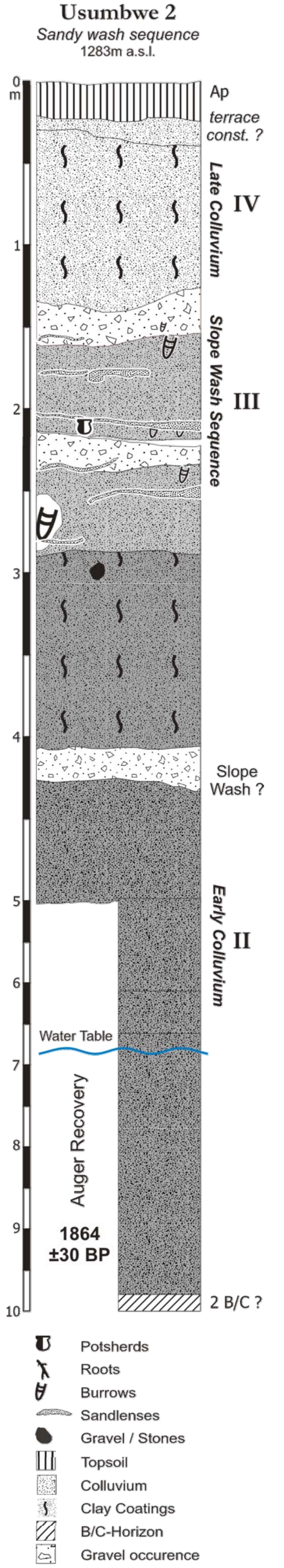
Vegetation:	Recently tilled open maize field. Few shade trees, occasionally banana plants.
Soil Cover:	bare soil
Alterations:	Terracing with substantial soil movement, agriculture, manure application
Erosion Feat.:	None observed, possibly destroyed by tilling
Archaeological Features:	Potsherd (210cm)

Usumbwe 2: Analysis Overview



Usumbwe 2

Soil Profile



Zones	Horizon	Description
IV Colluvium	**Ap** 0 – 50cm	Reddish yellow (7.5YR 7/6, dry) clay loam, few (5%) fine gravel, granular to subangular blocky structure, roots present, animal holes, charcoal common, gradual boundary.
	30 – 55cm	Reddish yellow (5YR 6/8, dry) clay loam, few (5%) fine gravel, granular to subangular blocky structure, roots present, animal holes, charcoal common, gradual boundary.
	55 - 120cm	Reddish yellow (5YR 6/8, dry) clay loam, few (5%) fine gravel, subangular blocky structure, moderate density, roots present, animal holes, charcoal common, clay coatings, clear smooth boundary.
III Sandy slope wash	120 – 288cm	Reddish yellow (5YR 6/6, dry) clay loam, moderate subangular blocky structure, low to moderate density, roots present, animals holes, diffuse and gradual boundaries Potsherd (210cm)
	Slope Wash (sand & gravel	120 – 150cm: common to many (5 – 20%, varying) medium gravel, 150 – 215cm: few (2%) medium gravel, abundant sand spots and sand lenses (black iron rich sand 215 – 230cm: common (5-15%, varying) medium gravel, 230 – 285cm: few (2%) medium gravel, abundant sand lenses and sandy spots, low to moderate density, spot of dark soft material, possibly infilled burrow, clay coatings.
	288 – 410cm	Yellowish red (5YR 4/6), very few (1%) gravel of a variety of different rock types, weak subangular blocky structure, moderate density, roots present, charcoal common, organic matter rich aggregates, clay coatings, diffuse boundary.
	Slope Wash 410 – 440cm	Yellowish red (5YR 5/6), few (5%) medium gravel of a variety of different rock types, weak subangular blocky structure, moderate density, roots present, charcoal common, organic matter rich aggregates, clay coatings, diffuse boundary.
II Lower Colluvium	440 – 610cm	Yellowish red (5YR 5/6, dry), very few (1%) gravel of a variety of different rock types weak subangular blocky structure, moderate density, charcoal present, organic matter rich aggregates ?
	610 – 670cm	Brighter coloures, charcoal present, organic matter rich agglomerates ?
	690cm	Watertable
	670 – 970cm	Brighter, charcoal present, organic matter rich aggregates. **Radiocarbon Date: 1864±30 ^{14}C BP** (910cm, charcoal)
I *in situ* soil	**2 B/C ?** 970 – 1000+cm	Common gravel, redoximorphic mottling, greenish to grey weathering gneiss.

Description:

Located on the middle footslope, 9 - 10m of colluvial sediments bury a truncated surface at Usumbwe 2. Terracing probably has affected the most recent slope deposits similar to Usumbwe 1. Between 120 and 288cm depth common occurrence of gravel and sand lenses indicate slope wash deposits (unit III). Between 410 and 440cm depth a further, separate and earlier phase of enhanced hillwash is recorded by an increased gravel content.

The slope deposit shows characteristic features for colluvial deposits like organic matter rich aggregates, weathered gravel rock fragments from a variety of rock types and charcoal. Clay coatings are recorded.

At 970cm depth common strongly weathered rock fragments suggest a B/C-horizon. The lack of distinct buried topsoil common in other profiles suggests truncation around 9m depth. Onset of colluviation commenced prior to the radiocarbon date of 1864±30 ^{14}C BP obtained from a charcoal fragment recovered at 910cm depth .

Usumbwe 3

Coordinates: (UTM WGS 84)

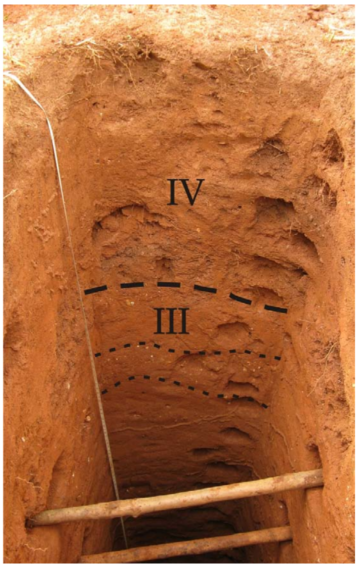
Easting:	351513
Northing:	9599208
Elevation:	1286m a.s.l.
Pit depth:	4.5 / 8.5m
Colluvium:	8.5m

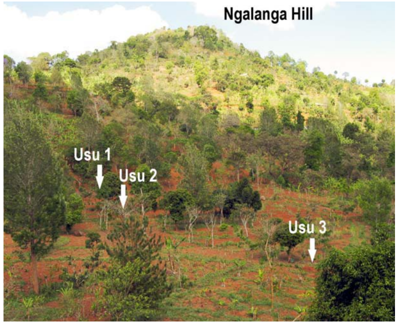
Relief

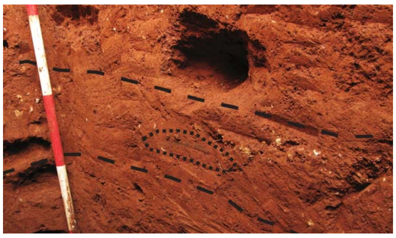
Slope:	2°
Aspect:	NS
Slope Pos.:	basin bottom
Slope Form:	concave - concave
Microrelief:	terraced

Geology

Geology:	valley sediments
Parent Mat.:	colluvial material
Outcrops:	none
Water table:	450cm







Description: The profile is located at the deepest point of Usumbwe valley head, below the Ngalanga hill. A seasonal stream emerges around the profile location during heavy rains but no permanent channel persists. More than the profiles on the footslope Usumbwe 3 is characterised by hillwash deposits consisting of gravel and sand rich material and the occurrence of sand lenses. The colluvial sediments at the valley bottom position are 8m deep and have buried an organic matter rich peat deposit in a depth of 780 and 820cm.

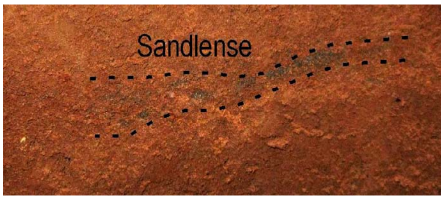
Vegetation: Terraced agriculture, maize, sugar cane, dispersed trees,

Soil Cover: Grasses, sugarcane,

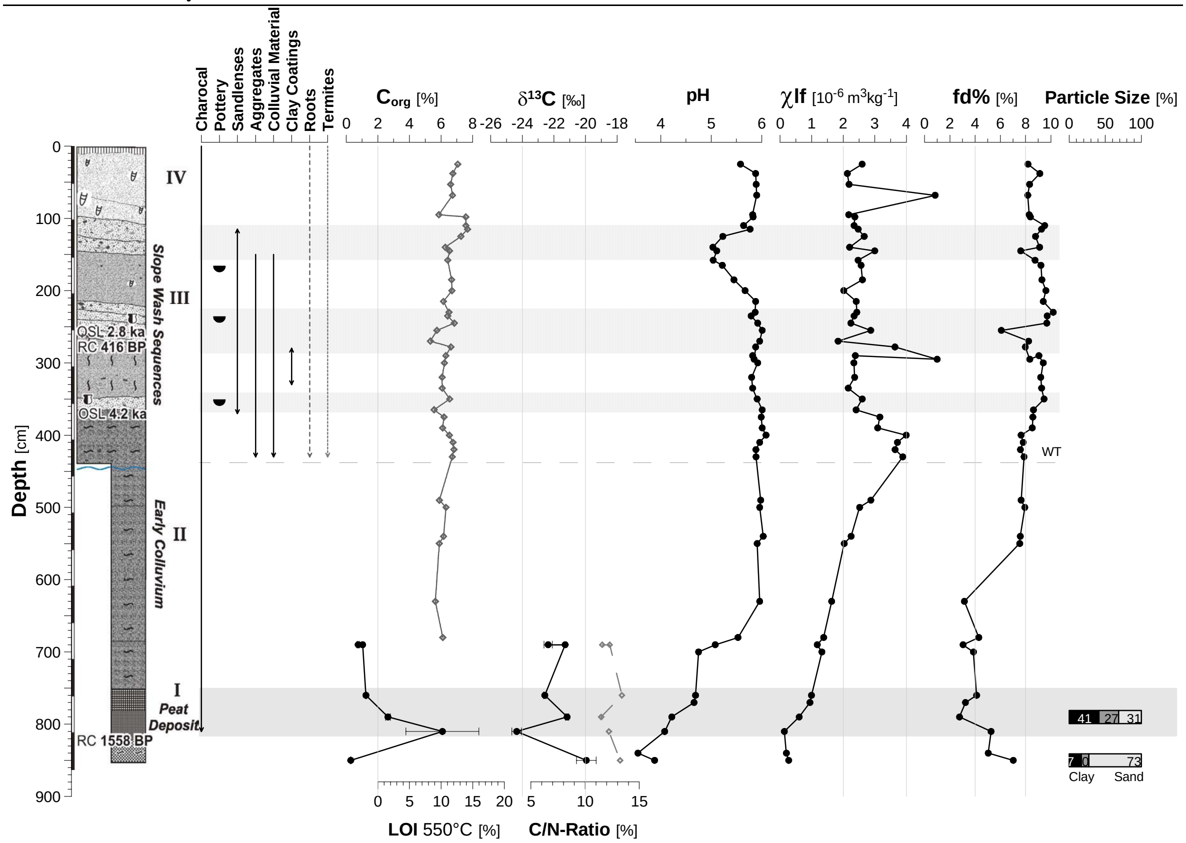
Alterations: Maize cultivation, terracing, contour trenches

Erosion Feat.: Runoff concentrates and gathers in an ephemeral channel near the pit location.

