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LANDFORM, SOILS AND EROSION IN THE NORTH-EASTERN IRANGI HILLS, KONDOA, TANZANIA

BY
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ABSTRACT. The north eastern Irangi Hills of the Kondoa District, Tanzania are severely affected by soil erosion with consequent land degradation caused by the loss of productive soil, gullying, sand deposition on lower slopes, and rapid siltation of lakes. Major changes in land surface morphology and soil characteristics have drastically altered the pattern of cultivation and settlement. A knowledge of soil and environmental conditions that existed prior to the phase of modern accelerated erosion is fundamental to the accurate assessment of land degradational processes, the extent of soil erosion and sedimentation, and the degree and sustainability of land recovery. This paper integrates the results of recent field-based geomorphological, pedological and sedimentological studies in the Haubi and Mwisanga catchments. Landforms, soil toposequences and recent colluvial and alluvial deposits are described in relation to erosion features, the dynamics of vegetation/land use changes and the development of Lake Haubi. Modification of the pre-existing soil landscape by accelerated erosional and depositional processes is discussed.

Introduction to the study area

The Irangi Hills of the Kondoa District in north central Tanzania have been extensively affected by severe soil erosion with consequent deterioration in land quality (Christiansson 1972, Östberg 1986, Christiansson *et al.* 1991, Yanda 1991). Some of the most severe effects of land degradation by gully erosion and sedimentation can be seen in the Haubi area located about 25 km north east of Kondoa town (Fig. 1). Here, ancient, strongly folded and faulted PreCambrian gneisses and schists have been uplifted and separated from similar rocks of the Maasai Plains to the east by a massive escarpment associated with the Central Rift Zone (Fozzard 1963). Less prominent, but clearly distinguishable fault lines are characteristic of many

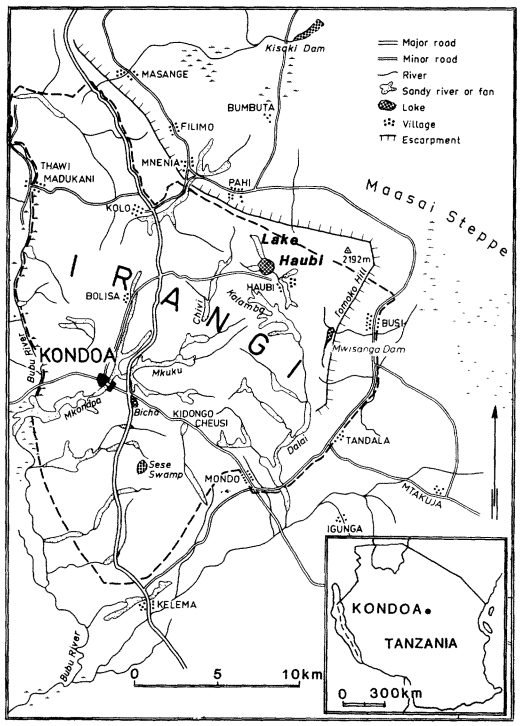


Fig. 1. Map of Kondoa–Irangi. The dissected Irangi fault block is bounded by a several hundred metres high escarpment overlooking the Maasai Steppe to the east and northeast. From its highest point, Tomoko Hill (2192 m), carrying a small area of moist evergreen forest, the general slope is westwards towards drier areas in the Bubu River Valley at 1300 m asl. The numerous and sizable sand fans on valley floors among the hills and on the eastern plains are a result of severe erosion higher in the catchments. The studies described in the present paper focus on the catchments of Haubi and Mwisanga. The dotted line indicates the boundary of the so called "Kondoa Eroded Area" to which the HADO soil conservation project concentrates its land rehabilitation activities.

parts of the Irangi Hills (Aitken 1950, Leedal 1954, Harpum 1970, Christiansson 1972).

In the higher parts of the area the PreCambrian rocks outcrop as steep rocky hills, largely bare of soil and rising to elevations up to above 2000 m. The lower lying ground is dominated by moderately sloping pediments cut across deeply weathered rock or saprolite. These essentially transportational surfaces fall from the base of the steeper hillslopes to the alluvial valley floors at about 1650 m above sea level. The hills are largely drained by south-west and south flowing rivers which form part of the 10,000 km^2 Bubu River Catchment. Valley floors have been subject to rapid sedimentation and aggradation as a result of accelerated erosion higher in the catchments, and are now infilled with wide sandy alluvial deposits. There are also several internal drainage basins within the area, the largest of which is Lake Haubi. Others include Lake Bicha and Seese Swamp. The central part of the Haubi Basin is occupied by a shallow lake heavily loaded with fine sediment and surrounded by alluvial deposits. These form low angle sand fans which grade upslope into the floors of erosion gullies dissecting the pediment slopes. The adjacent Mwisanga catchment at the eastern edge of the Irangi Hills has a man-made reservoir in which sediments from the eroded slopes within the catchment are being trapped (Fig. 7).

The climate of this north eastern part of the Irangi Hills is subhumid, with about 900 mm of rainfall per annum, and contrasts with much drier semi-arid conditions in the south around Kondoa town (Yanda 1991). The rain falls mainly between November and May, followed by a long dry season from June to October.

Objectives and methods

The work reported here is part of a wider research programme which aims to develop an understanding of processes of land degradation and of resource conservation in central Tanzania (Christiansson *et al.* 1991). To achieve such objectives it is important to understand the relative time scale or chronology of soil erosional and depositional events. The causes and effects of modern accelerated erosion need to be separated from the results of processes which have operated over much longer periods of geological time, and need to be related to evidence of changing land use and land quality. One approach to this problem is to investigate the effects of erosion in relation to landform, soil characteristics, and the nature and distribution of recent colluvial or alluvial deposits in the landscape in an integrated way.

