CHAPTER 1

BACKGROUND TO THE PRESENT STUDY AND HISTORICAL REVIEW OF SOIL SERIES AND OF THEIR SOIL PROPERTY VALUES

BACKGROUND TO THE PRESENT STUDY OF NATURAL SOIL BODIES

The hypothesis of natural soil bodies

Natural soil bodies could be identified with limited ranges of variation in soil properties, and in the extent of their location.

This statement is the central theme of this thesis. If follows the decision of the Soil Classification Working Group (1991) to recognise only those classes in the South African Soil Classification System which represent naturally occurring uniform soil bodies. Debate at the time held that classes which caused uniform soil bodies to be split by arbitrary determined class boundaries should be avoided. These class boundaries were excluded from the formal classification system. These boundaries were considered largely to be soil texture classes. It implied that the soil series class was not formally defined in the revised classification system. In an ideal situation, it was generally assumed that natural soil bodies would be readily recognised and would exhibit fairly sharp boundaries in the natural environment. The task at hand was then to document these natural soil bodies. It was also assumed that the data necessary to identify them was generally not available. However, given an adequate data source, insight into soil genesis, and an understanding of the soil distribution patterns, natural soil bodies could be identified. Classes representing further refinement of natural occurring soil bodies could then be formally defined.

This thesis examines naturally occurring soil bodies, and the property values which could be used to refine their definition within a formal soil classification system. This is achieved from review of an extensive database of soil profiles from KwaZulu-Natal and Mpumalanga. Attention is focused on the soil classification at the soil form level, and on soil textural properties. Natural soil bodies, with appropriate boundary criteria, could then be derived from this information. It also examines the literature surrounding soil series, tracing the concepts and differing perceptions of the soil series as a natural entity in the soil mantle. These could be seen as a natural soil body with varying degrees of precision and understanding in its morphology and its property values, to a class within a classification system defined by all relevant boundaries of that system.

Hypotheses

The central hypotheses relating to the recognition of natural soil bodies and the property values are set out. These are:

* Firstly, natural soil bodies could be recognised by resorting to the soil classification systems presently used in South Africa (MacVicar, de Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen, and Harmse. 1977; Soil Classification Working Group, 1991). The recognition may also be supplemented by considering soil classification systems implemented elsewhere in the world. Notably these could be the

Soil Taxonomy (Soil Survey Staff, 1999) and the World Reference Base for Soil Resources (ISSS, ISRIC, FAO, 1994; 1998). Soil classification criteria, applied at both the soil form and family levels, could be used to distinguish certain of the influences that the soil forming factors of climate, and of time, would have on the identification of natural soil bodies.

* Secondly, by identifying and linking a given soil profile to the dominant lithological rock type and geology stratigraphic unit reasonable separation of natural soil bodies could be performed. This would be expressed in at least certain of the soil attribute values, notably texture, but could also be expressed in other soil chemical, physical, mineralogy and micronutrient property values.

* Thirdly, that stratification of the available information sources would sufficiently reduce variability so as to provide reasonable extremities of the properties of the natural soil body or bodies when identified through means of normal soil classification classes.

The study would focus throughout on actual profile data.

Objectives

The major objectives of the study became:

* To prepare a set of soil profile databases containing information on soil profiles with their property values, and geographical coordinates. This would provide a link between the soil profile attribute values and other spatial natural resource information such as land types, climate and geology formations.

* To document the relationships between soils and the geology formations of KwaZulu-Natal and Mpumalanga. These relationships would be expressed as the soil form classification units, and would give their overview properties.

* To recognise within those natural soil bodies occurring on each major geology formation of KwaZulu-Natal and Mpumalanga, their natural range of textural variation.

* Provide a natural framework for the definition of soil series, and contribute to the development of the soil classification system.

Additional objectives became:

* To promote improved understanding of the soil properties and soil distribution through a review of measured soil property values.

* To provide by means of the commonly occurring natural soil bodies, and their ranges in soil property values, the information sources necessary for generalised Soil Technology Transfer Programs and for Decision Support Systems.

THE SOIL SERIES CONCEPT IN THE UNITED STATES OF AMERICA

The history and concepts of the soil series are reviewed as they remain central to the recognition of new soil series or natural soil bodies and their property values. The soil series emerged as a collective label for soil mapping units of the early soil surveys in the United States. Initially the soil type was adapted as a label for mapping units set apart in the first soil surveys. The kinds of soils were to be distinguished that differed significantly in their adaptions or yields of crops (Simonson, 1978, 1997). The soil series was introduced to relate soils of one survey area to those of another. Initially, a soil series was to consist of all soil types that were formed in materials derived in the same way during the same period of time. The series were meant to group soils of similar genesis. Assigned a place name from the locality in which it was first recognised, a series could cover soil types with the full particle size class range from gravel to clay.

The initial concept of soil series in the United States has undergone two major changes to reach that of 1992 (Simonson, 1997). According to the second concept the series consisted of a set of soils closely similar in morphology and composition. Presumably the soils were also closely similar in genesis, though the understanding of genesis has changed over time. Emphasis in the second series concept had shifted from the nature and origin of the regolith to the character of the soil profile. The third concept was outlined in Soil Taxonomy (Soil Survey Staff, 1975) and was to record pragmatic distinctions to be keyed to soil usefulness. Series were subdivisions of families, classes of the next higher rank in a multi-category system. Soil families were also subdivisions of still higher categories but differed from them in being focused primarily on the usefulness of soil for various purposes. As subdivisions of families, series were to have the same functions. The genetic thread running through the highest categories became tenuous at the family and series levels. Since the series were introduced in the United States the total number recognised has regularly increased to stand at 14 200 in 1992 (Simonson, 1997).

The soil series concept during the first period (1899 to 1920)

In this early period soil types were recognised. All soil types in a series would have shared the same rock sources, mode of accumulation and have occurred in one physiographic province or region. The soil series brought together all soils that had the same range of colour of the surface and subsoils, the same relative character of subsoil material, and the same general character of relief, drainage and origin as to source of material. Where soils have a common origin and differed only in texture (they were alike in colour and in physical properties other than those of texture) they are arranged in what was called a series. Initially certain series were recognised to cover a range of particle size classes. In classifying soils the texture was used to determine the place in the series while the structure and colour were used to determine what series the soil could be correlated with. Thus within the Miami series classes ranging from stony and gravelly through gravelly loam, sand, fine sand, sandy loam, fine sandy loam, silt loam, clay loam and clay were expected. There were for example the Miami gravelly loam, the Miami sandy loam, the Miami silt loam, and the Miami clay loam as prominent members of the Miami series (Simonson, 1997).

Simonson (1978) records that many of these concepts and descriptions have persisted for some time. Soil names coupled with a particle size class descriptions can be found in the soil literature today. Furthermore, the concept of the physiographic regions has been developed and appears in current literature. Examples are of the terms Major Land Resource Areas (MLRA) (Austin, 1965) which are used in the Field Office Technical Guides for each US state (Natural Resource Conservation Service, 1993; Soil Survey Staff, 1996b). These technical guides are extensively used by agricultural advisors when dealing with conservation and production information. The soil series information contained in the Technical Guides forms an important basis for information technology transfer.

The particle size classes used in these early descriptions requires some explanation. The term particle size class is now used to characterize the whole soil, while the term texture is used in describing the fine earth fraction, which consists of particles of diameter less than 2.0 mm. The particle size classes are defined in Soil Taxonomy (Soil Survey Staff, 1975), and in Keys to Soil Taxonomy (Soil Survey Staff, 1996a). Substitutes for certain particle size classes (pumiceous, cindery, skeletal, etc.) are also used where normal particle size classes do not characterize these components adequately. Strongly contrasting particle size classes are defined. Particle size classes are now accommodated in Soil Taxonomy at the family level.

The soil series concept during the second period (1922 to 1960)

The concept of the soil series and the classification system as a whole evolved. Soil classification based on properties of soils rather than on their origin and mode of formation became evident (Simonson, 1997). In the 1929 definition of soil series (Simonson, 1997) properties such as colour, texture (except in the surface layer), structure and consistence, chemical properties such as humus, lime, iron compounds, acids and alkalies were recognised. The thickness and arrangement of horizons held prominence in their recognition. The parent material was important in the 1937 definition of soil series (Simonson, 1997) as follows: " A series is a group of soils having genetic horizons similar as to differentiating characteristics and arrangement in the soil profile, developed from a particular type of parent material. The physical characteristics and thickness of soil horizons are not allowed to vary significantly within a series."

More detailed descriptions and identification of soil horizons became necessary, while improvement to the categories above the soil series were needed to complete the scheme. These statements by Simonson (1997) are important. Firstly it recognises the ongoing attempts by scientists all over the world to define and describe soil properties more precisely. Secondly, it places the soil series in the hierarchy of a classification system. The soil series was now being seen relative to the other classes in the system, not by the properties of the soil alone. The last attempt to define soil series as sets of natural bodies rather than as subdivisions of broader classes in a multi-category system was made in the 7th Approximation (Soil Survey Staff, 1960). Here the soil series was seen as a collection of individuals (natural soil bodies) uniform in differentiating characteristics and in arrangement of horizons; or if genetic horizons are thin or absent, a collection of soil individuals, that within defined depth limits, are uniform in all properties diagnostic for series. Series differentiae were to meet two requirements. Firstly, they were to be observable or reasonable inferrable in the field. Secondly, the properties that were used must have had at least limited significance to soil genesis. Series differentiae within families also were to have significance to either or both of plant growth or engineering. This definition (Soil Survey Staff, 1960) also recognised a control section in the phrase "within defined depth limits".

The soil series concept defined by Soil Taxonomy

An appreciable change was made in the concept of the soil series in the United States between 1960 and 1975. This change was reflected in the way the series was defined, first in the 7th Approximation (Soil Survey Staff, 1960) and next in Soil Taxonomy (Soil Survey Staff, 1975). In 1960 the soil series was defined as a collection of soil individuals. A further element was a requirement that the definitive characteristics had at least some genetic significance. Neither of these were required by the definition in 1975. In Soil Taxonomy, the series were defined as a subdivision of the family, which are in turn a subdivision of progressively broader classification classes. No mention was made of soil bodies or of genetic significance. **Instead the series were to have pragmatic significance, the classes were to be set apart on the basis of their utility.** The genetic thread that ran through the definitions of the classes in the upper four categories of Soil Taxonomy became tenuous in the family and series categories. An excerpt from the section about the soil series in Soil Taxonomy (Soil Survey Staff, 1975) explains these concepts as follows:

> ***The function of the soil series is pragmatic, and differences within a family that are important to use the soil should be considered in classifying the soil series. Differences in particle size, texture, mineralogy, amount of organic matter, structure, and so on that are not family differentiae should be considered at the series level.***

Other changes were in defining the control section and in setting series class limits. The control section was defined partly in terms of depth and partly in terms of horizons present. Initially the series limits were set as a typifying profile plus other similar and related profiles. In contrast, Soil Taxonomy sets quantitative limits between classes in all higher categories and these hold for constituent series as well. In distinguishing the soil family and soil series in Soil Taxonomy (Soil Survey Staff, 1975, 1999) much emphasis has been placed on the properties of the control section of that soil. The lower boundary of the control section may be at a specified depth below the mineral soil surface, or it may be at the upper boundary of a root-limiting layer. The control section is considered to be a subsurface layer.

Soil Taxonomy (Soil Survey Staff, 1975) comprises six categories called orders, suborders, great groups, subgroups, families and series. Differences of classes in several categories are in terms of limits between them rather than by reference to a norm or central concept. The current system has been completed by placement of all series in the United States into families and those in subgroups, and so on up the ladder (Simonson, 1978). This important goal achieved the grouping of thousands of existing soil series in the United States about which important statements concerning the use of soil for growing plants and for engineering purposes could be made. "Soil Series of the United States, Puerto Rico, and the Virgin Islands: Their Taxonomic Classification" (Soil Survey Staff, 1972) listed the recognised soil series within the then formative concepts of Soil Taxonomy. For example, the Abac series from the state of Montana is listed as a loamy, mixed (calcareous), frigid, shallow family of Typic Ustorthents. In Soil Taxonomy (1975) the family names are descriptive while the series names are abstract. Soil Taxonomy has been regularly updated through "Keys to Soil Taxonomy" publications (Soil Survey Staff, 1996a, 1998). A fully comprehensive Second Edition to Soil Taxonomy (Soil Survey Staff, 1999) has now been published. The numbers of soil series recognised in the United States by 1992 was 14 200, while with inactive and tentative series this number could grow to be 18 000 (Simonson, 1997).

Smith (1986, quoting from a publication of Mill, 1891) said that the best classification was the one that permitted the largest number of most important statements about a given class of objects. Soils are classified over time and space. This is not the case with the classification of plants and animals. Soil classification should reflect this fact. Smith (1986) explained the rationale behind the structural concepts used in Soil Taxonomy (Soil Survey Staff, 1975) which departed somewhat from the former concept of soil series as a class having genetic significance. At the commencement of the work that culminated in the development of the Soil Taxonomy there were many soil series (about 6 000) that needed to be accommodated into the new system (Smith, 1986). He explained that to group the series from the bottom upwards into higher level categories proved not to be attainable. He explained that it became necessary to establish some set of differentia for the higher categories and to test them to see how the series fell within the definitions that had been proposed. It was considered that the genetic factors that were of concern to the new classification had been sufficiently accommodated at the subgroup level. This permitted that the physical factors affecting plant growth and engineering could be accounted for at the family level. The family level was intended to be useful for making major interpretations concerning use for growing plants and for engineering purposes. The series level was intended to permit the most precise quantitative interpretations that current knowledge permitted (Smith, 1986). He explained that limits to taxa were preferred rather than the focusing on the central concept. This permitted the writing of an operational definition which could be applied uniformly by many people, rather than working through a single mind. This was the rationale behind using limits to taxa instead of adopting the central concept.

The series are distinguished within the family to facilitate quantitative interpretation of soil behaviour. The separation of soils at the series level of this taxonomy can be based on any property that is used as a criteria at higher levels in the system (Soil Survey Staff, 1996a). Those criteria most commonly used include presence of, depth to, thickness of, and expression of horizons and properties diagnostic for the higher categories and on differences in texture, mineralogy, soil moisture, soil temperature, and amounts of organic matter. The limits of the properties must be more narrowly defined than for the family. However, properties must be reliably observable or be inferable from other soil properties or from the setting or the vegetation. The differentiae used must be within the series control section. Differences outside the series control section are considered for phase distinctions in the United States. Soil Taxonomy (Soil Survey Staff, 1975) quotes profile descriptions and analyses, and the methods of analyses, for a selection of profiles.

Soils exhibit a natural range in properties. Where this natural range extends beyond the limits of a classification class a problem in assigning soils to that class may arise. Some kinds of soils differ from the established soil series (class) only to a minor extent in one or two properties. Such a soil is outside the established series, but differs only by a small amount. If no similar soil series has been established, the soil may be considered as a taxadjunct to the series or classification class that it resembles (van Wambeke and Forbes, 1986). Hewitt and van Wambeke (1985) point out that normal experimental error is associated in determining soil properties. This region of error could extend beyond the limit of the established series. Hewitt and van Wambeke (1985) describe soils having these properties as Error Taxadjuncts, and that they could be considered as part of the established soil series.

Nettleton, Brasher and Borst (1991) present data demonstrating that many soils sampled, analysed and correlated in the USA to be taxadjuncts to named series. They describe this as the Taxadjunct Problem. Imposing the limits of soil taxonomy that circumscribe soils from without frequently divides natural soil bodies. They describe a natural soil body as a collection of contiguous pedons (soil profiles) that are more similar to each other than to the soils that border them. They propose classifying the central concept of the series but allowing characteristics to range across the limits between two families, or between classes of any higher category. They give the reasons for this proposal to include that natural soil bodies would then not be subdivided by artificial boundaries, soil taxonomy would facilitate technology transfer and that the exchange of information about the use and management of series would be facilitated.

Re-evaluation of systematic soil surveys completed prior to the publication of Soil Taxonomy (Soil Survey Staff, 1975) is being considered in a number of US counties. Hartung, Scheinost and Ahrens (1991) describe methods to reassess map units with their soil series composition.

THE CONCEPTS OF SOIL SERIES AND OF NATURAL SOIL BODIES IN SOUTH AFRICA

The early soil series concepts

The early concepts of soil series appear to have been defined by Beater (1957) providing considerable insight into the soils of the coastal belt of KwaZulu-Natal. These brief but accurate descriptions of the major soils that are present on the geology formations of the coastal belt of KwaZulu-Natal clearly have establish the major soil groupings in this area. These descriptive soil groups are still in use today. Particle size analyses were reported in this early work, including the analysis of the coarse gravel fraction. However, the soil chemistry concentrates on total element analyses and ratios. Some exchangeable cations, phosphate, acidity and carbon values are reported. This establishes an understanding between the descriptive soil morphology and the physical and chemical properties. Twenty soil series names were reported with the central concept being their morphology associated with each geological formation. Texture is an important component in recognising these soil series. Horizons were recognised but their particle size properties are reported against their depth ranges rather than against the master horizons. Beater (1959, 1962) later added to the soil series list as more areas were surveyed. Many of these series names have been retained in the South African Binomial Soil Classification System (MacVicar, de Villiers, Loxton, Verster, Lambrechts, Merryweather, le Roux, van Rooyen, and Harmse, 1977). Their names have become common reference features of South African pedology understanding. The names Williamson (Glenrosa soil form) or Shortlands (Shortlands soil form) have been in frequent use and now convey meanings and interpretations far beyond those which is reported in the original publication (Beater, 1957). Five of these names have also been retained as soil form names in the current South African Soil Classification System (Soil Classification Working Group, 1991).

Beater (1970) later summarised the properties of thirty soil series, presenting colour photographs illustrating their morphology, together with profile descriptions and descriptive summaries of many of their soil properties. The soil series as defined by Beater were associated with geology formations of the coastal belt of KwaZulu-Natal. Typical series names such as the Williamson series (Dwyka tillite), Cartref series (Natal Group sandstone, formerly called Table Mountain sandstone), Fernwood series (Recent Sand), Shortlands and Rydalvale series (dolerite) are included in the original descriptions. For comparison purpose, the texture properties from soil profiles defined in a similar manner to many of these early series descriptions of Beater are reviewed in chapters 4 to 18. The relationships of soils to geology presently remains central within the soil technology information systems of the South African Sugar Industry (MacVicar and Perfect, 1971; MacVicar, 1973; Meyer, van Antwerpen and Meyer, 1996).

De Villiers (1962) studied the genesis of soils in the highlands and interior basins of KwaZulu-Natal and classified these soils according to the 7th Approximation (Soil Survey Staff, 1960). De Villiers (1964) discussed theory of the genesis and described the weathering intensity of the Clovelly, Kranskop and Balmoral soil series. Representative soil profiles with descriptions and soil chemical, physical and mineralogical analyses of these three important soil series in the Highland Sourveld and Midland Mistbelt of KwaZulu-Natal were reported. This firmly establish the central concept of these soil series occurring within the physiographic and climatic regions of the Highland Sourveld and Midland Mistbelt of KwaZulu-Natal. Variations in the soils with regard to texture and humus content were also reported. De Villiers (1965) also described the genesis of four soil series of the Interior Basins. Similarly, MacVicar (1965) described the weathering and the central concept of four soil series derived from dolerite over a climate and time sequence in the KwaZulu-Natal Interior Basins. Profile descriptions and typical chemical, physical and mineralogical analyses were published giving substance to the central concept of these soil series.

The soil series represented central concepts in soil profile morphology and properties. The soil series were associated with a given locality (though not necessarily bounded by this locality) and with geological formations (though not necessarily defined by their lithology), and with the climate and weathering intensity of that locality. These concepts were supported by concepts of soil genesis. The soil series represented a modal concept which could be regularly identified in profiles distributed over a wider area. However, the boundaries to this concept appear not to have been defined. The boundaries in these concepts could be sought in representative soil profiles by limiting the range of climate, topography and location factors. These boundaries were later to become well established in the threshold limits set for the higher levels of the South African Soil Classification System. They were also to become generally accepted by the soil science community.

The South African Soil Series List

Soil surveys commissioned elsewhere, notably in the Tugela Basin (van der Eyk, MacVicar and de Villiers, 1969), in Kroonstad (Loxton, 1962) and in the Langkloof Valley (MacVicar and Loxton, 1967) provided additional information. A greater range of soils had been identified and the properties of modal soil profiles determined. It became increasingly important to order and organise the thinking about soils in some comprehensible system. In South Africa the system of classification gained momentum. MacVicar, Loxton and van der Eyk (1965a, b) prepared a list of recognised soil series, including soil profile descriptions and analyses from modal sites. The series list also grouped soils in a comprehendible key, placing soils with similar genetic horizons together in the same key (MacVicar, Loxton and van der Eyk 1965a). The system recognised that soil properties did not follow a random pattern, but an orderly one, the key to which was the genetic processes which have contributed to the formation of soil properties. The most important of these is the contribution that soil genesis had made to classification by enabling soil horizons to be recognised, grouped into types of horizons, and subdivided according to the degree of expression of properties in each horizon (Loxton and MacVicar, 1965). Soil individuals could be grouped into taxonomic units. The individuals had the maximum number of properties in common and were therefore the most useful units of classification. The members of each unit had the same number and arrangement of horizons, and the properties of each horizon had a similar degree of expression. The soil series was the lowest category of soil classification (Loxton and MacVicar, 1965).

The series was recognised as a collection of individuals essentially uniform in differentiating characteristics and arrangement of genetic horizons (MacVicar, Loxton and van der Eyk, 1965a, b; Loxton and MacVicar, 1965) This follows the definition of Soil Survey Staff (1960). The qualification that it had been developed from a particular parent material had been omitted from earlier definitions (Soil Survey Staff, 1960). The South African soil series list (MacVicar, Loxton and van der Eyk, 1965b) gives the underlying lithology. This link of the soil series to the underlying lithology in South Africa was no longer a direct one.

Early Survey Reports

The nature of soils is that soil attributes and hence soil series merge (Loxton and MacVicar, 1965). If the classification was not conducted by systematic survey of a relatively large area, in which the full range of properties of the various series were likely to be found, the precise range of each series could not be accurately defined. This merging of soil series prompted the effort to prepare a comprehensive soil classification system. The system was also to increasingly serve as the vehicle by which agricultural advisors could bring results of research to the users of land. A number of soil surveys followed which contributed to the understanding of the South African soil mantle and to the recognition of soil series. These are reviewed by MacVicar (1978). Amongst other surveys, a program of key area surveys at Bethlehem (Roberts, 1969), Lichtenburg (van der Bank, 1978), Grootvlei (van der Bank, Verster, Roberts and MacVicar, 1978), Makwassie (Verster, 1971) and Rustenburg (Verster, 1973) were important in expanding the concepts and properties of the soil series. Other research in soil distribution and genesis in the interior of South Africa made significant contributions (Dohse, 1970; Schoeman, 1973).

It also became important to publicise to the agricultural community that series concepts should be used as the vehicle of agricultural technology transfer (Loxton and MacVicar, 1965; le Roux and Scotney, 1970; Orchard, 1965; van der Eyk, 1965).

Soil series within the Binomial System

The publication of Soils of the Tugela Basin (van der Eyk, MacVicar and de Villiers, 1969) marked a turning point in soil classification in South Africa. The system provided for a Binomial System of Soil Classification, with the soil form the higher class, and the soil series the lower class. Diagnostic horizons were defined. The sequence of diagnostic horizons was used to construct the soil form. This provided for a grouping of like soil individuals according to their morphology, properties and arrangement of horizons. In this manner similar soil series were placed together within the soil form category, meeting many of the earlier concepts in the soil series definitions (Soil Survey Staff, 1960). The classification largely grouped those natural soil bodies (MacVicar, 1969) commonly perceived by persons working within the sphere of soil mapping as recognisable natural soil entities. It also embraced concepts of soil genesis giving a generally greater depth of understanding to soils.

Soils of the Tugela Basin (van der Eyk, MacVicar and de Villiers, 1969) contained excellent photographs providing field guidance to specialists and agricultural advisors alike in series identification. The publication of soil profile descriptions, their locations and soil analyses sharpened an awareness of the commonly measured soil properties. Emphasis was however, still placed on the central value of properties and on single value properties.

The Soil Classification Projects (Loxton, Hunting and Associates, 1967; 1970a b, c) improved on the soil series classification, expanded on the concepts of diagnostic horizons and contributed to the soil knowledge over wider areas of the Mpumalanga Highveld, the North Western Free State and the North West Province. The projects contributed to the debate on threshold values for clay percentage and sand grades, and the parameters used to describe base status. They also provided soil profile descriptions and analyses for a range of soil attributes. Loxton *et al.* (1970a) point out that the classification is a natural taxonomic system in which each taxon can serve as a vehicle for cataloguing soil information.

Soil Classification: A Binomial System for South Africa (MacVicar, de Villiers, Loxton, Verster, Lambrechts, Merryweather, le Roux, van Rooyen, and Harmse, 1977) was published in 1977 after a lengthy period of performance testing by a variety of organizations and individuals. This book provided the first simple, definitive statement for classifying the soils of South Africa. Communication about soils in an accurate and consistent way was now possible. The book sets out a natural, two category system for classifying the soils of South Africa designed to permit their easy field identification. The higher category contains 41 soil forms, each made up of a vertical sequence of diagnostic horizons. Soil series (504 in all) constituted the lower category and was defined by series differentiae. These were expressed by a limited range of criteria used at the higher category, or in terms of texture using clay content and sand grading, base status, colour, reaction, and the nature of the C or underlying material.

The soil series category retained many of the concepts employed in their earlier methods of identification. Important here was the sequence of horizons (now diagnostic horizons), with their associated soil genetic implications. The central concept in terms of properties could also be traced through these new series definitions. So for example the former Clansthal series of Beater (1970) which was commonly a moderately leached, medium sand was now defined by clear limits in clay content (6 -15%), dominant sand grade (medium sand), and base status (mesotrophic class) (MacVicar *et al.*, 1977). The classification system provided categories, chiefly defined by texture and base status, to cover the full range expected within these soil series differentiae. The classification clearly reflected the understanding of the time, and debateably, the particular needs of this period with regard to soil mapping and soil technology transfer.

It being very pragmatic, allowed for the soil mapping to proceed over the greater part of South Africa at a more rapid pace than had hereto been possible. Many detailed scale surveys and soil identifications by a range of agricultural advisors and land users took place. The interpretations of soil investigations took place largely within this established framework. Mapping of soil resources at a national scale proceeded as well (Land Type Survey Staff, 1984 - 1998a). When considered at the series level of classification this approach had advantages to the general needs of this period, namely to accumulate and interpret essential soil information relatively quickly.

The series definition departed from earlier concepts where locality, range in soil properties (often only imprecisely expressed) and underlying material were inherent in the understanding of the series definition. In added dimension to those soil properties now defined at the form level of classification and which had previously been inherent in the soil series concepts. It defined the boundary limits to the soil series by those threshold values of the higher level of classification, and by the threshold values of the series differentiae. These series differentiae were largely expressed as clay content, dominant sand grade and base status.

