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LATE HOLOCENE SEDIMENTOLOGY AND PALAEOENVIRONMENT OF KILULI SWAMP, MOUNT KENYA

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ABSTRACT:- *Kiluli Swamp is an extensive valley swamp near the lower limit of the montane forest on the eastern slopes of Mount Kenya, East Africa. The swamp is fed by a small spring on the northeastern margin, and the water table lies a few centimetres below the surface. The swamp's sediments modify water chemistry: the Na-Mg-HCO_3 water-type at the input changes to a Ca-Mg-HCO_3 water-type in the central parts of the swamp. A short sediment core (2.12m) was retrieved from the central part of the swamp using a modified Livingstone piston corer. The sediments were mainly composed of silty organic mud, silty clay and coarse silt. Three radiocarbon dates were obtained. A suite of sedimentological analyses was carried out in order to reconstruct the palaeoenvironmental history of the area, and these included: mineral magnetic characteristics (susceptibility, IRM etc.); total organic carbon (TOC); total nitrogen (TN), and stable carbon isotopes. The sediment record stretches from about 4,000 yr BP (before present) to present. Indications are that the valley was initially dry and the catchment vegetation was characterised by dominant C_4-type grassland. The initiation of true swamp conditions occurred at ca.470 yr BP immediately following a phase of deep ponding and high diatom productivity within the swamp between 600 and 470 yr BP. A high incidence of charcoal from 470 to 0 yr BP probably marks the period of persistent anthropogenic activities within the catchment. There is a change in vegetation type from a predominantly C_4-type to predominantly C_3-type at about 130 yr BP that is attributed to crop cultivation within the swamp rather than due to climate change, since the arid phase which marks this zone would have, under natural conditions, abetted the continued dominance of C_4 plants which are more drought-resistant than C_3 plants. The changes observed are broadly synchronous with other palaeoenvironmental records from Mount Kenya and the surrounding region.*

INTRODUCTION

Mount Kenya lies on the equator at about 37°E (Figure 1). It is an extinct, heavily denuded volcano that lies in a zone of predominantly easterly winds characterised by two well-marked monsoon seasons, the northeast monsoon from December to March and the southeast monsoon from June to October (Thompson, 1966). Mean annual rainfall varies from about 1,015 to 1,270mm in the foothill areas (Survey of Kenya, 1970) to over 2,000mm in the Montane Forest Zone (alt. *ca.*1,800 to 2,400m) and declining to *ca.*1,015mm in the Alpine Zone (Thompson, 1966). Annual-mean maximum temperatures are generally less than 22°C and these decrease with increasing altitude. The annual-mean minimum temperatures are 10 to 14°C on the footslopes, and less than 6°C in the nival zone (Survey of Kenya, 1970). The annual-mean maximum temperatures are 22 to 26°C at the footslopes, and less than 18°C in the nival zone. Diurnal temperature variations are much more pronounced than variations in mean annual temperatures (Survey of Kenya, 1970).

The mountain exhibits vegetation zonation of a similar type to that of the other highland regions of East Africa (Hedberg, 1951; Coe, 1967). The lowermost zone, which extends up to the lowermost edges of the Mt. Kenya forest at altitudes between 1,000 to 2,000m is the cultivated or pastoral zone (Baker, 1967). It replaces the natural transition zone which one would expect to find connecting the Afromontane Belt and lowland phytochoria (White, 1983). The typical vegetation consists of *Themeda*