This essentially geomorphological, pedological and sedimentological approach is adopted in this paper which reports on, and integrates, the results of recent field studies carried out in the Haubi and Mwisanga catchments of the Kondoa Eroded Area (Payton and Shishira 1991, Yanda 1991, Eriksson 1991). These preliminary results are analysed and used to develop hypotheses which will be tested as the studies continue. The project eventually aims to determine the pattern of landforms and soils that existed in a state of dynamic equilibrium with vegetation prior to the phase of modern accelerated erosion; the modification of this pattern by accelerated soil erosion processes; the dynamics of those processes; and the implications of soil erosion and sedimentation for sustainable land use systems.

The research began with reconnaissance studies of landforms, soils, erosion features and recent sedimentation in relation to current vegetation/land use in the Haubi and Mwisanga catchments based upon interpretation of panchromatic vertical airphoto cover from 1977 and 1987, and SPOT satellite imagery. This was followed by more detailed investigations of landsurfaces, geological materials and soil toposequences from hillcrest to valley floor. Landform and slope elements of these toposequences were characterized. Soil erosion features were observed and measured. Weathering profiles, evidence of recent sedimentation, and soil characteristics were recorded in continuous, deep exposures provided by gullies and in soil pits excavated to 2 or 3 m depth.

Modal soil profiles representative of the principal slope elements in the catena were described in detail (FAO 1977) and sampled for physical, chemical and mineralogical analyses. Provisional classification is given according to the FAO system (FAO-UNESCO 1988). The presence of relatively permanent soil features such as argillic horizons, stonelines or vertic properties (Soil Survey Staff 1975), were used as datum points to analyse the modification of soil toposequences by recent or current erosional and depositional processes. Soil mineralogy, transported pedogenic features and the degree of profile development were used to assess the derivation and age of recent colluvial/alluvial soils.

Three sediment cores of the lacustrine deposits were collected from Lake Haubi. Two of the cores together form a continuous profile from 20 cm to 288 cm below the present lake bottom. A Zodiac

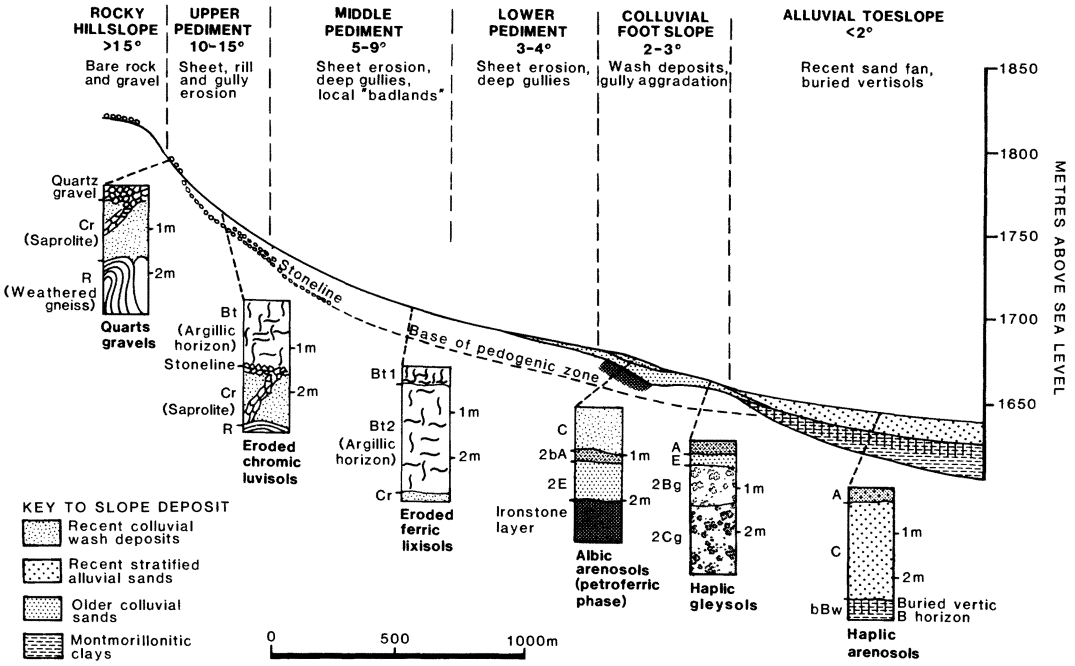


Fig. 2. Generalized soil catena on eroded slopes in the north-eastern Irangi Hills.

rubber boat equipped with a small outboard engine was used as a work platform and the samples were collected using a modified Livingstone sediment core sampler.

Soil erosion in relation to geology and landform

Slopes and the distribution of soil erosional/depositional features

Most of the slopes in the Haubi area can be divided into five major facets with distinctive erosional or depositional features as follows (cf. Fig. 2):

1. Steep rocky hillslopes (>15 degrees) leading to crests largely stripped of weathered regolith and littered with angular quartz gravel subject to movement by wash and creep.
2. Moderately sloping pediments cut across deeply weathered rock and regolith and subject to severe sheet and gully erosion. These are usually divisible into a short steeper upper section (10-15 degrees) with severe soil stripping and "V" shaped gully heads cut into weathered rock, a long straight midslope section (5-9 degrees) with deep gullies often coalescing to form badlands topography on the upper midslope, and a straight to concave lower section (3-4 degrees) with thin sheet wash deposits and with gullies eventually becoming shallower and showing signs of recent aggradation.
3. Gently sloping (2-3 degrees) concave depositional footslopes with sandy surface wash deposits still dissected by shallow gullies.
4. Low angle (<2 degree) sand fans extending towards the valley or basin floors and subject to periodic deposition in shallow active channels which grade upslope into gully floors.
5. Level alluvial valley floors often underlain by black clays.

Partially submerged, level lacustrine surfaces currently accumulating laminated clayey sediments occupy the lowest ground in the Haubi Basin and the area around the Mwisanga reservoir. These form a sixth landform facet in these catchments.

