1. INTRODUCTION

The project was based in the South Western province of the Republic of Cameroon and involved ecological / soil studies of ten forest plots set up at altitudinal intervals of 600 m on the south eastern slopes of Mount Cameroon from 180 m above sea level to 2180 m near the tree line. It forms part of a wider study of altitudinal zonation of tropical rain forests in Costa Rica (Marrs et al 1988) and Seram, Indonesia (Edwards et al 1990, 1993; Payton 1993). Mount Cameroon is the highest mountain in West Africa (4070 m) and was chosen for this study because the southern slopes of the mountain are one of the only areas in the region where rain forest exists in an unbroken transect over a range of altitudes from near sea level to the tree line. Above the treeline are montane grasslands and lichen-rich alpine communities. The forest is considered to be rich in endemic species, forming valuable reservoirs of genetic resources. The ecological and biological importance of this unique area has now been recognized by the recent creation of the Mount Cameroon / Etinde Genetic Conservation Reserve as part of the ODA-supported Limbe Botanic Gardens Project. However, the forests are under potential threat from clearance for cultivation and logging concessions at their lower altitudes. So called "chop farms" occur right up to 160 m above sea level, close to the start of the altitudinal transect examined in the study. These clearance areas extended between visits made in 1989 and 1991. The upper fringes of the Montane Forest are also receding through regular encroachment by fires set by hunters in the montane grasslands. Grassland fires swept into the edge of one of the forest plots at 2180 m near Mann's Spring during the course of the research project, destroying understorey vegetation and creating a gap in the canopy. Clearly there is an urgent need for an assessment of the floristics, ecology, soil resources and conservation value of Mount Cameroon's forests if they are to survive in the long term and be utilized on a sustainable basis.

The vegetation on Mount Cameroon has been previously described by Maitland (1932), Boughey (1955) and Keay (1955) and the altitudinal zonation by Richards (1963) and Hall (1973). These accounts concentrate on the less complex upper forest and grassland zones. Thomas (1985) gives descriptions and short species lists for the upper forest, mid-elevation forest and lowland forest on the south side of the mountain. The present study is the first to publish quantitative data comparing forests at different altitudes. Previous studies of soils on Mount Cameroon have been restricted to those occuring at lower altitudes under lowland rain forest or on farmland, mainly on the eastern slopes, and have been concerned with soil survey and classification for agricultural purposes (Hasselo 1961, FAO 1976, Ikawa and Tsuji 1987) or with studies of weathering and clay mineralogy (Sieffermann and Millot 1969, Sieffermann 1973, Delvaux et al 1989)).

The most recent studies formed part of the International Benchmark Soils Project to characterize young soils on volcanic ash, known formerly as Andepts and currently as Andisols (Ikawa and Tsuji 1987). The soil profiles analysed were again mainly from lower elevations under agriculture on the eastern side of the mountain where a development sequence was described from young, dark-coloured Andisols (classed as Lithic Dystrandepts) over recent volcanic ash and lava at 1112 m above sea level near Bokwango, to much more strongly weathered red Ultisols (Orthoxic Paleuhumults) over older Tertiary basalts at 220 m above sea level on the Moliwe Oil Palm estate near Limbe (van Barneveld 1987). A similar weathering sequence on the eastern slopes is discussed by Delvaux et al (1988). Soil observations on the south western slopes of Mount Cameroon are restricted mainly to descriptions of thixotropic Hydrandepts from the lowland forest below 300 m and well to the west of Mount Etinde in the perpetually wet West Coast district. These are given in the report of the FAO Soil Resources Project Ekona (FAO 1976), in the studies of clay mineralogy by Sieffermann (1973) and in Van Barneveld (1987). The present study is the first to report on the results of a systematic study of the altutudinal zonation of soils on the southern slopes of Mount Cameroon in relation to their genesis and to forest ecology.

The altitudinal zonation of rain forests on tropical mountains has been described from several locations and the more important studies are reviewed by Grubb (1977,1989), Proctor (1988) and Whitmore (1984, 1990). The general conclusions reached suggest that the causes of declining species diversity, changes in structure and physiognomy and declining productivity observed with increasing altitude are still poorly understood. Detailed pedological studies of the altitudinal zonation of soils on tropical mountains are more restricted (e.g. Askew 1964, Reynders 1964, Burnham 1978, Payton 1993). There are some detailed quantitative studies of the floristics and structure of montane forests in relation to selected soil properties (Grubb and Tanner 1976, Edwards and Grubb 1982, Tanner 1977, 1985 and Grubb and Stevens 1985) but, until recently, there have been very few integrated studies of forests and soils at a range of altitudes from near sea level to the tree line on single tropical mountains (Proctor et al 1988, Marrs et al 1988, Vitousek et al 1988, Edwards et al 1989, 1993, Payton 1993).

There have been suggestions that montane forests are not only limited by climatic or hydrological factors, but also by the supply of nutrients including nitrogen, phosphorus and, perhaps, potassium and calcium (Grubb 1977, Edwards 1982, Tanner 1977, Vitousek and Sanford 1986). Recent studies of altitudinal zonation in Seram, Indonesia indicate that soils developed from particular parent rocks have extremely small nutrient reserves in both surface and subsoil horizons, and that this, in combination with poor soil drainage and climatic effects, may limit the growth of some Montane Forests (Payton 1993). In contrast, the results of other recent research have shown that many species-poor Tropical Montane Forests do not appear to be limited by the supply of most essential nutrients other than nitrogen, suggesting that the availability of nitrogen may be limiting due to slower rates of mineralization at higher altitudes (Tanner 1985, Marrs et al 1988, Healey 1989, Heaney and Proctor 1989). There is also some evidence that the availability of phosphorous is limiting in certain cases (Healey 1989). Most ecological studies only measure soil properties of the 0-10 cm soil and pay little attention to horizon variability or to the subsoil. Wild (1989) has recently suggested that investigations should not only measure immediately available nutrient supplies, but also measure total nutrient amounts, particularly where weatherable minerals are present. Baillie (1989), and Burnham (1989), stress the importance of recognizing the contribution of soil parent material composition and nutrient reserves derived from weatherable minerals in the subsoil to forest variability in open systems of nutrient cycling, emphasizing the need to differentiate these from closed systems where inputs from weathering and subsoil nutrient supplies are minimal. These concepts are relevant to mountainous situations where soils are often relatively young and are rarely excessively deep, so that contributions of fresh parent material to soil nutrient reserves are more likely.

2. OBJECTIVES

The design of the Mount Cameroon project took many of the findings of the above research into consideration. It integrated quantitative studies of forest floristics and structure with detailed pedological studies of soil characterization and genesis of representative soil profiles located on forest plots set up at regular altitudinal intervals, and included a randomized sampling strategy of surface (0-10cm) and subsoil (50-60cm) horizons within plots. The original objectives of the project were as follows.

1. To investigate the altitudinal zonation of rain forests on Mount Cameroon by a quantitative assessment of floristics and structure of paired 0.25 hectare plots at 600m intervals from near sea level to the tree line.

2 To characterize soil physical and chemical properties of the forest plots and to assess soil changes with depth and with altitude; variation between plots; and relation to changes in forest floristics and structure.

3. To determine the dynamics of soil forming processes on basaltic lavas and volcanic ash under rain forest at a range of altitudes.

4. To provide a quantitatively evaluated altitudinal sequence of permanent forest plots which can be monitored at regular intervals in the future and provide a resource base for the Limbe Botanic Garden.

Long term monitoring of the plots will provide information on rates of growth of trees at different altitudes and other data relevant to both the management of natural forests and to their ecology and conservation. Limbe Botanic Gardens will be responsible for the management of the forest reserve in which the plots are located and it is envisaged that a continuing programme of research and training that makes use of the plots will be facilitated.

3. RELEVANCE TO ODA STRATEGY AND TO DEVELOPMENT

The project forms part of the ODA programme involved with the inventory, conservation and management of natural forests. South west Cameroon is one of the most biologically diverse areas in the Old World Tropics and the need for initiatives to enhance the conservation and sustainable use of rain forest resources has been recognized by the Cameroon Government. The rain forests of Mount Cameroon stretch from near sea level to about 2800 m and, in this respect, are unique in West Africa. They are considered to be rich in endemic species, forming valuable reservoirs of genetic resources. Yet, at the start of this research project, there had been no quantitative assessment of their composition or altitudinal variation and they were under no statutory protection. Mount Cameroon's rain forests are of particular conservation value because of their intrinsic biological interest, and because they are accessible to large centres of population. This provides a potential for environmental education to demonstrate the benefits of rain forest conservation but also poses threats to their survival.

The current research project provides an ecological assessment of the undisturbed forest and soil resources in an unbroken altitudinal sequence on the south side of Mount Cameroon. The results are directly relevant to the management of the reserve and the work of the Limbe Botanic Garden and Rain Forest Conservation project. The permanent forest plots established as part of the research will enable medium and long term changes to be monitored within the genetic reserve. They have already been used in the training of Botanic Garden staff, and, it is hoped that they may eventually form an integral part of the training programmes initiated by the ODA / Living Earth supported Cameroon Environmental Education Project. They will also provide a framework for further botanical and ecological work on genetic resources. In a broader development sense, the results of the this project will help the Cameroon education authorities and the Botanic Garden to demonstrate the diversity of Mount Cameroon's forests, the environmental factors that control their variation, and their value to the nation.

