MELANIC SOILS IN SOUTH AFRICA: COMPOSITIONAL CHARACTERISTICS AND PARAMETERS THAT GOVERN THEIR FORMATION

by

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Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is entirely my own original research and that it has not at any time, either partly or fully, been submitted to any university for the purpose of obtaining a degree.

Signed:.. Date: 14/02/2000

Through Him (GOD) all things were made; without Him nothing was made that has been made.

John 1:3

I desire to do your will, O my God; your law is within my heart.

Psalm 40:8

to my loving parents

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My Maker for His love and mercy so that I could persist.

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ABSTRACT

The melanic horizon is one of five diagnostic topsoil horizons distinguished in the South African soil classification system. Melanic soils span a wide spectrum, ranging from those that intergrade with a vertic to those that intergrade with a humic horizon. Melanic soils are therefore expected to vary considerably with respect to a variety of physical, chemical and clay mineralogical properties. During the course of an extensive land type survey, 89 profiles with melanic A horizons have been sampled and described. The correlation and combination of these data, however, is still missing. It was therefore the objective to a) translate information on climate , relief and parent material into a pattern of melanic soil distribution characteristic of South Africa, and b) to determine the clay mineral compositions of melanic horizons from a large number of modal profiles and to establish to what extent melanic soil properties are related to clay mineralogy. Special emphasis was placed on the characterisation of the clay fraction in terms of group and species identification. X-ray diffractometry was employed almost exclusively as the investigative technique in mineral identification and quantification.

Results showed that melanic soils cover a small area of South Africa (< 2%) and that their formation is favoured by an annual precipitation of 550 - 800 mm. The annual precipitation affects the two properties which are a prerequisite for classification into the melanic soil group, i.e. dark colour and structure/high base status, in different ways. Less rainfall retards OM formation/preservation and prevents development of dark colours. Unless the parent material is of a very low permeability a rainfall of >800 mm results in a degree of weathering, which is too advanced for the development of soil structure and the relatively high base status characteristic of melanic soils.

Although climate had an overriding influence on the distribution of melanic soils, topography and parent material played their part. As the annual precipitation reaches 750 - 800 mm, like in the Highveld, melanic soils form predominantly from mudstone/shale lithologies i.e. a parent material, which is clay textured, smectite-rich and therefore of low permeability. This combination of textural and mineralogical characteristics reduces the degree of leaching and promotes melanic soil formation in areas of relatively high rainfall and on up-slope positions.

The melanic A horizons showed a large degree of variation in regard to their clay mineral associations. More than half of them were dominated by smectite, 32% by kaolinite and the rest by an association of about equal proportions of mica, kaolinite and smectite. Talc and hydroxy-interlayered vermiculite occurred in a number of soils while one horizon was dominated by an illite/smectite interstratification. The smectite component was identified as belonging to the beidellite or vermiculite species, depending on the method employed. Only about a quarter of the smectitic soils also contained montmorillonite but not as the dominant swelling phase.

Key words: melanic soils, clay mineralogy, soil forming factors, layer charge

UITTREKSEL

Die melaniese horison is een van vyf diagnostiese bogrond horisonte wat in die Suid-Afrikaanse grondklassifikasie stelsel onderskei word. Omdat melaniese gronde se omvang van die vertiese tot by die humiese horisonte strek, kan verwag word dat melaniese gronde baie sal verskil ten opsigte van fisiese, chemiese en kleimineralogiese eienskappe. Tydens 'n uitgebreide landtipe opname is 89 profiele met melaniese A horisonte beskryf en grondmonters is daarvan geneem. Die grondmonsterdata is egter nog nie gekorreleer en gekombineer nie. Die doelwitte van die projek was om a) die klimaat, relief en moedergesteente wat karakteriserend van melaniese grond van Suid-Afrika is, te gebruik om 'n verspreidingspatroon te verkry en b) om die kleimineraalsamestelling van die melaniese horisonte (afkomstig van 'n groot aantal modale profiele) te bepaal en om vas te stel tot watter mate melaniese grondeienskappe verwant is aan die kleiminerale. Aandag is gegee aan die karakterisering van die kleifraksie in terme van groep en spesie identifikasie. X-straal diffraktogramme is gebruik om die minerale te identifiseer en kwantifiseer.

Resultate het getoon dat melaniese gronde slegs 'n klein area van Suid-Afrika bedek (<2%) en dat die vorming van dié gronde begunstig word deur 'n jaarlikse presipitasie van 550 - 800 mm. Die jaarlikse presipitasie beïnvloed die twee einskappe wat noodsaaklik is vir klassifikasie in die melaniese grondgroep, nl. donker kleure en struktuur/hoë basis status, op verskillende maniere. 'n Jaarlikse rëenval van 550 - 800 mm bevorder vorming van melaniese gronde. 'n Laer reënval vertraag organiese materiaal vorming/behoud en voorkom ontwikkeling van donker kleure. Met 'n reënval van > 800 mm sal die graad van verwering te gevorderd wees vir die omtwikkeling van grondstruktuur en 'n relatief hoë basis status (beide karakteriserend vir melaniese gronde), tensy die moedergesteente 'n baie lae permeabiliteit het.

Allhoewel klimaat 'n oorheersende invloed het op die verspreiding van melaniese gronde, speel topografie en moedergesteentes wel 'n rol. Wanner die jaarlikse presipitasie 750 - 800 mm bereik, soos in die Hoëveld, vorm melaniese gronde hoofsaaklik van moddersteen/skalie, dit wil sê 'n moedergesteente met 'n klei tekstuur, smektietryk en dus gronde met 'n lae permeabiliteit. Die kombinasie van 'n klei tekstuur en smektitiese eienskappe verlaag die graad van loging en bevorder die vorming van melaniese gronde in gebiede met 'n relatiewe hoë reënval en op bo-hellings.

Die melaniese A horisonte vertoon 'n variasie met betrekking tot die kleimineraal samestelling. Meer as die helfte van die gronde het smektiet as dominante kleimineraal, kaoliniet is in 32% van die gronde dominant tewyl die res met 'n assosiasie van gelyke dele mika, kaoliniet en smektiet domineer. Talk en hidroksie-tussengelaagde vermikuliet het in 'n paar van die gronde voorgekom, terwyl een horison gedomineer word deur tussengelaagde illiet/smektiet.

Die smektiet komponent is geïdentifiseer as behorende aan die beidelliet of vermikuliet spesies, afhangende van die metode wat gebruik is vir die bepaling. Slegs 'n kwart van die smektitiese gronde het ook montmorilloniet bevat, maar nie as 'n dominante swellings-mineraal nie.

Sleutelwoorde: melaniese gronde, kleimineralogie, grondvormings faktore, laaglading

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Resource surveys are largely driven by the need to improve agricultural production and much time and emphasis is devoted to studies of soil classification in relation to land use practices. The South African land type survey follows the above trend and is described as "a systematically compiled inventory of the natural factors that determine agricultural potential". This aspect, i.e. the optimum use of land for the production of biomass in agriculture and forestry, is a major challenge in South Africa, with its relatively poor land resources.

In more recent times the considerable volume of information, which is available from extended land type surveys, has been used increasingly for answering practical questions, put forward not only by farmers but by an array of stakeholders including engineers, environmentalists, mining industries, regulators and planners. These new areas of application of soil research require the input of additional soil information which must go beyond soil taxonomy. They need information on differences and similarities in specific soil characteristics between different soil taxa and the range of properties within a specific taxon. Soil surveys must therefore provide the required information for decision making regarding the suitability of a given area for a specific land utilization type.

Well defined diagnostic horizons form the basis for present-day taxonomic soil classification systems (Soil Survey Staff, 1998; WRB Working Group, 1998; Soil Classification Working Group, 1991). For the sake of practical feasibility, diagnostic horizons are defined in terms of morphological features and easy to conduct physical and chemical laboratory analyses. Because of cost and time factors clay mineralogical criteria are not included in the definitions of diagnostic horizons.

The melanic horizon is one of five diagnostic topsoil horizons distinguished in the South African soil classification system (Soil Classification Working Group, 1991). The South African melanic horizon (which is totally different from the concept of the internationally recognized melanic horizon) is similar to the mollic horizon of the international classification systems (WRB Working Group, 1998). It is by definition a well structured, dark coloured horizon with a high base saturation and a moderate to high organic matter content that lacks the swell-shrink properties of vertic soils (Soil Classification Working Group, 1991; WRB Working Group, 1998). Melanic A horizons are distinguished from organic A horizons by a lower organic matter content (<10%), from humic A horizons by a higher exchangeable base content (S-value > 0.28 cmol(+)/kg clay for every 1% organic matter present), from vertic A horizons by the lack of slickensides and cracks, the absence of a self-mulching surface morphology and from orthic A horizons on the basis of structure and/or colour (Figure 1.1).

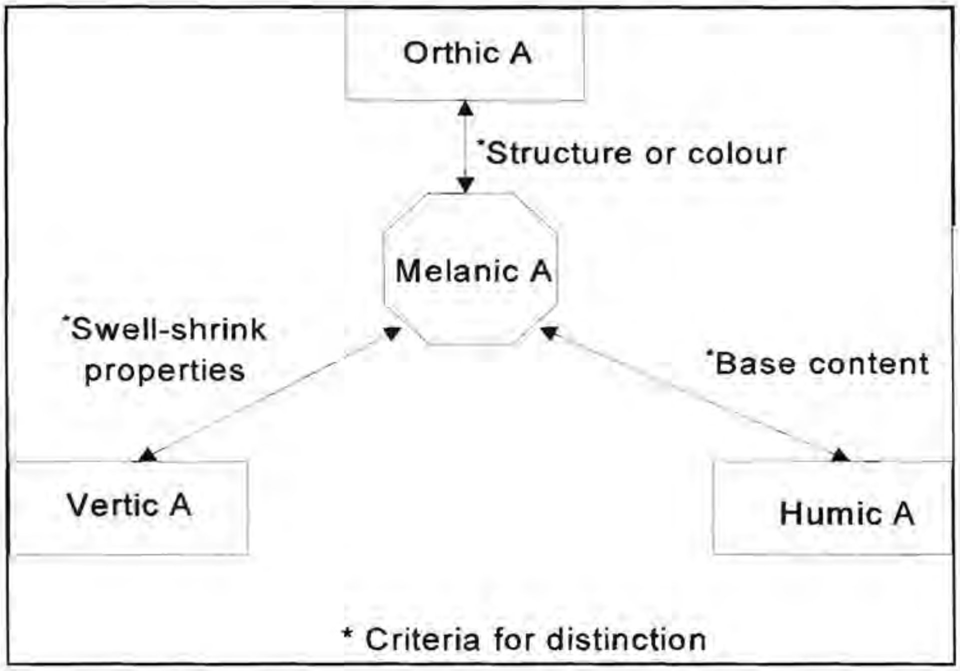

Figure 1.1 Relationships between melanic A horizons and the other diagnostic A horizons in the South African soil classification system

In the USDA's Soil Taxonomy (Soil Survey Staff, 1998) and the WRB classification (WRB Working Group, 1998) the mollic (= melanic) horizon is distinguished from the umbric (= humic) horizon on the basis of degree of base saturation, the mollic having a base saturation of more than 50% and the umbric less than 50%.

In South Africa melanic soils do not cover a wide area. They rarely form the dominant soil group in any area and therefore never feature prominently in broad scale soil maps, and rarely in large scale maps. Despite their restricted aerial extent melanic soils are an agriculturally important soil resource. Their favourable physical and chemical properties, especially the high porosity and available water holding capacity, their relatively high levels of organic matter (for South African conditions) and nutrients and near neutral pH values make these soils very fertile.

1.2 PEDOGENESIS

In terms of properties and pedogenic evolution melanic A horizons occupy a central position between vertic, humic and orthic A horizons. A particular question of interest concerns the environment for their formation, which can be described in terms of climate, parent material, topography, vegetation and time (Jenny, 1941). Generally held hypotheses consider that melanic soils develop under semi-arid to subhumid conditions from parent materials which are basic or intermediate as regards base reserve or in landscape positions (usually footslopes) which receive additions of bases via lateral drainage of water (MacVicar *et al.*, 1977).

Chemical weathering and leaching processes are essential to soil formation. ***Climate*** is of paramount importance in this regard, particularly the parameters rainfall and temperature. Annual precipitation determines the amount of water that can percolate through a soil, leading to leaching and eluviation/illuviation, or that is available as runoff, which may result in erosion. Under seasonal climates, the water flow may reverse direction and change to unsaturated upwards flow (capillarity) in the drier periods of the year. This results in evapotranspiration losses and tends to add materials through chemical precipitation (Richardson *et al.*, 1992). Water is therefore the most crucial agent in the transformation of a parent material into a specific soil in most countries of the world. Temperature strongly affects reaction rates and biochemical processes.

Water movement down the catena is the linkage between soil development and ***topography***. Soils at the upper part of a toposequence are usually shallow and display eluvial conditions. They undergo a net soil loss due to erosion. Soils on middle slopes are subject to lateral eluviation processes, involving both transport of clay in suspension and dissolved materials. On the lower parts of middle slopes and on footslopes these lateral losses of suspended and dissolved materials can be very intense. Constituents and water lost by the upper part of the slope usually accumulate at the lower part which is rich in clay and usually poorly drained (Hugget, 1976; Dan *et al.*, 1968). The magnitude of these translocations is dictated by the parent material, because it is much stronger in sandy materials than where the parent material leads to the production of a clay-rich matrix.

Parent material constitutes the initial state of a soil system. It determines the bulk of soluble elements, available for leaching and mineral formation and strongly influences texture and related porosity/permeability. The latter dictates textural and mineral element differentiation along the catena. Different parent materials also weather at very different rates (Chesworth, 1973; Clemency, 1975).

Vegetation is often regarded as the least important of the soil forming factors. This is probably because there is very much a "hen and egg" relationship between vegetation and soils, i.e. the type of vegetation is strongly influenced by the nature of the soil while certain soil properties are strongly influenced by the type of vegetation.

Time is an important soil forming factor, but also the one most difficult to quantify (Hugget, 1976). Processes of even a mild nature, active over extended periods of time, have an effect similar to aggressive conditions, prevailing over a short time interval.

1.3 CLAY MINERALOGY

Soils, which are morphologically and chemically similar can display drastically different physical properties due to differences in their clay mineralogical suites (Stern, 1990; Bloem, 1992). This is not only related to the dominant clay mineralogy, but often to effects of the presence or absence of small amounts of other clay minerals.

The mineralogical composition of the clay fraction of a soil is one of the critical factors determining many chemical and physical properties. Not only is there a close interrelationship between clay mineralogy and the criteria used for differentiating and classifying soils like base status, or structure, but other soil characteristics like erodibility, water infiltration capacity, sorption potential for heavy metals and/or pesticides and herbicides or K-fixation are closely linked to the presence or absence of certain clay minerals.

The South African soil classification system (Soil Classification Working Group, 1991) states that "the absence of vertic properties in melanic horizons are usually attributable to either a lower clay content (than in vertic horizons) or, if the clay content is high, a predominance of micaceous, vermiculitic or even kaolinitic rather than highly expansive clay minerals". But preliminary findings by Bühmann (1987) indicate that this statement may be incorrect as some of the melanic soils had smectite proportions identical to those of vertisols. As melanic soils range in compositional characteristics between the highly swelling vertic soils at one end and orthic, humic or organic soils at the other end, it can be assumed that the mineral composition of melanic horizons may display a considerable degree of variation. Some of them may well be smectite-dominated (in combination with a high clay content).

Swelling is synonymous with smectite and a large volume of information is available on the swelling of reference smectites in water. Swelling is generally associated with the nature of the saturating interlayer cation, electrolyte concentration, amount of fine clay and layer charge characteristics. Layer charge characteristics include aspects such as the magnitude of the negative charge, its location, i.e. whether it is predominantly tetrahedral or octahedral (Harward & Brindley, 1965), and charge heterogeneity (Lagaly *et al.*, 1972), that is whether there are differences in layer charge characteristics between the two layers that sandwich the interlayer.

All smectites swell, i.e. their c spacing changes with treatment. The extent of swelling, however, may vary dramatically. In smectites with a high layer charge and divalent cations in interlayer positions the unit cell distance changes from 15Å in the air dry state to about 18Å, when fully dispersed in water. In smectites with a low layer charge and monovalent counterions, however, dispersion may result in an increase in the c spacing from 12.4Å to > 100Å. Only the second type of smectite will display a high degree of physical swelling. In the first type, little expansion may be noticed as smectite in a soil generally does not reach the fully dispersed and sometimes also not the air dry state. Some smectites, consequently may show little change in their interlayer distance and thus in their swelling capacity, while others may be extremely expansive.

An impressive amount of information concerning the soil forming factors climate, parent material and relief are contained in the memoirs accompanying land type maps in South Africa (Land Type Survey Staff, 1984 - 1998), though the collation and interpretation of these data are sadly lacking. As far as mineralogy is concerned, however, virtually no basic studies have been conducted on the phyllosilicate associations of melanic horizons in South Africa.

The objectives of the present study were therefore two fold:

a) to translate information on climate, relief and parent material, obtained from Land Type Survey Memoirs, into a pattern of melanic soil distribution, characteristic of South Africa and

b) to determine the clay mineral compositions of melanic horizons from a large number of modal profiles and to establish to what extent melanic soil properties are related to clay mineralogy.

Results will also contribute to the correctness and reliability of information, provided by the South African Soil Classification Manual. Knowledge of the reasons for the non-development of vertic properties in a smectite-dominated melanic horizon will also aid in establishing causes for high/low swelling, which in turn is fundamental to our understanding of soil properties that are generally linked with swelling like crusting and erosion.

