Palaeoecology of Africa and Surrounding
Islands, 2001, 27:37-50

The palaeoenvironmental significance of Late Pleistocene and Holocene creep and other geomorphic processes, Butare, Rwanda

JAN MOEYERSONS

Royal Museum for Central Africa, Tervuren, Belgium

ABSTRACT

During the LGM, important river erosion and slope wash affected the Butare plateau, Rwanda. But the typical convex hill form, still preserved today, results from widespread creep and slow earth flow processes, active between only ± 15 000 and ± 5 000 years ago. Compared to the dry conditions of the LGM, the annual precipitation became more evenly distributed over the year. Evapotranspiration rates were lower than today and a savanna-like natural vegetation can be inferred. This period spans the post-LGM lake extensions in East and West Africa and the Holocene climatic optimum. About 5 000 years ago, the water table in the hills lowers and the slopes stabilize. Peat growth occurs around 3 000 BP and at ± 1 865 BP. After this date, erosion starts with tree exploitation for iron melting and culminates in the anthropogenic desertification-like landscape degradation, observed today.

INTRODUCTION

The Butare–Ngozi plateau in Southern Rwanda and Northern Burundi forms a succession of convex hills whose summits merge into an imaginary 'Gipfelflur' at ± 1750 m asl. The annual precipitation varies between 1 000 and 1 400 mm and is distributed over the months February-May and September-December. About 40% of the total precipitation falls during March, April and May (Prioul and Sirven, 1981). The geological substrate of the plateau (Fig. 1) contains shales and phyllites, seated in the roof of a granite batholith, but sound rock outcrops are rare. In most cases, the laterised or deeply weathered shales and phyllites are overlain by a mantle of red earths, several meters to tens of meters thick. Hills, covered by this red clayey mantle, are convex in form with flat summits and steeply ending sides (Plate 1). In the case of phyllite outcrops, the red earths are often well developed in hillslope valleys. From there, the red-earth bodies bulge out in the flat and wide valley bottoms between the hills (Plate 2), their nose displaying the same convex form as hillsides which are completely covered by this material. Also wide and thick lobes of red earths often extend from topographic hillslope hollows far into the valley (Plate 3). The red earths show no visible stratification, contain sometimes coarse, mostly quartzite debris, variable in size and form. Their clay content (< 2 μm) varies between 15 and 24%. They are clearly separated from the weathered but in situ phyllite rock by an often thick sand-gravel debris layer with a clay content often above 30%. Because of this stratigraphical separation from the weathered substrate, the red-earth mantle is considered as displaced material.

The intact and smooth convex hill form, as illustrated above, is rather rare. In most cases the convex hillslopes obviously appear to be in a state of disequilibrium with the ongoing geomorphological processes. An erosion survey in southern Rwanda (Moeyersons, 1989a) revealed the occurrence of a very large array of erosion processes, including hill-slope and valley gullying (Moeyersons, 1991), interrill- and rill erosion (Moeyersons, 1983; 1990) and several forms of rapid mass wasting (Moeyersons, 1989-1990). Without any exception, these processes tend to dissect and fragment in a number of ways the preexisting smooth convex hill topography. The erosion survey also amply demonstrates land use by man to be the ultimate cause of this geomorphic activity.

The question arises whether geomorphological process could have led to the development of the convex hill form in former times. A process-based explanation of hill-form evolution in southern Rwanda and its palaeoenvironmental significance in late Pleistocene and Holocene times is discussed.

EVIDENCE FOR CREEP AND SLOW FLOW AS PRINCIPAL MORPHOLOGIC AGENTS IN THE RECENT GEOLOGICAL PAST

The non-erosive nature of the convex hill shoulders in Southern Rwanda

Convex landforms in the unconsolidated red earths of the study area might be explained in two ways. They could be erosion features, resulting from increasing river incision, by analogy with the waxing development theory (Penck, 1924). Another possibility is that long-term soil creep and related slow flow give rise to convex slopes or slope segments (Schumm, 1956; Hurault, 1971; Tschierske, 1979).

Several geological sections in the study area clearly show that the convex hill shoulder on red earths continues below the ground surface. One section at the southwestern foot of Rwaza Hill (Fig. 2 and Plate 4) is discussed here. The underground part of the convex hill shoulder is visible. Against the nose of the convexity a succession of five complex layers is deposited. It comprises the upper silt complex, the upper peat layer, the middle silt complex, the lower peat layer and the lower silt complex. These deposits fill a former Kadahokwa channel. Further downstream in the valley, the upper peat layer has been dated at 1865 ± 80 BP (Roche, 1988). On the base of the findings of peat deposits in the Akanyaru basin (Roche, 1988), to which the Kadohokwa belongs, the lower peat layer in the Kadohokwa channel would be about 3 000 years old and the channel might have started to fill up at about 5 000 BP.

The contact between the channel and the convex nose is not erosive at all. Most of the layers in the edge of the channel are slightly bent, as if they were smoothly deposited on the steep convex edge of Rwaza Hill. The non-erosive contact between the red-earth lobe and channel calls for a non-erosive explanation of the convex hill form.

The long-term morphological effects of creep as deduced from field measurements

One geomorphological process, not mentioned in the introduction because it differs in so many aspects from the other processes active today, is soil creep (Griggs, 1936). The occurrence of soil creep in southern Rwanda has

