SOILS OF THE LONRHO TEA ESTATES, MUFINDI, TANZANIA

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INTERIM REPORT

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INTRODUCTION

This interim report describes the results of a soil survey of the Itona Division of the Lonrho Tanzania Tea Estates at Mufindi in the Southern Highlands of Tanzania undertaken by the Soil Survey and Land Research Centre in association with Silsoe College, Cranfield Institute of Technology as part of a larger study to investigate the potential costs and benefits of irrigating the area. The objectives of the project commissioned by Lonrho Tanzania include the evaluation and mapping of soil types on the estates. This aspect involves both a field soil survey and the quantification and interpretation of soil physical and chemical characteristics of the principal soil types, primarily in relation to irrigation need assessment but also, more generally, in relation to nutritional status and land use potential.

The field survey of soils on the Stone Valley, Itona, Idetero and Maganga tea Estates was completed in June 1990. The soil analytical work needed to support the soil survey is currently in progress. This is not expected to be completed until mid October due to the time required to measure some of the physical parameters used to estimate the available water capacity of the soils. This report describes those characteristics of the soils on the four estates that can be ascertained by field assessment. A provisional soil classification is attempted based on the field properties of the soils but this is likely to be modified after the analytical results become available. Detailed assessments of soil physical properties in relation to irrigation requirements must also await the completion of the analytical work.

A brief report is given of the reconnaissance survey undertaken to assess soil suitability for proposed extensions to the tea plantings. The suitability of soils at potential dam sites is also discussed.

METHODS

The soils were mapped using the free survey method described by Soil Survey Staff (1951). This involved prediction of the expected soil types according changes in environmental factors such as landform, slope and geology under the prevailing climate of the region using accepted principles of soil genesis. Soil inspection points were then sited to test these predictions and to cover the area to be surveyed. Soil were examined to 3 m depth using a soil auger with extension rods and described according to the methods given in the FAO Guidelines for the Field Description of Soils (1977) and in Hodgson (1976). Areas of similar soil types were delineated as units on the soil map.

The main soils encountered on the four estates were described in more detail in soil profile pits excavated to 3 m depth and sited to characterize the most extensive map units. The soil layers or horizons encountered in these soil pits were sampled for chemical and physical analyses, including their moisture retention characteristics. The main soil types mapped were provisionally classified according to the FAO-UNESCO system (FAO-UNESCO 1988) and subdivided into soil series according to soil texture and other properties deemed to be of significance to soil management. The soil series have been given local place names following the convention used elsewhere in the world. It should be noted that these names do not relate to nationally recognized soil series in Tanzania and have been defined for local correlation only.

GEOLOGY AND LANDSCAPE

This part of the Southern Highlands lies north east of the Mufinidi Escarpment at elevations generally between 1700 to 1800 metres on the Stone Valley and Itona Estates and between 1800 and 1900 metres on the Idetero Estate, attaining a height of 1930 metres on the highest parts of the Maganga Estate. The terrain is hilly and mainly strongly undulating, consisting of convex ridges falling away in long slopes of between 6 and 10^0 to narrow, steeper sided valleys which often remain in evergreen montane forest or secondary bush. The valley separating the Stone Valley and the Maganga estates is particularly steep-sided and the tea plantings in the northern part of the Maganga Division occupy steep, often rocky, slopes of 20^0 or more.

The rock type of the area is of granitic composition, consisting mainly of migmatites, but rarely outcrops at the surface and is covered by a deeply weathered mantle which attains depths of several metres on lower ridge flanks but often thins to depths of little more than a metre on ridge crests. The steeper terrain of the Maganga Division forms the exception to this rule Here outcrops of relatively fresh, hard, spheroidally weathered granite are common on summits and upper slopes.

The deeply weathered mantle which predominates on lower slopes has experienced strong weathering processes for a long period of time and gives rise to soil parent materials which are relatively high in clay minerals and oxides of iron and aluminium with few weatherable primary minerals. The shallower depth to rock on ridge crests and upper slopes results in parent materials with a greater reserve of minerals that can weather to release plant nutrients, and often in a coarser textured or more gritty material at depth. Shallow gritty, coarse textured soil parent materials directly over hard granite only occur in patches close to rock outcrops on the steep terrain of the Maganga Division.

SOIL CHARACTERISTICS AND DISTRIBUTION

Deep Well drained Soils of the Middle and Lower Slopes

The dominant soils of commonly occuring middle and lower slopes are deep, acid, well structured red loams and clay loams with dark-coloured granular loamy topsoils of relatively high organic matter content. Most have very porous, low density topsoils with abundant roots which extend downwards into only slightly less porous red subsoils with a well developed, stable granular or fine subangular blocky structure and a friable consistence when moist. These soils are formed from highly weathered parent materials with few primary minerals recognizable in the field. It is predicted that they are dominated by clay minerals which have a low cation exchange capacity and that the exchange complex will have a low saturation with respect to calcium, magnesium and potassium. Organic-rich topsoils are likely to be relatively high in exchangeable aluminium. Such soils have been provisionally classified as Humic Ferralsols (FAO-UNESCO 1988), and have been mapped as the Itona series (see Appendix, Soil Profiles No.1 and No.7). They are particularly widespread on the Itona and Idetero Estates and occur on about 50% of the Stone Valley estate. However, on midslopes, and particularly on the Idetero Estate they are mixed with slightly shallower (usually about 2 metres deep) Humic Acrisols (see Soil Profile No.4 in the Appendix) mapped as the Idetero series. These have a clay-enriched subsoil horizon with blocky or prismatic structure at about 70 cm depth and very firm, pinkish layers transitional to decomposed granite/migmatite are encountered at about 200cm depth.