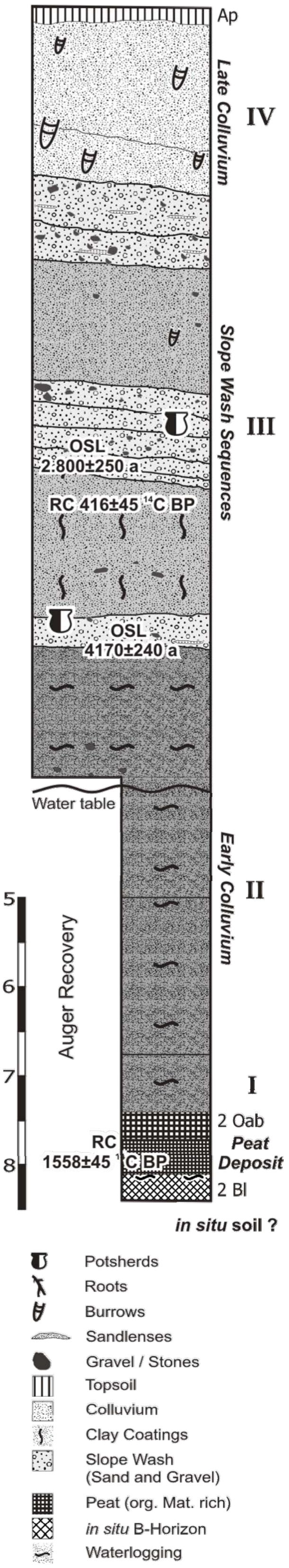
Archaeolog. F.: Potsherds (170, 240, 355cm)



Usumbwe 3: Analysis Overview



Usumbwe 3



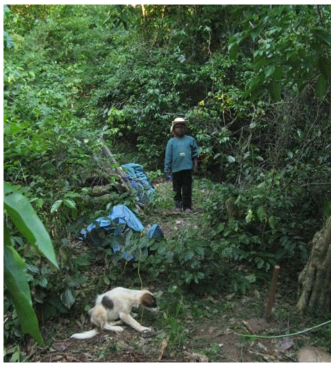
Zones		Horizon	Description
IV	Upper colluvium	**Ap** 0 – 40cm	**Recent plough horizon.** Clay loam, low humus content, very few (1%) strongly weathered medium gravel, weak subangular blocky to granular structure, common fine and coarse roots, high termite activity, frequent animal holes, charcoal present.
		40 – 95cm	Yellowish red (5YR 4/5, moist; yellowish red 5YR 5/6, dry) clay loam, **few (2%) medium strongly weathered gravel,** weak subangular blocky structure, moderate density, common fine and coarse roots, termites present, frequent animal holes, abundant charcoal, **clear boundary.**
III Slope Wash Sequence	**Slope Wash** (gravel & sands)	95 – 155cm	**Alternating layers (~20cm) of varying gravel content, clear boundaries.** Generally: Yellowish red (5YR 4/6, moist; yellowish red 5YR 5/6, dry) sandy clay **,** weak subangular blocky structure, moderate density, fine and coarse roots present, termites present, few charcoal, organic matter rich aggregates, **common sand lenses**. 95 – 115cm few (2%) medium gravel, iron gravel 115 - 135 common (5) up to coarse gravel 135 - 155 many (30%) up to coarse gravel
	Colluvium	155 – 220cm	Yellowish red (5YR 5/6, moist; yellowish red 5YR 5/6, dry) clay loam, **very few (1%) medium strongly weathered gravel**, weak subangular blocky structure, moderate density, fine roots present, termites present, **frequent organic matter rich aggregates, many charcoal. Potsherd (170cm)**
	Slope Wash (gravel & sands)	220 – 280cm	**Alternating layers (~10cm) of varying gravel content and clear boundaries.** Generally: reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6, dry) sandy clay loam, alternating many (20-30%) and few (1-10%) medium to coarse gravel, weak subangular blocky structure, moderate density, fine roots present, termites present, very few charcoal, 220 - 235 many (30%) up to coarse gravel, clayey 235 - 255 very few (1%) medium gravel, clayey, **potsherd** (240cm) 250 - 265 many (30%) up to coarse gravel, sandy, **OSL: 2.800±250 a** (260cm) 265 - 275 common (10%) medium gravel, sandy 275 - 280 many (20%) medium gravel, sandy **14C Date: 416±45 14C BP** (285cm, charcoal)
	Colluvium	280 – 350cm	Reddish brown (5YR 4/4, moist; **red 2.5YR 5/6**, dry), sandy clay loam, few (2%) to common (10%) medium to coarse strongly weathered gravel, low to moderate density, weak subangular blocky structure, fine roots present, termites present, many charcoal, **clay coatings in root channels**
	Slope Wash (sand lenses)	350 – 370cm	Reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6, dry), sandy clay loam, **sand lenses**, very few (1%) medium strongly weathered gravel, low density, weak subangular blocky structure, fine roots present, termites present, common charcoal, clear smooth boundary. **Potsherd (355cm). OSL2: 4.170±240 a** (365cm)
	Colluvium seasonally waterlogged	370 – 500cm	Dark reddish brown (5YR 3/3, moist; yellowish red 5YR 4/6, dry) **sandy clay**, very few (1%) medium strongly weathered gravel, low density, weak subangular to angular blocky structure, fine roots present, termites present, organic matter rich aggregates, charcoal present, **gleyed and discoloured due to seasonal waterlogging, grey reductimorphic colours increases below 430cm.**
II Lower colluvium		450cm	Watertable (13.11.08) – Recovery via auger survey
	colluvium permanently waterlogged	500 – 685cm	**Dark reddish brown** (5YR 3/3, moist; brown 7.5YR 5/4, dry) Very few (1%) fine gravel, **redoximorphic mottling**, organic matter rich aggregates ?, finely dispersed charcoal
		685 – ~750cm	**Dark brown** (10YR 3/3, moist; brown 10YR 5/3, dry) Very few (1%) fine gravel, **redoximorphic mottling, less coloured more gleyed,** organic matter rich aggregates ?, finely dispersed charcoal.
I Stable Surface	**Peat Deposit**	**2 Oab 1** ~750-780cm	**Very dark greyish brown** (10YR 3/2, moist; greyish brown 10YR 5/2, dry), clay, very few up to medium gravel, **organic matter rich**, **abundant charcoal**
		2 Oab 2 780 – 820cm	**Black** (10YR 2/1, moist; dark grey 10YR 4/1, dry), **organic matter rich, peat-like deposit** (bark fragments ?), few up to coarse gravel, **abundant charcoal. Radiocarbon Date: 1558±45 14C BP** (812cmm, charcoal)
in situ soil ?		**Sand** 820 – 850+cm	**Dark grey** (2.5Y 4/1, moist; grey 2.5Y 6/1, dry), loamy sand, discoloured grey, reductimorph matrix, reductive colour pattern, organic material diminishes at about 840cm (A13) 850cm (A14), homogeneous grey, **no organic matter, no charcoal.**

B.6 Kwa Kirumbi: Forest soils

Kwa Kirumbi 1 – *Forest Ridge* — Umbric Acrisol ?

Coordinates: (UTM WGS 84)			Geology	
Easting:	353659	E 37°40'56.4"	Bedrock Geology:	Gneiss, strongly weathered
Northing:	9597500	S 3°38'25.9"	Parent Material:	in situ weathered Gneiss
Elevation:		1408m a.s.l.	Rock Outcrops:	none

Relief		Profile Data	
Slope:	5°	Pit depth:	80cm / 180cm Auger
Aspect:	W 280°	Colluvium:	none
Slope Pos.:	ridge	Water table:	-
Slope Form:	convex – convex	Drainage:	good
Microrelief:	smooth	E37° 40 56.4	S3 38 25.9



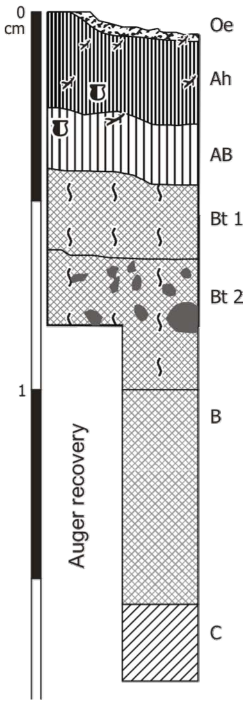
Description: Kwa Kirumbi was formerly a sacred groove of the Mshana clan before it was taken over by the Msuya clan and therefore has nowadays a less ridged protection status than other sacred groves. The Kwa Kirumbi Forest Ridge profile is located on top of the asymmetrical northern ridge about 20m from the forest boundary and about two meters from the steep slope into the head slope depression. The profile shows a well developed forest soils with a thick organic layer and an organic matter rich topsoil over a 1.5m deep subsoil. Clay coatings indicate argilluviation and led to the tentative classification of an Acrisol, although no clay increase was observed nor was a clay deplete eluvial horizon recorded.

Vegetation: Strongly intervened natural ridge forest with up to 30-40m high canopy trees, a 4m high intermediate layer of small trees and a 2m high shrub & bush layer. No grasses.

Soil Cover: Litter (about 1cm)

Alterations: Firewood extraction, selective timber logging, occasional litter and raw humus extraction for manure, ritual worship.

Soil Profile



Horizon	Description
Oi +0.5cm	Litter composed of leaves, twigs and bark
Oe 0 - 1.5cm	Thin layer of moderately decomposed organic material, many fine and common coarse roots, diffuse boundary.
Ah umbric Hz 1.5 – 28cm	Dark brown (7.5YR 3/2, moist; dark greyish brown 10YR 4/2, dry) organic matter rich (2-5%), moderate granular structure, many fine and common coarse roots, gradual wavy boundary. **Potsherd.**
AB 28 – 45cm	Yellowish red (5YR 4/6, moist; brown 7.5YR 5/4, dry), clay, very few strongly weathered coarse angular gravel, weak granular to subangular blocky structure, few fine and coarse roots, clear wavy boundary. **Potsherd**.
Bt 1 45 - 55cm	Yellowish red (5YR 4/6, moist; 5YR 5/6, dry), clay, **very few** strongly weathered coarse angular gravel, weak subangular blocky structure, clay coatings, few roots, gradual irregular boundary.
Bt 2 55 - 100	Yellowish red (5YR 4/6, moist; strong brown 7.5YR 5/6, dry), clay loam, **many** strongly weathered coarse gravel and stones, weak subangular to angular blocky structure, clay coatings, few roots
B 100 – 160cm	Reddish brown (5YR 4/4, moist; strong brown 7.5YR 5/6, dry) clay loam, **few** strongly weathered gravel, gradual boundary.
C 160 – 180+cm	Yellowish red (5YR 5/6, moist; reddish yellow 7.5YR 7/7, dry), abundant strongly weathered yellowish whitish gneiss gravel, saprolite.

