Postdoc Fellowships for non-EU researchers

Final Report

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Selection	2010 (ref. C/brs/l/10/rep/mail-prompo-n)
Host institution	Ghent University
Supervisor	Prof. Dirk VERSCHUREN (Limnology Unit, Biology Dept)
Period covered by this report	from 15/10/2011 to 15/01/2012; from 25/02/2012 to 23/05/2012
Title	**Calibration and validation of fossil phytolith tracers of important grasses and African food crops in lake sediment records of western Uganda**

Project Summary

Knowledge of historical (and ancient) landscape and vegetation changes, due either to natural climate variability of human impact, is required to develop sound strategies for the sustainable management of natural resources, and for evaluating the restoration potential of disturbed landscapes for biodiversity conservation. In tropical Africa, reconstructions of the past distributions of vegetation and types of land use that are based only on traditional pollen analysis (palynology) of lake-sediment records are defective in this regard, because all natural grasses and agricultural cereals have the same type of pollen, and because other important food crops do not produce enough pollen to be recovered from lake-sediment records. The BelSPO-SSD project SD/BD/03 'CLANIMAE: *Climatic and Anthropogenic Impacts on African Ecosystems*' (2007-2011) specifically aimed to differentiate between the past impacts of climate variability and ancient or historical human activity on African terrestrial ecosystems; and therefore focused substantial effort on the development of complementary fossil tracers of past vegetation composition preserved in lake sediments, such as fungal spores and plant phytoliths.

Phytoliths are small natural glass (non-crystalline quartz) particles built into the tissue of plants to prevent consumption by insects. Buried and preserved in lake sediments, their characteristic shapes and forms allow to distinguish between various types of grasses linked to particular types of tropical grassland, and to trace the past distribution of important African staple foods such as banana, maize and oil palm. The present fellowship project, which was executed during and after two three-month research visits of Ugandan phytolith expert Dr. Julius Lejju to Ghent University, aimed to calibrate and validate the potential of important types of fossil plant phytoliths as indicators of past human impact on East African landscapes. The calibration was done by assessing the quantitative relationship between the abundance of those phytolith types in the surface sediments of 25 Uganda crater lakes, and survey data of land use within the catchments of those lakes (for example, the percent fraction of the total area covered by banana plantations). The validation was done by using this improved phytolith-based methodology in a reconstruction of past climatic and anthropogenic vegetation changes around Lake Katinda in western Uganda spanning the last 3800 years.

The calibration aspect of the research yielded a total of 9212 diagnostic phytoliths which could be assigned to 10 different morphotypes. However, the yield per sample (i.e., lake site) was rather variable (range 66-778, mean 368), with 6 samples remaining below the threshold of 200 required to allow robust statistical analysis of phytolith distribution patterns among samples (lakes). Consequently, while the provisional results of this analysis could already be used in the validation aspect of the research, its completion awaits extraction and counting of additional phytoliths, using new sediment preparations. The validation study on the sediment record of Lake Katinda was highly successful. The phytolith data indicate that a moist or semi-deciduous forest persisted inside this crater basin throughout the past 3800 years, with somewhat greater fraction of open-canopy grassy areas in the last two millennia. Initially both tall and short grasses occurred, the latter possibly restricted to areas with shallow soil near the crater rim. A significant decline in palm phytoliths around 2100 years ago may be attributed to increased local human activity with use of palm materials for domestic purposes such as roofing, mats, fishing rafts and charcoal. In combination with the other phytolith data, it indicates that humans living in the Katinda area largely eradicated the lake-fringing

palm and sedge wetland, but did not substantially reduce forest cover inside the crater basin. Presumably, early iron-age farmers created and maintained agricultural fields on more gently sloping terrain in the surrounding landscape. This assessment contrasts with the widely held paradigm that iron-age farmers in southwestern Uganda are responsible for large-scale forest clearance as early as 2500 years ago.