4. SUMMARY OF WORK CARRIED OUT

4.1 Fieldwork

Ten paired 0.25 hectare forest plots at 600 m altitudinal intervals were set up in 1989 on the southern slopes of Mount Cameroon, west of Mount Etinde, between a point l km north of Bonenza at 180 m above sea level and Mann's Spring at an altitude of 2180 m. Plots were subdivided into 25 10x10 m subplots and all trees >10cm diameter at breast height (dbh) were numbered with aluminium tags, described and measured for dbh and height. Sets of specimens were collected for Royal Botanic Garden Edinburgh, Limbe Botanic Garden and Yaounde. Soils on the forest plots were described according to Hodgson (1976) and FAO (1977) in representative soil profiles selected after the assessment of soil variation on the plots by free survey techniques and by augering at the 10 points selected for random sampling employing a stratified random design based on the subplots. Samples from the soil horizons of representative soil profiles and ten random topsoil (10 cm depth) and subsoil (50 cm depth) samples were collected from each plot for chemical, physical and mineralogical analyses. Core samples for moisture retention measurements and undisturbed samples for soil thin section preparation and micromorphological observation were also collected from the soil profiles. The plots were maintained by Limbe Botanic Gardens staff and were revisited by Robert Payton and Stuart Ashworth in January to February 1991 to resample the soils in the moist state following analytical problems related to irreversible changes following air drying of the original samples. During this visit contacts with Limbe Botanic Garden and Ekona Soil Research Station were re-established. *In situ* studies of available nitrogen and nitrogen mineralisation on the plots were also undertaken with the co-operation of the Ekona Soil Research Station, Buea.

4.2 Plant Identification, Soil Analyses and Laboratory Methods

Identification of botanical specimens and work analysing the data on forest floristics and structure was completed by Dr Ian Edwards at the Royal Botanic Gardens Ednburgh during 1991 to 1992. A summary of the results are presented in Tables 2 and 3, and have been used to define the altitudinal zonation of the forest (Table 4). A programme of soil analyses was started by Stuart Ashworth on the orignal set of air dried soil samples in 1990 but difficulties were encountered with chemical analyses and physical analyses due to irreversible drying effects. Following the return fieldtrip to Mount Cameroon in January to February 1991, a large proportion of the planned soil analyses were repeated on the new moist sample set in the UK and at the Ekona Soil Research Institute, but this programme of work was interrupted in mid 1991 by unavoidable problems leading to the resignation of the project research assistant Stuart Ashworth (see section 4.3 below). The programme of soil analyses was finally completed in 1993.

The results of site and representative soil profile descriptions are summarised for each altitude in Tables 1, 5 and 6 and presented in more detail for each forest plot in Appendix 1. Measurement of the following properties was made on field moist < 2 mm soil samples according to methods detailed in Avery and Bascomb (1982) or Page et al (1982): soil pH in water and in KCl (1:2.5 ratio soil:solution); organic carbon by the Walkley-Black method; total nitrogen by the Kjeldahl method; exchangeable K, Ca, Mg, and Na extracted by ammonium acetate at pH 7.0 and exchangeable Al and H extracted by 0.1M KCl;, the results of the determinations of exchangeable cations were summed to give a measure of effective cation exchange capacity (ECEC) at the natural soil pH; cation exchange capacity (CEC) was also measured by the ammonium acetate method buffered at pH 7.0; and available P by the Bray 2 method. Phosphorous retention measurements were according to Blakemore et al (1981).

The following additional soil analyses were performed only on horizons sampled from the representative soil profiles from each plot: dithionite and pyrophosphate extractable Fe and Al according to Avery and Bascomb (1982); oxalate extractable Fe, Al and Si according to Parfitt et al

(1988); bulk density, porosity and soil moisture retention characteristics according to Hall et al (1977); soil micromorphology according to Bullock et al (1985) and X-ray diffraction of a limited number of the acid-dispersible < 0.002 mm clay fractions separated by the method of Farmer et al (1982) in the Newcastle University soil laboratories. Measurements of available nitrogen and nitrogen mineralisation rates were undertaken on surface soils sampled 0-10 cm using the field incubation techniques of Marrs et al (1988) at ten randomly selected sites on each forest plot; amounts of ammonium, nitrate and nitrite nitrogen in the initial field extracts, and in extracts made after a 14 day incubation period, were determined with an autoanalyser at the Ekona Research Institute.

The results of chemical and physical soil analyses for the representative profiles described in Appendix 1 are tabulated in Tables 7 to 11. In addition, the variation with altitude of individual soil properties at 10cm and 50cm depth ascertained from the analyses of the random topsoil and subsoil sample data sets from the forest plots is presented in Figures 1 to 16. Other studies of this kind have attempted to plot soil data on a logarithmic basis and fit polynomials, however, there is no *a priori* reason for expecting any one mathematical model to fit the data. This is born out by examination of the randomized sample data for Mount Cameroon which shows large within-plot variation of many soil properties and, whilst trends with altitude are evident for most determinants, they are not expressable as any one mathematical model. For this reason, no attempt has been made to fit lines or calculate the significance of the trends observed. Instead graphical presentation has been chosen which shows the means of determinants for each plot $\pm$ two standard errors within 95% confidence limits.

The project has shown that soils at all the altitudes studied on Mount Cameroon are varieties of Andisol (Soil Survey Staff 1992) developed from moderately alkaline basic pyroclastic deposits, including volcanic ash and cinders, and from basaltic lava. The measurements undertaken confirm several physical and chemical properties unique to this soil order that are associated with the high content of X-ray amorphous or para-crystalline mineral constituents, including resistance of the clay fraction to dispersion (Sieffermann 1973, Wada 1985, Parfitt and Clayden 1991). Several attempts to disperse the Mount Cameroon soils for particle size and clay mineralogical analyses at the SSLRC laboratories using conventional, ultrasonic treatment and acid dispersion techniques have failed to give reproducible results. The solution of these analytical problems, common to many Andisols, have not been possible within the time limits of the project. For these reasons particle size analyses are not presented and clay mineralogical data from X-ray diffraction studies of ultrasonically-treated, acid-dispersed clays, originally separated in the Newcastle laboratory, are restricted to soil profiles from the Lowland and Lower Montane Forest plots.

4.3 Problems Encountered During the Project

During 1991 a large proportion of the planned soil analyses were repeated on the new moist sample set in the UK and at Ekona, but this programme of work was interrupted by Stuart Ashworth's contraction of typhoid in Cameroon, his subsequent medical problems and his resignation while the principle researcher was overseas in Tanzania in mid 1991. Problems were compounded by the failure to find a suitable replacement at short notice who was prepared to work for the remaining six month period and also by the prolonged absence of the principle researcher from work himself due to illness from October 1991 to January 1992. Manpower difficulties continued to affect the project during 1992 stemming from Stuart Ashworth's resignation in and from the transfer of the principal researcher from the Soil Survey and Land Research Centre, CIT to a lectureship at the University of Newcastle upon Tyne on 1st April 1992. It was agreed with the Forestry Research Programme that the outstanding soil analyses should be completed in the main laboratories of the Soil Survey and Land Research (SSLRC) at Silsoe, Bedford and collated by Dr R.W. Payton in Newcastle for the production of the final report. An extension to the project, intially until 30th September 1992, was granted.

The final project report was further delayed by the analytical problems at SSLRC (see section 4.2) and, latterly, by the teaching commitments of the principle researcher in his new post at University of Newcastle upon Tyne since April 1992; the lack of a research assistant to undertake statistical analysis of randomized sample data; and the absence of Dr Ian Edwards on a year's sabattical leave in Australia from October 1992 to 1993. As a result of these difficulties, a revised completion deadline of 31st August 1993 was granted for the final report. Some of the soil analyses orginally planned, including: determinations of total elements (Si, Al, Fe, Ca, Mg, K ,P and Na) by X-ray fluorescence; particle size analysis and some mineralogical analyses have not been possible.

5. SUMMARY OF RESULTS

5.1 Physical Environment and Soil Parent Materials

5.1.1 Geology and Geomorphology

Mount Cameroon is an active Hawain type volcano without a central crater, subject to continued fissure eruptions on the flanks of the mountain that result in lava flows and small cinder cones. The most recent eruption, described by Fitton et al (1983), was in 1982 north-north-west of Mann's Spring and not far from the altitudinal vegetation and soils transect of the present project. This eruption resulted in a cinder cone and a flow of slaggy basaltic lava which extends into the Upper Montane Forest about 1 km west of Plots 7 and 8 at 2180 m. Volcanic activity started in the Upper Cretaceous but eruptions were most frequent from the Tertiary to the present. Lavas of the older volcanic eruptions occur mainly on the eastern side of the mountain north east of Ekona (Hasselo 1961) but those on the southern and western flanks, including the study area, are much younger, emanating from Holocene radial fissure eruptions. These are concentrated on a plateau lying just above Mann's Spring between 3000 and 3500 m that is dominated by young volcanic landforms, including cinder cones and lava ridges largely occupied by shallow, immature soils supporting montane grasslands, or bare lava and airfall pyroclastic deposits. However, the fissure eruptions have extended right down the steep south western flanks that are currently covered by rain forest. This results in a landscape consisting of steeply sloping (15 to 35º) rocky ridges conforming to individual lava flows separated by numerous dry channels or ravines that radially dissect the mountain side. The concave depressions between the lava ridges often have gentler slopes of between 4 and 12º. Further details of the geology and landform of the forest plots are summarised in Table 1.

5.1.2 Geology and Soil Parent Materials

The alkaline basic lavas are fine-grained vesicular olivine basalts (Fitton et al 1987, Halliday et al 1988) and underlie the soils of the rocky ridge tops and steep upper ridge flanks. The younger flows are little weathered and soil parent materials (Table 5) on some of the forest plots actually consist of thin (< 1m), almost stoneless, airfall deposits of cindery pyroclastics and ash which directly overlie hard fresh basaltic lava either on ridge crests, e.g. Profile No.6A at 1100 m, or on lower ridge flanks, e.g. Profile No. 7B at 2180 m, passing upslope onto rocky lava ridges with patchy soil development (see the site and soil profile descriptions in Appendix 1). Evidence, in soils of the forest plots at and above 1100 m, of young stoneless soils over unweathered or little

weathered cinder and ash layers that have buried much more stony soil profiles developed from a mixture of more weathered basaltic lava and airfall deposits, indicate the importance of relatively recent contributions of pyroclastics and ash for soil formation (see descriptions of Profile No.7A at 2180 m and Profiles 9 and 10 at 1800 m in Appendix 1). Thicker stoneless airfall deposits, consisting of cindery pyroclastics and ash, are found on the plateau above 3000 m and around cinder cones on the mountain flanks, such as those west of Mapanja village in the vicinity of Plots 5 and 6 at 1100 m. They also accumulate on moderately to strongly sloping (4-11^o) concave depressions between lava ridges at this altitude and form the parent material of Profiles No.5 and 6B (see descriptions in Appendix 1).