Predicted bulk densities for topsoil and subsoil layers of the Humic Ferralsols lie between 1.0 and 1.3 g/cm^{-3} and remain at these low values often to 3 metres depth. There is a low penetration resistance and root growth is physically unimpeded to similar depths. However, the bulk of fine roots are always encountered in a zone 0 to 50cm from the soil surface, with common to few fine or medium woody roots continuing down to about 3 metres. These deep roots are thought to enable the tea bushes to extract water from throughout this depth of soil when the plant roots at shallower depth have used up all the easily available water, i.e. they enable the plant to resist drought stress (Mike Carr, personal communication). In the Humic Acrisols total profile available water is likely to be less as roots do not penetrate to a significant extent below 200cm depth, however, there is likely to be more water available to plants at intermediate tensions. Infiltration rates are predicted to be rapid and probably in the region of 9 to 15cm per hour, and even more rapid still in the initial dry soil state.

The moisture retention properties of Ferralsols differ from other soils with similar clay contents. Their stable fine granular structure means that they behave more like sandy loams in that they release more water at low tensions (i.e. between 0.1 and 0.3 bars), representing drainage of interaggregate pore space. Consequently, a tension of 0.1 bar is recommended to represent field capacity (El Swaify 1980). Nevertheless, they also retain large amounts of water unavailable for plant growth at tensions greater than 15 bars, as do most clayey soils. If 0.1 and 15 bar are used as the limits of available water, most ferralic subsoil horizons with more than 25% clay, such as those in the present study, store about 14mm of water per 10cm of soil. This would give a profile available water content of 420mm for a 3 metre deep profile. However, transmission rates in unsaturated Ferralsols are often limited due to the rapid water loss held at low tensions from inter-aggregate pores. Thus, despite high water contents at 15 bar tension, such soils often display limited availability of water to plants at intermediate tensions due to the presence of abundant, coarse, air-filled between aggregates which restrict the flow of liquid water to roots. Actual figures for available water in these soils are being measured at present. The Humic Acrisols often associated with the Ferralsols on these midslope sites will have a lower total profile available water because of the slightly shallower rootiing depth but this will be partly offset by the greater amount of available water held at intermediate tensions, particularly in clay-enriched subsoil horizons. Thus the Humic Ferralsols and the deep Humic Acrisols of midslope sites in this study can be treated similarly for irrigation purposes.

Ridge Top and Upper Slope Soils

Gently to moderately sloping (1-5 degrees) ridge tops and upper slopes, particularly on Stone Valley and Maganga estates but also on Idetero Estate, carry soils which show a distinct clay increase with depth, displaying a more compact clayey subsoil layer with coarse prismatic or blocky structure at about 70cm depth. This usually passes into weathered but firm, massive decomposed granite/migmatite at about 150cm depth. Such soils have been provisionally classified as Humic Acrisols (FAO-UNESCO 1988) and have been mapped as the Stone Valley series (see Appendix, Soil Profiles No.2 and No.5). Topsoils have a similar moist colour and structure to those of the Humic Ferralsols described above but they have a sandy loam texture and often appear greyer when dry. The yellowish brown subsoil between about 30 and 70cm is a porous loam with weak structure and low soil strength that has been depleted of clay by downward translocation. This overlies a yellowish red, moderately compact blocky or prismatic clay or sandy clay which becomes very sticky and plastic when wet. Deposition of clay translocated from above is apparent from prominent clay coatings on structural surfaces and in root channels (forming an Argillic horizon or an Argic B horizon of the FAO-UNESCO 1988 classification).

At depths between about 150 and 180cm, the clay-enriched subsoil horizon passes into pinkish massive decomposed rock with abundant soft white specks which represent mineral (feldspar) crystals decomposed to secondary clay. This material can be cut with some difficulty by a spade but is dense and very firm when in place and restricts root penetration, so that roots are rare or absent below about 150 to 180cm depth in these soils. As in the Ferralsols, fine roots are concentrated in the 0 to 50cm zone but differ in that roots are only common to about 100cm depth below this zone of intense rooting. The presence of weathering rock at shallower depth than in the Humic Ferralsols will mean that weatherable minerals are still present, so that there is a potential for a slow release of nutrient elements as they decompose. This means that Humic Acrisols have a greater potential nutrient reserve than the more strongly weathered and leached Humic Ferralsols. Nevertheless, cation exchange capacities are still likely to be low although base saturation of subsoil horizons will probably be greater than in the Ferralsols.

Bulk density is predicted to be low in the topsoil and immediate subsurface horizon, and probably similar to values given for Humic Ferralsols. However, a sharp increase of bulk density and parallel decrease in total porosity will occur on passing into the clay-enriched blocky subsoil horizon at about 70cm depth. Initial infiltration rates will be rapid at the soil surface but water will be diverted laterally at the top of the denser subsoil horizon resulting in a major subsurface lateral flow component down the slope above the less permeable layer. Water holding capacity of these soils will be moderate but there will be less water held at low tensions and more at intermediate tensions than in the Ferralsols, particularly in the clayey subsoil horizons. Profile available water is predicted to be considerably lower than in the deep Humic Ferralsols because roots only penetrate to about 150cm or, in certain cases even less (see soil discussed below). This will lead to an earlier appearance of drought stress in tea crops growing on these soils and will require irrigation at an earlier stage in the dry season to offset adverse effects on growth and yields.

Some Humic Acrisols on ridge crests have particularly dense clay-enriched mottled subsoils (e.g. Soil Profile No.3 in the Appendix) which are slowly permeable and result in slight seasonal waterlogging of the overlying soil horizon. This results in pale colours and bright yellowish brown mottles or iron oxide segregations in the weakly structured sandy clay loam below the topsoil. Roots are rare below about 80 cm in such soils as penetration is impeded by high packing density and, during the wet season, by waterlogging of the subsoil.
As root penetration is further restricted in such soils, they are the most likely to show drought stress symptoms early in the dry season.