Natural Soil Body Concept

The stimulus for a second edition came when it was realised that a number of the soils, particularly the podzolic soils, were not well accommodated within the first edition (Soil Classification Working Group, 1991). The second edition retained the structure and many of the concepts of the first edition. It differed in that a number of additional diagnostic soil horizons were defined or existing definitions modified to reflect the occurrence and understanding of soil properties and their distribution known at that time. Additional soil forms were defined to accommodate those recognisable horizon sequences with the new diagnostic horizons. It differed further in an important principle namely that the classification would only include those classes which on the whole accommodated similar naturally occurring uniform soil bodies (Soil Classification Working Group, 1991). It excluded arbitrarily chosen classes (mainly texture) which were thought to cause uniform soil bodies to be split artificially by class boundaries. The soil series, particularly those defined on the basis of texture, made up the majority of those classes (Soil Classification Working Group, 1991). The Working Group considered that the information which was necessary to define the soil series class and would accommodate similar soil bodies was not generally available. Instead a higher category, the soil family, was recognised.

This change marked a new beginning toward the thinking on the natural soil body. It however directed this thinking away from the soil series which previously was the primary vehicle for soil technology transfer. MacVicar (1969) points to a concept of natural soil body by quoting the examples of a swelling smectitic clay on dolerite at Bethal on the Mpumalanga Highveld, or a yellow kaolinitic clay on Beaufort Sediments at Cedara in KwaZulu-Natal. There has been general acceptance that the threshold criteria used in the definitions of diagnostic horizons represented acceptably distinct boundaries in the soil landscape, when these were applied at the form level of soil classification. These distinct boundaries were expected, but generally not described, in the 1977 series definitions (MacVicar *et al.* 1977). The expectation of clear natural boundaries could, to some extent, be traced to earlier statements of soil series.

Additional detail on the concept of the natural soil bodies have not been extensively debated. In essence natural soil bodies could be considered at a number of levels within the soil classification system. Natural soil bodies have generally been accepted to be placed within soil forms and to take on a classification level similar to that of the soil series. However, characteristic combinations of similar soil forms with their associated distribution of soil properties are regularly encountered together in the landscape. The concept of a natural soil body with a defined classification, a type location, and range of soil physical, chemical and mineralogical properties has gained some acceptance. There is no formal publication of the requirements of natural soil bodies at this level of classification. However, discussions on minimum specifications for their recognition took place at a meeting of the Soil Classification Working Group meeting of 28-29 January 1983, and is recorded in the minutes. Standard methods of analysis were suggested to form part of these minimum specifications. It can be concluded from the prominent part suggested for soil analytical methods that accurate analyses of a range of soil attributes should form an important component of the recognition of natural soil bodies. This seems to place considerably more emphasis on the soil attribute values than on morphological descriptions. Morphological properties would have been accommodated at the soil form level. Considerable emphasis also seems to have been given to location requirements for natural soil bodies. This draws on the concepts of the early soil series, particularly those of Beater where underlying geology formations were of significant importance.

Schoeman (1989) has described natural soil bodies in North West and Free State Provinces. The natural bodies were considered to have location information (distribution and boundary), lie essentially within a single soil form, have limited range in texture and depth, and have a similar crop production potential. A statistical element was introduced in Schoeman's (1989) definition by including a statement of the mean and standard deviation of soil properties derived from a selection of soil profiles. The natural bodies were allowed to span base status classes (Soil Classification Working Group, 1991) with prominence given to soil texture. Ludick (1992) has defined natural bodies with similarities in the soil form classification and in underlying geological material.

MacVicar and Perfect (1971) describe soil series, including a brief description of the texture ranges, and their association with the underlying geological materials in the Overberg Lowveld of Mpumalanga. The soils are characteristic of those encountered over each of the geological formations of this area. These descriptions could in a sense be considered as natural soil bodies although no mention of the concept at a series level is made.

MacVicar, Fitzpatrick and Sobczyk (1984) discussed the classification and range of properties of highly weathered soils with thick humus-rich horizons. The central value (mean) and the range in property values for their physical, chemical and mineralogical properties are an expression of highly weathered soil bodies derived from Natal Group sandstone. In this article the concept of the natural soil body places the emphasis on the soil form classification, texture and organic matter status.

Duvenhage, Laker and Turner (1992) compared soils of the Avalon form sampled from two different localities. The soils were classified to the same soil form and the same family category. The soils differed in terms of their morphological, chemical and physical characteristics, as well as with regard to their cultivation and management practices used to grow crops. However they had significant different values for the mean and ranges in their textural properties. They suggested that a series category be developed below the family category to promote transfer of soil information.

During the period between the publication of the 1977 and 1991 editions the Soil Classification Working Group (SCWG) considered a number of problems associated with soil classification (Unpublished minutes SCWG Meeting, Fort Hare, June 1981; ISCW Archive file A95/38). Problems associated with improved definitions for soil texture were considered. These included the definition of the particle size classes, particularly for fine sand and silt, accommodating the silt fraction within the classification system and that of closely fitting textural class to the series.

Improvement was considered necessary to account for water holding properties of the fine sand and loam soils, and in the possible recognition of hard setting soils. A five fraction particle size analyses had applied (MacVicar *et al.* 1977). Seven particle size classes were introduced giving a more even class distribution in the fine sand and silt ranges. The new system divided the fine sand class into three classes, namely fine sand (0,25 - 0,1 mm), very fine sand (0,1 - 0,05 mm) and coarse silt (0,05 0,02 mm). The limit between medium and fine sand was adjusted slightly (from 0,20 to 0,25 mm), while the former silt class now assumed the descriptive name of fine silt while retaining the former class limits. The clay and coarse sand classes remained unchanged. These changes were initially implemented during 1982 through the medium of the minutes of the Soil Classification Working Group. The Group comprised representatives of research organizations, government departments, universities and the private sector. The modifications were later published in Soil Classification: A Taxonomic System for South Africa (Soil Classification Working Group, 1991). The problems of accounting for high silt contents within the classification system and of closely fitting textural classes to the soil series were resolved only to the extent that a texture description of the A horizon has been subsequently used (Soil Classification Working Group, 1991).

THE CONCEPTS OF SOIL SERIES ELSEWHERE IN THE WORLD

Soil Series in India

Soil series have been defined in India. Soil surveys and mapping are basic for preparing the inventory of soil resources in India. The mapping can be done at various taxonomic levels but the most comprehensive one is at the level of phases of soil series. India has recognised and established soil series of the country (Sohan Lal, *et al.*, 1994). The grouping of soils into soil series is to understand their properties and relationship for developing land use plans. The recognition of soil series is related to research, technology transfer and land use. Technologies developed for these series could be transferred to areas with comparable soil-site characteristics in similar agro-ecological regions. In establishing the soil series, correlation was done where qualifying soils were given the status of established series. The descriptions and analyses were standardised and published in the bulletin "Soil Series of India" (Sohan Lal, Deshpande and Sehgal, 1994). The publication recognises 180 soil series. The classification follows that of Soil

Taxonomy (Soil Survey Staff, 1975), uses Keys to Soil Taxonomy (Soil Survey Staff, 1992). It is correlated with the FAO-Unesco Legend (FAO-Unesco, 1988).

Soil series in India are defined as:

> A group of soil horizons, similar in differentiating characteristics and arrangements within the Series Control Section, except for the features of surface soil, and have developed on similar parent materials and under comparable climatic and geomorphic environments.

Soil properties including colour, texture, structure, consistence, reaction, and other chemical and mineralogical properties of horizons are important in the recognition of soil series (Sehgal, 1992). The attributes desired for distinguishing soil series include all criteria for distinguishing classes at higher categories. The distinction must be large enough to be recorded and comprehended clearly, should not overlap with other series, nor should it cross the limits of the family category. The soil control section plays an important role in the classification and recognition of soil series. Soil temperature and moisture regimes (or agro-ecological zones) are also essential in defining soil series.

The Canadian System of Soil Classification

In the Canadian System the family and series are the two lowest categories used in the system. The series category has been used throughout the history of soil survey in Canada. It has evolved to an increasingly specific category. Some of the series of a few decades ago would now be divided among several families. The family category has been a relatively recent development (Canada Soil Survey Committee, 1978). The differentiating criteria for families of mineral soils are: particle size, mineralogy, reaction, depth and soil climate. The particle size classes are of a practical nature with defined limits and occupy broad bands of the textural triangle (Canada Soil Survey Committee, 1978). They are recorded for the control section of the profile. By virtue of their definition, particle size classes do not make provision for natural range in particle size variation. Similarly, the mineralogy, reaction, depth and soil climate classes are defined to constitute the family criteria.

Soil series are subdivisions of soil families based upon relatively detailed properties of the pedon within the control section. They cannot transgress climatic, particle size or other boundaries recognised in the family separations. The recognition of potential series is based on guidelines which give emphasis to their consistent recognition, relative size and unique morphology. Surprisingly, little attention in these descriptions is given to the range of soil attribute values.

International Soil Information Collections

Collection of soil series information has been active for most of this century. One important international initiative in documenting soil profile information has been the NASREC Program (Kauffman, 1995). The program has described, sampled and analysed soil profiles in developing countries throughout the world. It has also prepared soil profile expositions in many of these countries. Stimulating an awareness of soil properties and their sustainable use has been one of the major objectives of the program. Generally attention has been given to understanding soil properties, supported by standardised and accurate soil analytical facilities (Brunt and van Reeuwijk, 1995) and the creation of soil databases (ISIS, SOTER and WISE) (Kauffman, Mantel and Spaargaren, 1995). Soil classification, via local and international systems, has taken a subordinate role in this program. This program has developed together with SOTER: Global and National Soils and Terrain Digital Databases (ISSS, ISRIC, FAO, 1993). In the SOTER database, terrain, soil and soil profile attribute information have been recorded in electronic format. Soil classification information is given by the FAO soil unit and subunit levels (FAO-Unesco, 1988). Local soil classification units may also be entered. However, profile attribute values are entered into the database, giving prominence to these values rather than to soil classification information.

The information content of soil profiles sampled during the NASREC Program (Kauffman, 1995) and that collected by a number of international soil survey organizations is very similar. The analytical results of soil profiles sampled in the NASREC Program in Zambia, (ISRIC, 1994), in Cote d' Ivoire (Idessa-ISRIC, 1994) and profiles sampled in Texas USA (Hallmark, West, Wilding and Drees, 1986), in India (Sohal Lal *et al.*, 1994), and those sampled in South Africa (Land Type Survey Staff, 1998b) show close similarities with respect to the soil attributes and the references to the analytical method of soil analyses.

SPATIAL VARIABILITY OF SOILS IN A STATISTICAL CONTEXT

Introduction

Soil variability is no stranger to the pedologist; in fact, landscape variability is the very essence of this discipline (Wilding and Drees, 1983). Increasingly attention is being focussed on soil variability as a means to further quantify the pedogenic concepts and to better understand the factors that cause the soil distribution patterns and landscape evolution. Wilding and Drees (1983) state that the development and implementation of classification systems have furthered pedogenic quantification of soils. This has been the experience in South Africa. They conclude that those sciences that have progressed rapidly in recent years have done so primarily through changing from a qualitative to a quantitative emphasis. Wilding and Drees (1983) list a number of reasons why pedologists study spatial variability. Two of these reasons are to estimate a central tendency and variance statistics for specified classes, and to determine spatial variability so that pedogenesis and soil behaviour can be easily visualized. It is the intention of this study to place emphasis on the quantitative aspects of pedological classification and of profile sampling.

Soils as landscape bodies contain ranges of physical, chemical, mineralogical and morphological properties, both laterally and vertically. Pedologists have represented many of these ranges in the soil maps or through soil classification systems. The manner in handling this variation is similar in both cases. The extent of this variation is described in the ranges employed in the mapping unit legends or in the defined range allowed within the class of the classification system. There is debate, particularly within the Unites States, as to the range of properties within soil mapping units (Young, Maatta and Hammer, 1991). This debate often centres around the purity of soil classification classes for mapping units. Important is to recognise that all soil attribute values vary over space and time. This variation could be viewed in the context of soil map units, or equally in soil classification units. Alternatively the variation could be viewed by a strictly statistical analysis. Geostatistical techniques are examples of this latter type of analysis.

Soil maps strive to group like soil individuals and represent these in a spatial context. Soil classification often serves to create consistent classes to represent these map units in a natural manner. Ideally variation should be small and limited to the map legend or classification class criteria. However, variation within any attribute value reflected by a soil map unit or classification class should be recognised. In many soil maps this variation is not well recognised or described.

Sampling Design

Increasingly soil sampling is being seen as simply a way of obtaining information about regions of the earth's surface (Webster and Oliver, 1990). They describe a number of procedures that can be adopted in preparing sampling designs for soil analyses. These include random, grid, transect and stratified sampling techniques (Wilding and Drees, 1983). Burrough (1991) indicates that no single sampling design for quantifying soil map unit composition is optimal for all requirements. A range of techniques can be used to meet different requirements and budgets. Each depends on the type of information required. In some situations researchers can achieve satisfactory results with single-stage sampling of the attribute of interest. In other situations it may be necessary to adopt a stratified or even multivariate approach. The aim of sampling is to reveal information about a population so that meaningful statements can be made with a given degree of confidence. The concept of the degree of confidence implies that the value for an attribute at an unvisited site, or the mean value for that attribute for a given block of land, can be inferred probabilistically with known variances from a sample that has been drawn without bias from the population (Burrough, 1991).

Burrough (1991) concluded that if the aim is to characterize map units that have been derived from field surveys, then the conventional methods of sampling using the knowledge of skilled surveyors is probably the most cost-effective way of working. This is provided that quantitative information is not required about the confidence limits of attributes. The purpose for sampling could range from a general qualitative description of the map unit to quantitative statements about the values of single soil attributes.

In this study, sampling has been pragmatic. It has been guided by practical considerations, largely aimed at quantitatively representing a type profile of the immediate vicinity, and by the ease of obtaining the sample. Sampling has commonly been along transects. It is uncertain, but unlikely that the sampling was generally performed without bias. Bear in mind that, in general, very little was known about the area prior to the sampling of a soil profile. The knowledge gained by the sampling then usually represented a significant gain in soil attribute information. The soil profile analyses have also focussed on the actual profile data that were available, and seeks to determine central values and ranges in property values from these data.

Measures of range

Estimating the value of an attribute at a given point in classical statistics is given by estimates of the mean and the variance (Burrough, 1991). These estimates of the mean and variance are given by many standard texts on statistics. Advanced statistical methods applicable in soil and land resource surveys have been documented by Webster and Oliver (1990). These advanced statistical methods demand considerable work effort. The level of understanding that could reasonably be gained by applying these statistical methods did not seem to bring greater clarity to this soil profile sample set. A simple mean and variance approach was adopted. The objective was simply to estimate the central tendency and variance statistics for specified classes of soil profiles. These classes were derived by stratifying the population using well established geology formations and soil form classifications as stratification criteria. The estimate of the variance is greatly affected by the map unit variance. This explains why soil surveyors have placed so much emphasis on soil classification in order to make the variance as small as possible (Burrough, 1991). This approach in stratifying the profile sample set was adopted to reduce sample variance within pedological groupings.

The coefficient of variation of many soil properties is reported by Beckett and Webster (1971) to be large. They report that up to half of the variance may be present within very short distances. However, comparisons reported in the literature on the one hand, and from this profile sample set from KwaZulu-Natal and Mpumalanga are difficult to make.

The simple cloropleth map model (Burrough, 1991) traditionally used in soil survey assumes implicitly that all spatial variation can be accounted for by differences between map units. This model of homogenous spatial units is often at odds with reality. Most soil attributes vary continuously over the space at all scales. However, mean and variance information can be extracted from this model (Burrough, 1991). Map units in which the points lie close together have a large degree of similarity and strong spacial dependence. The assumption is that sharp boundaries in soil property values are present. Taking additional samples in these map units could serve to consolidate the estimates of the mean and would generally yield less additional information since the samples would be highly correlated (Burrough, 1991). In this study, those soil profiles that have been sampled extensively tend to cluster strongly in a given area of the textural triangle. It suggests that additional sampling may not give much additional information.

Geomorphology and digital terrain modelling could be expected to play an increasing role in the future in elucidating spatial variation. This modelling approach could be used together with soil classification information, or with geostatistical approaches as outlined below. Sampling and interpretations would be conducted with elevation control, or with reference to geomorphic surfaces, and projected in three dimensions to account for spacial variation.

Methods in Standard Statistics and in Geostatistics

Geostatistics is a field of analyses based on the theory of regionalised variables which uses the variogram and a method of prediction known as kriging (Burgess and Webster, 1980a, 1980b, Webster, 1985, Webster 1994). Values of an attribute at a given point are considered as related to their neighbours. Regionalised variable theory assumes that a spatial variation of any variable can be expressed as the sum of three major components namely: a structural component, associated with a constant mean value or a trend; a spatially correlated random component; and a residual error term that is spatially uncorrelated. The analyses has as objective to estimate the value of a attribute, and the confidence that can be attached to this estimate, at a given point relative to those values measured from neighbouring points. The degree of spatial variation of the soil attribute can be modelled by the variogram (Burrough, 1991). In future it will perhaps be as common for variogram functions to be recorded in soil information systems as profile descriptions and laboratory data are stored today. Many soil information systems now contain large amounts of quantitative data about soil properties. If these data are linked to geographic coordinates it should be a relatively simple matter to retrieve data for any single or multiple occurrence of a mapping unit. The programs for computing variograms are now available for personal computers (Rijksuniversiteit Utrecht, 1988; Englund and Sparks, 1988). The lack of computing tools should thus not be a reason for not attempting this type of analyses (Burrough, 1991).

Fuzzy logic and soil classification

Burrough, van Gaans and Hootsman (1997) trace the development of conceptual paradigms of soil classification and mapping from the pre-1960 model of crisp classes in attribute space linked to crisply delineated mapping units in geographical space, to modern approaches using fuzzy classification and geostatistical interpolation. These approaches simultaneously handle continuous variation in both attributes and location. The dominance of any class at any location can be expressed by a confusion index. If spatial correlation is strong, zones of high confusion index are concentrated in narrow geographical transition zones between locally dominant classes. These can be refined to delineate class specific boundaries. If spatial correlation in membership values is weak then broad zones of large values of confusion index occur all over the map. Further improvements in identifying and mapping significant soil groupings should be possible using numerical models of soil processes. Simple models are based on non-overlapping hierarchical soil classes linked to areas of geographical space that are assumed to be homogeneous. Developments in fuzzy classification and geostatistics permit soil class membership values to be treated as continua in a joint attribute and geographical space. Mapping of even the most compact classes in attribute space cannot be achieved without strong spatial correlation. At detailed scales there is a near equivalence between taxonomic class and mapped soil unit. The model is visually expressed by the choropleth map in which geographic distributions of like soils are represented by homogeneous, sharply delineated polygons. The polygons are linked by a map legend to the attributes of the soil which are recorded at a limited number of profile pits. The model is practical because it means that by locating a site on a map and determining the mapping unit the soil properties can be retrieved from the survey report. It however ignores spatial variation. In many cases important soil differences are associated with abrupt, clearly observable physiographic features such as changes in lithology, drainage or breaks in slope. These could be seen as primary boundaries which are relatively sharp. Secondary boundaries are less sharp. According to this model a site can only belong to a single soil unit. Membership of the site is either 0 (not a member or outside the area) or 1 (is a member or inside the area) (Burrough, van Gaans and Hootsman, 1997).

In the 1970's, the concept was that compact classes must exist. It was just a question of finding them, defining them and mapping them (Burrough *et al.*, 1997). The chloropleth model was extensively used. In contrast, the latest methods of numerical taxonomy when applied to sample data sets often had disappointing results. Developments in geostatistics have since taken place (Burgess and Webster, 1980a, 1980b). Burrough *et al.*, (1997) claim that geostatistical interpolation - kriging- is superior to other methods of interpolation (splines, trend surfaces and inverse distance weighting). However, some geostaticians have recognised that physiographically district regions may have distinct attribute covariance as well. Each region may have a different variogram for each attribute. If the regions can be separated by primary boundaries on the basis of physical information (different lithology, climate are quoted as examples), it may be sensible to divide the area before interpolation, provided each major region contains sufficient data points. This implies about 50 data points per region. However, if individual delineations of soil classes are so small that they contain only a limited number of data points, variogram modelling can only proceed with pooled data. This seems to not to bring together concepts of classical soil mapping and geostatistical techniques. Clearly there is no single rule which states that classification is always inferior to continuous interpolation. The best method may be a compromise depending on the insights and amounts of data available (Burrough *et al.*, 1997).

During the 1990's developments of continuous and overlapping attribute classes and of fuzzy-k means took place. The principle is that a site can belong to more than one class and admits the idea of partial overlap of classes in attribute space. This has been possible with the introduction of ideas of fuzzy logic and continuous classification. It expresses the degree with which a soil property has the characteristics of the central concept of the class. The principles are reviewed by Burrough, Macmillian, and Van Deusen (1992) and McBratney and Odeh (1997).

Continuous (fuzzy) classes can be constructed based on the central concepts of conventionally defined classes such as Soil Taxonomy and other classification systems (McBratney and Odeh, 1997). Mazaheri, Koppi and McBratney (1995) and Mazaheri, McBratney and Koppi (1997) have published an application of this approach to the Australian Great Soil Group classification scheme. This classification scheme appears to have strong affinity to central concept for each class. The approach could be used to sharpen numerical values around a central concept of soil classes.

Studies on (a) the reproducibility of interpreted soil boundaries, (b) within map unit variability, (c) geostatistics and spatial variability, and finally (d) continuous or fuzzy classification, have demonstrated that there is no single soil classification and mapping paradigm that can be used at all locations and at all levels of resolution (Burrough *et al.*, 1997). Primary boundaries and zonations based on important differences in lithology, landform or drainage must be taken into account. Similarly processes governed by moisture, geomorphic processes, temperature and organisms need consideration. The paradigm of soil variation that is now emerging from the combination of soil taxonomy, soil formation processes, soil information systems, geostatistics and fuzzy classification is more complex than the crisp model of the 1960's. There are now geographic information systems with sufficient detailed data on soil and land properties (landform, climate, evaporation, nutrient status and drainage etc.) that it could be asked (Burrough *et al.*, 1997) whether soil taxonomy and conventional soil mapping is still useful. Solutions to land evaluation problems of sites with detailed information is becoming feasible using the original georeferenced data of soil attributes, together with geographic information system techniques, geostatistics and models. These techniques are increasingly able to create groupings and maps for complex land use problems. Expert information on the major soil forming factors can be used to set a site in context, both taxonomically and in the landscape. At lower levels, numerical modelling studies using data from soil profiles, site and elevation data and other relevant information, can be grouped and mapped as the user requires (Burrough *et al.*, 1997).

CHAPTER 2

EXTENT OF THE STUDY AREA, SOURCES OF DATA AND METHODS OF ANALYSIS

EXTENT OF THE STUDY AREA

The study area was chosen to cover KwaZulu-Natal and the southern and eastern part of Mpumalanga. Two factors were considered in selecting this study area. Firstly, a first hand knowledge of many of the soil profiles located in the area had been gained at the commencement of the study. Experience had been gained during the Land Type and other soil surveys covering much of KwaZulu-Natal, and to some extent in eastern Mpumalanga. Many of the profiles that were to be used in the study had been sampled or visited first hand by the author. A mental picture of the soil profiles could readily be formed when later studying their soil analyses. Secondly, geology was considered to be a major component in formulating the hypothesis for the grouping of soil profiles. Since the geology formations of the Karoo Sequence, and particularly those of the Ecca Group, covered most of the Northern Interior Basins of KwaZulu-Natal, the study area was extended into those areas of southern and eastern Mpumalanga where these formations also cover large areas. Inclusion of these areas of southern and eastern Mpumalanga should provide an improved range and confidence in determining the properties of soils derived from these sediments. Finally, for specific comparison purposes, certain soil profiles from the Springbok Flats and from selected granite derived soils of the Northern Province were also included. The extent of the study area is illustrated in Figure 2.1.

SOURCES OF SOIL PROFILE DATA

The profiles were derived from the Land Type Survey and from other published and unpublished soil survey reports, documents and theses. Three minimum requirements were set for inclusion of profiles in the data set. The profiles should have comprehensive physical and chemical soil analyses. Preference was given to data sets where soil analyses followed the methods of the Non-Affiliated Soil Analysis Working Group (NASAWC) (1990). Soil classification information and accurate profile location information should be available. Usually a profile description was also available, although the descriptive information was not entered onto the database.

An important source of profile information has been the 813 modal profiles of the Land Type Survey (Land Type Survey Staff, 1985; 1986a; 1986b; 1987a; 1987b; 1987c; 1989a; 1989b; 1994a; 1994b; 1996; 1997a; 1997b; 1998a). In addition to the modal profiles of the Land Type Survey, soil analysis data from 2 742 series identification profiles collected during this survey were also included (Land Type Survey Staff, 1972 - 1991). Samples from one or more of the A, E and B horizons were collected and analysed to identify soil texture and base status properties at chosen localities. The results of these analyses were available in the archives of the ARC-Institute for Soil, Climate and Water (ARC-ISCW). The locations of these profiles were recorded on field maps which were stored at ARC-ISCW. In many instances profile descriptions ranging from an abbreviated format to a more comprehensive description (Verster, 1972; Land Type Survey Staff, 1991) were also available. These descriptions proved to be valuable in reviewing the properties of selected profiles. Additional soil profiles (495) from within the study area were

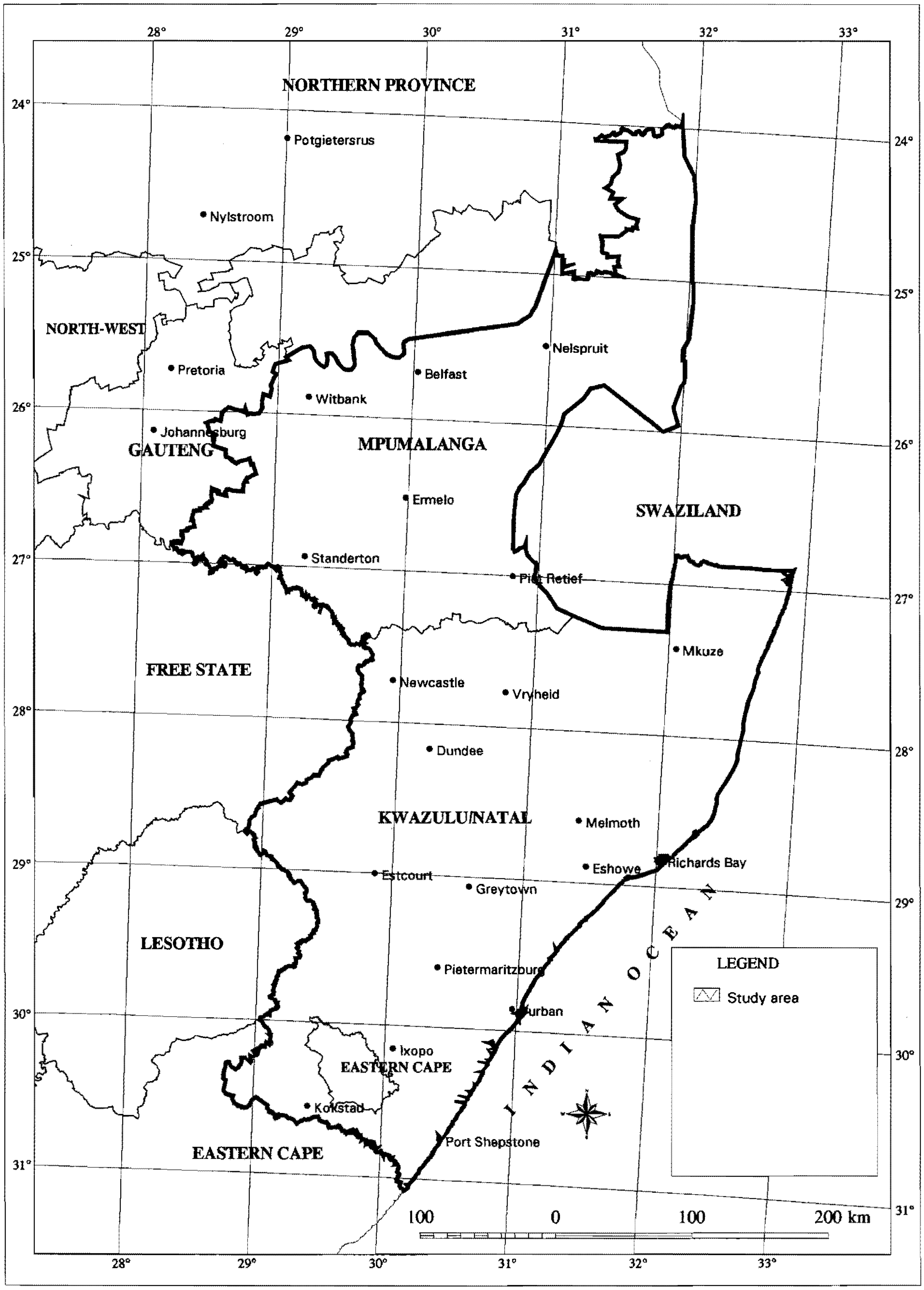


Figure 2.1. Location of the study area in KwaZulu-Natal and Mpumalanga.

obtained from published and unpublished survey reports, documents and theses. These additional sources are listed in Table 2.1. The methods of analyses of these profiles are given in their respective reference sources. In general they follow closely the methods recommended by The Non-Affiliated Soil Analysis Work Committee(1990). The soil classification information is taken directly from profile descriptions or map sources and follows the soil classification system in place at the time of sampling. The data set largely reflects information from Soil Classification: A Binomial System for South Africa (MacVicar *et al.* 1977). Horizon notation follows that recommended by the Soil Classification Working Group (1991).