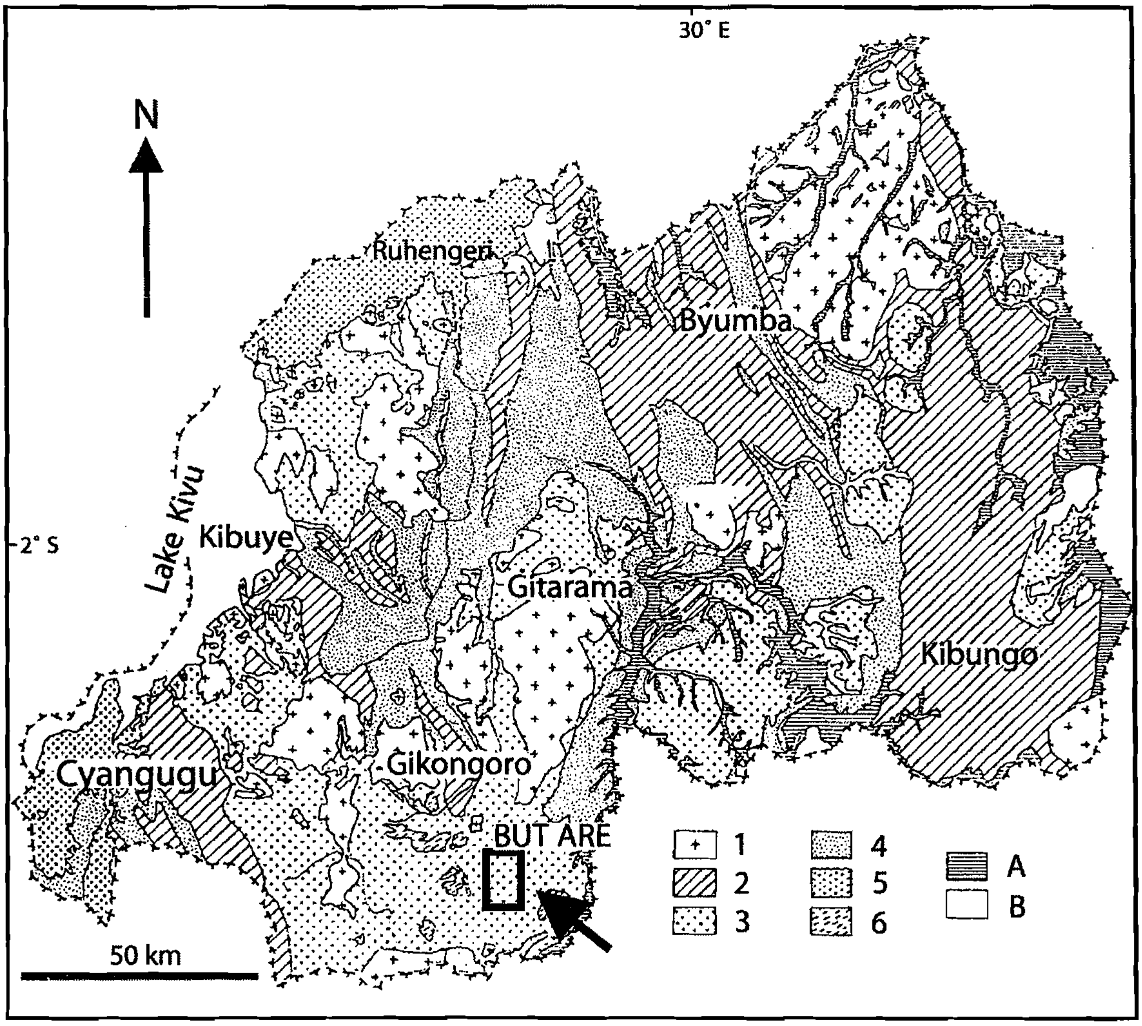

Figure 1. Lithological map of Rwanda (Ministère des ressources naturelles, Rwanda, 1981), showing the phyllites and shales in the Butare region. 1: granites; 2: sandstones, quartzites, schists; 3: granitic rocks with inclusions of shales and phyllites; 4 schists and quartzitic micaschists; 5: volcanic rocks; A: marshlands; B: surface waters.

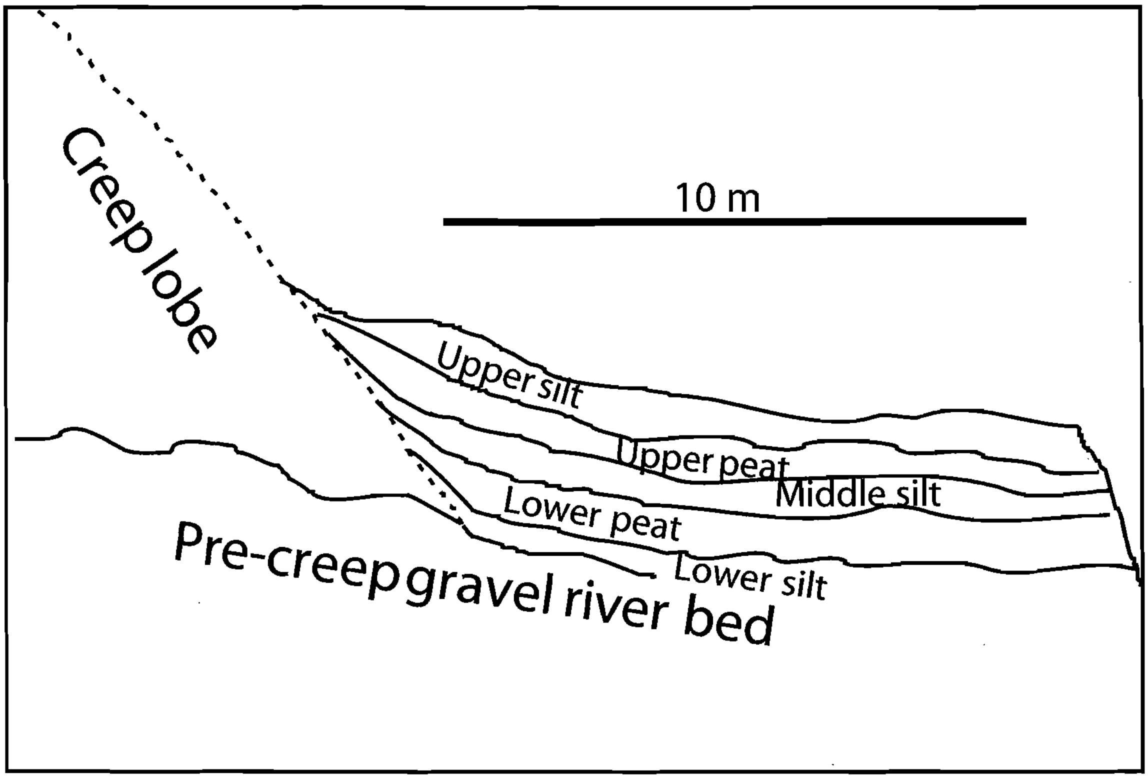

Figure 2. Section at the foot of Rwaza Hill. Stratigraphical explanation of Plate 4 (for location see Fig. 3).

been exhaustively proved by a high number of measurements using different measurement techniques (Moeyersons, 1988; 1989b), applied at Rwaza Hill (see Fig. 3). The red-earth mantle body creeps downslope in a hillslope valley which is actively undercut by the Kadahokwa river. The combined Young-pit (Young, 1960) and iron stake measurements show that the bigger part of the creep movement takes place in the clayey gravel layer, separating the base of the red earths from the top of the phyllites at 3 m depth. Big *Eucalyptus* trees have been shown to undergo this deep seated creep movement. The secondary creep movements, occurring close to the surface of this red-earth 'flow' have been described elsewhere (Moeyersons, 1988).