Older airfall deposits have often been subject to colluvial movement on the steep slopes, frequently as mudflows after heavy rainfall. These colluvial materials usually include both fresh and weathered basaltic stones and form thicker deposits in moderately to strongly sloping (4-11^o) depressions between lava ridges and on concave lower ridge flanks, resulting in deeper soils in these topographic positions. They are common at lower the altitudes and form the parent materials of many of the soils in concave sites on Plots 1 and 2 at 180 m and on Plots 3 and 4 at 600 m (see Profiles No. 1, 2, 3A and 4 in Appendix 1). They overlie more reddish (5YR 4/2) strongly weathered olivine basalts in Profile No.1 at 180 m above sea level. Profile No.3B occurs in a depression between lava ridges on Plot No.3 at 600 m and is developed in thin colluvial deposits containing fresh basaltic stones overlying strongly weathered, stoneless, reddish (2.5YR 3/4 to 5/4) vesicular saprolite derived from older basaltic lavas at 90 cm depth. The fact that these soils pass upslope into rocky shallow soils on lava ridges consisting of fresh basaltic lava indicates that lavas at these lower altitudes can vary considerably in degree of weathering and therefore also in age.

5.1.3 Climate

Mount Cameroon has a strong influence on climate causing considerable orographic rainfall, especially on the rain-bearing windward south western side of the mountain. The meterological station near sea level at Debunscha in the West Coast area receives nearly 10,000 mm mean annual rainfall, one of the largest recorded precipitations in the world. This extremely high figure rapidly declines in an easterly direction to about 5000 mm near sea level at Bonenza (Embrechts and Tavernier 1987), close to the start of the altitudinal transect of the present project. Mean annual rainfall decreases with altitude to approximately 4000 mm at 1000 m and, again, to approximately 3000 mm above 2000 m, i.e. around Mann's Spring in the Upper Montane Forest (Table 1). The Lowland Rain Forest of the study area thus receives just under 5000 mm rainfall on Plots 1 and 2 at 180 m declining to about 4000 mm close to the transition to the Lower Montane Forest discussed in the next section. A short dry season occurs some time between December and February but humidity remains at 75 to 80% due to the maritime influence and the high incidence of mist and orographic cloud formation, giving the lowest figures for annual sunshine hours in West Africa.

The air temperatures at sea level are constantly high throughout the year, mean monthly air temperatures at sea level varying from 27^{o}C to between 32-35^{o}C during the hottest period from March to April. Embrechts and Tavernier (1987) calculated a negative gradient of mean annual air temperature (MAAT) of 0.45^{o}C per 100 m increase in altitude up to 2000 m for Mount Cameroon. Using a regression equation for the negative gradient of mean annual soil temperature (MAST), they predict that soil temperature regimes (according to classes defined by Soil Survey Staff 1992) are isohyperthermic (MAST $\geq$ 22^{o}C) below 1600 m; isothermic (MAST 15-21^{o}C) between 1600 and 3120 m; and isomesic (8-14^{o}C) above 3120 m (Table 1). According to data from Ekona Soil Research Station, the upper isohyperthermic limit lies at 1200 m rather than 1600 m altitude due to the effect of descending cold air masses and the high incidence of cloud around the mountain. Measurements of noon air temperatures beneath the forest canopy and equivalent soil temperatures at 10 cm and 50 cm depth undertaken during the current project in February 1991 demonstrated that air temperatures decreased from 27.4^{o}C at 180 m to 22.0^{o}C at 1100 m to 20.3^{o}C at 2180 m, whilst soil temperatures at 10 cm depth declined from 25.2^{o}C to 20^{o}C to 14.7^{o}C at those altitudes. The soil temperatures are buffered from the diurnal fluctuations of air temperature and are more likely to reflect mean annual temperatures. The rate of decrease of measured soil temperatures with increasing altitude is actually much closer to the widely accepted rate of 0.6^{o}C decrease for each 100 m increase of altitude (Van Wambeke 1992) than the rate suggested by Embrechts and Tavernier (1987). Moreover, the 0.6^{o}C rate agrees better with the 1200 m upper limit for the isohyperthermic soil temperature regime suggested by the Ekona data. This altitude coincides broadly with the transition to Montane Forest as found in the present study (see below).

5.2 Floristics and Forest Structure

5.2.1 Evidence for Altitudinal Zonation of the Forest

Over 200 voucher specimens were collected from the ten forest plots. These were divided into 142 taxa, of which 69 were identified to species level, 59 to genus, 14 to family and the remaining 12 have still to be identified. Full species lists for the plots are available from Dr I. Edwards, Royal Botanic Gardens Edinburgh. Table 2 shows the number of trees > 10 cm dbh (N); number of tree species (S); number of families (F); total basal area (BA) m^2 ha^{-1}; dominant species (% total basal area) and most numerous species (NUM SP. % total number of trees) in each of the ten plots. Table 3 shows the altitude; number of trees > 10 cm dbh (N); total number of species (S); total number of families (F); indices of species richness (D = S/N, Odum 1971) and dominance ($C = (ni/N)^2$, Odum 1971) and basal area (BA) m^2 ha^{-1}. The data shows a clear distinction in terms of both structure and floristics between Lowland Forest below 600 m altitude and Upper Montane Forest above 1800 m. The intermediate zone, represented by Plots 5 and 6 at 1100 m, is classed as Lower Montane Forest (Table 4). Species area curves showing the relationship between number of species and area from 0.01 to 0.5 ha (nb. data from adjacent 0.25 ha plots combined) were analysed by Dr Edwards. At the higher altitudes species area curves flatten out quite rapidly but at 300 m altitude the curve continues to rise suggesting that a larger plot size would have yielded even more species.

5.2.2 The Lowland Forest

The plots at 180 and 600 m contain large emergent trees, up to 45 m tall, including a number of deciduous species such as *Pycnanthus angolensis* and *Berlinia bracteosa*. The largest emergent recorded was an *Entandophragma angolensis*, 191 cm diameter, 45 m tall in and representing 23.6% of total basal area of Plot 2 at 180 m. A large *Lebruniodendron sp.* and a large *Berlinia bracteosa* account for 23.9% and 14.5% of total basal area of Plot 1 at the same altitude. These large trees represent valuable timber specimens. The forest canopy is not continuous but forms an undulating surface, frequently plummeting to the understorey or even to the forest floor. Gaps in the canopy were most frequent in the plots at 600 m, where they were generally occupied by thickets of small trees, especially *Rinorea welwitchii*, and acanthaceous shrubs. Above this altitude larger trees are confined to ridges.

The density of trees >10 cm diameter in the lowland forest plots was between 352 and 440 per hectare. This is similar to the range, 352 to 521 per hectare, given for four lowland forest areas in Nigeria and South Cameroon in Paijmans (1976). The forest below 1100 m contained characteristic features of lowland rain forest, including buttresses, woody lianes, non-woody lianes, non-woody vines and stranglers. Bryophytes were particularly abundant above about 500 m, probably a reflection of the frequent sea mists that create a permanently humid atmosphere on the southern side of the mountain for much of the year. The lowland forest is relatively species-rich, especially at the 180 m level. The number of tree species (> 10 cm dbh) per 0.5 hectare was

between 45 and 63, which is within the range given for Korup National Park, Cameroon (35 to 135 for an equivalent area) in Whitmore (1990). The most important familes are the Euphorbiaceae (12 species), Rubiaceae (11 species), Olacaceae (8 species), Leguminosae (7 species) and Sapotaceae (6 species). Thomas (1985) claimed that a major difference between this forest and other lowland forests in the area was the paucity of arborescent Cesalpinoid legumes and the relative abundance of Sapotaceae. This is not corroborated by the present study.

5.2.3 The Lower Montane Forest

There were large areas between 600 and 1800 m with a very low density of trees. Describing the vegetation at mid-elevations, Thomas (1985) notes that "the forest forms a mosaic with shrubs and herb-dominated meadows". These open areas, with only a scattering of trees, were not sampled during this study. Instead, the 1100 m plots were deliberately sited in a tongue of more dense forest approximately 3 km east of the transect line about 3.5 km west of Mapanja village. Plots 5 and 6 at 1100 m were as species-rich as the plots at 600 m (see Table 2), however, a number of lowland species common below 600 m altitude, such as *Rinorea welwitchii, Hymenostegia afzelii and Berlinia bracteosa*, were absent. Moreover, the 1100 m plots contained a number of species that are characteristic of the montane forest at the lower end of its altitudinal range, including: *Allophyllus bullatus; Clausena sp.; Crassocephalum mannii; Nuxia congesta and Rapanea rhodendroides*. The forest sampled at 1100 m therefore has a similar structure to the lowland forest but is floristically intermediate between lowland and montane forest. It has therefore been classified as Lower Montane Forest, however, the transition between Lowland and Lower Montane forest is a gradual ecotone rather than a sharp boundary.