Soils of the Steep Slopes

Soils on slopes greater than 15 degrees occur on parts of the Stone Valley Estate but are only common on the Maganga Estate, particularly in the north. Here rock outcrops are common and soils are often shallow around the outcrops leading to low available water capacities and poor drought resistance. The physical limitations of such soils are obvious and no detailed sampling of them was undertaken. However, substantial parts of these steep slopes are still covered by somewhat deeper soils similar to the Humic Acrisols described from ridge tops on Stone Valley (e.g. Soil Profile No.2 in the Appendix). Pinkish, decomposed granite/migmatite is generally reached within a metre depth. The extreme variation in soil thickness and water holding capacity of soils on these steep slopes results in highly variable crop performance and tea yields locally within fields. These areas will be mapped as the Maganga Complex on the soil map and are regarded as poorly suited or uneconomic for irrigation, as many limitations to achieving high yields would remain and water, in most cases, is difficult to lead to such areas.

Soils of Concave Depressions

A small proportion of all the tea estates are occupied by concave depressions between ridges and at the foot of long moderate slopes on ridge sides. Such land accounts for less than 5% of the estates but is locally common around the lake to the north west of Itona Camp. New tea plantings have recently been extended onto such land at the southern side of the lake but establishment has been poor. The soils found in such sites are affected by often prolonged waterlogging due to a high groundwater table in the valley bottom. Black, highly organic and often wet peaty topsoils, which sometimes extend to 50cm or more, overlie waterlogged, grey mottled sandy clay loam. This in turn passes into pale grey to white sticky, plastic waterlogged clay at about 1 metre depth. It is predicted that such soils may have a higher nutrient status than the Humic Ferralsols and Acrisols of adjacent well drained slopes, but the performance of the tea is limited by very poor drainage which is difficult to improve in such low-lying situations. Soil pH levels may also be higher in these soils and this could adversely affect tea growth. The fertility status of these soils requires confirmation from the soil analyses being undertaken. Land drainage, rather than irrigation is required on such sites.

A few examples of extremely deep, dark-coloured, granular, organic-rich soils with topsoils over-deepened by deposition of soil eroded from upslope were encountered in sloping concave depressions. These generally did not display signs of severe waterlogging and the tea crop appeared to be perfectly healthy. Such soils are of extremely small extent.

SOILS OF THE PROPOSED NEW PLANTINGS

Reconnaissance soil surveys of areas of potential new tea plantings along the valley at the southern edge of the Itona Estate and on the valley sides to the north of the Walihanga stream were undertaken during the fieldwork in June, but lack of time prevented completion of the surveys. Some preliminary results are reported here.

Soil transects were made through the Eucalyptus plantations north of the Walihanga and aligned from the ridge top down towards the stream in the valley bottom. These revealed that most of the soils on the valley side slopes are naturally well drained Humic Ferralsols (similar to Soil Profile No.6 in the Appendix) or deep varieties of Humic Acrisols (similar to Profile No.4). Both these soil types have unrestricted rooting depth to at least 2 metres and large predicted profile available water capacities. Organic-rich topsoils are likely to be acid or very acid (soil pH probably 4.5 or less) with appreciable amounts of exchangeable aluminium. Cation exchange capacity is likely to be low, but should be adequate in surface horizons due to the relatively high organic matter levels that are indicated by the dark topsoil colours. This should facilitate retention of nutrients added in the form of fertilizer. These predictions need confirmation by collection and analysis of soil samples from this area.

Such soils are regarded, on the evidence of the field observations, as suitable for tea planting and should respond well to irrigation. They are likely to be equivalent to some of the better yielding tea soils on the estate. Moreover, the Walihanga Dam site proved to have a suitable valley configuration and suitable soils for dam construction (see Interim Report by Keith Weatherhead). Seasonally waterlogged Gleysols affected by lateral seepage of water in the valley bottom were of only local extent. These are poorly suited to tea planting but would largely be inundated by the effects of the dam. However, it is recommended that a 50 metre wide zone immediately around the proposed lake should not be planted so as to avoid any adverse effects that these soils could have on the newly established tea plantings. Slopes to the south of the Walihanga were not examined during the survey and further investigations are recommended before extension work is undertaken.

Reconnaissance soil surveys along the valley to the south of the Itona Factory, which is largely covered by secondary thicket or in parts by Eucalyptus plantations, showed that midslope soils comprised largely of Humic Ferralsols and deep Humic Acrisols with at least 2 metres of rooting depth which are well suited to tea plantings for reasons mentioned above. However, lower slopes carried seasonally waterlogged sandy loams over pale, mottled sandy clay loams affected by lateral seepage of water from upslope and/or high groundwater table levels in the valley bottom. Rooting depth would be restricted by waterlogged anaerobic subsoils in these soils. Tea plantings are not recommended on these lower slope sites, although soil sampling for chemical analysis is required before final soil classification and recommendations can be made. It should also be stressed that the survey of this area was incomplete because of inadequate time that was available.

Parts of the lower valley sides are covered by deep waterlogged grey sandy soils affected by seepage from upslope, including critical areas on the proposed dam site for irrigation works in this valley. The depth of the sandy deposits on which these soils have developed were not investigated in detail but preliminary observations suggest that they are deep and widespread at the narrowest part of the valley where the configuration of the land is otherwise most suited to dam construction. As permeable sandy materials such as these form unsuitable foundations, damming the valley at this point is not recommended (see Interim Report by Keith Weatherhead). It is recommended that in the short term, the extension of tea plantings should be concentrated in the Walihanga Valley where the soils are suitable for both tea and for dam construction.