The study shows that the morphological effect of long-term creep compares with the horizontal stretching and vertical compression of the upper half of a flat-lying ellipsoid of constant size, representing a cross section through an imaginary hill. Long-term creep, therefore, implies a gradual morphological change of the hills by flattening and lowering of the hilltop, the slope toes diverging away from the hill centre, creeping over the valley and showing increasingly convex bulging during the process (Moeyersons, 1989a). In the case of hillslope valleys, the creep behavior of the red-earth body is comparable with the one of a glacier. Finally, it is assumed that differential deep seated creep movements contribute to the formation of wide 'lobes', protruding from wide and diffuse hillslope depressions and even to the formation of biconvex hills when the phyllites are present at small depth below the hilltop. The idea that deep seated creep (Hurault, 1971) and/or slow 'flow' (Tschierske, 1979) might explain the convex or multiconvex form of hills is not new but the data from Rwaza are the first field measurements to confirm the former theoretical considerations.

The major conclusion of the creep measurements in southern Rwanda is that creep, active between 2 and more than 4 m deep in the thick red-earth mantle, has a geomorphological effect, opposite to all the other processes, active today in the region: it does not lead to destruction but to the further moulding and development of the preexisting convex landforms.

Stratigraphical evidence for the former occurrence of wide-spread creep

Ample and convincing stratigraphical evidence supports, directly or indirectly, the idea that creep and slow flow were very active in the geological past.

1. First of all, there is the stratigraphical evidence, already mentioned above: the mantle of red earths covers the greater part of the hill from where it originates but it also overlays fossil river beds often present near the base of the hill side. Moreover, the convex border of the mantel, the so-called convex hill shoulder, seems not to be an erosional feature. Such a situation is difficult to explain unless the red-earth mantle underwent deformation by deep-seated creep or slow flow, giving rise to thick earth lobes, slowly invading the valley.

Red earths from the hillsides did indeed invade the valleys as they often rest on old fluvial deposits or on old laterite soils. Cases have been described where the underlying fossil lateritic soils have been pushed and deformed in their upper part by the creep movement of the red-earth glacier-like body over it (Moeyersons, 1989a). In the case of the section at the foot of Rwaza Hill (Fig. 2; Plate 4), the red-earth body covers an older valley floor slightly incised by a gravel riverbed with a high terrace, visible (Plate 4), and a low terrace, hidden below the Holocene riverbed. The red color of the creep lobe contrasts with the light brown color of the fossil valley bottom and related gravel riverbed. However, the latter does not show any disruptions or deformations that might be related to the installation of the creep lobe above it. This case illustrates that a creep lobe does not always provoke mechanical destruction and erosion of the surface over which it moves. It is thought that the creep lobe toe not necessarily slid over its substrate. It rather might have rolled over it in a caterpillar-track fashion, much like solifluction lobes are known to progress (Elliot, 1996).

2. Other stratigraphical evidence of creep of the red-earth mantle over the weathered substrate is generally to be found in the gravelly-clayey transition layer between the two lithologies in midslope position. Many of the coarse debris inclusions have their long axes parallel to the slope lines and also to the upper and lower boundary of the transition layer. Furthermore, the fines, including quartz sands and micas, often show a pseudostratigraphy, due to a comparable orientation. Such orientation characterizes creep-like and solifluction-like deformation (Glen, Donner and West, 1957; Harris and Ellis, 1980).

3. The occurrence of the stone-line-like clayey transition layer between the red earths and the very weathered substrate might be an argument in favor of creep movements. The origin of the thick red-earth mantles, sometimes showing an important humic illuviation horizon on top, remains a matter of speculation. But the weathered substrate below the transition layer is in many places very similar in macromorphological appearance and variegated coloration to the vesicular laterite which covers the African Surface (Maud, 1965). Subsequent weathering gave rise to the transformation of this 'laterite' into a thick humic ferallitic soil (Maud, 1965; Partridge and Maud, 1987), having most of the macromorphological and coloration characteristics in common with the mantle of red earths from the study area. It is hypothesized that these red earths started to creep over the clear hydraulic discontinuity between their base and the unweathered "African" laterite underneath. The stone-line-like gravelly-clayey transition layer below the creeping mantles has been developed by squeezing out of the coarse debris (Pierson, 1980; Takalashi, 1981; Nieuwenhuijzen and Van Steijn, 1990; Bertran and Texier, 1994) and by other mechanisms of subsurface stone concentration in creeping grounds (Moeyersons, 1989c). Unlike other stone-lines in the region (Peyrot, 1983), the gravelly-clayey transition layer below the red-earth mantle never contains stone-artifacts, suggesting it never formed a surficial lag deposit.

Morphological evidence for the former occurrence of wide-spread creep and slow flow

Creeping earth-flows also occur today in many places in the world. The characteristic bulging at their toe and their potential to dam rivers and lakes have been abundantly described (Crozier, 1984).

The morphographic map of part of the Butare plateau (Fig. 3), made on the base of aerial photographs and entirely checked in the field, shows the hillside convexities, creep tongues and lobes as the major constituents of the hilly topography in the area. The map shows several places of former valley blocking or valley narrowing and the general mono- or biconvex character of the hillslopes.

This map and the justifying geological sections in the field have been discussed elsewhere (Moeyersons, 1989a) and show overwhelming evidence for a topography still having preserved the characteristics of a landscape deeply affected in recent geologic times by very wide-spread creep and slow flow.