The nature and purpose of the hypothesis was to collectively examine the properties of a variety of soils covering areas as large as the provinces of KwaZulu-Natal and Mpumalanga. To effectively achieve this examination it became necessary to assume a direct relationship between the properties of the soil and the underlying geology formation (Hypothesis, Chapter 1). In the opinion and experience of the author this assumption was justified. For this reason analysis of the profiles from the Masotcheni Formation (Geological Survey, 1981a, 1988a, 1988b, 1988c, 1992) in the Interior Basins of KwaZulu-Natal were not considered. The Masotcheni Formation comprises much recent transported material where numerous examples of differing cycles of soil formation can readily be observed (Botha, Scott, Vogel and von Brunn, 1992, De Villiers, 1962).

Field maps were examined and lists prepared per map of profiles that had been sampled. The profile positions were marked and subsequently digitized from these maps. The geology stratigraphic unit was determined by carefully comparing the location of the sampled profiles on the field maps to the equivalent location on geology maps. In general the 1:250 000 geology maps were used to determine the geology symbol and hence the nature of the underlying material (Geology Survey, 1878, 1981a, 1981b, 1885a, 1985b, 1985c, 1986a, 1986b, 1986c, 1986d, 1988a, 1988b, 1988c, 1988d, 1992). However, in some instances it became necessary to use the 1:1 million geology map (Geology Survey, 1984). Topocadastral features such as original farm boundaries, rivers and roads provided an important means of comparison when determining the geology map symbol for each soil profile. On both sets of maps the cadastral features were clearly marked so that the symbol of the underlying geology material could be determined with reasonable accuracy. Where a soil profile was located very near to a geological formation boundary, and it could possibly be associated with either formation, both symbols were noted. However, for most profiles only one symbol was recorded. The notation of the Geology Map of South Africa (Geology Survey, 1984) was followed. However, occasionally the same geology formation had different symbols on adjacent maps. The symbols were then altered slightly to give a uniform notation. Since more detail is given on the 1:250 000 geology maps than on the 1: 1 million maps the former detailed source was preferred. The geology notations were confirmed by descriptions given by the South African Committee for Stratigraphy (1980).

CONSTRUCTION OF COMPUTER DATABASES

Four databases were prepared to record the geology, coordinate and soil analyses information. Two separate databases were initially required to record the soil analyses for the series identification profiles (Table 2.1) and the soil analyses for the Land Type Survey modal profiles.

Table 2.1 Soil survey reports and theses which served as additional sources of soil profile information.

Reference	Location (District)	Reference	Location (District)
Bester, 1993	Hendrina, Mpumalanga	Paterson, 1992a	Witbank, Mpumalanga
Bester and Liengme, 1993	Estcourt, KwaZulu-Natal	Paterson, 1992b	Warmbad, Northern Province
Beytell and Schoonwinkel, 1993	Bronkhorstspruit, Mpumalanga	Plath, Vivian, Grundling, Smith-Baillie and Dohse, 1982	Eshowe, KwaZulu-Natal
Dekker, Jeffrey and Scotney, 1980	Pietermaritzburg, KwaZulu-Natal	Potgieter and Wilke, 1991	Bronkhorstspruit, Mpumalanga
Demarest, 1992	Bronkhorstspruit, Mpumalanga	R.F. Loxton Hunting and Associates, 1981	Mahlabatini, KwaZulu-Natal
Drennan, Maud and Partners, 1988a	Empangeni, KwaZulu-Natal	Scotney, Jeffrey and Dekker, 1978	Kokstad, KwaZulu-Natal
Drennan, Maud and Partners, 1988b	Empangeni, KwaZulu-Natal	Smith-Baillie, Bester and Liengme, 1991	Mkuzi, KwaZulu-Natal
Geers and Dohse, 1980	Mtubatuba, KwaZulu-Natal	Smith-Baillie and Dohse, 1975	Moeketsie, Northern Province
Geers, Dohse and Schoeman, 1981	Komatipoort, Mpumalanga	Smith-Baillie, 1986a	Pongola, KwaZulu-Natal
Grundling, Gordon and Smith-Baillie, 1986	Paulpietersburg, KwaZulu-Natal	Smith-Baillie, 1986b	Mooi River, KwaZulu-Natal
Jeffrey and Scotney, 1979	Mooi River Valley, Muden, KwaZulu-Natal	Smith-Baillie, Snyman, Pallett, Grundling and Turner, 1989	Pongola, KwaZulu-Natal
Jeffrey, Dekker and Scotney, 1981	Hluhluwe, KwaZulu-Natal	Snyman, 1987	KwaZulu-Natal
Land Type Survey Staff, 1972-1991	Soil series identification profiles from throughout the study area, KwaZulu-Natal and Mpumalanga	Soilscapes 93 Organizing Committee, 1993	Mpumalanga
Ludorf and Scotney, 1975	Lions and Mooi River Districts, KwaZulu-Natal	Steenekamp, 1989	Bronkhorstspruit, Mpumalanga
MacVicar and Sobczyk, 1984	KwaZulu-Natal Coast Hinterland	Turner, 1976	Howick, Estcourt, KwaZulu-Natal
Oberholster, 1969a	Warmbad, Northern Province	Van der Bank, Verster, Roberts and MacVicar, 1978	Grootvlei, Mpumalanga
Paterson, 1991a	Witbank, Mpumalanga	Van der Eyk, MacVicar and de Villiers, 1979	Tugela Basin, KwaZulu-Natal
Paterson, 1991b	Witbank, Mpumalanga	Venter, Folscher and Oberholster, 1969	Ermelo, Mpumalanga

Geology Information

Geology information was entered into a set of computer files, one file for each one degree of latitude-longitude. These files were printed, proofread and corrected for typing errors. Once correct, the files were appended to one another to form the geology master file (GEOMAST.DBF).

Coordinate information

Most of the profile coordinate point information was obtained by digitizing from the original field maps. A set of computer files were prepared, one file for each one degree of latitude-longitude. The profile coordinate points for certain profiles were entered directly from profile descriptions. All initial coordinate points were transferred from the digitizing tablet format to a UNIX database format for processing. The points were plotted on maps, proofread and corrections made to ensure complete data sets. Uniform file structures were required to account for differences that arose during digitizing. Printouts of the coordinate points were made for future reference purposes. These files were appended to one another to form the coordinate master file (COOMAST.DBF).

Soil Analysis Information: Series Identification Profiles

The majority of these profiles were analysed in the ARC-ISCW laboratory. The sequence of reporting soil attributes (particle size classes, extractable cations) was in a standard order. Soil analysis results were entered into separate computer files depending on the nature of the data sources. One file was created respectively for each pedologist responsible for sampling the profile, or for each survey report (Table 2.1). Soil analytical data from the remaining survey reports (Table 2.1) were entered into separate computer files. Here the order of reporting the soil attributes differed from that of the ARC-ISCW reports. The file structure of these files was subsequently altered to conform to a standard order. Printouts were prepared, proofread and corrected. The analyses were reviewed to establish their correctness. Soil horizon and depth information was deduced and added as these data were occasionally missing on the original laboratory reports. A test program was prepared (DATATEST). The program tested that the sums of certain of the attribute values were correct, and that the likely range in attribute values was not exceeded. Error messages were reviewed and corrections made where necessary. These files were appended to one another to form the analysis master file (ANA_MAST.DBF).

Corrections were made to the profile numbers in each of the geology, coordinate and analyses master files. This step was necessary as the profile numbers were not always exactly unique in each of the original map, coordinate or soil analysis data sources. Linking of the databases was performed by the unique profile number. To obtain a complete record of each profile in each of the databases a unique profile number was essential.

Soil Analysis Information: Modal Profiles Files

The entry of the soil analysis data for the modal profiles of the Land Type Survey was performed periodically by ARC-ISCW staff. Data verification of some of the profiles had been performed by the time that these modal profile data were required. Much effort was directed to obtaining a correct and complete data set, and the proofreading of this set of files. These files were also subject to a test program which checked the sum of particle size determinations, and the sum of exchangeable cations against cation exchange capacity. The program also tested the likely ranges of most attribute values. Error messages were reviewed against the original data sources and corrections made where necessary. The review of the Land Type Survey modal profile analyses has been an ongoing task at ARC-ISCW, to the point where a high degree of data verification has now been achieved.

The Land Type modal profile data were stored in four files containing soil physical (A), chemical (B), saturation extract (C), and mineralogy and micronutrient (M) data respectively. These four files were duplicated for each of the eighteen Land Type maps within the study area. A fifth set of files was required to add soil form and soil series (MacVicar *et al.*, 1977) information. To ensure complete data records in each of the five files, detailed proof-reading of all the records in the soil physical file was performed. A computer program (DATATEST) was prepared to check that these records (determined by their unique profile numbers) also appeared in each of the other four files. Corrections were made and missing data were entered. Finally the files were appended to prepare five master files (MODMAS_A.DBF, MODMAS_B.DBF, MODMAS_C.DBF, MODMAS_M.DBF and MODMAS_S.DBF).

Program Files

Three programs were used to prepare the final version of the geology, coordinate and soil analysis master files. The first program (AP_ANAL.PRG) (using query view LAS_A.QBE and LAS_BSC.QBE) appended the soil analyses from series identification profiles (ANA_MAST.DBF) to the modal profile data files (MODMAS_A.DBF, MODMAS_B.DBF, MODMAS_C.DBF, MODMAS_M.DBF, MODMAS_S.DBF). In doing this soil attributes (clay percentage, exchangeable Na, etc.) for each profile were added to the respective modal profile files.

The MERK programs checked that there was a record for each profile in respectively the geology, coordinate and soil analyses master files. By selecting a record from the geology file, and systematically searching for this record in the coordinate and soil analysis files respectively, linking of the profiles could be achieved. Matching of the respective files was done by the unique profile number. Where mismatches were noted a simple correction to the respective profile numbers was sufficient to achieve a correct match. The MERK programs were run several times until a complete set of records was obtained in each of the respective geology, coordinate and soil analyses master files.

The NEW_MAST program automated these processes which facilitated the appending of files, the correct placement of soil analyses data and the correct matching of unique soil profile numbers. It was from these seven master files that all subsequent soil analysis selections were performed.

INFORMATION DERIVED FROM THE SOIL PROFILES DATABASE

Construction of computer databases: Profile selection for geology, soil form and horizon

The hypothesis considered that grouping of soil profiles according to geology symbol and soil form would account for the major differences in soil properties. These groupings could then be used to determine the range of numerical values over which a soil attribute (clay percentage, exchangeable Na, etc.) was known to occur. The natural soil body could be defined collectively as the ranges of a number of appropriate soil attributes.

In practice a database query view (Borland, dBASE IV, 1993) was required, where soil data files with appropriate sets of boundary conditions could be extracted from the database. Standard query view files were prepared to extract the physical (PHYS_A1.QBE), chemical (CHEM_A1.QBE), saturation extract (SAT_A1.QBE), and mineralogy and micronutrient data (TEMP_A1.QBE). Within each query view file only the geology symbol, soil form symbol (or soil form symbols), and soil horizon symbol was systematically altered. Files for a given geology, soil form (or group of soil forms), and for each of the major soil horizons were systematically prepared, and manually labelled. Systematic file naming used abbreviations for the geology, soil form and horizon symbols. The physical (P), chemical (C), saturation extract (S) and mineralogy and micronutrient (M) files were also appropriately labelled. Standard Dbase report form print files (SELECTA1.PRN, SELECTE1.PRN, SELECTB1.PRN, SELECTB2.PRN) were prepared so that paper copies of any of the extracted soil data files could be prepared. Soil data files were stored in directories for each major geology formation.

Soil texture data appeared to be the most promising in identifying ranges in natural soil bodies. Subsequent investigations concentrated on soil textural information for each geology formation. Soil profile analyses prior to 1980 contained essentially five classes of particle size. This represented the bulk of the available data. Subsequently data with seven particle size classes became available. Soil data files were extracted with both five and seven particle size classes. However, analyses of files with combinations of five and seven class particle size data proved difficult. Since subdivision of particle size class limits were essentially within the fine sand fraction only conversion of the data to the original five classes were possible. Five particle size classes were used in all subsequent data manipulations.

Calculation of Means and Range Values

Programs (labelled BEWERKP.PRG, BEWERKC.PRG, BEWERKS.PRG, BEWERKM.PRG; Pienaar, 1998) were prepared to calculate the mean, median, standard deviation, standard error, lower quartile, upper quartile, minimum, maximum and sample count. They used the standard physical, chemical, saturation extract and micronutrient soil data files. The statistics were determined sequentially for each horizon and soil form within each geology formation. These sets of statistical data were then subsequently used to compile the tables quoting maximum and minimum values (Chapters 4 to 18; Refer to Table 4.2 as an example), the graphs visually depicting maximum, minimum and mean values (Chapters 4 to 18; Refer to Figure 4.2 as an example), and the tables quoting mean and standard deviation values (Chapters 4 to 18; Refer to Table 4.3 as an example). In these tables only the particle size classes from the physical soil data files are quoted. The respective programs have the capacity to determine the statistics for other soil attributes as well.

Graphical representation of soil data files

Soil texture graphs: Soil texture graphs were prepared using the standard soil physical data files (dBASE file format: Borland dBASE IV, 1993) in a Quattro Pro (Borland Quattro Pro, 1993) program. A master texture diagram figure was prepared and copied into each file. Actual soil texture data were then superimposed on this figure giving the series of soil texture figures reported in Chapters 4 to 18. The traditional three axis texture diagram (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991) representing clay, silt and sand in an equilateral triangle did not facilitate easy computer programming. The textural triangles used here (Figure 2.2; Canada Soil Survey Committee, 1978) represents essentially the same information in a format which can be readily reproduced in standard Quattro Pro graphical packages. The texture diagram has percentage sand plotted on the horizontal axis and percent clay plotted on the vertical axis. The scale ascending from the intersection of the two axes is from 0 to 100 percent (Canada Soil Survey Committee, 1978). The texture classes (Figure 2.2), although in a different format, present exactly the same information as in the traditional format (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991). The standard names of these texture classes are presented for reference purposes (Figure 2.2). Silt percentages can be visualized by drawing lines parallel to the main diagonal line joining the 100 percent sand and clay points.

Dominant sand grade graphs: The dominant sand grade graphs were prepared in a similar manner to those of the texture graphs. A master sand grade figure was prepared and copied into each file. Actual sand percentages, recalculated to sum to 100 percent, were then superimposed onto this figure. Figures showing sand grades have fine sand dominant in the top polygon. Medium and coarse sand are dominant in the lower left and lower right polygons respectively (Figure 2.3). These figures representing dominant sand grades are reported in Chapters 4 to 18.

Histogram figures: Histograms of selected particle size distribution data were prepared for selected soil data files using the Quattro Pro graph package. These data are reported in Chapters 4 to 18 respectively.

Minimum and maximum graphs

Minimum and maximum values for particle size data in the respective soil data files were determined using the BEWERK Program (Pienaar, 1998). These data were transferred to Quattro Pro files and graphs prepared using standard minimum, maximum and mean graph functions. These graphs were exported to a drafting program (Coral Corporation, 1997) and aligned with one particle size class above the other to give a visual comparison. The graphs for each geology formation are reported in Chapters 4 to 18 respectively. Data used in these graphs is the same as that presented in the numerical tables.

Luvic Properties

To compare the ratios of the clay percentages in an overlying soil horizon to another horizon the LUVIC database was necessary. This database contained records reporting the clay percentages of a soil horizon with that of horizon record appearing below it in the master database. The database is much smaller than the master database since many of the profiles contained only one horizon per profile. Files were extracted per soil form and sorted per horizon. Luvic Properties are reported simply as the ratio of the clay percentage in a horizon with that in an overlying horizon. Luvic properties were considered to be present when the ratio of the lower to the upper horizon was 1.3 times greater. This method of expression differs from the traditional definitions of Luvic Properties (Soil Classification Working Group, 1991; Soil Survey Staff, 1996; World Reference Base for Soil Resources; ISSS, ISRIC, FAO, 1994) where both absolute increases and ratios are defined. Non-luvic properties were considered present when this ratio had values of 1.3 or less. Eluvic properties were considered present when the ratio was less than 1.0. This definition follows standard pedological conventions. Histogram graphs showing the distribution of Luvic Properties are reported for selected soils in Chapters 4 to 18.

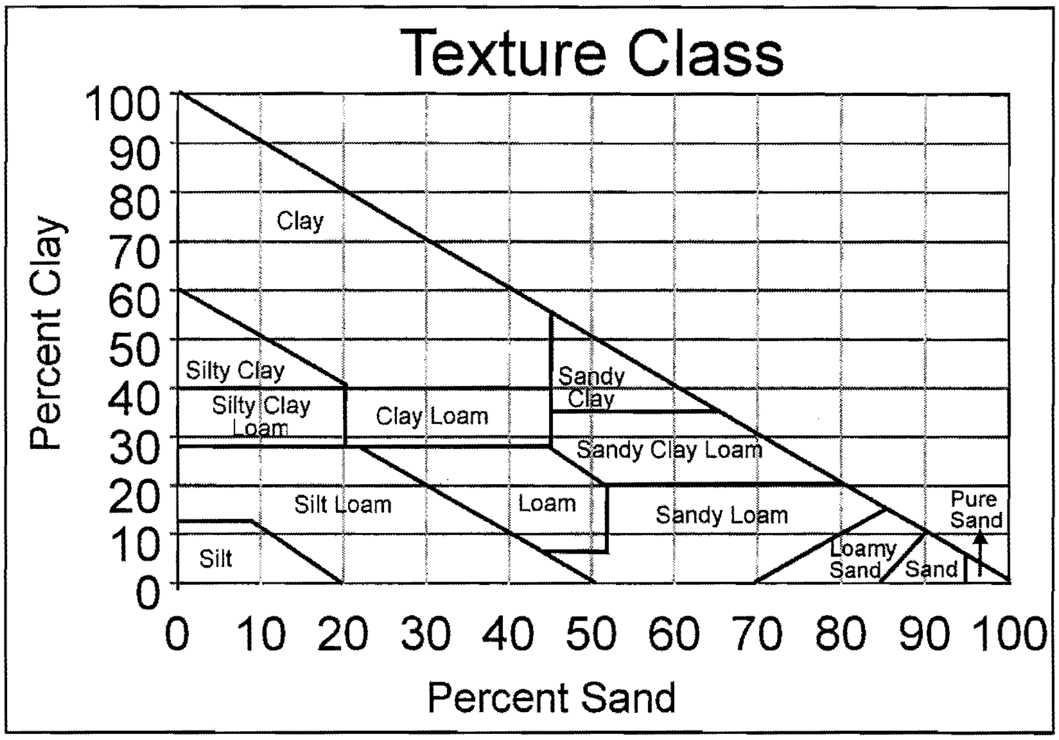


Figure 2.2 The texture triangle chart showing soil texture classes (Canada Soil Survey, 1978).

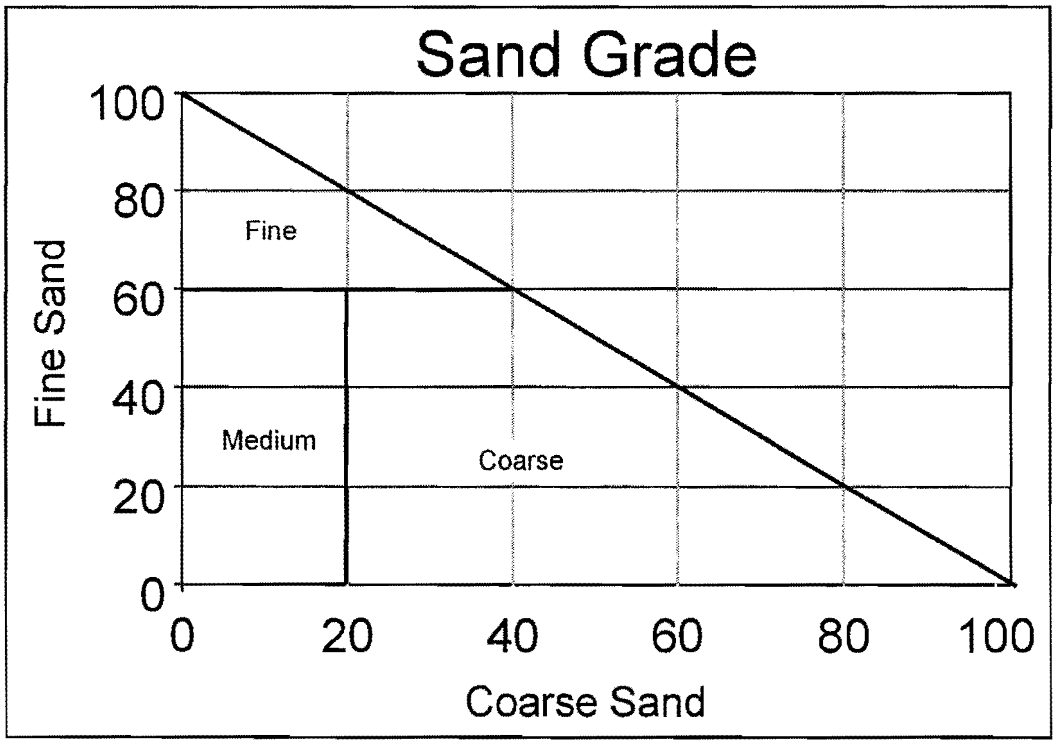


Figure 2.3 The dominant sand grade chart (Soil Classification Working Group, 1991).

Recognition and Separation of Natural Soil Bodies (Soil Texture)

Soil data files were extracted for each geology formation, soil form and horizon. These data were plotted on the texture triangle graphs. The number of profiles available per geology formation and soil form varied greatly. Many profiles were available for the Hutton soils derived from Jurassic dolerite. Various soil forms from the Vryheid Formation, Ecca Group and the Natal Group sandstones, and others, were also well represented. Other soil form and geology formation combinations were less commonly sampled, but still presented results sufficient to demonstrate clustering in a particular texture class. Where there are a relatively larger number of profiles, and these are clustered close together, the recognition of a natural soil body with respect to soil texture is not too difficult to visualize. However, as the available data sources diminish the recognition of natural soil bodies becomes more subjective. Populations may also exist, with or without some form of stratification, where there is simply no clustering. In this case no natural soil bodies with respect to the particular soil property exist. If the hypothesis (that geology formation and soil form can be practically used to group the properties of like soil individuals) is true, then stratification of the soil texture data, and visual representation of natural soil bodies is feasible.

The simplest form of identifying the soil body is to mark the boundaries by inspection of the extremities of the data points. These boundaries were mechanically transferred to the graphs reported in Chapter 3 for soil forms and geology formations. The corresponding texture graphs with the individual data points are reported in those chapters dealing with the respective geology formations (Chapters 4 to 18). Webster and Oliver (1990) discuss the mathematical theory of separating populations (which could be natural soil bodies representing texture) where these are represented on two axes (two variates). In their example the populations are represented by ellipsoids. The need to identify the number of populations would seem to be important. There would seem to be little difference to be gained between the more rigorous mathematical approach and that by simple visual inspection. Opportunities to develop the mathematical approach during this study were simply not available. The visual definition of natural soil bodies with respect to texture provided estimates within a short period.

In certain geology formations it was clear that more than one natural soil body was present. Reporting the means and variance of these combined populations would be of little value. The populations were separated at appropriate threshold values, creating separate computer soil data files. The threshold values separating more than one natural body within a given geology formation are reported in the text. The means and variances of the individual populations were calculated as reported earlier. Usually one cluster of points could be fairly easily recognised. The other often comprised individual points forming a poorly defined cluster. These were commonly profiles with high silt values. It is probable that these silt values are in fact present, and that they do not represent laboratory or data capture errors.

INFORMATION DERIVED FROM THE LAND TYPE SURVEY DATABASE

Dominant Soil Forms and Series occurring on a given Geology Formation

Soils do not form randomly in the landscape, but are the products of the soil forming factors (Jenny 1941, Simonson, 1959). The regular occurrence of certain soils on a given geology formation is a striking observation of many soil surveys, and has been regularly reported in the literature (Beater, 1957, 1959, 1962, 1970; MacVicar, 1978). The data of the Land Type Survey were available to give a summary expression to this observation. It is also considered an important and central part of the hypothesis; namely that characteristic soil forms and soil series occurring regularly on a given geology formation should be considered as an expression of this natural soil body. The range of their textural properties, and indeed other properties as well, is similarly further expression of the natural soil body.

The method explained here aims at giving a general expression to this statement. The method seeks to provide the dominant geology for each Land Type. The Land Type Survey maps of the study area were placed over the 1:1 million geology map of South Africa. For each Land Type the proportional area of a given geology symbol was determined using standard Geographic Information System (GIS) techniques. These proportional areas of the computer files were examined manually and a dominant geology symbol determined for each Land Type. Identifying the dominant geology symbol (comprising greater than 70% of the area) for most of the Land Types was relatively simple. A relatively smaller number of Land Types (less than 30%) were associated with two or more geology formations. The Land Type was assigned simply to that formation with the greatest proportional area. The method should nevertheless give a relatively good overview picture of the soils and their proportions associated with a given geology formation.

Editing the computer files was done so that only one geology formation was associated with each Land Type. The Land Type database was accessed and the total area and proportion of each series was calculated over each Land Type and geology formation (OPSOM Program; Pienaar, 1998). These data were reviewed and entered into the tables dealing with the dominant soils (Chapters 4 to 18; Refer to Table 4.1 as an example). These tables show the dominant soils and their relative proportions derived from a given geology formation. General climate statistics are shown adjacent to each soil grouping.