A more detailed description of the soils at potential dam sites will be given in the final report.

APPENDIX

SOIL PROFILE DESCRIPTIONS

Profile No.1: Stone Valley I

Location: Stone Valley Tea Estate, Mufindi, Southern Highlands, Tanzania. Southern sector, at the southern extremity of Field No.6 (old field numbers) near the boundary to Field No.7.
Date: 20/6/90 **Surveyor:** R.W. Payton
Relief: Strongly undulating hilly terrain. Convex midslope (6^0) of convex spur from ridge. Land falls away to major valley to the west.
Aspect: SW **Elevation:** 1730 m
Parent material: Colluvial deposits over deeply weathered granitic saprolite.
Soil classification (provisional): Humic Ferralsol (FAO-UNESCO 1988). Itona series.
Soil drainage class: Well drained
Land use: Mature tea. Good yields from this part of the field.

Profile description:
0-30 cm Ah
Dark reddish brown (5YR 3/3) moist stoneless loam; weak fine subangular blocky breaking to moderate fine granular structure; extremely porous; low packing density; very weak ped strength; very friable; abundant fine fibrous and fine and medium woody tea roots; clear smooth boundary.

30-54 cm EB
Reddish brown (5YR 4/4) to yellowish red (5YR 4/6) moist stoneless loam (5YR 5/6 rubbed); weak medium subangular blocky breaking to fine moderate granular structure; very oorous; low packing density; moderately weak ped strength; friable; slightly sticky and modeartely plastic when wet; common fine and medium fibrous roots; irregular gradual boundary.

54-150 cm Bt/Bws

Red (2.5YR 5/8) moist stoneless clay loam/clay (n.b. field texture feels like a loam); variable structure with moderate fine and medium blocky breaking to medium granular structure interspersed with medium granular structure; variable soil consistence, moderately firm blocky ped strength with friable consistence when crushed in some parts but very firm ped strength in others (moderately strong ped strength when dry), granular areas are loose; moderately sticky and very plastic after manipulation when wet; semi-deformable to brittle failure of blocky peds; very porous; low to medium packing density; common continuous dark reddish brown (5YR 3/6 to yellowish red (5YR 4/6) clay coats on on blocky ped faces; common fine woody roots and common medium fibrous roots between and within peds; irregular gradual boundary.

150-225 cm Bws1
Red (2.5YR 4/8 to 5/8) moist stoneless clay loam/clay (n.b. at first field texture feels like a loam); massive with widely spaced vertical planes of weakness breaking to moderate fine granular structure; very porous; low packing density; moderately weak soil strength; friable; semi-deformable; moderately sticky and very plastic after manipulation when wet; few fine woody roots and few medium fibrous roots; smooth diffuse boundary.

225-300 cm Bws2
Yellowish red (5YR 4/8) moist stoneless fine sandy clay loam; massive breaking to fine granular structure; very porous; low packing density; moderately weak soil strength; very friable; slightly sticky and moderately plastic after manipulation when wet; few fine woody roots and few medium fibrous roots; lower boundary unobserved.

Comments: Irregular development of the blocky argic Bt horizon with some parts having strongly developed blocky to prismatic peds with prominent continuous clay coats on peds and very firm consistence when moist, other parts having moderately or weakly developed fine and medium blocky structure with moderately firm ped strength breaking easily to friable fine granular material, and yet other parts having a very porous very friable fine granular structure. The horizon thus has structural characteristics of both argic Bt horizons and ferralic Bws horizons. The blocky Bt horizons tongues into the underlying moe uniform ferralic Bws1 horizon giving an irregular boundary.

Soil samples collected:
Bulk samples: 1. 0-30cm; 2. 30-54cm; 3. 54-150cm; 4. 150-225cm; 5. 225-300cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C: 50-55cm; 3A,B and C. 100-105cm; 4A,B and C. 200-205cm.

Profile No.2 Stone Valley II

Location: Stone Valley Tea Estate, Mufindi, Southern Highlands, Tanzania. Eastern sector, Field No.1 (old numbering system).
Date: 23/6/90 **Surveyor:** R.W. Payton
Relief: Strongly undulating hilly terrain with long convex ridge tops ($0-5^0$) falling away to long moderate $6-11^0$ slopes on ridge sides before falling steeply into narrow valleys. Site occupies upper slope on convex ridge top. Land slopes at 5^0 along line of the ridge which is aligned N-S.
Aspect: North **Elevation:** 1800 m

Parent material: Deeply weathered granite saprolite.
Soil classification (provisional): Humic Acrisol (FAO-UNESCO 1988). Stone Valley series.
Soil drainage class: Well drained.
Land use: Mature tea. (N.b. Leaves of tea plants yellow early in the dry season along these ridge top soils probably due to drought stress).

Soil profile description:
0-30 cm Ah
Very dark greyish brown (10YR 3/2) moist stoneless fine sandy loam/loam; weak fine granular structure; loose to veryweak ped strength; very friable; extremely porous; very low packing density; many fine and medium woody roots and many fine fibrous roots; clear wavy boundary with tongues down abandoned coarse root channels 5cm wide penetrating to 65cm depth.

30-72 cm E
Brown (10YR 5/3 to yellowish brown (10YR 5/4) moist stoneless medium sandy clay loam with common faint medium-sized yellowish brown (10YR 5/5) mottles; massive to very weak coarse angular blocky structure; very porous with abundant root channels and irregular voids (vughs); low packing density; moderately weak soil strength; friable; semi-deformable failure; moderately sticky and slightly plastic after manipulation when wet; common fine fibrous roots and common fine woody roots; irregular tongued clear boundary.