LANDSCAPE DYNAMICS IN LATE PLEISTOCENE AND HOLOCENE TIMES

Soil mechanical conditions for creep and their palaeoenvironmental significance

Deep-seated creep in the study area has been measured on slopes, actively eroded at their toe by a river. This is a classical case of slope destabilization (Zaruba and Mencl, 1969). The section at the foot of Rwaza Hill (Fig. 2; Plate 4) and several other sections in the study area show that the pre-creep valleys between the hills were wider than today. Valley widening by braided river systems and related slope pedimentation (Rohdenburg, 1969) are considered as active in Rwanda during that time (Peyrot, 1983). Today, local lateral river erosion is sufficient to reactivate creep above undercut slopes. Therefore, the general valley widening during the pre-creep period, related to the fossil braided river beds below the edge of the red-earth mantle, would have resulted in massive mass wasting, if the soil mechanical conditions during that time and today were similar. But the complete absence of stratigraphical or morphological indications for such activity is an indication that the gravelly-clayey transition layer was more stable than today, what implies a much lower water table than today.

On the other hand, the subsequent period of creep seems to be characterized by much wetter soil conditions. Mono-axial tests on soil samples from the basal layer between the red earths and the substrate show that plastic flow can affect slopes of less than 23° (Moeyersons, 1989a). However, increasing thickness of the overlying red earths and their increasing water content can lead to a drastic reduction of this angle to below 12°. Creep of the red-earth mantles in southern Rwanda, if not destabilized at their toe, necessitates a much higher long-term red-earth water content than today.

It is also interesting to note that diffuse erosion at the surface, as well as deep hillslope gullying are creep stabilizing factors. The first might reduce thickness and weight of the overburden of the transitional gravelly-clayey layer. The latter contributes to the permanent lowering of high water tables.

The landscape dynamics prior to the period of creep and slow-flow mass wasting

Section Fig. 2 and other sections (Moeyersons, 1989a) show:

- the valleys were wider than today, in some places only a few meters, in other places apparently by tens of meters.
- the valleys were occupied by rivers with important gravel bedload. Flood and minor beds seem to have been present. Such river bed morphology is in strong contrast with the peat bearing river channels of Holocene times. The channel form and load indicate an environment with very contrasting seasonal, or even irregular, precipitation patterns (Reid and Frostick, 1989), environments considerably drier than the one in southern Rwanda today.

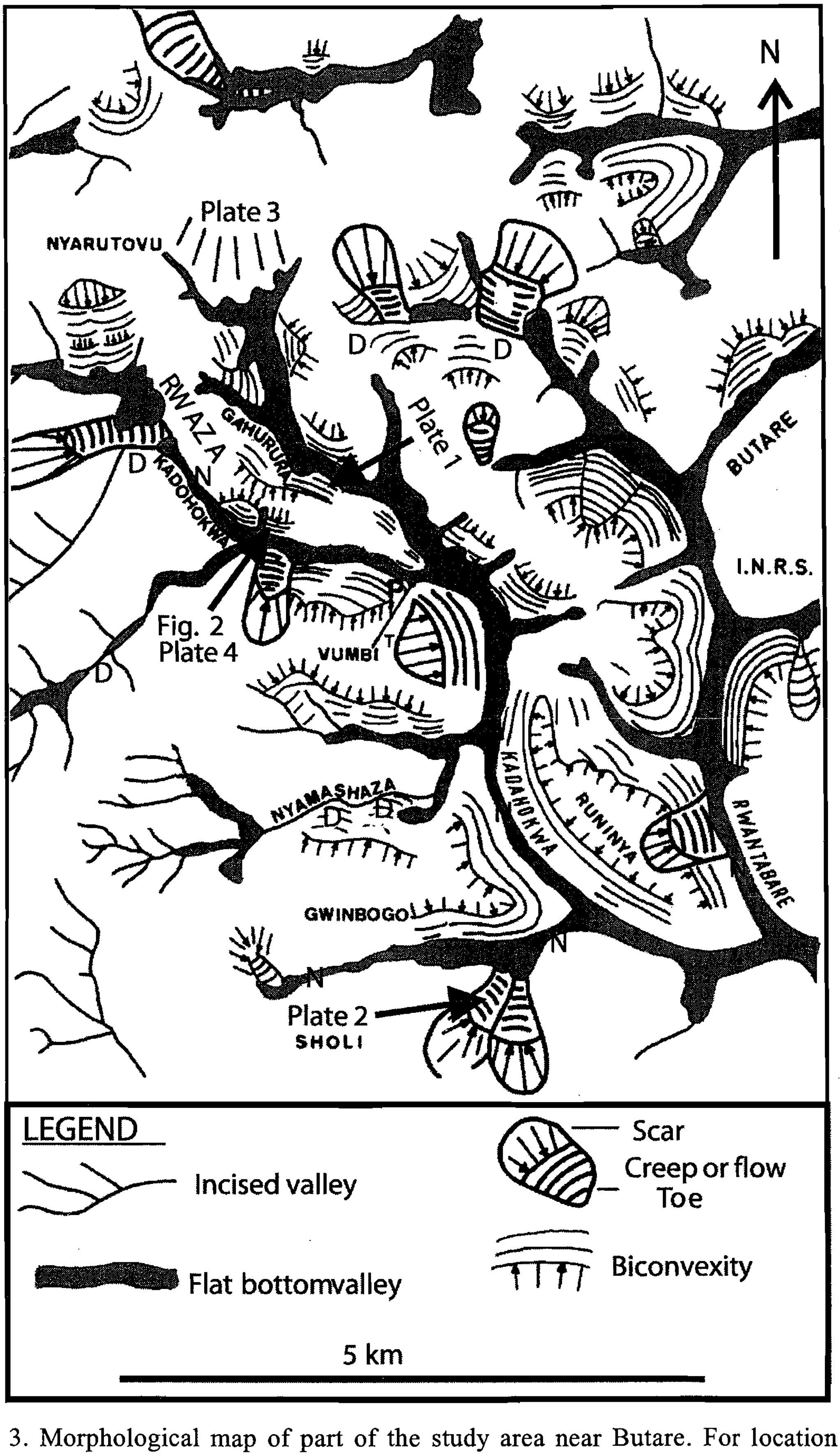

Figure 3. Morphological map of part of the study area near Butare. For location see Fig. 1. D: manifest valley damming; N: manifest valley narrowing.