Climate Properties

Climate statistics are reported for dominant soil patterns occurring on a given geology formation (Chapters 4 to 18; Refer to Table 4.1 as an example). These were derived from the climate database component of the Land Type Survey (Land Type Survey Staff, 1998; Dent, Lynch and Schulze, 1988). Files containing mean annual rainfall, heat units, and Class A-Pan evaporation for the study area were obtained. The units are expressed as annual values. Heat units are derived from the sum of daily mean temperatures. Aridity index is defined as the ratio of mean annual rainfall divided by mean annual evaporation. Climate statistics were calculated using a hand calculator after data were extracted from the appropriate files. While actual measured rainfall values for a given Land Type climate zone were usually available, it was usually necessary to estimate the annual evaporation. Refinement in these estimates would be desirable.

CHAPTER 3

A SUMMARY OF THE SOILS AND THEIR TEXTURAL PROPERTIES IN KWAZULU-NATAL AND MPUMALANGA

Introduction

Soils form in response to conditions at the earth's surface which interact on their composition and are reflected in their nature and properties. Soils thus have a degree of predictability. All soil properties cannot be accurately predicted, but where the five soil-forming factors; climate, living organisms, parent material, time and relief (Jenny, 1941) are similar, similar soils should be formed. The cumulative, but differing effects of these factors on soil formation are commonly expressed as observable properties. Because of the observable relationships of soil properties we say that soil with discrete sets of properties have a degree of predictability in the landscape (Soil Survey Staff, 1980). This is the scientific basis of soil surveys (Hartung, Scheinost and Ahrens, 1991). These observable properties form the basis upon which our evaluations of how soils will respond to external management impacts are made. A knowledge of the soils and their inherent properties thus forms the cornerstone to the issues of their sustained and wise utilization.

The soil scientist is not able to probe every hectare of the survey area. Commonly it is also not feasible to use random sampling techniques that would allow that each member of the soil population is exposed to an equal probability of being sampled. This is certainly true for the soil profile information sources available at the commencement of this study. We should however, not be daunted by these shortcomings in our information sources. The soil scientist should rather use these information resources, and available scientific technology, to document the soil relationships and to enhance our knowledge of the soil mantle. The objective of this study has been to access as much of the known and reliable soil profile information as was available at the commencement of the study. The objective was further to collate and document this information that students of the discipline could further build on the information base. By following this process it should be feasible for soil users to better understand the relationships between soils, the natural resources that give rise to their formation, and their range of properties.

An early perspective of soil series: A personal viewpoint

These few paragraphs provide simple mental pictures across time of views that have contributed to formulating concepts of soil series and of natural soil bodies. These views are shared in the hope that they would bring perspective in our search to give expression to soil series and natural soil bodies. Four incidents are recounted. The first image relates to those sandy red soils on the dunes of coastal Durban, KwaZulu-Natal. These are followed by the mental pictures of a red apedal Balmoral soil monolith, and of photographs of soil profiles with descriptions and soil analyses published in the book on the soils of the Tugela Basin. For the last picture readers are invited to construct a mental image of the Mfolozi Basin, from near to the coast of KwaZulu-Natal stretching to the source of the river valley in the Interior. These valley landscapes are somewhat remote to many travellers, readers could imagine countryside over which they are familiar. The objective of this picture is to place the soils and their properties, their distribution over the hills and valleys, and of their uses to people, in context.

An introduction to soils that remains imprinted on memory as a child was the red, and sometimes whitish, sands of coastal Durban. These soils comprised usually soft red and sometimes whitish sandy profiles with a fine loose material at the surface. Sometimes a litter layer could be noticed, or possibly this layer had in places become darkened by organic matter. In addition to the dominantly red soils were those soils where white sand shone in the sun from the otherwise darker surface of small mounds made by burrowing animals. These soils were spongy underfoot. The thick roots of the coastal trees and shrubs grew horizontal below the surface, but they also penetrated to deeper layers. Cohesion of the surface material was seldom present. Below these generally red, sandy topsoils the soil became redder and increased in hardness with depth. Well below the normal depth of a hand spade lay abruptly the sticky and appreciably harder red layers. In fact, these horizons were the medium sandy topsoils and sandy clay loam subsoils of what has been described as the Clansthal series (MacVicar, *et al.*, 1977) and the Lytton series (Beater, 1959; MacVicar, Loxton and van der Eyk, 1965b). In the bottomlands lay the black spongy organic rich soils, soils that we now classify as belonging to the Champagne form.

These images were followed by those of monoliths of representative soil profiles (series) placed in the students lecture room. Professor Orchard, first professor of soil science at the University of Natal, made frequent reference to the Balmoral soil series, with its porous physical properties, its high physical stability, its apedal appearance, and the high levels of acidity. The influences that these properties would have on crop plant growth were conveyed to students. Alongside the monolith of the Balmoral soil series stood the monoliths of the Estcourt, Avalon, and Rensburg soil series, providing visual evidence of their sharply contrasting properties. These contrasting properties were described in terms of their physical, chemical and mineralogy properties. A picture of different soils; differing in their morphology, their properties, and in their potentials for wise land use emerged. These differences were expressions of measurable and factual evidence of soil properties, but remained somewhat separated pieces of information in a wider expanse of knowledge. A third mental picture in the development of the concept of a soil series came with study of the book: Soils of the Tugela Basin: A Study in Subtropical Africa (van der Eyk *et al.*, 1969). The book has an excellent set of photographs of soils depicting soil horizons, their colours, structure and underlying material. Students viewing this book (and similar publications on soil classification) are introduced to many of the salient features of the soil profiles that make up the soil mantle. The picture in this book of the Estcourt Soil Form is most striking. Examples such as those of the Avalon or Rensburg Forms provide a reference framework to central concepts of soil bodies that are identifiable, but also repeatedly encountered in the soil mantle by those people who work with soils. Profile descriptions and analyses reinforced the information provided by the photographs. They establish the connection between the photograph (representing the real soil profile) and their detailed properties.

Finally, the fourth mental picture could be that of the hills and valleys of the Mfolozi River Valley. It was here that an awareness of the relationships of soil patterns formed over the whole extent of the valley became obvious. Indeed, the image could be repeated at many other locations to give expression to the soils, their distribution, and how they are used. The striking recognitions over many months of soil surveys of the exciting relationship of like soil individuals occurring regularly, and in our limited comprehension, almost predictably across large tracts of the soil mantle has implications for recognising natural soil bodies. The valley is composed of large areas of tillite of the Dwyka Formation. On the edges of the valley, in the highly weathered and upland locations, Griffin soils are dominant. As the landsurfaces become progressively younger and more arid, other characteristic broad soil patterns have developed. In the upper reaches of the valley plinthic soils, usually with an eluvial horizon, but occasionally with a yellow-brown apedal horizon, are present. Subsequently duplex soils, which usually lack eluvial horizons, become dominant. Finally, lithosols with characteristic morphology developed over a commonly hard, crumbly B horizon cover wide areas of the valley. Occasionally, these lithosols are located in higher rainfall areas. Here the more intense weathering regime is reflected in a soft B horizon (as opposed to a hard B horizon) which still has evidence of the original tillite structure.

Perceptions of the natural soil body

The soil classification unit (the soil form in the South African Soil Classification System), is as much a part of the natural soil body as is the soil texture, the base status or any of the other regularly measured soil attributes. The natural soil body is certainly expressed in the soil classification unit. It is however, more than this; it is an expression of the uniqueness of soil profile morphology and its ranges of properties. Soils formed within a given location, associated with a given geology rock type, and climate and time regimes, often have unique morphology features, and ranges in properties. The humic soil profiles formed on sandstones of the Natal Group; or the Avalon and Longlands soils, with plinthic horizons, developed on Vryheid Formation of the KwaZulu-Natal Interior Basins; or the Glenrosa soils on tillite of the Dwyka Formation are but a few examples of this striking uniqueness in soil profile morphology. Indeed, many other examples could be named as characteristic of other geology formations, and climate and time regimes. Soils classified to the same taxonomic class but derived from differing geology rock types, or climate or time regimes regularly express differing soil morphology and ranges in soil properties. They should then constitute separate natural soil bodies, although each may show some commonality with respect to their morphology features and an overlap in their ranges in property values. This expression of uniqueness in soil profile morphology is often obscured, even in accurately described soil profiles. Prominence of these commonly unique features to groups of soil profiles could be recognised within the natural soil body.

Natural soil bodies do occur regularly in the soil mantle, a fact upon which many experienced soil scientists would agree. During the process of soil survey hypotheses to assist in detecting, documenting and explaining the repeatable features in soil maps and reports are prepared. On the other hand, persons viewing soil profiles and their properties in isolation, or for the first time, may become bewildered by the variation.

The broad groups of soils, recognised at the soil form level of soil classification, for the tillite of the Dwyka Formation in KwaZulu-Natal have been described briefly. Similar broad soil groups can be recognised for all the major geological formations within KwaZulu-Natal and Mpumalanga. In general for the sedimentary rocks, the range of soils would be from red and yellow-brown apedal soils of low base status, through plinthic soils, duplex soils and lithosols. This range of soils for the basic igneous rocks would be from red apedal soils of low base status, through red apedal and structured soils of higher base status, to black clay soils and lithosols. These broad soil groups are summarized briefly (Table 3.1) listing the dominant soil forms present on each geology formation. The broad soil groups are described in more detail in each of the Chapters 4 to 18 giving the soils

Table 3.1 Broad groups of soils which occur on the major geology formations of KwaZulu-Natal and Mpumalanga.

Red and yellow apedal soils	Plinthic soils	Soils with an E horizon	Duplex soils	Black and red clay soils	Lithosols
Quaternary Period Geology: Sand. Chapter 4					
Hutton Clovelly		Fernwood Fernwood (wet) Champagne	Kroonstad Vilafontes		
Cretaceous Sediments: Siltstone. Chapter 5					
Hutton			Valsrivier Sterkspruit	Bonheim Arcadia Rensburg Shortlands	
Karoo Dolerite: Dolerite. Chapter 6					
Hutton Griffin Clovelly Inanda Magwa Kranskop				Shortlands Arcadia Rensburg Bonheim Mayo	
Drakensberg Formation: Basalt. Chapter 7					
Hutton Clovelly				Mayo Bonheim	Mispah
Letaba Formation: Basalt. Chapter 8					
Hutton				Shortlands Arcadia Bonheim Mayo	Glenrosa
Tugela Group: Amphibolite. Chapter 9					
Hutton				Shortlands Mayo	
Tarkastad Formation: Sandstone, mudstone. Chapter 10					
Hutton Clovelly Griffin	Avalon Pinedene		Estcourt Valsrivier Swartland Sterkspruit		Glenrosa Mispah
Adelaide Subgroup: Mudstone, sandstone. Chapter 11					
Hutton Clovelly Griffin	Avalon	Longlands Wasbank Westleigh Cartref	Estcourt Valsrivier Sterkspruit Swartland Oakleaf		Glenrosa Mispah
Estcourt Formation: Shale, sandstone. Chapter 12					
Hutton Griffin Clovelly	Avalon Glencoe	Longlands Wasbank Westleigh Cartref	Valsrivier Swartland Estcourt Sterkspruit		Mispah Glenrosa

(continues)

Table 3.1 continued. Broad groups of soils which occur on the major geology formations of KwaZulu-Natal and Mpumalanga.

Red and yellow apedal soils	Plinthic soils	Soils with an E horizon	Duplex soils	Black and red clay soils	Lithosols
Volksrust Formation: Mudstone, shale. Chapter 13					
Hutton Clovelly Griffin	Avalon	Longlands Wasbank Westleigh	Kroonstad Swartland Valsrivier Estcourt		Glenrosa Mispah
Vryheid Formation: Sandstone, shale. Chapter 14					
Clovelly Griffin Hutton	Avalon Glencoe	Longlands Cartref Wasbank Westleigh	Swartland Valsrivier Sterkspruit Estcourt Kroonstad		Mispah Glenrosa
Pietermaritzburg Formation: Shale. Chapter 15					
Hutton Clovelly Griffin		Westleigh Longlands	Swartland Valsrivier Estcourt	Shortlands Milkwood Bonheim	Mispah Glenrosa
Dwyka Formation: Tillite. Chapter 16					
Griffin Hutton Clovelly	Avalon	Longlands Westleigh	Swartland Estcourt Sterkspruit Valsrivier		Glenrosa
Natal Group: Sandstone. Chapter 17					
Inanda Kranskop Magwa Hutton Clovelly Griffin		Cartref Longlands Westleigh	Kroonstad		Nomanci Glenrosa Mispah
Granitic rocks of KwaZulu-Natal and Mpumalanga: Granite. Chapter 18					
Hutton Griffin		Cartref			Glenrosa Mispah

forms, and the relative proportions of soil series (as defined in the 1977 classification, MacVicar, *et al.*, 1977). Summary climate statistics for each group are also given (Chapters 4 to 18; Refer to Table 4.1 as an example). This data is derived from the Land Type Survey (Land Type Survey Staff, 1998b)

The recognition of natural soil bodies derived from first principles

The recognition of natural soil bodies is dependant on there being natural and recognisable breaks in the natural continuum of properties. The hypothesis that stratification of the available data would assist in recognising breaks within the continuum has been applied. MacVicar (1969) points to the concept of a natural soil body, also described as a classical soil series, by noting the striking regular occurrence of similar soil profiles. Examples may be the black, smectitic clay at Bethal on the Mpumalanga Highveld, or the yellow kaolinitic clay at Cedara in the KwaZulu-Natal Midlands.

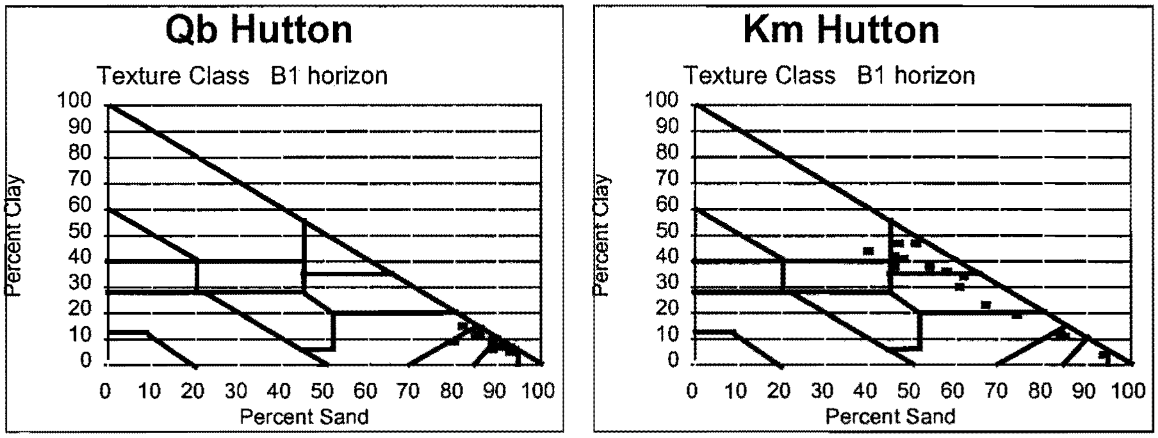
Soil classification has gained widespread acceptance in South Africa as a form of this stratification. The grouping of soils into classes to reduce the range of variability in a class to rational proportions has long been practised by soil scientists. In South Africa little attention has been paid to the natural range in variability of the attribute values of the soils. An understanding of the variability of these attribute values is now increasingly required for predictive and modelling purposes. This chapter presents a summary of the natural range in soil textural variability of most of the soil groups in the provinces of KwaZulu-Natal and Mpumalanga. In addition to detailing the ranges of sand, silt and clay particle size proportions the information provides a basis for assessing the variability to be expected within naturally occurring soil bodies.

The concept of stratification to reduce the variability has been applied in this study. A number of resource factors could be considered, of which a soil classification unit, geology, climate and a defined geographic locality are probably most relevant. In this study, soil form and geology formation were used as the primary stratification criteria. The geological formations are accurately mapped and readily available. It also has the advantage of demonstrating soil variability at a provincial scale, showing the maximum variability that can reasonably be expected. Variations of the climate on soil properties are to some extent incorporated within the soil form selection. (These selection criteria have successfully shown the range of soil textural variability as demonstrated for the soils reported in this chapter.)

To establish the concept of a natural soil body it may be useful to review the grouping of soil properties in two examples where the natural range of soil textural property is fairly limited. The examples chosen are the soils derived from Quaternary Sand and Cretaceous Sediment on the coastal belt of KwaZulu-Natal. Detailed information is provided in Chapters 4 and 5 respectively.

In the Quaternary sands the narrow range in clay contents makes it possible to easily distinguish individually the Hutton, Clovelly and Fernwood soils this natural soil body. In contrast, the Hutton soils derived from Cretaceous Sediments have higher clay contents, and thus can be distinguished on the basis of their higher clay content and the origin of the material. The exceptions in the data set from both the Quaternary Sands and Cretaceous Sediments for Hutton soil profiles do arise. These Hutton soils could be assigned on the basis of their clay content to either of the groups of the Quaternary Sands or Cretaceous Sediments on the basis of expert opinion and judgement. Since the clay contents are essentially mutually exclusive (Figures 3.1a and b), and by virtue of their location (within the KwaZulu-Natal Coastal Belt), and differences of geology material (Quaternary Sand as opposed to Cretaceous Sediment) this does not pose a problem in assigning soil profiles to one of the two soil groups. However, exceptions to the general rule with regard to clay content will apply.

The concept of natural soil bodies may be further expressed in any luvic or non-luvic properties. Non-luvic and luvic texture ranges between the A1 and B1 horizons were determined for Hutton soils on Quaternary Sand. Non-luvic properties were dominant (60% of 11 profiles). Sharp increases in clay between the B1 and B2 is common in the coastal belt. This represents the former Lytton series of Beater (1957, 1970). It could be argued that the non-luvic or luvic nature of these profiles represents two natural soil groups. The dominant genetic processes within the control section of the soil profiles (the B horizons) are different. They could then be regarded as two differing soil series. Alternatively, the clay increases present in either the upper or lower B horizons respectively, represent the natural textural ranges possible in soils derived from these geological materials. As such they could also be considered as only one natural soil body. The author favours this second approach.



(a) (b)

Figure 3.1 Distribution of soil textures for Hutton profiles from Quaternary Sand (Qb) and Cretaceous Sediments (Km).

The limited range of silt and of sand contents is also characteristic of this natural group of soils. The presence of dominantly medium and fine sand grades, but also the presence of some coarse sands in a few profiles, makes these sand grade features characteristic of this natural soil body.

The natural range in textural properties for a selection of red apedal soils

During the development of the revised South African soil classification system (Soil Classification Working Group, 1991) it was decided that the series category (the lowest formally recognised category) should represent natural soil bodies and not artificial subdivisions. It became apparent, however, that the required data was not readily available, or not consolidated into a single usable format, to enable definition of natural soil bodies to proceed. Consequently the series category was not developed in the revised classification (Soil Classification Working Group, 1991).

The natural soil bodies with respect to soil texture are illustrated for a selection of four groups of red apedal soils (Figure 3.2). The soils are those derived from Jurassic dolerite, granitic rocks of KwaZulu-Natal, and the Vryheid and Volksrust Formations of the Ecca Group. The soil profile points for dolerite (Fig. 3.2, Jd Hutton) fill the clay to clay loam texture classes with the diagonal line at 40% silt apparently being a significant natural boundary. The profile points for the Vryheid Formation (Fig. 3.2, Pv Hutton) show a characteristic and distinct sandy to sandy clay loam texture natural soil body with silt values less than 20%, associated with sandstone, and a less distinct clay texture natural body, associated with shale. The mudstones and shales of the Volksrust Formation (Fig. 3.2, Pvo Hutton) also give two natural Hutton soil bodies in the clay and in the clay loam to sandy clay textural classes. The Piet Retief biotite granite gives a single clay to sandy clay soil body with relatively low silt (Fig. 3.2, Z-Rg Hutton). This is in contrast to the generally sandier Hutton soils derived elsewhere from granite. The sand grades of the soils on the Piet Retief granite are coarse to medium, in contrast to the fine to medium sand of the soils from dolerite and from the Volksrust and Vryheid Formations.

The probable boundary conditions for each of these examples is illustrated in Figure 3.3. when superimposed on one textural triangle the overlap in boundaries is clearly illustrated. The boundaries were drawn to pass through the outermost observation points (Figure 3..2). They illustrate that the boundaries determined in this manner are not mutually exclusive. In certain extreme cases a natural soil body can be totally encompassed within another. An example is the case of one Pvo soil body that falls totally within the textural ranges for the Jd soil body. The other Pvo soil body largely overlaps with the Jd soil body (Figure 3.3). Furthermore the Z-Rg soil body largely overlaps with the Jd soil body, totally encompasses the one Pvo soil body and largely overlaps with the other Pvo soil body. Guideline procedures based on preferred factors would be required in assigning the soil to a given natural soil body. These factors could be geology (as used in this study), climate, location or some similar criteria.

Well-defined natural soil bodies could be identified and the range of textural properties determined. Means and standard deviation values can be estimated. These estimates provide a measure of the precision when using attribute values for interpretations or when used in models. Similarly the maximum and minimum values of those attribute values can be determined which will give broad overview perspectives. The use of natural soil bodies in this way could have considerable advantages. It introduces the concept of variation within a soil classification unit and within the chosen stratification criteria. As soil databases become more accessible, this provides a real option to understanding and managing soil variability. It should provide a measure of soil variability where access to large volumes of point values are not available.

Two problems should be noted in a quest to use these natural soil bodies for interpretation of soil attribute values in the same way that arbitrary soil series boundaries were previously used. ***Firstly, in many instances the textural ranges are much wider than has been traditionally accepted in soil series classes.*** This places limitations on the practical usefulness of natural soil bodies when interpretations using a class interval approach is required or preferable. This class interval approach has been favoured in many of the qualitative land evaluation systems. The quantitative approaches are expected to be increasingly used in future land assessments. Indeed, a qualitative screening followed by quantitative approaches seems to have much promise in soil and land assessment approaches. *Where the ranges in soil attribute values are large, arbitrary chosen threshold values, used in combination with the natural boundaries, could improve this situation when defining soil series.*

The second problem is that definite, often large overlaps in attribute values occur between different natural soil bodies. A given combination of sand, silt and clay will seldom belong to a single, mutually exclusive natural soil body. Alternatively, if the starting point were a given combination of sand, silt and clay, then it could conceivably be assigned to more than one natural soil body.

Finally, if the path of natural soil bodies, as opposed to arbitrary chosen threshold values is preferred, then the concept of single mutually exclusive entities should be dispensed with.

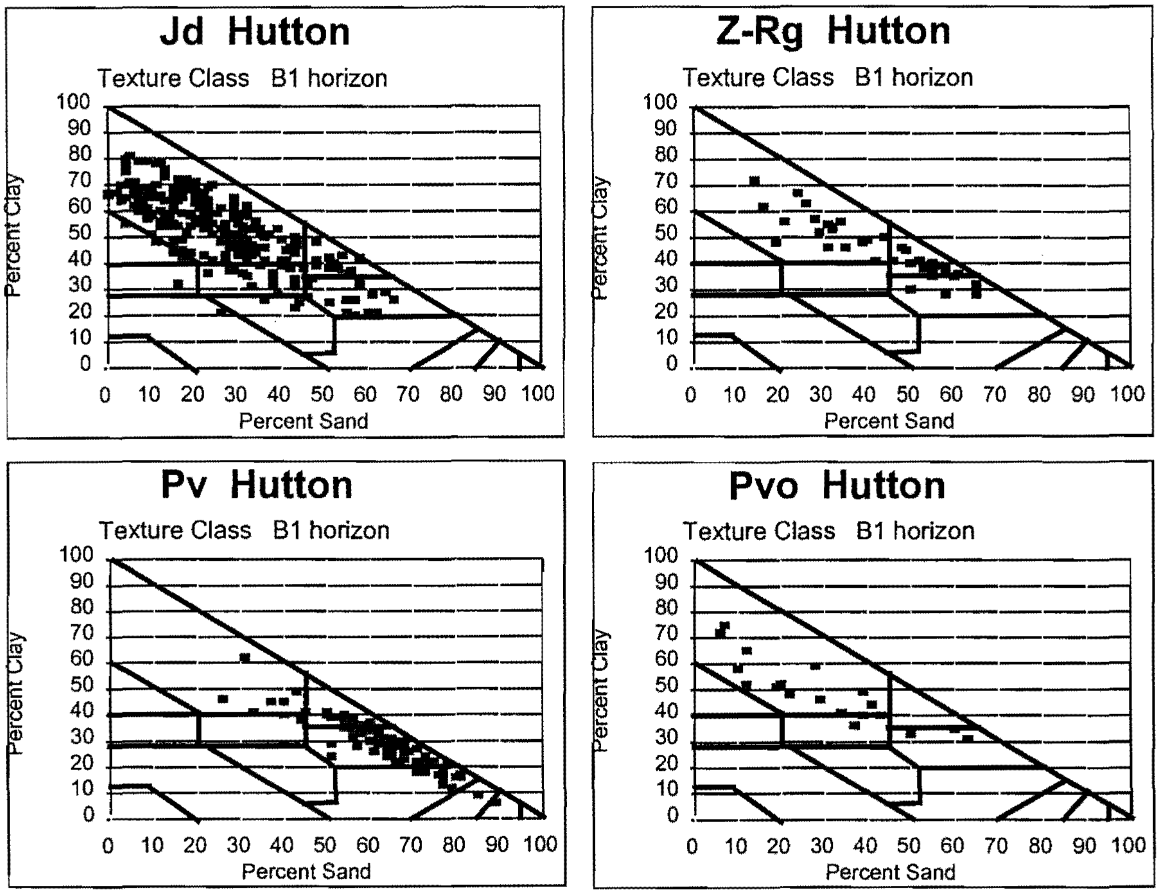


Figure 3.2 Distribution of soil textures for Hutton profiles from Jurassic dolerite (Jd), granite of the Piet Retief District (Z-Rg), and from the Vryheid (Pv) and Volksrust (Pvo) Formations, Ecca Group.

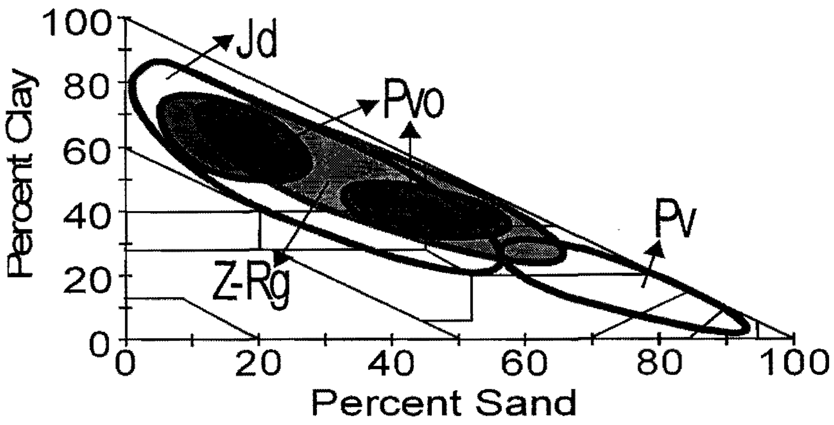


Figure 3.3 Soil texture distributions for four geology formations from KwaZulu-Natal and Mpumalanga.

The remainder of this chapter summarises in a series of tables the natural ranges of variation which were found for soil profiles of KwaZulu-Natal and Mpumalanga. Table 3.2 provides an outline of where the textural information for six major soil groups is quoted. This summary information, ranging from that for red apedal soils to red structured and black clay soils, appears as Tables 3.3 to 3.8. Actual ranges for particle size distributions are derived from more than 4 000 soil profiles. The Tables 3.3 to 3.8 describe the textural properties in the left column and show this distribution in the graphs in the right column. Summary statements concerning natural soil bodies are given in Chapter 19.