72-110 cm Bt
Yellowish red (5YR 5/8) moist stoneless clay; moderate to strongly developed medium prismatic structure with continuous yellowish red (5YR 54 to 4/6) moderately thick clay coatings on ped faces and in abandoned root channels; moderately porous; medium packing density; moderately to very firm ped strength; friable when crushed; moderately to very sticky and very plastic after manipulation when wet; common fine fibrous roots; tongues of paler 10YR 5/3 material penetrate along fissures between peds often associated with degrading clay coatings of the same colour; diffuse irregular boundary.

110-140 cm Bt(g)
Reddish yellow (5YR 6/8) moist gritty sandy clay loam with common distinct coarse sharply defined pale yellow (5Y 7/4) to reddish yellow (7.5YR 7/6) irregularly distributed mottles; common very small angular quartz particles and a few strongly weathered pale yellow or white rotted small granite fragments with moderately weak strength and brittle failure; moderately developed coarse prismatic to fissures massive structure; slightly porous with very occasional root channels; medium to high packing density; many thick continuous yellowish red (5YR 5/6 and reddish brown (5YR 4/4) clay coatings on fissure walls, ped faces and in

channels; compact, very firm; semi-deformable failure; moderately sticky and moderately plastic after manipulation when wet; occasional fine fibrous roots along fissures but otherwise absent roots; clear irregular boundary.

140-180 cm BC
Light red (2.5YR 6/8) moist finely gritty crumbly fine micaceous sandy clay loam; common strongly weathered white-speckled rotted granite corestones up to 5cm diameter; massive with occasional widely-spaced (10-20 cm) clay-lined fissures; moderately compact and slightly porous; medium to high packing density; very few clay-lined abandoned fine root traces; slightly sticky and slightly plastic after manipulation when wet; diffuse irregular boundary.

180-300 cm Cr
Light red (2.5YR 6/6) moist deeply weathered granite with abundant fine white (5YR 8/2) angular speckles consisting of kaolinized feldspars;finely gritty micaceous fine sandy clay loam to silty clay loam when crushed; massive; very slightly porous; high packing density; compact and very firm in place but only moderately firm strenght in hand specimen; roots absent except for very occasional fine root along clay lined fissure (one such root observed to penetrate to 250 cm depth); lower boundary unobserved.

Soil samples collected:
Bulk samples: 17. 0-30cm; 18. 30-72cm; 19. 72-110cm; 20. 110-140cm; 21. 140-180cm; 22. 180-300cm.
Moisture tins (in triplicate): 1A,B and C: 10-15cm; 2A,B and C. 50-55cm; 3A,B and C. 100-105cm; 4A,B and C. 200-205cm.
Thin section samples: 1. E horizon 50-60cm; 2. Bt1 horizon; 3. Bt2 horizon; 4. BC horizon; 5. Cr horizon.

Profile No. 3 Stone Valley III

Location: Stone Valley Tea Estate, Mufindi, Southern highlands, Tanzania. Sloping ridge top in the north eastern part of the estate in the centre of Field No. 7 (old numbering system).
Relief: Convex ridge top in strongly undulating hilly terrain on upper slope (4^0). Land falls away in long convex to straight moderate slopes ($6-9^0$) to the west and east finally dropping more steeply into narrow concave valley bottoms.
Aspect: NNE 30^0 **Elevation:** 1790 m.
Parent material: Deeply weathered granite saprolite.
Soil classification (provisional): Humic Acrisol (shallow stagnic phase). Stone Valley series, shallow stagnic phase.
Soil drainage class: Moderately well to imperfectly drained.

Land use: Mature pruned tea. (N.b leaves yellow early in the dry season, probably due to drought stress).

Soil profile description:

0-28 cm Ah

Dark reddish brown (5YR 2/2) moist stoneless sandy loam; moderately developed fine granular structure; extremely porous; very low packing density; loose to very friable with very weak ped strength; slightly sticky and slightly plastic after manipulation when wet; abundant fine fibrous roots and common fine to coarse woody roots; clear wavy boundary with tubular extensions to 40 cm depth along abandoned coarse root channels.

28-40 cm E

Brown (10YR 5/3) moist stoneless sandy loam; massive to weakly developed medium subangular blocky structure; very porous; low packing density; loose or very weak soil strength with brittle failure; very friable when crushed; slightly sticky and non-plastic after manipulation when wet;common very fine fibrous roots; few medium and coarse woody roots; clear smooth boundary.

40-80 cm E(g)

Light yellowish brown (2.5Y 6/4) moist stoneless sandy clay loam with common medium and coarse clear yellowish brown (10YR 5/6) mottles; weakly developed medium and coarse subangular blocky structure; very to moderately poropus; low to medium packing density; moderately firm soil strength but friable when crushed; semi-deformable failure; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots and few medium woody roots; many irregularly shaped discrete voids and abandoned root channels have stripped surfaces with loose exposed quartz grains; abrupt smooth boundary.

80-88 cm

Stoneline consisting of medium and small angular quartz fragments.

88-130 cm 2Bt(g)

Brownish yellow (10YR 6/6) moist stoneless sandy clay loam with many coarse clear very pale brown (10YR 6/6) and strong brown (7.5YR 5/8) mottles;moderately developed coarse prismatic structure with continuous moderately thick clay coatings on ped faces; compact, slowly permeable, slightly porous; high packing density; moderately strong ped strength; semi-deformable failure; moderately sticky and moderately plastic when wet; many waxy clay coatings affected by mottling plugging former root channels and irregularly shaped voids; occasional fine fibrous roots follow clay-lined vertical fissures but fail to penetrate ped interiors; diffuse irregular boundary.