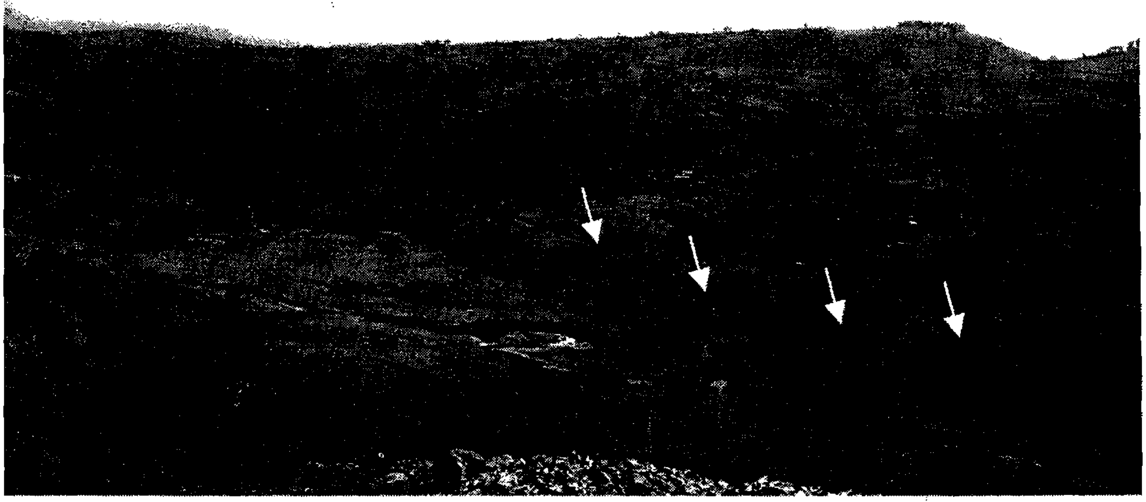

Plate 1. Intact convex hill shoulder, Rwaza Hill (see Fig. 3). In the vicinity of the incision of the Guharura river, the shoulder is creeping further in the valley at a rate of 0.5 cm a year (Moeyersons, 1989a).

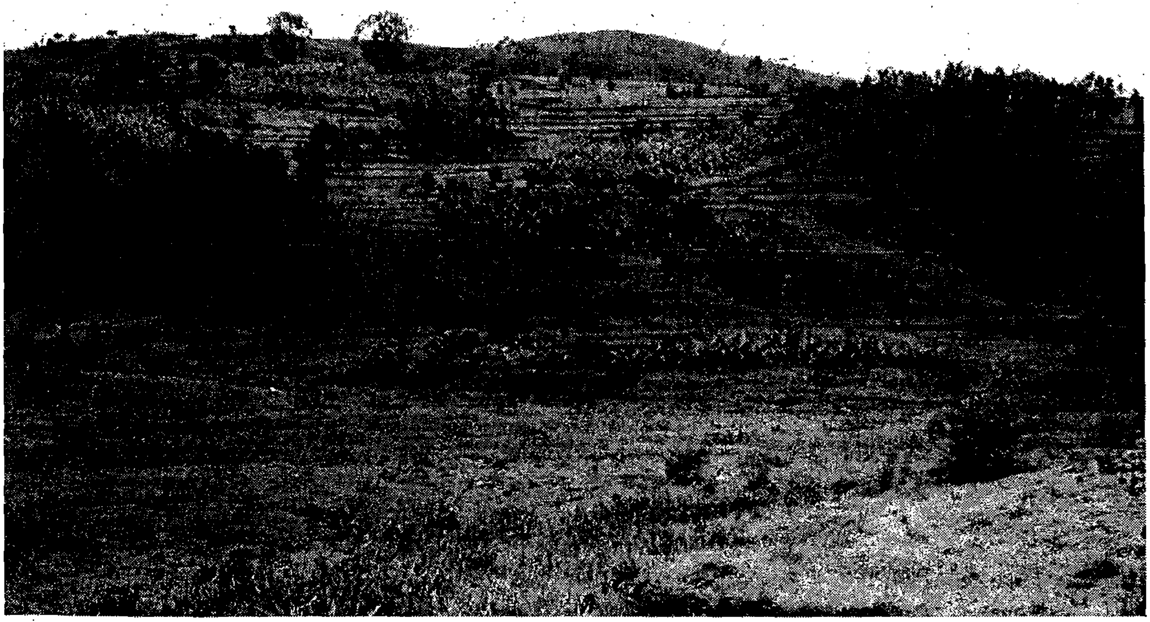

Plate 2. Perched hillslope valley, ending with a marked nose or toe, reflecting the former glacier-like advancement of the red-earth body in the valley in front. Sholi (see Fig. 3).

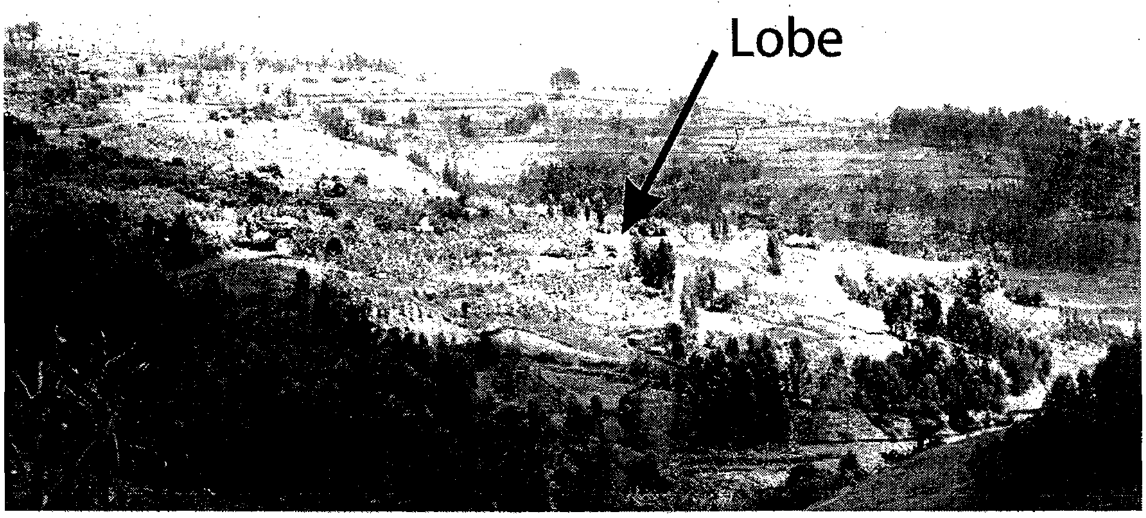

Plate 3. The creep lobe of Nyarutovu (for location see Fig. 3).