1. Objectives of the Fellowship (1/2 page)

Reconstructions of past vegetation change produce the long-term perspective to the current distribution of vegetation and land-use types that is required to develop sound strategies for sustainable management of natural resources, and to evaluate the restoration potential of disturbed African landscapes for biodiversity conservation. Reconstructions based only on traditional pollen analysis (palynology) are somewhat defective in this regard because all natural grasses and agricultural cereals have the same type of pollen, and because other important food crops do not produce enough pollen to be recovered from lake-sediment records. Aimed specifically to differentiate between the past impacts of climate variability and ancient human activity on African terrestrial ecosystems, the BelSPO-SSD project SD/BD/03 '*Climatic and Anthropogenic Impacts on African Ecosystems*' (CLANIMAE; 2007-2011) therefore focused substantial effort to development of complementary tracers of past vegetation composition preserved in lake sediments, such as fungal spores and plant phytoliths. Phytoliths can be uniquely used to distinguish between the past distributions of C4 short grasses (Chloridoideae) adapted to warm and dry environments, C4 long grasses (Panicoideae) adapted to warmer and wetter environments, and C3 grasses (Festucoideae) adapted to cool temperate and high-altitude environments; and thus to elucidate how tropical grasslands have responded to climate change in the past, in order to better predict how they will evolve in the future. Further, many African food staples such as banana do not produce sufficient pollen to be recorded in pollen preparations, but do form characteristic phytolith types. In this case, phytolith analysis can produce unique information about the history of agriculture, and past human-ecosystem relationships in general. The research visit of phytolith expert Dr. Julius Lejju to Ghent University created a cross-pollinating, win-win situation in which his expertise enhanced the scientific output of the CLANIMAE project, while broadening his perspective on the role of phytolith analysis in policy-supporting research on climate-human-ecosystem interactions.

2. Methodology in a nutshell (1/2/ page)

Phytoliths are small natural glass (non-crystalline quartz) particles built into the tissue of plants to prevent consumption by insects. These glass particles survive organic decay and are transported together with eroded soil into lakes, where they are buried and preserved in the lake's bottom sediments. Fossil plant phytoliths are extracted from accumulating lake-sediment records together with fossil diatoms, which are unicellular algae with a skeleton that is also composed of non-crystalline quartz. Because the phytoliths of many plant species have a characteristic shape, they can be used as palaeo-environmental indicators (or tracers) of the plant communities which occurred in a lake's drainage basin during previous times. Within the context of the CLANIMAE project, this study aimed to calibrate and validate important types of fossil phytoliths (banana, oil palm, maize) as indicators of past human impact on the Ugandan landscape. This calibration is done by quantifying the relationship between the abundance of various important phytolith types in the surface sediments of 25 Uganda crater lakes sampled in 2007, and survey data of land use within their catchments (for example, the percent fraction of the total area covered by banana plantations). The surveys differentiate between 2 types of natural vegetation, 6 types of cultivated crops or plantations, cattle meadows and fallow agricultural land. To quantify the vulnerability of individual lakes to anthropogenic soil erosion and nutrient enrichment, these land-cover classifications are transformed into a human-impact index, i.e. the summed product of local land-cover fractions and a 'soil erosion susceptibility' factor specific to each type of natural and anthropogenic vegetation. In a later stage, the established relationship between phytolith assemblage composition and land use is used to reconstruct the history of past land use from fossil phytolith assemblages preserved in dated sediment records, in a (semi-) quantitative manner. This project also includes an application of this improved methodology, through a phytolith-based reconstruction of past climate-driven and anthropogenic vegetation changes around a crater lake in western Uganda spanning the last 3800 years.