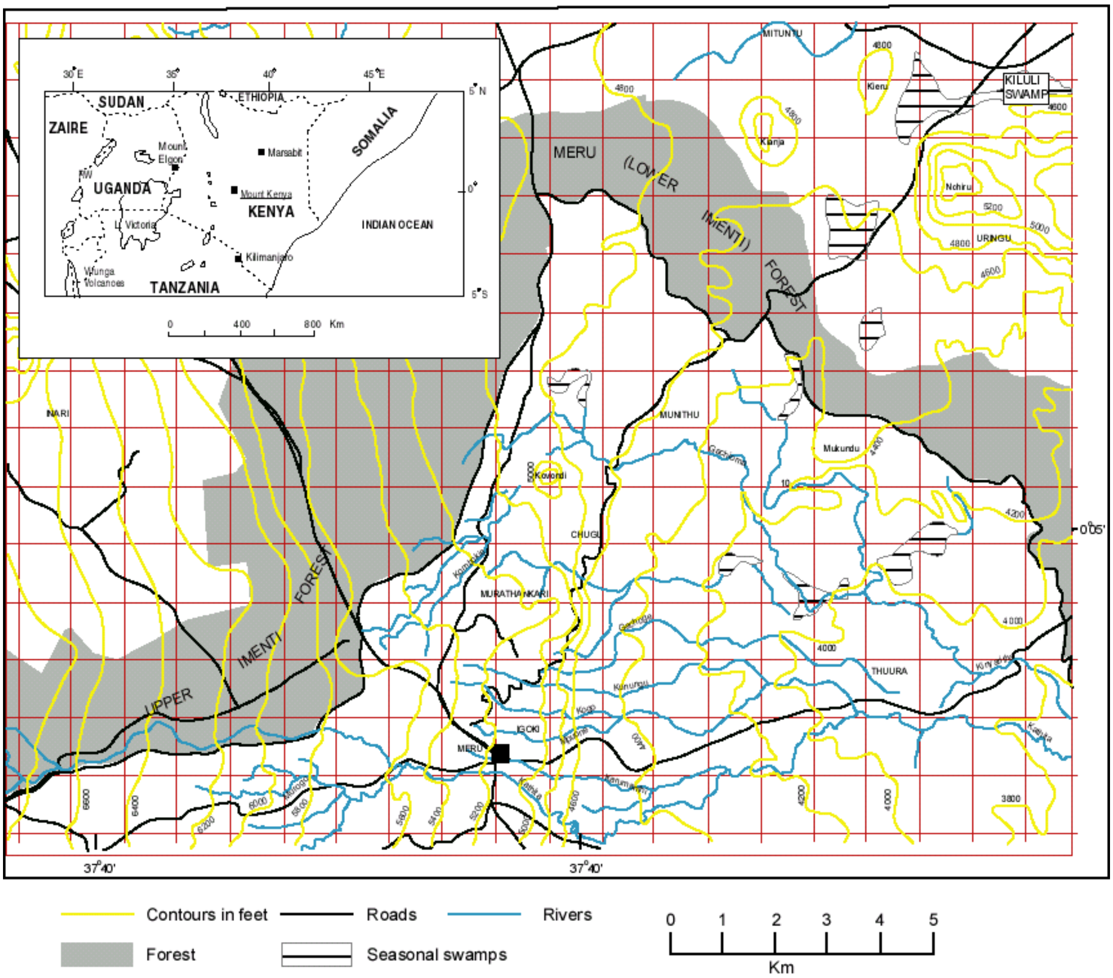

Figure 1. Location of Mount Kenya and Kiluli Swamp, Kenya

grassland to the west and scattered Acacia savanna elsewhere (Coetzee, 1967). Gallery forest comprised of trees such as *Syzygium cordatum*, *Podocarpus gracilior* and *Erica arborea* is found along stream channels radiating from the mountain (Coetzee, 1967). The Montane Forest Zone generally lies between *ca.*1,980 and 3,000m a.s.l. (Ojany and Ogendo, 1973), and extends up to levels of *ca.*3,350m on the west and south sides, and *ca.*3,000m on the eastern and northern sides (Baker, 1967; Ojany and Ogendo, 1973). The forest can be distinguished into two types: Humid Forest which occurs on the northeast, east and south slopes, and Dry Montane Rain Forest on the west and northwest slopes (Coetzee, 1967). The Humid Forest is characterised by tree species such as camphor (*Ocotea usambariensis*), *Myrica salicifolia*, *Pygeum (Prunus) africanum*, *Macaranga kilimandscharica*, and patches of *Podocarpus milanjianus* (Coetzee, 1967; Ojany and Ogendo, 1973) and reaches its maximum development on the southeast sector of the mountain (Baker, 1967; Ojany and Ogendo, 1973). The Dry Montane Rain Forest is mainly characterised by *Juniperus procera* (Cedar), *Podocarpus milanjianus*, *Olea africana*, *O. hochstetteri*, *Maytenus undatus*, *Neoboutonia macrocalyx*, and *Cassipourea malosana* (Coe, 1967; Coetzee, 1967; Ojany and Ogendo, 1973). The Bamboo Zone (comprised of *Arundinaria alpina*) occurs between 2,800 and 3,300m. The *Hagenia-Hypericum* Zone is generally narrow and well-defined. The levels of this zone are *ca.*3,200m to 3,300m on the west and 2,900m to 3,000m on the east, but small patches occur higher in sheltered valleys (Baker, 1967; Coe, 1967). At approximately 3,000m there is another gradual change to a shrubby moorland dominated by *Philippia trimera* and *Erica* sp., *Helichrysum* sp. and several other shrubs, as well as species of the sub-genus *Dendrosenecio* (giant groundsel) (Baker, 1967; Flenley, 1979) which together form the Ericaceous zone. The Alpine Zone shows an altitudinal vegetation transition culminating in a narrow nival zone (Coe, 1967). The Alpine Zone is open, with often marshy ground, and is characterised by *Dendrosenecio*, *Alchemilla* shrubs and *Helichrysum* (everlasting flowers).

Kiluli Swamp (0°08'N, 37°45'E, altitude 1020m a.s.l) is a valley swamp near the lower limit of the montane forest east of Meru where mean annual rainfall is *ca.*1,020mm (Figure1). It is an extensive valley swamp with no surface water: across it runs a flowing water channel fed by a spring situated at the northeast edge of the swamp. The water table lies just a few centimetres beneath the surface.

MATERIALS AND METHODS

The swamp water was analysed in the field for temperature, pH and conductivity (using temperature, pH and conductivity meters respectively), alkalinity (Hach kit) and dissolved oxygen content (Merck kit). Sample 1 was taken from a flowing water channel fed by a spring at the northeast edge of the swamp. Sample 2 (representative of interstitial waters in the swamp) was taken from a man-made drainage ditch near the centre of the swamp, close to the sediment coring site.

Two sediment cores (KS1 - 2.12m and KS2 - 2.34m) were retrieved from the central part of the swamp, and the observable lithology was described in the field. They were then wrapped and placed in hard plastic tubes for transportation, and were stored at 4°C at University of Oxford. Laboratory analyses included determination of: detailed lithology, bulk density, mineral magnetic parameters, total carbon and nitrogen contents, and stable carbon isotope ratios.

Core Chronology

Three AMS radiocarbon dates have been obtained for core KS1 (Table 1).

Table 1. ^{14}C dates for the Kiluli core KS1 (uncalibrated)

Depth (cm)	14C years BP
40	130 ± 50
98	480 ± 45
197	3,345 ± 50

Linear sediment accumulation rates are 0.035cm yr^{-1} between 197 and 98cm, 0.166cm yr^{-1} between 98 and 40cm, and 0.308cm yr^{-1} from 40 to 0cm. Extrapolating the sediment accumulation rate to the base of the core yields an age of 3,970 yr BP. The lithostratigraphic changes occur at 3,288 yr BP (195cm), 2,800 yr BP (178cm), 2,245 yr BP (162cm), 470 yr BP (97cm) and 120 yr BP (37cm).

RESULTS

Water Chemistry

The water is weakly acidic (pH 6.3 to 6.7) with a fairly uniform temperature of about 22°C due to its very shallow depth (Table 2).

Kiluli Swamp water chemistry is distinctively different at the two sample sites, and is a pointer to the fact that different factors can be attributed to their respective chemical characteristics. Sample 1, taken from a flowing water channel fed by a spring at the northeast edge of the swamp, reflects the characteristics of the groundwater inflow to the swamp. The core site sample 2 is reflective of the *in situ* modification of the chemistry of the inflow waters within the swamp itself. It is characterised by intermediate dissolved oxygen concentrations in the spring channel water, and anoxic interstitial water. The cation loadings are: Na>Mg>Ca>K>Fe at the Sample 1 site, and Ca>Mg>K>Na>Fe at the core site (Table 2). Anion loadings are $HCO_3 >> Cl > NO_3 > PO_4$ at the sample 1 site, and $HCO_3 >> Cl > SO_4 > NO_3 > PO_4$ at the core site. The water therefore changes from a Na-Mg-HCO_3 type near input sources, to a Ca-Mg-HCO_3 type within the central parts of the swamp (Table 2). The very low concentration of Na at the sample 1 site, contrasted with the relatively high concentration of Ca at the core site, suggests that as the groundwater moves into the swamp, Na may be replacing Ca and Mg at the exchangeable sites on clay minerals, thus increasing the concentrations of Ca and Mg in solution, while the concentration of Na decreases. This interaction is supported by the chemical equilibria calculations (PCWATEQ; Truesdell and Jones, 1974). Some nitrate and phosphate are supplied to the lake by the groundwater inflows, and these nutrient ions are quickly taken up by active organisms, resulting in their depletion within the swamp. There appears to be some production of authigenic sulphate within the swamp (Table 1). It may be as a result of the reaction between ferric iron and H_2S produced by decaying organic matter, resulting in the reduction of Fe^{3+} to Fe^{2+} and the formation of SO_4^{2-} ions (Brownlow, 1979), and/or may reflect anthropogenic pollution.