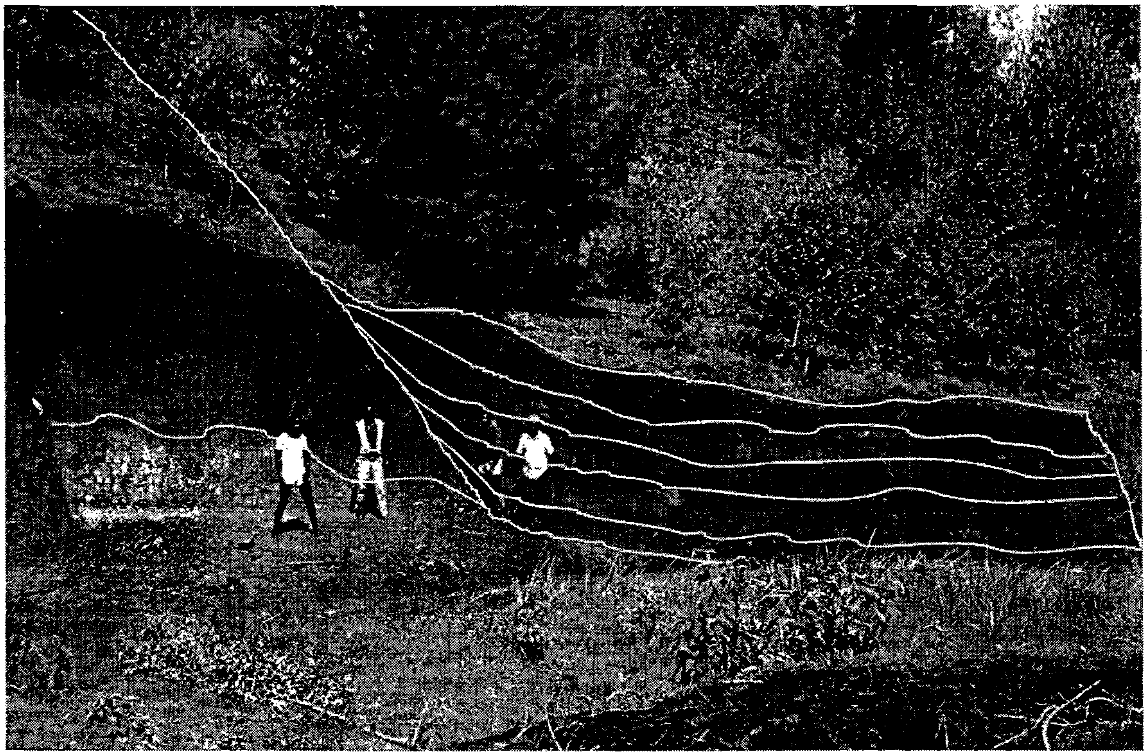

Plate 4. Section at Rwaza, showing the continuation of the convex hill shoulder below the surface. The late Holocene peat-bearing Kadohokwa channel leans against the lobe. The whole rests on a former gravel riverbed. The actual arroyo-like incision of the Kadohokwa is visible on the right part of the picture (for location see Fig. 3; further explanation in Fig. 2).

- the rounded river gravels are mainly composed of quartz and quartzite, the least alterable materials, found in the Kadohokwa basin. This material might be a lag deposit, liberated from the fine-earth weathering product of the phyllites, which would indicate strong water erosion on slopes.

If at that time, the water table would have been at the level of today, mass wasting should probably have resulted in a complete loss of the red-earth mantle. Its preservation until today argues in favour of dry, arid conditions during the pre-creep period.

Creeping earth-flows and valley damming

The drier conditions with a very low water table and important water erosion have been followed by a marked change in landscape dynamics. The pre-existing thick mantles of red earths started to creep or to flow slowly from the hills. The flat valley bottoms, probably still widening during the former period, are now invaded by creep lobes and the toes of slow flows. Examples of narrow river sections, apparently old broken barriers, occur at several places in the study area. It has been calculated (Moeyersons, 1989a) that the blocking of a 100 m wide valley by creep and slow flow should take several thousands of years. Rivers apparently did not tend anymore to erode laterally. The resultant topography, shown in Fig. 3, might bridge a time span of the order of ten thousand years. On the other hand, as argued above, the period of creep was characterized by higher soil water contents than today, the red earths being saturated over a considerable part of their thickness. Important hydraulic slope erosion can be ruled out during that time because the developing convexities would have quickly incised and fragmented.

Such a situation is incompatible with the water balance and slope hydrology of today. In the nearby Burundian Karuzi basin (Bodeux, 1972), more than 83% of the annual precipitation of 1175 mm evapotranspirates. This gives rise to annual water shortages during the dry season. Runoff, estimated at about 4% of the annual precipitation, causes appreciable hydraulic erosion. The period of creeping earth-flows experienced, therefore, an infiltration rate approaching 100%, a source hydrograph fed by deeply percolating waters, showing only low variation over the year, and very restricted source erosion. Assuming annual precipitation to be of the same order as today, a natural vegetation cover, able to prevent runoff, but keeping evapotranspiration percentages lower than measured today, has to be postulated. Not much about the environment and vegetation of that time can be deduced from these few elements. But as a general rule, evapotranspiration losses in similar climatic and soil conditions are higher in forests than in grasslands (Larcher, 1995) and a more savanna-like vegetation instead of forest-like vegetation is likely. Pollen and peat analysis (Roche, 1988) confirm, indeed, that the central plateau in South Rwanda saw since the end of the arid LGM about 15 000 years ago, the development of grass savanna vegetation, became increasingly forested during Holocene times before 5 000 BP.