5.2.4 The Upper Montane Forest

The Upper Montane Forest, represented by the plots at altitudes of 1800 and 2100 m, has a lower canopy (20-25 m) and a similar tree density (280-524 stems per hectare) compared with the lower forest plots. However, the plot basal area is greater (Table 2). *Schefflera abyssinica* and *S. mannii* are are common and generally grow as strangling epiphytes on a variety of hosts, including *Pittosporum* and *Ilex mitis*. These stranglers are capable of reaching an enormous diameter (up to 3 m). Frequently the host is destroyed, leaving a wide hollow in the centre of the strangler up to 2 m across. Estimates of individual basal area calculated from this huge girth measurement are responsible for an exagerated basal area for the Upper Montane Forest plots. This is most marked on Plots 9 and 10 at 1800 m where *Schefflera* accounts for 52.8% and 45.9% of the basal area and its host *Ilex mitis* 30.7% and 33.7% of the basal area respectively. Excluding *Schefflera* from the calculations of basal area gives a more "normal" 42.4 and 50.2 m^2 ha^{-1} for these plots. The basal area of plots 7 and 8 at 2180 m is high (90.72 and 62.03 m^2 ha^{-1}) due to a large number of mature *Syzygium staudtii* of substantial girth.

The Upper Montane Forest, with 12 and 14 tree species (>10 cm dbh) per 0.5 hectares at 1800 m and 2180 m respectively, is species-poor relative to the Lowland Forest. several families which do not occur at lower altitudes, including "temperate" familes Aquifoliaceae and Rosaceae are present and the Myrtaceae are more important. The Rubiaceae are numerically abundant at all altitudes. several species of tree fern are present in the Lower and Upper Montane Forests above 1100 m but *Cyathea mannii* was particularly common at 2180 m.

5.3. Forest Soil Characteristics

5.3.1 Soil Morphology and Variability

The soil profiles from forest plots at all altitudes are of variable depth ranging from shallow very stony soils with hard basaltic lava at less than 50 cm depth on lava ridges, to much deeper, sometimes stoneless, soils in more gently sloping concave depressions and lower ridge flanks. However, all the soils have a collection of distinctive morphological properties characteristic both of Andosols (FAO-UNESCO 1988) and the recently defined Soil Taxonomy order of Andisols (Soil Survey Staff 1992). Table 5 gives the predominant Andisol subgroup and the closest FAO-UNESCO Andosol equivalent for each of the altitudes studied, together with some indication of soil variation from these modal profiles. A summary of the morphology of the soils is provided in Table 6.

The Ah horizons are dark-coloured (10YR 2/2, 2/3 or 3/3), loamy and very porous, with a granular structure and a very friable, fluffy consistence when moist, thus having many of the characteristics of mull humus forms and the umbric epipedon of the US Soil Taxonomy. In addition, they show certain specific physical properties, having a very low packing density, retaining their friability even when very moist, usually releasing water and becoming smeary or slippery when rubbed but remaining non-sticky and non-plastic in the wet state. Soil colour darkens with increasing altitude and the Ah horizon extends to greater depth (30-50 cm) in the profiles of the Montane Forest plots above 1000 m, reflecting an increase in both the content and the depth of incorporation of organic matter. The Ah horizon becomes divisible into a very dark brown upper part (Ah1) and a dark brown lower part (Ah2), but a distinct black H layer characteristic of mor humus forms is not encountered until the highest altitudes in the Upper Montane Forest above 2000 m, and even here, still overlies a deep, well developed mull-like Ah horizon with all the morphological properties mentioned above.

The underlying Bw horizons are of slightly higher chroma but remain dark-coloured (7.5YR to 5YR 3/3 to 3/4), often throughout their depth at altitudes above 1000 m, but are frequently divisible into a dark Bw1 horizon and a brighter (7.5YR or 5YR 4/4 to 4/6) Bw2 below this altitude. Some of the soils on the plots at 600 m have distinctly reddish (2.5YR 3/4 and 5YR 4/4 to 4/6 Bw horizons suggestive of more advanced weathering and leaching, whilst soils on Plots 1 and 2 at 180 m above sea level have strong brown (7.5YR 4/4) Bw2 horizons. The Bw horizons have many morphological and physical properties of the Ah horizons (Table 6). Granular structure, very low packing density, high porosity, friability and low plasticity persist throughout their depth, providing an excellent rooting medium restricted only by the stoniness of many profiles. Differences include higher chroma colours; often a more smeary or thixotropic consistence when moist and often increased stoniness. Soils above 1000 m tend to be more gritty sandy silt loams or sandy loams due to a high content of cinder fragments derived from their pyroclastic parent materials discussed in section 5.1. In this Montane Forest zone there is an increased incidence of little-weathered cinder and ash layers in the middle of the soil profiles, i.e. between about 30 and 60 cm from the soil surface, that overlie buried former surface horizons designated bAh (see Table 6 and descriptions of Profile Nos. 7A, 7B, 9 and 10 in Appendix 1). This indicates the contribution of recent airfall volcanic deposits to soil parent materials that have important effects on soil properties and the stage of soil evolution.

Soils at all altitudes are extremely permeable and overlie permeable soil parent materials over great depths of porous vesicular lava, consequently, although they are very moist for much of the year because of persistently high rainfall and high humidity, they show no evidence of impeded soil drainage.

5.3.2 Analytical Evidence for 'Andic' Soil Properties

The morphological properties discussed above and the results of chemical and physical soil analyses reported in Tables 7 to 11 show that all the soils do indeed qualify as Andosols (FAO-UNESCO 1988), and also fall within the recently designated and more strictly defined Soil Taxomony order of Andisols (Soil Survey Staff 1992). Andisols must have certain distinctive diagnostic 'andic' properties, including critical amounts of oxalate extractable active aluminium and iron resulting from large proportions of X-ray amorphous, poorly crystalline (short-range-order) or paracrystalline aluminosilicates, such as allophane and imogolite, and poorly crystalline hydrous oxides in their clay fractions; very low bulk densities; and a large capacity to fix phosphate (Soil Survey Staff 1992). The amounts of active iron and aluminium, extracted by acidified ammonium oxalate at pH 3.0 from both Ah and Bw horizons of the forest soils studied on Mount Cameroon (Tables 7 to 11), are present in large amounts that are well above the required 2.0% (20 g kg^{-1} soil). Bulk density, measured at approximately 33KPa water retention, is very small and below the required 0.9 g cm^{-3} in all horizons throughout the altitudinal range. Similarly, phosphate retention values (Blakemore et al 1981) equal or exceed the required 90% for Bw horizons in all profiles except for 3A and B at 600 m (Table 8).

5.3.3 Forms of Active Aluminium and Iron

In the Lowland Forest soils, oxalate extractable aluminium and iron both fall generally in the range 30 to 60 g kg^{-1} soil in the Ah horizons. Aluminium increases with soil depth to between 40 and 80 g kg^{-1} soil in the andic Bw horizons, while iron often increases to between 50 and 100 g kg^{-1} soil (Tables 7 and 8). There is no significant progressive increase in the levels of oxalate extractable aluminium with increasing altitude but a maximum (109.3 g kg^{-1}) occurs in the lower Bw horizons of Hydric Fulvudands at 2180 m, whilst oxalate extractable iron declines in soils of the Upper Montane Forest (Tables 10 and 11). These forms are regarded as being combined in poorly crystalline (short-range-order) hydrous oxides, or aluminium combined in allophane and allophane-imogolite, as long as organic-complexed forms extractable with potassium pyrophosphate are subordinate (Parfitt and Hemni 1982, Farmer et al 1983, Soil Survey Staff 1992). Results for pyrophosphate extractable aluminium indicate that about 50% of active Al in Ah horizons is in the form of organo-Al complexes. This falls to < 2% in the lower Bw horizons, suggesting a large proportion of allophane below the Ah horizons (see section 5.3.6 for further discussion).

Comparison of the results for sodium dithionite extractable iron, which extracts crystalline as well as X-ray amorphous oxides, with those for oxalate extractable iron shows that 50% or more of the iron is in poorly crystalline forms. Results for pyrophosphate extractable iron in Ah horizons at all altitudes indicate that only between 20 and 35% of the oxalate extractable active iron is in organic-complexed forms (Tables 7 to 11). This falls to <10% in Bw horizons, indicating a very small proportion of iron-organic complexes and suggests a predominance of the poorly crystalline (short-range-order) hydrous oxide ferrihydrite. The large amounts of oxalate extractable iron found in the Lowland Rain Forest Andisols on Mount Cameroon are relatively unusual for Andisols in general, but similar amounts have been reported and linked to large amounts of ferrihydrite, detectable by Moessbauer techniques, from Andisols (Hydrudands) formed under humid tropical conditions (3800 mm mean annual rainfall) from basaltic tephra in Hawaii (Parfitt et al 1988).

5.3.4 Clay Mineralogy

X-ray diffraction studies of the <0.002mm clay fractions gave no indication of layer-lattice clay minerals other than traces of kaolinite in Ah and Bw horizons of soil profiles from the Lowland

Forest, i.e. Plots 1-4. The only other secondary crystalline minerals detectable in the X-ray diffraction traces are gibbsite and haematite found in the Lowland Forest soils. Haematite and kaolinite were absent from the young Vitric Andisols at 1100 m but gibbsite persisted, although in smaller amounts than in the Acrudoxic Hapludands of the Lowland Forest. Gibbsite and haematite were also detected in the Hawaiin Hydrudands reported by Parfitt et al (1988). Under the high rainfall of the Lowland Rain Forest on Mount Cameroon, strong leaching and desilication would be expected to favour the formation of gibbsite rather than halloysite from allophanic precursors.

The large amounts of ammonium oxalate extractable active aluminium (Al_o) and silicon (Si_o) present in Ah and Bw horizons at all altitudes (Tables 7 to 11) suggests that non-crystalline (short-range-order) allophane, or paracrystalline allophane with a disordered imogolite type structure, are the predominant minerals in the clay fraction and that they increase in frequency the andic Bw horizons. Amounts of aluminium extractable by potassium pyrophosphate (Al_p), taken to be that combined in organic complexes (Wada and Higashi 1976, Parfitt and Hemni 1982), is generally about 20 g kg^{-1} soil in the Ah horizons at all altitudes, with an Al_p:Al_o ratio of 0.5 indicating that about half the active aluminium is in this organic-complexed form. Amounts of aluminium-organic complexes decrease to < 15 g kg^{-1} soil in the Bw1 horizons declining further to < 0.5 g kg^{-1} soil in the Bw2 horizons, where the Alp:Alo ratio falls to < 0.2. This indicates that the complexes are pedogenetically immobile and saturated by aluminium.