Kwa Kirumbi 2 – *Upper Slope* — Umbric Acrisol ?

Coordinates: (UTM WGS 84)		
Easting:	n/a	n/a
Northing:	n/a	n/a
Elevation:		1411m a.s.l.

Geology	
Bedrock Geology:	Gneiss, strongly weathered
Parent Material:	in situ & slope creep mat.
Rock Outcrops:	1 Boulder Ø3m in 10m

Relief	
Slope:	20-25°
Aspect:	SSW 210°
Slope Pos.:	upper ridge slope
Slope Form:	convex – convex
Microrelief:	smooth

Profile Data	
Pit depth:	125cm / 230cm Auger
Colluvium:	35cm
Water table:	-
Drainage:	Good

Description: On the upper slope, Kwa Kirumbi 2 shows a buried topsoil rich in pottery fragments suggesting disturbance related to ritual practices. The buried horizon is overlain by the present mineral topsoil and a thick organic layer. A deep subsoil reflects the potential depth of soil development in the absence of accelerated soil erosion. Although disturbance can not be ruled out for forest soils they indicate the potential development of soils under reduced anthropogenic influence.

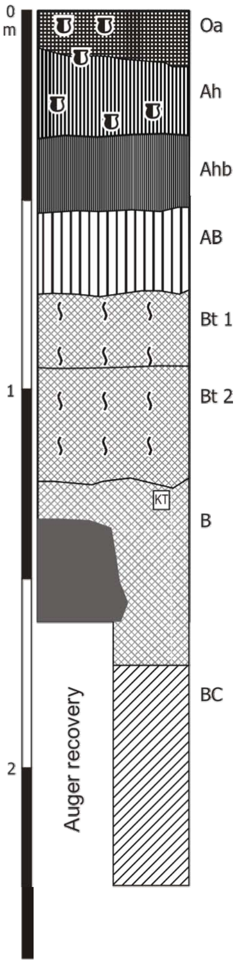
Vegetation: Strongly intervened natural ridge forest with up to 25m high canopy trees, a 5m high intermediate layer of small trees and a 2m high shrub & bush layer. Lianas characterize the canopy. No grasses.

Soil Cover: Litter (about 0.5cm) occasionally fine gravel

Alterations: Firewood extraction, selective timber logging, occasional litter and raw humus extraction for manure, places of worship. Former soil pits in the vicinity and the presence of abundant potsherds indicate disturbance due to cultural activities.

Erosion : Fine gravel on the surface indicates disturbance and initial movement of material

Soil Profile



	Horizon	Description
	Oi + 1cm	Litter composed of leaves, twigs and bark, about 1% fine fresh gravel
Colluvial material	**Oe** 0 – 1cm	Thin layer of moderately decomposed organic material, about 1% fine fresh gravel, many roots, abrupt smooth boundary.
Colluvial material	**Oa** 1 – 15cm	Decomposed organic material, dark brown (7.5YR 3/2, moist; brown 7.5YR 4/3, dry) about 1% fine weathered gravel, moderate granular structure, very low bulk density (1.06g ccm^{-1}, 5cm), many fine and coarse roots, abrupt smooth boundary. **Abundant potsherds (3x), abundant charcoal, root matt**.
Colluvial material	**Ah umbric Hz.** 15 – 35cm	Dark reddish brown (5YR 3/3, moist; brown 7.5YR 4/4, dry) clay, about 1% fine weathered gravel, weak granular structure, many fine and coarse roots, clear smooth boundary. **Abundant potsherds (4x), few charcoal**.
	Ab buried Hz 35 - 55cm	Dark reddish brown (5YR 3/2.5, moist; dark brown 7.5YR 4/3.5 dry) Buried organic matter rich topsoil, about 1% fine weathered gravel, weak subangular blocky structure, very low bulk density (1.08g ccm^{-1}, 40cm), many fine roots, common coarse roots, gradual wavy boundary.
	AB 55 – 75	Dark reddish brown (5YR 3/3, moist; 6YR 4.5/6, dry), clay, about 3% medium strongly weathered gravel, weak subangular blocky structure, low bulk density (1.20g ccm^{-1}, 65cm), common fine roots, few coarse roots, clay coatings, gradual wavy boundary.
in situ soil	**Bt 1** 75 – 95cm	Red (2.5YR 4/6, moist; yellowish red 5YR 5/6, dry), clay, about 3% medium strongly weathered gravel, clay coatings, diffuse wavy boundary.
in situ soil	**Bt 2** 95 – 125cm	Red (2.5YR 4/6, moist; yellowish red 5YR 5/7, dry), clay, 10% coarse strongly weathered gravel, moderate subangular blocky structure, low to moderate bulk density (1.33g ccm^{-1}, 95cm), clay coatings, very few fine roots, few coarse roots, diffuse boundary
in situ soil	**B** 125 – 170cm	Red (2.5YR 4/6, moist; yellowish red 5YR 5/7, dry), clay, 5-20% strongly weathered up to coarse angular gravel, occasionally fresh large boulder, moderate bulk density (1.44g ccm^{-1}, 125cm), diffuse boundary
	BC 170 – 230cm	Red (2.5YR 4/6, moist; reddish yellow 5YR 6/8, dry) clay, 50% strongly weathered gravel and stones, gradual boundary
	CR 230+ cm	Saprolite, hard in situ weathering gneiss. No further recovery by the soil auger possible.

Kwa Kirumbi 3 – *Steep Forest Slope*

Cambisol (colluvic)

Coordinates: (UTM WGS 84)	
Easting:	n/a
Northing:	n/a
Elevation:	~1405n/a

Geology	
Bedrock Geology:	gneiss
Parent Material:	colluvium
Rock Outcrops:	None

Relief	
Slope:	30°
Aspect:	290°
Slope Position:	middle slope
Slope Form:	straight-straight
Microrelief:	none

Profile Data	
Pit depth:	25cm / 190cm Auger
Colluvium:	80cm
Water table:	-
Drainage:	good

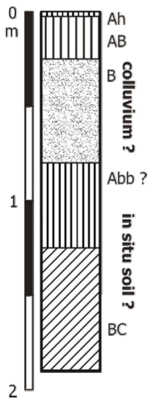
Description: Located on a steep slope between the ridge and the head slope depression, Kwa Kirumbi 3 is based on an auger survey. Despite its location on a steep slope a darker soil layer in a depth between 80 and 125cm suggests a colluvial slope deposit in the transportation zone. Recovery of charcoal from about 120cm depth supports this interpretation.

Vegetation: Intervened but natural forest with up to 30-40m high canopy trees, and a 2-3m high shrub / small tree layer.

Soil Cover: Litter (about 1cm

Alterations: Firewood extraction, selective logging, religious worship

Soil Profile



	Horizon	Description
Colluvial material	**Oi** +0.5cm	Litter composed of leaves, twigs and bark
	Oe 0 - 0.5cm	Thin layer of moderately decomposed organic material with no clear boundary to the mineral horizon.
	Ah 0.5 – 5cm	Brown (7.5YR 4/3, moist; 7.5YR 5/3, dry), moderate granular to subangular blocky structure, frequent roots, gradual boundary.
	AB 5 – 25cm	Brown (7.5YR 4/4, moist; brown 7.5YR 5/4, dry), occasional weathered coarse gravel, weak subangular structure, frequent roots, diffuse boundary. Locally buried dense root mat.
	B 25 – 80cm	Yellowish red (5YR 4/6, moist; brown 7.5YR 5/5, dry), occasionally strongly weathered gravel, clear boundary, charcoal common
in situ soil ?	**ABb** ? 80 – 125	Yellowish red (5YR 4/6, moist; brown 7.5YR 5/4, dry), abundant charcoal, clear boundary.
	BC 125 – 190cm	Yellowish red (5YR 4/6, moist; brown 7.5YR 7/6, dry), abundant strongly weathered gravel and stones, increasing with depth, no charcoal.
	Cw 190+ cm	Yellow (10YR 8/8, moist; white 7.5YR 9/4), strongly weathered saprolite

Kwa Kirumbi 4 – *Head Slope Depression* Cambisol (colluvic)

Coordinates: (UTM WGS 84)

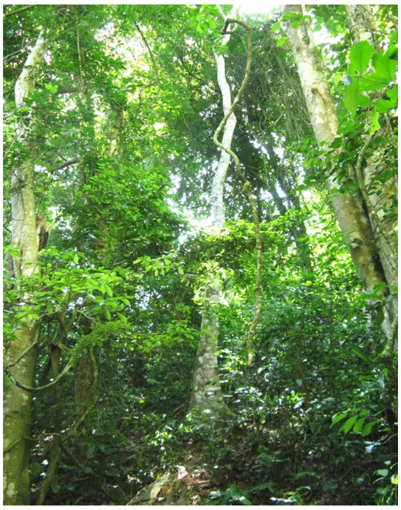
Easting:	n/a
Northing:	n/a
Elevation:	~1400m
Pit depth:	25cm &
Colluvium:	240cm

Relief

Slope:	15°
Aspect:	SSE 160°
Slope Pos.:	head slope
Slope Form:	concave – concave
Microrelief:	variable

Geology

Geology:	gneiss
Parent Mat.:	colluvium
Outcrops:	none



Description: At the bottom of a small, permanently dry head slope valley this auger profile was recovered. The small valley bottom shows a variable microrelief. No reliable information about runoff events could be obtained. The auger profile shows a homogeneous deposit in the upper two metres and a slightly darker layer between 250 and 280cm, pointing to the burial of a former land surface. The assumed original soil is characterised by comparable high gravel/stone content, which impeded further augering. Charcoal found in depths of about 250cm supports the interpretation as a colluvial deposit.

Vegetation: Intervened natural forest with up to 30-40m high canopy trees, and a 2-3m high shrub / small tree layer.