The Holocene natural environment and growing human impact since 5 000 years ago

The deposition of peat bearing channel layers started, as mentioned before, maybe ± 5 000 BP. The stabilization of the creep lobes points to a lowering of the water table in the red earths. The non-erosive character of river flow is attested by the contact between creep lobes and channels. Three periods of silt deposition alternate with two mayor periods of peat development. The latter point to clear water and negligible erosion on the hills. On the other hand, silt deposition in an otherwise not eroding river channel might indicate incomplete vegetation cover in the catchment and hydraulic slope erosion. It has been well established (Van Grunderbeek, Doutrelepont and Roche, 1984) that the base of the upper silts above the ± 1 865 years old peat layer corresponds with intense use of wood for iron melting and associated forest clearing. Future research might shed some more light on the origin of the other late-Holocene silts. Since the period of iron melting, the landscape is believed to have been under slow, but increasing human pressure, by the introduction of agro-pastoral activities at ± 2 000 BP (Roche, 1996). Deforestation is known to lead to a runoff increase and infiltration reduction, high enough to decimate source discharge (Geomines-Somirwa, 1981). A study of actual erosion processes (Moeyersons, 1989a) illustrates the direct and side-effects of man induced runoff in the region of Butare. Today runoff is so important that gully- and arroyo-like (Leopold, Wolman and Miller 1964) stream incisions develop. The Kadohokwa (Plate 4), makes no exception.

REGIONAL CONTEXT

There are some marked similarities in the environmental evolution of the Butare plateau and the palaeo-climatic data derived from Kivu and Tanganyika lakes some 200 km to the West. Haberyan and Hecky (1987) show that both lakes experienced late Pleistocene low stands around 15 000 BP. However, the subsequent rise in water level took several millennia before culminating at 9 400 BP with the overflow of Lake Kivu into Lake Tanganyika. The situation has been disturbed by volcanism and hydrothermal activity in Kivu around 5 000 years ago. More recent research on the water-level fluctuations of Lake Tanganyika (Gasse et al., 1989) shows that the re-establishment of a positive water balance occurred during the first step of deglaciation, but that the level rise shows irregularities at 13 000 and 10 600 BP. Another study (Vincens et al., 1993) shows that postglacial wet climatic conditions were established by 12 700 BP, temperature and wetness further increasing from this date onward. It appears that the water level fluctuations of Lake Tanganyika, being in phase with oceanic changes during the last glaciation and deglaciation (Gasse et al., 1989), resemble the evolution of many other

East-African lakes. The general lake level rise and the period of maintenance of these high lake levels in the Western (Haberyan and Hecky, 1987) and Eastern (Butzer, Isaac, Richardson and Washbourn-Kamau, 1972) Rift appear to coincide with the rise and maintenance of high water tables in the red earths on the Butare Plateau.

The gradually drier conditions since about 5 000 BP are well documented in a broad belt of Africa between 4°S and 33°N (Goudie, 1996) and even beyond (Moeyersons, et al. 1999). The nature of this environmental change is more and more questioned in the light of the debate concerning the anthropogenic factors in environmental degradation in prehistoric times. In the case of Rwanda, the latest Holocene erosion phase started around 1 700 BP with wood exploitation for iron melting. The two other erosion periods, represented by the silts below the peat layers of respectively ± 3 000 BP and ± 1 800 BP, are, however, not documented. Taking into account the presence of lithic archaeological material (Nenquin, 1967), human impact on the Holocene environment can not be ruled out *a priori*, because of the difficulty of separating natural from human factors governing slope erosion (Goudie, 1981).

CONCLUSIONS

1. Before 15 000 BP, including the LGM at 18 000 BP, the Butare Plateau in southern Rwanda underwent slope and river erosion, resulting in considerable valley widening. The water tables were appreciably lower than today.

2. The post-LGM period, with the general rise of lake levels in eastern Africa and western Africa, was characterized in southern Rwanda by a considerable rise of the water tables, very reduced hydraulic slope and river erosion, and probably reduced evapotranspiration compared to today. Thick pre-existing red-earth mantles, covering most hills, started creeping and flowing. Many lobes eventually dammed the valleys. This situation started some 15 000 BP and continued during the climatic optimum of the Holocene, to end around 5 000 BP.

3. About 5 000 BP, mass wasting ends as a result of water-table lowering. Peat growth around 3 000 and 1 850 BP indicates stable environments with a complete protective vegetation cover. These two periods of peat growth intercalate between 3 silt layers, indicating some slope erosion as a result of openings in the protective vegetation mantle. At least the upper silt layer, at its base less than ± 1 800 BP, results from human activities (Roche, 1996). No evidence is forwarded that the silt layers below the 3 000 and 1 850 BP peats would result from anthropogenic erosion.

REFERENCES

Bertran, P. and J.-P. Texier 1994. Structures sédimentaires d'un cône de flots de débris (Vars, Alpes Françaises Méridionales). *Permafrost and periglacial processes,* 5: 155-170.

Bodeux, A. 1972. Hydrologie et bilan de l'eau du bassin versant de la Karuzi au Burundi. Koninklijke Academie voor Overzeese Wetenschappen, Klasse voor Natuur- en Geneeskundige Wetenschappen, N.R., XVIII-7 en laatste, Brussel, 3-39.

Butzer, K.W., Isaac, G.L., Richardson, J.L. and C.K. Washbourn-Kamau 1972. Radio carbon dating of East African lake levels. *Science* 175: 1069-1076

Crozier, 1984. Field assessment of slope instability, in Brunsden, D. and D.B. Prior (eds.). Slope instability, Wiley and Sons, Chichester, 103-142.

Elliot, G. 1996. Microfabric evidence for podzolic soil inversion by solifluction processes. *Earth surface processes and landforms,* 21: 467-476.

Gasse, F., Lédée V., Massault, M. and J.-C. Fontes 1989. Water level fluctuations of Lake Tanganyika in phase with oceanic changes during the last glaciation and deglaciation. *Nature*, 242: 57-59.

Geomines–Somirwa 1981: *Evolution entre 1958 et 1979 du couvert forestier et du débit des sources dans certaines régions du Rwanda.* Etude Geomines / AIDR-Rwanda, 13 pp.

Glen, J.W., Donner, J.J. and R.G. West 1957. On the mechanism by which stone in till become oriented. *American Journal of Science*, 253: 194-205.

Goudie, A.S. 1996. Climate, past and present. In W.M. Adams, A.S. Goudie and A.R. Orme (eds.). *The physical geography of Africa*: 34-59. Oxford University Press.