CHAPTER 2

MATERIALS AND METHODS

2.1 COLLATION OF FIELD DATA

A systematic land type survey, which defined areas into climate, terrain and soil classes, was initiated at the Institute for Soil, Climate and Water in 1971 and results are now available in the form of soil maps and accompanying memoirs (Land Type Survey Staff, 1984 - 1998) for all of South Africa with the exception of the former Transkei and Ciskei.

Soils were classified in the field according to Soil Classification: A Binomial System for South Africa (MacVicar *et al.*, 1977). For soils with melanic A horizons classification into different soil forms, the higher category in the system, is determined by the nature of the material underlying the melanic horizon (Table 2.1).

Table 2.1 Subdivision of soils with melanic A horizons into forms, based on diagnostic subsoil horizons and materials, according to Soil Classification: A Binomial System for South Africa (MacVicar *et al.*, 1977)

Topsoil	**Subsoil**		**Soil Form**
Melanic	G horizon		WILLOWBROOK
Melanic	Pedocutanic B	unconsolidated material	BONHEIM
Melanic	Soft plinthic B		TAMBANKULU
Melanic	Neocutanic B		INHOEK
Melanic	Stratified alluvium		INHOEK
Melanic	Lithocutanic B		MAYO
Melanic	Hard rock, etc.		MILKWOOD

Subdivision of forms into soil series, the lower category in the system, is based on the clay content (less or more than 35%) and on the absence or presence of lime in the A and/or its underlying horizon. In the case of the Bonheim form, colour of the B horizon is also used for series differentiation (Table 2.2).

The number of modal profiles available from the Land Type Survey varies considerably between different soil forms, probably in relation to the extent of their occurrence. Some series have not been included into the selection at all while others are represented by a relatively large number of profiles (Table 2.2).

In the course of the survey 89 profiles with melanic A horizons were sampled of which all were used for the investigation on the soil textural and chemical properties but only 72 for studies on their clay mineralogy in the present study. The rest could not be investigated mineralogically as no soil material was available. The profiles are situated predominantly in the eastern half of the country (Figure 2.1). Melanic soils are essentially absent from the semi-arid to arid western part of South Africa.

In the establishment of relationships between soil forming factors and melanic soil distribution, the total area covered by melanic horizons was taken as the basis for quantification (land type/climate zone). Results may therefore be different from those determined on the basis of modal profiles only.

The melanic soil - parent material pattern was established by using only those soils for which the soil precursor could be positively identified.

Subdivision into families in Soil Classification: A Taxonomic System for South Africa (Soil Classification Working Group, 1991), the revised version of the South African binomial system, is based on the presence or absence of lime (a) in the material/horizon underlying the melanic A horizon in the Willowbrook, Bonheim and Mayo forms or (b) in the melanic A horizon itself in the Milkwood, Steendal and Immerpan forms or (c) in or immediately below the melanic A horizon in the Inhoek form. Additional criteria for subdivision into families are B horizon colour and structure in the Bonheim form, the amount of bedrock in the lithocutanic B horizon of the Mayo form and signs of wetness in the Inhoek form. The Tambankulu form (a melanic A horizon overlying a soft plinthic B) of the 1977 classification has been excluded from the 1991 version due to its scarcity of occurrence while two new forms, Immerpan and Steendal, have been added. The latter two have soft carbonate or hardpan carbonate horizons (brittle or solid lime pans) respectively underlying the melanic A horizon.

The sets of diagnostic features used for identification of diagnostic subsoil horizons and materials underlying melanic A horizons are outlined by MacVicar *et al.* (1977).

Table 2.2 Criteria for subdivision of melanic soils into forms and series and number of modal profiles available

Soil form	Diagnostic horizon underlying A	Soil series	Clay (%)	Lime	Colour	No. of profiles investigated
WILLOWBROOK	G	EMFULENI	15-35	_		0
		SARASDALE	15-35	+		1
		WILLOWBROOK	> 35	_		1
		CHINYIKA	> 35	+		0
TAMBANKULU	Soft plintic B	FENFIELD	15-35	_		2
		LOSHOEK	15-35	+		1
		TAMBANKULU	> 35	_		0
		MASALA	> 35	+		0
INHOEK	Stratified alluvium or Neocutanic B	CROMLEY	< 35	_		1
		INHOEK	< 35	+		2
		CONISTON	> 35	_		0
		DRYDALE	> 35	+		1

Table 2.2 Continued

MAYO	Lithocutanic B	MAYO	15-35	_		5
		TSHIPISE	15-35	+		1
		MSINSINI	> 35	_		7
		PAFURI	> 35	+		2
MILKWOOD	Hard rock	DANSLAND	15-35	_		2
		SUNDAY	15-35	+		0
		MILKWOOD	> 35	_		7
		GRAYTHORNE	> 35	+		1
BONHEIM	Pedocutanic B	KIORA	15-35	_	red	0
		BUSHMAN	15-35	+	red	2
		DUMASI	15-35	_	non-red	5
		WEENEN	15-35	+	non-red	3
		STANGER	> 35	_	red	7
		RASHENI	> 35	+	red	6
		GLENGAZI	> 35	_	non-red	7
		BONHEIM	> 35	+	non-red	8

+: lime present in B (Bonheim, Tambankulu, Mayo), A (Milkwood), in or immediately below A (Inhoek) or upper G (Willowbrook) horizons;

-: Lime absent

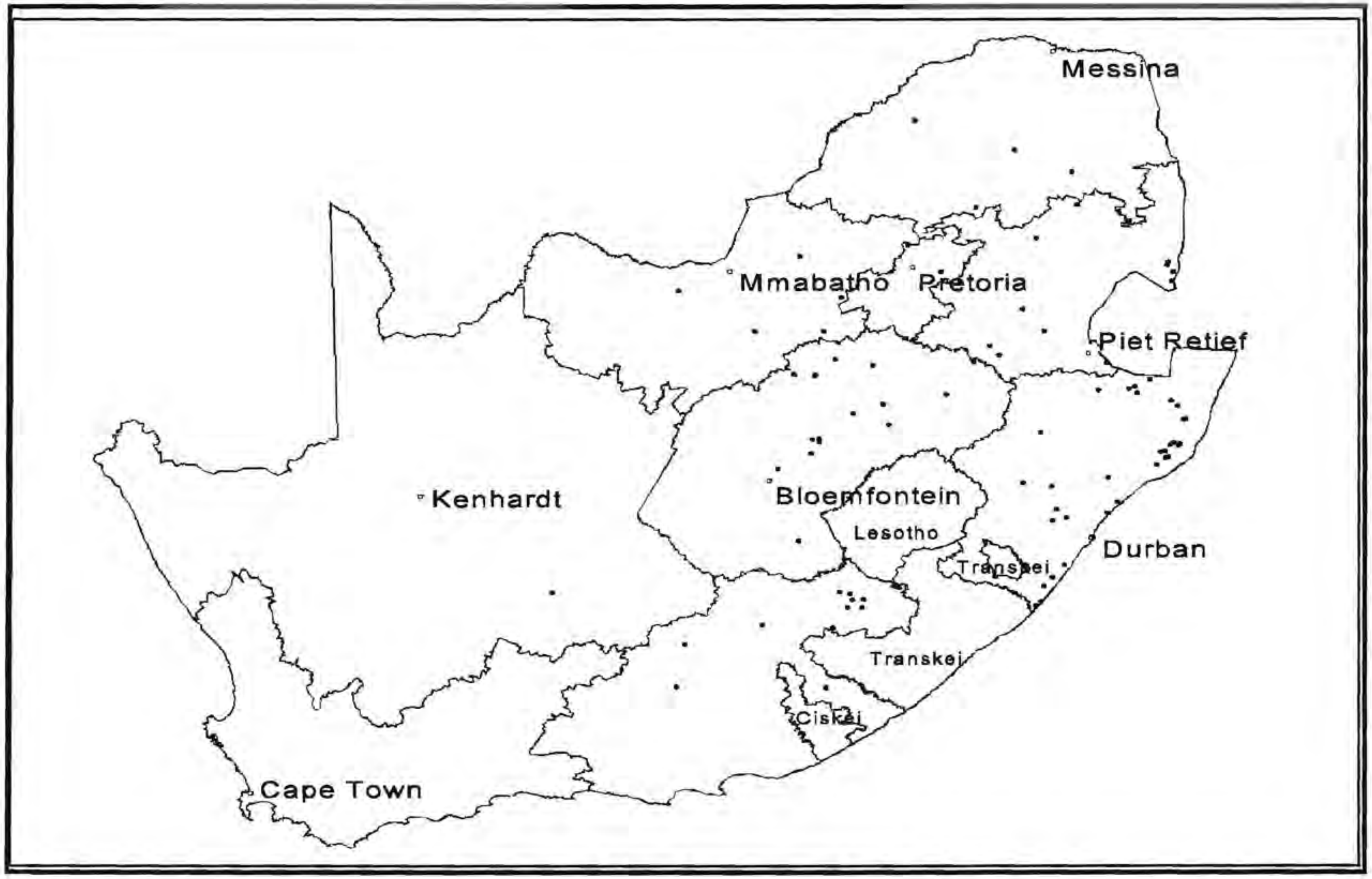

Figure 2.1 Locality map of the melanic A horizons included in the study

2.2 PHYSICAL ANALYSES

2.2.1 Particle size analyses

The method of Day (1965) was used to determine particle size distribution. Organic matter was removed from the air-dried soil sample (10 g) by oxidation with 30% H_2O_2 (10 cm^3). Carbonates were destroyed by adding sufficient 2 mol/ℓ HCl. The soil suspension was flocculated with 10% $CaCl_2$ (10 cm^3), suction filtered and soluble salts leached from the soil. Dispersion was accomplished by means of stirring (7 000 rpm for 10 min). On soils where dispersion was inadequate, a sodium hexametaphosphate dispersing agent (Calgon; 10 cm^3) was used.

Clay (< 2μm) and silt (2 - 20μm) were determined by sedimentation and pipette sampling. The sand fractions, fine (0.02 - 0.2 mm), medium (0.2 - 0.5 mm) and coarse (0.5 - 2 mm) were determined by dry sieving.

Results are expressed as a percentage of the mass of oven-dried soil. All size fractions were determined individually, i.e. none were estimated by difference.

2.2.2 Plasticity index (PI)

The method using the SA Standard Casagrande cup for determining the PI was applied (TMH 1, 1986).

2.3 CHEMICAL ANALYSES

2.3.1 Cation exchange capacity (CEC)

The soils were saturated with LiCl and then washed with 150 cm^3 of 80% ethanol added in 3 - 4 portions allowing complete drainage between portions. The soil was then transferred with the filter paper to an 800 cm^3 beaker and 500 cm^3 of 0.25 M $Ca(NO_3)_2$ solution was added. The suspension was heated in a water bath at 80 - 90°C for 30 min and stirred at intervals to completely disintegrate any aggregates.
The suspension was filtered through a Buchner funnel until suction drainage was complete. Lithium was determined in the filtrate by flame photometer and expressed in me/kg soil at pH 8.

2.3.2 Citrate-bicarbonate-dithionite (CBD) extractable cations

Extraction was carried out by adding 200 cm^3 Na-citrate/bicarbonate buffer (pH 8.5) solution (0.3 mol/ℓ Na-citrate and 1.0 *mol/ℓ* $NaHCO_3$), shaking the sample into suspension, adding about 10 g Na-dithionite and allowing it to react, with intermittent stirring on a water bath at 70°C. After the colour change (about 30 min), the suspension was centrifuged and the citrate dithionite extract poured off into pre-weighed plastic bottles. After a further washing with 200 cm^3 Na-citrate/bicarbonate solution and centrifugation, the supernatant was added to the plastic bottles.
Iron, manganese and aluminium were determined in the extract by atomic absorption and results recorded as per cent (*m/m*) Fe, Mn and Al on a soil (< 2 mm) basis.

2.3.3 Organic matter content (OM)

The OM content was determined by a slightly modified Walkley-Black method as described by Allison (1965). The soil was ground to pass a 44 mesh (approx. 0.355 mm) sieve. Masses of 0.5 g, 1 g or 2 g soil were used, depending on the amount of carbon present and 15 cm^3 concentrated H_2SO_4 were added. An amount of 196 g

$(NH_4)_2Fe(SO_4)_2.6H_2O$ plus 5 cm^3 concentrated H_2SO_4 was made up to 1ℓ to replace the ferrous sulphate o-phenanthroline monohydrate solution used to back-titrate the unreacted $K_2Cr_2O_7$ (initially 0.5 mol/ℓ).

2.3.4 pH

Two pH measurements were conducted, one on a 1:2.5 soil to water suspension and one on a suspension prepared by adding 75 cm^3 0.01 mol/ℓ $CaCl_2$ solution to 15 g soil. In both instances, suspensions were stirred intermittently for 15 min and allowed to stand for at least 1 hour. The electrodes were positioned in the supernatant liquid.

2.4 MINERALOGICAL ANALYSES

2.4.1 Separation of the clay fraction (< 2 μm)

The methods described by Jackson (1956) were modified to facilitate the handling of a large number of samples. All samples received the same pretreatment. Sufficient soil to yield between 6 and 12 g clay was weighed into a plastic 500 cm^3 centrifuge bottle and treated with 200 cm^3 1 mol/ℓ NaOAc (buffered at pH 5) in a water bath at 70°C with intermittent stirring to dissolve carbonates. After centrifugation, the NaOAc was decanted and discarded. The treatment was repeated to extract as much carbonate as possible. The OM was removed by adding 50 cm^3 30% H_2O_2. After the initial vigorous reaction had subsided, the removal was brought to completion on a water bath. The procedure was repeated with 20 cm^3 H_2O_2 for most soils, and with 50 cm^3 for soils rich in OM. The peroxide treated samples were then shaken by hand in 300 cm^3 1 mol/ℓ NaCl, centrifuged, and the supernatant was decanted. About 500 ml of distilled water was added to the flocculated soil. After being shaken horizontally for half an hour, the samples were centrifuged for 5 min at 750 rpm. The individual clay fractions were decanted into glass bottles. A total of 5 cycles of treatment were conducted.

2.4.2 Clay saturation and solvation treatments

Clay fractions were rendered homo-ionic by shaking in a chloride solution of the desired cation, then left to equilibrate overnight. Cations were used in the following concentrations: Mg and K - 1 mol/dm^3; Li - 3 mol/dm^3. The flocculated clay was freed of excess salt by repeated centrifuge washings and orientated specimens were prepared on a ceramic tile by the suction-through method (Gibbs, 1965).

Mg-saturated samples were X-rayed in the air dry state as well as after solvations with ethylene glycol (vapour at 60°C for 24 h) and glycerol (vapour at 80°C for 24 h; Novich and Martin, 1983) to establish expansion characteristics of the clay minerals.

Patterns of K-saturated samples were recorded in the air-dried state and after heating to 550°C for at least 4 hours.

The clay fractions, saturated with LiCl, were heated at 280°C for a minimum of 4 h and solvated with ethylene glycol before being X-rayed (Greene-Kelly test).

2.4.3 Intercalation with dodecylammoniumchloride

Dodeacylamine (to give a final concentration of a 0.1 M solution) was dissolved in a small amount of ethanol. A water:ethanol mixture (1:1) was slowly added, avoiding intense clouding, and the pH adjusted to 6 - 7 with HCl (Lagaly, 1979). A 7.5 cm^3 aliquot of this dodecylammoniumchloride solution was added to about 30 mg of clay. The suspension was heated at 65°C for two days, the solution being replaced after one day. Excess dodecylammoniumchloride was removed by 10 washings with a water-ethanol (1:1) mixture and one final washing with pure ethanol. The paste was then sucked through a ceramic tile for orientation, dried at 65°C and stored in a desiccator.

2.5 CRITERIA FOR THE INTERPRETATION OF DIFFRACTOGRAMS

X-ray diffraction (XRD) analyses were carried out on a Phillips X-ray diffractometer with PW 1010/25 generator, PW 1050/25 goniometer and AMR 3 - 202 graphite monochromator, using Fe-filtered Cobalt Kα radiation at 1.0° divergence slit with a 0.1° receiving slit, and a proportional counter. Standard experimental conditions were 45 kV and 40 mA and a scanning speed of 1°2θ/min. Oriented specimens were scanned from 2 to 35°2θ.

2.5.1 Mineral identification

The identification of various clay minerals is based on the position and possible shift of a series of basal reflection, applying auxiliary tests (Bailey, 1980). Generally a discrete mineral must give a rational series of basal reflection with $d_{005} \times 5 = d_{004} \times 4 = d_{003} \times 3 = d_{002} \times 2 = d_{001}$ (Å) with a low background to both sides of the peak maximum.

The following basal spacings were selected as being characteristic of individual clay minerals:

Mica: A 10Å (9.8°2θ) spacing which did not change with any of the treatments applied.

Talc: A 9.3Å (11°2θ) spacing which did not change with any of the treatments applied.

Kaolinite: A 7Å basal spacing (14°2θ), independent of saturating cations or solvation with ethylene glycol or glycerol. The peak disappeared, however, on heating to 550°C, as kaolinite is transformed into X-ray amorphous metakaolinite at temperatures above 500°C.

Hydroxy-interlayered vermiculite (HIV) also referred to as pedogenic chloride: A 14Å mineral (7°2θ) spacing (Table 2.3), independent of solvation with ethylene glycol or glycerol, and saturation with K. On heating to 550°C a very broad shoulder forms between 10Å and 14Å. HIV is positioned in the mineral classification scheme somewhere between swelling clay minerals and chlorite, having the lack of expansion typical of chlorite, but peak intensity ratios and charge characteristics of smectites.

Illite/smectite interstratification: A peak position, that migrates between that of mica and that of the discrete swelling clay phase, depending on proportional characteristics (Table 2.3).