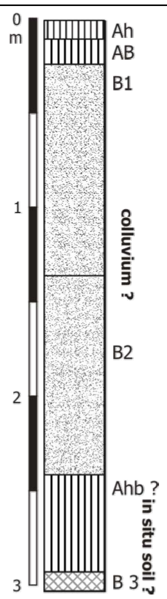
Soil Cover: Litter (about 1cm)

Alterations: Firewood extraction, selective logging and religious worship

Erosion Feat.: -

Archaeological Features: -

Soil Profile



	Horizon	Description
colluvium ?	**Oe** ~1cm	Un-decomposed organic material (litter, twigs, bark)
	Oa ~1cm	Very dark greyish brown (10YR 3/2, moist; brown 10YR 5/3, dry), clear boundary
	Ah 0 – 10cm	Reddish brown (5YR 4/3, moist; 5YR 5/4, dry)
	AB 10 – 25cm	Reddish brown (5YR 4/4, moist; 5YR 5/4, dry), common (10%) fine gravel, **charcoal**
	B1 25 - 135cm	Yellowish red (5YR 4/6, moist; yellowish red 5YR 4.5/6, dry), common (10%) fine gravel, **charcoal**, clear boundary.
	B2 135 – 240cm	Yellowish red (5YR 4/6, moist; yellowish red 5YR 5.5/6, dry), common (15%) medium gravel,
In situ soil ?	**Ahb ?** 240 – 295v cm	Dark reddish brown (5YR 3/3, moist; reddish brown 5YR 4/3.5, dry), common (15%) fine gravel, **charcoal**
	B 3 295 – 310cm	Reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6, dry), increasing gravel content, strongly weathered saprolite / rotten rock.

B.7 Kwa Kirumbi: Eroded soils under agricultural land use

Kwa Kirumbi 5 – *Terraced banana grove* Truncated Acrisol ?

Coordinates: (UTM WGS 84)		
Easting:	353570	E 37°40'53.5"
Northing:	9597525	S 3°38'25.1"
Elevation:		1411m a.s.l.

Geology	
Bedrock Geology:	Gneiss, strongly weathered
Parent Material:	in situ & transported Mat.
Rock Outcrops:	none

Relief	
Slope:	30° (terraces 20°)
Aspect:	W 280°
Slope Pos.:	upper slope
Slope Form:	convex – convex
Microrelief:	smooth

Profile Data	
Pit depth:	80cm & Auger
Colluvium:	none
Water table:	-
Drainage:	Good

Description: Terraced and irrigated banana groove about 50m below a house platform. Terraces spaced about 15-20m reducing the slope angel from about 30° to 20°. The complete soil profile shows an intact soil development although soil depth appears slightly reduced compared to the nearby forest soils. Well developed clay coatings indicate argilluviation.

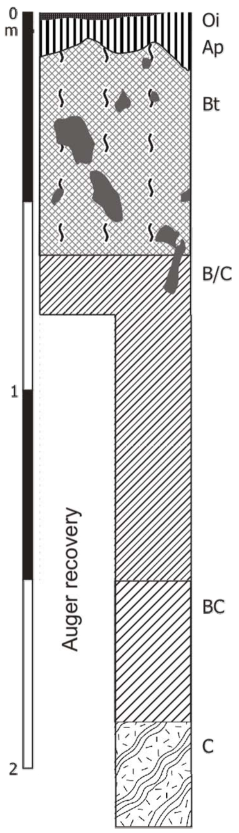
Vegetation: Banana groove, dominated by banana with a few trees and bushes planted on the terrace steps, dispersed coffee and cocoyam. Beans together with weeds and grasses cover the ground.

Soil Cover: 60% bare soil, 40% litter

Alterations: Terracing, animal husbandry (chicken, cattle), manure application, fires, house construction works

Erosion Feat.: Exposed bare soil. Incipient sheet and rill erosion

Soil Profile



Horizon	Description
Oi +0.5cm	Discontinuous (10%) litter layer consistent of banana and tree leaves, very few (1%) fine gravel, occasional stones, abrupt brocken boundary.
Ap 0 – 10 (25)cm	Dark brown (7.5YR 3/3, moist; brown 7.5YR 5/4, dry) clay, very few (1%) medium weathered gravel, moderate granular to subangular blocky structure, low bulk density (1.17g ccm^{-1}, 8cm), few roots, abundant charcoal, clear irregular boundary.
Bt 10 – 60cm	Reddish brown (5YR 4/4, moist; yellowish red 5YR 5/6, dry) clay, common weathered and strongly weathered coarse gravel, occasional weathered **in situ boulders**, weak subangular blocky to blocky structure, high bulk density (1.45g ccm^{-1}, 20cm), frequent clay coatings, very few roots, frequent charcoal, gradual boundary.
B/C 60 –150cm	Yellowish red (5YR 4/6, moist; reddish yellow 5YR 6/8, dry) clay, **common strongly weathered coarse gravel**, weak subangular blocky to blocky structure, very high bulk density (1.61g ccm^{-1}, 80cm), frequent clay coatings, gradual boundary.
BC 150 – 190	Yellowish red (5YR 4/6, moist; reddish yellow 5YR 6/8, dry) clay, **many strongly weathered gravel.**
C 190 – 215+cm	Yellowish red (5YR 5/6, moist; reddish yellow 7.5YR 7/8) clay, many strongly weathered gravel. Continuous saprolite, no further penetration possible, spinning.

## Kwa Kirumbi 6 –*Eroded Slope* 				Truncated Acrisol ?

Coordinates: (UTM WGS 84)		Geology	
Easting:	353583 E 37°40’54.0”	Bedrock Geology:	gneiss, strongly weathered
Northing:	9597554 S 3°38’24.1”	Parent Material:	in situ gneiss
Elevation:	1402m a.s.l.	Rock Outcrops:	6 in 10m radius

Relief		Profile Data	
Slope:	25-30°	Pit depth:	65cm & Auger
Aspect:	W 270°	Colluvium:	Ap as transport layer
Slope Pos.:	upper – middle slope	Water table:	-
Slope Form:	convex – convex	Drainage:	Good
Microrelief:	terraced		

Description: Fallow agricultural field on a steep slope, about 20m below a house terrace. Boulders (<200cm) are frequent (4 within 10m radius). Transport processes and redeposition of material are active in the surface layers. Truncation is evident by the lack of a well developed topsoil and the reduced soil depth compared to soils under forest cover. Abundant clay coatings in the subsoil indicate argilluviation.

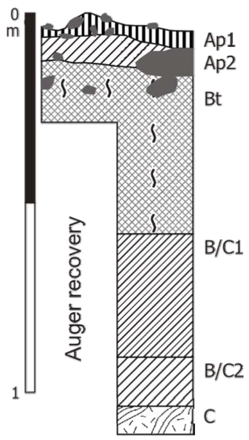
Vegetation: Fallow with a cow grass, beans and weeds, mainly bare soil.

Soil Cover: 70% bare soil, 25% gravel, 5 % litter

Alterations: Terracing, animal husbandry (chicken, cattle), fires, house construction works upslope

Erosion Feat.: Strong eroded slope. Exposed bare soil showing moderate gravel accumulation, strong sheet and rill erosion (10cm deep rills) and sealing due to puddle erosion.

Soil Profile



Horizon	Description
Oi	Discontinuous (<5%) litter layer, many (20%) gravel accumulation on surface, occasional stones, abrupt broken boundary. Rill erosion up to 10cm deep.
Ap 1 0 – 2/10cm	Yellowish red (5YR 4/6, moist; light brown 7.5YR 6/4, dry) clay, common (10%) medium weathered gravel, weak subangular blocky structure, medium packing density, common roots, clear irregular boundary. Active colluvial transport and redeposition of top-, subsoil and organic material.
Ap 2 2/10 – 25 cm	**Plough horizon, incorporating colluvic material.** Yellowish red (5YR 4/6, moist; yellowish red 5YR 5/6) clay, common strongly weathered coarse gravel, weak granular to subangular blocky structure, high bulk density (20cm: 1.41g ccm^{-1}), clay coatings present ???, very few roots, gradual boundary.
Bt argillic Hz. 25 – 60cm	Reddish brown (2.5YR 4/5, moist; reddish yellow 5YR 6/6, dry), clay, common weathered coarse gravel and boulders, weak subangular blocky to blocky structure, very high bulk density (50cm: 1.49g ccm^{-1}), **abundant clay coatings**, very few roots, gradual boundary.
B/C 1 60 – 90cm	Yellowish red (5YR 4/6, moist; reddish yellow 5YR 6/7, dry), clay, common strongly weathered gravel,
B/C 2 90 – 105cm	Yellowish red (5YR 4/6, moist; reddish yellow 5YR 6/7, dry) clay, many strongly weathered gravel.
C 105+ cm	Saprolite. No further recovery possible.

B.8 Kwa Chegho: Forest soils

Kwa Chegho 3 – *Secondary Forest* Truncated Folic Cambisol

Coordinates: (UTM WGS 84)		
Easting:	347865	E 37°37'48.3"
Northing:	9589625	S 3°42'42"
Elevation:	1807m	
Pit depth:	90cm	
Colluvium:	?	

Relief	
Slope:	22°
Aspect:	NNW 345°
Slope Pos.:	middle slope
Slope Form:	straight – straight
Microrelief:	none

Geology	
Geology:	gneiss, strongly weathered
Parent Mat.:	gneiss
Outcrops:	none

Description: This profile is located in a secondary forest on the mountain range between Kwa Chegho and Kamwalla. The hill was deforested in the first part of the 20th century and reforested since 1954 as part of colonial forest conservation measures. The open shrub and bushland vegetation is a mix of planted eucalyptus and indigenous secondary vegetation. The shallow depth of the soil profile indicates partly truncation of the original forest soils probably related to the earlier deforestation. Since then, the surface stabilised under secondary vegetation and a thick topsoil and organic matter developed. This interpretation is supported by stable carbon isotope analysis.

Vegetation: Secondary forest dominated in this part by indigenous trees. Other parts of the hill are pure Eucalyptus forests. Open forest with grass and herb undergrowth.

Soil Cover: n/a

Alterations: Firewood and timber extraction, charcoal production

Erosion Features: none on site, elsewhere strong rill erosion is observed along paths and bare subsoil is exposed under vegetation dominated by eucalyptus.

Kwa Chegho 3

Horizon	Description
Oi 0 - +4 cm	Continuous litter layer.
Oe 0 – 6cm	Dark brown moderately decomposed organic matter, root mat, clear boundary
Oa folic Hz. 10 - 22m	Very dark brown (7.5YR 2.5/2, moist; brown 7.5YR 4/3, dry) folic (?) horizon of decomposed organic matter, dense root mat, clear boundary
Ah 22 – 34cm	Dark brown (7.5YR 3/2, moist; brown 7.5YR 4/3, dry), few weathered fine gravel, weak subangular blocky structure, low bulk density, common roots, gradual boundary.
AB 34 – 56cm	Reddish brown (5YR 4/4, moist; light brown 7.5YR 6/4, dry), clay loam common weathered medium gravel, weak subangular blocky structure, moderate bulk density, very few roots, gradual boundary.
B 56 - 101cm	Yellowish red (5YR 4/6, moist; reddish yellow 7.5YR 7/6, dry), clay loam, many coarse gravel, weak subangular blocky structure, high bulk density, clear boundary.
B/C 101 – 140+cm	Yellowish red (5YR 5/6, moist; reddish yellow 7.5YR 7/6, dry), clay loam, abundant coarse gravel, angular blocky structure, high bulk density.