Table 2. Water chemistry of Kiluli Swamp at core site and sample 1 site

Sample Site	Details	pH	Temperature (°C)	Conductivity (uS/cm)	Oxygen (mg/l)
KILULI	Sample 1	6.7	22.1	150	4.5
SWAMP	Sample 2	6.3	21.8	195	BDL

Sample Site	Details	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	Ca(%)	Mg(%)
KILULI	Sample 1	0.17	0.428	0.304	0.044	18	45
SWAMP	Sample 2	0.719	0.658	0.087	0.065	47	43

Sample Site	Details	Cl (meq/l)	SO_4 (meq/l)	Alkalinity (meq/l)	Cl (%)	SO_4 (%)	Alkalinity (%)
KILULI	Sample 1	0.073	0	1.3	5	0	95
SWAMP	Sample 2	0.085	0.008	1.74	5	0	95

Stratigraphy

Five lithological units are recognised; silty clays, coarse silts, silty organic mud, porous fibrous peats and a root mat unit (Figure 2). There are also fibrous plant macrofossils above 125cm. The sediments are non-diatomaceous except at 103 to 97cm. The five lithological units are divided into three zones: the silty clay and coarse silt beds (212-162cm); the silty organic mud bed (162-97cm); and the porous fibrous peat (97-0cm).

The Silty Clay and Coarse Silt Beds (Zone 3: 212-162cm)

Clastic, non-diatomaceous sediments are dominant from 212 to 162cm: silty clay sediments sandwich a coarse silt bed between 195 and 178cm (Figure 2). The change from silty clay to a coarse silt bed at 195cm is marked by a gradual boundary. The sediments in this zone are stained with yellow-brown Fe oxides which probably indicate the prevalence of limonite and goethite within the sediments.

The Silty Organic Mud Bed (Zone 2: 162-97cm)

These sediments (162 to 97cm) show some textural variations. From 162 to 130cm silty organic clay sediments occur. From 162 to 130cm, organic matter is contained within the sediments. The Fe staining observed in Zone 3 continues in this zone upto 130cm. The sediments above 130cm are organic-matter rich. From 130 to 112cm a black, silty organic mud with occasional very fine fibrous macrofossils occurs, and a clear boundary demarcates it from a grey silty organic clay at 112 to 103cm (Figure 2). Between 103 to 97cm the sediments are characterised by a black silty organic mud bed (similar to that at 130 to 112cm) and contain occasional fine fibrous macrofossils as well as a rich diatom assemblage. The diatom assemblage includes *Navicula confervacea*, *Synedra ulna*, *Pinularia (acrosphaeria)*, *Cyclotella (meneghiniana)*, *Gomphonema (gracile)*, *Nitzschia* and *Eunotia* sp. (A. Parkes, pers. comm.).

3.2.3 The Porous Fibrous Peat (Zone 1: 97-0cm)

From 97 to 0cm the sediments are comprised of a soft, porous, fibrous peat with common medium size to large hairlike macrofossils between 97 and 38cm, and abundant medium-sized macrofossils from 36 to 0cm (Figure 2). A root mat containing very large, fibrous plant macrofossils and marked by abrupt, irregular upper and lower boundaries occurs between 38 and 36cm (Figure 2).

Dry Bulk Density and Moisture Content

Dry bulk density (DBD) values are generally low and decrease from 1.14 g/cm^3 at the base of the core to 0.07g/cm^3 at the top, while moisture content increases upwards from about 40% at the base to >90% at the top (Fig. 3). Water contents span a range of 40 to 98% (Fig.3). The lowest values, averaging *ca.*50% are found between 212

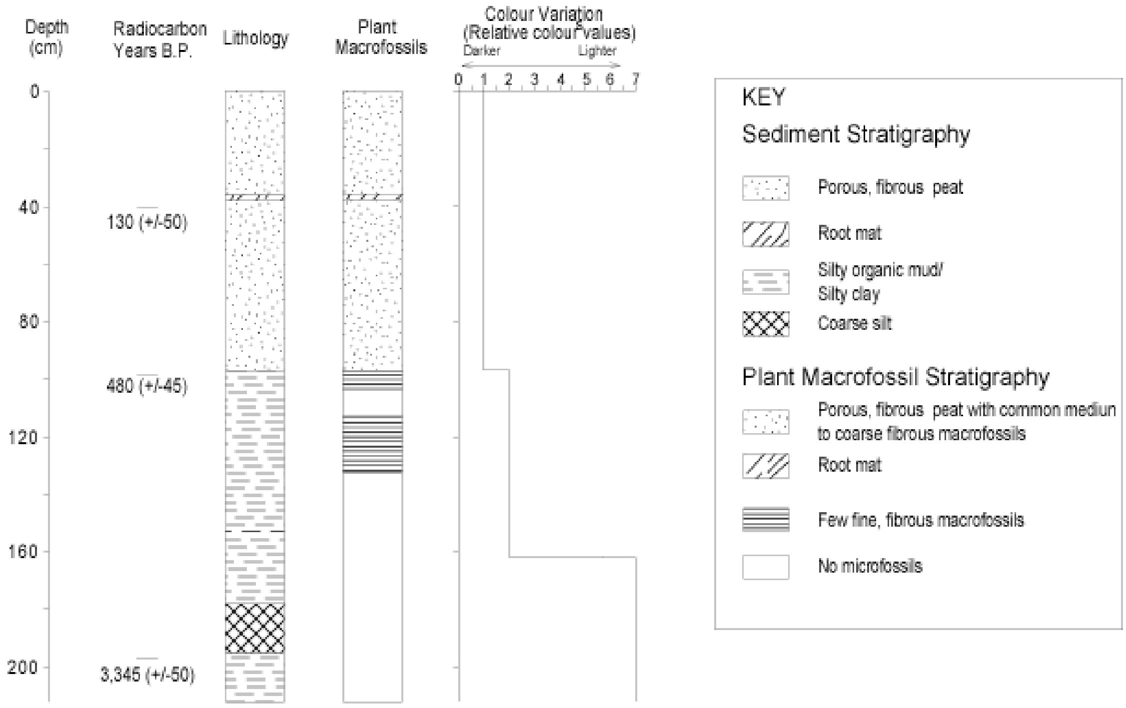

Figure 2. Stratigraphy of core KS1. Relative colour values are assigned as outlined in Olago (1995)