130-190 cm BC/Cr

Mixed horizon with areas of undisturbed weathered granite saprolite (Cr horizon, see description below) and light red (2.5YR 6/6) moist finely gritty, micaceous fine sandy clay loam or silty clay loam ; massive with occasional clay-lined vertical fissures; moderately porous but few interconnected voids (mainly voids left after mineral grain weathering); medium packing density;compact and very firm in place but moderately firm, brittle and crumbly in hand specimen; slightly sticky and non-plastic after manipulation when wet; very occasional fine fibrous roots in fissures or occasional clay-lined root channels but largely unexploited by roots; common white soft kaolinized felspar grains; broken diffuse boundary.

190-250 cm Cr
Light red (2.5YR 6/6) deeply weathered granite saprolite with abundant fine angular soft white (5YR 8/2) kaolinized feldspar grains; massive, compact and very firm in place but moderately firm and brittle in hand specimen, crushing to a finely gritty micaceous fine sandy loam or sandy silt loam; non-sticky and non-plastic after manipulation when wet; moderately porous but mainly unconnected irregularly shaped to angular voids left after mineral weathering; occasional clay-lined fine root channels and fissures penetrate to about 220 cm depth; living roots absent; becoming more gritty and paler in colour (2.5YR 7/6) with depth with white corestones of rotted granite surrounded by reddish yellow (7.5YR 6/8) halos of iron oxidation.

Comments: This profile represents a Humic Acrisol with undisturbed deeply weathered granite at relatively shallow depth, probably due to slow erosion of upper soil layers. The compact, mottled argic Bt(g) horizon is slowly permeable and impedes water percolation causing periods of seasonal waterlogging. The smaller volume of the soil exploitable by roots will reduce the amount of available water and therefore increase droughtiness during the dry season.

Soil samples collected:
Bulk samples: 33. 0-28cm; 34. 28-40cm; 35. 40-80cm; 36. 88-130cm; 37. 130-190cm; 38. 190-250cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 55-60 cm; 3A,B and C. 110-120cm.
Thin section samples: 1. 50-60cm; 2. 110-120cm.

Profile No.4 Idetero I

Location: Idetero Tea Estate, Mufindi, Southern Highlands, Tanzania. North eastern sector of the estate, Field No.44.
Date: 22/6/90 **Surveyor:** R.W. Payton
Relief: Strongly undulating bifurcating convex ridges and hills with narrow intervening valleys. Predominantly long 6-10^0 convex to straight slopes on ridge flanks with 1-5^0

convex slopes on ridge tops. Site lies on convex 8^0 slope on ridge spur.
Aspect: North 30^0 **Elevation:** 1840 m
Parent material: Colluvial deposits over deeply weathered coarse-grained granite and vein quartz..
Soil classification (provisional): Humic Acrisol (FAO-UNESCO 1988). Idetero series.
Soil drainage class: Well drained.
Land use: Mature tea with good yields.

Soil profile description:
0-30 cm Ah
Dark reddish brown (5YR 3/3) moist stoneless sandy loam/loam (5TR 3/4 to 4/4 rubbed colour);strongly developed fine granular structure; extremely porous; very low packing density; very friable; very weak ped strength;slightly sticky and slightly plastic when wet; abundant fine fibrous roots ramify all parts of the soil; common medium and coarse woody roots; abrupt wavy to irregular boundary with tubular extensions down coarse root channels to 35 or 40cm in places.

30-70 cm EB
Strong brown (7.5YR 4/6) slightly moist sandy clay loam or loam; massive to weak fine and medium subangular blocky structure breaking easily to fine subangular blocky and granular structure; very porous; low packing density; very friable; moderately weak ped strength; brittle to semi-deformable failure i.e. ruptures suddenly to many smaller peds; slightly sticky and moderately plastic when wet; many fine woody roots; common coarse woody roots; gradual irregular boundary.

70-130 cm Bt1
Red (2.5YR 4/8) moist stoneless clay loam to clay with slightly duller coloured ped faces (2.5YR 4/6); moderately developed coarse blocky and medium prismatic structure breaking easily to fine subangular blocky; very porous with many fine root channels; low packing density; friable; moderately weak to moderately firm ped strength; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots; common moderately thick patchy clay coatings on ped faces; common continuous clay coatings in abandoned root channels; diffuse irregular boundary.

130-198 cm Bt2
Dark yellowish brown (10YR 4/8) stoneless clay loam/clay with slightly duller ped faces (10YR 4/6); strongly developed medium and coarse prismatic structure breaking to coarse angular blocky structure; moderately porous; medium packing density; friable to firm consistence with brittle failure breaking to fine subangular to granular peds; moderately firm to very firm ped strength; moderately sticky and moderately plastic after manipulationwhen wet; common roots as above; continuous dark yellowish brown (10YR 4/6)

clay coatings on ped faces and in abandoned root channels;diffuse irregular boundary.

198-240 cm BCt
Red (2.5YR 5/8) moist gritty sandy clay loam; many very small angular quartz grains; common soft strongly weathered granite corestones forming coarser sandy or coarse loamy areas up to 20 cm in diameter and increasing in frequency with depth; few slightly hard small to medium granite stones and smasll fragments of angular vein quartz; massive; moderately porous with many interstitial macrovoids left after weathering of mineral grains and occasional clay-lined fissures less than 0.2 mm wide; medium packing density; moderately firm soil strength; brittle failure breaking to a friable mass of fine subangular blocky units and loose grains; moderately sticky and slightly plastic when wet; few fine fibrous roots; few fine woody roots; common broken or locally continuous clay coatings in former root channels and angular voids left after mineral grain weathering; gradual irregular boundary.