Al_o - Al_p : Si_o ratios of close to 2.0 are characteristic of paracrystalline allophane with a disordered imogolite structure. Several of the Bw horizons, particularly those in soils of the Lowland Rain Forest plots, have ratios between 1.80 and 2.40. This permits the use of oxalate extractable silicon values to compute the amounts of allophane with a disordered imogolite structure by the method of Parfitt and Hemni (1982) and shows that contents of allophane range from 8 to 26% in the Bw horizons, (i.e. a somewhat larger range than to the 7 to 13% allophane estimated for the Hawaiin Hydrudands by Parfitt et al 1988), with the largest amounts in the Bw2 horizons where organic carbon contents are at their minimum. No clear trend with increasing altitude is evident. However, the Bw horizons of young soils with a large volcanic cinder content on Plots 5 and 6 at 1100 m altitude, that are classified as Vitric Andosols or Vitric Hapludands, have lower Al_o - Al_p : Si_o ratios of between 1.25 and 1.55 indicative of non-crystalline (short-range-order) allophanes. Most of the Ah horizons of the Mount Cameroon Andisols studied, regardless of altitude, also have ratios within or just below this range, suggesting that the non-complexed forms of active aluminium are present mainly in this form of allophane.

Several of the mineralogical properties of the clay fractions of the Andisols at and below 600 m on the southern slopes of Mount Cameroon, including the large amounts of inorganic, oxalate extractable iron indicative of ferrihydrite, the importance of allophane, and the presence of gibbsite and haematite with negligible amounts of layer silicates other than traces of kaolinite, are very similar to the Hawaiian Hydrudands described by Parfitt et al (1988). This combination of properties relates to the similar conditions of soil genesis in the two areas, i.e. very high rainfall, well-drained permeable soils, high temperatures and an isohyperthermic temperature regime, all resulting in rapid weathering and desilication of basaltic tephra.

5.3.5 Bulk Density and Water Retention Characteristics

Bulk density, measured at approximately 33KPa water retention, is very small, with Ah horizons in the range 0.47 to 0.52 g cm-3 (Plots 1 and 2) at 180 m altitude (Table 7); 0.76 to 0.77 g cm^{-3} (Plots 3 and 4) at 600 m (Table 8); 0.40-0.75 g cm^{-3} (Plots 5 and 6) at 1100 m (Table 9); and 0.36 to 0.39 g cm^{-3} (Plots 7 and 8) at 2180 m (Table 11). Profile data shows a tendency for bulk density to decrease slightly with depth, being lowest in the subsoil Bw horizons where it lies withinthe range 0.40 to 0.50 g cm^{-3} at all altitudes. Bulk density results for random samples give means of 0.45-0.60 g cm^{-3} for both Ah and Bw horizons at and above 1100 m altitude (Figure 1). The slightly greater values on the low altitude plots are attributed to a greater proportion of high density olivine basalt particles in the sand fractions of these soils observed in thin sections compared to low density, highly vesicular cinder fragments in the higher altitude plots.

The 1500 KPa water retention capacity for Ah horizons falls in the range 18-25% by volume at most altitudes, with available water capacities of 18-20%. These values usually increase in Bw horizons to give relatively large water retention capacities at 1500 KPa (30-35%) and a large available water capacity (20-25%). However, despite their very high rainfall, none of the soils on Mount Cameroon qualify as Hydrudands according to the recent criteria adopted by Soil Survey Staff (1992) because their undried 1500 KPa water retention are below the required 100% by weight, i.e. equivalent to approximately 50% by volume assuming a bulk density of 0.5 g cm^{-3} (Tables 7 and 8). Even the gravimetric field moisture contents (approximately equivalent to 0.33 KPa retention) for < 2 mm soil, determined at the driest time of the year in February (Figure 2), rarely exceed 100% at any altitude. In the Lowland Forest, only the Bw2 horizon of Profile 3B in the depression on Plot 3 at 600 m has 'Hydric' properties (n.b. 70-100% 1500 KPa water retention by weight is required for inclusion in the 'Hydric' subgroups of Andisols), having a retention of 39% by volume and a bulk density of 0.49 g cm^{-3} (equivalent to 80% by weight), placing this soil as an Acrudoxic Hydric Hapludand. Hydric properties are better developed in some Fulvudands at 2180 m (e.g. Profile No.7B) but others (Profile No.8) with Bw horizon values by weight of 65-69% are Typic Fulvudands. The lower 1500 KPa retention value of 28.5% by volume measured in the young Bw horizon of the Vitric Hapludand (Profile No.6B) at 1100 m (Table 9) is attributed to the lower clay content and a large content of < 2 mm vitric volcanic cinder fragments, confirmed as vesicular volcanic glass by micromorphological studies. There are no significant trends of water retention capacity with altitude but minimum available water contents of 14% for the Ah horizon are encountered in the young Vitric Hapludands of Plot 6 (Table 9).

5.3.6 Organic Carbon and Nitrogen Content

Profile analytical data shows that organic carbon content is large in both Ah and Bw horizons (Tables 6-11). Amounts in the Ah horizons increase with altitude from a range of 50-100 g kg^{-1} in Lowland Forest plots below 600 m, to 125-145 g kg^{-1} in the Lower Montane Forest plots at 1100 m, reaching a maximum of about 150 g kg^{-1} in the Montane Forest plots at 1800 m. Values remain large to the base of the Bw horizon (i.e. often to 1 m depth) with Bw amounts increasing from a range of 38-75 g kg^{-1} below 600 m, to 80-90 g kg^{-1} at 1100 m and 80-130 g kg^{-1} above 1800 m. Total nitrogen shows a parallel increase from a range of 5.9-9.0 g kg^{-1} below 600 m, to 15.3-15.8 g kg^{-1} at 1100 m, reaching a maximum of 19.1-22.0 g kg^{-1} at 2180 m in the Upper Montane Forest. The analyses of random samples confirm these trends with a significant increase between the Lowland and Montane forest soils (Figures 3 and 4).

The increase of total nitrogen with altitude is not paralleled by any significant increase of available ammonium-nitrogen (Figure 6), whilst nitrate-nitrogen actually decreases from 3.70 mg NO_3^- kg^{-1} soil on Plot 1 at 180 m to 2.13 mg on Plot 8 at 2180 m (Figure 5). This suggests a slight decrease in nitrification and availability of nitrogen with increasing altitude. Mean values for mineralisation of nitrogen measured under field conditions over a 14 day incubation period during February 1991 showed a decrease with altitude from about 5 mg N kg^{-1} soil mineralised at 180 m to 2 mg N kg^{-1} soil at 1800 and 2100 m, but results were highly variable and not significant (Figure 7). Similar measurements undertaken by Marrs et al (1988) on Volcan Barva in Costa Rica showed a greater decrease in nitrogen mineralisation rates with increasing altitude. The Cameroon measurements were undertaken at the driest time of the year when Ah horizons were only slightly moist and when microbial activity would be at its minimum.

5.3.7 Soil Acidity and Exchange Properties

Soil reaction in the Lowland Rain Forest soils is moderately acid with an overall trend to increase with altitude becoming only slightly acid in Upper Montane Forest soils. Soil pH in water of the topsoil Ah horizons varies between 5.0-5.2 in the representative soil profiles of the Lowland Forest plots (Tables 7 and 8), increases to 5.5 in the Lower Montane Forest at 1100 m (Table 9) and reaches a maximum of between 5.5 and 6.3 in the Upper Montane Forest plots at 1800 and 2180 m (Tables 10 and 11). The random samples demonstrated a similar trend of rising pH for both the Ah (10 cm depth) and the Bw horizons (50 cm depth), with significant increases between the lowermost and uppermost plots (Figure 8). The increase of soil pH with increasing altitude is more marked than on rain forest soils derived from andesitic volcanic ash on Volcan Barva, Costa Rica (Marrs et al 1988) where pH changed only marginally from 4.2 at 100 m to 4.5 at 2600 m. It is the reverse of that found in several other studies of altitudinal zonation of soils on tropical mountains where pH decreases with altitude (Grubb 1977), particularly where soils are developed over non-calcareous sedimentary and metamorphic rocks, as found in parallel studies by the present authors on Gunung Kobipoto in Seram, Indonesia (Edwards et al 1990, Payton 1993). Soil pH of soil profiles on Mount Cameroon increases by about 0.5 of a pH unit with depth at most altitudes, however, at the highest altitudes there is little increase with depth. Exchangeable aluminium and exchangeable hydrogen are present in small amounts in the Lowland Rainforest soils but decrease to negligible quantities in soils at and above 1100 m (Tables 7 to 11).

With only one exception, the delta-pH (pH measured in 1M KCl minus the pH in water after Uehara and Gillman 1981), is negative for all soils analysed, indicating a net negative charge on the exchange complex. However, Bw horizons in the Lowland Forest plots (Tables 7 and 8) have a delta pH between -1 and -0.4 indicative of soils with a low net negative charge dominated by variable charge minerals, whilst the Bw1 horizon of Profile No.1 has a positive delta-pH value of +0.2 indicating a net positive charge. Ah horizons in the soils of these plots have delta-pH values of about -0.6 indicating a predominantly negatively charged exchange complex. Above an altitude of 600 m, delta pH of both Ah and Bw horizons falls within the range -0.5 to -1.5.