3. Results (6-8 pages)

3.1. Sample preparation

Fossil phytoliths were extracted from recently deposited sediments in 25 crater lakes in western Uganda, and from an 8.22-m long sediment sequence from Lake Katinda covering the last 3800 years. The ca. 2 cm^3

sediment samples were prepared using the standard procedure (Piperno 1988; Lenttfer & Boyd 1998; Pearsall 2000) of drying in an oven at 105 °C overnight, and burning in a furnace at 500 °C for three hours to remove all organic materials. The samples were then deflocculated in 5% sodium hexametaphosphate solution by repeated stirring and shaking, wet sieved through 150-µm mesh to remove coarse sand, and allowed to settle in a beaker for ca. 5 minutes. Clays and fine silt was removed by repeated decantation until the supernatant was clear. The samples were then transferred into 10 ml test tubes filled with 5 ml of sodium polytangestate, a heavy liquid with a density of 2.3. Centrifugation at 2000 rpm for 5 minutes floated the phytoliths, which were carefully removed with a Pasteur pipette and transferred to a clean test tube. This procedure was repeated until no floating phytoliths remained in the original test tube. Distilled water was added in a ratio of 3:1 and stirred vigorously to mix the heavy liquid and water. This lowered the specific gravity, allowing phytoliths to settle. The samples were centrifuged two times at 2000 rpm for 5 minutes and the supernatant twice decanted after each run, to remove all the heavy liquid. The phytolith fraction was then washed twice with distilled water, dried in an oven at 40 °C overnight, and mounted on microscopic slides with xylene.

3.2. Phytolith counting and classification

Phytolith morphotypes were identified and counted under a Zeiss microscope at 400x magnification. The number of phytoliths counted per sample ranged from 500 to >1000, including at least 200 taxonomically diagnostic short-cell phytoliths as advised by Pearsall (2000). Grass (Poaceae) phytoliths were identified following Twiss et al. (1969) and Mulholland (1992); non-grass phytoliths were identified following to Piperno (1988), Runge (1999), and Madella et al. (2005). All morphotypes were also compared with voucher material from own previous research in the region (Lejju, 2005). Phytoliths with distinguishing taxonomic characters were classified into eight morphotypes as follows: (i) cross-shaped, (ii) short and long bilobate, and polylobate, (iii) rectangular/rondel-shaped, (iv) saddle-shaped, (v) spherical-rugose (trees/shrubs), (vi) spherical-crenate, (vii) cone/hat-shaped (Cyperaceae), and (viii) cone with trough (banana). Phytolith morphotypes that are produced by epidermal cells and occur in all grasses or both in grasses and other plants were sorted into elongate (smooth & sinuous), point-shaped, fan-shaped, and cork-cell morphotypes following Alexandre et al. (1997) and Barboni et al. (1999). Figure 1 presents a collection of microscopic images illustrating the principal phytolith morphotypes encountered in this study.

Different sub-families of grasses can be separated according to phytolith morphotypes (Twiss et al. 1969; Mulholland 1992; Bremond et al. 2008; Barboni & Bremond 2009). Tall grasses belonging to the Panicoideae produce cross-shaped and bilobate phytoliths. Short C4 grasses belonging to the Chloridoideae produce saddle-shaped phytoliths (Twiss et al. 1969; Piperno 1988). C3 grasses of the Festucoideae produce rectangular/rondel-shaped phytoliths. Among the other types, spherical rugose phytoliths are produced by trees & shrubs; the spherical-crenate morphotype is characteristic of palm trees; and the cone/hat-shaped morphotype is typical for sedges (Cyperaceae; Piperno 1988; Hart 1990). Morphotypes produced by wild and domesticated banana have a raised cone with a trough (Piperno 1988).

The phytolith index D/P was used as a proxy for tree cover in the local vegetation. It is defined as the ratio of spherical-rugose and -crenate morphotypes (derived trees and shrubs including palms) versus the sum of characteristic morphotypes derived from grasses (Alexandre et al. 1997; Barboni et al. 1999), and was successfully applied in previous vegetation reconstructions in western Uganda (Lejju 2005).