Weathering and erosion on steep rocky hillslopes

The rocky hillslopes are mostly developed over relatively resistant but weathered quartzo-feldspathic gneiss cut by numerous quartz veins. The landsurface consists of hard spheroidal rock

m on some midslope sites with up to 17 m of soil and saprolite over strongly weathered rock.

Where developed from biotite schists, the saprolite is a red clay which falls in massive blocks from undermined gully sides to give relatively featureless sheer walls. Some of the deepest gullies occur on middle pediment slopes developed over this red saprolite. In contrast, the deeply weathered biotite gneiss gives a pinkish gritty sandy clay loam saprolite. This weathers into fluted forms and is often diversified by subhorizontal outstanding ribs which are the result of differential erosion of bands of contrasting mineralogy. Quartz veins are common but are not so frequent as on the upper pediment. Complex interbanding and folding of the two rock types result in abrupt changes in character and colour of the derived saprolites both laterally and vertically in the weathering profile.

Some pediments are shorter, for instance to the south of Lake Haubi. A quartzo-feldspathic gneiss, poor in mafic minerals, dominates the central area of these southern slopes, extending from rooky hillside onto the lower pediment. Middle and upper sections of these short pediments slope at about 10 degrees and are cut across pale yellow, gritty quarzitic saprolite. These slopes are severely gullied, but the gullies do not attain the depths encountered on saprolite from schists. Elsewhere on these short pediments the gneisses contain more ferro-magnesium minerals and give rise to deeper, redder saprolites, thus demonstrating the effects that variable mineralogical composition has on weathering products.

Depositional footslopes

The geological materials which form the footslopes at the base of the pediments are rarely well exposed because gullies tend to be shallower and often inactive. The gullies commonly have aggrading marshy floors in this section of the slope and gully walls are frequently obscured by slumping. A grey, mottled, gritty. sandy clay loam saprolite was common in the north west of the Haubi Basin, whilst a red, more clayey saprolite with grey mottling occurred in some of the lower parts of gullies in the south east and near Mwisanga reservoir. Original rock structure is difficult to discern but thin quartz veins serve as indicators of in situ weathering origins.

Colluvial sandy deposits often form the uppermost member of these weathering profiles which have been subject to additions of material from upslope for long periods of geological time. The deposits may be separated into older colluvial sands, and recent sandy wash deposits related to modern soil erosion and deposition.

Alluvial sand fans

Particularly large accumulating fans occur west and north of Lake Haubi and south of the Mwisanga reservoir. Several smaller fans were distinguished on the wide strip of low-lying ground to the east of Lake Haubi. Some of these sand fans are active and remain largely unvegetated with stratification to the land surface, others have been cultivated. Five sites were sampled east of Lake Haubi (Payton and Shishira 1991). Where cut by shallow gullies, plane or crossbedded sands and gravels are revealed confirming the alluvial origin of these materials, which, in places, have buried black clay soils developed from lacustrine clays. The age and origin of these sand fans based on stratigraphic and pedological observations is discussed later in this paper.

Many of the active sand fans nearer the lake consist of micaceous, pinkish or reddish fine to medium sands with local concentrations of dark coloured ferro-magnesium minerals such as hornblende and biotite. Three pits were dug in an active sand fan west of the lake (Eriksson 1991). The top 10-20 cm exposed in these pits showed alternating thin silty and sandy layers over a thick (50-90 cm) layer of laminated sand. This passed down into alternating layers of varying thickness of sand, silt and clay in two of the pits examined. The transition from coarser to finer material in the uppermost 10-20 cm may reflect the introduction of grazing restrictions in 1979 with subsequent recovery of the vegetation cover and reduced erosion intensity.

Lacustrine deposits

The sand fans finally pass into concave lacustrine surfaces beneath the marshland and reedbeds at the edge of Lake Haubi which are underlain by semi-fluid, unripened silts and clays permanently affected by a high ground watertable related to lake levels. The lake itself is about 1 km^2 in area. The average depth at the end of the dry season is about 1.5 m, as revealed by depth soundings undertaken in October 1991 (Eriksson 1991). It is presumed that the average maximum depth in the wet season is around 2.0 m.

Detailed analyses of the lower part of one of the sediment cores extracted from Lake Haubi (from



Fig. 4. Quartz gravels exposed on the upper pediment close to the transition to steeper rocky hillslope pass below the blocky yellowish red agrillic horizon of a Chromic Luvisol to form a stone line at the top of the saprolite (Mwisanga catchment). (Photo: R.W. Payton)

158 to 288 cm below the lake bottom) have been carried out to date. Three stratigraphical units can be distinguished, possibly representing three distinctly different stages in the history of the lake. The bottom unit from below 250 cm depth consists of a very firm black clay containing calcium carbonate nodules, iron nodules, and many charcoal fragments. The unit passes into a 20 cm thick dark grey layer with high organic matter content and some diatoms. This unit ends abruptly at 235 cm depth where laminated clay with low organic matter content begins. This consists of alternating 8-30 mm thick red and grey varves which tend to thicken upwards in the sedimentary sequence. These varved sediments continue up to at least 158 cm below the lake bed.

Soil characteristics and distribution

A generalized soil catena

Although there is some variation in the toposequences of soils found in the Haubi area due to local differences in landform and parent material, most transects from rocky hillslope to low angle sand fans revealed broadly similar sequences of soil types in relation to slope (Payton and Shishira 1991, Yanda 1991). This repetition of soils in the landscape epitomizes the catena concept first conceived by Milne (1935) on similar rock types elsewhere in Tanzania. A generalized soil catena, typical of both Haubi and Mwisanga catchments, is illustrated in Fig. 2. The component soils are described briefly below and in more detail by Payton and Shishira (1991, 1992). The soil classes used are those of the revised FAO system (FAO-UNESCO 1988) unless otherwise stated.