The effective cation exchange capacity at the natural soil pH (ECEC = sum of ammonium acetate exchangeable bases and 0.1M KCl exchangeable Al and H) shows a wide variation from the cation exchange capacity by the ammonium acetate method buffered at pH 7.0, e.g. an ECEC of only 1.33 cmol+ kg^{-1} soil compared to a CEC at pH 7.0 of 23.86 cmol+ kg^{-1} soil for the Ah horizon of Profile No.2 in the Lowland Forest at 180 m (Table 7) This is attributed to the large pH-dependent variable charge, characteristic of Andisols with large amounts of organic matter and X-ray amorphous mineral constituents in their clay fractions. Both ECEC and CEC show a trend that increases at higher altitudes, reaching a maximum in Profile No.8 at 2100 m which has an ECEC of 54.88 and a CEC of 65.57 cmol+ kg^{-1} soil in the Ah horizon, and 10.99 and 58.67 cmol+ kg^{-1} soil respectively in the Bw horizon (Table 11). These trends are confirmed by the results for random topsoil and subsoil samples (Figure 9) and are most significant for ECEC (Figure 10).

5.3.8 Exchangeable Cations and Base Saturation

The concentrations of exchangeable basic cations are very small throughout the profiles of the Lowland Forest plots at 180 m, falling within the range 0.60-1.45 cmol+ kg^{-1} soil, but both profile analyses (Tables 7 to 11) and the results for random samples (Figure 11) show a clear tendency to increase significantly with altitude, particularly in the Ah horizon. Thus Ah values increase to 2.29-4.48 cmol+ kg^{-1} soil at 600 m, with more significant increases to 14.29-38.15 cmol+ kg^{-1} at 1100m; 24.07-68.83 cmol+ kg^{-1} at 1800 m and 43.22-54.88 cmol+ kg^{-1} at 2180 m. The results for soils at 180 m are similar to values of 1.8 cmol+ kg^{-1} soil found in Lowland Forest soils at

100 m altitude on Volcan Barva, Costa Rica (Marrs et al 1988) but the increase to only 15.6 cmol+ kg^{-1} in the soils of the Upper Montane Forest at 2600 m on Volcan Barva is much less marked than that on Mount Cameroon. The subsoil Bw horizon values show no sign of increasing beyond a range of 0.60-1.45 cmol+ kg^{-1} until the Lower Montane Forest plots at 1100m and thereafter increase progressively to maximum values of between 10.99-15.15 cmol+ kg^{-1} at 2180 m (Figure 11). The extremely small amounts of exchangeable cations result in classification of the Lowland Rain Forest Andisols as Acrudoxic Halpudands (Table 5). Calcium invariably accounts for 70 to 80% of total exchangeable basic cations, with very small amounts of 0.52-1.03 cmol+ Ca kg^{-1} (Table 7) in the Ah horizons under Lowland Rain Forest at 180 m that are similar to those found in soils at 100 m on Volcan Barva. Values increase progressively with altitude to between 31.51-67.21 cmol+ Ca kg^{-1} soil in the Montane Forest profiles at 2180 m (Tables 7 to 11) compared to 9.2 cmol+ Ca kg^{-1} soil at 2600 m on Volcan Barva. Random samples at 10 cm and 50 cm depth on Mount Cameroon confirmed this distinct trend with significant increases in soils of the Upper Montane Forest (Figure 12). The greater range of exchangeable calcium values in the Upper Montane Forest soils (21.70-83.31 cmol+ kg^{-1} soil) is attributed to the more variable organic matter contents of the samples within plots compared to Lowland Rain Forest soils.

Exchangeable magnesium results for Mount Cameroon soils are highly variable but amounts are generally deficient (< 0.15 cmol+ kg^{-1} soil) in the Lowland Forest soils at 180 m (Tables 7 and 8). The range of 0.01 to 0.36 cmol+ Mg kg^{-1} soil found in the random samples at this altitude (Figure 13) is similar to amounts in soils at 100 m on Volcan Barva (Marrs et al 1988). Exchangeable magnesium content of Ah horizons increases to large amounts in the soils of the Montane Forest on Mount Cameroon (Figure 13), especially in the organic-rich Ah1 horizons which show a range from 3.50 to 21.22 cmol+ kg^{-1} soil in random samples collected at 10 cm depth from the plots at 2180 m altitude. Exchangeable potassium contents are deficient in the Lowland Forest soils below 1100 m, i.e. 0.10-0.12 cmol+ kg^{-1} soil in the Ah, but increase to between 0.31-0.59 cmol+ kg^{-1} above this altitude. Exchangeable potassium contents of Bw horizons rise from 0.03-0.06 cmol+ kg^{-1} soil below 1100m to 0.08-0.22 cmol+ kg^{-1} in the Montane Forest above. These trends are apparent from the mean values plotted in Figure 14. Low levels of exchangeable potassium of about 0.2 cmol+ kg^{-1} soil were also found in the Volcan Barva soils at 100 m altitude. The deficiencies relate to the small total mineral reserves of potassium in the parent material; the high leaching rates; and the low affinity of allophane for monovalent cations. Potassium deficiency is a common problem on the Andisols cultivated for bananas on the south eastern slopes of Mount Cameroon (Delvaux et al 1988) but did not appear to be a factor in determining the structure or floristics of the Lowland Rain Forest on Plots 1 to 4.

5.3.9 Availability of Phosphorous

Available phosphorous in the Ah horizons, measured on the random soil samples (10 cm depth), is relatively small and decreases with altitude (Figure 15). The four Lowland Rainforest plots have mean values of between 10.6 and 21.1 mg kg^{-1} soil that are considered adequate for the growth of most tropical agricultural crops. No measured values were as low as the $\leq$ 5 mg kg^{-1} wet season values found to be limiting for many rain forest trees and associated with the distribution leguminous Caesalpinioideae in Korup National Park, Cameroon (Gartlan et al 1986). More recently, Newberry et al (1988) found greater dry season amounts (12.3 mg kg^{-1} soil) in the same Korup soils, i.e comparable to the mean of 10.6 mg kg^{-1} soil on Plot 2. As the measurements in the present study were undertaken on soils sampled in the driest part of the year, it is conceivable that phosphorous may also be locally limiting in the Mount Cameroon forests below 600 m. The generally larger values for the other Lowland Forest plots are, nevertheless, well above 12.3 mg kg^{-1}. Values decrease to amounts that are deficient for most agricultural crops (7.0 to 9.9 mg kg^{-1} soil) for the four Upper Montane Forest plots. This contrasts markedly with results of certain other studies, such as Marrs et al (1988) on Volcan Barva, that showed an increase with altitude.

Mean phosphate retention values (Blakemore et al 1981) measured on the ten random Ah horizon samples (0-10cm) and the ten random Bw horizon samples (50-60 cm) from each forest plot is in the range 85 to 95%. The largest phosphate retention values are encountered in the Bw horizons which usually approach or exceed 90%.. No significant trends are observed with increasing altitude (Figure 16). The high phosphate retention capacity throughout the altitudinal sequence reflects the soil mineralogy and, in particular, the large amounts of active iron and aluminium in the clay fractions of these Andisols. It helps to explain the relatively low availability of phosphorous but does not explain the decline in availability of phosphorous in topsoils at higher altitudes.

5.4 Soil Genesis, Classification and Altitudinal Zonation

5.4.1 Origin of Soil Microstructure and Favourable Physical Properties

Observations of soil micromorphology in thin sections of Ah and Bw horizons from all the forest plots confirm that strong biotic activity is a major process in soil structure development, regardless of altitude. They show abundant faunal channels and chambers 0.25-3.00 mm diameter. The soil mass comprises porous granular peds 1-2 mm diameter that are actually faunal droppings. These consist of smaller, loosely aggregated rounded faecal pellets 50-150 um diameter. Larger faecal material is aggregated into common (25% by area) subangular crumbs 2-5 mm diameter. The subangular crumbs increase in frequency in the Ah horizons of the Fulvudands of the Upper Montane Forest.

The Hydric and Vitric Hapludands (Profile No.5, 6A and 6B) in the Lower Montane Forest show a predominance of highly porous vesicular cinder fragments consisting of volcanic glass but rounded and ovoid faecal pellets are found between these grit (2-4mm) and sand-sized particles, even at 150cm in the BC horizon which has a matrix consisting of > 75% vesicular cinders. This demonstrates the deep penetration of the soil mesofauna in these porous soil parent materials and their importance in the initial stages of soil formation and weathering. Vitric cinder fragments continue to be an important component of the upper parts of soil profiles on the Montane Forest Plots, particularly in those young soil horizons within the upper 50 cm that have developed from recent pyroclastic airfall deposits. These youngest soil horizons, e.g. the AB horizon above the recent ash and cinder layer in Profile No.9, has very weakly developed very fine granular microstructure with no evidence of crumb formation indicating that biotic activity is restricted, probably by particle size. Stronger granular microstructure and evidence of biotic voids is observed in the underlying buried bAh horizon confirming its biotic origins.

The soil forming environment, soil morphology and analytical results discussed previously for the Andisols of the southern slopes of Mount Cameroon indicate that they owe many of their properties to the effects of parent material and climatic factors on soil forming processes. High temperatures, high rainfall and constantly high humidity, combined with the large porosity, rapid permeability, mineralogy and young age of the basic volcanic ash and cinder deposits, and a constant supply of organic matter, have encouraged rapid weathering and leaching and the formation of mainly poorly-crystalline clay constituents. The large organic matter content in both Ah and Bw horizons of the Andisols is attributed to protection of the humified organic components against bio-degradation by micro-organisms through complex associations with poorly crystalline clay constituents such as allophane, and the formation of aluminium- and iron-organic complexes (Wada 1985). The initially porous parent materials and the porous structure of allophane and allophane-imogolite, that form rapidly by the weathering of volcanic glass, have encouraged the deep rooting and deep incorporation of humified organic substances through faunal and microbial activity, leading to a granular microstructure giving very small bulk densities throughout the Ah and Bw horizons.