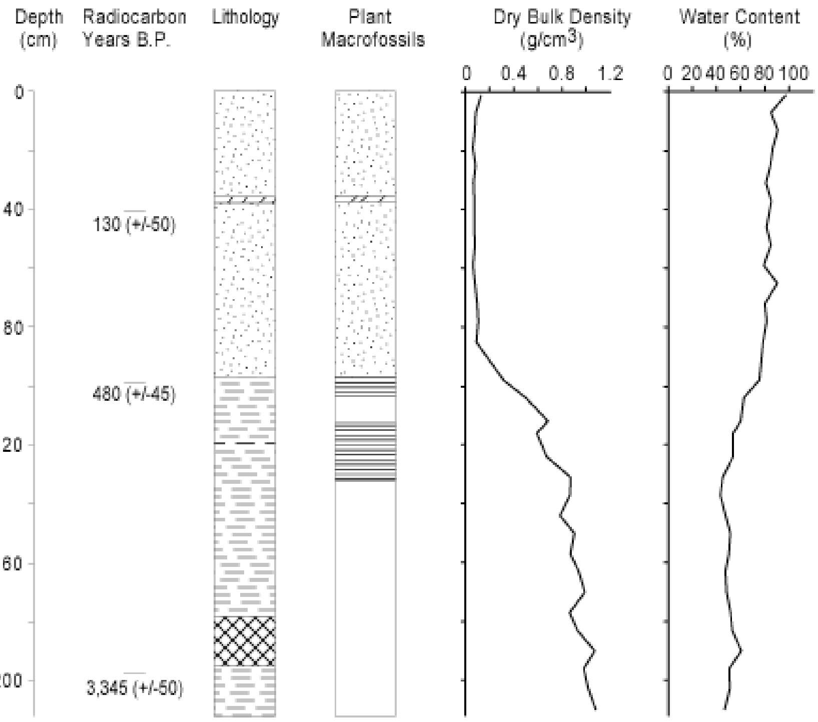

Figure 3a. Dry bulk density and water content in core KS1

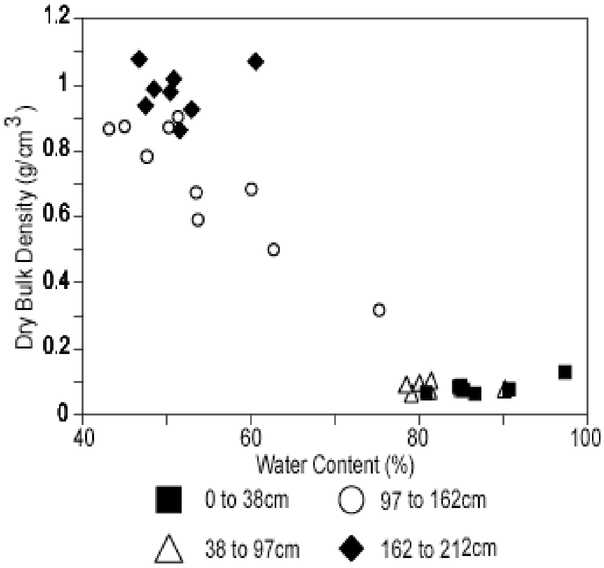

Figure 3b Bulk sediment features and characteristics of Kiluli Swamp sediments

and 128cm with a positive peak at 192cm (60%) and a low at 138cm (42%). Between 128 and 100cm water contents increase from 50 to 76%, and from 100 to 2cm further increases from 76 to 98% are recorded (Fig.3).

Changes in the DBD values and water contents reflect the sediment characteristics, higher DBD values and corresponding lower water contents are thus found in the more clastic, inorganic sediments while lower values are found in the peats. No significant correlations are observed between DBD and water content save for the sediments between 162 and 97cm (Fig.3). These sediments have a strong negative correlation (r = -0.91) between DBD and water content, and are transitional between the high density sediments at the base and the low density sediments at the top of the core (Fig.3). The change in DBD from higher to lower values (and vice versa for the water content) marks the change from a dry to wet environment in Kiluli valley (Figs.8.2 and 8.3). The gradual increase in water contents from 97 to 0cm and the almost invariant DBD values within this zone indicate that the trends in the water content are mainly a factor of reduced sediment autocompaction with decreasing depth (Fig.3).

Mineral Magnetic Features

The mineral magnetic concentrations are highest within the more clastic sediments from 212 to 85cm, and in the top 45cm (Figs.4 and 5).

Highest magnetic mineral concentrations occur within the coarse silt bed at 195 to 178cm, and within the top 4cm. The correlation of χ and SIRM with DBD is not significant. However, in the low density organic sediments above 97cm, large variations in both χ and SIRM at invariant DBD values indicate changing proportions in the types and overall concentrations of magnetic minerals present (i.e. superparamagnetic, single-domain magnetites, or paramagnetic minerals (including haematite). Relatively smaller ranges in the values occur between 212 to 97cm, but the range in SIRM values is large indicating the importance of haematite and goethite contributions within this zone (Fig.5). The SIRM and χ have a regression coefficient of 0.76 and a ratio of *ca*.8kAm^{-1}, and reflects a strong influence of magnetite in the sediments (Fig.6) (*cf*. Thompson and Oldfield, 1986). Principal components analysis shows that most of the variance in the data set is explained by the first two components (91% and 7% respectively) (Fig.5).