Vermiculite characterization: A 14Å diffraction peak in the Mg saturating state, which does not expand with either ethylene glycol or glycerol solvation (Table 2.3), but collapses to 10Å after K-saturation.

Smectite characterization: A 15Å peak that expands to 17Å after ethylene glycol treatment and may or may not expand to 18Å after glycerol treatments, depending on the layer charge (MacEwan and Wilson, 1980; Table 2.3). K-saturation generally results in a decrease to 12.4Å and heating to 550°C leads to a 10Å peak.

2.5.2 Determination of layer charge characteristics of swelling clays (Table 2.3)

Glycerol solvation also permits differentiation of swelling clays on the basis of the layer charge (Harward & Brindley, 1965): in discrete smectites a high, vermiculite-type layer charge leads to monolayer formation with glycerol and generally also with ethylene glycol, while a low, smectite-type layer charge results in bi-layer formation with both solvating agents.

Table 2.3 X-ray identification criteria of 14Å minerals

Mineral	Mg AD	Mg EG	Mg Gl	G-K	C_{12}	K AD	K 550°C
	Å						
Chlorite	14.2	14.2	14.2	14.2	14.2	14.2	14.0
HIV	15	15	15	15	15	15	10-14broad
Montmorillonite	15	17	18	9.5	13.6	12.4-15	10
Beidellite	15	17	15/18	17	17.6	12.4	10
Vermiculite	15	15	15	15	>20	10	10

Mg AD - Mg-saturated, air dry;

Mg EG - Mg-saturated, ethylene glycol solvation;

Mg Gl - Mg-saturated, glycerol solvation;

G-K - Greene-Kelly test;

C_{12} - Intercalation with dodecylammonium chloride;

K AD - K-saturated, air dry;

K 550°C - K-saturated, heated to 550°C

Greene-Kelly test: The Greene-Kelly (1953) test differentiates dioctahedral smectites on the basis of the seat of layer charge. After Li-saturation and heating to 280°C, irreversibly collapsed interlayers denote montmorillonite, while re-expanding interlayers are ascribed to beidellite. The proportion of montmorillonite interlayers in a smectite crystal (i.e., in a montmorillonite/beidellite interstratification) was estimated by comparing the position of the reflection between 0.8 and 1.0 nm from the Mg-saturated, ethylene glycol solvated clay with that of the corresponding peak produced by the Li-saturated, heated, ethylene glycol solvated material (Reynolds, 1980). Any increase in the value of this peak is attributed to the presence of irreversibly collapsed interlayers (montmorillonite) in a smectite crystallite.

Dodecylamine (C_{12}): The dodecylammoniumchloride method permits identification of interlayer charge density (Lagaly, 1982; Lagaly *et al.*, 1976). Low-charge montmorillonites are characterised by basal spacings of 13.6Å (mono-layer), beidellites by 17.5Å (bi-layer) and vermiculites by >20Å (paraffine-type structures).

K-saturation: Measurement of the spacing of the K-saturated, air-dried smectite; a 12.4Å line was assumed to be characteristic of beidelite or low-charge vermiculite, whereas a spacing of 15.2Å was taken to indicate montmorillonite (Machajdik & Cicel, 1981) and a 10Å peak was ascribed to vermiculite. A peak position between the two values was regarded as indicative of charge heterogeneity within the smectite crystallite, i.e., water monolayer/water bilayer interstratification.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 GEOGRAPHIC DISTRIBUTION OF SOILS WITH MELANIC HORIZONS

Soils with melanic horizons do not constitute a major proportion of the soils in South Africa and their aerial extent amounts to only 2.34 million ha or about 2% of the country. Different regions, however, differ considerably in the percentage of their melanic soil cover (Figure 3.1). Melanic soils are particularly common (75%) in the Aliwal North district southwest of Lesotho, and in the eastern Lowveld; while they are almost absent from the western half of the country (Western and Northern Cape provinces).

3.2 SOIL FORMING FACTORS

The distinctive features of a soil can be ascribed to a particular set of soil forming factors (Jenny, 1941). This study aimed a) at identifying the factors that are conducive for the formation of melanic topsoils and b) to establish the aerial extent and distribution pattern of melanic topsoils in South Africa.

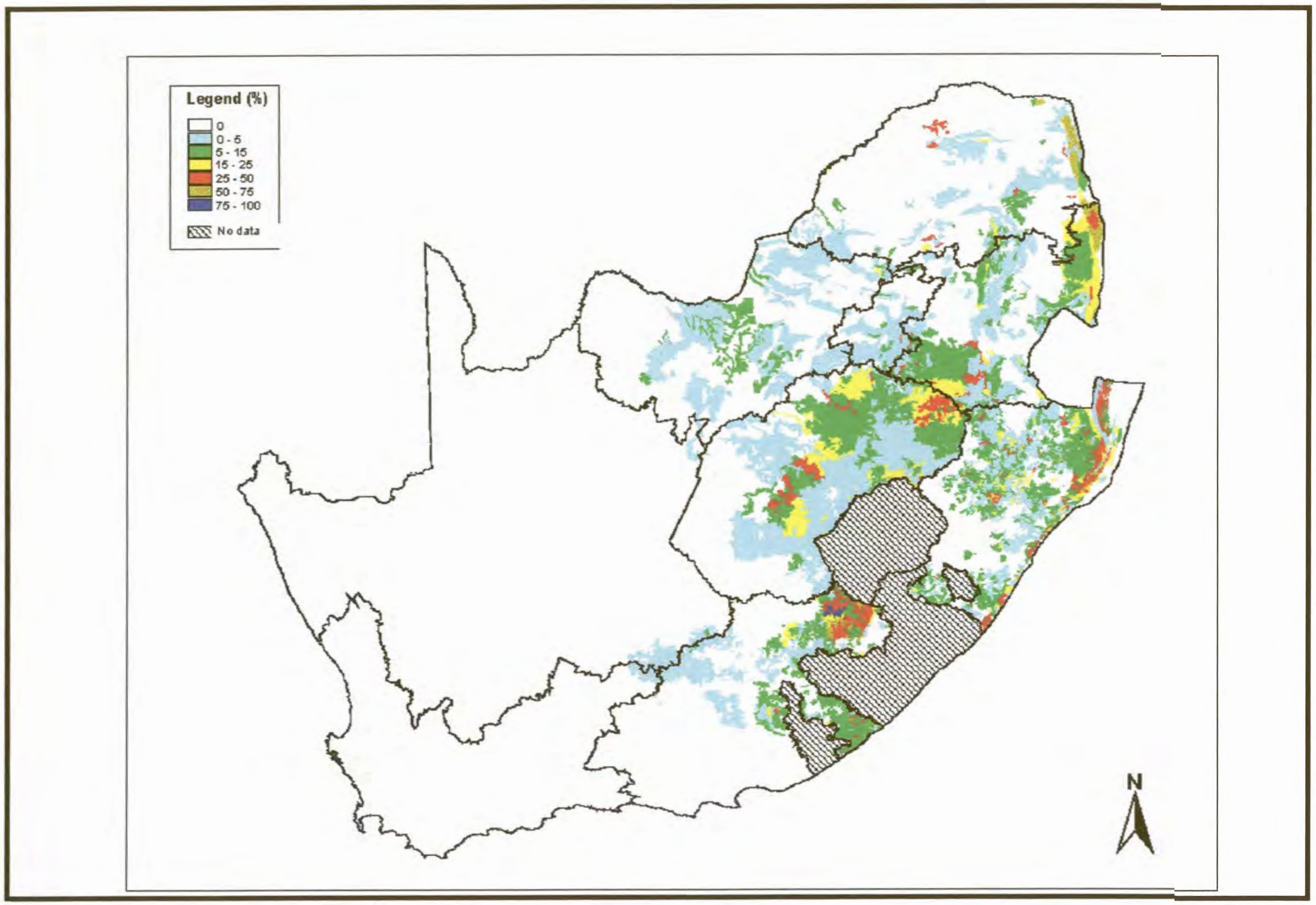

Figure 3.1 Geographic distribution of melanic soils in South Africa

3.2.1 Climate

Climate and consequently weathering intensity are generally regarded state factors of soil formation. Melanic soils in South Africa occur under rainfall regimes that range from 274 mm to 1708 mm per annum, but are concentrated in areas with a mean annual precipitation of 550 - 800 mm (Figure 3.2). About three quarters of melanic soils fall into this rainfall bracket. The strong concentration of melanic soils in this precipitation range is a reflection of the importance of rainfall as a soil forming factor in the development of melanic horizons and of the intimate association of melanic morphology with areas of moderate leaching intensity.

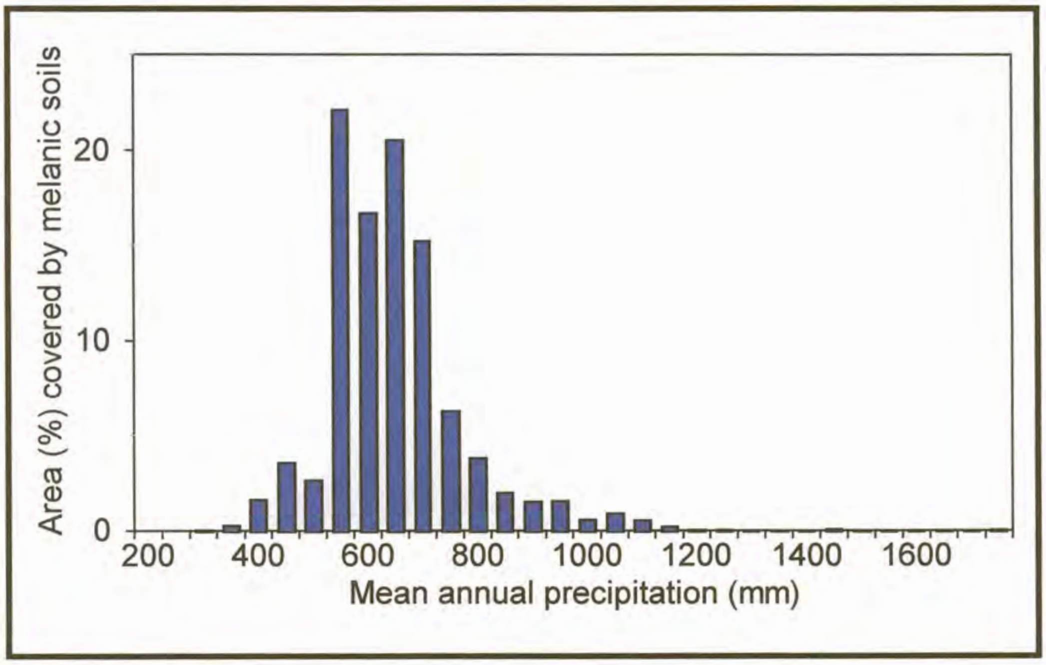

Figure 3.2 Relationship between the occurrence of melanic soils and average annual precipitation

Ecca and Beaufort sediments, for example, form the dominant parent material for soils over a large part of South Africa (SACS, 1980). Development of significant proportions of melanic soils from these sediments is limited to the 550 - 800 mm rainfall bracket, however.

There is a large overlap between the rainfall regimes under which melanic and vertic topsoils respectively are concentrated, with a skew towards a 50 mm higher rainfall bracket for melanic horizons (about 80% of all vertisols formed under 500 - 700 mm annual precipitation: Bühmann & Schoeman, 1995).

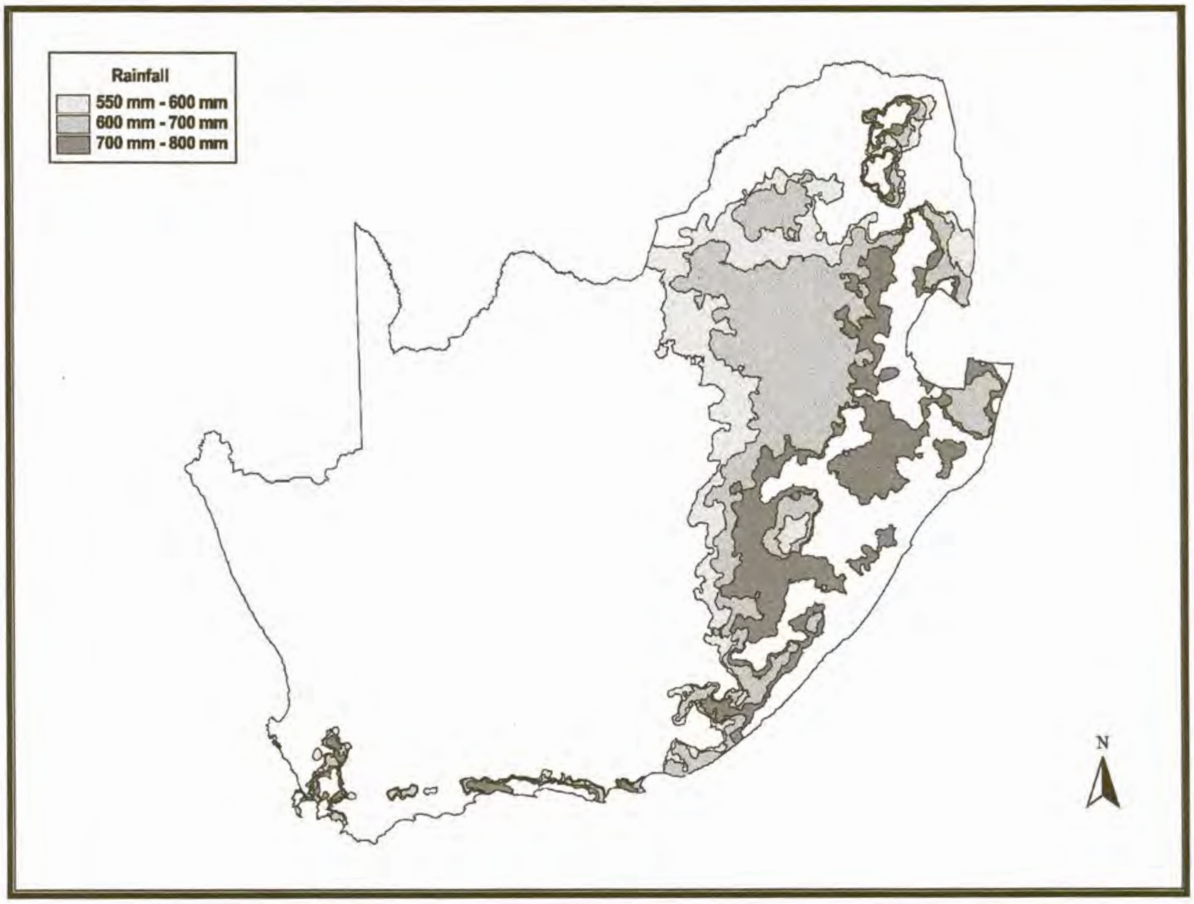

Figure 3.3 Distribution of mean annual precipitation in the 550 mm - 800 mm range in South Africa

As vertisols reflect a slightly less advanced state of soil formation compared to melanic soils, a lower precipitation and associated lower leaching intensity correlates well with the interrelationship of weathering intensity and soil formation. The virtual absence of melanic soils from areas with more than 800 mm or less than 550 mm rain (compare Figure 3.1 and Figure 3.3) is a reflection of weathering intensity and organic matter (OM) addition/preservation characteristics. Rainfall of > 800 mm leads to a leaching intensity which is too high to maintain the relatively high base status required per definition for melanic horizons. The higher leaching associated with higher rainfall will favour the formation of humic topsoils which, per definition, have a lower base status than melanic horizons. Rainfall below 500 mm on the other hand restricts plant growth and biomass production and therefore the amount of organic matter added to the soil. Areas receiving < 500 m rainfall annually closely fit those with an average OM content of < 0.5% in the A horizon (Scotney & Dijkhuis, 1990). As the annual precipitation reaches the lower range for the development of melanic horizons, low OM addition/preservation is obviously the limiting factor preventing the formation of the dark colours and well-developed structure which are, per definition, required in melanic horizons. The few melanic soils formed in the 400 - 500 mm rainfall bracket, were situated on the lower slopes, most of them on valley bottom and footslope positions (Table 3.1b), where there is lateral addition of water. Even in the 500 – 600 mm rainfall bracket a strikingly larger proportion of the melanic horizons are on the valley bottoms and footslopes than is the case at higher rainfall (Table 3.1b). In these situations topography is the co-dominant soil forming factor.

Table 3.1 Interrelationships between topographic position and the percentage of melanic soils, developed

a) from different parent rocks

Parent rock	Crest	Scarp	Midslope	Footslope	Valley bottom
	%				
Basalt	19	1	27	26	27
Dolerite	29	0	45	3	23
Granite	24	0	37	12	27
Sandstone	26	1	44	7	22
Shale	35	0	47	1	17

b) under different climatic conditions

Annual precipitation (mm)	Crest	Scarp	Midslope	Footslope	Valley bottom
	%				
400 - 500	0	0	11	21	68
500 - 600	6	5	11	28	50
600 - 700	26	1	41	9	23
700 - 800	28	0.5	45	5.5	21
800 - 900	29	0	45	1	25
900 - 1000	31	0	45	0	24
1000 - 1100	29	0	42	10	19

3.2.2 Parent material

Rock type has a profound influence on soil formation, governing parameters like texture and availability of bases (Barshad, 1966; Clemency, 1975). The influence of precursor material on soil characteristics increases with decreasing degree of weathering (Eberl, 1984). In the present study melanic soils were associated with parent lithologies as contrasting as ultramafic rocks and wind blown sand. Mafic and sedimentary rocks, however, were identified as the dominant substrata from which more than 37% and 44%, respectively, of the melanic soils developed (Table 3.2).