5.4.2 Factors Controlling the Altitudinal Zonation of Soils

The altitudinal zonation of soils in relation to forest types is summarised in Table 5. The high temperatures and particularly large rainfall of the Lowland Forest combines with young easily weathered volcanic parent materials to form strongly leached Acrudoxic Hapludands (Haplic Andosols), characterized by well-developed andic properties; moderately acid pH and small base saturation values; and very small ECEC values of < 2 cmol+ kg^{-1} soil. They contain large amounts of active aluminium, silicon and iron in the form of allophane and ferrihydrite, particularly in their Bw horizons, but gibbsite is also present. Strong desilication favours the formation of gibbsite rather than kaolinite in these soils. Deeper Acrudoxic Hydric Hapludands have the largest amounts of allophane and ferrihydrite but are only found locally in depressions.

Organic carbon increases in the soils of the Lower Montane Forest at 1100 m but very dark-coloured horizons do not extend below 30 cm depth. ECEC and the concentration of exchangeable basic cations both increase significantly to levels of 28-38 cmol+ kg^{-1} soil in the Ah horizons and 4-6 cmol+ kg-1 soil in the Bw horizons, resulting in replacement of Acrudoxic Hapludands by other subgroups of Hapludands. Most of the soils at this altitude are relatively young, stoneless and very porous Vitric Hapludands (Vitric Andosols) developed in cindery airfall deposits. They have gritty, coarse loamy textures with smaller clay contents because of the higher frequency of unweathered glassy cinder fragments, resulting in water retention capacities at 1500 KPa of <30% in all horizons. The relative youth of these soils affects soil mineralogy. Allophane is present in smaller amounts, mainly as poorly crystalline forms rather than paracrystalline, amounts of gibbsite decrease to low values, and haematite and kaolinite are entirely absent. The soils on Plot 5 are developed in more weathered, older airfall deposits and have a 1500 KPa water retention of > 30% by volume, attaining 80% by weight in the Bw horizon and hence they are classed as Hydric Hapludands. The development of Hydric properties correlates with considerably greater amounts of oxalate extractable active aluminium, silicon and iron,

Soil organic carbon contents attain their maximum in the Upper Montane Forest where the soils are classed as Hydric and Typic Fulvudands (Soil Survey Staff 1992) because of their deep, friable, very dark-coloured organic matter-rich upper horizons that extend to > 30 cm depth and possess andic properties. As active aluminium and iron show no tendency to increase with altitude on the Mount Cameroon transect, and soil acidity and rainfall actually decrease, the observed increases of organic carbon are attributed to slower organic matter decomposition rates due to decreasing soil temperatures and, consequently some decline in soil faunal and microbial activity. This is supported by the slightly decreased nitrogen mineralisation rates measured in the Upper Montane Forest but thin section evidence shows that faunal activity is still well marked. Compared to other studies of tropical altitudinal zonation of soils on other parent materials, the gradient of organic carbon increase with altitude appears less marked because of the large amounts retained even under the hot humid conditions of the Lowland Rain Forest. This recalcitrance to mineralisation of the humified organic matter within the organo-mineral soil horizons is attributed to the large colloidally-protected pool of organic matter that develops in Andisols due to the formation of linkages with soil minerals such as allophane and ferrihydrite, or the formation of immobile organo-metal complexes with other forms of active aluminium and iron.

5.4.3 The Influence of Geological History, Topography and Time on Soil Variability

The higher saturation with basic cations; only slightly acid pH values and the greater ECEC and CEC at pH 7.0 of the high altitude soils can only be partly explained by the general trend of increasing organic matter and nutrient capital with increasing altitude on tropical mountains observed by other authors (Grubb 1977, Edwards and Grubb 1982, Marrs et al 1988). The results of the Mount Cameroon study suggest that the relatively young age of these soils compared to those of the Lowland Forest, and their rejuvention by additions of airfall deposits of basic volcanic ash and cinders are critical factors in explaining their greater pH values, exchangeable basic cation content and higher ECEC. Weathering and leaching have been retarded by these additions, some of which are recent enough to give profiles with buried bAh horizons at shallow depth resulting in classification as Thaptic Fulvudands (Tables 5 and 6). Large field moisture contents suggest that these soils have hydric properties but retention at 1500 KPa was not measured at this altitude. It is unlikely that the lower rainfall at this altitude is a significant factor in reducing leaching intensity, as 3000 mm per annum produces a strongly leaching environment under the freely draining conditions. It is concluded that parent material and time factors are paramount in determining both the stage of soil evolution and the soil nutrient regime in the Upper Montane Forest.

Topographic factors and geomorphic processes are largely responsible for the common occurence of shallower (< 50 cm) Lithic subgroups of Hapludands (on Plots 1-6 below 1100 m) and Fulvudands (on Plots 7-10 above 1100 m). These soils are restricted to rocky lava ridge tops and steep upper ridge flanks (Table 5), where mass movements over time have limited both the depth of accumulation of pyroclastic deposits and the depth of soil formation. However, the continued periodic eruption during the past 10,000 years of basaltic lava from radial fissures on the south western flanks of the mountain makes the situation more complex in some areas. Thus at 600 m on Plot 3, younger lava flows and pyroclastic deposits overlie older more weathered basalts resulting in a distinctive soil pattern. Lithic Hapludands occupying the ridges are developed largely from shallow, relatively young pyroclastic deposits of ash and cinders resting upon fresh or little weathered lava. The deeper Acrudoxic Hydric Hapludands that occupy the intervening depressions are formed from layered parent materials consisting of young pyroclastic and colluvial deposits overlying older, more strongly weathered red clayey or fine loamy 2Bw horizons developed from older basaltic lava. Thus both topographic and time factors are sometimes important determinants of soil variability on the forest plots.

5.5 Relationships Between Vegetation and Soils

5.5.1 Limiting Factors in the Upper Montane Forest and the Nutrient Controversy

The changes in forest floristics and structure observed with increasing altitude on Mount Cameroon, including the strong decline in species diversity and lower canopy of the Upper Montane Forest and the occurence of several families that do not occur at lower altitudes, are well known from rain forest studies elsewhere in the world (Richards 1952, Grubb 1977, Proctor 1988). However, the structure of the Upper Montane Forest on Mount Cameroon has several unusual characteristics. These include the relatively high proportion of mature trees of substantial girth; the high frequency of large specimens of *Schefflera abyssinici*a and *S. mannii*; and the uneven distribution pattern of the forest, which is often restricted to the vicinity of ridges with extensive intervening gaps or 'meadows' dominated by acanthaceous shrubs.

The observed trends with greater altitude of increases in soil pH, the substantial increases of many of the major elements required for plant growth, the failure to find any significant decrease of available nitrogen and the neglible amounts of exchangeable aluminium, all indicate that nutritional factors are unlikely to be important in limiting forest growth, or in influencing forest structure in the Upper Montane Forest. This statement is vindicated by the fact that exchangeable potassium and magnesium are present in amounts which are considered deficient for agricultural crops only in the Acrudoxic Hapludands of the Lowland Forest, where species diversity and canopy height are at their greatest. The presence of an abundance of weatherable primary minerals in these Lowland Forest soils has provided for a slow release of nutrient cations which maintain the essential exchangeable cations at low but adequate levels, despite the high leaching intensity of the soil environment. Nutrient cycling can therefore be considered as an open system (Baillie 1989), with contributions from the decomposition of a substantial reserve of weathereable primary minerals, observed in soil thin sections. These include ferro-magnesian minerals such as olivine and augite and calcic plagioclase feldspars, that are derived both from airfall volcanic deposition and from older pyroclastic deposits and basaltic lava.

Recent airfall deposits have been particularly important in maintaining the high pH, base status and availability of essential nutrients of the Upper Montane Forest soils. This, together with the large quantities of incorporated soil organic matter, strong biotic activity, favourable soil structure and absence of impeded soil drainage help to explain the large girth attained by species such as *Syzygium staudtii* found at these high altitudes, despite the low insolation and relatively lower temperatures.

Exploratory soil surveys above the tree line north of Mann's Spring indicated that soils change rapidy to very young, very shallow coarse-textured Entisols with very small available water contents, interspersed with extensive areas of bare recent lava flows and cinder deposits. This suggests that recent volcanic activity and immature droughty soils are the major factors limiting tree growth above 2200 m, rather than climatic effects. Tongues of deeper Andisols similar to those on the forest plots but lacking the very dark Ah1 horizons, indicate that forest formerly extended locally to higher altitudes but has been destroyed. Evidence of forest destruction by annual fires was observed during the short lifespan of the project and it seems certain that the present boundary with the montane grasslands is fire-controlled. This conclusion is further supported by the common occurence of large trees of considerable girth within a few meters of a sharp boundary to grassland communities.

5.5.2 Possible Factors Influencing Montane Forest Structure

The patchiness of the Montane Forest has not previously been given any adequate explanation. The present study has demonstrated that the forest soils at and above 1100 m have been subjected to recent additions of airfall volcanic deposits. These additions have been of sufficient magnitude to bury pre-existing forest Andisols with 30 to 60 cm of volcanic ash and cinders on parts of the forest plots, particularly on concave lower ridge slopes and in depressions. In some parts of the plots soil formation has kept pace with airfall additions of ash and cinders so that buried soil horizons are not present, here Ah horizons are often particularly thick, e.g. Profile No.8 at 2180 m. More commonly, a distinct layer of little weathered or unweathered cinders and ash that buries a preexisting topsoil horizon is encountered somewhere between 30 and 60 cm depth. The upper parts of these recent pyroclastic or tephra deposits have been in place long enough to weather sufficiently to develop andic properties and to accumulate large amounts of well humified soil organic matter, intimately incorporated with the mineral soil to give a granular to fine subangular blocky structure. Time has not, however, been prolonged enough for these processes to extend below about 30 or 40 cm depth or, in most cases, to form well developed Bw horizons. In other places, often outside the study plots in extensive open depressions dominated by acanthaceous shrubs and herb communities, the depth of recent pyroclastic additions, and/or colluvial deposits derived from them, increased to > 60 cm leading to deeper burial of former soils. This observed soil pattern in the Montane Forests of Mount Cameroon, suggest that additions of airfall volcanic deposits have not been laid down in layers of uniform thickness, but that considerable local variation in deposition has occured.