The first principal component (PC1) reflects the total concentration of magnetic minerals within the sediments, and mirrors the SIRM trend. The much higher scores at the top compared to the bottom of the core (as opposed to the SIRM curve which shows similar magnitude concentrations) is attributed to an artificially high weighting of magnetite due to the inclusion of χ and χ_{fd} which solely reflect the magnetite content of the sediments (Fig.4). The second principal component shows the influence of high haematite and goethite concentrations, most marked between 212 and 162cm. This is reflected in the normalised curves which show high concentrations of haematite and goethite from 212 to 162cm, especially in the coarse silt bed (up to 80%), and the 'hard' IRM (HIRM) concentrations (Fig.5). Although haematite is ubiquitous within the whole core, goethite makes significant contributions only up to 130cm.

Normalised mineral magnetic IRM, and the HIRM values between 212 and 162cm indicate that the magnetic signal in this zone is dominated by haematite/goethite, especially in the coarse silt bed where the relative proportions are up to 80%, and HIRM has values up to 200x10^{-5} Am^{3} kg^{-1} (Fig.5). Below 16cm, haematite and goethite dominate the magnetic mineral signature (>50%) (Fig.5). The sharpest changes in magnetic mineral concentrations tend to occur at boundary positions and can be related to changes in the influx rates of magnetic minerals (and more generally, allochthonous material) to the swamp, as facilitated by unstable environmental and climatic conditions. Maximum goethite concentrations occur within the coarse silt bed (195 to 178cm), where it contributes 20% of the SIRM signal. Its presence suggests

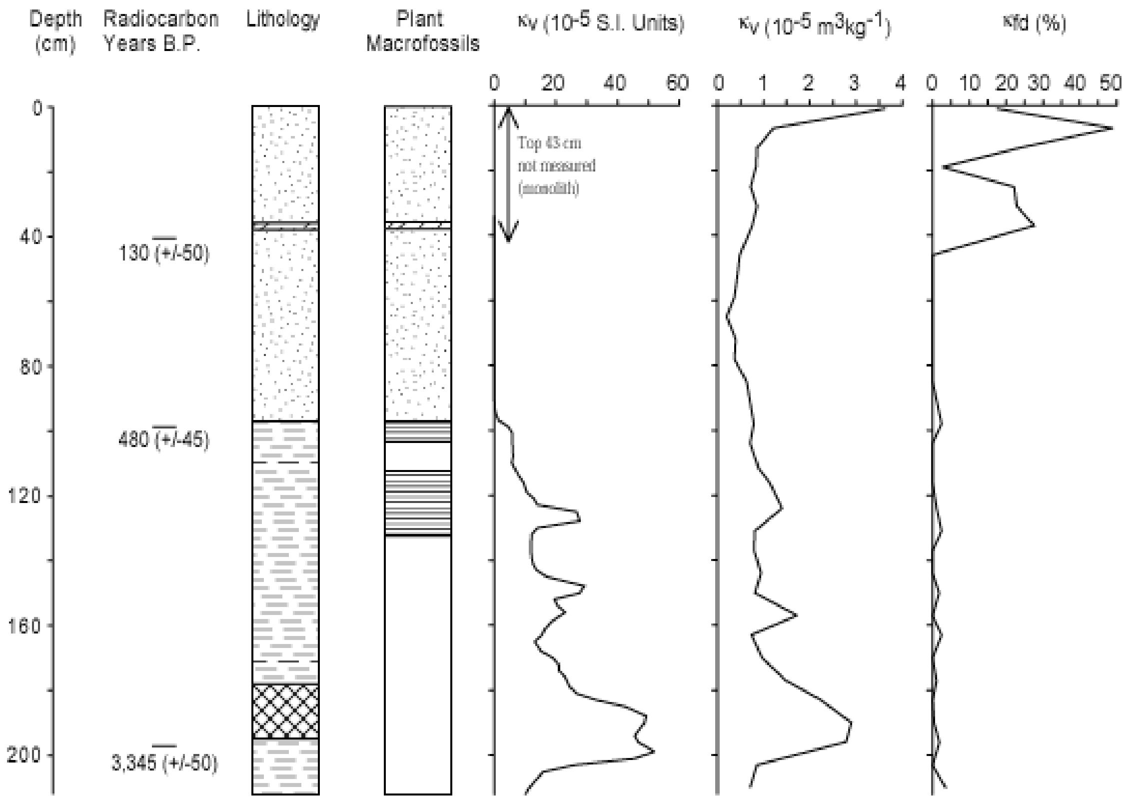

Figure 4. Trends in magnetic susceptibilities by depth, core KS1. κ_v - volume susceptibility; κ - mass specific susceptibility; κ_{fd} - dual frequency susceptibility

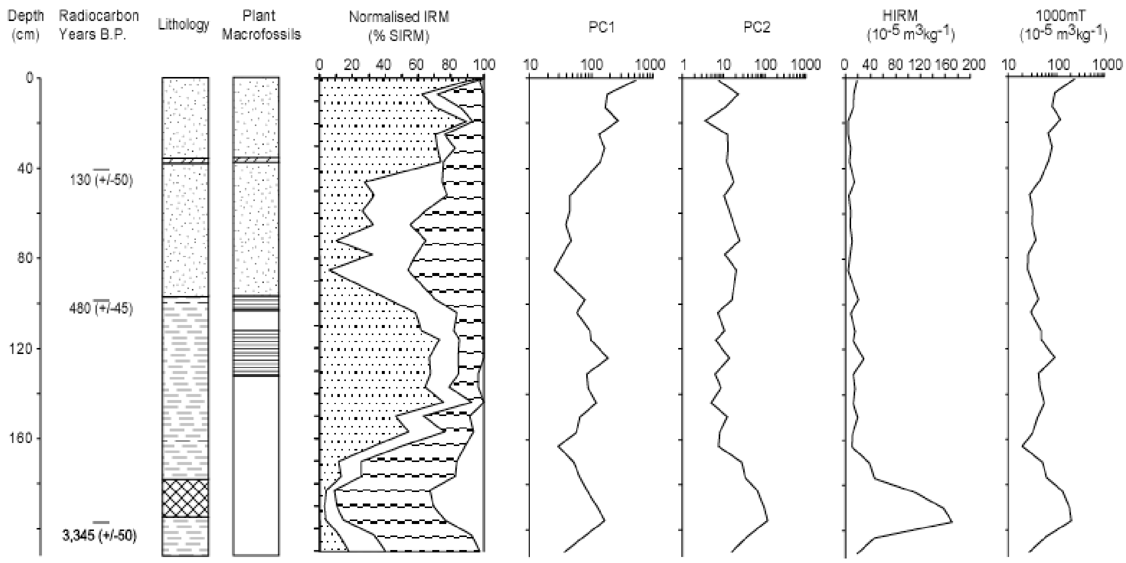

Figure 5. Summary diagrams of isothermal remanent magnetism properties and principal components analysis in core KS1

that the swamp was well-drained and climatic conditions were generally mild, especially between 195 and 178cm (*cf*. Thompson and Oldfield, 1986). High concentration gains in the 100 to 300mT field within the coarse silt bed suggests that there is a high loading of impure magnetite grains.