Table 3.2 Summary of texture properties for six major soil groups.

Table 3. 3	Red apedal soils on igneous rocks	Table 3.6	Soils with an Eluvial horizon
Table 3.4	Red apedal soil on sedimentary rocks	Table 3.7	Duplex soils
Table 3.5	Plinthic soils, Avalon and Glencoe Soil Forms	Table 3.8	Red structured and black clay soils

Table 3.3 Summary of textural properties of red apedal soils from igneous rocks.

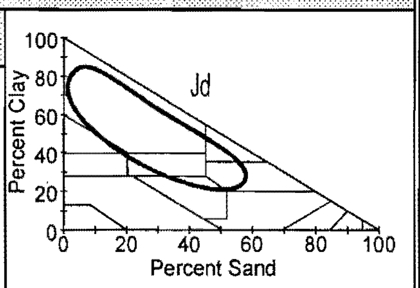
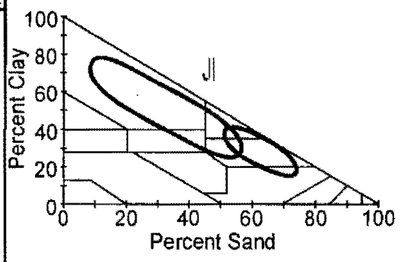
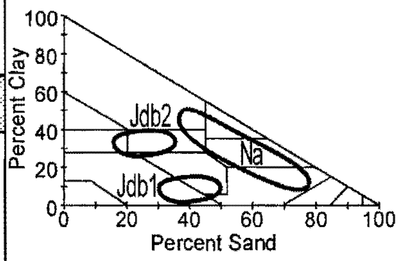
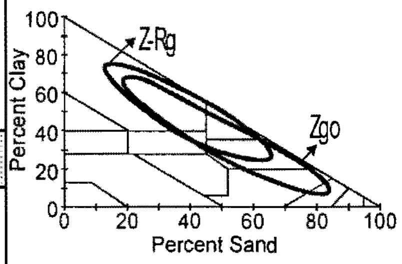
Igneous rocks	
Jurassic dolerite Jd	
* One natural soil body. * Distributed over clay textural class, extending into sandy clay loam in limited number of profiles. * Similar texture distributions in A1 and B1 horizons. * Soils extensively sampled that texture distribution can be described with confidence.	
Letaba Formation, Lebombo Group Jl (basalt)	
* Two (2) natural soil bodies with regard to soil texture. * One natural body is derived directly from basalt, with clay textural classes. Similar distribution to dolerite but occupies only the central part of the clay class. Generally have lower silt values than dolerite. * Other natural body with sandy clay loam textures (A1 and B1 horizons) resulting from probable mixing from sand sources, likely to be the Clarens Formation. Sandy clay loam textured profiles located in Springbok Flats, KwaZulu-Natal and Northern Province.	
Drakensberg Formation Jdb (basalt)	
* Two natural soil bodies can be distinguished with clay loam and loam textures respectively. * Textural properties appear to be related to youthful profile weathering, terrain morphology and climate. * Textual groups also show differences in base status and organic carbon.	
Amphibolite rocks of the Tugela Group Na	
* Single natural soil body. * Clay to sandy loam textures. * Textures generally sandier than dolerite or basalt derived soils. * Profiles tend to have low, and relatively constant silt range. This contrasts with dolerite derived soils with relatively higher and variable silt contents. * Sandier textures could be the result of other sandier rock types together with the amphibolite rock, or less intense profile weathering.	
Biotite Granite: Piet Retief (Z-Rg), Mapumulo Metamorphic Suite: North (NmpN), Mapumulo Metamorphic Suite: South (NmpS)	
* Textures in clay to sandy clay class with narrow of variability of silt (11 to 19%). * Sand grades: coarse and medium. * Limited range in base status associated with clay textural class.	
Goudplaats Granite Zgo	
* Large range in variability of clay percentage from sandy loam to clay classes. Clay textures associated with low base status, sandy loam textures with high base status. * Limited range in silt variability.	

Table 3.3 (continued). Summary of textural properties of red apedal soils from igneous rocks.

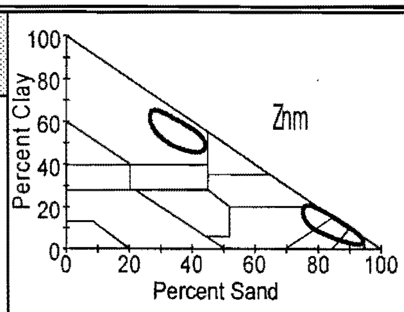
Nelspruit Suite Znm (Potassic gneiss and migmatite component of Nelspruit Suite)	
* Two texture clusters (loamy sand to sandy loam and clay) associated with high and low base status respectively. * Limited range in silt variability.	

Table 3.4 Summary of textural properties of red apedal soils from sedimentary rocks.

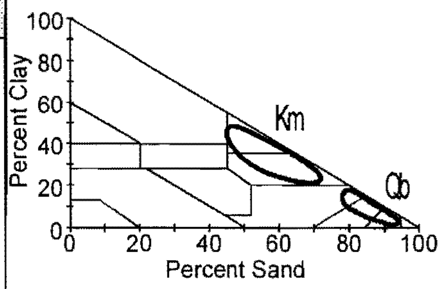
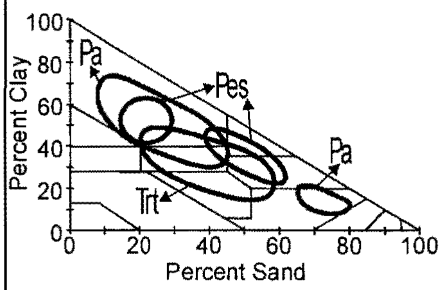
Sedimentary rocks	
Quaternary Sand Formations Qb and Cretaceous Sediment Formations Km (siltstone)	
* Single natural body in each group. * Qb: Sand and loamy sand textures. Medium and fine sand. Generally non-luvic properties between A1 and B1 horizons were determined, with commonly larger clay increases to B2 or lower horizons. * Km: Sandy clay loam to sandy clay textures. Medium and fine sand. Soils generally show luvic properties between A1 and B1 horizons. Occasionally younger, sandy profiles (similar to those of the Quaternary Sands) overlie Cretaceous sediments.	
Beaufort Group.	
Tarkastad Formation, TRt (sandstone, mudstone) * Single natural soil body. * Textures located in the loam classes. * Fine sand grades. * Non-luvic and luvic soils. Adelaide Subgroup Pa (mudstone, sandstone) * Two natural soil bodies can be distinguished with clay and sandy clay loam textures respectively. * Profiles in clay to clay loam texture extends over whole clay class with silt range between 10 and 40% silt. * Individual profiles in sandy clay loam class. * Similar clusters for A1 and B1 horizons. * Dominantly fine sand grades. Estcourt Formation Pes (shale, sandstone) * Three indistinctly defined natural soil bodies in apedal soils (Hu, Gf, Cv). * Hutton Form is represented in only two natural bodies, with clay and sandy clay loam textures. * Fine sand grade.	

Table 3.4 (continued). Summary of textural properties of red apedal soils from sedimentary rocks.

Sedimentary rocks

Ecca Group

Volksrust Formation Pvo (mudstone, shale)

* Three natural bodies distinguished from all available soil profiles. A dominant feature is the clay textural class in Pvo.
* Hutton soils are represented in only two natural bodies with clay and clay loam textures.
* Fine sand grade dominant.
* Soils dominantly non-luvic.

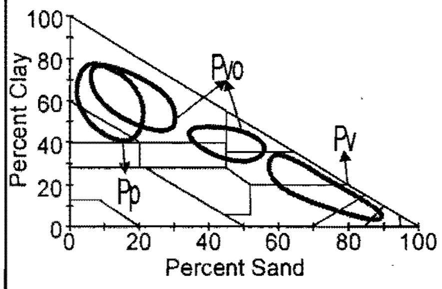
Vryheid Formation Pv (sandstone, shale)

* Two natural soil bodies corresponding to sandstone and to shale parent materials. A dominant feature is the sandy loam textural class in Pv.
* Textural range from fine to medium sand to sandy clay loam.
* Individual profiles in clay textural class.
* Luvic and non-luvic soil profiles.

Pietermaritzburg Formation Pp (shale)

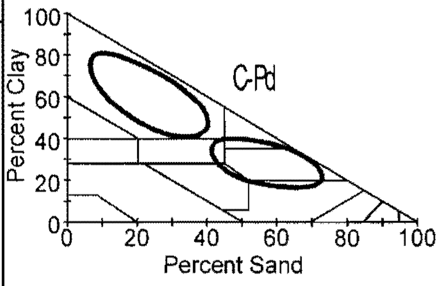
Two indistinct natural soil bodies in the clay and clay loam textural classes. A dominant feature is clay textural class in Pp.

* Individual profiles with higher silt values.



Dwyka Formation C-Pd (tillite)

* Three natural soil bodies distinguished from all available soil profiles. Characterized by large range of variation in textures over C-Pd, but locally clay or sandy clay loam textures predominate.
* Hutton Form is represented in only two natural bodies with clay to clay loam, and sandy clay loam textures.
* Fine sand grades commonly dominant.
* Soils dominantly non-luvic.
* Clay soils lack the erratic drop-stones common in lithosolic soils.



Natal Group O-Sn (sandstone)

* Single natural body present per soil form.
* Humic Soils (Ia, Kp, Ma with thick humic A1) have sandy clay loam to clay texture classes. Clay to sandy clay textures was commonly sampled.
* Orthic Soils (Hu, Gf, Cv with orthic A1) have sandy loam to clay textures classes. Sandy loam to sandy clay loam textures was commonly sampled.
* Fine, medium and coarse sand grades present.
* Shape of texture distribution similar to Vryheid Formation (Pv).

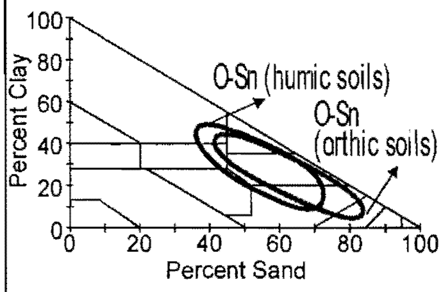


Table 3.5 Summary of textural properties of Avalon and Glencoe soils.

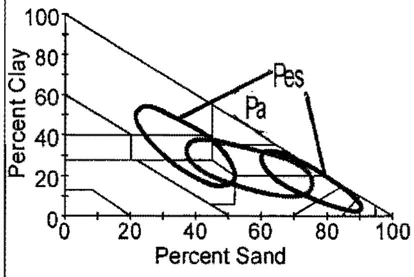
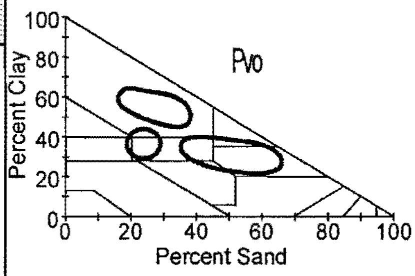
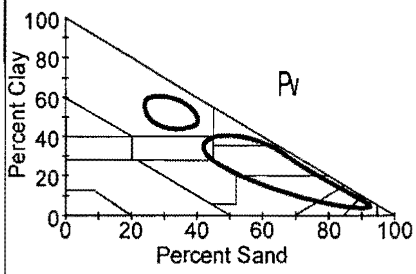
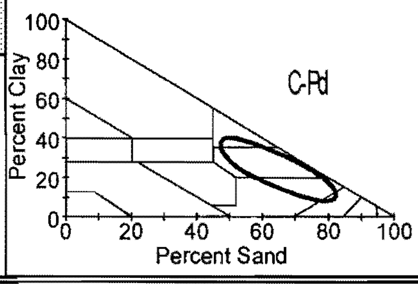
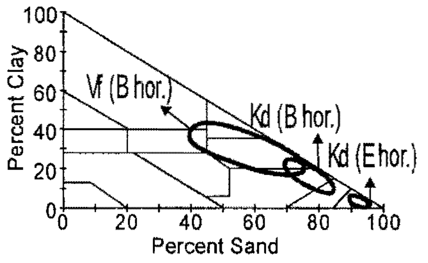
Sedimentary rocks	
Beaufort Group	
Adelaide Subgroup Pa (mudstone, shale) * Avalon (and Glencoe) profiles are represented in the sandy loam textural class. A single profile is from the clay loam textural class. Observations are made from a limited sample size. Estcourt Formation Pes (shale, sandstone) * Two natural soil bodies for Avalon and Glencoe soils. * Profiles are dominantly in the loam to clay loam classes. Profiles have intermediate clay contents (17 to 50%) and high silt values (20 to 35%). Textures for Avalon and Glencoe are displaced to the loam class. (Cv, Gf, Hu located in clay to clay loam) * Profiles are also located in sandy clay loam class but with low (<15%) silt. (Similar textured profiles in Cv, Gf, Hu soils). * Fine sand dominant throughout. * Profiles essentially non-luvic.	
Ecca Group	
Volksrust Formation Pvo (mudstone, shale) * Three natural bodies can be visually identified. Dominant features of each are the (1) clay, (2) sandy clay class and (3) clay loam texture classes. * Largest sample size from sandy clay loam class, with intermediate silt values (20%) and fine sand dominant. * Individual profiles with clay loam textural class (mean clay 35%, silt 40%). Vryheid Formation Pv (sandstone, shale) * Two natural bodies ranging in sand through to sandy clay loam, and in the clay textural classes respectively. Characteristic textural range is also expressed in other Pv derived soils. * Characteristic silt values of <20%, with fine and medium sands. * Soils extensively sampled that textural distribution can be described with confidence.	
Dwyka Formation C-Pd (tillite)	
* Avalon and Glencoe soils are represented in only one natural soil body, the sandy loam to sandy clay loam textural class. Av, Gc soils seldom occur on tillite.	

Table 3.6 Summary of textural properties of soils with an Eluvial (E) horizon.

Sedimentary and Igneous rocks

Quaternary Sand Formations Qb

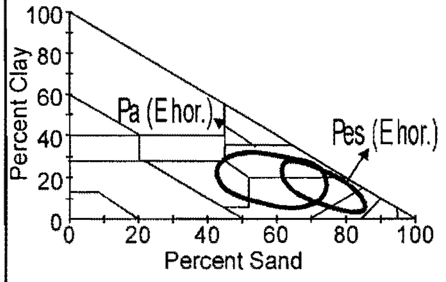
* Single natural body in each soil form (Fw, Ch, Vf, Kd) with regard to the E horizon. B1 horizons (where present) may have limited to larger clay accumulation.
* Sand and loamy sand textures in E horizons. Medium and fine sand. Silt values are less than 8%.
* Kroonstad (Kd) soils, profiles with limited clay increase in B1 horizons,
Vilafontes (Vf) soils, profiles with both limited and larger clay increases in B1 horizons.

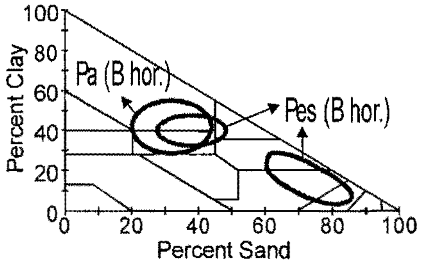


Beaufort Group

Tarkastad Formation, TRt (sandstone, mudstone)
Data not shown in graph on right of page
* Apparently two natural soil bodies (limited data), with textures located in the loam, and in sandy loam classes.
* Fine sand grades.

Adelaide Subgroup Pa (mudstone, sandstone)
* Apparently single natural soil body for soils with an E horizon (Lo, Es) (Limited data with poor clustering.)
* Profiles with textures in sandy loam to sandy clay loam classes.
* Fine and medium sand grades.
* Longlands (Lo) soils, profiles with limited clay increase in B1 horizons.
* Estcourt (Es) soils, profiles with larger clay increases in B1 horizons.





Estcourt Formation Pes (shale, sandstone)
* Two indistinctly defined natural soil bodies in E horizon soils (Lo, Wa, Es, Kd).
* Sandy clay loam textures (A1 and E1) horizons with clay textures (B1 horizons) in Longlands and Estcourt soils. Intermediate silt contents (15 - 30%).
* Loamy sand texture (A1 and E1 horizons) in Longlands soils with low silt contents (<15%).
* Individual profiles in loam textures (A1 and E1 horizons) with high silt contents (>30%) only sampled in Estcourt soils.

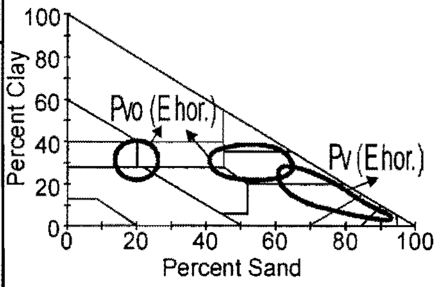
Table 3.6 (continued). Summary of textural properties of soils with an Eluvial (E) horizon.

Sedimentary and Igneous rocks

Ecca Group

Volksrust Formation Pvo (mudstone, shale)

* Two natural soil bodies are represented in soils with an E horizon. A dominant feature is loam texture class.
* Longlands and Estcourt soils are represented in loam and in the sandy clay loam textural classes.
* Fine and coarse sand dominant.

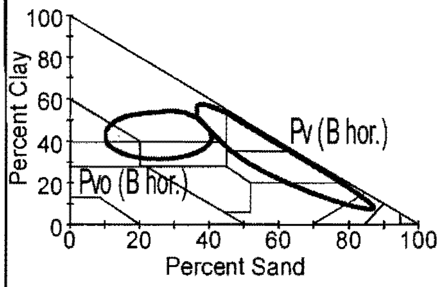


Vryheid Formation Pv (sandstone, shale)

* Longlands and Cartref profiles are represented in only sandy loam textural class.
* Fine and medium sand grades dominant.

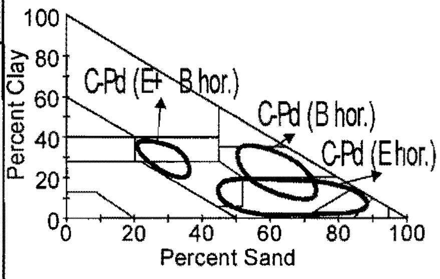
Pietermaritzburg Formation Pp (shale)

* Longlands and Estcourt soils (A1 and E1 horizons) have clay loam textural classes. (Observations are made from a limited sample size.)



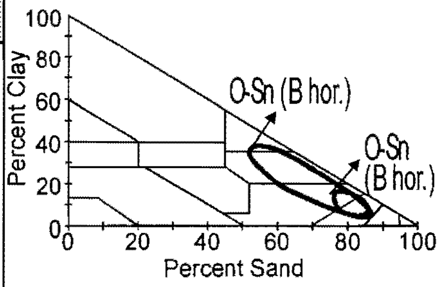
Dwyka Formation C-Pd (tillite)

* Three natural soil bodies can be distinguished. A dominant feature is the sandy loam texture class (A1 and E1 horizons). Individual profiles were sampled in the loam, and clay loam classes. Textures of B1 horizons are similar to those of A1 and E1 horizons.
* Estcourt soils of similar texture represented only in the sandy loam class.
* Fine, medium and coarse sand grades sampled.



Natal Group O-Sn (sandstone)

* Single natural soil body. A dominant feature is the sand to loamy sand texture class (A1 and E1 horizons). Profiles of the Cartref and Kroonstad soil forms. Textural class is much sandier than apedal soils on Natal Group sandstone.
* Dominantly medium sand grades, with profiles of fine and coarse sands.



Granite of the Piet Retief District Z-Rg.

* Longlands and Estcourt soils (A1 and E1 horizons) have clay loam textural classes. (Observations are made from a limited sample size.)

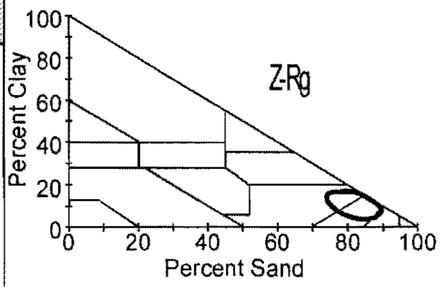


Table 3.7 Summary of textural properties of Swartland, Valsrivier, Estcourt and Kroonstad soils.

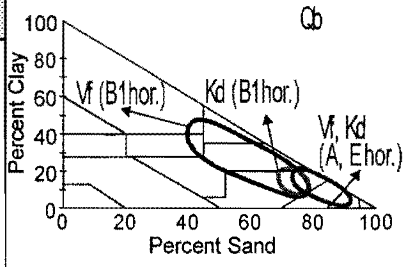
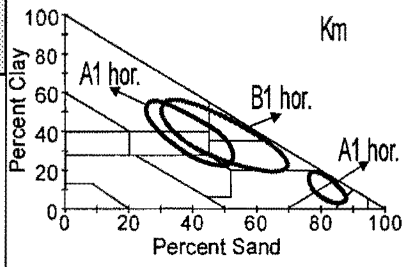
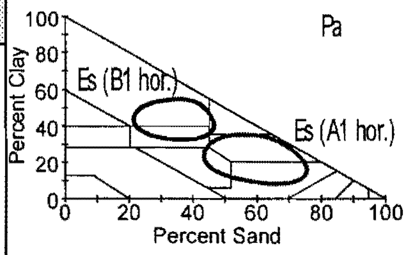
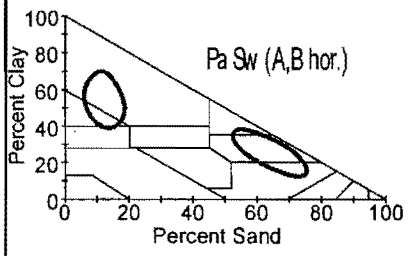
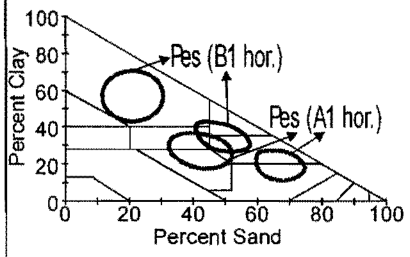
Igneous and Sedimentary rocks	
Quaternary Sand Formations Qb of the KwaZulu-Natal Coastal Plain * Single natural body. Vilafontes(#) and Kroonstad Soils. Medium and find sand to loamy sand in A1 and E1 horizons. Vilafontes have a larger clay texture increase to B1 horizon spread over sandy loam through to clay loam. Kroonstad has smaller clay texture increase in the B1 horizon limited to sand and sandy loam classes (Determined from a limited sample size). Note (#): Vilafontes not generally regarded as a duplex soil.	
Cretaceous Sediment Formations Km (siltstone) of the KwaZulu-Natal Coastal Plain * Single natural body. Valsrivier and Sterkspruit soils. Textures in the sandy clay loam through clay loam and sandy clay to clay classes. Clusters show little difference between A1 and B1 horizons, but with clay increases in the B1 horizons of between 1.3 and 2.1 times that of the A1 horizons.	
Beaufort Group Tarkastad Formation TRt (sandstone, mudstone) * Estcourt Soils. Samples are from a single natural body. Sandy loam over clay textures (limited data). Fine sand dominant. (Note: Data not shown in figures on opposite column) Adelaide Formation Pa (mudstone, sandstone) * Estcourt soils: Profiles from a single natural body for Estcourt soils. Textures clustered in the sandy loam to sandy clay loam classes (A1 and E1 horizons), and in the clay class (B1 horizons). (Clay percentage of these B1 horizons tend to be lower than those of the clay texture group of the Swartland, Clovelly and Hutton soils suggesting association with the sandy loam group rather than the clay texture group.) * Swartland soils: Two natural soil bodies for the Swartland soils. Textures clearly clustered in the sandy clay loam and the clay classes respectively (both A1 and B1 horizons). Estcourt Formation Pes (shale, sandstone) * Estcourt soils. Two indistinct natural bodies have been distinguished on basis of higher and lower silt values. Textures lie in the sandy clay loam through to clay loam classes (A1 and E1 horizons), and in the clay class (B1 horizons). B1 horizon clay percentages appear to be higher than those of the Estcourt soils of the Adelaide Formation.	  

Table 3.7 (continued). Summary of textural properties of Swartland, Valsrivier, Estcourt and Kroonstad soils.

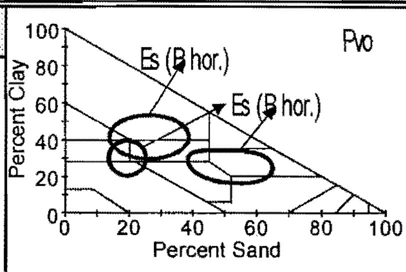
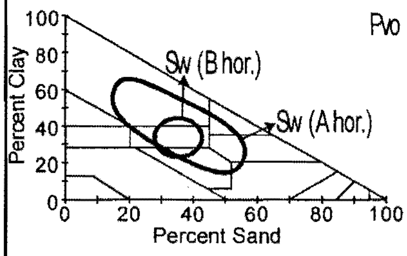
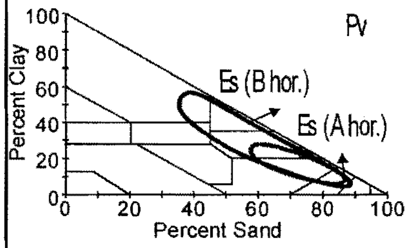
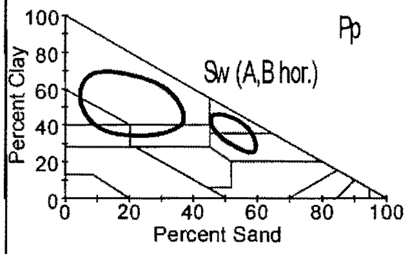
Ecca Group	
Volksrust Formation Pvo (mudstone, shale) * Estcourt soils. Two indistinct natural soil bodies have been recognised based on higher and lower silt contents. Textures are spread about the sandy loam to sandy clay loam classes, and in the (unusual) clay loam class respectively (A1 and E1 horizons). Textures for the B1 horizons are in the clay loam, silty clay and clay classes and are poorly distinguished between the natural soil bodies. * Swartland soils: A single natural body has been recognised. Textures range from loam to clay loam, and from sandy clay loam and loam to clay for the A1 and B1 horizons respectively.	 
Vryheid Formation Pv (sandstone, shale) * Estcourt and Sterkspruit soils. Textures characteristically range form sand to sandy loam, with individual profiles of sandy clay loam texture (A1 and E1 horizons). Silt values are <15%. Textures of the B1 horizon are noticeably displaced to the sandy clay loam through the sandy clay to clay classes. * There were no profiles of the clay textural class as determined from A1 and E1 horizons.	
Pietermaritzburg Formation Pp (shale) * Swartland soils. Two natural soil bodies were determined in the sandy clay, and in the clay to silty clay classes respectively (A1 and B1 horizons). Clusters show little differences between A1 and B1 horizons, but with clay increases in the B1 horizons of between 1.3 and 1.9 times that of the A1 horizons.	

Table 3.7 (continued). Summary of textural properties of Swartland, Valsrivier, Estcourt and Kroonstad soils.