240-300 cm BC/Cr
Strong brown (7.5YR 5/8) moist gritty sandy loam; many medium and large soft sandy corestones of strongly weathered coarse-grained granite; a few slightly hard weathered granite fragments; massive; moderately porous; medium packing density; moderately weak to moderately firm soil strength (does not cohere easily); brittle failure breaking to a mass of lose grains and weak aggregates of grains; few fine roots with surface of this horizons but absent below 260 cm depth; diffuyse irregular boundary.

300 cm + R
Strongly weathered moderately hard coarse-grained granite.

Comments: The BC/Cr horizon of this soil is less compact and coarser in texture than the micaceous feeling light red granite saprolite encountered elsewhere on the estates. It probably represents a coarser grained variant of the granite or the site may occur over coarser vein intrusions of different compostion.

Soil samples collected:
Bulk samples: 6. 0-30cm; 7. 30-70cm; 8. 70-130cm; 9. 130-198cm; 10. 198-240cm; 11. 240-300cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 50-55cm; 3A,B and C. 150-155cm.

Profile No. 5 Idetero II

Location: Idetero Tea Estate, Mufindi, Southern highlands, Tanzania. Approximately 100 m from the south eastern corner of Field No.H3.
Date: 22/6/90 **Surveyor:** R.W. Payton
Relief: Elevated convex ridge top sloping 3^0 NNW in strongly undulating hilly terrain. Ridge extends NW to SE. Land falls away to the east and west with moderate 8^0 slopes towards narrow steeper-sided valleys.
Aspect: NNW 320^0 **Elevation:** 1810 m
Parent material: Deeply weathered granite saprolite.
Soil classification (provisional): Humic Acrisol (FAO-UNESCO 1988). Stone Valley series.
Soil drainage class: Well drained.
Land use: Mature tea on land originally cleared from forest.

Soil profile description:
0-35 cm Ah
Dark reddish brown (5YR 3/3) slightly moist stoneless medium sandy loam,moderately devloped fine granular structure; loose to very fraible; extremely porous; very low packing density; slightly sticky and slightly plastic when wet; abundant fine fine fibrous roots ramify all parts of the soil mass; common fine to coarse woody roots; clear irregular boundary.

35-64 cm EB
Strong brown (7.5YR 4/6, 7.5YR 5/6 to 5/8 rubbed) slightly moist stoneless loam; massive to very weak medium subangular blocky structure; very porous; low packing density; friable; moderately weak soil strength; brittle failure; slightly sticky and slightly plastic when wet; common fine fibrous roots; few fine and medium woody roots; diffuse irregular boundary.

64-145 cm Bt
Red (2.5YR 4/8 to 5/8) moist stoneless clay; strongly developed medium prismatic structure breaking to coarse angular blocky with continuous clay coatings (2.5YR 4/6 to 5/6) on ped surfaces and in root channels; moderately porous; moderate packing density; very firm ped strength but still friable when crushed breaking to many fine angular blocky aggregates; very sticky and very plastic after manipulation when wet; common fine fibrous roots; few fine to coarse woody roots; clear wavy boundary.

145-180 cm BC
Light red (2.5YR 6/6) moist stoneless very fine sandy clay loam or silty clay loam; massive with occasional closed vertical fissures plugged with continuous (2.5YR 4/6 to 5/6) clay coatings; moderately to slightly porous; medium packing density; very firm soil strength; slightly sticky and moderately plastic when wet; brittle failure breaking to fragments; occasional patchy clay coatings in abandoned root

channels; occasional to few fine woody or fibrous roots mainly along fissures; diffuse wavy boundary.

180-300 cm Cr
Light red (2.5YR 6/6) slightly moist compact deeply weathered granite saprolite with abundant soft white (5Y 8/3) angular speckles consisting of kaolinized feldspar grains; common higher chroma staining (2.5YR 6/8); massive, slightly porous and very firm in place with brittle failure in hand specimen breaking to a loose mass consisting of finely gritty micaceous fine sandy clay loam to silty clay loam; very strong soil strength in parts where less weathered with many hard or slightly hard weathering granite corestones below 250cm depth; very few fine woody roots penetrate to this depth but are absent below; a few abandoned clay-lined fine root channels to 250 cm depth;lower boundary unobserved.

Comments: Granite saprolite can be cut with a spade with some difficulty between 180 and 250 cm depth but becomes harder below. It represents in situ constant volume weathering and disintegration of this crystalline igneous rock. The material can be augered with some difficulty and appears as soil material once disturbed by the auger bit but has a distinctive texture and consistence. Horizons transitional to hard rock such as this are very firm and compact in place with little interconnected vopid space and generally prevent the penetration of roots.

Soil samples collected:
Bulk samples: 12. 0-30cm; 13. 35-64cm; 14. 64-145cm; 15. 145-180cm; 16. 180-250cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 90-95cm; 3A,B and C. 170-175cm.

Rock samples collected:
2. 250-300cm from granite saprolite transitional to disintegrating granite zone.

Profile No. 6 Itona I

Location: Itona Tea Estate, Mufinidi, Southern Highlands, Tanzania. Recently cleared (1987) area in the north eastern sector of the estate under newly established tea, formerly under evergreen montane forest.
Date: 23/6/90 **Surveyor:** R.W. Payton
Relief: Upper slope (7^0) of convex ridge in strongly undulating hilly terrain. Slope falls to narrow valley 500 m to the south.
Aspect: SES 160^0 **Elevation:** 1760 m
Parent material: Colluvial deposits over deeply weathered granite saprolite.

Soil classification (provisional): Humic Ferralsol (FAO-UNESCO 1988). Itona series.
Soil drainage class: Well drained
Land use: Young tea recently planted on former montane evergreen forest site prior to 1987.