From 162 to 97cm, magnetite dominates the magnetic mineral assemblage, averaging *ca*.80% (Fig.5). As in the preceding zone (212 to 97cm), the largest changes in the magnetic mineral concentrations occur at boundary positions related to an unstable and changing environment. Goethite concentrations taper off at 130cm and may indicate that the climate was becoming drier. The significant contributions of 'soft' magnetite between 163 and 90cm can be related to increased soil inputs (Figs.4 and 5).

The generally very low susceptibilities from 97 to 38cm can be attributed to an overall reduction in the concentration of magnetite and an increase in haematite/goethite contents (Fig.5). During this period, then, higher temperatures, good aeration, rapid decomposition of organic matter, and a relatively high pH within the swamp may account for the increase in haematite (*cf.* Schwertman and Taylor, 1977) and macrophyte development (Fig.5). Where soils are developed from igneous rocks containing predominantly Fe^{2+} in magnetite and/or within the silicates, weathering is dominated by hydrolytic and oxidative reactions that result in the formation of haematite and/or goethite (Thompson and Oldfield, 1986).

From 38 to 0cm, higher magnetite concentrations are indicated by the magnetic mineral parameters (Figs.4 and 5). A slight increase in magnetite contributions is observed following desiccation at 38 to 36cm. Soft magnetite concentrations are also significant in this zone, and their insurgence is attributed to geomorphic instability as a result of climate change to lower precipitation indices and slightly enhanced erosion (Figs.4 and 5). The high concentration and domination of the magnetic mineral assemblage by magnetite in the top 4cm is not associated with any change in the sediment characteristics and suggests that this is probably an effect of cultivation and concomitant enhanced soil erosion within the swamp area; burning may have also enhanced the susceptibility signal. Le Borgne (1955) showed that the magnetic susceptibility of topsoil is often higher than that of the underlying

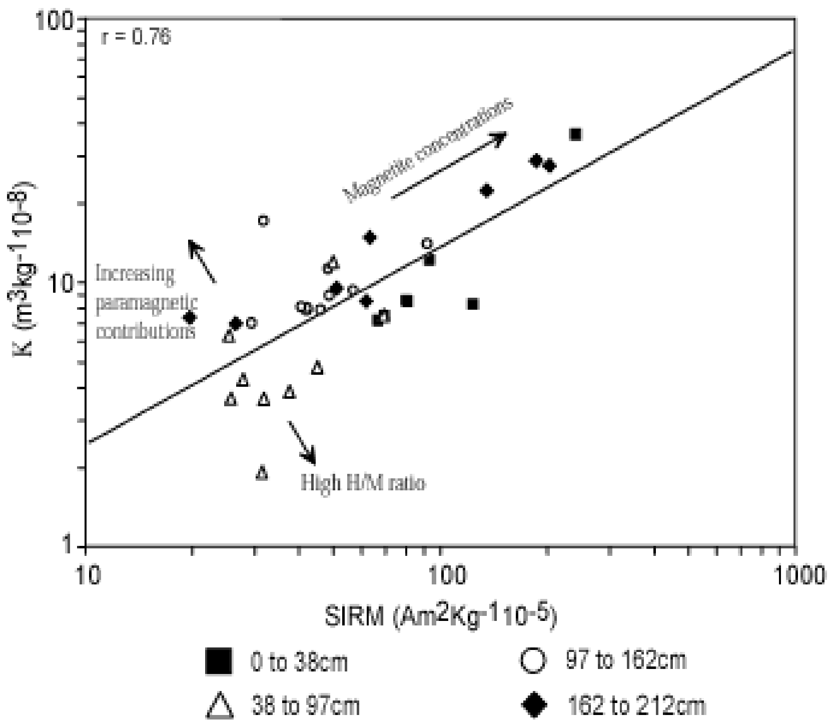

Figure 6. Scatter plot of saturation isothermal remanent magnetism versus magnetic susceptibility, core KS1

material, and ascribed this to the formation of secondary ferrimagnetic oxides within the clay size fraction of the soil. Burning (generally accepted as a major factor in magnetic enhancement) may partly account for the magnetic enhancement in the surface and near-surface sediments of this zone. Maghaemite is undoubtedly produced by burning (Longworth and Tite, 1977), and non-stoichiometric magnetite may also be formed (Longworth *et al.*, 1979).

Features of the Organic Component

The TOC contents generally increase from the base of the core to the top (Fig.7). Between 212 and 130cm TOC contents are extremely low, averaging 3%. Concentrations increase from 3 to 12% between 130 and 98cm. From 98 to 85cm a steeper increase (12 to 40%) is recorded. A further increase in TOC concentrations is registered from 85 to 19cm (40 to 50%). From 19 to 0cm TOC concentrations decrease from 50 to 36% respectively (Fig.7).

Total nitrogen (TN) concentrations generally increase from the base to the top of the core. Lowest concentrations are recorded between 212 and 203cm (0 to 0.4%) (Fig.7). From 203 to 185cm TN concentrations average 0.4%, and between 185 and 1300cm they average 0.5%. Fro M130 to 80cm there is a relatively large increase from 0.5 to 2.6%. From 80 to 0cm, relatively high TN concentrations persist, and lie between 2.4 and 3% (Fig.7). Higher concentrations are centred at 31cm (3.3%) and 19cm (3.4%). These trends in the TN concentration mirror the TOC concentrations and can be attributed to similar causes (Fig.7).