The data presented in Table 3.2 do not give a true reflection of the preferential development of melanic horizons from specific parent materials. It is largely masked by the large differences in the aerial extent of the different geological materials. Comparisons between dolerite (and other mafic rocks) on the one hand and Karoo siltstones, mudstones and shales on the other hand, clearly illustrate this. Dolerite intrusions in total cover very small areas compared with the Karoo siltstones, mudstones and shales, and even the Karoo sandstones, and yet dolerite is the most common precursor for the formation of melanic horizons (22.65%).

At a local scale the difference can be very striking. In the sub-humid/semi-arid parts of the central Eastern Cape (former Ciskei) melanic horizons are, for example, directly associated with dolerite, while bleached, massive orthic A horizons are found on the Karoo mudstones and shales which dominate the area. A striking regional example of the preferential development of melanic horizons from mafic rocks is found in the eastern Lowveld of Mpumalanga and the Northern Province (Figure 3.1). The narrow strip with high melanic horizon incidence, running from the Swaziland border to the Zimbabwean border, is associated with a strip of basalt, with much lower occurrence of melanic horizons on the Karoo sediments and granites to the west of it.

An unexpectedly large proportion (21.46%) of the melanic horizons have developed on Karoo sandstones, with unexpectedly small proportions on the finer grained Karoo sediments (considering the vast aerial extent of the latter and the fact that melanic horizons have fairly high clay contents). Karoo sandstones are immature and rich in feldspar (predominantly plagioclase, but also K-feldspar) and in some cases analcime throughout the Karoo Basin (Bühmann, 1988; Van Vuuren, 1983). These sandstones therefore resemble granites in their chemical composition. The clay fractions are dominated by illite/smectite interstratifications, chlorite and kaolinite (Rowsell & DeSwardt, 1976; Bühmann, 1992), a mineral association which is regarded particular characteristic of melanic soils (MacVicar *et al.*, 1977). The observed extended formation of melanic soils from sandstone lithology may therefore be a reflection of both the rock's immaturity and its fairly large aerial extent.

Table 3.2 Distribution of melanic soils in relation to parent material

Igneous and metamorphic rocks					
Mafic		Intermediate		Felsic	
Amphibolite	0.38%	"Lava"	5.70%	Gneiss	0.22%
Andesite	0.22%	Rhyodacite	2.34%	Granite	9.45%
Basalt	13.58%			Tonalite	0.16%
Dolerite	22.65%			Rhyolite	0.22%
Gabbro	0.49%				
TOTAL	37.32%		8.04%		10.05%
Sediments/sedimentary rocks					
"Waterborne" deposits		Chemical deposits		Aeolian deposits	
Tillite	7.71%	Marble	0.05%	Sand	0.54%
Siltstone	2.45%				
Shale/ Mudstone	8.31%				
Schist	1.79%				
Sandstone	21.46%				
Alluvium/ Colluvium	2.28%				
TOTAL	44.00%		0.05%		0.54%

In an undisturbed west-east transect, the so-called Rietpan firebreak road, in the Kruger National Park there is a striking difference between the grass biomass production on the basalt and Timbavati gabbro areas, where melanic horizons are abundant, and the grass biomass production on adjoining Karoo mudstones and shales and the base-rich footslopes of the granitic areas, where melanic horizons are rare. On the basalt and gabbro the grass biomass production is estimated at more than

7 t/ha/y and on the sediments and granites at barely 1.5 t/ha/y. The low organic matter additions on the latter severely restrict the development of the dark colours and well-developed structure which are, per definition, characteristics of melanic horizons and consequently melanic horizons are rare on these rock types. The rainfall remains the same along the transect, only the parent materials differ. (The effect of grass biomass production on the development of melanic horizons will be discussed further under Section 3.2.4: Living organisms).

3.2.3 Topography

Formation of a specific soil is reportedly closely related to its position in the landscape (Hugget, 1976; Van Ranst *et al.*, 1997). In the present study, however, no distinct relationship could be established between physiographic position and the distribution of melanic soils (Table 3.1 and Figure 3.4).

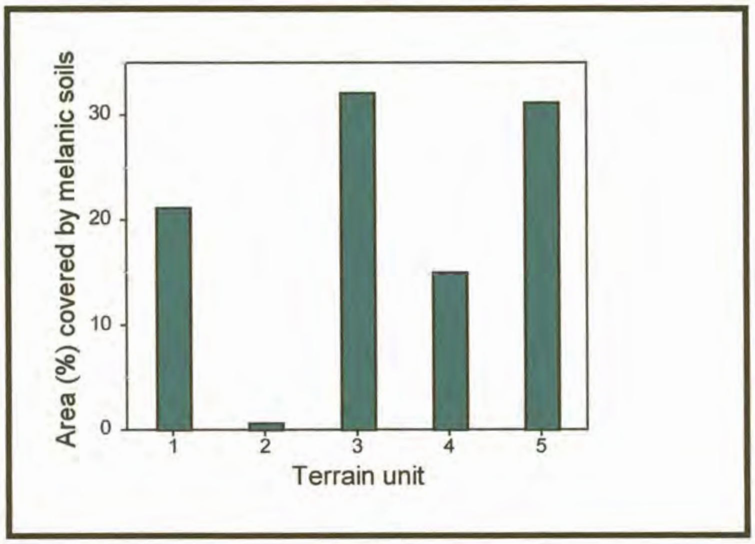

Figure 3.4 Spatial distribution of melanic soils in relation to their physiographic position

Most of the soils developed on terrain unit 3 (midslope), closely followed by 5 (valley bottom). Footslopes did not constitute the preferential position of formation, as suggested by MacVicar *et al.* (1977). Terrain unit 2 represents scarps and is irrelevant.

Melanic horizons that developed from contrasting parent rocks did not occupy widely different topographic positions (Table 3.1a). This finding is particularly evident in the percentage of melanic soils that formed from dolerite, granite and sandstone.

The strong interrelationships between topography and rainfall in the formation of melanic horizons on different topographic positions have been discussed in Section 3.2.1.

3.2.4 Living organisms

Dense sweetveld grassland, giving high biomass production and high organic matter additions to the soil, seems to be intimately related to the development of melanic horizons, as was discussed under Sections 3.2.1 and 3.2.2. This fits in well with the internationally well-known relationship between dense grassland (steppe; prairies) and mollic (= melanic) horizons (e.g. WRB Working Group, 1998).

3.2.5 Time

The time factor in soil formation is difficult to quantify for most soils. It is well established that the weathering history of South Africa is complicated. The northern part of South Africa is a remnant of the so-called African Weathering Cycle 1 surface which formed between Cretaceous and mid-Tertiary times and which is characterized by great depth of weathering and massive duricrusts (Partridge & Maud, 1987). Erosion of this surface may have commenced either in the late Tertiary or as late as 30 000 - 12 000 years ago. African Weathering Cycles 2 and 3, which affected areas more to the South, were of less intensity and duration (Partridge & Maud, 1987), but may still have had an influence on the degree of leaching of some soils. The absence of melanic soils from part of the 550 - 800 mm rainfall areas may, in some areas at least, reflect wetter paleoclimatic conditions.

3.3. MINERALOGICAL ANALYSES

3.3.1 Clay mineral associations

The melanic A horizons investigated in the present study showed large variations with regard to their clay mineral associations (Figure 3.5). Some striking patterns are evident, however.

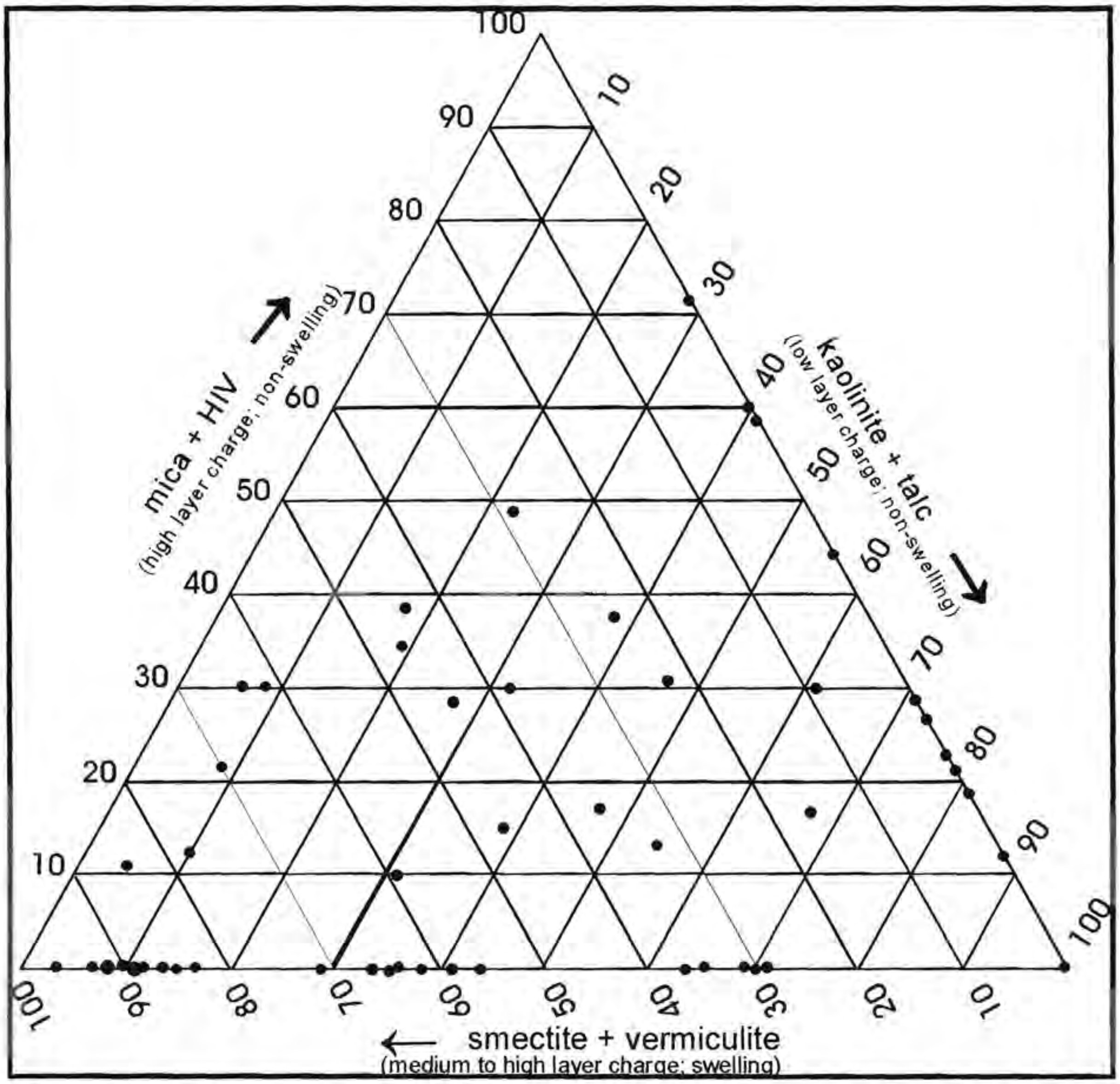

Figure 3.5 Clay mineral associations in melanic A horizons from South Africa

The first is the extremely small number of cases (5) in which mica + hydroxy interlayered vermiculite (HIV) constitute the dominant clay mineral association. In four of these HIV is making the whole contribution, with no mica present. In all four cases the soils also contained no swelling clays. No less than 24 (> 40%) of the melanic horizons contained no mica + HIV, the vast majority of the latter soils having smectite + vermiculite as dominant clay mineralogy. All the soils contained one or more of the following clay minerals (Table 3.3): kaolinite, mica, talc, smectite, illite/smectite interstratifications, vermiculite and hydroxy-interlayered vermiculite (HIV). This interlayered vermiculite is also often referred to as pedogenic chlorite.

Viewing micaceous clay mineralogy as a predominant factor in creating melanic features is a misconception in all probability. In fact, in the Eastern Cape the clay fractions of the dense, structureless, bleached, orthic A horizons developed from mudstones and shales which are dominated by illite. In this area the melanic soils found in between the above are associated with dolerite as parent material.

The clay fractions of more than half of the melanic horizons are dominated by swelling clay minerals (smectite, vermiculite, illite/smectite interstratifications), with the latter minerals comprising more than 75% of the clay fraction in about half of these. Since many of these soils have high clay contents they could be expected to show strong swell-shrink characteristics, i.e. to be vertic. It should be kept in mind, however, that swell-shrink phenomena are influenced by a variety of factors, e.g. electrolyte concentrations and ESP. Wilding & Tessier (1988) indicated that high-charge smectites have lower swell-shrink potential than low-charge smectites. Some melanic horizons will grade towards vertic horizons. They may even have strong enough swell-shrink characteristics to pose a hazard for buildings, though the expansion is not enough to qualify them as vertic (Soil Classification Working Group, 1991).

Nearly 30% of the melanic horizons studied had kaolinite as the dominant clay mineral. Some of these were devoid of swelling clay minerals, others of mica + HIV (Figure 3.5). Few kaolinite dominated horizons contained both smectite + vermiculite and mica +

HIV. According to Stern (1990) and Bloem (1992) major differences regarding physicochemical properties, especially dispersion and crusting, could be expected between the kaolinitic soils with and without smectite "impurities". The kaolinite-dominated melanic A horizons could logically be expected to be the ones that grade towards humic A horizons. Some melanic and humic horizons resemble each other closely morphologically. They are purely distinguished from each other according to the base status limits in the 1977 definition (MacVicar *et al.*, 1977) and on a combination of base status and plasticity index (PI) in the 1991 edition (Soil Classification Working Group, 1991). The gradation of melanic to humic horizons on the one (more highly weathered) side and to vertic horizons on the other side is illustrated by the fact that one of the studied "melanic" horizons according to the original criteria (MacVicar *et al.*, 1977) had to be reclassified as humic according to the slightly revised criteria (Soil Classification Working Group, 1991), while another had to be reclassified as vertic.

The clay mineralogical data for the melanic soils in the present study are almost identical to those found by Bühmann & Schoeman (1995) for vertic soils in the northern regions of South Africa, most of the vertic soils being dominated by smectite, all containing at least some proportions of kaolinite (up to 65%) and very little mica. Since melanic horizons cover the range between humic horizons on the one hand and vertic on the other hand, it is logical to expect a clay mineralogy ranging from predominantly kaolinitic to predominantly swelling clays.

Table 3.3 Average clay mineral contents in relation to parent material

	Swelling clays	Kaolinite	Mica	Talc	HIV
Average (%)	46.1	35.8	11.3	1.5	5.3
Sediment (%)	49.2	25.0	25.8	0	0
Mafic rocks (%)	43.0	37.9	8.1	2.3	8.7
Granite/gneiss (%)	29.4	60.8	9.8	0	0

Melanic soils develop from a variety of parent materials (Table 3.2; Appendix 1). There were distinctive differences in clay mineral associations between melanic soils formed from different precursors (Table 3.3). The mica content was on average much higher in sediment-derived pedons, while granitic substrates resulted in high kaolinite contents. Talc and HIV were restricted to soils formed from mafic rocks.

3.3.2 XRD Patterns

The XRD patterns of the two melanic soils in Figure 3.6 display features characteristic of kaolinite and mica. Kaolinite is a 7Å mineral with resultant peak position at about 14°2θ.

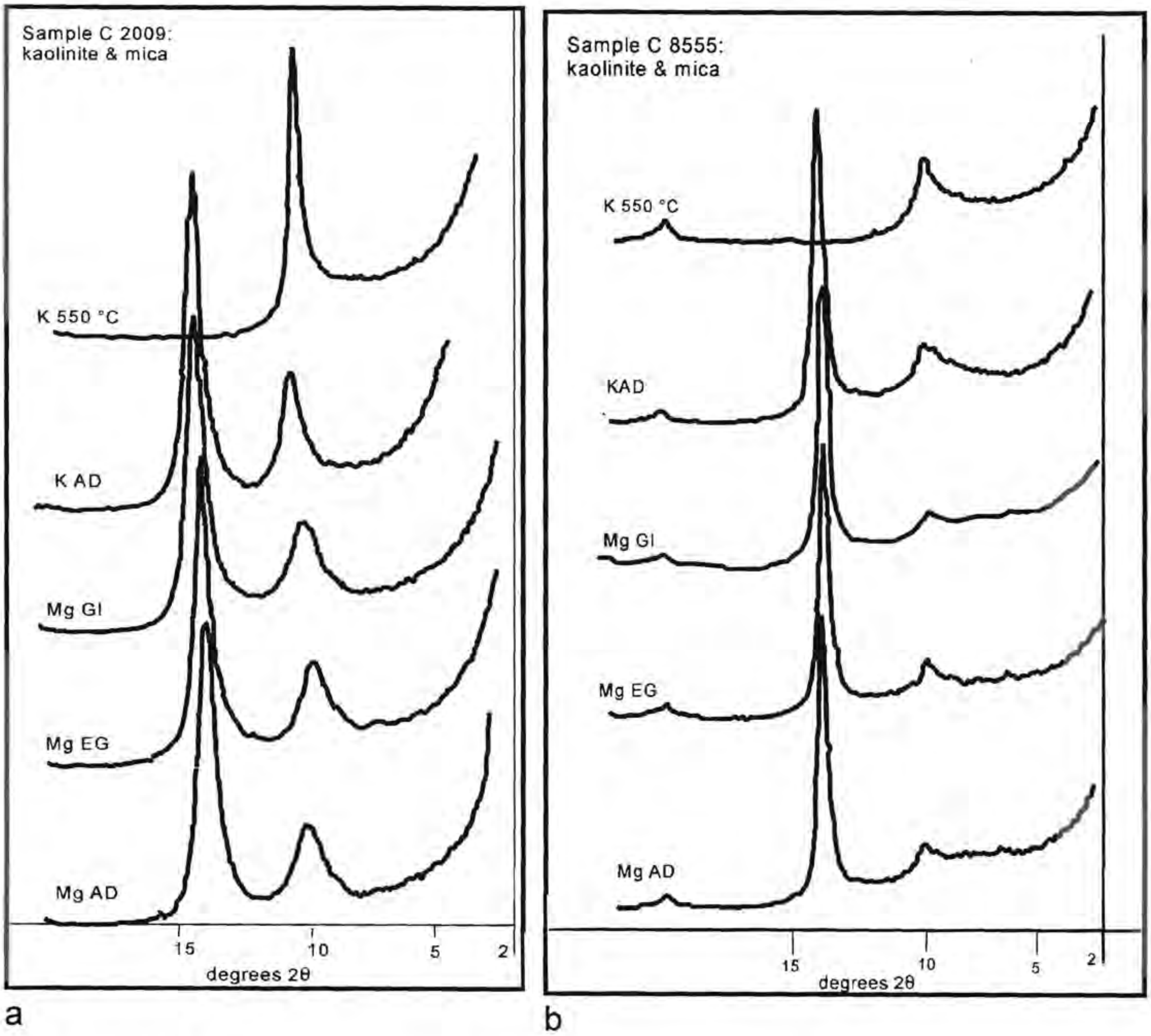

Figure 3.6 XRD patterns of two melanic soils containing kaolinite and mica

This characteristic basal reflection (MgAD) does not shift on treatment with ethylene glycol (MgEC) or glycerol (MgGl), as the mineral is non-swelling. The peak position also does not change following saturation with K (KAD). The peak, however, disappears on heating to 550°C, as kaolinite is transformed into X-ray amorphous metakaolinite at temperatures above 500°C.