3.3. Calibration and validation of the phytolith-vegetation relationship

The phytolith calibration aspect of this project involved an analysis of plant-phytolith assemblages in the recently deposited bottom sediments of 25 crater lakes in western Uganda, and direct comparison of the phytolith-inferred composition of local vegetation with actual vegetation surveys conducted in 2007. To avoid analyst bias (inadvertent or deliberate) towards a favorable outcome, the 25 microscope slides with phytolith preparations carried coded labels rather than the name of their lake of origin. The analysis yielded a total of 9212 diagnostic phytoliths which could be assigned to 10 different morphotypes. However, the yield per sample was rather variable (range 66-778, mean 368), with 6 samples remaining below the threshold of 200 required to allow robust statistical analysis of phytolith distribution patterns among samples (lakes). Consequently, completion of this aspect of the research awaits extraction and counting of additional phytoliths, using new sediment preparations.

3.4. The fossil phytolith record of Lake Katinda

Down-core variation in fossil phytolith assemblages from the Katinda record (Figure 2) defines four stratigraphic zones (KZ1-KZ4) from the base of the section (3800 yr BP) to the top (Present, i.e. 2007 AD).

Zone KZ1 (3800-3200 years ago) shows dominance of rugose and smooth spherical phytoliths which are characteristic of trees and shrubs. Spherical crenate phytoliths (palms) are relatively scarce in this period, contributing less than 5%. Grass phytoliths are significantly less common than those of trees and shrubs, and dominated by the short bilobate morphotype. The saddle-shaped morphotype originating from sedges is initially rare but increases towards the end of this period. In summary the phytolith data indicate a forest habitat with slightly open canopy allowing limited understory of short and long grasses.

Zone KZ2 (3200-2100 years ago) is marked by the continuing dominance of mostly rugose spherical phytoliths (trees and shrubs), but the smooth spherical morphotype is replaced by a nodular spherical type. Further strong increases of crenate spherical phytoliths (palms) and cone-shaped phytoliths (sedges) are accompanied by reduced abundance of the short bilobate and saddle-shaped phytoliths derived from grasses. In summary KZ2 represents a period of closed forest habitat with a widening lake margin, allowing development of a lakeshore fringe of palms and sedges inside the crater.

Zone KZ3 (2100-800 years ago) is characterized by a significant decline and disappearance of crenate spherical and cone-shaped phytoliths (palms and sedges), and a reduction in the nodular spherical types derived from trees. However, rugose spherical phytoliths remain high, reaching percentages of 70-80%. Short bilobate phytoliths (tall moist grasses) recover to abundances of 10-20%, and also polylobate grass phytoliths are found in most samples. The declining D/P index (to values <10) suggest a reduced level of forest cover in the catchment, although this may be largely due to disappearance of the palm fringe.

Zone KZ4 (800 years ago to Present) is characterized by the slightly declining abundance of rugose spherical phytoliths of trees, but re-appearance of smooth spherical types (though still scarce) and even the crenate spherical types derived from palms. The short-bilobate type from tall grasses is relatively abundant, and also polylobate phytoliths are found.

The phytolith assemblages in Lake Katinda sediments provide evidence for environmental dynamics and human activity in western Uganda over the past 3800 years. The smooth and rugose spherical morphotypes derived from trees and shrubs represent the medium-altitude evergreen (closed-canopy) and semi-deciduous (open canopy) forest common to the region. Palms in tropical Africa can occur in a diversity of habitats at different altitudes, but in forested environments they are mostly restricted to wet and swampy, habitats with adequate sunlight. The most likely source of crenate spherical phytoliths in Katinda sediments is *Phoenix reclinata*, which commonly occurs in the riverine forests of western Uganda (Hamilton 1991). Considering that the recovered crenate spherical phytoliths characteristic of palms must originate from within the crater catchment (since they are not airborne, such as pollen), their relative abundance is indicative of the presence of a gently sloping lakeshore with shallow groundwater table. This implies that during the period between 3200 and 2100 years ago, climate drying had resulted in lower lake level, such that palms and (rather than forest trees) were allowed to colonize the exposed parts of former lake bottom. They were joined by sedges, which similarly prefer sunlit and swampy lakeshore habitat.