From 212 to 203cm C:N ratios are low, generally <1 (Fig.7). Between 203 and 184cm a broad peak is recorded with C:N values of 7 to 8 between 197 and 190cm. From 184 to 65cm a gradual increase in the ratios, from 1 to 20 respectively is observed. The C:N ratios are <10 from 184 to 96cm, and >10 from 96 to 65cm. From 46 to 0cm C:N ratios decrease from a peak of 20 to *ca.*12 respectively; a positive excursion within this zone occurs at 25cm (C:N = *ca.*17) (Fig.7).

The $\delta^{13}C$ values are between -16.2 and -26.8‰ (Fig.7). From 212 to 49cm the $\delta^{13}C$ values are between -21.8 and -19.9‰. From 49 to 40cm there is a large shift towards more negative values, i.e. from -19.9 to -26.8‰. From 40 to 0cm the $\delta^{13}C$ values are between -24.3 and -26.8‰ (Fig.7).

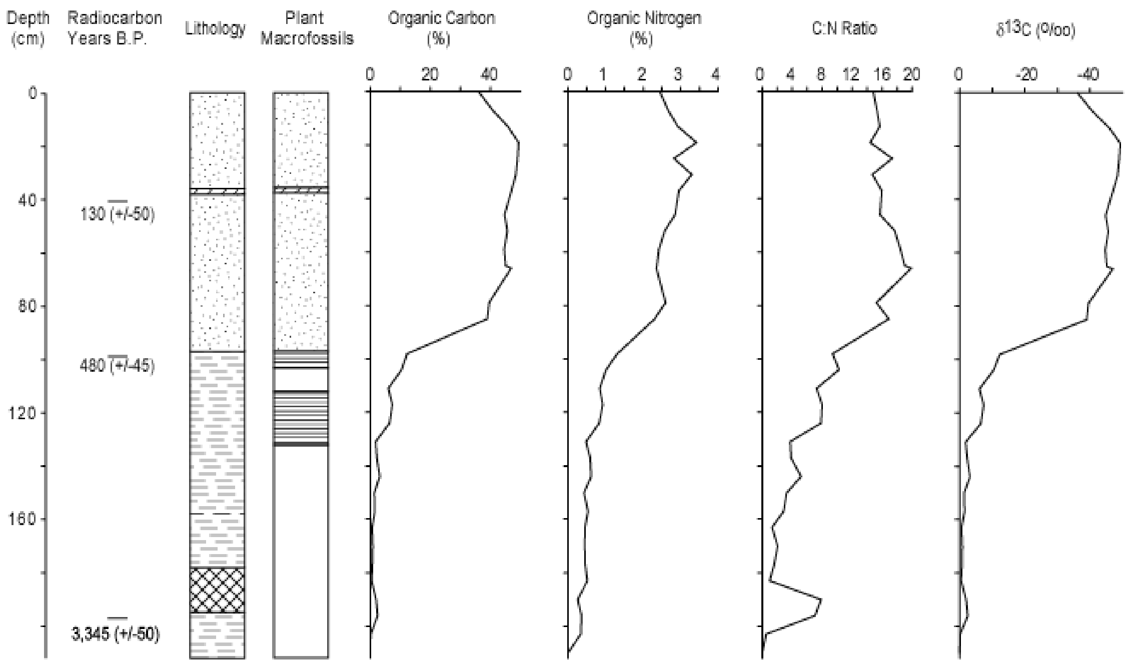

Figure 7. Trends in the organic carbon and nitrogen concentrations, C/N ratios and $\delta^{13}C$ in core KS1, by depth

TOC is the most dominant organic component and shows a strong positive correlation to organic matter abundance (C+H+N). Low TOC contents below 130cm reflect the highly clastic nature of the sediments, and little or no productivity within the swamp area (Fig.7).

Low C:N ratios (<8 and in most cases <4) from 212 to 130cm reflect the importance of soil organic matter (derived from areas extraneous to the swamp) within the sediments. The higher incidence of charcoal between 140 and 130cm reflects the importance of fires (natural or man-made) during this period. Higher C:N ratios (10 to 20) above 96cm reflect the importance of macrophyte contributions within the swamp itself. The slight carbon peak at the silty clay - coarse silt boundary (*ca.*195cm) suggests an episode of increased inputs from the surrounding area. The increases from 163 to 97cm (1 to 13% respectively) indicate increasing inputs from locally derived organic material, with largest increases being associated with the zones containing few fine fibrous macrofossils (Fig.7). This trend reflects the encroachment of the swamp by terrestrial vegetation. Deep ponding and probably well aerated waters between 103 and 97cm supported a diverse diatom population; this is the only section containing diatoms.

A large change in the carbon and nitrogen contents and the C:N ratio occurs at the boundary at 97cm and reflects a major hydrological and ecosystem change within Kiluli valley (Fig.7). It represents a marked shallowing of the swamp waters, and encroachment of the swamp by highly productive macrophytes, and thus marks the initiation of swamp conditions within Kiluli valley. The increased incidence of fire is reflected in the relatively higher charcoal contents (1 to 2%) and probably reflects anthropogenic disturbance related to cultivation practices in the swamp.

The $\delta^{13}C$ values show that Kiluli Valley consisted mainly of C_4 grasslands between 212 and 49cm; a mixed C_3-C_4 ecosystem existed between 195 and 178cm in the section comprised of the coarse silt bed (Fig.7). The transition from the C_4-dominated to C_3-dominated ecosystem occurred just prior to the desiccation event between 39 and 36cm, above which the C_3 ecosystem is dominant to the present (Fig.7). Since this change from C_4 to C_3 ecosystems occurs as an arid event was being approached (and thus one would expect drought-resistant C_4 species to persist), this change is most likely due to anthropogenic-related cultivation of C_3 plants within the swamp (Fig.7).

PALAEOCLIMATE AND PALAEOENVIRONMENT

Local

Zone 3 (212-162cm; 3970 to 2245 yr BP)

The minerogenic nature of these sediments, and the lack of diatoms (A. Parkes, pers comm.) indicate that it was relatively dry compared to today. The well-defined peak in the C:N ratio (C:N = 8) at about 200cm, coincides with maximum susceptibility values (high magnetite concentrations) and a shift from fine to coarser detritus. This implies that the material may have accumulated C and N under slightly pedogenic conditions, and is supported by magnetic mineral data which show development of haematite and goethite under a hydrolytic and oxidative regime in the area. The presence of goethite additionally suggests that the area was well-drained (*cf.* Thompson and Oldfield, 1986). These data suggest that during this period, swamp conditions were non-existent. The vegetation in the area consisted of mixed C_3-C_4 type plants.