Additional to kaolinite, these samples contain a 10Å mineral, which does not change its spacing in response to any of the treatments applied in the present study. This feature is typical for the clay mineral mica. These samples, therefore, contain an association of mica and kaolinite. The mica content is significantly higher in sample C 2009 (Figure 3.6a), compared to sample C 8555 (Figure 3.6b), as reflected in a markedly higher intensity of the mica peak relative to the kaolinite reflection. In sample C 8555 a high background at the low angle side of the mica peak indicates small amounts of 14Å minerals, interstratified with mica.

Sample C 5959 (Figure 3.7) contains kaolinite in association with a 14Å (7°2θ) mineral which does not expand with ethylene glycol or glycerol, nor does it collapse upon K saturation. These spacing characteristics are common to chlorite. On heating, however, a very broad shoulder developed between 10 and 14Å; a feature uncharacteristic of chlorite. In reference chlorite, the intensity of the 14Å peak increases significantly on heating. The 14Å mineral in this sample shows all the characteristics of Al-hydroxy interlayered smectite or vermiculite, commonly referred to as pedogenic chlorite. This pedogenic chlorite is positioned in the mineral classification scheme somewhere between swelling clay minerals and chlorite, having the lack of expansion typical of chlorite, but peak intensity ratios and - to a lesser extent - charge characteristics of smectites. This sample also contains quartz and feldspar.

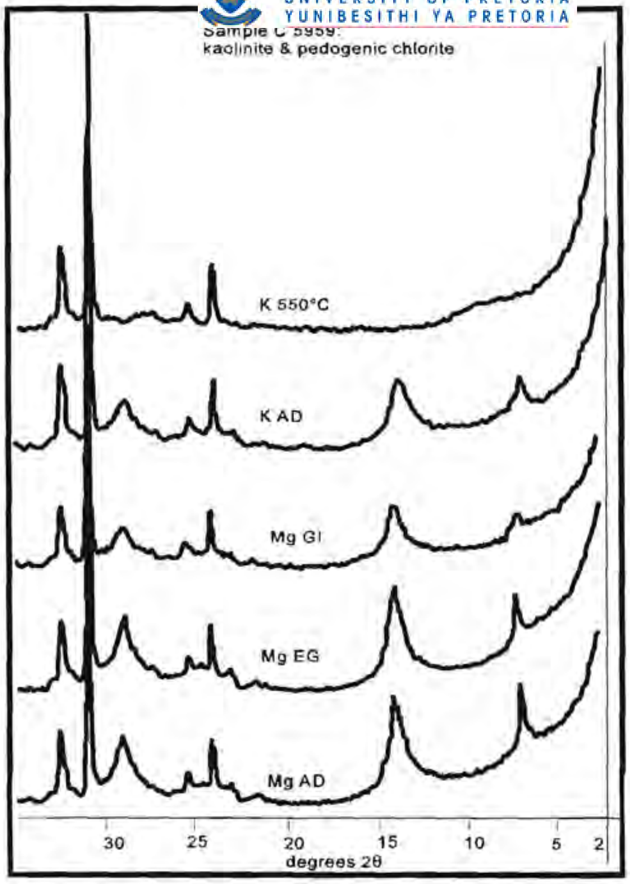

Figure 3.7 XRD pattern of a melanic soil containing pedogenic chlorite and kaolinite

Figure 3.8 depicts X-ray traces of two melanic soils with fundamentally different clay mineral suites. The dominant clay component is characterised by a spacing of about 15Å in the Mg-saturated, air dry state. On solvation with ethylene glycol the peak shifts to about 17Å, indicating expanding interlayers. Glycerol treatment results in further expansion and in a spacing of about 18Å. This expansion upon treatment with both solvents is characteristic of discrete smectite. After K saturation, the basal spacing decreases to about 12.4Å and heating to 550°C results in a collapse of this structure to 10Å.

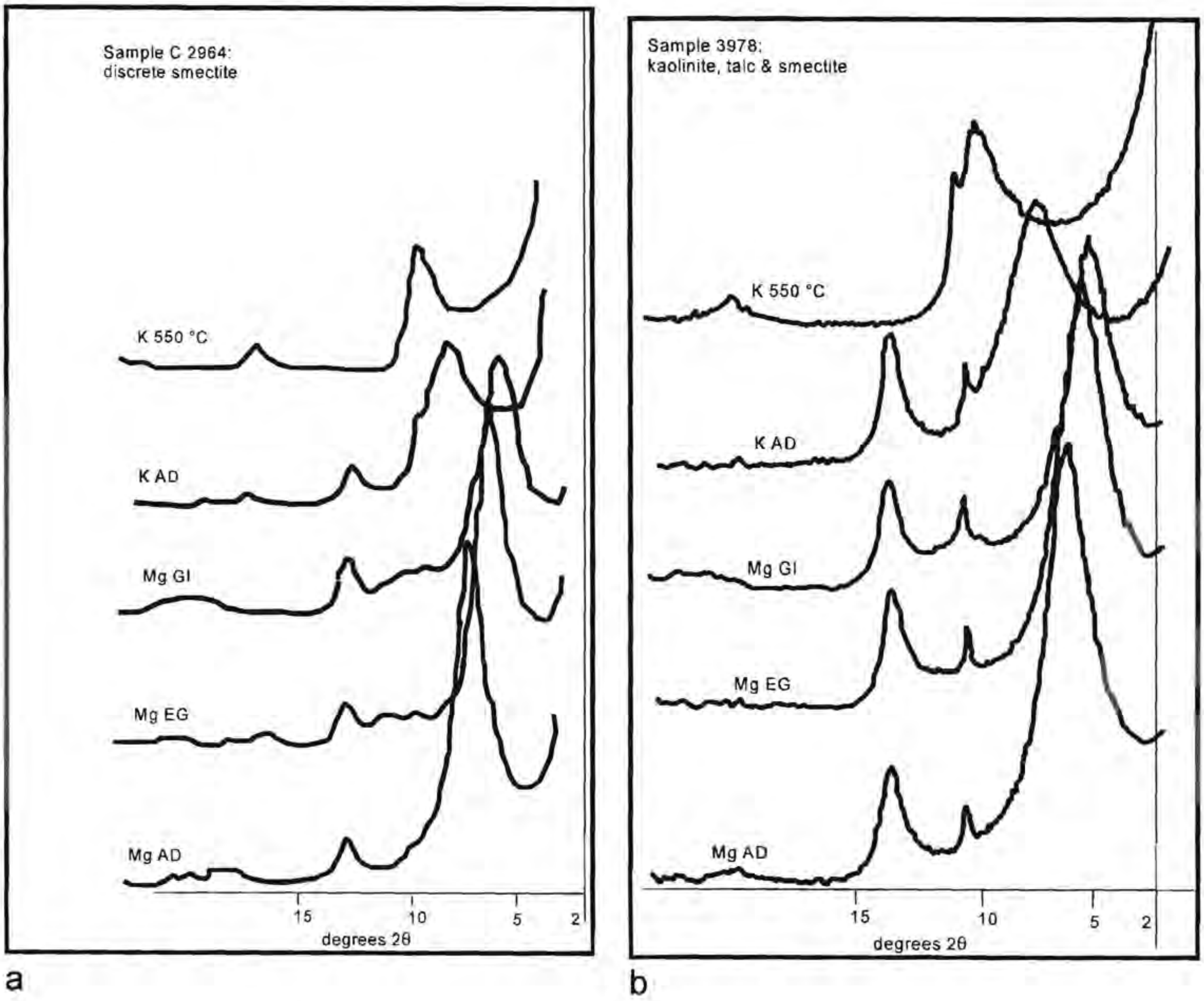

Figure 3.8 XRD patterns of two melanic soils containing smectite, associated with a) kaolinite and traces of mica; b) kaolinite and talc

Figure 3.8 depicts all the X-ray characteristics of discrete smectite. In sample C 2964 (Figure 3.8a), smectite is associated with a small amount of kaolinite and traces of mica and in sample C 3978 (Figure 3.8b) with kaolinite and talc.

Figure 3.9 displays the patterns of two melanic soils, with still another clay association: smectite and vermiculite.

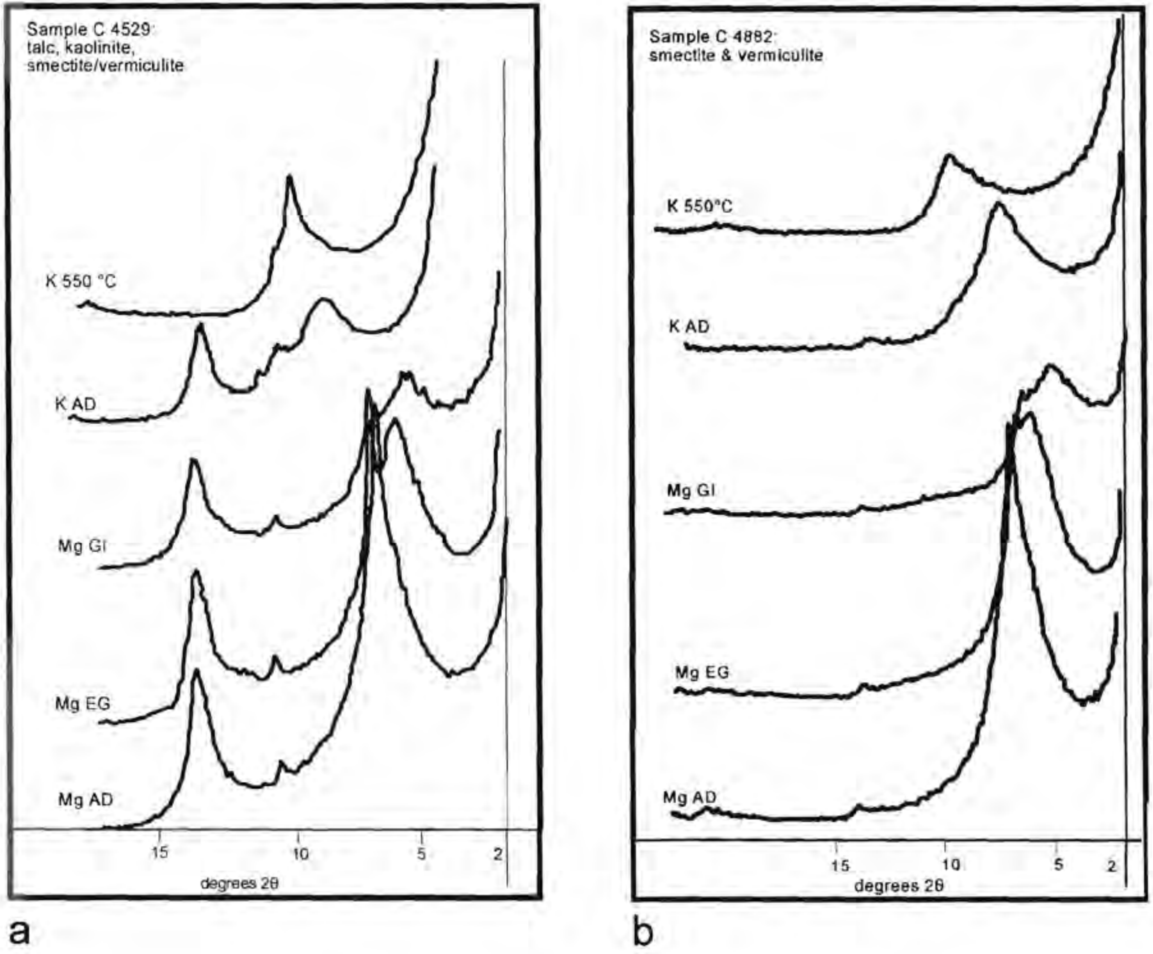

Figure 3.9 XRD patterns of two melanic soils containing smectite and vermiculite, associated with a) kaolinite and talc and b) traces of kaolinite

In the Mg-air dried state, the feature is very similar to the previous soil. After solvation with ethylene glycol and glycerol, however, conditions are different. Only part of the 15Å peak expands a feature characteristics of smectite. An about equal part remains at 15Å. Saturating the mineral with K leads to a significant decrease in the interlayer spacing and peaks were record at 12Å in the air dry state and at 10Å upon heating to 550°C. This sample also contains kaolinite. This sample is therefore composed of smectite which expands with ethylene glycol as well as glycerol and of vermiculite, which gives a 7°2θ peak after all Mg-saturated treatments and a 10Å peak on K-saturation. In sample C 4529 (Figure 3.9a) kaolinite and talc are associated with the swelling clays, while in sample C 4882 (Figure 3.9b) the swelling minerals dominate the clay fraction and only traces of kaolinite are detected.

In some soils, the kaolinite component is characterized by a symmetric diffraction line with a low background at both sides of the peak (Figure 3.8b). These are the features of discrete, crystalline kaolinite. In some samples, however, poorly developed 7°2θ peaks occur, which have a very high background at the low angel side peak that stretches almost to 2°2θ (Figure 3.10). Kaolinites which are randomly interstratified with 2:1 layer silicates are characterized by this peak broadening. On heating to 550°C, the broad shoulder covers the < 10°2θ range.

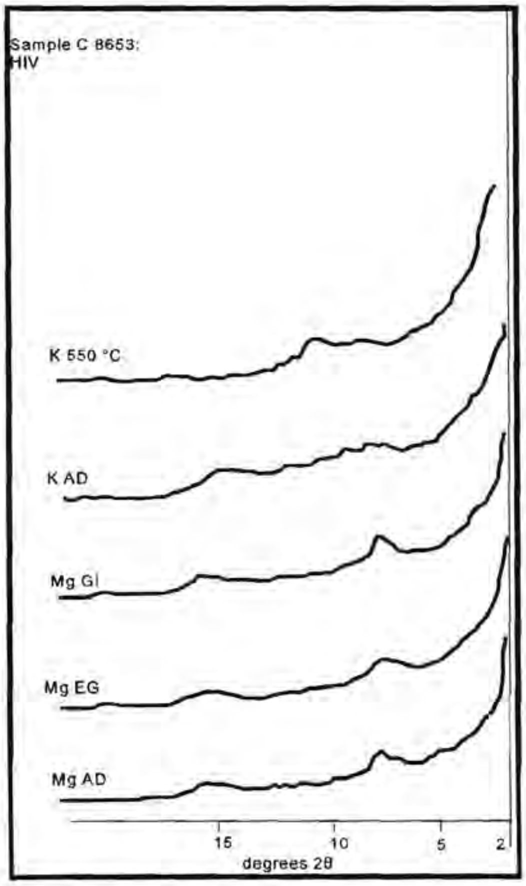

Figure 3.10 XRD pattern of a melanic soil with kaolinite displaying a high background

The XRD patterns of an illite/smectite interstratification are shown in Figure 3.11. The mineral is characterized by a peak at 11.8Å in the Mg-saturated air dried state and a shift to 12.2Å upon ethylene glycol and to 12.5Å upon glycerol solvation. Following K saturation, a 11.2Å reflection was recorded, which shifted to 10Å on heating to 550°C. After saturation with dodeacylamine (C_{12}) the peak shifted to about 14°2θ. According to the X-ray patterns of this sample, beidelite is the dominant smectite component in this soil. Peak positions about halfway between those of mica (10°2θ) and smectite (7°2θ) are indications of interstratifications, consisting of about equal properties of the two components. The absence of a superlattice reflection (4°2θ) indicates a random stacking arrangement.