Values for the vegetation index D/P vary between about 3 and 30. However, if the local shoreline plants (palms and sedges) are excluded from the calculation, D/P values range between 3 and 10, with higher values more common in the lower half of the sequence (KZ4 and KZ3) than in the upper half (KZ2 and KZ1). Based on material from Congo, Alexandre et al. (1997) stated that semi-deciduous (and moist) forest is represented by a D/P value of at least 7. Lejju (2005) reported a range between 1 and 8 along the ecotone from savanna to forest in the interlacustrine region of western Uganda. Thus, our phytolith data indicate that a moist or semi-deciduous forest persisted inside Katinda crater throughout the past 3800 years, with on average somewhat greater fraction of open-canopy grassy areas in the last two millennia. Initially both tall and short grasses occurred, the latter possibly restricted to areas with shallow soil near the crater rim. In the last 2000 years, grassy patches have been characterised by a greater diversity of tall grasses.

The significant decline in crenate spherical phytoliths at the base of KZ3, indicating strong reduction of palms inside the crater basin, may be attributed to increased anthropogenic activity with use of palm materials for domestic purposes such as roofing, mats, fishing rafts and charcoal. In combination with the other phytolith data, it indicates that humans living in the Katinda area largely eradicated the lake-fringing palm and sedge wetland, but did not substantially reduce forest cover inside the crater basin. Presumably, early iron-age farmers created and maintained agricultural fields on more gently sloping terrain in the surrounding landscape. This assessment contrasts with the widely held paradigm that iron-age farmers in southwestern Uganda are responsible for large-scale forest clearance as early as 2500 years ago (e.g., Hamilton et al. 1986).

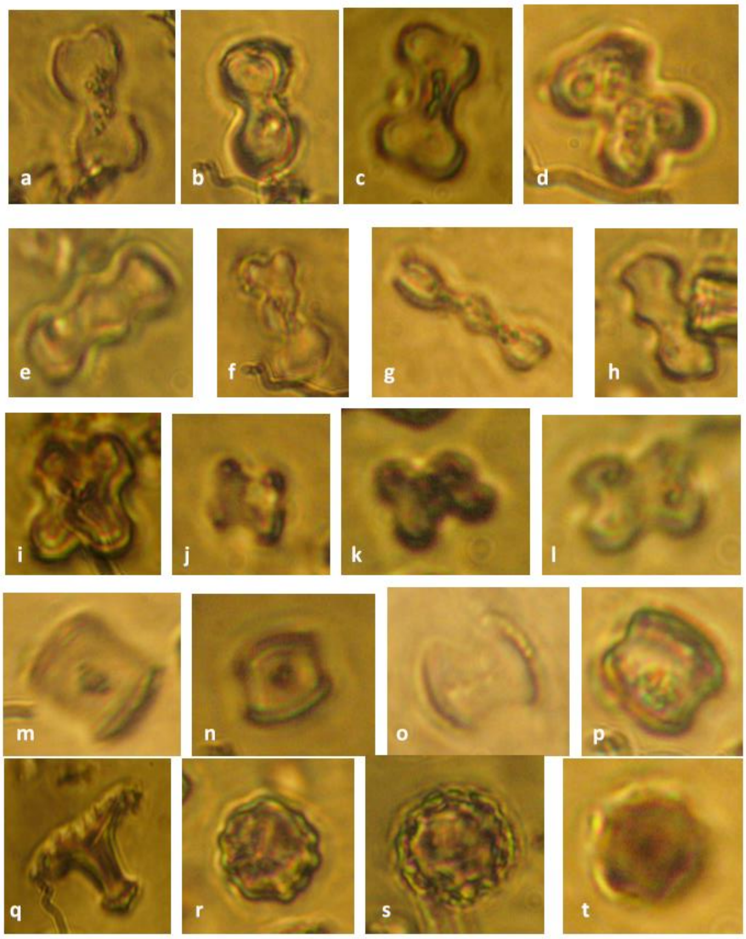

Figure 1. Diagnostic plant phytoliths recovered from lake sediments in western Uganda. a-d) bilobate (tall C4 grasses); e-h) polylobate (tall C4 grasses); i-l) cross-shaped (tall C4 grasses); m-p) saddle-shaped (short C4 grasses); q) cone-shaped (sedges); r-s) rugose spherical (trees and shrubs); t) crenate spherical (palms).