Quartz gravels, bare rock and lithosols of the steep hillslopes

Rocky hillslopes are dominated by angular quartz gravels overlying weathered quartzo-feldspathic gneiss interspersed with common hard rock outcrops and shallow Lithosols (FAO-UNESCO 1974). Thick, vertical and sub-horizontal quartz veins up to 1 m wide disintegrate close to the surface and become incorporated into the mobile layer of quartz gravel. The origin of these gravels is most readily explained by residual accumulation following extensive stripping of soils and weathering profiles from these steep slopes. Relics of a former soil cover survive in a few places as isolated patches of strong yellowish brown B horizon material containing common weatherable minerals. Scattered termite mounds are also characteristic. These consist of fine earth rich in micas, suggesting that the mounds overlie saprolite.

Chromic luvisols, saprolite and regosols of the upper pediments

Angular quartz gravels directly overlying saprolite often extend onto upper pediments, where they usually pass below an eroded, argillic B horizon to



Fig. 5. Very light grey Albic Arenosols exposed in the badland area close to Mwisanga reservoir. These are developed from colluvial sands in concave footslope positions. The bleached albic horizon rests upon cemented ironstone or petroplinthite which stands out in the gully walls. (Photo: C. Christiansson)

form a stoneline within 100 m from the base of the steeper hillslope (Fig. 4). The stoneline separates stoneless, argillic sandy clay loam from gritty, yellowish saprolite formed from quartzo-feldspathic gneiss and cut by common quartz veins. Reddish clay coatings present on blocky peds in the argillic horizon extend along fissures into the saprolite. The presence of high chroma colours (Munsell Colour 5YR 5/6), weatherable minerals (Soil Survey Staff 1975) and pH values above 5.5 in the argillic horizon suggest that these soils are Chromic Luvisols. Topsoil and upper subsoil horizons have been removed by sheet erosion so that the argillic horizon forms the landsurface. Remnants of similar argillic B horizons survive closer to the transition to rocky hillslope, but here soils have been more extensively removed by sheet and rill erosion, leaving up to 30 cm of residual quartz gravel over saprolite. In places, where there is some interstitial fine earth in the gravels, weak A horizons have developed to give immature Haplic Regosols.

Red argillic soils (ferric Lixisols) of the middle/lower pediments

Middle to lower pediment slopes are usually dominated by deeper, redder, more clayey argillic soils widely affected by severe sheet erosion and gullying. These soils are developed from deeply weathered biotite schists, or gneisses of intermediate composition, often interbedded with biotite schists and thin amphibolites. Saprolite sometimes extends to 20 m depth or more. The argillic horizons are often exposed by sheet erosion and may extend to 2 or 3 m depth. Where only the A and E horizons have been removed, they have a medium blocky upper part (0-150 cm) with prominent clay coatings and a coarse blocky lower part containing common iron oxide nodules. Weatherable minerals decrease relative to the Luvisols higher in the catena but pH values remain above 5.5. The soils are therefore provisionally classed as Ferric Lixisols pending determination of cation exchange capacity.

On the lower pediment, Ferric Lixisols become increasingly overlain by sandy wash deposits and the frequency of iron oxide nodules increases in the lower argillic horizon. As the concave footslopes are approached soil colours become more yellowish and eventually the lower argillic horizon may become mottled or develop layers of petroplinthite (Soil Survey Staff 1975).

Albic arenosols, petroplinthite and gleysols of the footslopes

Loose sandy soils classed as Albic Arenosols occur in a narrow zone (<100 m wide) immediately below the break of slope from lower pediments to the concave footslopes (Fig. 5). Weakly developed, light greyish brown A horizons about 20 cm thick overlie deep albic horizons of bleached, medium quartz sands which rest upon dusky red, nodular or pisolitic lateritic ironstone (petroplin-

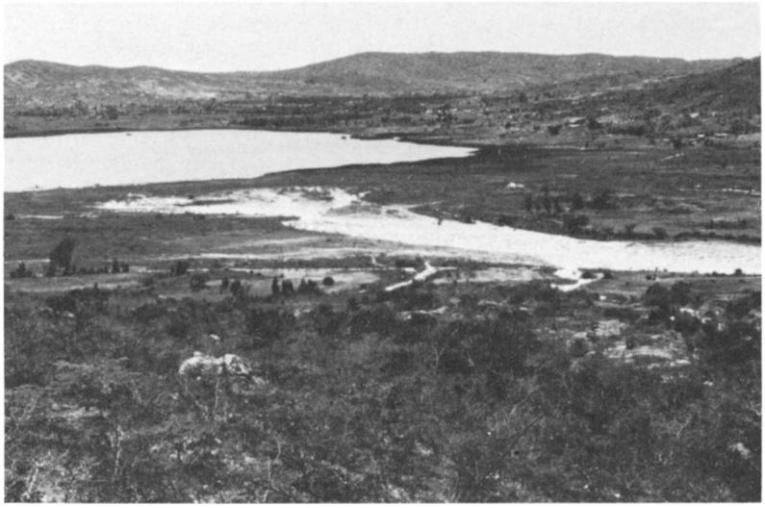


Fig. 6. A large, actively accumulating sand fan, largely bare of vegetation, is seen here extending towards Lake Haubi from the west. The fan deposits grade back into gully floors dissecting the adjacent pediment slopes. (Photo: R.W. Payton)

thite). The ironstone horizon is developed in lithologically distinct sandy clay loam and rests upon mottled, fine loamy gleyed C horizons or plinthite developed from gneissic saprolite. These soils are particularly common in the south Mwisanga catchment but are not present in all soil catenas. They pass downslope quite rapidly into grey, mottled Haplic Gleysols, also with pale sandy or coarse loamy upper horizons overlying prominently mottled, cambic Bg horizons of sandy clay loam texture at less than 50 cm depth.