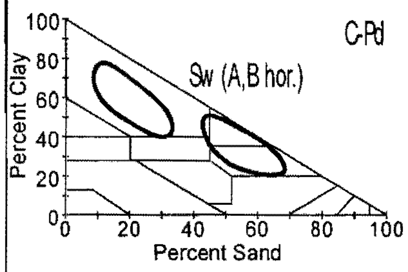
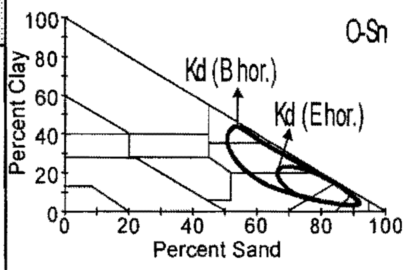
<table>
<tr><td>Dwyka Formation C-Pd (tillite)</td><td rowspan="2">
</td></tr>
<tr><td>* Swartland soils. Show similarities to Swartland soils of the Pietermaritzburg Formation. Two natural soil bodies were determined in the sandy clay loam, and in the clay classes respectively (A1 and B1 horizons). Clusters show little differences between A1 and B1 horizons, but with clay increases in the B1 horizons of between 1.0 and 3.9 times that of the A1 horizons.
* Estcourt soils. Profiles from a single natural body were sampled. Textures range from sand to sandy clay loam, but located dominantly in the sandy loam class (A1 and E1 horizons). Textures of the B1 horizon range from sandy loam to clay, but are dominantly within the sandy clay loam class. Textures of the respective horizons show similarities to those of the Longlands and Glenrosa soils.</td></tr>
<tr><td>Natal Group O-Sn (sandstone)</td><td rowspan="2">
</td></tr>
<tr><td>* Kroonstad soils. Textures are sand (A1 and E1 horizons) over sandy clay loam (B1 horizons). Show similarities to equivalent soils of the Vryheid Formation.</td></tr>
<tr><td>Granite of the Piet Retief District Z-Rg.</td><td rowspan="2"></td></tr>
<tr><td>* Longlands and Estcourt soils (A1 and E1 horizons) have clay loam textural classes. (Observations are made from a limited sample size.)</td></tr>
</table>

Table 3.8 . Summary of textural properties of Shortlands (red clay soils), Arcadia and Rensburg (vertic black clay soils), and Mayo, Milkwood and Bonheim (melanic black clay soils).

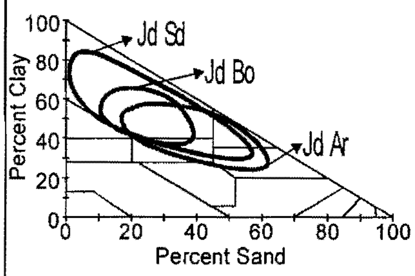
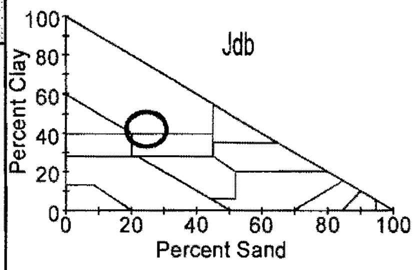
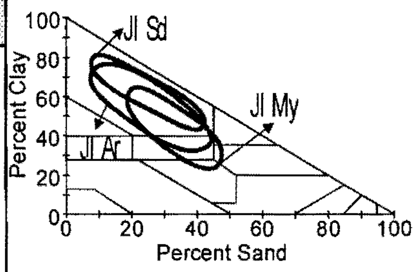
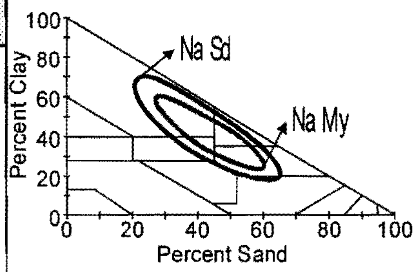
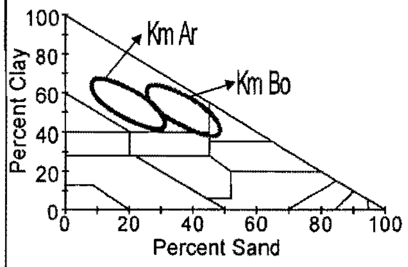
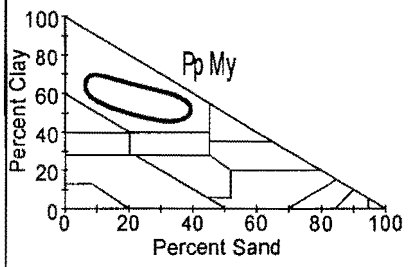
<table>
<tr><th colspan="2">Igneous and Sedimentary rocks</th></tr>
<tr><td>Igneous Rocks Karoo Dolerite Jd</td><td rowspan="2">
</td></tr>
<tr><td>Shortlands (red soils)
* Clay class (spread over whole class), extends into sandy clay class.
* Silt value range (10 - 40%).
* Dominantly (75%) non-luvic profiles.
* Soils have been extensively sampled.
Arcadia (vertic soils)
* Clay class, located in the central portion only with limited sampling.
Mayo and Bonheim (melanic soils)
* Greater scatter within clay and sandy clay classes. B1 horizons of Bonheim are located essentially within the clay class.</td></tr>
<tr><td>Drakensberg Formation Jdb (basalt)</td><td rowspan="2">
</td></tr>
<tr><td>Mayo and Milkwood (melanic soils)
* Clay loam A1 horizons from limited sampling.</td></tr>
<tr><td>Letaba Formation Jl (basalt)</td><td rowspan="2">
</td></tr>
<tr><td>Shortlands (red soils)
* Clay class, located within the central portion only with limited sampling. Silt values were relatively constant.
Arcadia soils (vertic soils)
* Clay class.
Mayo and Bonheim (melanic soils)
* Textures are displaced to the clay and clay loam classes.</td></tr>
<tr><td>Amphibolite of the Tugela Group and Mapumulo Metamorphic Suite Na</td><td rowspan="2">
</td></tr>
<tr><td>Shortlands (red soils)
* A1 horizons spread over sandy clay loam to clay, with B1 horizons dominantly in clay class.
Mayo (melanic soils)
* Spread over sandy clay loam to clay.</td></tr>
</table>

Table 3.8 continued. Summary of textural properties of Shortlands (red clay soils), Arcadia and Rensburg (vertic black clay soils), and Mayo, Milkwood and Bonheim (melanic black clay soils).

Igneous and Sedimentary rocks	
Sedimentary Rocks Cretaceous Sediment Formations of the KwaZulu-Natal Coastal Plain Km (siltstone)	
Shortlands (red soils) * Inconclusive information of calcareous sandy clay Shortlands soils formed over Cretaceous Sediments. Arcadia and Rensburg (vertic soils) * Calcareous clay textural class formed in bottomland topographical positions. Bonheim (melanic soils) * Sandy clay to clay textural classes and of similar morphology and properties to the dominant Valsrivier soils of Cretaceous Sediments.	
Ecca Group	
Pietermaritzburg Formation Pp (shale) Shortlands (red soils) * Clay class. The group is difficult to distinguish from Shortlands soils formed from dolerite and should be considered as one natural body. Rensburg (vertic soils) * Clay class, limited profiles. Mayo (melanic soils) * Two indistinct natural bodies are visually observed, both within the clay textural class, with higher and lower silt values. * Mayo soil textures correspond closely with those of the apedal soils derived from Pp shale.	

CHAPTER 4

SOILS OF THE QUATERNARY GEOLOGY FORMATIONS IN THE KWAZULU-NATAL COASTAL BELT

Location and Extent

The Quaternary geological formations cover some 605 200 hectares and are located mainly in the north of KwaZulu-Natal. Their location stretches from the border with Mozambique in the north, and the Pongola River in the north west, to the east coast covering a broad and nearly level sandy plain of some 70 kilometres in extent. The plain ends on the coast in a high coastal dune. This dune is most prominent in the north, but flattens somewhat in places south of the Tugela River. This belt narrows southwards to be approximately 30 kilometres wide at Lake St Lucia. South of Richards Bay and the Mlalazi River, and stretching southwards to the KwaZulu-Natal southern border, the belt of Quaternary sands narrows to between three and 6 kilometres wide (Geological Survey, 1984). Here in the south, the Quaternary geological formations also rest on rocks of the basement granites and of the Karoo System (Geological Survey, 1988c, 1988d). In the south erosion by numerous rivers and streams where they enter the sea, have left many isolated dune remnants (Geological Survey, 1988c, 1988d). The location of Quaternary geology formations is illustrated in Figure 4.1.

Geology and Geomorphology (Geology Symbol Abbreviation **Qb**)

The Quaternary geology comprises a number of geological formations and units from which soil profiles have been located and sampled. In addition to the Blown Sand (Qbsa) and Yellowish Redistributed Sands (Qs) which cover extensive areas of the northern KwaZulu-Natal coastal plain are the Berea and Muzi Formations. The products of soil formation on these parent materials are similar. The soil profiles located on these geological formations have thus been grouped together. For reference purposes the discussion of soils of the Quaternary Formations and associated geological materials have been prefixed by the letters Qb.

The blown sand and yellowish redistributed sand units are located largely between the Pongola River and the coastal dune and stretch southwards to Richards Bay. The Berea Formation (Qb) is located as the dune ridges stretching virtually continuously from Kosi Bay to the southern KwaZulu-Natal border. It also forms a number of less prominent ridges west of Lake Kosi, Lake Sibayi and Lake St. Lucia, and further inland west of the Muzi Drainage Line and False Bay (Geological Survey, 1985a, b). It comprises red dune cordon sand (South African Committee for Stratigraphy (SACS), 1980) which has undergone weathering and decalcification (Beater, 1970). In northern KwaZulu-Natal five cordons have been traced, while in the southern region it appears that the cordons overlie each other (SACS, 1980). The red sands have been reworked into thin discontinuous beds of white, pink and brown sands. Gravel beds and stones lie on occasions at the base of the sands of the Berea Formation. These flattened stone beds are said to represent wave cut platforms and are evident at a number of locations along the coast, including those at the Mgeni River mouth. These wave cut platforms are indications of changes in sea level that took place during the Quaternary Period (Maud, 1968).

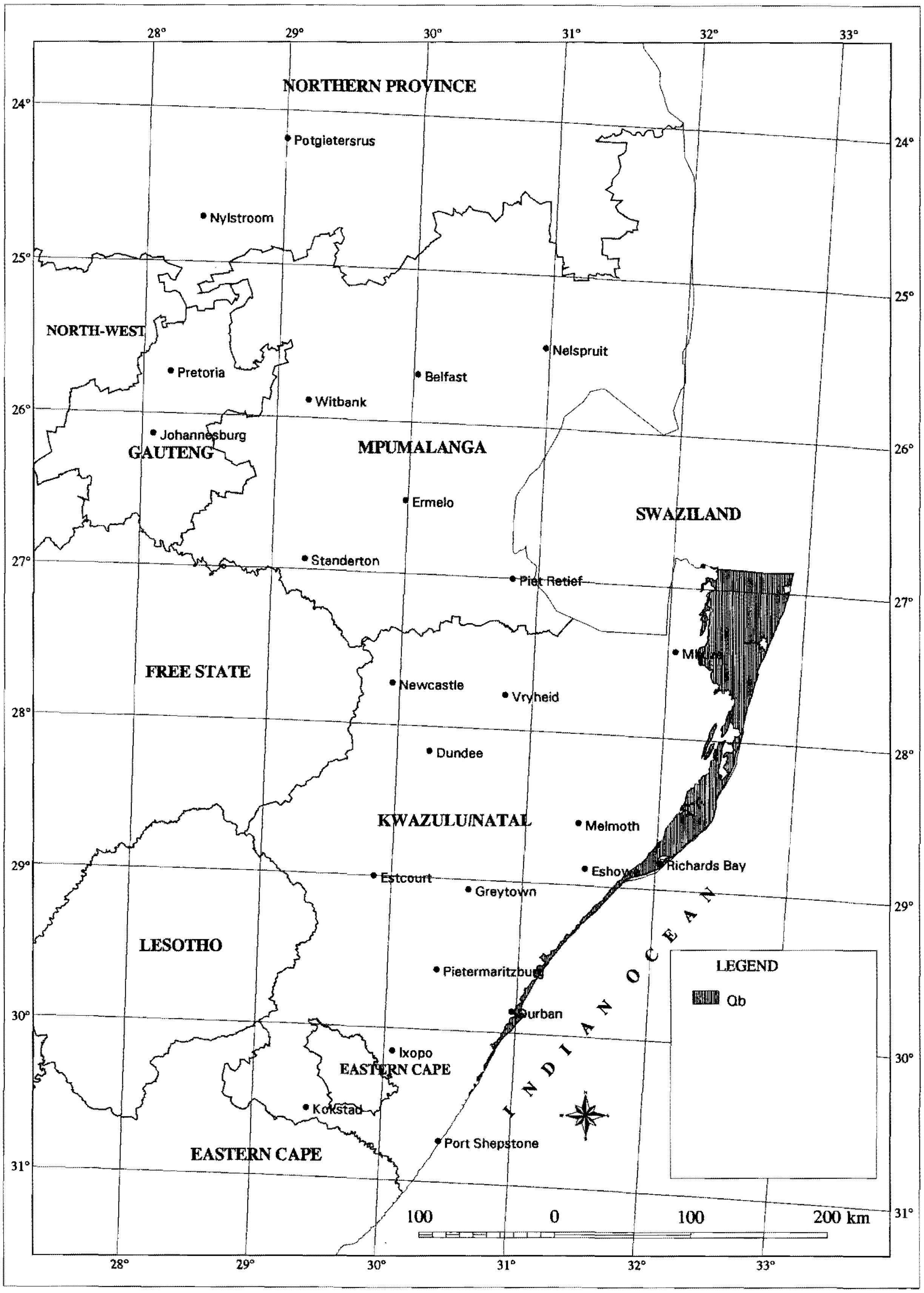


Figure 4.1. Location of Quaternary geology formations in the coast belt of KwaZulu-Natal (after Geological Survey, 1984).

The Muzi Formation (Qm) is described as comprising of argillaceous sand (Geological Survey, 1985a, 1985b) and by the SACS (1980) as mottled, brown clayey sand. It is probably no more than 50 m thick, and older in the stratigraphy than the Berea Formation. The Muzi Formation is exposed in a belt eight to 16 km wide, stretching from west of Lake St. Lucia northwards to the Pongola River floodplain. It is generally bounded in the west by Cretaceous Sediments of the Mzinene Formation (Geological Survey, 1985a, 1985b).

Partridge and Maud (1987) described the principle cyclic land surfaces of southern Africa. They describe the northern coastal plain as of Neogene marine and coastal aeolian sediments. In the southern portion dissected areas of various ages are present.

Physiography and Drainage Features

The terrain morphology of the northern region is a level plain of low relief (Kruger, 1983; ISSS-ISRIC-FAO, 1993). Slopes are flat (0-2%) to gently undulating (2-5%). Drainage density is low (Kruger, 1983). The coastal dune has however, rolling to moderately steep slopes (ISSS- ISRIC-FAO, 1993) of 8-30% (Land Type Survey Staff, 1986a). South of the Tugela River and stretching to the southern KwaZulu-Natal border the terrain morphology is rolling to moderately steep land with slopes of eight to 30% (Land Type Survey Staff, 1994a, 1994b).

With the high water permeability of these sand materials major rivers and drainage features are generally absent. In the northern coastal belt numerous fresh water lakes, pans and marshes are present. The northern central zone is drained through the Muzi drainage line and the slowly flowing reaches of the Mkuze River. In the south the Quaternary Sediments are crossed by the major rivers before flowing into the sea. Lagoons are commonly present at the river mouths.

Vegetation

The coastal belt is of the Savannah Biome and comprises of Coastal Bushveld/Grassveld (Low and Rebelo, 1996). West of the Pongola River floodplain is an area of Subhumid Lowveld Bushveld. Isolated occurrences of Sand Forest of the Forest Biome are scattered throughout the area.

Soils

A number of major soil patterns are evident on the Quaternary Sediments of the KwaZulu-Natal Coastal Belt with varying proportions of red, yellow-brown and grey sands (Table 4.1). Grey sands with marked accumulation of organic matter are present to varying degrees in the wet depression topography. Alluvium and marshes are located in the flood plains of the rivers (Land Type Survey Staff, 1986a, 1987c, 1994a, 1994b).

Table 4.1 Dominant soils and selected climatic information for soil patterns occurring on Quaternary Sediments within the KwaZulu-Natal Coastal Belt.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rainfall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red Apedal Sandy Soils (Coast Dune Ridges)										
Hutton	Hu24 Hu34	69	Clovelly	Cv24	6	Ave	1146	1603	4246	0.71
	Hu23		Fernwood	Fw11	6	Std	127	124	36	0.03
Hutton	Hu26 Hu36	9				Max	1323	1807	4309	0.73
Hutton	Hu11 Hu14	2				Min	964	1470	4223	0.66
Total Area: 11 740 Ha			Means of 12 Land Types							
Broad Soil Pattern: Red and Yellow Apedal Sandy Soils (Interior Dune Ridges)										
Hutton	Hu34 Hu24	19	Fernwood	Fw11	24	Ave	681	1688	4526	0.40
Hutton	Hu31 Hu21	16				Std	26	408	106	0.21
Clovelly	Cv31 Cv30	26				Max	703	1975	4646	0.90
Clovelly	Cv21 Cv24	5				Min	618	680	4409	0.31
	Cv34									
Total Area: 39 330 Ha			Means of 10 Land Types							
Broad Soil Pattern: Grey Sands (Coastal Plain)										
Fernwood	Fw11 Fw10	85	Clovelly	Cv31	9	Ave	837	1562	4434	0.53
Fernwood	Fw31	9				Std	125	379	91	0.19
						Max	1148	1966	4646	0.90
						Min	674	680	4223	0.35
Total Area: 381 300 Ha			Means of 52 Land Types							
Broad Soil Pattern: Grey Sands (Coastal Plain Depression Topography)										
Fernwood	Fw31	27	Champagne	Ch10	12	Ave	855	1405	4428	0.60
Fernwood	Fw11	39	Kroonstad	Kd11	3	Std	116	472	113	0.20
			Longlands	Lo20	3	Max	964	1838	4582	0.90
						Min	674	680	4227	0.49
Total Area: 55 890 Ha			Means of 8 Land Types							
Broad Soil Pattern: Grey and Yellow Sandy Soils (Coastal Dune Ridge, Northern KwaZulu-Natal)										
Fernwood	Fw11 Fw10	61				Ave				
Clovelly	Cv21 Cv31	34				Std				
						Max				
						Min				
Total Area: 33 890 Ha			Means of 5 Land Types							
Broad Soil Pattern: Grey and Red Sandy Soils (Coastal Dune Ridge, Southern KwaZulu-Natal)										
Vilafontes	Vf20 Vf21	27	Glenrosa	Gs16 Gs17	13	Ave	1037	1459	4328	0.71
Shepstone	Sp21	21				Std	169	222	126	0.01
Fernwood	Fw11 Fw10	9				Max	1330	1845	4401	0.72
Hutton	Hu20 Hu21	13				Min	939	1330	4108	0.71
	Hu30									
Total Area: 13 020 Ha			Means of 2 Land Types							

Table 4.1 continued. Dominant soils and selected climatic information for Soils Patterns occurring on Quaternary Sediments within the KwaZulu-Natal Coastal Belt.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rainfall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Soils on River Alluvium										
Rensburg	Rg10 Rg20	26				Ave	778	1451	4463	0.54
Bonheim	Bo31 Bo41	5				Std	130	499	78	0.25
Dundee	Du10	16				Max	939	1975	4582	0.99
Valsrivier	Va31 Va41	9				Min	618	680	4401	0.31
Total Area: 39 870 Ha			Means of 7 Land Types							

Dystrophic and mesotrophic sandy red apedal soils are dominant on the coastal dune ridges, the high rainfall giving rise to appreciable leaching of the original calcarenite material. Slopes tend to be steeper, giving rise to dominantly red freely drained soils. The interior dune ridges north of the Mfolozi River are commonly less steep than those of the coastal belt and have a greater proportion of yellow-brown soils on the lower midslopes and grey soils in the bottomlands. The red soils are located dominantly on the crests. Leaching is less intense and eutrophic base status is present. The higher base status is also evident in the CEC values and the mineralogy. The coastal dune ridges of Northern KwaZulu-Natal have dominantly grey and yellow sands. An interesting soil pattern is present on the coastal dune ridges of Southern KwaZulu-Natal. Vilafontes (and Shepstone) form soils are dominant with a grey sand to loamy sand overlying red and yellow mottled sandy clay subsoil.

Grey Fernwood sands are dominant on the flat slopes of the coastal plain. These deep, medium and fine grade sands show minimal profile development. There is often only limited accumulation of organic matter in the surface horizon. Thin, fine lamella may be present in some profiles (van Reeuwijk, 1967), while in certain profiles there may also be evidence of slight colour variations, mottling and eluvial clay loss. The presence of slowly permeable soil horizons may be present at depth in some profiles giving rise to the accumulation of water in these grey sands.

In the depression topography the water table rises to near the surface. Marshes are present in many bottomlands. Accumulation of organic matter to elevated levels takes place. Soils of the Champagne and Fernwood forms are present. In these bottomland positions a slowly permeable horizon of pedological or geological origin is assumed to be present, giving rise to the accumulation of water in bottomlands and marshes. With the accumulation of water tables within the profiles, anaerobic conditions in the surface horizons develop. There is commonly an accumulation of organic matter in the A horizons of these bottomland soils. It is likely that there is a wide range of expression of this soil feature from limited accumulation of organic matter, through to those horizons with marked darkening and appreciable organic matter accumulation.

This soil feature has been recognised in soil classification within the Fernwood Soil Form as the soil families with "Dark coloured A horizon", (four families) and within the Champagne Soil Form where accumulation of organic matter has proceeded to the extent than an organic horizon is recognised. It is conceivable that additional classes may be required, particularly at the lower levels of organic matter accumulation. These soils are reflected in Table 4.1 as soil units Fw31 and as Ch10 (Soil Classification Working Group, 1991).

Each of the above soil patterns is dominated by sandy materials within the coastal plain and dune ridges. However, there are zones where the deposition of alluvium has taken place. Examples are in the lower reaches of the Mkuze River, before it enters Lake St. Lucia, and in the Mfolozi River mouth. The grades of these two rivers at their mouths are so low that largely fine materials are likely to be deposited. Alluvium is likely to be present in most of the river mouths and lagoons of the coastal belt.

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Clovelly, Fernwood, Kroonstad and Vilafontes Forms were extracted from the database. Their ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on their luvic properties are presented in Table 4.2.

Table 4.2 Textural properties of soils of the Quaternary geology derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1 B2	Sa-LmSa Sa-SaLm Sa-SaCl Lm	2-11 5-15 5-39	1-16 1-22 2-10	12-64 10-68 14-36	15-57 5-75 25-58	1-16 1-13 1-13	Fi,Me,	- NL3, L1, EL1 NL3,L2
Clovelly	A1 B1 B2	PuSa-Sa PuSa-Sa PuSa-Sa	2-9 2-9 2-9	1-4 1-4 1-4	15-76 19-81 35-54	9-63 10-62 32-39	1-15 1-16 1-26	Fi,Me	- NL3, EL2, L1 -
Fernwood Fernwood (w) Champagne	A1 E1	PuSa-Sa PuSa-Sa	2-8 1-7	1-10 1-7	17-66 38-77	25-68 15-56	1-15 1-14	Fi,Me	- NL3, EL1, L1 -
Kroonstad	A1 E1 E2 B1	PuSa-Sa PuSa-Sa PuSa-Sa LmSa-SaLm	3-11 3-12 1-4 10-21	2-6 2-6 6-9 1-6	44-78 26-73 65-82 38-66	12-51 16-58 11-20 15-49	1-5 1-16 1-3 1-13	Fi,Me	- L3, NL2 EL5 L5
Vilafontes	A1 E1 B1 C1	PuSa-Sa PuSa-SaLm Sa-SaCl SaClLm-SaCl	2-11 3-17 5-40 23-47	2-8 2-6 3-10 4-10	48-70 32-73 37-67 8-25	9-46 20-44 3-43 24-55	1-3 1-4 1-9 3-4	Fi,Me	NL3, L2 - L5

Luvic Properties: Explanation of symbols; L - Luvic, NL - Non-luvic, EL - Eluvic Properties. Numbers indicate relative dominance of property from occasionally (1) to dominantly(5).

These ranges are represented graphically in Figure 4.2. The figure allows for overview comparison between different soil forms and over particle size classes. It shows the sandy nature of these soils with the accumulation of clay only in the lower horizons of certain Hutton, in the Vilafontes and the Kroonstad Soil Forms. It further shows the dominance of medium and fine

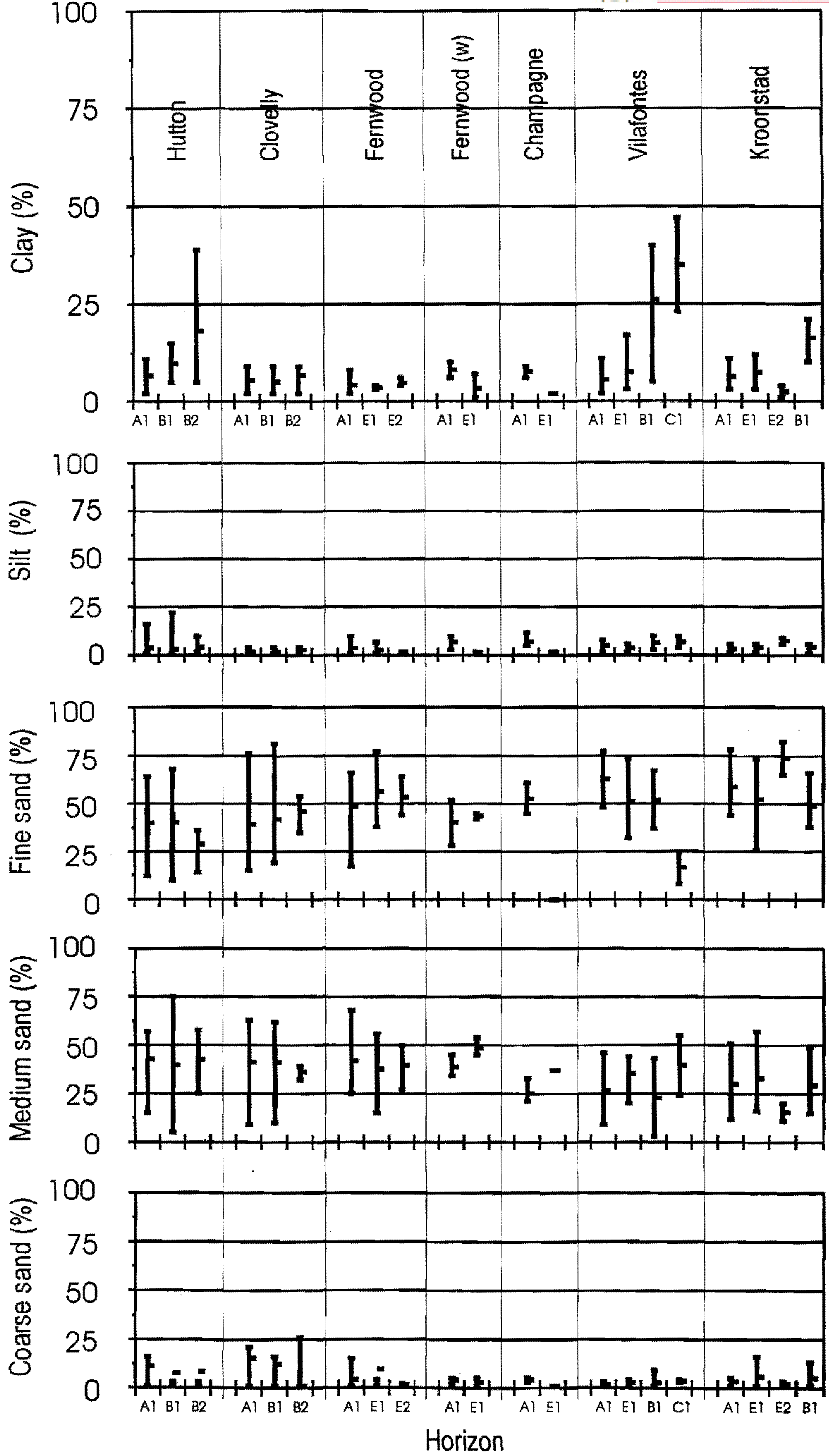


Figure 4.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Quaternary geology. Maximum, minimum and mean values are shown for each horizon.

sands, while the silt and coarse sand fractions have low proportions. A limited number of soil profiles (seven in number) have been located in the adjacent Cretaceous Sediments. Their soil form classification and range of properties are very similar to these profiles of the Quaternary Sediments. They have been included with those of the Quaternary soils. Since pockets of the sand mantle could well extend beyond the mapped boundaries of the Quaternary Sediments, their inclusion would seem reasonable.