Soil profile description:

0-40 cm Ah
Dark brown (7.5YR 3/3) moist stoneless loam; weakly to moderately developed fine granular structure; extremely porous; very low packing density; very friable; many fine fibrous roots and common fine woody roots; common coarse dead woody tree roots; clear irregular boundary.

40-72 cm EB
Yellowish brown (10YR 5/6) moist sandy clay loam; massive; very porous with many abandoned root channels and intergrain voids between clean washed quartz grains;low packing density; moderately weak soil strength breaking to a friable mass; slightly sticky and slightly plastic when wet; common fine and medium woody roots; diffuse irregular boundary.

72-110 cm Bt/Bws
Red (2.5YR 4/8, 2.5YR 5/8 rubbed colour) moist stoneless clay loam; areas of weakly developed medium prismatic structure interspersed with massive structure breaking easily to fine and medium granular structure with a friable consistence; prisms are moderately firm and have a medium to low packing density and a semi-deformable failure; massive to granular structured areas are very porous with a low packing density; moderately sticky and moderately plastic after manipulation when wet; common fine and medium woody roots; diffuse irregular boundary.

110-200 cm Bt
Red (2.5YR 5/8) moist stoneless clay loam; moderately developed medium prismatic structure breaking to a friable mass of fine subangular blocky aggregates; moderately to very porous; medium packing density; very firm or moderately firm ped strength; moderately sticky and very plastic after manipulation when wet (n.b. only slightly plastic according to FAO methods); common fine woody roots; diffuse wavy boundary.

200-300 cm Bws
Red (2.5YR 5/8) moist stoneless fine sandy clay loam; granular to massive structure; very porous; low packing density; moderately weak soil strength; semi-deformable failure; very friable; slightly sticky and moderately plastic after manipulation when wet; few fine woody roots; lower boundary unobserved.

Comments: A mixed horizon with the physical properties of both a ferralic Bws horizon and an argic Bt horizon occurs above an argic Bt horizon which in turn overlies a ferralic

Bws of considerable depth. Under the new FAO-UNESCO classification guidelines (1988) such a soil would be classed as a Ferralsol if it meets the chemical criteria.

Soil samples collected:
Bulk samples; 23. 0-40cm; 24. 40-72cm; 25. 72-110cm; 26. 110-200cm; 27. 200-300cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 55-60cm; 3A,B and C. 120-125cm; 4A,B and C. 200-205cm.

Profile No. 7 Itona II

Location: Itona Tea estate, Mufindi, Southern Highlands, Tanzania. South eastern sector of the estate, Field 8 (old numbering system.
Date: 24/6/90 **Elevation:** 1770 m
Relief: Strongly undulating hilly terrain. Straight midslope (7^{0}) falling to slightly concave lower slope 150 m to the south before falling more steeply into anarrow valley.
Parent material: Colluvial deposits over deeply weathered granite.
Soil classification (provisional): Humic Ferralsol (FAO-UNESCO 1988). Itona series.
Soil drainage class: Well drained.
Land use: Mature tea; yields well.

Soil profile description:
0-38 cm Ah
Dark reddish brown (5YR 3/2) slightly moist stoneless loam; moderately developed fine granular structure; loose; very friable when moist; extremely porous; very low packing density; slightly sticky and slightly plastic when wet; abundant fine fibrous roots ramify all parts of the soil mass; few coarse woody roots; clear to abrupt irregular boundary tonguing down coarse abandoned root channels to 45 cm depth.

38-55 cm EB
Strong brown (7.5YR 4/6) moist loam; massive breaking easily to fine granular structure; very porous; low packing density; very friable; moderately weak soil strength; soft and brittle when dry; slightly sticky and moderately plastic when wet (n.b. non-plastic according to FAO assessment); common to many fine fibrous roots; common fine and medium woody roots; diffuse smooth boundary.

55-150 cm Bws1
Red (2.5YR 4/8) moist stoneless loam; massive with very weak soil strength breaking easily to fine granular structure; very porous with mainly channels or inter granular ped voids; low packing density; very friable; moderately sticky

and moderately plastic after manipulation when wet (n.b. slightly plastic according to FAO method of assessment); common fine fibrous roots; common fine and medium woody roots; some areas have very weakly developed coarse prismatic structure but vertical fissure uncoated; diffuse irregular boundary.

150-220 cm Bws/Bt
Yellowish red (5YR 4/6) stoneless clay loam; some parts have weakly developed coarse prismatic structure with patchy clay coatings on ped faces which appear partially degraded and porous rather than waxy; moderately porous; medium packing density; very firm or moderately firm ped strength breaking with brittle failure to fine subangular blocky aggregates; other parts are massive and very porous with very weak soil strength breaking easily to fine granular structure and having a low packing density and a friable consistence; moderately sticky and moderately plastic after manipulation when wet; common fine fibrous roots (slightly less than above); diffuse irregular boundary.

220-300 cm Bws2
Red (2.5YR 5/8) moist stoneless loam; massive breaking to fine granular structure; very porous; low packing density; moderately firm soil strength with brittle failure crushing to friable mass; slightly sticky and moderately plastic after manipulation when wet (n.b. slightly plastic according to FAO method of assessment); common fine fibrous roots; few fine woody roots; few indistinct vertical planes of weakness; lower boundary unobserved.

Soil samples collected:
Bulk samples: 28. 0-38cm; 29. 38-55cm; 30. 55-150cm; 31. 150-220cm; 32. 220-300cm.
Moisture tins (in triplicate): 1A,B and C. 15-20cm; 2A,B and C. 60-65cm; 3A,B and C. 160-165cm.
Thin section samples: 1. 10-20cm; 2. 70-80cm; 3. 170-180cm.