Kwa Chegho 1 & 2 – *Forest Slope* Folic Umbrisol

Coordinates: (UTM WGS 84)

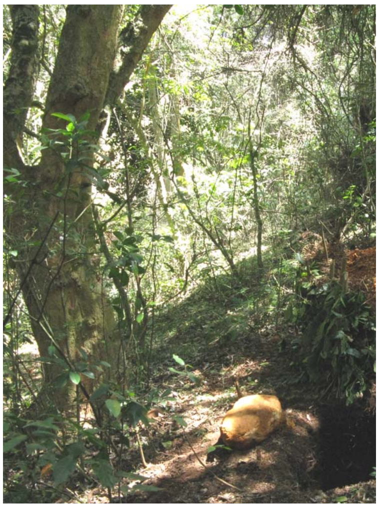
Easting:	347935	E 37°37’50.7”
Northing:	9589420	S 3°42’48.6”
Elevation:	1793m	
Pit depth:	90cm	
Colluvium:	?	

Relief

Slope:	22°
Aspect:	NNW 345°
Slope Pos.:	middle slope
Slope Form:	straight – straight
Microrelief:	none

Geology

Geology:	gneiss, strongly weathered
Parent Mat.:	gneiss
Outcrops:	none



Description: The Kwa Chegho forest is disturbed by selective lodging and firewood extraction as well as local clearings. The two profiles are located within 5m distances and show high variability in soil depth and genesis. Whereas Kwa Chegho 1 shows disturbance and probably material movement in 1m depth, Kwa Chegho 2 is located over a big boulder and very shallow.

Vegetation: Disturbed natural forest with indigenous forest trees. Open forest with grass and herb undergrowth, frequent vines.

Soil Cover: 80% litter, 10% mosses, 10% bare soil.

Alterations: selective lodging, firewood extraction

Kwa Chegho 1

	Horizon	Description
	Oi, 0 - +5 cm	Continuous litter layer.
folic Hz.	**Oe** 0 – 4cm	Dark brown moderately decomposed organic matter, root mat, clear boundary
folic Hz.	**Oa** 4 - 35m	Dark brown folic horizon of decomposed organic matter, dense root mat, clear boundary
umbric Hz.	**Ah** 35 – 40cm	Dark brown (7.5YR 3/3, moist; brown 7.5YR 4/4, dry), few weathered fine gravel, weak subangular blocky structure, very low bulk density, common roots, gradual boundary, **few charcoal.**
umbric Hz.	**B 1** 40 – 90cm	Dark reddish brown (5YR 3/3, reddish brown 5YR 4/4, dry), common weathered fine gravel, weak subangular blocky structure, low bulk density, very few roots, gradual boundary, **few charcoal.**
	Ab 90 – 144cm	Dark brown (7.5YR 3/3, moist; strong brown 7.5YR 4/6, dry), common weathered fine gravel, weak subangular blocky structure, moderate bulk density, very few roots, gradual irregular boundary, **charcoal**
	B 2 144 - 175cm	Reddish brown (5YR 4/4, moist; Reddish yellow 7.5YR 5/6, dry), common weathered fine gravel, weak angular blocky structure, moderate bulk d.
	BC 175 – 200+cm	Yellowish red (5YR 4/6, moist; reddish yellow 7.5YR 6/6, dry), many weathered coarse gravel, angular blocky structure, moderate bulk density..

Kwa Chegho 2

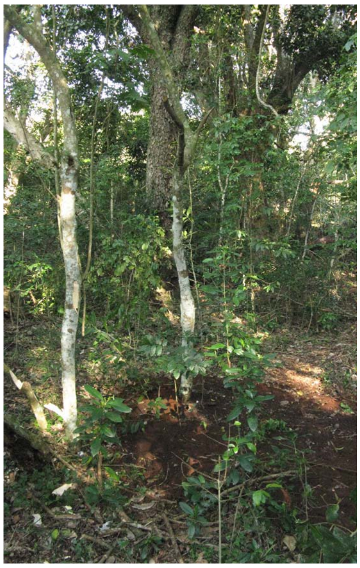
	Horizon	Description
	Oi 0 - +4 cm	Continuous litter layer.
folic Hz	**Oe** 0 – 6cm	Black (moist; dark brown 7.5YR 3/4 dry) partly decomposed organic material, root mat, clear b.
folic Hz	**Oa** 6 – 26m	Black (moist; dark brown 7.5YR 3/2, dry) org. matter, root mat, clear boundary, charcoal
umbric Hz.	**Ah** 26 – 30cm	Very dark brown (7.5YR 2.5/2, moist; brown 7.5YR 4/4, dry), very few weathered fine gravel, weak subangular blocky structure, very low bulk density, common roots, irregular boundary.
umbric Hz.	**B** 30 – 80cm	Dark reddish brown (5YR 3/3, moist; reddish brown 5YR 4/4, dry), very few weathered fine gravel, weak subangular blocky structure, very low bulk density, common roots,.
	R, 80+cm	Big boulder. Abrupt boundary

Chegho 2 – *Slope deposit, Chegho swamp* Folic Umbrisol

Coordinates: (UTM WGS 84)	
Easting:	E 347738
Northing:	S 9589656
Elevation:	1762m a.s.l.
Pit depth:	220cm
Colluvium:	180cm

Relief	
Slope:	6°
Aspect:	W 245°
Slope Pos.:	footslope
Slope Form:	Concave –straight
Microrelief:	None

Geology	
Geology:	Gneiss
Parent Mat.:	Colluvial slope creep
Outcrops:	None
Water table:	300 cm



Description: On the footslope of the Kwa Chegho hill, about 10m from the Chegho swamp, the profile Chegho 2 shows evidence of three former slope instability events. Two buried topsoils in 105 – 135cm.and 180 -220cm depth separate similar and homogeneous slope deposits. At 235 - 250cm depth reddish material with a high magnetic susceptibility suggests a local fire event. Below 250cm, the deposit is compacted and a high bulk density complicates excavation. Faint reddish and greyish mottles accompany a fluctuating water table recorded at 300cm depth (Nov. 2008). Continuous rock - or a large boulder - at 320cm depth impedes drainage.

Vegetation: Large mature trees, few undergrowth..

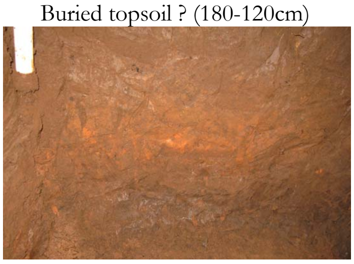
Soil Cover: 100% litter

Alterations: direct vicinity to a foot path

Erosion Feat.: none

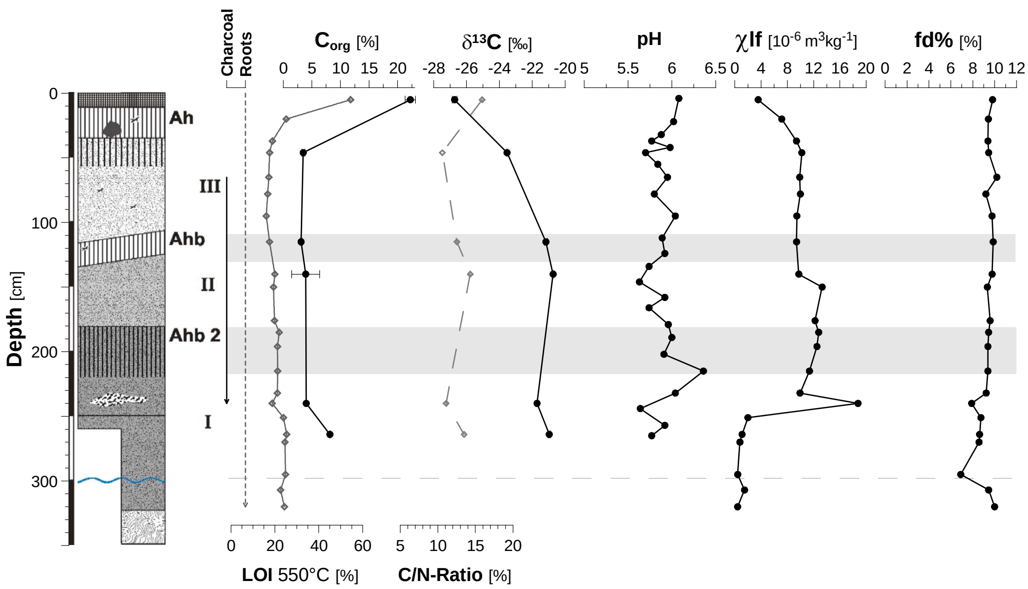
Archaeological Features: fire event ?

Buried topsoil ? (180-120cm)



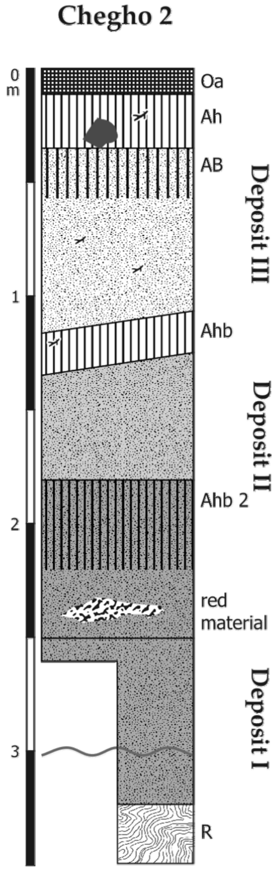
Compact, bright red clay (~240cm)