Hutton Form

The textural properties of A1 and B1 horizons indicate a single cluster in the sand to loamy sand class. Limits to the clay ranges are between 2 and 11%, and between 5 and 15 % for the A and B horizons respectively (Figures 4.3 and 4.4). Medium and fine sands are dominant in all horizons (Figure 4.3). A single natural body based on texture is present.

There are narrow ranges in the variation in all 5 particle size classes. The particle size class distribution for the B1 horizon of the Hutton profiles is shown in Figure 4.4. Similar distributions with narrow ranges were determined for the other soils and horizons.

Data from 11 profiles was available to evaluate the trend in luvic properties (Figure 4.9). Soils with a red or yellow-brown apedal B horizon are classified to have luvic properties in this horizon when there is a defined absolute increase in clay, or when the ratio of clay in the surface to subsurface horizons exceeds a defined value.

Soils are considered to be luvic when:

> the clay content of the A or E horizons is less then 15%, then the B1 horizon must have an absolute increase in clay of 5%.

or

> the clay content of the A or E horizons is greater than 15%, the clay content of the B1 horizon must be at least 1.3 times greater than that of the A or E horizon (whichever is the greater) (Soil Classification Working Group, 1991).

All profiles had less than 15% clay in the A1 horizon. Only one profile had a clay increase of more than 5%, thus qualifying it for the luvic families. The remainder were classified into non-luvic families. Figure 4.9 shows the clay ratios of the B1 to A1 horizons in these sandy Hutton, Clovelly and Kroonstad soils. Small increases in clay are present in Hutton soils. Figure 4.9 thus considers only the second criterion, namely the ratio of clay in the lower to that of the upper horizon. The bar labelled 2.4 in the graph for Hutton soil represents the soil with a greater than 5% clay increase. In view of the sandy nature of these soils, non-luvic families would appear to dominate in the surface horizons. Two profiles had lower (or equal) clay in the B1 horizon (exhibiting eluvic properties) (Figure 4.9). Four profiles had a ratio of clay in the B1:A1 horizons of less than 1.3, while for five profiles this ratio exceeded 1.3 (Figure 4.9).

Non-luvic property extends to depths greater than a metre in many B2 horizons in these Hutton Form soils. However, clay contents in the B2 horizon (and deeper horizons) of greater than 25% were also noted. Recognition of the illuvic properties of these deeper horizons is important within the red Quaternary sands. This suggests that there is thus a relatively strong illuvial process operative within these profiles. Alternatively the higher clay contents of some B2 horizons may indicate multiple phases of soil formation. An extended period of weathering giving rise to these B2 horizons, followed by burial by fresh material could have taken place. The

Table 4.3 Means and standard deviations of five textural classes for soils of the Quaternary Sediments.

Hori zon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton (Non Luvic B2 horizons)												
A1	294	6.6	2.5	3.9	4.1	40.1	14.8	42.7	12.7	11.2	13.8	13
B1	804	9.7	4.6	3.2	4.4	4.8	15.9	39.8	15.4	7.5	11.5	23
B2	1200	12.0	15.5	52.3	4.4	26.3	8.8	6.0	4.0	8.0	2.1	3
Form: Hutton (Luvic B2 horizons)												
Refer to values for Hutton Form A1 and B1 horizons with non luvic character in B2 horizons												
B2	1200	33.5	5.5	2.5	0.5	32.5	3.5	27.5	2.5	3.0	0.0	2
Form: Clovelly												
A1	430	5.4	2.1	1.8	0.9	39.2	20.2	41.3	15.3	15.4	12.6	10
B1	937	5.1	2.2	1.8	0.9	41.8	17.7	41.0	14.8	12.3	12.2	13
B2	1240	6.7	3.3	3.0	1.0	46.0	8.0	36.3	3.1	10.3	11.2	3
Form: Fernwood												
A1	455	4.2	1.9	3.7	2.8	48.4	14.2	41.8	14.1	4.0	4.4	10
E1	930	3.5	0.5	2.7	2.0	56.1	11.2	37.5	10.6	9.4	16.6	8
E2	1073	4.7	0.9	1.7	0.5	53.3	8.2	39.3	9.5	1.5	0.5	3
Form: Fernwood (Dark coloured A horizon)												
A1	423	8.0	1.6	7.0	2.9	40.3	9.8	38.7	4.6	4.0	1.4	3
E1	950	3.3	2.6	1.7	0.5	43.7	1.3	48.7	3.9	3.0	1.6	3
Form: Champagne												
A1	317	7.7	1.3	7.3	3.3	52.7	6.5	25.3	5.4	4.0	1.0	3
C1	1100	2.0	-	2.0	-	58.0	-	37.0	-	1.0	-	1
Form: Vilafontes (Luvic B1 horizons)												
A1	506	5.5	3.1	5.0	1.9	62.5	10.8	26.6	13.4	1.5	0.7	8
E1	850	7.4	5.5	3.6	1.4	51.0	14.9	35.2	9.6	2.6	1.4	5
B1	1036	26.1	12.5	6.4	2.4	52.0	10.7	22.6	14.1	2.7	2.9	5
C1	1225	35.0	12.0	7.0	3.0	16.5	8.5	39.5	15.5	3.5	0.5	2
Form: Vilafontes (Non Luvic B1 horizons)												
Refer to values for Vilafontes Form A1 and E1 horizons with luvic character in B1 horizons												
B1	1036	9.0	4.0	3.0	1.0	61.5	0.5	17.0	7.0	1.0	0.0	2

Table 4.3 continued. Means and standard deviations of five textural classes for soils of the Quaternary Sediments.

Hori zon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Kroonstad												
A1	290	6.3	3.0	3.3	1.6	58.5	12.8	29.8	15.3	3.3	1.5	4
E1	840	7.3	3.3	4.0	1.6	52.5	17.3	32.3	17.3	5.5	6.1	4
E2	870	2.5	1.5	7.5	1.5	73.5	8.5	15.5	4.5	2.0	1.0	2
B1	1200	16.3	4.0	4.3	1.9	48.8	10.9	29.3	13.4	5.0	4.7	4

luvic properties are thus most apparent at greater depths.

Clovelly and Fernwood Forms

A sand textural class is present in the Clovelly (yellow-brown) and Fernwood (grey) soils (Figures 4.5 and 4.6), with similarities in their textural properties. These similarities extend to other properties as well. The range in clay contents is between 1 and 9 percent with no clay increase within the normal depth of the solum (Table 4.2). The range in textural properties is given in Table 4.2, while mean values appear in Table 4.3.

While the Hutton soils are located on the crest positions and where the slopes are generally steeper, the Clovelly soils are found in slope positions below the Hutton soils, or on the flatter slopes. Fernwood soils are located on the crest to bottomland positions, on flat to gently undulating slopes. Permeability of these soils is high, such that water would move freely through the profiles. Clay eluviation (loss) has taken place in soil groups. Clay values lower than those for the Hutton soils in A1, B1 and E1 horizons (Figures 4.5 and 4.6). Analyses indicate that the Clovelly soils are non-luvic and that clay increases at depth are absent. The latter is in contrast to the Hutton soils. There are similarities in the CBD-iron values of the Clovelly and Fernwood soils (Table 4.4), and this is probably reflected in similarities in their water regimes. CBD-iron values are about one third of those of the Hutton soils. There is a small increase in the CBD-iron in the B2 horizon of the Clovelly soils as opposed to the E2 horizon of the Fernwood soils (Table 4.4). This probably implies a slightly improved water drainage regime in the Clovelly soils. The CBD-iron of the sandy Champagne soils is even lower than those of the Fernwood and Clovelly soils (Table 4.4) and is probably indicative of longer periods of water saturation.

Medium and fine sands are present throughout (Figure 4.6).

Champagne Form and Fernwood Form :Family Dark Coloured A Horizon

Texture properties for these carbon rich soils are similar to those for the other Fernwood and Clovelly soils (Tables 4.2 and 4.3).

Table 4.4 Means of CBD-Iron values for soils of the Quaternary Sediments. Horizon notation is given.

Hutton		Clovelly		Fernwood		Champagne		Vilafontes		Kroonstad	
Horizon	%	Horizon	%	Horizon	%	Horizon	%	Horizon	%	Horizon	%
A1	1.0	A1	0.3	A1	0.3	O1	0.4	A1	0.6	A1	0.2
B1	1.9	B1	0.3	E1	0.2	E1	0.6	E1	0.6	E1	0.4
B2	2.6	B2	0.4	E2	0.3	-	-	B1	3.6	B1	0.6

Vilafontes Form

Soil profiles classified into the Vilafontes (Soil Classification Working Group, 1991) and former Shepstone Soil Forms (MacVicar *et al.*, 1977) have been included together in this section. Both soils have in common sandy orthic A and E horizons. However, the Shepstone Form soil profiles seldom exhibited colours sufficiently uniform to strictly qualify for the definition of the "Red Apedal" horizon. The third horizon of the Shepstone Form is now considered as a red coloured neocutanic B horizon and accommodated within the Vilafontes Soil Form at family level.

The texture properties of the A1 and E1 horizons of the Vilafontes are similar to the other soils formed from Quaternary Sediments with the textural classes as medium and fine grained sands and loamy sands (Table 4.2, Figure 4.7). However, the feature of the grey sands overlying a fairly uniform coloured red to yellow-brown sandy clay loam through sandy clay to clay loam is interesting. There are similarities in the texture of these Vilafontes soils to those of the Hutton Form with a luvic B2 horizon (Table 4.3). Bleaching, and loss of iron (Table 4.4) of the surface A and E horizons have occurred, while a degree of mottling and clay illuviation into the B and C horizons has taken place. Whilst the B1 horizon commonly has colour variations, even with gley colours, it commonly retains a fairly uniform red or brown colour.

In studying the morphology of the Vilafontes soils it would appear that the process of reduction and loss of iron from surface horizons is advanced to give rise to grey colours. However, it would appear incomplete, because remnants of the red colours remain within the horizon. Further, the profiles have a red luvic B horizon being classified to the Vilafontes form (Vf2220 Jongensfontein family). The implication of classification to this family is that a somewhat improved drainage over the corresponding family with grey coloured E horizons is postulated. Profiles with colours of the E horizon that are grey when moist, and overlying luvic, non-red horizons have also been recorded (Land Type Survey Staff, 1994b).

A dominant feature of the B horizons of profiles in this sample collection is the strong clay illuviation (Table 4.3). The ratio of clay in the A/E horizons to that of the B horizons indicates a 2 to 12 times increase. These profiles are classified within the luvic family. Only one profile has non-luvic properties, while a further profile has a clay increase from 3 to 13 percent. This latter profile would formerly have been classified to the Shepstone tergniet (Sp10) or non-luvic class (MacVicar *et al.*, 1977). The luvic classes appear to be dominant, while non-luvic classes have also been recorded.

The classic concept for the genesis of an Eluvial horizon, incorporating bleaching and loss of iron and clay is evident in two of the four Vilafontes profiles. In a further two profiles clay increases of the order of two (2) times that of the A1 horizon was recorded. Individual profile values are not quoted here, but are to some extent shown in the higher standard deviation for clay in the E horizon (S.D. = 5.5%) (Table 4.3). The remnants of red sand within the grey E horizons and the incomplete loss of clay from the E horizon would point to the relatively young nature of these soils. In southern KwaZulu-Natal it is reported that successive dune cordons of the Berea Formation overlie each other (SACS, 1980). Weathering and clay formation of successive dune cordons may provide an explanation for the sandy clay loam properties of the B and C horizons and hence the luvic nature of these Vilafontes soils.

Kroonstad Form

There are relatively few profiles of the Kroonstad Form within the database. Reference to two Kroonstad profiles described and sampled from this area has been made by MacVicar, Loxton and Van Der Eyk, 1965a, 1965b). The soils are located in the lower slope positions, but appear to be associated with those sites where the sand mantle overburden over the Cretaceous Sediments becomes thinner. The samples in this data set have these characteristics. The pedogenesis giving rise to the slowly permeable gleyed horizons is not well documented and profiles of the Kroonstad Form in other localities should be expected.

The texture properties of the surface A1 and E1 horizons of the Vilafontes (B horizons have non-red colours) are similar to the other soils formed from Quaternary Sediments with the textural classes as medium and fine grained sands and loamy sands (Table 4.2, Figure 4.8). The A1 and E1 horizons have similar textural properties. Profile descriptions give darker colours for the A1 horizons (Land Type Survey Staff, 1986a, 1988b) and a small increases in organic carbon levels. The CBD-iron values are similar through the A1, E1 to E2 horizons (Table 4.4). In the E2 horizons of two Kroonstad profiles there are lighter colours and loss of clay relative to the overlying A1 ad E1 horizons. There are also lower CBD-iron values indicating longer periods of water saturation relative to the overlying horizons despite the grey E horizon colours. Further, despite the relatively low clay content of the B1 horizon (clay = 16.3%; Table 4.3); a water impermeable horizon must be inferred. This contrasts with the Vilafontes soils, that despite the higher clay content and red colours, the horizon must remain relatively permeable.

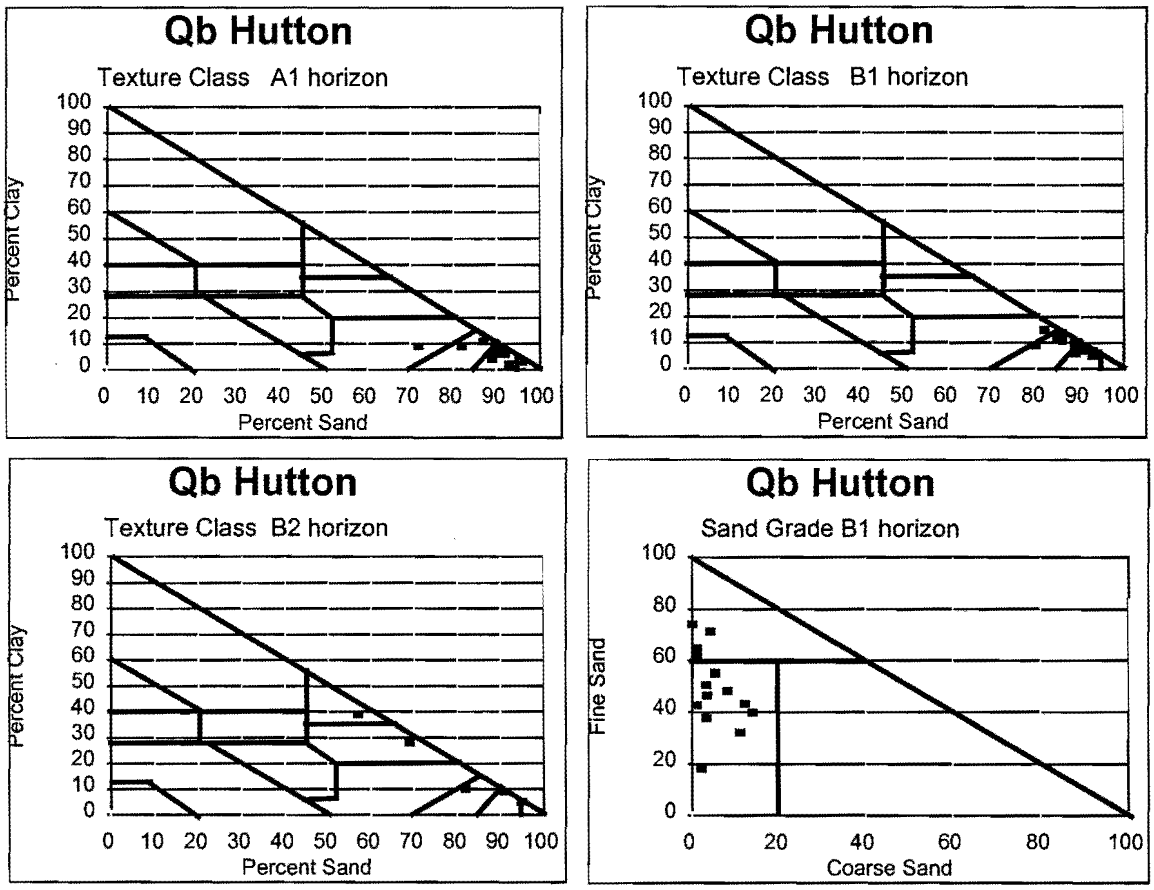


Figure 4.3 Distribution of soil textures, and sand grades, within soils of the Hutton Form.

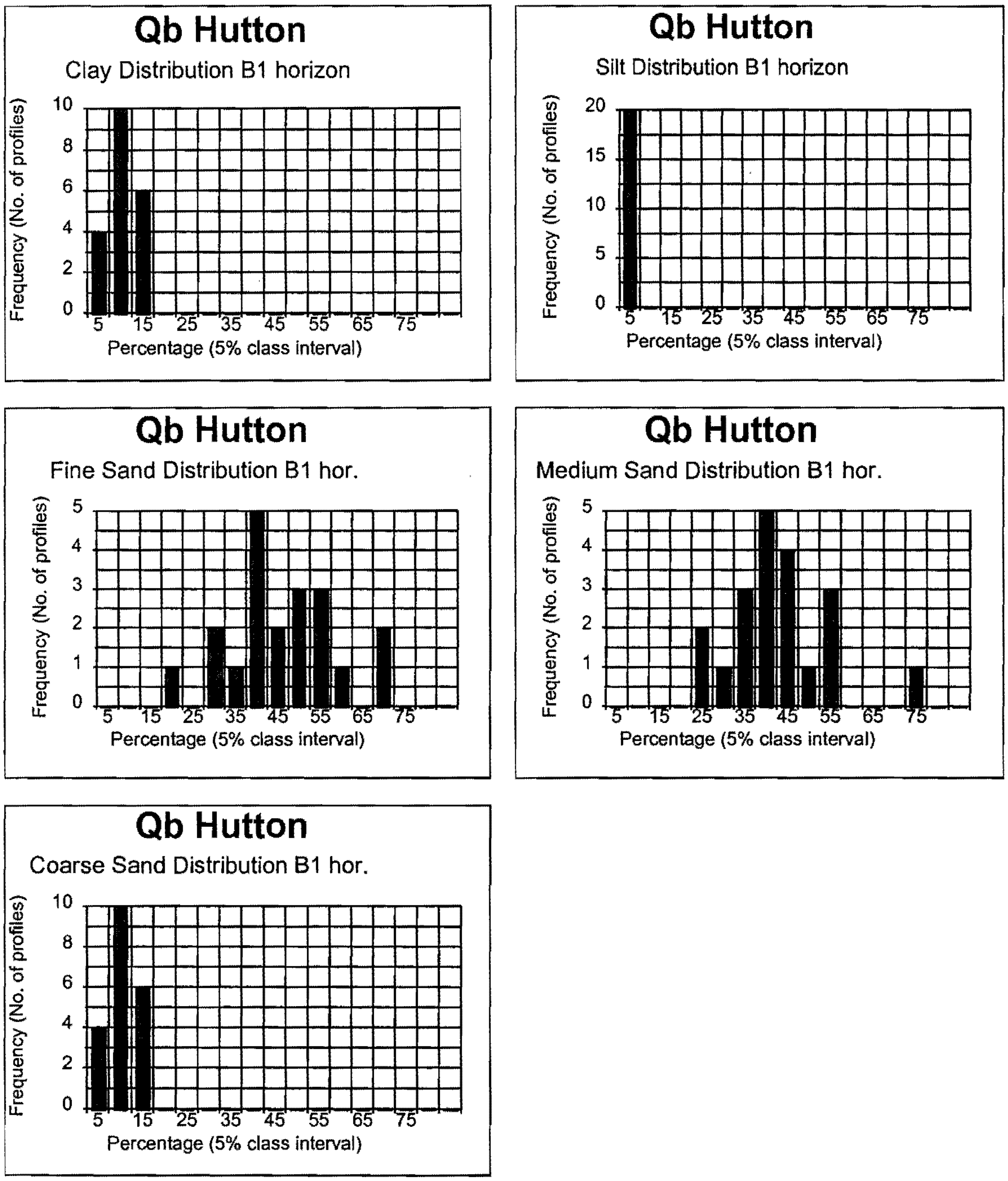


Figure 4.4 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

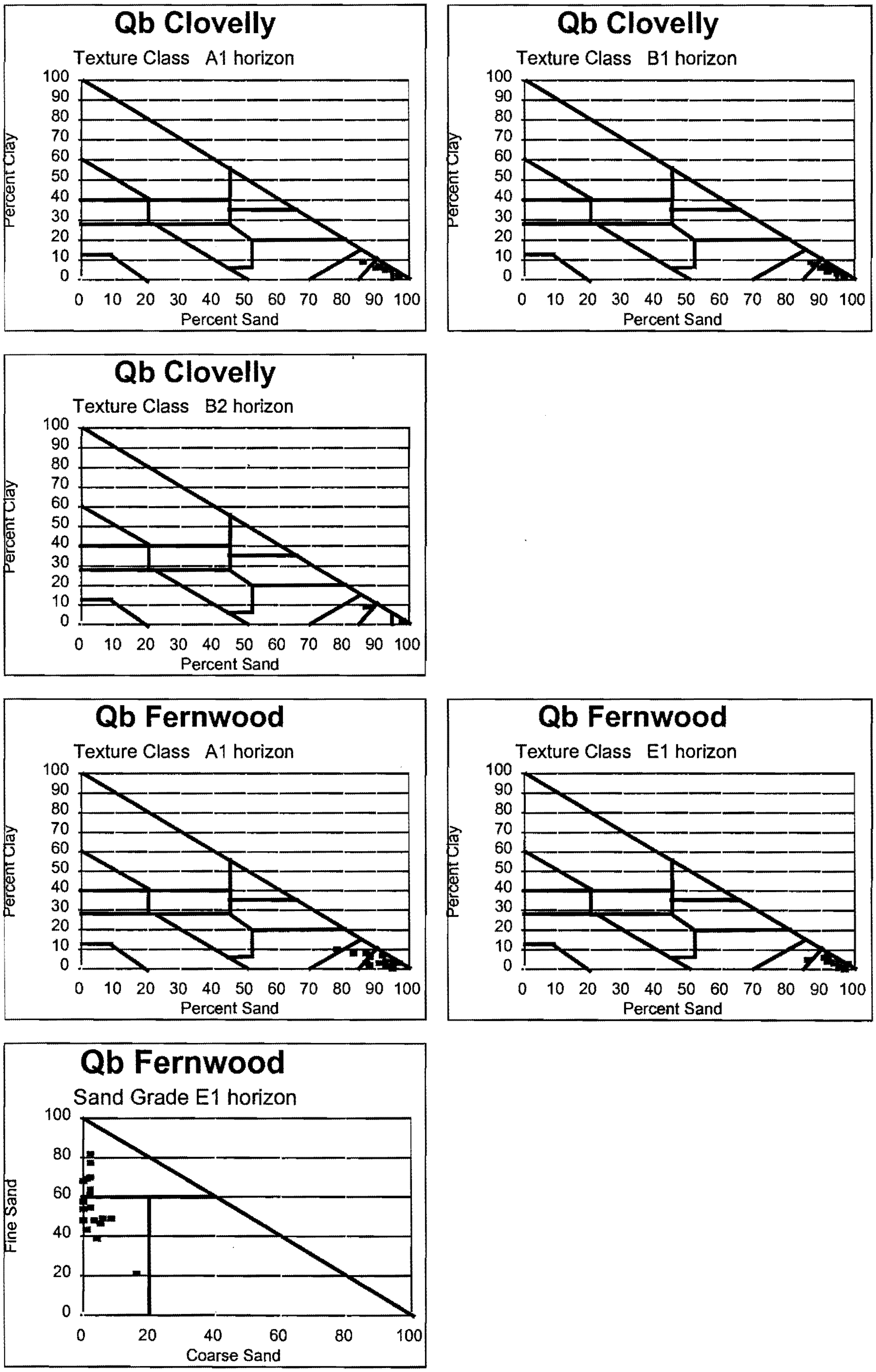


Figure 4.6 Distribution of soil textures, and sand grades, within soils of the Fernwood Form.

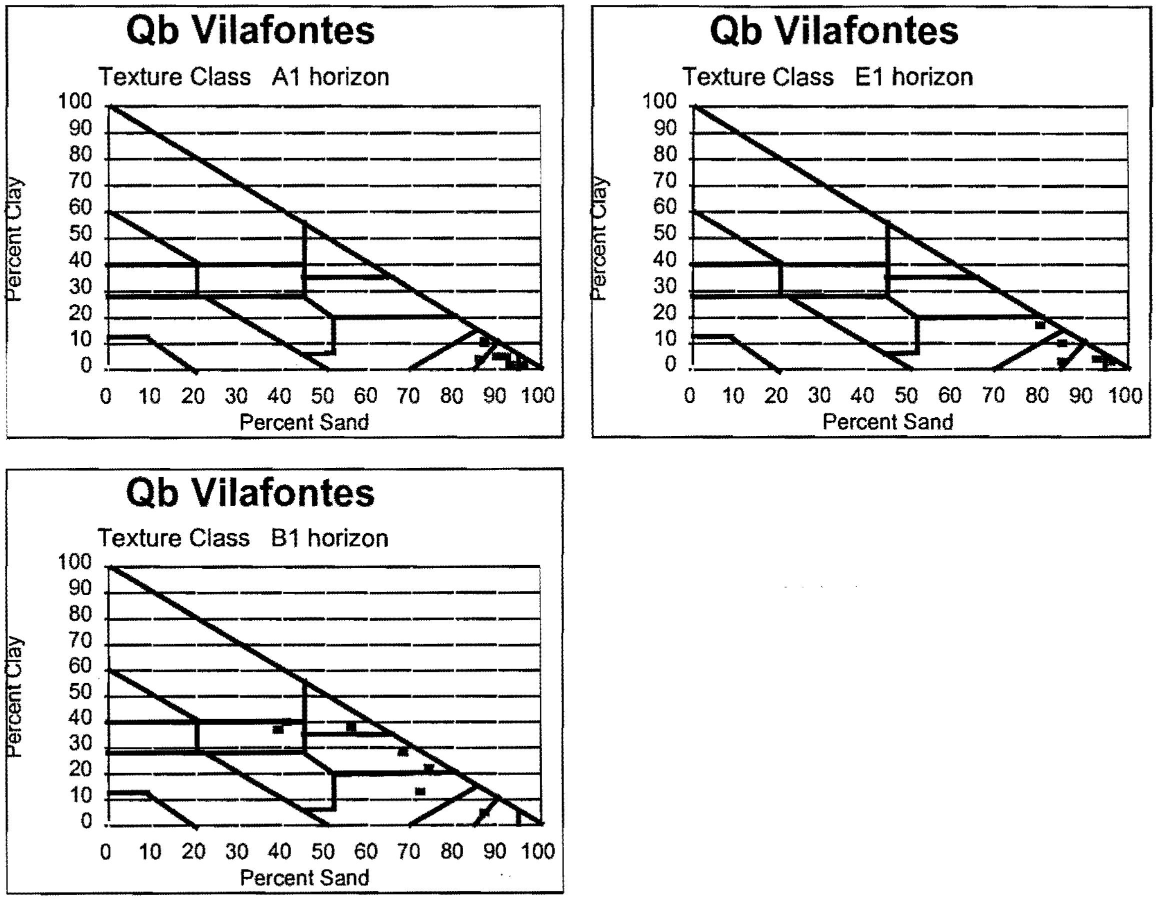


Figure 4.7. Distribution of soil textures within soils of the Vilafontes Form.