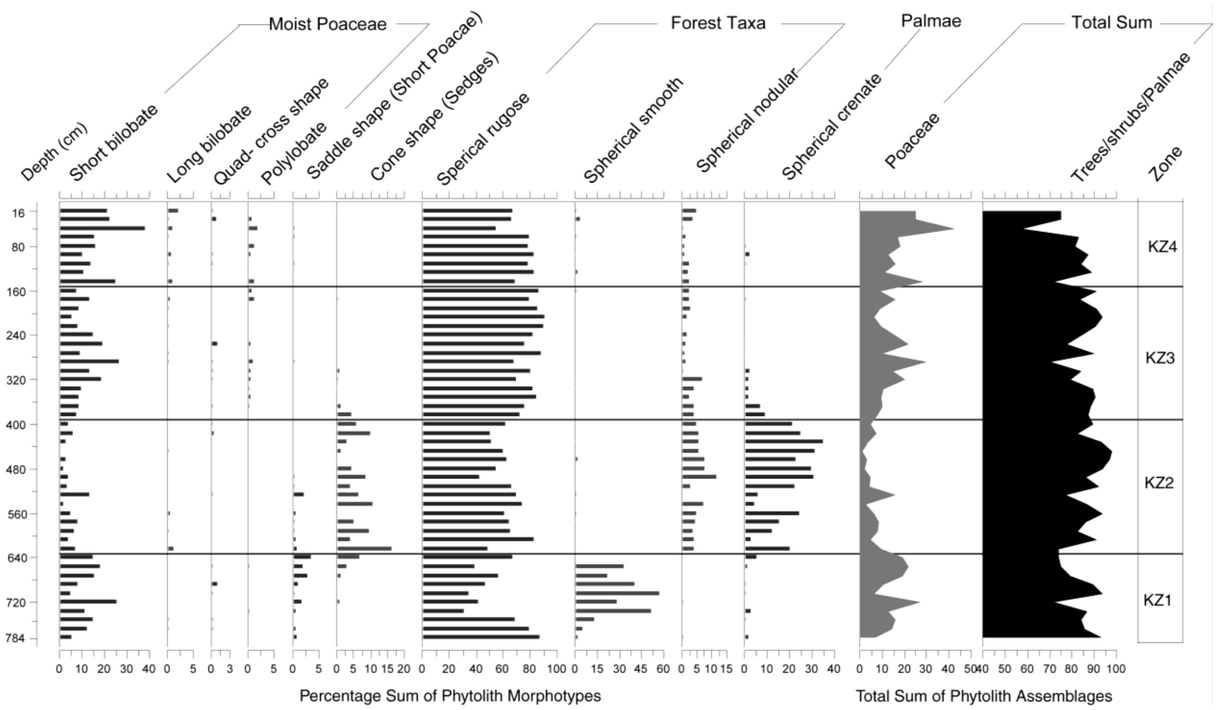

Figure 2. Stratigraphic distribution of fossil phytolith morphotypes and their plant association in a 8.22-meter sediment record from Lake Katinda in western Uganda, representing local vegetation history over the past 3800 years.

3.5. A 3800-year climate and vegetation history of western Uganda (Verschuren et al. 2014)

Integration of the fossil phytolith data (this project) with other paleo-environmental tracers recovered from the Katinda sediment record (results of the linked BelSPO project CLANIMAE) and an independent reconstruction of regional climate history (Russell & Johnson 2005) reveals the history of climatic and anthropogenic influences on the vegetation of western Uganda over the past 3800 years (Verschuren et al. 2014). During the past 5000 years at least, western Uganda experienced significant century-scale variability in moisture balance (rainfall and evaporation) superimposed on a long-term trend of climatic drying; this gradual drying trend was punctuated by two episodes of severe drought ca. 1900-1800 and ca. 1000-750 years ago. The water level of Lake Katinda (which reflects the depth of the regional groundwater table) experienced a modest decline ca. 3700-3400 years ago, but recovered during the period lasting from 3400 to 2800 years ago. It then started a new gradual decline, accelerating after ca. 2300 years ago to reach minimum levels between ca.1800 and 900 years ago, broadly coeval with the period of a drier regional climate. This climatic drying shifted the forest-savannah ecotone southeastward towards the shoulder of the Rift Valley, closer to and beyond the Lake Katinda area. This resulted in a local replacement of moist semi-deciduous forest by open woodland savannah, starting ca.2300 years ago and completed by ca.1700 years ago.