Chegho 2: Analysis Overview

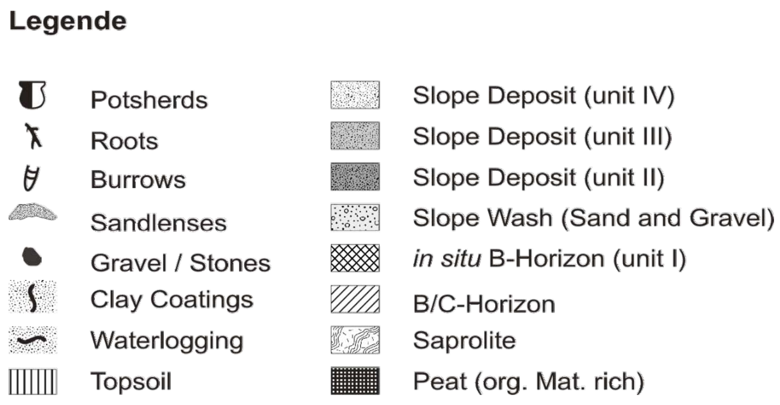


Chegho 2

Soil Profile



Zones		Horizon	Description
		Oi +1 – 0cm	Litter. Leaves and visible plant remains, slightly decomposed, clear wavy boundary.
	folic Hz.	**Oe** 0 – 4cm	Moderately decomposed organic matter with a very dense root matt
		Oa 4 – 12cm	Black (7.5YR 2.5/1 moist) moder horizon with abundant roots, gradual wavy boundary.
		Ah 12 – 38cm	Black (7.5YR 2.5/1 moist and dry) clay loam, few (<5%) angular weathered medium gravel, one boulder (<60cm) weak subangular blocky structure, many roots, gradual smooth boundary.
Slpe deposit III	**Umbric Hz.**	**AB** 38 - 60cm	Very dark brown (7.5YR 2.5/2 moist, dark brown 7.5YR 3/3 dry) clay loam, few (<5%) weathered angular fine gravel (<0.6cm), weak subangular blocky structure, many fine and coarse roots, clear irregular boundary; tongues of Ah material within the Bw horizon.
		60 – 105cm	Dark reddish brown (5YR 3/3 moist & dry) clay loam, very few (<2%) weathered angular fine gravel (<0.6cm), weak to moderate subangular blocky structure, few fine and coarse roots, charcoal common, clear wavy boundary
Slope deposit II	**Buried topsoil**	**Ahb** 105 – 135cm	Black (5YR 2.5/1 moist, very dark grey 7.5YR 3/1 dry) clay loam, very few (<2%) weathered angular fine gravel (<0.6cm), weak subangular blocky structure, many fine and few coarse roots, charcoal common, clear wavy boundary; distinct mixing of Bw material along root and animal channels, in the lower part spots of bright reddish material
		135 – 180cm	Very dark brown (7.5YR 2.5/2 moist, reddish brown 7.5YR 4/4 dry) clay loam, very few (<2%) weathered angular fine gravel (<0.6cm), weak subangular blocky structure, few fine and very few coarse roots, few charcoal, gradual wavy boundary.
	Buried topsoil	**Ahb 2** 180 – 220cm	Black (7.5YR 2.5/1 moist, dark brown 7.5YR 3/2 dry) clay loam, very few (<2%) weathered angular fine gravel (<0.6cm), weak-moderate subangular blocky structure, very few fine and coarse roots, charcoal common, gradual wavy boundary, distinct mixing of B material along animal and root channels.
Slope deposit I		220 – 248cm	Black (10YR 2/1 moist, brown 7.5YR 4/3 dry) clay loam, very few (<2%) weathered angular fine gravel (<0.6cm), weak-moderate subangular blocky structure, very few fine and coarse roots, charcoal common, diffuse broken boundary.
	fire ?	235 – 250cm	About 2dm² spot on east wall of dark reddish brown (5YR 3/4 moist, yellowish red (5YR 5/6 dry) hard clay loam
		248 – 320cm	Black (7.5YR 2.5/1 moist, very dark grey (7.5YR 3/1 dry) clay loam, high bulk density, moderate organic matter ?, with many (20%) faint reddish and greyish mottles with diffuse boundaries, few (<2%) weathered angular fine gravel (<0.6cm), moderate subangular blocky structure, few charcoal.
		300cm	Watertable
	Boulder ?	**R** 325cm	Weathered gneiss bedrock or boulder, above bedrock free groundwater.



C Palaeoecological Data

Tab. A: Lomwe Swamp pollen record.. Arboreal pollen record and pollen summaries

			Arboreal Pollen: Montane Forest																Introduced T.				Woodland														Overview					
Pollen zone	Depth	Stratigraphy	Hagenia	Ilex	Myrica	Nuxia	Podocarpus	Tapura	Rapanea	Allophyllus	Apodytes	Lasianthus	Alchornea	Schefflera	Macaranga	Canthium	Olea	Polyscias	Cup. / Junip.	Euc. / Syz	Pinus	Phoenix	Acacia	Dob / Maesa	Tarrenna	Terminalia	Commiphora	Grewia	Celtis	Croton	Euclea	Lannea	Ficus	Combretum	Tamarindus	Tarchonan.	Pollen Types	Total Counts	Pollen Sum	Arboreal	non-arboreal	wetland
	21	Peat				3			4	2	1								60	15	8					1			2	1							28	1981	1449	7	93	523
	26	Peat			25	5					6								1	155	2		4		6	10	2	3									26	1052	697	31	69	347
	32	Peat							3										172	78			6	5		3											16	1324	947	28	72	375
III	46	Peat			10		1	35	3	6				13		1			22	3		9	2	3		22	10				10	1					31	2309	896	17	83	1412
	56	Peat			5	3	1	2									1		33					1	7		8	5	1								22	1082	616	11	89	466
	64	Peat			3							1							2				5	5	1		2		1								25	779	501	4	96	275
	74	Peat			2							5					1		2				3	5	1	3	5	8	3		5						29	708	477	9	91	229
	86	Transition			1																			0	3	5		1	2								21	862	522	2	98	340
	97	Transition				2										2							4	1	2	1		1	1								19	972	664	2	98	307
	106	Transition																					7				1	3	5								18	751	575	3	97	176
	117	Loam			1	1																	10														14	642	551	2	98	90
	124	Loam																					17					1								1	12	682	621	3	97	61
	133	Loam																					17					1									12	486	469	4	96	17
III	145	Loam																					7														11	691	650	1	99	41
	154	Loam		7																		4		5		3											15	853	606	3	97	244
	164	Loam																																			8	562	540	0	100	22
	175	Loam																																			7	256	228	0	100	28
	185	Loam																																			10	772	717	0	100	55
	195	Loam																																			7	594	574	0	100	20
	205	Loam																							1												10	742	656	0	100	85
	217	Loam / Clay								1						2							5	9	5		5		6	7							19	816	792	5	95	22
	228	Peat		15																			1	3	6		2										16	811	543	5	95	268
	232	Clay inwash																					3	3			2			4							16	586	547	2	98	39
	236	Peat (Leave Mat)					1																											1			9	1023	13	15	85	243
	244	Peat (woody)																						2			8										8	1126	79	13	87	1002
	255	Peat (clayey)																																			4	1114	60	0	100	1027
	266	Peat (clayey)																					1	1	2	1		5									15	1231	431	2	98	180
	280	Peat																																			3	386	6	0	100	380
I	285	Peat																	24					2													7	1050	56	46	54	920
	289	Peat																					5	4	13	3							1				13	693	475	5	95	117
	295	Clay inwash		3																				325			2						1				13	390	384	86	14	2
	306	Peat (woody)				1																	1	14													13	500	84	19	81	385
	315	Peat (woody)			1	2					3								7	210			15		5	1		10		4	6						20	1210	885	30	70	320
	324	Peat (woody)		5														1					2	3			1		1			1					18	399	51	27	73	276
	330	Peat (woody)															1		235					19		7						1			3		22	1220	713	37	63	289
	335	Peat & Inwash	4												1									3													15	582	71	11	89	493
	346	Transition																																			7	386	178	0	100	192
	356	Transition	2										1													1											13	362	289	1	99	16
	364	Clay																						4													6	43	36	11	89	3
	375	Clay																									2										7	78	67	3	97	2
	385	Clay																																			3	6	1	0	100	2
omitted	395	Clay																																			1	1	0	0	0	0
	407	sandy Clay																																			2	6	0	0	0	2
	419	sandy Clay																		1																	2	2	2	50	50	0
	426	Sand						1																													1	2	1	100	0	0
		Occurence (excl. <1, =18):	2	4	8	7	3	3	3	3	3	2	1	1	1	3	3	1	10	6	2	2	19	21	12	13	13	10	9	4	3	3	2	1	1	1						
		Percentage <5% / <2%:	5,6	9,8	3,6	1,2	7,7	3,9	0,3	0,7	0,9	1,0	0,3	1,5	1,4	0,3	0,2	2,0	43	24	0,6	1,0	3,9	84,6	2,7	2,5	10,1	1,7	2,0	0,9	1,1	2,0	0,3	7,7	0,4	0,2						

Tab. A: continued: Lomwe Swamp pollen record. Non-arboreal pollen record and wetland taxa.

			Non-arboreal Pollen																														Wetland						Spores		Indet.	
			Montane Forest							Woodland													Clearings and Glades						Anthro.													
Pollen zone	Depth	Stratigraphy	Acaly. / Urt.	Rubiaceae	Acantha. t.	Asystasia	Ericaceae	Polygala	Impatiens	Euphorbia	Cissampelos	Commicarpus	Rhus	Solanum	Sansevieria	Aloe	Capparis	Cleome	Fabaceae	Asparagus	Indigofera	Apiaceae	Malvaceae	Justicia	Lamiaceae	Phyllanthus	Ama. / Cheno.	Asteraceae	Rumex	Commelina	Zea mays	Poaceae	Cyperaceae	Typhae	Liliaceae	Ludwigia	Hydrocotyle	Asclep.	Trilete S.	Monolete S.	Unknown	Indet.
IV	21	Peat	2	5			2			3			1							8				1			7	14	15	2	62	1230	514	3	5	1				3	4	2
	26	Peat	12										1			6										7	7	78	7		2	358	328	9		5	2	3		4		4
	32	Peat		5						2						62									4		2	53				552	369		5			1				2
	46	Peat	22							1	3					1	1							4		41	7	85	2		3	575	1410		2					0		1
III	56	Peat	10														3								45	20	15	247		2	6	201	465		1							
	64	Peat	15	1								2				2	1							2	10	5	30	190		25	3	195	248	3	5	19						3
	74	Peat	37					1			1	2		2										1	16	7	15	165	3	8	6	170	200		11	18					2	
	86	Transition	42	3																			5	10	9	3	35	187	2	5	25	184	334	1		5						
III	97	Transition	15											1									21	20	15	5	122	162		7		282	307									1
	106	Transition	5													1	1						35	12	3	1	162	137		2		200	173	2		1						
	117	Loam	22														1						20	10	18	5	195	91		2		175	90									1
	124	Loam																					20	12	15	1	216	113		5		220	61									
	133	Loam	5																				10	21	22	2	199	45		5		142	17									
	145	Loam	2																				18	11	13	3	297	45		5		249	41									
	154	Loam	2												6								45		9		120	65		5		335	238	3		3					3	
	164	Loam															2						43	6	12		158	48				271	22									
	175	Loam																					22		2		43	18		3		140	28									
	185	Loam	1													1							77	5	40	3	105	125				360	55									
	195	Loam		2																			15		2		145	70				340	20									
	205	Loam	17																				15		20	10	95	68		2		428	85								1	
I	217	Loam / Clay	9	5																			45		35	4	50	153		1		450	20	2								2
	228	Peat	35	9													5						2		13	7	23	195		2		225	268									
	232	Clay inwash	15	7																				7	10	7	40	159	2	1		287	38	1								
	236	Peat (Leave Mat)																						1				4				6	7					236	2	765		
	244	Peat (woody)	2	7																												60	7					995		45		
	255	Peat (clayey)																														60	7					1020		27		
	266	Peat (clayey)	21																				10		30	20	15	140				185	180					0		620		
	280	Peat							3																							3						380				
	285	Peat																										5				25	25					895		72		2
	289	Peat	35																						8	18	10	175				203	117							100	1	
	295	Clay inwash	4								5							8								7	12	7				10	2							1	3	
	306	Peat (woody)	2																5						2		2	2				55	93					292	15	13	1	2
	315	Peat (woody)	5																								7	50	7	2		550	315			5				2	2	1
	324	Peat (woody)	5			1				1												1						12	2	1		14	276						63	7	2	
	330	Peat (woody)	5		5					1		5												1		3	22	210	1	59		135	235	3				51	3	215		
	335	Peat & Inwash	3														1	4			1					1	2	20		1		30	493						9	3	6	
	346	Transition	1															2									10	64				101	192						14		2	
	356	Transition	1															211						1		3	25	23				21	16						14	25	18	
omitted	364	Clay																								6	1					25	3						4			
	375	Clay																							3	2						60	2						7	2		
	385	Clay																									1						2							2	1	
	395	Clay																																					1			
	407	sandy Clay																															2							4		
	419	sandy Clay																									1															
	426	Sand																																							1	
		Occurence (excl. <1, =18):	29	9	1	1	1	1	1	5	3	3	2	2	1	6	8	4	1	1	1	1	16	17	24	25	35	35	9	21	7	40	41	9	6	8	1	10	10	19	14	11
		Percentage <5% / <2%:	9,8	8,9	0,7	2,0	0,1	0,2	50	2,0	1,3	0,7	0,1	0,4	1,0	6,5	1,4	73	6,0	0,6	1,4	2,0	11	7,7	7,3	5	46	40	3,9	8,3	4,8	100	85	0,9	1,6	2,5	0,3	98	16	75	5	0,4