Both these hydromorphic soil types have developed under seasonally waterlogged conditions influenced by a fluctuating watertable. The albic horizons have formed in old sandy wash deposits which predate, and are often buried by, thicker pale brown to reddish sands deposited as a result of modern accelerated erosion, transport and sorting of soil materials from higher points in the catenas.

Haplic arenosols, raw sands and buried vertisols of the toeslopes

In the lowest parts of the soil catenas Gleysols become buried by sands of recent, low angle alluvial fans (Fig. 6). In places these fans consist of actively accumulating, stratified sands and are clearly visible on aerial photographs. Elsewhere they have stabilized sufficiently for weak ochric A horizons to have developed to give Haplic Arenosols which are now widely cultivated. Field observations indicate considerable mineralogical variation in these recent sandy parent materials which range from red micaceous fine sands to medium sands dominated by quartz and feldspar or, on some of the youngest sand fans, by dark coloured heavy minerals including hornblende and magnetite.

East of Lake Haubi, these immature sandy soils and their stratified parent materials overlie buried black montmorillonitic clays at 2 to 5 m depth. Morphological evidence of cracking and slickensided peds indicates that these were Vertisols which would formerly have comprised the end member of the soil catena. Similarly buried Vertisols occur south of Mwisanga reservoir but here they also occur at the surface in the lowest parts of the present valley floor beyond the influence of sand fan deposition. Raw, actively accumulating micaceous sands often increase in frequency in the lowermost parts of the present soil catenas. These pass into raw gleyed silts and clays beneath the marshland surrounding Lake Haubi.

Soil erosion, vegetation and land use

Those parts of the steep hillslopes covered by bare rock, quartz gravel or Lithosols are generally bare of vegetation or have a sparse grass cover. A pattern of clumped vegetation observed on aerial photographs was found to relate to stunted and usually heavily coppiced *Brachystegia spp.* scrub growing either on termite mounds, or on other soil mounds. These are relicts of a formerly more ex-

tensive soil cover which supported miombo woodland. Occasional stands of *Brachystegia microphylla* woodland still survive on some hilltops, particularly where patches of soil developed from mica schists have survived, protected between beds of quarzite. Elsewhere, a few stands of mature woodland were observed growing on quartz gravel over saprolite, or on isolated eroded remnants of argillic B horizons. This suggests that Chromic Luvisols formerly covered parts of these steep hillslopes but that soil cover was probably patchy even before the degradation and removal of the natural woodland cover (Payton and Shishira 1991).

On the upper pediments severe sheet and rill erosion has widely exposed the argillic B horizon of Chromic Luvisols resulting in large expanses of almost bare, very hard, slowly permeable, sealed sandy clay surfaces between gullies up to 6 m or more deep. The soil surface is etched into a blocky microrelief, often surrounded by thin scattered splays of pale, washed medium sand. The patchy vegetation cover consists of scattered grasses and heavily coppiced, stunted *Brachystegia spp.* scrub. Larger clumps of *Brachystegia spp.* survive on termite mounds. Smaller soil mounds left after sheet and rill erosion are often scattered over parts of these upper pediments. In the Mwisanga catchment measurements indicate a density of between 5 and 29 per hectare and a loss of between 20 and 50 cm of soil between the mounds (Yanda 1991). Total soil loss is much greater than this as the mounds themselves are usually developed from argillic horizon material. Within 100 m of the steeper rocky hillslope, topsoil and argillic horizons have been completely removed by sheet and rill erosion which have exposed the stoneline and involved a loss of 2 to 3 m of soil.

Sheet erosion has also exposed the hard, relatively impermeable red argillic horizons of Ferric Lixisols over large parts of the pediment midslopes. The argillic horizon forms a marker from which the extent of erosion can be estimated. In most areas topsoil has been totally lost or replaced by scattered sandy wash deposits. In some places, the absence of the medium blocky upper argillic horizon indicates loss of up to 2 m of soil. These are also some of the most severely gullied soils in the Kondoa area. Some gullies attain depths of 22 m in the Haubi Catchment, whilst interfluves were as narrow as 6 m in places (Payton and Shishira 1991). Widths of gullies on pediment slopes in the Mwisanga Catchment varied from 8 to 150 m, with depths up to 21 m (Yanda 1991). Coalescing gully heads on upper midslopes result in soil degradation to pinnacles and pedestals forming severe "badlands" (Fig. 7).

Anthropological evidence indicates that some gullies had cut to these depths by the beginning of this century. A cave cut close to a gully floor east of Lake Haubi is said to have been used for shelter during tribal wars. Local opinion also stated that gullies formed along former cattle tracks aligned directly down the slope. This type of information is extremely valuable when related to soil and geomorphological evidence and will be pursued during the rest of the project.

Cultivation of most Ferric Lixisols on pediment midslopes has been abandoned and they are mainly under sparse *Brachystegia* scrub and patchy grass with extensive bare ground still subject to sheet erosion. Many areas are so cut up by gullies that terrain factors alone restrict their use. However, interviews with local farmers indicate that these soils were formerly the main areas for cultivation and settlement. This is confirmed by remnants of these settlements on the upper pediments, together with traces of field boundaries and trenches constructed to keep out wild pigs. A study of these features in the Mwisanga catchment showed that the trenches are aligned diagonally or parallel to the slope and have often determined the lines of gully extension upslope through concentration of runoff (Yanda 1991). The origin of several deep narrow gullies on pediment slopes in both Mwisanga and Haubi catchments were traced to the point where such trenches intersect.