Initially, fires occurred only in distant grasslands beyond the forest margin. During the period of climatic drought 3700-3400 years ago, charcoal influx to Lake Katinda increased somewhat, but the moist forest vegetation prevented local burning. The first evidence that climatic drying caused real moisture stress is a local fire (or sequence of fires) that occurred ca. 2550 years ago; however the forest recovered and maintained a fully closed canopy until at least 2300 years ago. A rapid (<100 years) and permanent increase in burning occurred around 2170 years ago, when forest/woodland tree pollen dropped below 80%. At the century time scale, biomass burning was inversely related to moisture balance for much of the next two millennia, until ~1750 AD when burning increased strongly despite the regional climate becoming wetter. This decoupling of fire and climate reflects the onset of a dominant anthropogenic influence on savannah fire regimes. A sustained decrease in burning since the mid-20th century reflects today’s intensive landscape conversion to cropland & plantations.

An abrupt rise in the ferromagnetism recorded in Lake Katinda sediments ca. 2000 years ago, i.e. halfway through the forest-savannah transition, indicates that human activity inside the crater catchment started to enhance soil erosion. Soil erosion peaked in the period between 1600 and 900 years ago, i.e. during the time when palm phytoliths are largely absent. After 900 years ago, ferromagnetism fell back to the level from before 1700 years ago and remained low for most of the last millennium until the 20th century.

Apparently, indigenous subsistence farmers moved out of the area during medieval drought (ca.1000-750 years ago) and returned only around 1650 AD, with a modest level of environmental impact until the 20th century. Initially scarce, expansion of the lake-fringing stand of palms from ca. 3200 years ago was possibly promoted by the lake-level decline (and thus gentler sloping shoreline) inferred to have developed from around 2800 years ago. The striking inverse correlation between palm phytolith abundance and ferromagnetism throughout the last 2000 years suggests that anthropogenic disruption of the lake's riparian zone (including eradication of the palm fringe) included destruction of the vegetation buffer which had previously protected Lake Katinda against excess soil input.

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4. Perspectives for future collaboration between units (1 page)

Although not yet run to completion, this project has already demonstrated the substantial value of phytolith analyses for reconstructions of past vegetation change under the combined influence of climate variability and human impact. Given the scarcity of written and other documentary information on the distribution, demography and activity of ancient indigenous African populations, it is set to become an essential tool to reconstruct the environmental framework of the cultural and political history of East Africa (and beyond) over the past 3000 years (and before); as well as to use this framework to develop scientifically sound strategies of natural-resource use and ecosystem restoration. Since this research theme is the central tenet of the university-based research programmes of both Dr. Lejju (now Prof. Lejju) at Mbarara University of Science & Technology (MUST) and Prof. Verschuren at Ghent University (UGent), establishment of a long-term research collaboration is logical and guaranteed. This partnership is stimulated by formal agreements between the governments of Uganda and Belgium that resulted in recent (from 2010) selection of Uganda as one of 20 countries enjoying strategic VLIR-OUS funding (in the form of bilateral projects and scholarships) as a roadmap for further development cooperation. At present, MUST and UGent are formal collaborators on Uganda National Council for Science and Technology (UNCST) research permit NS 522 'Climatic and human influences on long-term vegetation dynamics and biomass burning in forests of western Uganda', awarded in the context of BelSPO BRAIN-be project BR/132/A1 '*Genetic and paleoecological signatures of African rainforest dynamics: pre-adapted to change?*' (AFRIFORD; 2014-2017).