Tab. B: Lomwe Swamp phytolith record. Total counts and percentages of total, respective short cell sum.

Total Counts

		Grass Short Cell Phytoliths							Grass phytoliths					Non-Grasses			Non-Diagnostics				Sums	
Depth	Stratigraphy	Pooideae	Panicoideae	Chloridoideae	Bambusoideae	Aristidoideae	Pharoideae	Short dumbells	Elongante, smooth	Elongate, sinuate	Blocky, rectangular	Bulliform, para.epiped.	Bulliform, cuneiform	Perforated platelets	Sclerenchyma	Cyperaceae	Stomtal cells	Trichomes	Hair cells	Unidentified	Grass short cells	Total Sum
32	Peat	20							2		5	1					8				20	36
46	Peat	175		2	4	5		5	112	25	24	27				6	42				191	427
56	Peat	240			14				355	58	45	3				2	27	15			254	759
64	Peat	18							304	15	65	18		3			15	3			18	441
74	Peat	45			25			2	245	13	53	20					2	30	3		72	438
86	Transition	2							15	2	2						1				2	22
97	Transition	2							10	2	2	1						1			2	18
106	Transition	30			20			10	210		90	29	10			1		13			60	413
117	Loam	15			13			3	60	15	55	40					9	40			31	250
124	Loam	45	15		155			10	20	2	40	70	5	35						35	225	432
133	Loam	45	2		48				2	5	62	30	5	50			3	1			95	253
145	Loam	10	2						22		10	11		7			2	3		2	12	69
154	Loam	3			27				235		95	30					10	5			30	405
164	Loam								22			1					1	1			0	25
175	Loam	20	18				7		45		5	11		5			3	20		26	45	160
185	Loam	10	20		25				90	5	15	55					5	23	5		55	253
195	Loam	30	25		40				25		5	25	5								95	155
205	Loam	15	22		95				78	13	10	74		15				20	10		132	352
217	Clay	20	2		15				25	5		8						1			37	76
228	Peat	4	7		5	4			390	87	7	5		55			7	5			20	576
232	Clay Inwash	62	9		40				10			10						3		69	111	203
236	Peat	145	100		40				215	5		12	5					15		80	285	617
244	Peat	130	20	7	35	5			280	97		25						24		40	197	663
255	Peat	65	30	7				5	168	45	2	28		5	7		12	25		13	107	412
266	Peat								25	47		3					8				0	83
280	Peat	2		1											2						3	5
289	Peat								15	110				1			5				0	131
295	Clay Inwash																				0	0
306	Peat		35	2		2		3	20			7								60	42	129
324	Peat			2						20							1			5	2	28
335	Peat & Inwash	10	7	2	1				10		2	9			2					7	20	50
346	Transition		5						2												5	7
356	Transition		3						2											2	3	7
364	Clay	5							2				2							1	5	10
375	Clay								5	4	3							3			0	15
385	Clay								1	1	1										0	3
395	Clay	2							5			3									2	10
407	Sandy clay	33	8						35	5		15						35			41	131
419	Sandy clay								3	3	4	5						8			0	23
426	Sand								5	5	10		2								0	22

Percentages

		% of grass short cells							% of total sum											
32	Peat	100							6		14	3					22			
46	Peat	92		1	2	3		3	26	6	6	6				1	10			
56	Peat	94			6				47	8	6	0				0	4	2		
64	Peat	100							69	3	15	4		1			3	1		
74	Peat	63			35			3	56	3	12	5					0	7	1	
86	Transition	100							68	9	9						5			
97	Transition	100							56	11	11	6						6		
106	Transition	50			33			17	51		22	7	2			0		3		
117	Loam	48			42			10	24	6	22	16					4	16		
124	Loam	20	7		69			4	5	0	9	16	1	8						8
133	Loam	47	2		51				1	2	25	12	2	20			1	0		
145	Loam	83	17						32		14	16		10			3	4		3
154	Loam	10			90				58		23	7					2	1		
164	Loam								88			4					4	4		
175	Loam	44	40				16		28		3	7		3			2	13		16
185	Loam	18	36		45				36	2	6	22					2	9	2	
195	Loam	32	26		42				16		3	16	3							
205	Loam	11	17		72				22	4	3	21		4				6	3	
217	Clay	54	5		41				33	7		11						1		
228	Peat	20	35		25	20			68	15	1	1		10			1	1		
232	Clay Inwash	56	8		36				5			5						1		34
236	Peat	51	35		14				35	1		2	1					2		13
244	Peat	66	10	4	18	3			42	15		4						4		6
255	Peat	61	28	7				5	41	11	0	7		1	2		3	6		3
266	Peat								30	57		4					10			
280	Peat	67		33											40					
289	Peat								11	84				1			4			
295	Clay Inwash																			
306	Peat		83	5		5		7	16			5								47
324	Peat			100						71							4			18
335	Peat & Inwash	50	35	10	5				20		4	18			4					14
346	Transition		100						29											
356	Transition		100						29											29
364	Clay	100							20				20							10
375	Clay								33	27	20							20		
385	Clay								33	33	33									
395	Clay	100							50			30								
407	Sandy clay	80	20						27	4		11						27		
419	Sandy clay								13	13	17	22						35		
426	Sand								23	23	45		9							

D Analytical Techniques

D.1 Optically-stimulated lumincescence dating

Dose recovery preheat test

The OSL signal is a compound signal from different electrons traps and it is not possible to discriminated luminescence from different types of traps by means of the shine down curve (AITKEN 1998). Therefore, it is crucial to empty thermally shallow and unstable traps before the optical stimulation by heating the sample to an adequate preheat temperature. This ensures that only energy released from deep and stable traps is considered (WINTLE & MURRAY 2000). To evaluate the suitability of the SAR protocol parameters for the specific samples from the different environmental settings a dose recovery preheat test (Fig. A) was performed to determine adequate preheat temperatures. The test involves the irradiation of a previously totally bleached sample with a known artificial dose, which subsequently is treated as unknown and measured by a SAR protocol (WINTLE & MURRAY 2006). A dose recovery preheat plateau test was performed for a representative sample and suitable preheat temperature was selected after evaluation of the recovery ratio, the recycling ratio and the recuperation of charge measured by the zero dose regeneration point. For each temperature three samples were irradiated by a known artificial dose, which was treated as unknown and measured by a full SAR protocol. The temperature which best recovered the laboratory dose and showed acceptable recycling ratios was used as preheat temperature in the subsequent SAR protocols.

The recovery ratios as well as the recuperation of charge data of the two preheat tests samples increase with higher temperatures. This suggests some contribution from the thermal transfer of charge during preheating and optical stimulation or in the case of charge recuperation carry over from the previous test dose signal (WINTLE & MURRAY 2006). Preheat temperature for the samples from colluvial sediments of Usumbwe and Mrongo were determined from the sample Shfd09059 - Usumbwe 3 (260cm) and a preheat temperature of 240°C was chosen because of a good recovery ratio and better growth curve behaviour than observed for lower temperatures also showing good recuperation values (Fig. A). OSL signals were measured at 125°C for 80 s after 10 s of experimentally determined preheat. To correct for sensitivity changes the luminescence signals were corrected using the response to a test dose of 6.1 Gy after a cut-heat of 160°C (MURRAY & WINTLE 2000). The luminescence signal was determined as the difference between the integrated OSL signal of the first 1.6 s of illumination and the background signal integrated over the final 16 s of the shine down curve. MURRAY & WINTLE (2000) as well as BANERJE et al. (2000) recommend only the first 0.3 – 0.8 s of the initial signal to be used to obtain an enhanced signal-to-noise ratio. For most of the samples a delayed increase in luminescence from the first to the second/third channel (0.6, 0.96 s) was observed. The larger integral for the initial signal was chosen to cover all of this initial delay of the luminescence signal.

Dose rate calculation

The amount of ionising radiation the sample received during burial is measured from subsamples of the immediately surrounding material. Ionising radiation is made up of α-, β-, and γ-, radiation emitted by the decay of radioactive elements (mainly U, Th, K and Rb) within the minerals of the sample itself and the surrounding material and additionally contributions from cosmic radiation. The dose rate was measured by quantification of parent nuclides via ICP-MS (Inductively-coupled plasma mass spectrometry) and calculation of the resulting radiation. The cosmogenic dose rate is calculated from the geographic location and elevation of the sample and sampling depth. (PRESCOTT & HUTTON 1994; MUNYIKWA 2000)

Water content

Water in the interstices of the sediment absorbs part of the ionising radiation (AITKEN 1998). Variability of the soil moisture content during the time span of burial is difficult to predict or to model. OSL samples of colluvial deposits were taken from well above the groundwater table and present soil moisture was used to calculate radiation attenuation.