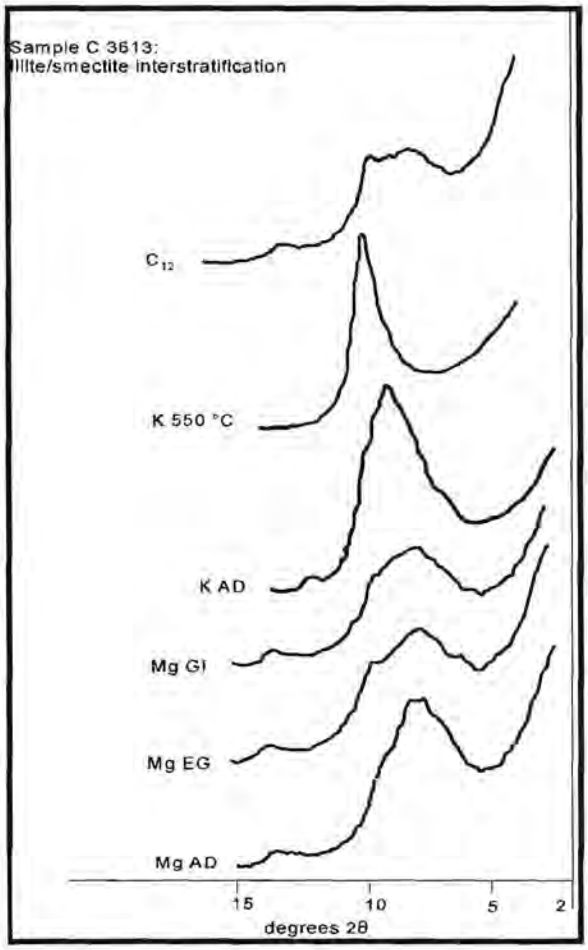

Figure 3.11 XRD patterns of a melanic soil containing a 10Å/swelling 14Å interstratification, associated with small amounts of mica and traces of kaolinite.

Most melanic soils contain kaolinite, some as a discrete mineral, which can be identified by a low background on either side of the diffraction line. Many samples, however, contain a kaolinite which is heavily interstratified with a 2:1 layer mineral. This mixed-layer component is either smectite or - more commonly - a hydroxy-interlayered vermiculite. We then do not have a well developed kaolinite peak, but rather a broad shoulder at the low angle side of the kaolinite peak or sometimes even a high background, stretching from 7Å all the way to 2°2Θ.

As a summary we can state that melanic soils seem to need a certain amount of 2:1 layer silicates in order to develop the structural characteristics required for classification. The question arises, of course, why a soil may be dominated by smectite in association with a high clay content and still not develop vertic properties? Alternatively, why are some melanic soils dominated by kaolinite and still develop strong structure, while most kaolinitic soils are unstructured?

3.3.3 Layer charge characteristics

Melanic soils, per definition, must exhibit a blocky structure (MacVicar *et al.*, 1977) and structure refers to the natural aggregation of primary soil particles into compound units. Aggregates are composed of minerals, organic matter, water and air. Some of these constituents are chemically inert phases like quartz, lime, feldspar and air. Others possess a strong dipole character but are otherwise uncharged, like water, while still others carry a layer charge which may be permanent (mica, HIV, smectite, vermiculite) or variable (secondary Fe and Al phases, edge sites in phyllosilicates). Organic matter may feature in any of these groups, depending on its nature. In order to form aggregates, the primary soil constituents have to be bound together, which requires the existence of bonding sites. As inert phases do not possess bonding sites, they cannot be involved in aggregate formation. The interaction of charged and/or polar sites, on the other hand, may lead to cohesive bonding and resultant formation of heterogeneous aggregates (Bühmann *et al.*, 1998). Charged sites are restricted almost exclusively to the soil's organic matter and phyllosilicate fractions which occur intimately associated with each other. The presence of minerals with charged sites, particularly permanently net negative sites, is therefore an important factor in soil structure formation.

Based on the layer charge characteristics of the dominant clay mineral, three groups could be distinguished in the present study (Figure 3.5):

a) essentially uncharged minerals with a net negative charge of < 0.2 per O_{10} unit cell and non-swelling, i.e. kaolinite and talc,

b) clays of a high layer charge of > 0.8 per O_{10} unit cell, which are essentially non-swelling, i.e. mica and HIV and

c) clays of medium to high layer charge with a net negative charge of 0.2 to 0.8 per O_{10} unit cell, which exhibit swelling properties i.e. smectite, vermiculite and/or illite/smectite interstratifications.

a) Soils dominated by clay minerals with a low layer charge

All melanic soils in the present study which are dominated by kaolinite and talc also contained at least some charged phases, either associated or interstratified. Even the soil with 100% kaolinite had a high background at the low angle side of the kaolinite diffraction line, a clear indication of the presence of 2:1 layer interstratification components. These components, unfortunately, could not be quantified and were very difficult to qualify. The CEC of the soil clay of 40 cmol(+)/kg clay also indicates the presence of charged material, discrete kaolinite having a CEC < 20 cmol(+)/kg clay. A small amount of charged minerals - in combination with a relatively high content of OM (1.9%) and major proportions of sesquioxides (Fe: 6.8%) - is obviously sufficient to induce aggregation.

b) Soil dominated by non-swelling clay minerals with a high layer charge

Mica and chlorite are generally assumed as being associated with the formation of melanic characteristics, being non-swelling and therefore not conducive to the development of vertic properties, but having a sufficient number of charged sites available for binding soil constituents into aggregates. The present study, however, contradicts the above hypothesis. Only very few of the soils studied were dominated by mica and/or HIV, while chlorite was absent from all soils.

c) Soil dominated by swelling clay minerals

Soils dominated by smectite in combination with a high clay content are generally assumed to develop vertic properties.

In the present study the clay fractions of more than half of the melanic horizons are dominated by swelling clay minerals (smectite, vermiculite, illite/smectite interstratifications), with the latter minerals comprising more than 75% of the clay fraction in about half of these. Since many of these soils also have high clay contents they could be expected to show strong swell-shrink characteristics, i.e. to be vertic. The clay mineral association of the melanic soils in the present study in fact is almost identical to those found by Bühmann & Schoeman (1995) for vertic soils in the northern regions of South Africa; most of the vertic soils being dominated by smectite, all containing at least some proportions of kaolinite (up to 65%) and little mica. The fact that some melanic horizons have a clay mineralogical composition identical to that of vertic horizons was unexpected. It should be kept in mind, however, that swell-shrink phenomena are influenced by a variety of interrelated chemical, physical and parameters like OM, carbonates, sesquioxides (Fe and Al) and silica, which bind the soil fabric, apart from content of expansile clay minerals, particularly that of smectite. Wilding & Tessier (1988) indicated that high-charge smectites have lower swell-shrink potential than low-charge smectites. The extent of swelling in smectites can vary greatly and natural smectites range from strongly swelling to non-swelling, depending on the magnitude and location of the layer charge (Wilding & Tessier, 1988) and on charge heterogeneity (Lagaly *et al.*, 1972). The tendency of clay interlayers to take up water decreases with increasing interlayer charge density and charge homogeneity.

Layer charge characteristics of smectites can be determined by solvation with ethylene glycol and glycerol and by saturation with C_{12} and the Greene-Kelly test. These two tests were therefore performed on those melanic soils that were dominated by smectite.

Ethylene Glycol Solvation

According to the ethylene glycol treatment, most of the swelling clays were essentially smectitic, i.e. they formed a double layer (17Å). Some samples, however, also contained some vermiculite, associated or interstratified with smectite.

Glycerol Solvation

Glycerol solvation provided a slightly different picture and indicated an association of smectite with vermiculite in many of the samples. From the above treatments it must be concluded that the smectite species, that dominates South African melanic soils, is of the high-charge variety (high-charge smectite and/or low-charge vermiculite), and should therefore not be prone to osmotic swelling.

C_{12}

Intercalation with dodecylamine also points to a high interlayer charge density and related low swelling capacity (Table 3.4). Only one of the soils investigated contained some montmorillonite, while most were composed of vermiculite or an association of beidellite and vermiculite.

Greene-Kelly Test

Most soil smectites were characterised as beidellite and only 23% of the melanic soils which are dominated by smectite, contained montmorillonite, the highest amount being 37%. Montmorillonite occurred associated with beidellite (Table 3.4). This composition differs markedly from that reported for South African vertisols, which all contained montmorillonite, average proportions ranging from 20% to 30%.

As a high degree of swelling is generally associated with a low layer charge, arising predominantly from octahedral substitutions, i.e. montmorillonite *sensu stricto* and not with beidellite or vermiculite, vertisols in South Africa must have a considerably higher swelling capacity compared to melanic soils. This finding may explain the presence of a high proportion of swelling clay despite an absence of a high degree of expansiveness.

Table 3.4 Characterisation of swelling clay minerals in the melanic horizons studied

Soil no.	C_{12}	LiCl	EG	Gl	% b	% m
1785	b + v	b	s	s + v		
1971	v	b + m	s	s + v	63	37
1991	v	b	i	s + v		
2234	v	b + m	s	s + m	76	24
2283	b + v	b	s	s + v		
2332	v	b + v	s	s + v		
2347	b + v	b + v	s/v	s		
2878	v	b	s/v	s + v		
2964	b + v	b + m	s	s	92	8
3277	b	b + m	s	s	85	15
3279	b	b	s	s		
3282	b + v	b	i	s		
3714	b + v	b + m	s	s + v	92	8
3978	b	i	s	s		
4223	i	b	s	s + v		
4304	v	b	s	s + v		
4529	v	b	s	s + v		
4654	v	b + v	s	s + v		
4671	i	b	s/v	s + v		
4882	v	b	s/v	v		
5405	i	b	s/v	v		
6436	i	b	i	v		
7666	v	b	i	s		
8517	v	b	s	s		
8649	i	b	i	s		
8669	v	b	i	s		
D246	b +m	b + m	s	s	82	18

b - beidellite;

m - montmorillonite;

I - interstratified clay minerals;

s/v - smectite/vermiculite

3.3.4 Implications of the clay mineralogical data for soil classification in South Africa

Taxonomic soil classification is essential for proper communication about soils. As in taxonomic classification in other fields, like plants and animals, taxonomic classifications of soils are not practical classifications upon which detailed decision making or planning can be based. Especially in higher categories each taxon usually includes a wide range of soils with different properties around limited commonalities in their features. In the South African taxonomic system the soil form is the highest category (Soil Classification Working Group, 1991). Each soil form is characterised by a specific assemblage of diagnostic horizons. Some of these diagnostic horizons cover a wide range of properties, e.g. an apedal B horizon can be anything from a dystrophic clay to an eutrophic sand.

It has already been pointed out that melanic A horizons span the spectrum from those that integrate with humic A horizons to those that intergrade with vertic A horizons. The challenge is to make meaningful subdivisions of these for classification in lower categories. Thus far, only the absence or presence of lime, clay content and colour have been used for series or family classification in soils with melanic horizons (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991). When looking at international trends, it would seem that it will be important in South Africa to also distinguish between the "soft" granular structured melanic soils and the "hard" ones which show vertic properties, but not strong enough to qualify as vertic horizons. Khitrov (personal communication; 1996) has attempted to derive criteria that distinguish between "hard" Chernozems (those that tend towards Vertisols) and "normal" Chernozems. The mollic (= melanic) horizon is the key horizon in Chernozems. In the WRB system "vertic" is at the top of the priority listing of lower level units in the Chernozem, Kastanozem and Phaeozem reference units. These are the reference units with mollic horizons as key horizons.

Clay mineralogical studies may be important in this regard. Very detailed studies of the clay mineralogy will be required, however, which go beyond mineral group identifications and focus on different species and the specific nature of interstratifications (Wilding & Tessier, 1988; Fitzpatrick & Le Roux, 1977).

3.4 PHYSICAL ANALYSES

3.4.1 Particle size distribution

A minimum amount of clay (15%) is required to impart melanic characteristics (MacVicar *et al.*, 1977). Most melanic soils, however, contain a higher percentage of clay.

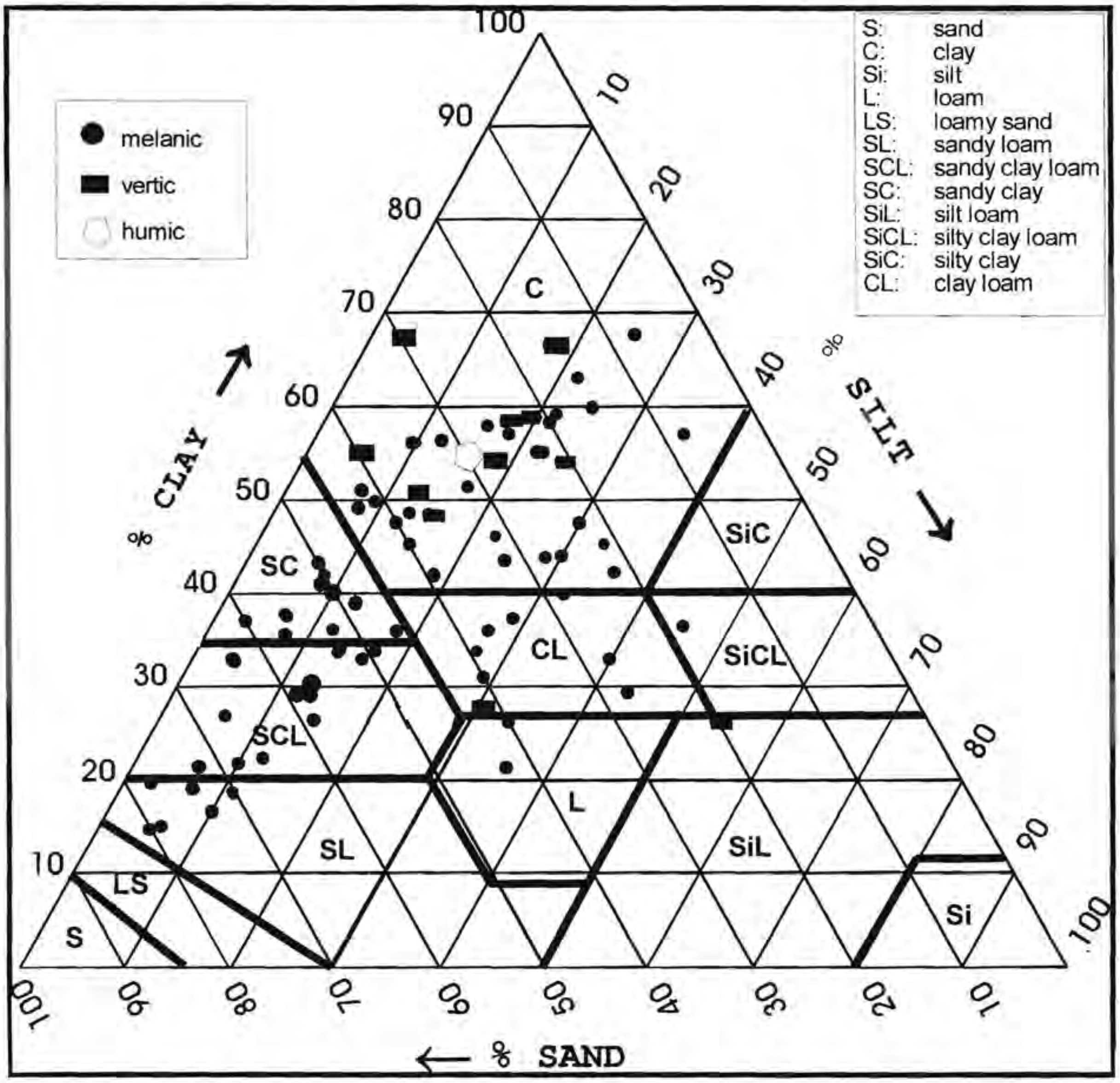

Figure 3.12 Textural characteristics of horizons identified as melanic from field evidence

Most of the melanic soils investigated fall into the clay © textural class. Of the remaining horizons, 15 were classified as sandy-clay-loam (SCL), 11 as sandy-clay (SC), 8 as clay-loam (CL), 6 as sandy loam (SL), 2 as loam (L) and 1 each as silty-clay-loam (SiCL) and silty-loam (SiL) [Figure 3.12]. Clay (< 0.002 mm) dominated 38% of the soils, sand (2.0 - 0.05 mm) 35% and silt (0.05 - 0.002 mm) 4%, while the rest of the soils (23%) were intermediate in particle size distribution characteristics (Appendix 2). Average values were lowest for silt (19%) and highest for sand (40%). The average for clay (39%) was almost identical to that for sand. The degree of variability within the various grain size fractions was significant. Sand contents varied between 8 and 78%, clay contents between 15 and 65% and silt percentages between 3 and 49%.

3.4.2 Plasticity index (PI)

According to the revised South African soil classification system (Soil Classification Working Group, 1991), a PI of < 36 (using the British Standard cone to determine liquid limits) is a determining characteristic distinguishing melanic horizons from vertic horizons. The melanic soils of the present study have a PI which ranges from 3 to 52, with an average of 26. About half of the soils (47%) had a PI less than 25, 39% had a PI between 25 and 36 and 14% had a PI of more than 36. The A horizons with a PI more than 36 (11 soils) are, according to the 1991 criteria, vertic and not melanic horizons and should be reclassified (Figure 3.12; Appendix 2).

The plasticity index is a measurement of soil plasticity and accordingly closely related to clay fraction characteristics, particularly to those of smectite. In the present study, the PI was more closely associated with the amount of clay than with swelling clays (smectite).

In Figure 3.13 a relationship is depicted between the PI and the clay percentage in the soils. The PI slightly increased with increasing amount of clay with $r^2 = 0.30$. The percentage of smectite in the soil, however, hardly increased with the PI (Figure 3.14, $r^2 = 0.21$), indicating that the amount of clay is more influential to PI than the nature of the clay fraction. The soils devoid of smectite fell in the PI brackets of 13 - 41, with an average of 23. Half of the soils exhibited a PI between 20 and 30.