Weathering and soil formation in volcanic ash and cinders can be extremely rapid due to the rapid decomposition of volcanic glass. Rates of Ah and incipient Bw horizon formation within 100 to 500 years, and Bw horizon formation within 500 to 1000 years, have been reported under cool temperate conditions in Japan (Wada 1985). Rates in the humid equatorial tropics are likely to be much more rapid, and complete decomposition of volcanic glass, initially to allophane and then to halloysite, has occured in less than 4000 years on St. Vincent (Hay 1960). Stabilisation of organic matter levels is likely to occur in much shorter periods of 100 to 200 years. Given these rapid rates of soil development, it is feasible that the pyroclastic deposits, which bury former Ah horizons on the Montane Forest plots, and in which the Ah, AB and incipient Bw or BC horizons are developed, were deposited within the lifespan of some of the large specimens of *Syzygium staudtii* and *Schefflera sp*.. If this is so, the patchiness and differences in magnitude of airfall deposits can provide the basis of a hypothesis to explain the patchiness of the Montane Forest.

It is proposed that rapid and deep soil burial would have killed off areas of the vegetation. After several decades of soil formation the immature soils would become colonised by herb-dominated communities, but only more slowly by shrubs and trees. The deepest accumulations of airfall deposits are likely to have accumulated in concave depressions on the less steep slopes, both by direct airfall deposition and through secondary mass movement. This is exactly where extensive gaps in the forest occur today. This hypothesis therefore suggests that the open areas are a stage in the soil and vegetation succession following the catastrophic and irregular deposition of airfall pyroclastics. In other areas, where the deposition of airfall volcanic materials was much less, i.e. on ridge tops, soils and vegetation survived without major modification. In intermediate positions, often on ridge flanks, such as those sampled in the forest plots, shallow burial of the former Andisols would have allowed trees to grow through the fresh deposits but selective die off of sensitive species is likely to have occured. The ash and cinder fall may have destroyed younger trees and buried the seedbank of the topsoil, thus preventing rapid regeneration. The physical and chemical composition of fresh ash and cinder deposits are not conducive to seedling establishment, forming a dry, initially nutrient-poor substrate. Many larger trees could have survived the fall, drawing upon deeper soil reserves of moisture and nutrients and have grown on to form old specimens. This hypothesis can not only account for the extensive forest gaps, but also for the dominance of parts of the forest by old trees of substantial girth and of a restricted number of species.

6. ACHIEVEMENTS OF THE PROJECT

6.1 Realisation of the Objectives

The objectives of the project have in a large part be realised as shown by the results discussed in section 5.

(a) An altitudinal sequence of permanent paired 0.25 ha forest plots has been established between Bonenza and Mann/s Spring and the floristics and structure of the forest have been quantitatively assessed.

(b) Soil physical and chemical properties from the forest plots have been measured and the significance of soil changes with altitude have been analyses and discussed. In so far as the data allows, relationships between soil variation with altitude and changes in forest floristics and structure have been examined.

(c) Soil forming processes on basaltic lava and pyroclastic deposits have been assessed from the analytical and field data. The exercise has proved particularly timely as it has allowed the systematic testing of the application of the new Soil Taxomony order of Andisols in a humid tropical location under a range of environmental conditions.

(d) The established sequence of permanent forest plots has been visited and maintained by the Limbe Botanic Garden staff and has already been used in training exercises.

6.2 Implications for Forest Conservation and Resource Management

The findings of the project have a number of implications for the conservation and management of Mount Cameroon's forests. These are listed briefly below.

(a) The Lowland Rain Forest below 600 m altitude is in equilibrium with strongly leached varieties of Andisol that have small amounts of easily available essential plant nutrients. Potassium, magnesium and, in some cases, phosphorous are present in quantities that are deficient for the growth of many agricultural crops. Nutrient reserves present in primary minerals are released only relatively slowly and, whilst this replenishment of nutrients is sufficient to maintain growth over the lifespan of a forest tree, it would be inadequate for sustained agricultural production. The high pH dependent charge and large capacity of the soils to fix phosphate mean that large amounts of lime and phosphatic fertilizer would be required. Moreover, the high frequency of steep slopes and shallow rocky soils would further limit land use options. It is erroneous to associate these soils with the much deeper and more nutrient-rich varieties of Andisol found on the eastern slopes of Mount Cameroon. For these reasons the clearance of the forest for agriculture is considered to be ecologically unsound.

(b) The stable soil structure and high organic matter contents of Andisols suggests that they would be more stable than many tropical soils to soil erosion after forest clearance. However, the large soil water holding capacity combined with steep slopes and a very high rainfall make them prone to mass movements, particularly to landslides and mudflows. Past evidence of such slope processes is clearly evident on the mountain and any destabilisation of the forest cover will increase the risk of catastrophic mass movements of this kind.

(c) The Montane Forests contain a complex array of microhabitats and seral successions towards mature forest determined by slope, past volcanic activity and soil type. The investigation of the variety of these vegetation communities was outside the scope of the present project but preliminary observations suggest that some may be particularly susceptible to human disturbance. A fuller investigation of these communities to assess their conservation value and develop a management strategy is recommended. Well developed, mature montane forest studied by the project has been shown to form a scattered mosaic, and whilst forest regeneration on the deeper soils would not be limited by nutrient deficiencies, the current distribution pattern, associated with the often shallow soils of rocky ridges, make these areas particularly sensitive to disturbance.

(d) The droughty shallow soils of the montane grasslands make them particularly susceptible to fires which are destroying the uppermost edge of the Montane Forest and resulting in the extension of grassland onto deeper forest Andisols. Burning is leading to a decrease of species diversity, disappearance of certain plant communities, such as the formerly more extrensive giant heath and Hypericum shrubland, soil degradation and forest destruction. . The majority of these fires are set by man and where the grasslands fall within the Mount Cameroon/Etinde Reserve a management strategy should be developed to prevent burning.

6.3 Objectives not fully achieved

(a) Quantitative data vegetation was collected from the 25 10 x 10 m subplots of each 0.25 ha forest plot, and soil analyses of topsoil and subsoil samples are available from 10 subplots at randomly sited locations. These two data sets should provide the possibility of examining vegetation/soil variations within plots. This has not been possible due to the time and manpower limitations of the project.

(b) X-ray diffraction studies of clay mineralogy for the Upper Montane Forest plots, which would have allowed a more complete discussion of weathering at high altitude, were not completed due to manpower difficulties and analytical problems in the SSLRC, Silsoe soil laboratory. Particle size analyses were not possible due to the difficulties encountered in reliably dispersing the Andisols but this was not a major drawback as water retention measurements and soil thin section observations provided a useful guide to physical behaviour and mechanical composition of the soils.

(c) It now seems less likely that the Living Earth / ODA supported Cameroon Environmental Education Project will directly utilize the forest plots. This is because of revised priorities determined by the local staff of that project. It is still hoped that the results of the altitudinal study can be used to promote rain forest conservation in Cameroon through the auspices of the Limbe Botanic Garden.

7. DISSEMINATION OF THE RESULTS AND FOLLOW UP PRIORITIES

The scientific results of the project are being prepared for publication in appropriate refereed international journals by Drs Payton and Edwards. The soil micromorphological work, which has not been presented in detail, will form part of a specialist paper on the formation of tropical Andisols at a range of altitudes.

Priority should be given to the production of a fuller, modified version of this report, illustrated with photographic plates of forest types and soils, that can be used as a reference and a training manual for educational purposes by Limbe Botanic Gardens. A copy of the present report should be sent immediately to the director of the Limbe Botanic Garden and Genetic Rain Forest Conservation Project. It would be beneficial if a workshop could be arranged at Limbe Botanic Gardens to discuss the findings of the project and the implications for the management of the Mount Cameroon/Etinde Genetic Conservation Reserve. It would also be useful to obtain some feedback on the most appropriate form for a training manual and the possibilities for producing promotional or educational literature from the results of the project.

Discussions should be initiated with Limbe Botanic Gardens on the scope for future monitoring of the plots and the development of targeted research projects within the Reserve, emanating from the project findings.

Discussions held during 1991 with Joe Watts, the Limbe Project forester, and Mark Bovey the Botanic Gardens project co-ordinator, revealed the need to undertake ecological research in other contrasting areas of the Reserve in order to draw up the final management plan. These areas are identified below and it is suggested that a second phase of the project should be considered.

(a) There is a very marked rainfall gradient from west to east in the reserve decreasing from some of the highest rainfall figures recorded of about 10,000 mm north of Debundscha in the west, to about 3000 mm near Buea in the east. Little information is available on what influence this dramatic decrease in rainfall has on soils and forest types within the reserve. It is therefore suggested that paired forest plots be set up at the wet and dry end of this gradient at mid altitude sites.

(b) There is an area of contrasting, much older Tertiary lavas which form Mount Etinde. These rocks are characterized by the presence of nepheline and leucite resulting in rare rock types of tephrite or etindite of contrasting chemical composition to the Holocene olivine basalts of Mount Cameroon. The ecological significance of these parent materials on soil development and forest composition and structure has not been investigated and may be unique. It is suggested that paired forest plots be set up at the foot of Mount Etinde in lowland forest, and in the stunted montane forest which lies within the zone of persistent cloud cover nearer the summit.

(c) It is proposed that studies of the montane grassland/forest boundary within the reserve be initiated as a matter of priority. This should start with an aerial survey and continue with plots set up to monitor the dynamics and ecology of the forest/grassland ecotone.

(d) Finally, it is proposed that further data be collected to investigate the hypothesis presented to explain the numerous and extensive gaps in the montane forest above 1200 m, to study the ecology of the plant communities in the open areas, and to explain the predominance of very old, large trees with little regeneration in parts of this forest.

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