Data Analysis

To remove noise in the data set outliers were removed using the quartile approach (BOULTER & BATEMAN 2008) and equivalent doses falling outside the 25th and 75th percentiles were excluded from further statistical analysis. The remaining data is plotted as a probability distribution for further evaluation. If the probability curve suggests a normal distribution with few scattered values the easily to calculate weighted or probability mean are reliable estimates (BOULTER & BATEMAN 2008). High scatter on the other hand is normally dealed with by applying the Common Age Model or the Central Age Model (GALBRAITH et al. 1999).

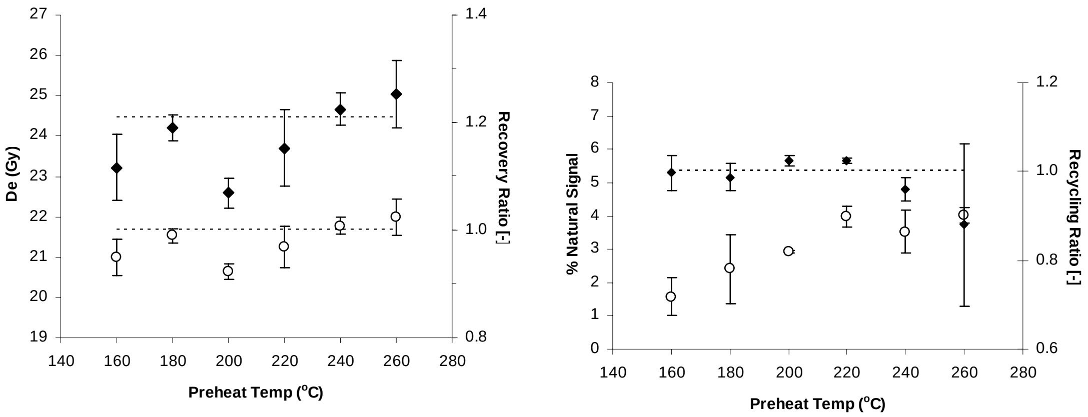


Fig. A: Preheat test for a representative samples from Usumbwe ´3 (Shfd09059). A preheat temperature of 240°C was chosen for all three samples. The given equivalence doses are indicted by dotted lines. Recovery of the respective artificial equivalence dose (black circles) and the derived recovery ratio (white circles) are shown to the left. Recycling ratios (black circles) and recuperation of charge (white circles) are given to the right.

More often, dose distributions however are skewed or show a non-normal distribution. The deposits might have undergone some sort of post-depositional mixing or the quartz grains were insufficiently bleached at the time of burial. The results are complex palaeodose distributions, which might even show multiple peaks related to the mixture of different deposition events. Several sophisticated statistical models have been put forward to deal with special situations, for example when insufficient bleaching is assumed. Application of statistical models which extract a specific part of the equivalent dose distribution relies on further information about the deposition history or on an informed guess about possible disturbance or deposition processes. The application of one or the other statistical model therefore always involves some sort of subjective decision by the analyst.

Partial bleaching of fluvial or colluvial quartz is the most common bias and a number of methods have been developed to derive a statistically sound and reproducible age estimate for tailed distributions. OLLEY et al. (1998) proposed that the lowest 5% of aliquots were sufficient to calculate the burial age in a strongly skewed distribution. LEPPER et al. (2000; 2002) on the other used the 'leading edge' of the distribution to, whereas FUCHS & LANG (2001) used a running mean and a standard deviation threshold to obtain the palaeodose. The lowest peak from a multicomponent distribution curve is separated by the minimum age model (MAM) developed by GALBRAITH et al. (1999).

Finally equivalent doses of multicomponent distribution curves related for example to the mixture of material from different bleaching events can be extracted by using the finite mixture model (GALBRAITH & GREEN 1990; GALBRAITH & LASLETT 1993; ROBERTS et al. 2000). Trying to standardize the choice of a statistical model, BAILEY & ARNOLD (2006) developed a decision making tree and recommend the most common procedures according to the characteristics of the probability distribution of the equivalent dose distribution. Following the procedure outlined by BAILEY & ARNOLD (2006) and BOULTER et al. (2007) the probability mean was accepted for the near Gaussian equivalent dose distribution obtained for Mrongo 5. Colluvial deposits at Usumbwe show multicomponent equivalent dose distributions and suggest a complex bleaching history (Tab. C). The finite mixture model (GALBRAITH & LASLETT 1993; ROBERTS et al. 2000) was applied to obtain the peak with the highest probability, most likely representing the most important redeposition event.

Tab. C: Equivalent doses extracted from multi-component probability distributions by finite mixture model and relevant corresponding OSL ages. Note that the youngest extract peaks are not the most dominant ones at Usumbwe 3 indicating the dominance of an insufficiently bleached older quartz fraction.

Site		Equivalent Dose [GY]	Probability [%]	Age [ky]
Usumbwe 3	260cm	**1.93** ± 0.23	**5**	
		4.21 ± 0.14	**55**	**4.17** ± 0.24
		6.67 ± 0.42	**20**	**6.61** ± 0.52
	365cm	**2.76** ± 0.21	**13**	**2.80** ± 0.25
		4.52 ± 0.22	**47**	**4.58** ± 0.31
		6.69 ± 0.32	**39**	

D.2 Loss-on-ignition

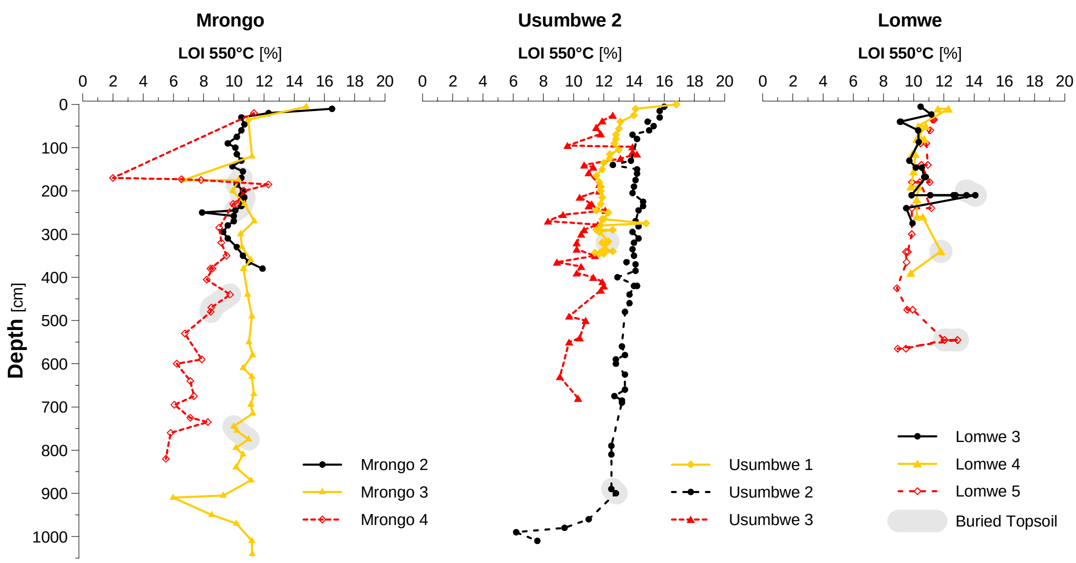


Fig. B: Loss-on-ignition at 550°C of selected slope deposits. Note that distinctly dark, and slightly organic carbon enriched buried soils of the late Holocene (Mrongo & Usumbwe) are not reflected in the LOI values. Organic carbon rich, late Pleistocene buried topsoils at Lomwe show up in the LOI record.

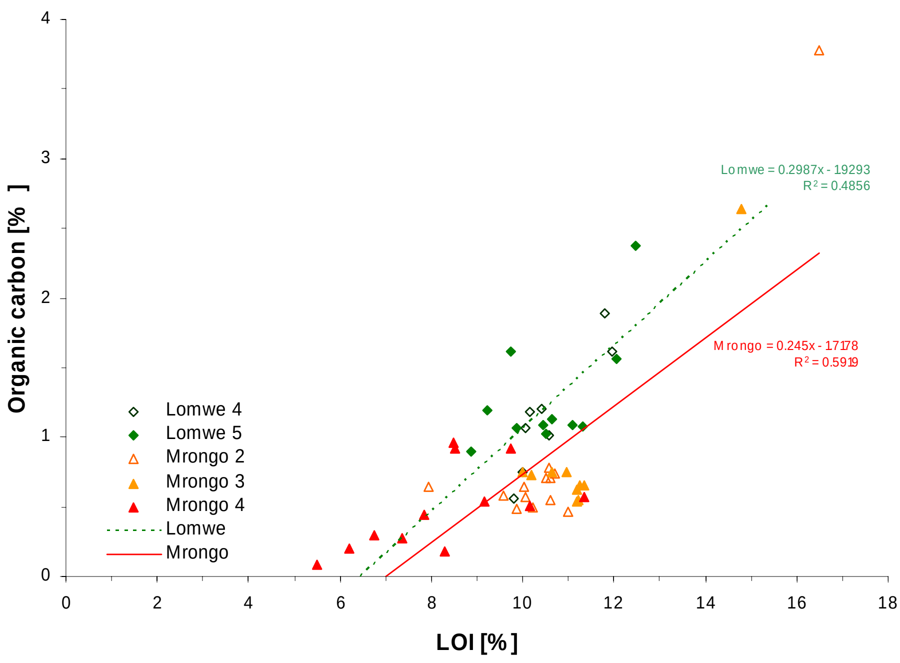


Fig. C: Prediction of organic carbon based on the LOI method. LOI at 550°C is plotted against C_{org} values from element analysis. Regression functions are outlined for Lomwe and Mrongo profiles.

D.3 Nitric-acid-resistant carbon: profile Lomwe 10

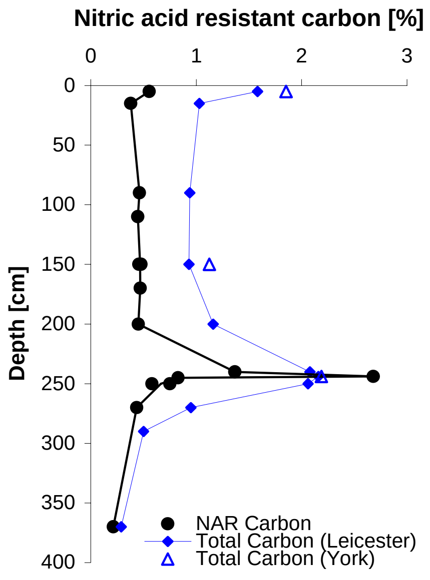


Fig. D: Nitric-acid-resistant carbon and total organic carbon record of the Lomwe 10 soil profile. NARC for individual samples (black dots) and average charcoal record (black line). Organic carbon content (blue triangles) for selected samples.

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