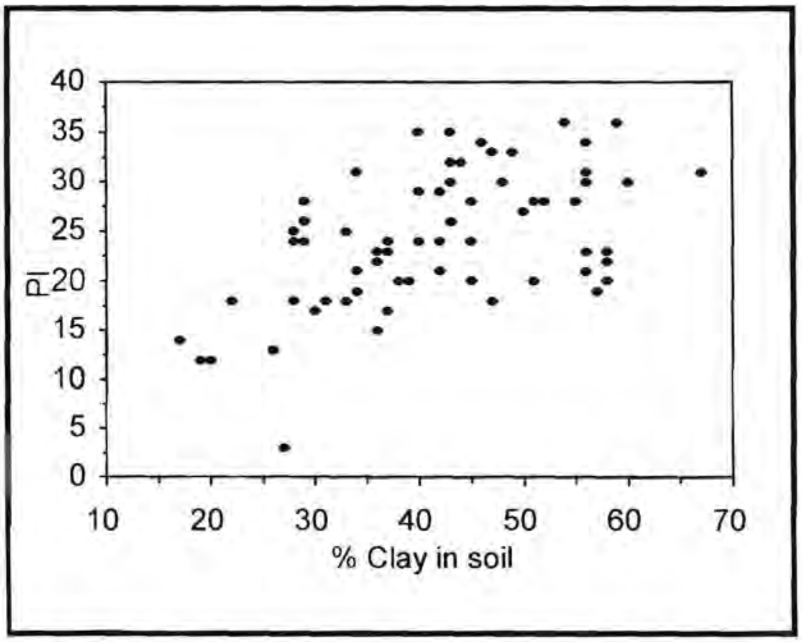

Figure 3.13 Relationship between PI and percentage clay in the melanic A horizons

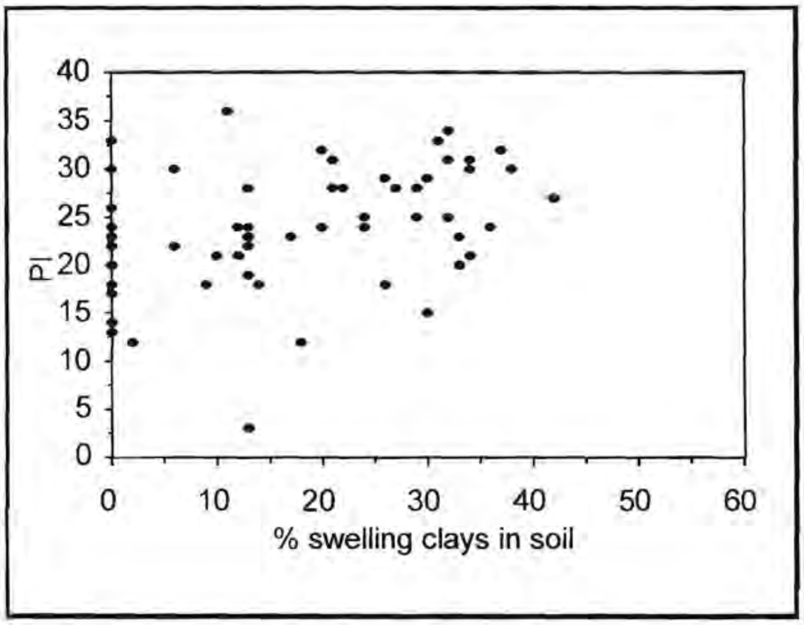

Figure 3.14 Relationship between PI and percentage swelling clays in melanic A horizons

3.5 CHEMICAL ANALYSES

3.5.1 Cation exchange capacity (CEC) and exchangeable bases

The CEC of a soil is closely associated with substitutions of divalent cations for trivalent cations in the octahedral sheets of clay minerals or trivalent for tetravalent cations in the tetrahedral sheets. Negative charge may also arise from octahedral vacancies. The resulting charge deficit is balanced by adsorption of cations on to the clay surface and into the interlayer regions. Study of reference clays indicates that a high CEC is generally associated with smectite [80 - 120 cmol(+)/kg] and/or vermiculite [120 - 160 cmol(+)/kg]. Kaolinite, talc and mica have a CEC < 20 cmol(+)/kg.

In the present study, however, even soils devoid of smectite had moderate to high CEC's per unit clay. This feature may be associated with kaolinite which was neoformed from high-charge minerals like mica or smectite, where Si remains part of structural cation substitutions or with kaolinite which is interstratified with high-charge minerals.

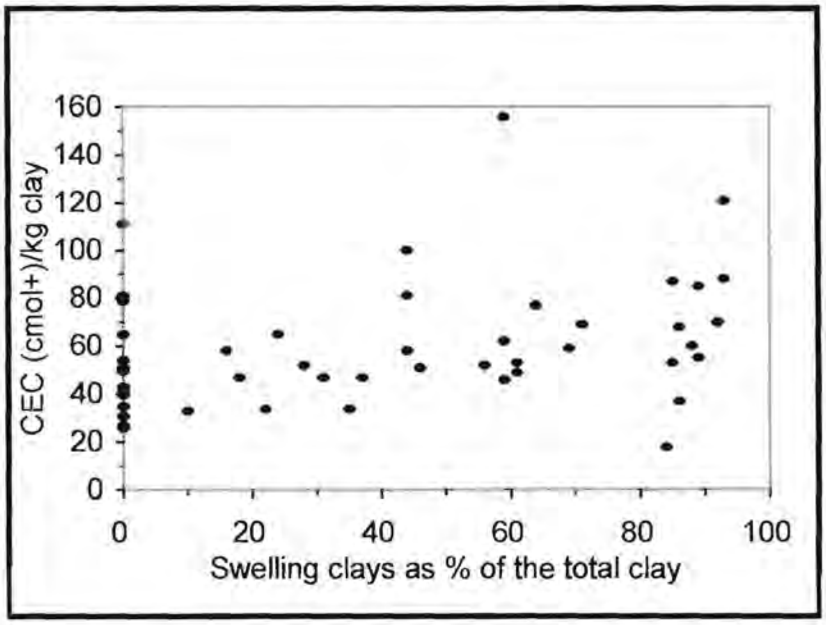

Figure 3.15 The relationship between the CEC per unit clay and the percentage swelling clays in the clay fractions of melanic A horizons

The average CEC for the soils investigated was 22.6 cmol(+)/kg. The highest value was 53.4 cmol(+)/kg for a soil with a clay content of 65% and the lowest was 9 cmol(+)/kg, with a clay content of 52% (Appendix 2). No less than 93% of the soils have a CEC lower than 40 cmol(+)/kg.

The interlayer cation is fundamental to the swelling capacity of smectites and vermiculites; only when saturated with a monovalent cation, particularly with Na, will smectites exhibit a high degree of expansiveness. Divalent cations, particularly Ca, "stabilize" swelling clays. Figure 3.16 displays the distribution patterns of the exchangeable cations Na, Ca and Mg + K in the soils investigated. Exchangeable cations were grouped according to their effect on the stability of soil structure, with Na being dispersive, Ca stabilizing and Mg + K somewhere in between.

Most of the soils had a low to very low exchangeable sodium percentage. In 78.5% of the soils, the exchangeable Na percentage (ESP) ranged below 5, a value regarded as being below the "dispersion level" for Australian (Emerson, 1983) and South African (Gerber & Harmse, 1987) soils. Soils with high exchangeable Mg:Ca ratios (>1.5:1) have been found to be very unstable (Laker, 1997). Only five of the melanic horizons in the present study had high Mg:Ca ratios. Most of the melanic soils should therefore be stable, as far as their structure is concerned. Almost all the melanic soils in the present study have an ESP of < 15, a value adopted by American soil scientists (Soil Survey staff, 1998) for sodic/problematic soils.

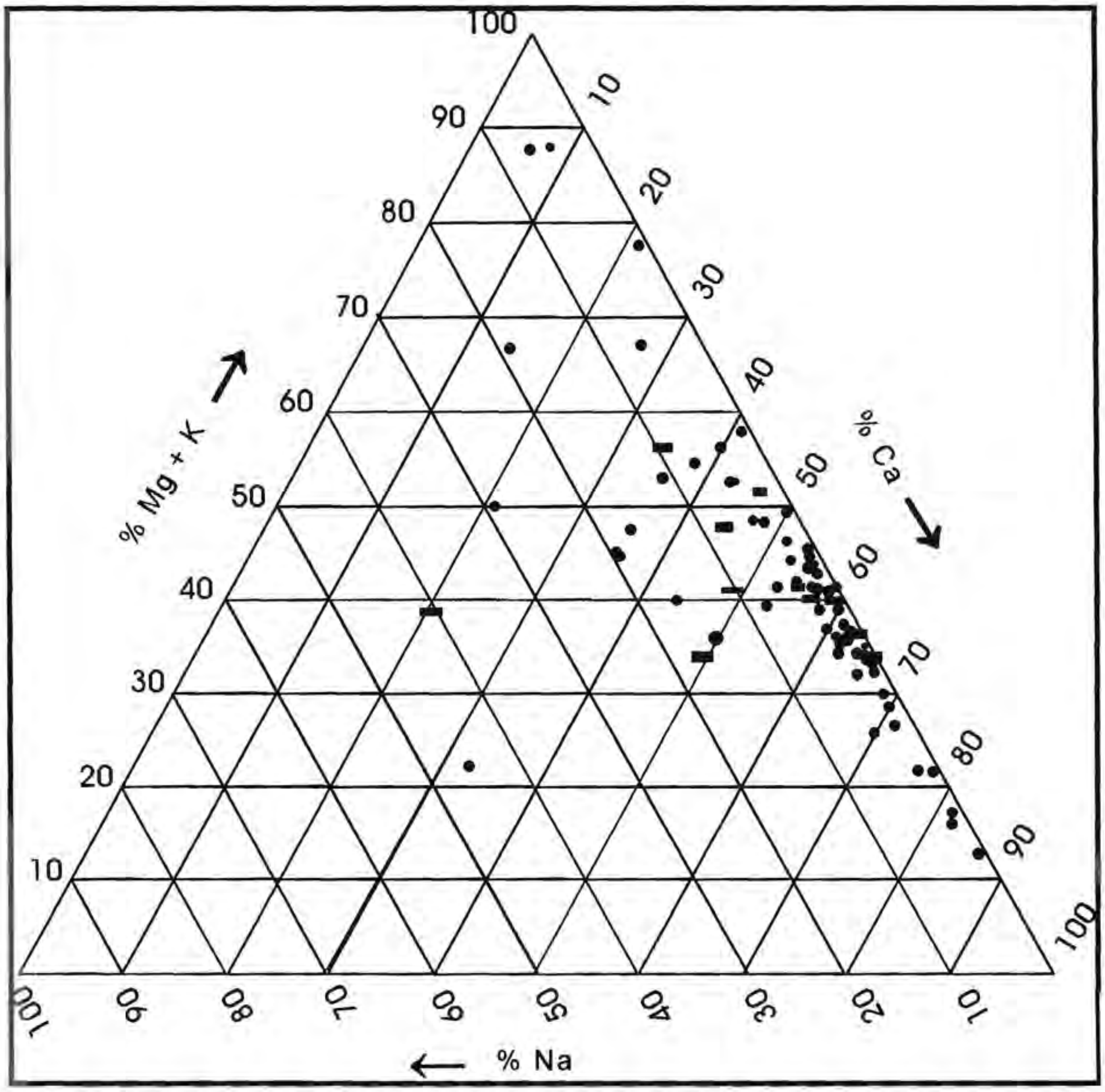

Figure 3.16 Exchangeable Na, Ca and Mg + K percentages in the melanic A horizons studied

3.5.2 Citrate-bicarbonate-dithionite (CBD) extractable cations

This method was used to quantify the percentage of the secondary Fe, Al and Mn present in the soils. Extractable Fe ranged from 0 to 12.37%, Al from 0 to 1.36% and Mn from 0 to 0.65% with average values of 2.57, 0.23 and 0.13% respectively (Appendix 2). Melanic soils, accordingly, may be free of secondary Fe/Al/Mn components or contain significant proportions of them (12.4% Fe).

3.5.3 Organic Matter (OM)

The organic matter contents range from 0.5 to 4.3%, with an average of 1.8%. Half of the soils have an organic matter content between 1 and 2%, 21% between 2 and 3%, 15% less than 1%, 10% between 3 and 4% and 3% above 4% (Appendix 3).

3.5.4 pH

The pH of a soil is an indicator of the degree of weathering, being low in highly leached soil, neutral to slightly acid in moderately leached soils and neutral to alkaline in soils with a low degree of weathering. In the present study the average pH measured in H_2O and $CaCl_2$ was 6.9 and 6.0 respectively. The highest pH(H_2O) was 9.3, the lowest 5.4 (Appendix 3). These pH values reflect a low to moderate degree of weathering, which is in line with the hypothesis of melanic soil formation (Soil Classification Working Group, 1991).

CHAPTER 4

CONCLUSIONS

The main conclusions from the present study are:

- melanic soils cover about 2% of the territory of South Africa;
- formation of melanic soils is favoured by an annual precipitation of 550 - 800mm;
- melanic soils are common in crest, midslope and valley bottom positions;
- mafic igneous and Karoo sedimentary rocks are the dominant parent materials from which melanic soils develop, the former because of preferential development of melanic horizons from these rocks and the latter because of their wide geographic distribution;
- a minimum of 0.5% of OM is required to impart melanic characteristics;
- smectite was established as the dominant clay mineral group in most of the melanic horizons;
- the dominant smectite species in the melanic horizons was classified as beidellite or low-charge vermiculite, depending on the method employed. Few soils contained montmorillonite;
- all melanic horizons contain kaolinite, a significant number of them as the dominant clay mineral;
- plasticity index was not related to the amount of swelling clays in the soil, putting a question mark behind the validity of using plasticity index as a parameter to distinguish between melanic and vertic horizons. It may be better to replace it with a parameter that gives a direct indication of the degree of swelling, like the coefficient of linear extension (COLE), which is internationally used to indicate vertic properties;
- the results of this study, especially the clay mineralogical data, confirm the central position of melanic horizons between vertic, humic and orthic A horizons;
- the results of this study may help to derive basic criteria for distinguishing between normal "soft", granular structured melanic A horizons and "hard" or "vertic" melanic horizons, for classification at lower categories (family or series level).

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APPENDIXES

Appendix 1 Classification and soil forming factors of melanic soils from South Africa

Profile	C no	Soil group	Soil family	Rainfall (mm/a)	Parent material	Topography
187	3277	Bonheim	bonheim	574.5	ns	5
188	D246	Bonheim	bonheim	485.4	basic	5
316	2349	Bonheim	bonheim	nd	basic	3
598	2878	Bonheim	bonheim	411.6	ns	4
646	4247	Bonheim	bonheim	608.1	basalt	3
1161	6436	Bonheim	bonheim	789.5	sandstone	3
1533	6142	Bonheim	bonheim	490.8	basic	3
2010	7666	Bonheim	bonheim	693.0	basic	3
644	4282	Bonheim	bushman	608.1	basalt	4
903	2234	Bonheim	bushman	612.8	dolerite	5
311	2361	Bonheim	dumasi	640.8	ns	5
742	5405	Bonheim	dumasi	597.1	andesite	3
955	4654	Bonheim	dumasi	690.7	gneiss	4
1127	5105	Bonheim	dumasi	720.0	dolerite	3
1937	8462	Bonheim	dumasi	413.8	ns	5
56	3978	Bonheim	glengazi	659.5	ns	5
214	4381	Bonheim	glengazi	560.6	ns	4
481	1968	Bonheim	glengazi	549.8	shale	3
696	3517	Bonheim	glengazi	684.3	dolerite	3
762	5428	Bonheim	glengazi	619.0	ns	5
1673	8651	Bonheim	glengazi	579.6	basic	3
1835	7937	Bonheim	glengazi	596.5	mudstone	3
470	2712	Bonheim	rasheni	506.0	ns	4
507	3697	Bonheim	rasheni	619.7	mudstone	3
901	2238	Bonheim	rasheni	612.8	basalt	3
964	4671	Bonheim	rasheni	428.4	quartzite	4
1247	5870	Bonheim	rasheni	918.1	basalt	3
1705	8517	Bonheim	rasheni	476.8	basic	5
657	1790	Bonheim	stanger	918.1	basalt	1
707	3580	Bonheim	stanger	737.3	ns	3
725	3609	Bonheim	stanger	1055.6	ns	3
1087	4543	Bonheim	stanger	650.0	dolerite	3
1105	2009	Bonheim	stanger	804.8	lava	3
1115	2484	Bonheim	stanger	720.0	dolerite	4
1502	6256	Bonheim	stanger	290.8	basic	4
184	3279	Bonheim	weenen	532.6	ns	5
197	4327	Bonheim	weenen	638.2	ns	3

Appendix 1 Continued

Profile	C no	Soil group	Soil family	Rainfall (mm/a)	Parent material	Topography
655	4304	Bonheim	weenen	888.2	colluvium	4
199	3714	Inhoek	cromley	574.5	dolerite	5
1383	6731	Inhoek	drydale	516.8	shale	4
1607	7527	Inhoek	inhoek	210.9	ns	5
1968	8669	Inhoek	inhoek	637.3	ns	4
142	2345	Mayo	mayo	633.0	dolerite	1
419	3637	Mayo	mayo	1100.3	granite	3
428	4131	Mayo	mayo	879.0	marble	3
432	4129	Mayo	mayo	1029.7	granulite	3
1557	7383	Mayo	mayo	1029.7	granite	3
185	3282	Mayo	msinsini	532.6	dolerite	3
421	3639	Mayo	msinsini	1100.3	amphibolite	3
656	1785	Mayo	msinsini	918.1	basalt	3
699	3832	Mayo	msinsini	755.2	granite	3
1245	5959	Mayo	msinsini	816.4	amphibolite	3
1669	8646	Mayo	msinsini	765.7	basic	3
2064	8131	Mayo	msinsini	nd	basic	3
900	2283	Mayo	pafuri	612.8	dolerite	3
1111	4882	Mayo	pafuri	634.3	dolerite	3
658	4223	Mayo	tshipise	918.1	basalt	4
581	1705	Milkwood	dansland	644.0	dolerite	1
2022	8653	Milkwood	dansland	1000.0	basic	3
605	1991	Milkwood	graythorne	550.5	dolerite	4
133	1322	Milkwood	milkwood	720.3	ns	1
317	2347	Milkwood	milkwood	680.2	basic	1
477	1963	Milkwood	milkwood	506.0	dolerite	3
483	1971	Milkwood	milkwood	549.8	sandstone	3
710	3613	Milkwood	milkwood	1004.0	ns	3
1709	8664	Milkwood	milkwood	579.6	basic	1
2023	8572	Milkwood	milkwood	1000.0	basic	1
1107	5017	Tambankulu	fenfield	720.0	dolerite	3
1670	8649	Tambankulu	fenfield	765.7	basic	3
660	4529	Tambankulu	loshoek	918.1	ns	5
106	2964	Willowbrook	sarasdale	445.9	ns	3
1961	8555	Willowbrook	willowbrook	569.3	basic	4

ns - not specified
nd - not determined

Appendix 2 Selected soil physical and sesquioxide characteristics of melanic soils in South Africa