See also under section 6.

5. Valorisation/Diffusion (including Publications, Conferences, Seminars, Missions abroad...)

Considering that the practical work for this project was carried out in late 2011 and early 2012, and continued after Dr. Lejju's return home, its results could not be incorporated in the final report of the CLANIMAE project that was submitted to BelSPO in January 2011. Notwithstanding the solid nature of collected data, publications resulting from this project remain in preparation, until they can be expanded (the calibration aspect) or incorporated into a broader-scale reconstruction of landscape history in western Uganda (the application aspect). In part this is because since his return home, Dr. Lejju has been promoted to Associate Professor in Biology and Associate Dean of the Science Faculty at MUST, and has accepted the functions of Secretary General of the International Union for Quaternary Research (INQUA) and Associate Editor of the African Journal of Ecology.

In meantime, the results of this project have been disseminated via highlights in oral and poster presentations at four international conferences, as listed below.

Verschuren, D., 2013. Bio-indicators for lake-based climate and ecosystem reconstruction in East Africa. Kenya Wildlife Service workshop on 'Mt Kenya lakes: archives for past climate change and glacier dynamics', Langata, Nairobi, Kenya, 30-31/05/2013.

Verschuren D, Colombaroli D, **Lejju J**, Ssemmanda I, Rumes B, Bessems I, Gelorini V, 2014. Resolving the timing and relative magnitude of ancient versus modern human impact on East African landscapes: a 3800-year example from western Uganda. IGBP 'Past Global Changes' Focus 4 conference 'Towards a more accurate quantification of human-environment interactions in the past', Leuven, 3-7/02/2014.

Verschuren D, 2014. Relative robustness of various paleo-indicators of past human activity in an African context. Joint ACACIA and ComPAg workshop 'The environmental transition of the Iron Age in Africa', London, 17-19/06/2014.

Verschuren D, Colombaroli D, **Lejju J**, Ssemmanda I, Rumes B, Bessems I, Gelorini V, 2015. Resolving the timing and relative magnitude of ancient versus modern human impact on East African landscapes: a 3800-year example from western Uganda. IGBP 'Past Global Changes' inaugural workshop on LandCover-6k program, Paris, 18-20/02/2015.

6. Skills/Added value transferred to home institution abroad (1/2 page)

During his visit to Ghent University, Dr. Lejju and host Prof. Verschuren explored options to expand the capacity of Dr. Lejju's home institution in research and teaching of climate and environmental change for the benefit of sustainable development in Uganda. This resulted in an official proposal by Dr. Lejju, submitted to the MUST Faculty of Science, to re-orient the MSc programme in Biology towards a new MSc programme in Climate and Environmental Sciences. Its revised curriculum will give special attention to adaptive strategies promoting resilience to climate-related shocks through livelihood diversification and mitigation mechanisms, and consists of seven modules:

Module 1: Climate dynamics, Future challenges, Adaptation and Mitigation
Module 2: Ecosystem services, degradation and sustainable management
Module 3: Water quality & climate Change

Module 4: Quaternary Palaeo-climate and Palaeoecology
Module 5: Stable Isotopes and Environmental Change
Module 6: Environmental Geographic Information Systems
Module 7: Numerical Analysis of Biological and Environmental Data

In addition, this revised MSc programme will create opportunities for collaborative research projects between the Departments of Biology at MUST and UGent. Key research areas of interest include (i) a long-term monitoring programme of the Lake Victoria basin and the crater lakes of western Uganda to further study the processes controlling the relative vulnerability of the water quality resulting from human impact; and (ii) assessing the timing and magnitude of past human impact on the lakes and the surrounding terrestrial ecosystems to determine the resilience to current human impact. In turn, this research collaboration will create opportunities for exchange of staff and research students between the two universities and facilitate the use of available research facilities in the two institutions. Finally it will stimulate the joint writing of research grant proposals and publications by academic staff of the two institutions.