Limited farming and settlement still continues between gullies on the pediment slopes. Hoe cultivation of the exposed subsoil argillic horizon was observed in several places but crop performance was poor. Thin sandy wash layers overlying the red argillic horizon become more widespread on lower pediments, particularly in the long catenas east of Lake Haubi. Some of these layers appear to be of considerable age, have developed distinct A horizons and are extensively cultivated for pigeon peas, maize and finger millet. Remnants of such soils isolated as interfluve fragments within coalesced gully systems indicate that the deposition of the wash layer on these lower pediments preceded gully formation and therefore must have occurred before the start of the 20th Century.



Fig. 7. View of the south-eastern part of Mwisanga catchment and the site of Mwisanga reservoir before the damming of the Busi river. Note the heavily dissected lower pediment slopes on the left. Fig. 5 shows details of this area. (Photo: C. Christiansson)

Effects of sedimentation on land use in lower slope sites

Footslope sites have received sandy wash deposits, which result from transport and sorting of soil eroded from the upper parts of the catena, for long periods of time. Pedogenic evidence, discussed below with the formation of ironstone layers, indicates that the deposition of the thick sands in which the Albic Arenosols are formed considerably predates the period of modern surface wash. The particle size distribution and mineralogy of these colluvial deposits have influenced soil formation and productivity. The Albic Arenosols are almost everywhere cultivated but form some of the most nutritionally poor soils in the area. Their quartzitic composition, sandy texture and lack of weatherable minerals mean that nutrient reserves are confined to the organic fraction in the topsoil. As organic matter levels are low, crop performance is poor and further hampered by low moisture reserves and by cemented ironstone layers. Sheet erosion is not severe as rainfall penetrates the surface rapidly but these soils are affected by gullying originating elsewhere on the slope. In some cases, where they lie in shallow depressions, they have become buried by up to a metre of red coarse loamy colluvium derived from recent sheet erosion higher in the soil catena.

Most of the cultivated land in the Haubi and southern Mwisanga catchments is concentrated on the extensive sandy soils that form the lowest member of the modern soil catena. The full extent and significance of recent sand deposition and its relation to soil erosion higher in the soil catenas was not fully appreciated until recent fieldwork revealed the very wide extent of immature Haplic Arenosols with weak A horizons directly overlying bedded sands. Such soils occupy most of the land between active sand fans. Much of the agricultural production of the Haubi and southern Mwisanga catchments depends on these young Arenosols. Their properties are therefore of particular importance. The history of their formation, which has come to light through the recent investigation of their relationships with landform and recent sedimentation, holds particular significance for land use change. The buried Vertisols beneath the sand fans indicate that these lower catenary positions were formerly occupied by contrasting montmorillonitic clays. Where these still survive at the surface they are left as semi-natural grassland and are not generally cultivated.

Discussion and conclusions

Origin of stonelines and the age of hillslope stripping

The argillic horizon and the stoneline present in the Luvisols and Lixisols described above form potentially useful marker layers from which the amount of soil erosion can be estimated. The relationships between stonelines, argillic horizons and the surface quartz gravels of the rocky hillslopes also provide a possible means to estimate a relative date for the erosion which stripped the hillside, and for the sheet and rill erosion on the

pediment slopes. Stonelines have been variously attributed to the incorporation and concentration of quartz fragments, derived from disintegration of quartz veins present in saprolite, into the base of a migratory soil layer (Berry and Ruxton 1959); the concentration of stones at the base of termite activity with the thickness of the upper stone-free layer being augmented by soil creep or wash processes on slopes (Nye 1955, Smyth and Montgommery 1982, Williams 1968); or the burial of stripped landsurfaces covered by lag quartz gravels requiring cyclic erosional and depositional processes related to climatic change (Folster *et al.* 1971).

Field evidence indicates that the angular quartz gravels on the rocky hillslopes of the Kondoa Eroded Area have been left after regolith removal; that they are ultimately derived from the disintegration of quartz veins in the gneiss saprolite; and that they are subject to current movement by wash and creep on the steep slopes. In several locations they pass beneath the argillic horizons of Chromic Luvisols on the upper pediment to form stonelines. If a common origin for the concentration of quartz into surface gravels and stonelines by geomorphological stripping is postulated, then one has to envisage first, the differential erosion of fine earth material to leave a lag of quartz gravel over both the steep hillslope and the upper pediment, followed by burial of this gravel-strewn surface by deposition on the upper pediment, followed by argillic horizon formation in the colluvial deposits (pedisediments) above the stoneline.

Well developed argillic horizons take several thousands of years to form. As the erosion which caused the stripping must predate argillic horizon formation, it must also considerably predate the phase of more recent accelerated erosion which has caused gullying and sheet wash on the pediment slopes. If this hypothesis is accepted, the erosion of steep hillslopes must be related to an earlier stage of geomorphological evolution and may have been triggered by climatic change or uplift. If this common origin for quartz gravel and stonelines can be proved it shows that the steep rocky hillslopes have been a part of the landscape for a long period.

There are however problems with this hypothesis. If severe stripping occurred on both hillslopes and pediments, what then was the source of the pedisediments which buried the quartz gravel to form a stoneline prior to argillic horizon development? There does not appear to have been a ready source of fine sediment on the rocky hillslopes, unless it is postulated that regolith stripping was incomplete. It is also possible that the common termite activity currently observed may have continued to bring up fine earth material to the surface from saprolite below, thereby providing a source of pedisediment as termite mounds have disintegrated over time. A simpler hypothesis is that erosion of soils, which formerly occupied both the steep hillslopes and the uppermost parts of the pediment, has exposed a pre-existing stoneline concentrated at the base of termite activity and/or the migratory soil layer. The erosion could then be ascribed to a more recent phase of erosion, possibly triggered by removal of the miombo woodland cover by the first Wairangi farmers in the area. However, this hypothesis requires that termite activity and soil movement had been inactive for a long period prior to the erosion phase in order that the argillic horizons could form above the stoneline.

These alternative hypotheses need careful consideration and further testing through observations of field relationships before the significance of quartz gravels, stonelines and argillic horizons as tools for dating soil erosion on the steep hillslopes can be fully realized.