C no	% sand	% silt	% clay	PI	% CEC/soil	% CEC/clay	% CBD Fe	% CDB Al	% CBD Mn
3277	45	13	39	20	21	53	0.59	0.07	0.49
D246	60	9	28	24	24	87	0.35	0.05	0.02
2349	27	19	51	36	28	55	1.40	0.14	0.08
2878	34	10	54	31	28	51	0.89	0.15	nd
4247	28	17	45	20	18	40	6.82	0.63	0.07
6436	53	12	36	23	18	51	2.32	0.18	0.06
6142	40	15	43	28	24	55	2.57	0.17	0.07
7666	20	35	40	32	22	54	1.47	0.12	0.09
4282	49	7	43	26	34	79	1.63	0.14	0.05
2234	66	6	28	25	19	68	0.70	0.10	nd
2361	71	7	19	sandy	12	62	0.37	0.04	0.02
5405	25	37	35	19	20	56	2.40	0.20	nd
4654	67	13	22	sandy	15	67	1.18	0.12	0.01
5105	15	49	37	21	27	74	3.00	0.35	0.16
8462	38	34	26	13	14	54	0.40	0.10	0.10
3978	38	19	40	29	29	72	1.22	0.06	0.03
4381	47	8	42	24	16	39	2.23	0.12	0.33
1968	42	7	52	28	51	98	1.75	0.20	nd
3517	20	22	53	23	25	47	5.32	0.51	0.19
5428	68	11	19	12	10	52	2.00	0.20	nd
8651	23	30	39	18	37	95	1.23	0.08	0.08
7937	28	31	36	29	22	62	3.48	0.02	0.01
2712	56	7	38	20	14	37	0.93	0.09	nd
3697	19	22	59	36	28	47	2.67	0.17	nd
2238	31	23	43	34	27	63	4.08	0.07	0.02
4671	22	23	55	28	27	48	5.26	0.20	0.04
5870	15	22	65	nd	53	82	3.92	0.34	0.13
8517	26	30	44	32	35	80	1.00	0.10	0.10
1790	31	13	52	30	19	36	6.08	0.28	0.41
3580	8	29	61	23	26	43	4.47	0.39	0.17
3609	26	16	53	20	18	34	5.67	1.36	0.01
4543	54	3	37	23	13	34	2.98	0.55	0.01
2009	25	15	54	22	16	29	7.28	0.48	0.04
2484	31	18	41	20	26	64	5.17	0.36	0.04
6256	47	17	34	19	20	59	0.00	0.00	0.00
3279	75	3	20	12	11	55	0.31	0.04	0.10

Appendix 2 Continued

C no	% sand	% silt	% clay	PI	% CEC/soil	% CEC/clay	% CBD Fe	% CDB Al	% CBD Mn
4327	58	12	29	26	12	41	0.88	0.11	0.23
4304	78	5	15	sandy	10	69	0.24	0.03	0.01
3714	55	13	29	28	26	88	1.14	0.05	0.28
6731	50	10	40	35	29	73	0.20	0.00	nd
7527	37	30	31	18	18	58	1.11	0.07	0.09
8669	41	30	28	18	34	121	1.00	0.10	0.10
2345	48	13	34	21	16	46	0.70	0.23	0.40
3637	67	10	17	14	14	81	1.16	0.28	0.01
4131	42	36	22	nd	34	156	7.26	0.49	0.27
4129	55	15	27	3	19	71	6.28	0.18	0.09
7383	53	13	30	17	14	48	1.34	0.32	0.01
3282	52	8	36	15	21	57	1.58	0.12	0.20
3639	22	22	54	21	30	55	4.20	0.62	0.12
1785	31	17	50	28	27	54	6.21	0.60	0.65
3832	44	18	36	22	17	47	3.93	0.46	0.08
5959	32	25	39	30	28	72	4.81	0.68	0.09
8646	21	34	44	24	36	83	2.44	0.15	0.12
8131	8	25	63	31	32	50	4.88	0.06	0.10
2283	39	27	34	31	31	91	1.50	0.06	0.02
4882	51	16	33	25	23	68	2.33	0.18	0.20
4223	75	6	15	sandy	11	70	0.61	0.08	0.03
1705	40	13	46	33	12	27	4.79	0.64	0.17
8653	27	43	34	18	37	107	2.22	0.58	0.01
1991	39	13	50	30	25	50	0.56	0.11	nd
1322	34	10	53	34	27	50	2.90	0.37	0.58
2347	45	9	40	24	26	66	0.99	0.09	0.10
1963	43	8	47	33	38	80	1.40	0.13	nd
1971	41	9	49	27	9	18	0.91	0.13	nd
3613	14	25	55	30	31	57	3.65	0.32	0.32
8664	28	29	44	35	44	100	1.40	0.20	0.00
8572	18	43	37	24	18	50	3.69	0.52	0.16
5017	38	27	36	22	21	58	12.37	0.40	0.19
8649	27	42	29	24	17	58	1.03	0.10	0.12
4529	70	7	22	18	17	77	0.67	0.08	0.23
2964	61	5	33	25	20	60	0.35	0.07	0.07
8555	34	29	37	17	13	35	1.10	0.10	0.00

nd - not determined

Appendix 3 Selected soil chemical properties of melanic soils

C no	% OM	pH H_2O	pH Ca	Na	Ca	Mg	K
				cmol(+)/kg			
3277	0.5	9.0	7.9	4.0	11.0	9.8	0.2
D246	1.5	8.5	nd	0.3	34.9	4.8	0.5
2349	1.3	7.3	6.4	0.3	6.6	23.3	0.3
2878	1.0	8.4	7.2	0.5	22.4	5.8	0.5
4247	1.9	6.8	5.2	1.7	3.6	4.7	0.1
6436	1.1	7.5	6.4	0.1	8.5	5.6	0.2
6142	1.8	7.4	6.4	0.2	11.5	8.9	0.1
7666	1.6	7.3	nd	3.2	10.5	13.4	1.5
4282	1.6	8.7	7.4	1.9	17.7	13.4	0.4
2234	0.7	9.3	7.8	6.0	4.5	10.1	0.4
2361	1.6	6.3	6.0	0.1	8.6	3.3	0.2
5405	1.3	6.3	5.6	0.1	7.8	7.4	0.3
4654	1.1	6.1	5.2	0.1	6.8	3.1	0.1
5105	2.2	6.6	5.6	0.4	8.5	9.7	0.1
8462	1.2	7.6	nd	0.2	9.7	4.2	0.8
3978	1.1	7.0	6.4	0.3	10.3	14.4	0.2
4381	1.4	5.4	5.0	0.3	6.7	5.0	0.3
1968	1.2	6.7	6.0	0.1	2.8	1.3	0.7
3517	2.7	6.1	5.4	0.4	9.1	5.5	0.1
5428	1.2	7.4	6.6	0.1	5.2	2.4	1.0
8651	2.4	6.8	nd	0.3	21.7	14.9	0.4
7937	2.8	6.3	nd	0.3	11.0	8.0	0.4
2712	1.0	7.5	7.1	0.2	11.9	3.5	0.7
3697	1.7	6.7	5.5	0.8	8.6	9.9	0.7
2238	1.1	8.7	8.3	15.7	11.2	7.7	0.3
4671	0.9	7.0	6.4	0.4	11.5	8.7	0.2
5870	2.5	8.4	7.5	8.7	18.2	21.7	0.2
8517	1.5	6.7	nd	0.3	21.1	14.0	0.6
1790	2.6	6.3	5.5	0.5	6.0	5.9	0.1
3580	1.8	6.4	5.8	0.6	11.9	8.0	0.1
3609	2.7	5.8	5.0	0.4	2.0	4.7	0.0
4543	1.5	6.2	5.1	0.1	4.8	2.1	0.0
2009	2.2	6.4	5.2	0.2	4.7	3.4	0.1
2484	1.1	6.7	5.8	0.4	9.5	5.1	0.3
6256	1.2	6.7	5.8	0.2	10.8	5.4	0.3
3279	0.6	8.7	7.5	0.5	6.7	6.4	0.2
4327	1.2	6.2	5.2	0.0	5.3	2.5	1.2

Appendix 3 Continued

C no	%	pH	pH	Na	Ca	Mg	K
	OM	H_2O	Ca	cmol(+)/kg			
4304	0.7	6.4	5.2	1.5	2.9	3.5	0.1
3714	1.8	7.3	6.2	0.2	15.1	8.5	0.1
6731	0.7	8.2	7.0	0.9	18.2	10.1	0.3
7527	0.8	7.7	nd	0.2	8.5	6.9	0.7
8669	2.0	6.8	nd	0.3	22.6	11.3	0.4
2345	1.4	5.9	5.3	0.1	7.0	5.6	0.4
3637	2.8	5.7	4.4	0.3	2.0	1.5	0.0
4131	2.9	7.7	7.0	0.3	27.1	5.3	0.5
4129	2.0	6.0	5.6	0.2	5.5	4.8	0.1
7383	2.6	5.9	nd	0.4	5.2	3.9	0.1
3282	0.8	7.5	6.8	0.4	12.9	7.2	0.2
3639	3.2	5.9	5.2	0.8	7.9	11.2	0.1
1785	3.6	6.4	5.7	0.8	12.9	10.2	0.5
3832	1.9	6.6	5.6	0.4	8.4	4.1	0.1
5959	4.2	5.7	4.9	0.2	11.7	5.7	0.1
8646	3.6	6.3	nd	0.2	22.1	10.7	0.4
8131	4.3	6.3	nd	0.5	17.5	10.5	0.3
2283	1.7	8.5	5.7	0.4	30.4	8.3	0.1
4882	2.2	7.9	7.4	0.3	21.2	4.4	0.2
4223	1.3	6.3	5.2	0.5	2.9	3.7	0.3
1705	3.3	5.8	5.1	0.1	4.9	3.1	0.3
8653	3.1	5.8	nd	0.3	16.2	8.1	0.8
1991	1.2	7.1	6.3	0.7	19.7	6.9	0.5
1322	1.5	nd	5.8	0.3	12.3	6.9	1.0
2347	1.7	6.7	6.1	0.3	14.5	11.0	0.5
1963	1.5	6.7	6.0	0.3	19.3	11.3	0.3
1971	0.8	6.9	6.1	0.1	0.3	2.3	0.6
3613	2.6	5.6	4.5	2.2	1.7	7.7	0.1
8664	2.9	6.4	nd	0.3	25.0	16.2	0.8
8572	3.5	5.4	nd	0.1	4.8	2.7	0.7
5017	2.4	6.3	5.2	0.3	8.1	4.4	0.5
8649	1.7	6.2	nd	0.5	0.6	7.1	0.6
4529	1.3	6.4	5.7	1.7	6.0	4.2	0.0
2964	0.5	7.4	6.7	0.8	14.9	5.3	0.2
8555	1.4	6.5	nd	0.3	6.3	3.2	0.7

nd - not determined

Appendix 4 Clay mineral associations in melanic soils of South Africa

No	% Kaolinite	% Mica	% Talc	% HIV	% Vermic/Smect
3277	15				85
D246	15				85
2349	nd	nd	nd	nd	nd
2878	9*	30			61
4247	100*				
6436	39	15			46
6142	23*	17		32*	28
7666	19*	35			46*
4282	23*		18	59*	
2234	7*		7		86
2361	31*	10			59
5405	47			31*	22
4654	55	13			32*
5105	39	9		28*	24
8462	32	68			
3978	20		9		71
4381	71*				29*
1968	18*	38			44*
3517	77			23*	
5428	61	30			9*
8651	nd	nd	nd	nd	nd
7937	35*				65*
2712	14*				86
3697	21	61			18
2238	17	14			69
4671	32	30			38*
5870		11			89
8517	5*	11			84*
1790	90				10
3580	41				59
3609	74			26	
4543	65				35
2009	79	21			
2484	60		28	12	
6256	nd	nd	nd	nd	nd
3279	11				89
4327	29*	71			
4304	36				64*

Appendix 4 Continued

No	% Kaolinite	% Mica	% Talc	% HIV	% Vermic/Smect
3714	7*				93
6731	nd	nd	nd	nd	nd
7527	45		25		30*
8669	7				93
2345	47	17			36*
3637	74	26			
4131	41				59
4129	51				49*
7383	nd	nd	nd	nd	nd
3282	17*				83*
3639	26*		13		61
1785	44				56
3832	63				37
5959	56			44	
8646	28	28			44
8131	57		12		31
2283	3		4		93*
4882	4				96*
4223	8*				92
1705	82	9		9	
8653	40*			60	
1991	9*	21			70*
1322	nd	nd	nd	nd	nd
2347	10*				90*
1963	22	14			64
1971	5*	11			84
3613	7*	30			63*
8664	nd	nd	nd	nd	nd
8572	71	29			
5017	67			17*	16
8649	28*	28			44
4529	27		7		66*
2964	12				88
8555	71	29			

* - interstratified
nd - not determined

Appendix 5 Soil profiles identified as melanic based on field evidence, that classify as vertic or humic according to PI or CEC, respectively

Appendix 5.1 Classification and soil forming factors of the soils

Profile	C no	Soil group	Soil family	Rainfall (mm/a)	Parent material	Topography
Vertic						
909	2240	Bonheim	bonheim	612.80	rhyolite	4
490	3691	Bonheim	bonheim	549.80	mudstone	5
659	4226	Bonheim	bonheim	888.20	basalt	5
484	1966	Bonheim	bonheim	549.80	ns	3
647	4286	Bonheim	glengazi	722.70	basalt	4
947	1726	Bonheim	stanger	808.20	basic	3
1613	6631	Mayo	msinsini	706.30	dolerite	3
1248	5872	Mayo	pafuri	888.20	dolerite	3
643	1776	Milkwood	graythorne	608.10	basalt	3
1674	8665	Milkwood	milkwood	727.90	basic	3
1252	1797	Tambankulu	fenfield	918.10	basalt	4
Humic						
661	3962	Bonheim	stanger	1078.70	ns	3

ns - not specified

Appendix 5.2 Selected soil physical and sesquioxide characteristics of the soils

C no	% sand	% silt	% clay	PI	% CEC/soil	% CEC/clay	% CBD Fe	% CDB Al	% CBD Mn
Vertic									
2240	21	25	53	39	33.8	64	3.59	0.15	0.02
3691	36	13	48	42	32.0	67	0.59	0.11	nd
4226	15	17	65	52	47.7	73	3.05	0.19	0.34
1966	40	5	56	45	27.5	49	0.64	0.11	nd
4286	21	20	60	45	34.8	58	5.31	0.53	0.12
1726	36	15	46	41	19.7	43	4.41	0.50	0.08
6631	24	18	59	38	27.3	46	2.17	0.23	0.20
5872	27	19	55	46	39.8	72	2.94	0.22	0.11
1776	30	2	69	41	40.1	58	3.56	0.16	0.04
8665	44	29	28	52	49.8	178	1.40	0.20	0.15
1797	20	49	26	42	27.8	107	4.42	0.44	0.79
Humic									
3962	30	17	52	19	2.5	5	3.15	0.17	0.15

nd - not determined

Appendix 5.3 Selected soil chemical properties of the soils

C no	% OM	pH H_2O	pH Ca	Na	Ca	Mg	K
				cmol(+)/kg			
Vertic							
2240	1.2	8.7	7.6	5.9	17.7	11.9	0.5
3691	0.9	8.6	6.9	3.1	10.3	16.7	0.2
4226	1.5	8.0	7.3	3.5	20.5	22.1	0.2
1966	0.7	7.7	7.1	1.3	16.2	12.2	0.6
4286	1.8	7.7	7.3	14.7	7.3	13.9	0.2
1726	2.3	5.9	5.4	0.1	8.5	3.9	1.1
6631	2.4	6.8	6.1	1.0	15.0	10.5	0.2
5872	1.3	8.3	7.7	4.4	18.9	15.8	0.5
1776	2.8	7.1	6.6	0.6	25.1	15.6	1.2
8665	4.5	6.5	nd	0.6	32.2	16.1	0.5
1797	3.4	6.2	5.4	0.5	8.3	9.2	0.5
Humic							
3962	3.9	6.0	5.2	0.4	8.6	5.2	0.0

nd - not determined

Appendix 5.4 Clay mineral associations in the A horizons

No	% Kaolinite	% Mica	% Talc	% HIV	% Vermic/Smect
Vertic					
2240	31	19			50
3691	4		24		72
4226	16		16		68
1966	18	25			57
4286	34	11			55
1726	81	19			
6631	30				70
5872	20				80
1776	27				73
8665	10	14	14		62
1797	77	14			9
Humic					
3962	100				