Zone 2 (162-97cm; 2245-470 yr BP)

The increasing concentration of organic matter within the sediments, and reduction of goethite concentrations reflecting increasingly poor drainage trends in this zone signifies the progressive development of swamp conditions. It is not clear how this may have been initiated, but it could perhaps be related to progressive silting and consequent damming at the valley outlet. It suggests that vegetation had began to encroach the coring site, but does not unambiguously reflect an increase in humidity in the area. The magnitude of change in TOC (1 to 13% from 163-97cm) indicates increasing inputs from locally derived organic material, with largest increases being associated with the zones containing some fine fibrous macrofossils (Fig.7). This trend reflects the encroachment of the swamp by local terrestrial vegetation.

The diatom-rich black silty organic mud bed containing occasional fine fibrous macrofossils between 103 to 97cm reflects deep ponding in the swamp, leading to high productivity of aquatic plankton and the development of macrophyte communities. This is the only section containing diatoms.

Zone 1 (97-0cm; 470-0 yr BP)

The significant change at 97cm, marked by the disapearance of diatoms, a large change in the carbon and nitrogen contents and the C:N ratio and development of peats reflects a major hydrological and ecosystem change within Kiluli valley. The soft, porous, fibrous peats with common to abundant plant macrofossils indicate high aquatic macrophyte productivity, and the boundary at 97cm marks the initiation of true swamp conditions. Lack of diatoms indicate that the water table was below ground level. The generally very low magnetic volume susceptibilities from 97 to 38cm can be attributed to an overall reduction in the concentration of magnetite and an increase in haematite/goethite contents (Fig.4). During this period, then, higher temperatures, good aeration, rapid decomposition of organic matter, and a relatively high pH within the swamp may account for the increase in haematite (*cf*. Schwertman and Taylor, 1977) and macrophyte development. Mixed C_3-C_4 type plants characterised this zone up to about 40cm.

The root mat between 38 and 36cm represents an abrupt dry phase. The $\delta^{13}C$ values indicate that vegetation shifted sharply from a mixed C_3-C_4 to C_3 type during this time.

From 36 to 0cm, C_3 type vegetation is prevalent in the area. A modern day floristic analysis of the low altitude grasslands (<1500m a.s.l.) suggests that nearly all the Poaceae (e.g. Chlorideae, Eragrosteae, Sporoboleae, and Aristideae) are of the C_4 photosynthetic type and are associated with low soil moisture (Tieszen *et al.*, 1979). The dominant C_3 types therefore reflect an increase in humidity in the region.

The high concentration and domination of the magnetic mineral assemblage by magnetite in the top 4cm is not associated with any change in the sediment characteristics and suggests that this is probably an effect of cultivation and concomitant enhanced soil erosion within the swamp area; burning may have also enhanced the susceptibility signal. Le Borgne (1955) showed that the magnetic susceptibility of topsoil is often higher than that of the underlying material, and ascribed this to the formation of secondary ferrimagnetic oxides within the clay size fraction of the soil. Burning (generally accepted as a major factor in magnetic enhancement) may partly account for the magnetic enhancement in the surface and near-surface sediments of this zone. Maghaemite is undoubtedly produced by burning (Longworth and Tite, 1977), and non-stoichiometric magnetite may also be formed (Longworth *et al.*, 1979). Destruction by fire and, more recently, encroachment by agriculturists has raised the lower limit of the indigenous forest of Mount Kenya to its present position (Baker, 1967); cultivation takes place at altitudes up to about 2,300m (Hastenrath, 1973).

Regional

The dry phase at 4,000 yr BP reflected by an increase in *Podocarpus* pollen at Sacred Lake and the Hohnel valley mire (alt.4,265m) (Perrott, 1982), is correlated with the prevalence of mixed C_3-C_4 plants at Kiluli Swamp. Climate became progressively more humid at Kiluli valley from 2,245 to 470 yr BP. True swamp conditions were initiated at *ca*.470 yr BP immediately following ponding of the valley. This correlates with the advent of sedge peat in lake Nkunga at *ca*.510 yr BP and reflects a slightly arid event. A C_4-ecosystem was dominant in Kiluli Swamp until 130 yr BP, following which C_3-ecosystems were became dominant. The high incidence of charcoal in Kiluli Swamp probably reflects anthropogenic fires, and may be related to cultivation practices within the swamp.

The initiation of drier conditions on Mount Kenya at *ca*.4,000 yr BP, indicated by an increase in *Podocarpus* pollen at Sacred Lake and the Hohnel valley mire (alt.4,265m) (Perrott, 1982), and by a shift towards more positive $\delta^{13}C$ values in the Sacred Lake (Olago *et al.*, 1999) and C_4 plants in Kiluli Swamp, is also evident at other sites from pollen records: dry montane forest taxa replaced wet montane forest taxa in the high altitude regions, while at lower altitudes, trees gave way to herbaceous elements. The $\delta^{13}C$ of palaeosols in a transect from Naivasha to the Mau Escarpment, shows a mid-Holocene rise (>300m) in the altitude of the savanna-forest ecotone and reflects the onset of drier conditions in the Naivasha basin (Ambrose and Sikes, 1991). Aucour *et al.* (1994) observed an increase in C_4 plant types from *ca*.4,500 yr BP in Kashiru, Burundi. A similar observation is made in the Nilgiri Hills, southern India, by Sukumar *et al.* (1993) for the period 4,700 to 3,000 yr BP. In both cases these changes are attributed to an increase in aridity. These dry conditions generally characterised the rest of the Holocene period.

SUMMARY

The Kiluli Swamp record covers the late Holocene, from *ca*.4,000 to 0 yr BP. The valley was initially dry and the catchment vegetation was characterised by dominant C_4-type grassland. The initiation of true swamp conditions occurred at *ca*.470 yr BP immediately following a phase of deep ponding and high diatom productivity within the swamp between 600 and 470 yr BP. The high incidence of charcoal from 470 to 0 yr BP probably marks the period of persistent anthropogenic activities within the catchment. The change from C_4- to a C_3-type vegetation at *ca.*130 yr BP is probably due to a change in type of agronomic crops grown within the swamp rather than due to climate change, since the arid phase which marks this zone would have, under natural conditions, abetted the continued dominance of C_4 plants which are more drought-resistant than C_3 plants.

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