Inception and extent of accelerated erosion on pediment slopes

The original vegetation on pediments appears, from the relics observed, to have been miombo woodland dominated by *Brachystegia spp.* and increasingly dominated by *B. microphylla* on the steep hillslopes. Historical evidence indicates that pressures on land increased in the latter part of the 19th Century (Mun'gon'go 1991) and subsequently land clearance accelerated both for cultivation and tsetse control (Banyikwa *et al.* 1979, Christiansson 1981). Livestock numbers also increased due to better veterinary services in the early part of the present century, leading to degradation of the vegetation cover by overgrazing. The weakly structured topsoils of the Luvisols and Lixisols predominant on pediment slopes would have been particularly susceptible to surface crusting, increased runoff and sheet erosion once their protective vegetation cover was removed, and this would have been accentuated as organic matter contents declined under cultivation (EI Swaify *et al.* 1985). The intensity of runoff increases markedly once the slowly permeable argillic horizon is exposed and rill erosion increases, particularly where augmented by runoff from the rocky hillslopes above. From our preliminary observations, we can state

that up to 2 metres of soil has been lost by sheet and/or rill erosion on pediment slopes and that gullying on these slopes has removed up to 22 m of soil, saprolite and rock from large areas.

Judging from the estimated age of soils on recent sand fans discussed below, the field evidence that these sand fan deposits have been derived from gully erosion on the pediments, historical accounts, and the spoken historical evidence of the local people, we believe that severe sheet, rill and gully erosion probably started no more than 150 years ago and intensified at the turn of the century. Whilst the high frequency of sheet and rill erosion on pediments can be attributed to a combination of rainfall erosivity, slope, high soil erodibility and land use factors, the incidence of gullying seems to be controlled more specifically by human influences. The alignment of field boundary trenches and cattle tracks normal to the slope seem to be locally important. The latter were also considered to be the principal causes of gully inception in Kondoa District by Gillman (1930) and, elsewhere in Tanzania, by Murray-Rust (1972) and Christiansson (1981). These preliminary conclusions require confirmation by laboratory work and further examination of field relationships.

The influence of the mineralogical composition of saprolites on soil properties affecting erodibility and the incidence of gullying needs further study. Initial observations indicate that redder, more clayey argillic soils occur over saprolites derived from deeply weathered biotite schists and are associated with very deep, sheer walled gullies particularly prone to basal sapping and headwall collapse. Saprolites from gneisses of more felsic composition give yellowish red sandy clay loam argillic soils which tend to be associated with wider gullies with more stable walls prone to fluting and pinnacle development. Quartz- rich gneisses give rise to shallower, yellowish, coarse textured soils which are more prone to rilling and shallow gullying.

Ironstone layers as a key to dating colluvial wash deposits

Plinthite formation requires mobilisation and accretion of iron oxides under reducing conditions in soils subject to a fluctuating water table, together with an external supply of mobilised iron from the weathering zone, either from below or from upslope (Eswaran *et al.* 1990). Irreversible hardening to form ironstone or petroplinthite is usually associated with the change to permanently oxidizing conditions on lowering of the watertable. This is usually related to geomorphological processes such as retreat of lakes, lowering of base level or uplift. Currently, the Albic Arenosols with ironstone layers in footslope sites are no longer affected by a fluctuating watertable.

The initial phase of sand deposition on footslopes must date to a period which preceded ironstone hardening because the bleaching of these deposits to form the sandy albic horizons, found immediately above the ironstone, also required seasonal waterlogging. The same phase of high watertable that resulted in the formation of albic horizons and plinthite also resulted in the gleying of deeper C horizons. Iron mobilised under anaerobic conditions in the upper sandy layers would have been lost by lateral percolation through these more porous materials perched above less permeable, fine loamy plinthite. Perching of water and lateral movement above plinthite layers has been recently proven elsewhere (Blume et al 1987). Plinthite formation in the lower horizons would have been encouraged by lateral enrichment of iron mobilised from weathering zones higher in the catena, and by more sluggish drainage due to soil porosity and water retention factors.

If the Albic Arenosols with petroplinthite prove to be at accordant heights around the Haubi Basin, these soils could form a useful indicator of former lake levels.

Age and significance of sedimentation on lower slopes

Geomorphological and pedological evidence suggest that the age of sandy deposits on lower slopes differs widely. Thin sandy wash deposits on the lower pediment slopes and the thicker bleached sand deposits of the Albic Arenosol zone on footslopes predate modern sand deposition and relate to the effects of normal erosion and deposition in the catena. This zone of sandy footslope soils has been recorded in several soil catenas from the semi-arid to sub-humid savannas (Milne 1936, Watson 1965). In the present study, these deposits are often overlain by modern wash deposits which thicken downslope into recent alluvial sand fans on toeslopes.

Several aspects of the morphology of the Haplic Arenosols in the Haubi Basin indicate the recent origin and provenance of their parent materials (Payton and Shishira 1991). Their often reddish colour and common presence of transported iron

nodules identical to those found in the Ferric Lixisols of pediment midslopes, suggest that the sandy materials represent the eroded coarse fraction of these soils. The additional presence of balls of grey, mottled gleyed Bg horizon material derived from Haplic Gleysols, which lie immediately upslope of the Arenosols, points to transport of eroded materials from the lower parts of the catena. Finally, the large content of mica and the common presence of dark-coloured ferro-magnesium minerals in the sands indicate derivation from saprolite exposed by deep gullying of the pediment slopes, rather than from the more weathered soils above.

These findings indicate that the sand fans have formed from material derived by severe soil erosion of the pediment slopes higher in the soil catena. This is further confirmed by the fact that they grade upslope into the floors of the major gullies. The immaturity of the Arenosol profiles, with their weakly developed A horizons and no evidence at all of cambic B horizon formation, suggests an age of less than about 100 to 150 years. This agrees well with information collected by interviews with the local people that suggests black clay soils were present in these landscape positions three to four generations ago. Preliminary investigations of the lake bed sediments also indicate a relatively recent age for the formation of present Lake Haubi.