Goudie, A.S. 1981. *The human impact: Mans role in environmental change.* Basil Blachwell, Oxford, 640 pp.

Griggs, D.T. 1936. Deformation of rocks under high confining pressures. *Journal of Geology*, 44: 541-577.

Haberyan, K.A. and R.E. Hecky 1987. The late Pleistocene and Holocene stratigraphy and paleolimnology of Lakes Kivu and Tanganyika. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 61: 169-197.

Harris, C. and S. Ellis 1980. Micromorphology of soils in soliflucted materials. *Geoderma*, 23: 11-29.

Hurault, J. 1971. La signification morphologique des lavakas. *Revue de géomorphologie dynamique*, XX: 121-128.

Larcher, W. 1995. Physiological plant ecology, Springer, Berlin, 506 pp.

Leopold, L.B, Wolman, M.G. and J.P. Miller 1964. Fluvial processes in geomorphology. Freeman, San francisco, 522 pp.

Maud, R.R. 1965. Laterite and lateritic soils in coastal Natal. *J. Soil Sci.*, 16: 60-72.

Ministère des ressources naturelles, Rwanda 1981. *Carte lithologique du Rwanda, 1:250.000*, Bruxelles.

Moeyersons, J. 1983. Measurements of splash-saltation fluxes under oblique rain. Rainfall simulation, Runoff and Soil Erosion. *Catena*, supplement 4: 19-31.

Moeyersons, J. 1988. The complex nature of creep movements on steep sloping ground in Southern Rwanda. *Earth Surface Processes and Landforms*, 13: 511-524.

Moeyersons, J. 1989a. La nature de l'érosion des versants au Rwanda. *Annales Royal Museum for Central Africa, Series Economic Sciences*, 19, Tervuren, Belgium, 396 pp.

Moeyersons, J. 1989b. A possible causal relatonship between creep and sliding on Rwaza Hill, Southern Rwanda. *Earth Surface Processes and Landforms*, 14: 597-614.

Moeyersons, J. 1989c. The concentration of stones into a stone-line as a result of subsurface movements in fine and loose soils in the tropics. *Geo-Eco-Trop.*, 11: 11-22.

Moeyersons, J. 1989-1990. Les glissements de terrain au Rwanda occidental: leurs causes et les possibilités de leur prévention. *Cahiers O.R.S.T.O.M., série pédologique*, XXV,1-2: 133-151.

Moeyersons, J. 1990. Soil loss by rainwash: a case study from Rwanda. *Z. Geomorph.* N.F. 34, 4: 385-408.

Moeyersons, J. 1991. Ravine formation on steep slopes foward versus regressive erosion. Some case studies from Rwanda. *Catena*, 18: 309-324.

Moeyersons, J., Vermeersch, P.M., Beeckman, H. and P. Van Peer 1999. Holocene environmental changes in the Gebel Umm Hammad, Eastern Desert, Egypt. *Geomorphology*, 26: 297-312.

Nenquin, J. 1967. Contribution to the study of prehistoric cultures of Rwanda and Burundi. Annales du Musée Royal de l'Afrique Centrale. Sciences humaines 20, Tervuren, Belgique, 92 pp.

Nieuwenhuijzen, M.E., and H. Van Steijn 1990. Alpine debris flows and their sedimentary properties. A case study from the French Alps. *Permafrost and periglacial processes,* 1: 111-128.

Partridge, T.C. and R.R. Maud 1987. The geomorphic evolution of Southern Africa since the Mesozoic. *S. Afr. J. Geol.*, 90: 179-208.

Pierson, T.C. 1980. Erosion and deposition by debris flows at Mt Thomas, North Canterbury, New Zealand. *Earth Surface Processes,* 5: 227-247.

Penck, W. 1924. Die Morphologische Analyse. *Geographische Abhandlungen,* 2,2: 1-283.

Peyrot, B. 1983. Note à propos de quelques gisements préhistoriques au Rwanda et sur leurs enseignements sur le paléo-environnement quaternaire des Hautes Terres de l'Afrique Centrale. *L'anthropologie*, 87,1: 27-47.

Prioul, C. and P. Sirven 1981. Atlas du Rwanda. Association pour l'Atlas du Pays de Loire, Paris, Kigali, 75 pp.

Reid, I. and L.E. Frostick 1989. Channel form, flows and sediments in deserts; In D.S.G. Thomas (ed.), *Arid zone geomorphology*: 117-135, Belhaven Press, London.

Rohdenburg, H. 1969. Hangpedimentation und Klimawechsel als wichtigste Faktoren der Flächen- und Stufenbildung in den wechselfeuchten Tropen und Beispiele aus Westafrika, besonders aus dem Schichtstufenland Südost-Nigerias. *Giessener Geographische Schriften*, 20: 57-152.

Roche, E. 1988. D.2 – La tourbe du Burundi et du Rwanda. *Pangea,* 12-13: 65-92.

Roche, E. 1996. L'influence anthropique sur l'environnement à l'âge du fer dans le Rwanda ancien. *Geo-Eco-Trop.* 20: 73-89

Schumm, S.A. 1956. The role of creep and rainwash on the retreat of badland slopes. *Am. J. Science*, 254: 693-706.

Takalashi, T., 1981. Debris flow. *Annual Review of Fluid Mechanics,* 13: 57-77.

Tschierske, N. 1979. Uber die mögliche Fliessbewegunbg ganzer Tonberge. *Rock mechanics*, 19: 99-113.

Van Grunderbeek, M-C., Doutrelepont, H. and E. Roche 1984. Influence humaine sur le milieu au Rwanda et au Burundi à l'âge du Fer Ancien (220–665 A.D.): apports de la palynology et de l'étude des charbons de bois. *Revue de Paléobiologie.* Volume spécial, ISSN 0253-6730: 221-229.

Vincens, A, Chalié, F., Bonnefille, R., Guiot, J. and J.J. Tiercelin 1993. Pollen-derived raifall and temperature estimates from Lake Tanganyika and their implication for late

Pleistocene water levels. *Quaternary Research*, 40,3: 343-350.
Young, A. 1960. Soil movement by denudational processes on slopes. *Nature* 188: 120-122.
Zaruba, G. and V. Mencl 1969. *Landslides and their control.* Academia and Elsevier, Prague, 205 pp.