It can be concluded from the field evidence that the lower parts of the original soil catenas were formerly represented by Gleysols and Vertisols which have been extensively buried by sand resulting from accelerated soil erosion on pediment slopes higher in the catena during the last 150 years. Field assessments of the immature Haplic Arenosols that have developed in this sand suggest that they are nutritionally poor and rapidly permeable but probably have perched water reserves above the buried Vertisols at about 2 m depth. Some contain a high proportion of weatherable minerals capable of slow release of nutrient cations. These soils contrast markedly with the Vertisols of the low-lying areas which preceded the phase of modern soil erosion and still exist in parts of the area. The change in land quality involved has meant far reaching changes in farming systems and settlement pattern which are only just being realised. Their sustainable use for crop production will depend on building up organic matter reserves, the reliability of shallow groundwater supplies, and the availability of fertilizers.

Development of Lake Haubi

The following hypothetical development of Lake Haubi is based on the preliminary interpretation of one sediment core (Fig. 8) and remains to be confirmed by future research (Eriksson 1991).

The black calcareous clays found at 2.5 m below the bottom of Lake Haubi were at the landsurface during a drier period in its recent history, possibly corresponding to the period when the Haubi area was first settled. The evidence for this includes the organic-rich layer present at the top of the black clays which indicates a very wet marshy habitat or seasonally inundated grassland where organic matter decomposition was retarded due to permanent or prolonged seasonal waterlogging of the landsurface. The calcium and iron nodules, found in the underlying clays, may have formed in this very poorly drained 'mbuga' environment, which would have received solutes leached from the surrounding soil catenas. The charcoal fragments found in the black clays must have originated from forest clearings on the slopes surrounding the basin floor and therefore must have been washed into the accumulating clays. The absence of diatoms in the clays further supports the idea that a lake was not present at this time. As the base of these clays has not yet been ascertained, the previous history of the lake is at present unknown and the origin of the black calcareous clay uncertain.

It is tentatively proposed that the clearings and intensified land use on the hillslopes and pediments surrounding the marshy basin floor eventually led to accelerated erosion. Sand fans formed on low angle footslopes and toeslopes, and at one stage one of these fans extended and blocked the outlet of the basin forming the present lake. The wetland vegetation of the basin floor was then flooded and eventually buried by accumulating lacustrine sediments. Under the waterlogged conditions, the organic-rich layer was preserved in the stratigraphic column. In this new lacustrine environment diatoms developed and indicate that a permanent lake had formed.

Increasing erosion on the surrounding slopes would have led to considerable turbidity and the extension of the continuously shifting surfaces of the alluvial sand fans towards the lake. During times of surface runoff the coarser fractions were trapped on the lower fans, while clay was washed out into the lake to form varves. The different colours of the varves indicate differing conditions of oxidation. The predominance of different size fractions within each varve are due to slightly differing

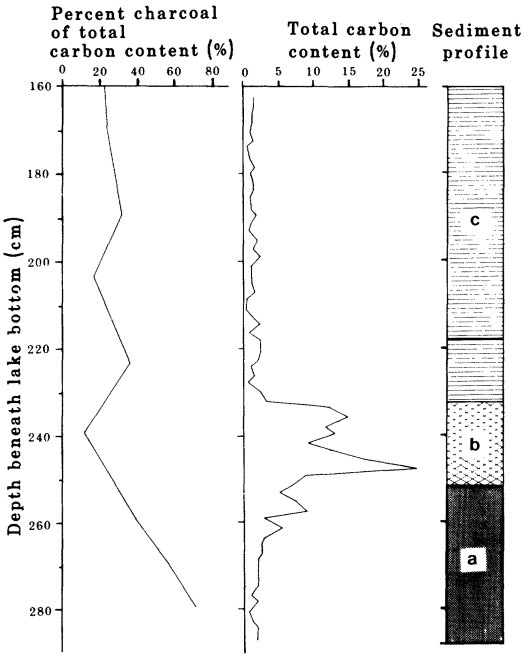


Fig. 8. Sediment profile from Lake Haubi showing the stratigraphical units from 160 to 288 cm below the present lake bottom. Three major units can be distinguished, possibly representing three distinctly different stages in the history of the lake. The following properties relate to the three major strata: **a**) very firm black clay containing nodules rich in calcium carbonate and iron and microscopic fragments of carchoal; **b**) dark grey layer with high organic matter content and some diatoms; **c**) laminated clay with low organic matter content, alternating red and grey varves.

sedimentation conditions during the year. The finest fractions remain in suspension longer than the coarse, and will only gradually settle out during the dry season. If this hypothesis of a distinguishable annual sedimentation cycle is correct, it will be possible to estimate the time that has elapsed since the present lake formed from the record contained in the sediment cores.

Future work

Many of the conclusions drawn above are preliminary and based mainly on the results of field investigations. The soils need further study through laboratory analyses and soil micromorphology to test many of the proposed ideas on their properties and genesis. Landform/soil relationships and the generalized soil catena proposed need to be tested by further detailed field measurements on gully transects. Uncertainties about parts of the catena still exist, such as the phase of erosion which stripped the rocky hillslopes and the relation of this erosion to woodland clearance or much earlier geomorphological stripping. The studies of lacustrine sediments are still at an early stage.

The future research programme will involve continuing fieldwork and a programme of chemical, physical and mineralogical soil analyses to confirm some of the hypotheses about the origins of soils and recent deposits that we have developed in the field this year. Soil microscopy of selected soil and weathered rock thin sections will also be employed. Sedimentological analysis of the lacustrine deposits in Lake Haubi will be continued.

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