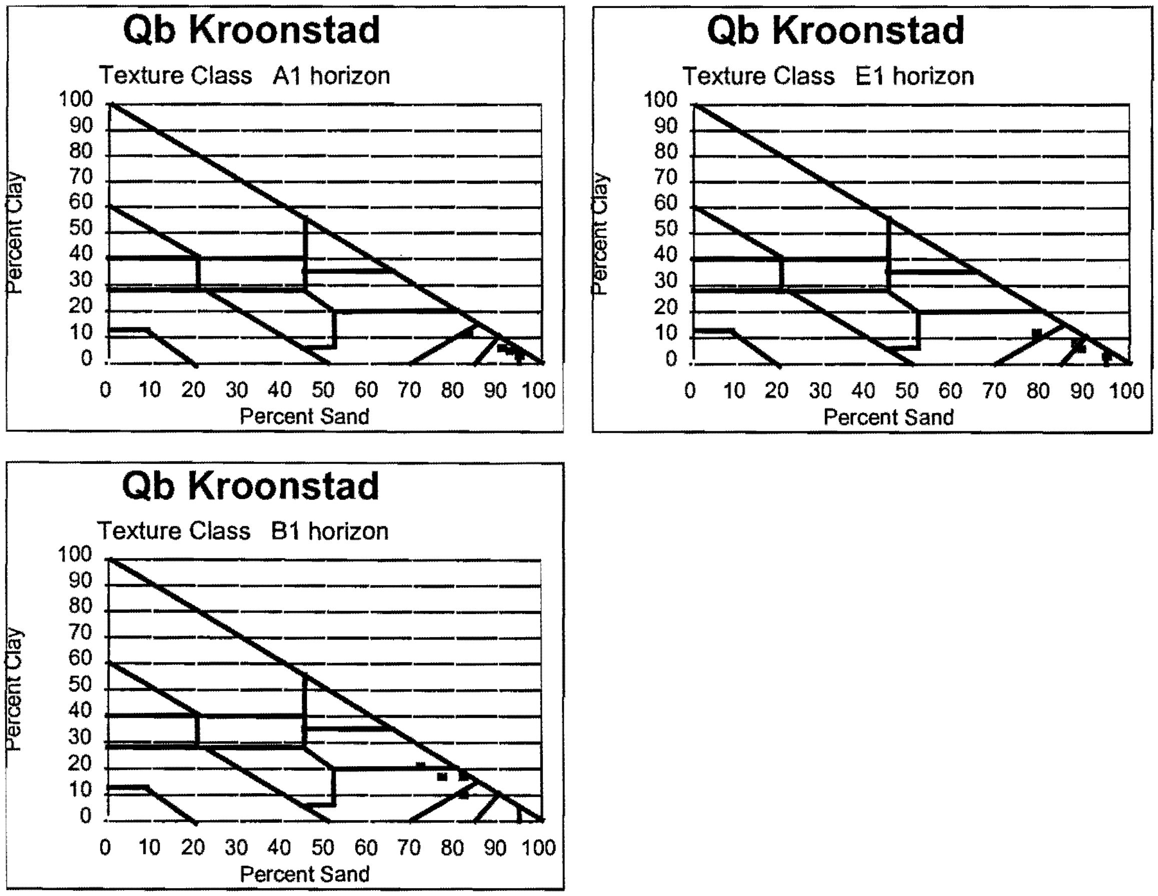


Figure 4.8 Distribution of soil textures within soils of the Kroonstad Form.

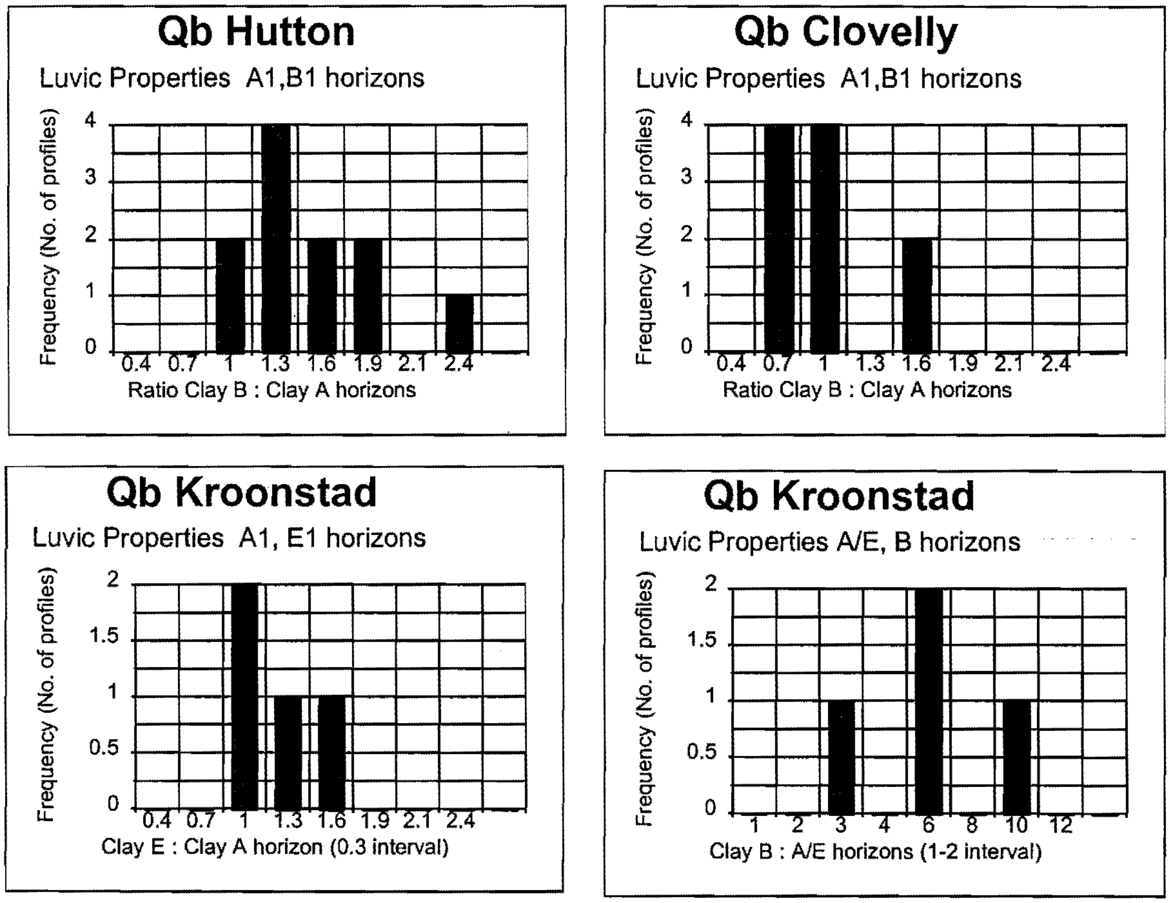


Figure 4.9 Luvic properties within soils Hutton, Clovelly and Kroonstad Forms.

CHAPTER 5

SOILS OF THE CRETACEOUS GEOLOGY OF THE KWAZULU-NATAL COASTAL PLAIN

Location and Extent

The Cretaceous geological formations are exposed in the KwaZulu-Natal Coastal Plain between 26° 30' S and 28° 30' S in a belt of between 8 and 15 km wide. This belt stretches west of the Quarternary formations (Chapter 4) from the border with Mozambique southwards to Lake St. Lucia. In this zone the Cretaceous Sediments are exposed between sea level and an altitude of approximately 150 m above sea level (Geological Survey, 1984). They cover an area of approximately 160 000 hectares. These sediments are exposed on a gently undulating plain east of the Lebombo Mountains or on the valley sides following incision by the major rivers, the Ngwavuma, Pongola, Mkuze, Msunduzi, Mzinene and Hluhluwe Rivers. Resting in part on these sediments are red sands and calcarenite of the Uloa and Berea Formations (Geological Survey, 1985a, b) which give rise to a different and unique soil pattern. There are further isolated occurrences of the Cretaceous Sediments along the southern KwaZulu-Natal coast. However, they have only a very limited influence on soil formation south of the Tugela River. The location of Cretaceous Sediment geology formations is illustrated in Figure 5.1.

Geology and Geomorphology (Geology Symbol Abbreviation **Km**)

Three formations of Cretaceous Sediment rocks have been recognised in northern KwaZulu-Natal (SACS, 1980). They are the St. Lucia, Mzinene, and Makatini Formations of the Zululand Group. They are located to the east of the Lebombo Mountain Range and lie west of the sandy Quaternary Formations (Geological Survey, 1985a, b). They are described and named as follows (SACS, 1980):

The St Lucia Formation (K-Ts) consists of siltstone with concretionary and shelly horizons.

The Mzinene Formation (Kmz) consists of marine glauconitic siltstone with shelly and concretionary horizons.

The Makatini Formation (Km) consists of sandstones, siltstones and conglomerates.

The three formations have very similar lithologies (SACS, 1980), with those of the upper two formations being almost identical. Their separation was based essentially on geological unconformities (SACS, 1980). Since the lithologies of each of the three formations are very similar, and since there are only a limited number of soil profiles sampled on these geological formations, the soil profiles have been grouped to determine their soil properties. These soil properties from each formation are nevertheless similar. Resting on these sediments are isolated occurrences of younger Tertiary Sediments of the Uloa Formation. These sediments are mainly red sands and red calcarenite. The Uloa Formation (Tu) is exposed as a number of isolated dune hills rising above sediments of the Mzinene Formation on the Pongola and Mkuze Floodplains. The formation comprises red sand, red calcarenite, and calcareous sandstone (Geological Survey, 1985a, b). The soils formed on these materials differ from those of the remainder of the Cretaceous Sediments of the northern KwaZulu-Natal Coastal Plain and deserve attention.

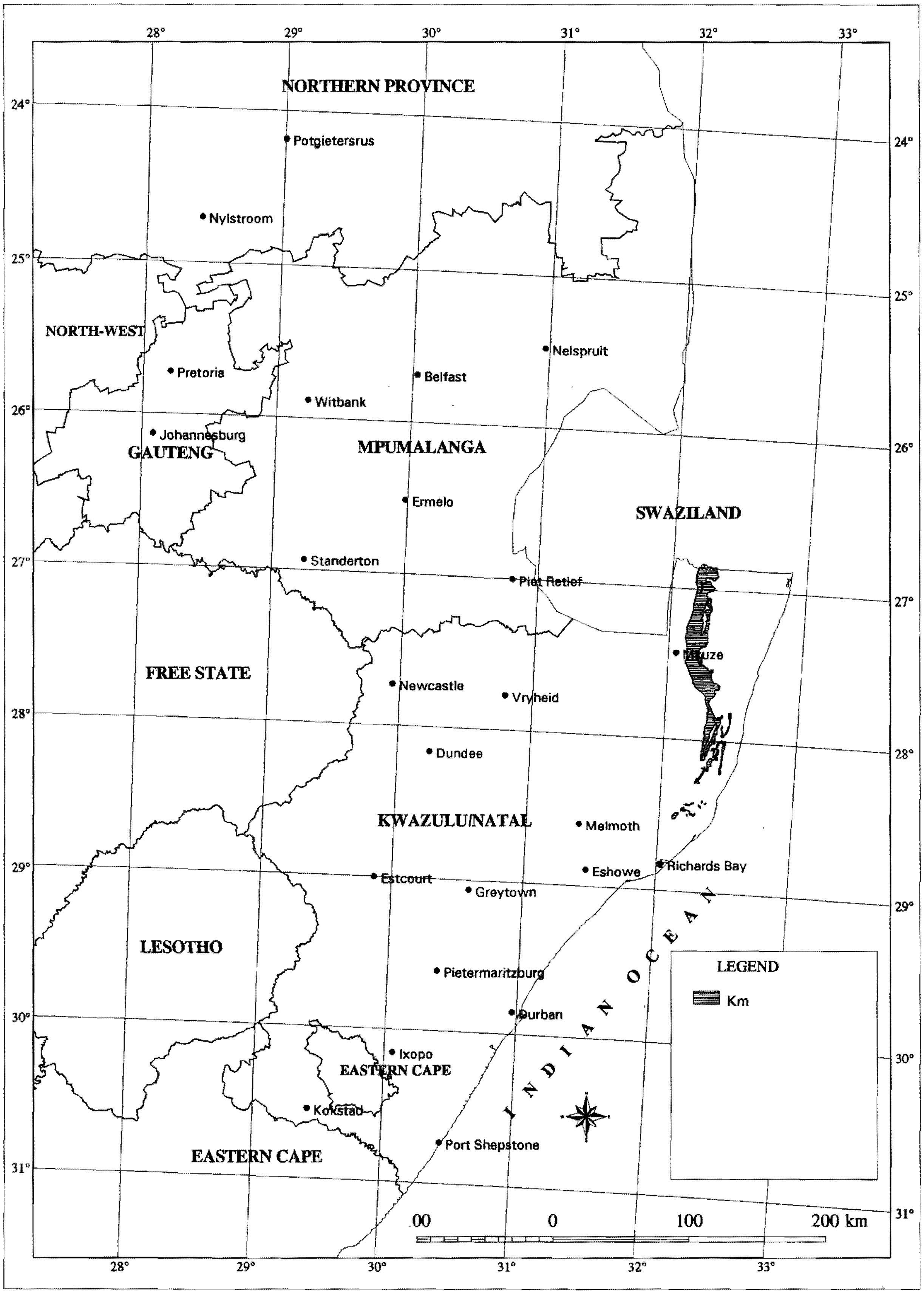


Figure 5.1. Location of Cretaceous geology formations in the coast belt of KwaZulu-Natal (after Geological Survey, 1984).

Partridge and Maud (1987) describe this zone as a partly planed Late African II land surface of late Pliocene age.

Physiography and Drainage Features

The physiography of the zone is moderately undulating plains with slopes commonly of less than 5% (Kruger, 1983). A number of components of the zone can be recognised. The foothills of the Lebombo Mountain Range comprise undulating (5-8% slopes) to gently undulating (2-5%) slopes, while the flat areas (0-2% slope) occur within depression topography and adjacent to the Quaternary sand mantle in the east of the zone (Land Type Survey Staff, 1986a, 1987c). The flood plains of the Pongola, Ingwavuma, Msunduze, Mkuze and Hluhluwe Rivers have flat slopes, often with seasonally flooded depression pans. The Tertiary Sediments, resting on the Cretaceous Sediments, could be described as an old, gently undulating dune with slopes 2-5%.

Vegetation

The vegetation is described by Low and Rebelo (1996) as mainly Subhumid Lowveld Bushveld. The lower reaches of the Pongola River Flood plain are described as Natal Lowveld Bushveld.

Soils

Three major soil patterns are evident on the materials derived from, or overlying, the Cretaceous Sediments. These are a duplex soil pattern, one comprising black and red clay soils, and the red apedal sandy loam soils of the Tertiary Sediments (Table 5.1).

The duplex soil pattern (Table 5.1) comprising largely soils of the Valsrivier and Sterkspruit Forms are most common and can be readily associated with the underlying partly consolidated sediments. The loamy sandy to sandy clay loam topsoils overlie a strongly structured yellow-brown clay loam to clay. These soils commonly exhibit coarse blocky structure (Valsrivier Form) to prismatic structure (Sterkspruit Form), with the B horizon grading through a clear to gradual transition into the underlying partly consolidated sediment below. For classification purposes the Valsrivier Form has been preferred, to that of the Swartland Form, since the underlying partly consolidated material commonly has only a firm to slightly hard consistence. Soils of the Kroonstad Form occur where a gleyed sandy loam B horizon is overlain by a sandy surface mantle. This occurs where the sand mantle to the east becomes a thin wedge over the partly consolidated Cretaceous Sediment. These soils are often indicated by an *Acacia tortilis* vegetation component (Low and Rebelo, 1996). Calcareous soils of the Bonheim Form, with a darker melanic topsoil and an otherwise similar subsoil morphology to the Valsrivier soils, have formed to a lesser degree on these sediments (Table 5.1).

Black and red clay soils of the Bonheim, Arcadia and Shortlands soil forms (Table 5.1), and to a lesser degree soil of the Mayo and Milkwood Soil forms, are present in areas underlain by Cretaceous parent materials. Only a limited number of soil profiles from these zones have been sampled. Colluvial materials from basalt, riodacite and even intruded dolerite into the adjacent Lebombo Group rocks, may be inferred as comprising at least partly the parent material of these soils. Parent materials derived from colluvium together with those of the underlying Cretaceous Sediments are likely. The genesis of these black and red clay soils remains uncertain. The samples from two Shortlands profiles exhibited contrasting textures, and both contained free lime within the profiles. Both features are unusual. In contrast Shortlands soils, within the basalt of the Mkuze Valley east of the Lebombo Range where uniform soil parent materials are likely, have uniform soil textures and rarely contained free lime. Colluvial materials should be suspected. Aridity indices are low which could promote the luvic nature of these soils. These black and red clay soils have been included within the soil patterns of the Cretaceous Sediments (Table 5.1) since the contribution of these partly consolidated sediments and that of the colluvial material has not been quantified.

Table 5.1 Dominant soils and selected climatic information for soil patterns occurring on Cretaceous Sediments within the KwaZulu-Natal Coast Interior.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rainfall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Soil Pattern: Duplex Soils (Sub-dominant black and red clay soils)										
Valsrivier	Va31 Va40	30	Bonheim	Bo40 Bo41	11	Ave	716	1793	4463	0.39
	Va41 Va42		Shortlands	Sd31	5	Std	87	180	121	0.06
Swartland	Sw31 Sw41	2	Arcadia	Ar20	5	Max	618	1522	4401	0.31
Sterkspruit	Ss21 Ss24 Ss26	8	Oakleaf	Oa36	3	Min	899	1974	4646	0.48
Kroonstad	Kd11 Kd14	15								
Total Area: 70 560 Ha			Means of 15 Land Types							
Soil Pattern: Black and Red Clay Soils (colluviation suspected)										
Bonheim	Bo41 Bo11	34	Valsrivier	Va30 Va31	12	Ave	618	1974	4464	0.31
Arcadia	Ar20 Ar30	17		Va40 Va41		Std				
Shortlands	Sd31 Sd32	7	Mispah	Ms10	11	Max				
			Mayo	My11 Mw11		Min				
			Milkwood							
Total Area: 44 700 Ha			Means of 2 Land Types							
Soil Pattern: Red Apedal Sandy Loam Soils (Uloa Formation)										
Hutton	Hu36 Hu34	58	Shortlands	Sd21 Sd22	15	Ave	618	1974	4464	0.31
	Hu31 Hu37			Sd31		Std				
			Bonheim	Bo41	6	Max				
			Valsrivier	Va41 Va42	4	Min				
Total Area: 43 140 Ha			Means of 4 Land Types							

The red apedal sandy clay loam to sandy clay soils of the Uloa Formation (Table 5.1) should be distinguished from the red apedal loamy sand of the Quaternary Sediments (Chapter 4). They have higher clay contents (range in clay is 20 - 50%), luvic properties between the A1 and B1 horizons and high CEC/clay ratios, in contrast to the red sandy soils of the Quaternary geology.

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Valsrivier, Sterkspruit, Bonheim, Arcadia and Rensburg, Shortlands and of Hutton Forms were extracted for the database. Their ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on their luvic properties are presented in Table 5.2.

Table 5.2 Textural properties of soils of the Cretaceous Sediments derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Valsrivier	A1 B1 B2	LmSa-Cl SaLm-Cl ClLm-Cl	11-53 24-66 34-70	2-29 3-36 11-32	18-49 11-47 10-40	3-30 2-26 3- 9	1-10 1- 6 2- 8	Fi,Me Fi,Me	L5
Sterkspruit	A1 B1 B2	Sa-ClLm SaLm-ClLm SaLm	8-28 16-44 21-36	1-24 1-18 1-21	29-35 20-27 25-28	10-49 7-56 8-46	6-11 6- 7 3- 7	Fi,Me Fi,Me	L5
Bonheim	A1 B1	SaClLm-Cl SaCl-Cl	37-58 41-59	8-17 5-28	13-30 13-23	3-14 2-12	5-7 6-8	Me Me	NL5
Arcadia/ Rensburg	A1 A2	SaCl-Cl Cl	42-69 66-68	18-45 17-24	6-42 7-10	2- 7 2	1- 7 1- 2	Fi	-
Shortlands	A1 B1	SaClLm-Cl SaCl-Cl	37-65 40-48	6-12 11-22	12-32 20-31	3-15 4-12	3- 5 2- 4	Fi Fi	NL5
Hutton	A1 B1 B2	LmSa-SaClLm SaLm-SaCl SaClLm-Cl	13-38 19-47 32-54	3-11 2-11 5-14	29-52 20-49 24-43	7-23 5-21 4-12	2-6 1-7 1-4	Fi Fi Fi	L4,NL1 -

Luvic Properties: Explanation of symbols; L - Luvic, NL - Non-luvic, EL - Eluvic Properties. Numbers indicate relative dominance of property from occasionally (1) to dominantly(5).

These ranges are represented graphically in Figure 5.2. The figure allows for overview comparison between different soil forms and over particle size classes.

Valsrivier and Sterkspruit Forms

Textural triangles for the A1 horizons of Valsrivier and Sterkspruit Forms (Figure 5.3) indicate essentially two clusters; the more dominant one concentrated in the sandy clay loam class (Figure 5.3), the other (largely profiles of the Sterkspruit Form) in the loamy sand class. A single widely spaced cluster for the B1 horizon was determined (Figure 5.3). However, outliers with higher silt values, and with low clay values are also evident. Natural breaks in the clay percentage distribution appear above and below 45% (Figure 5.4). They could constitute a natural threshold value as a soil series criterion. The clay percentages for the B1 horizon range largely from 25 to 45% (Figure 5.4) and represent the dominant textural property of these soils. However, high clay values can also be expected in both the A and B horizons. The textural properties of the 2 natural soil bodies, namely those from the sandy clay loam, and from the clay classes are presented in Table 5.3.

The sand grade for the A1 horizons is evenly distributed between the fine and medium sand grade classes (Figure 5.5). Data for the B1 and B2 horizons shows a similar trend.

Clay increases from the A1 to the B1 horizons of between 1.0 and 1.6 times were determined in the Valsrivier Form (eight profiles). A single profile showed an increase of 2.4 times (Figure 5.6). These profiles were classified to have a pedocutanic B horizon, and lacked an abrupt

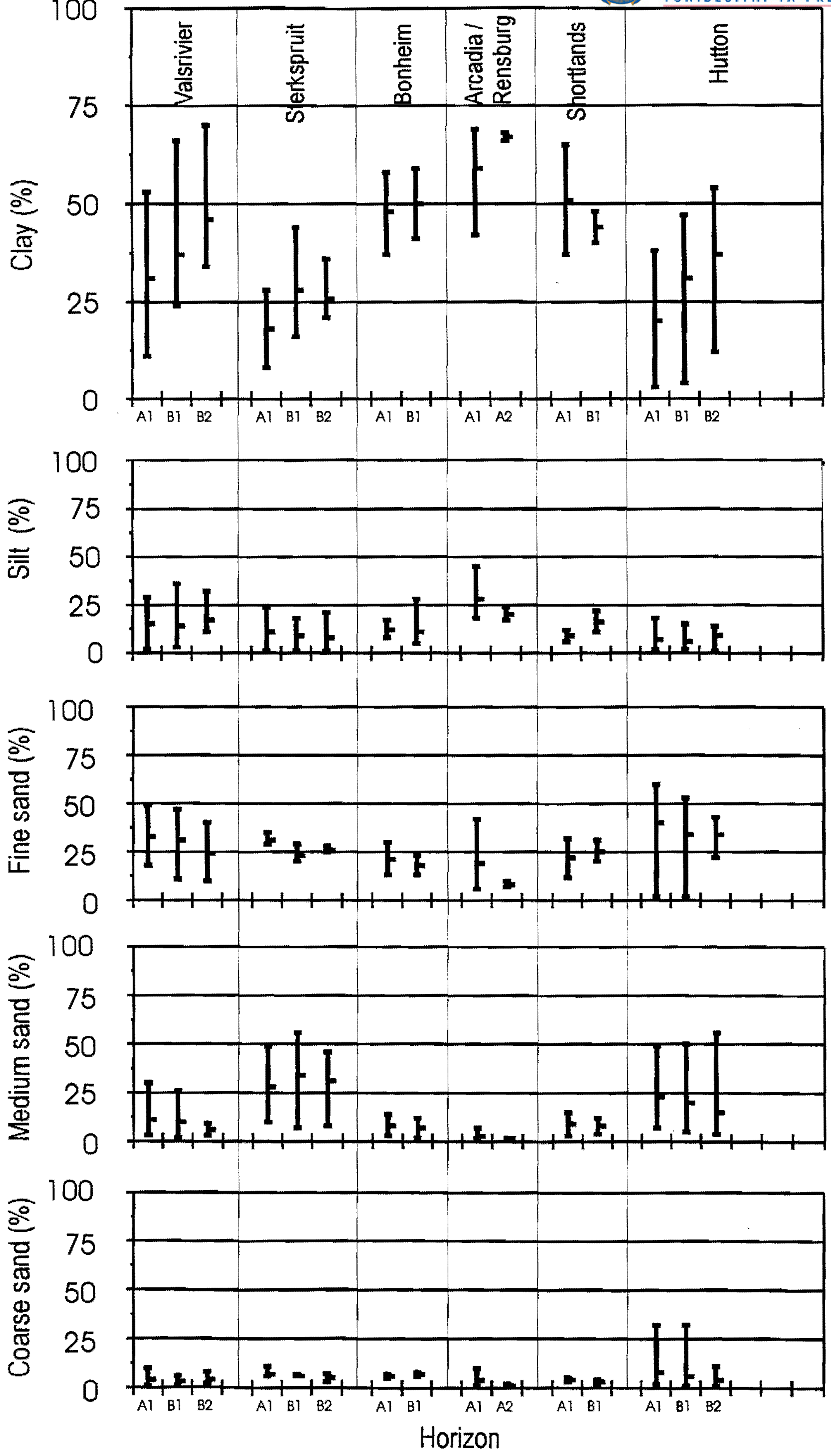


Figure 5.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Cretaceous geology. Maximum, minimum and mean values are shown for each horizon.

transition. The profiles do not demonstrate a doubling in clay content, as would be required in the definition of prismacutanic B horizons (Soil Classification Working Group, 1991). The soil classification criteria for pedocutanic B horizons would appear to be appropriately met. The Sterkspruit soils (3 profiles) showed of a ratio in the clay percentage between the A1 and B1 horizons of 1.6 to 2.2 (Figure 5.4). Each of these profiles exhibited an abrupt transition with respect to structure (with prismatic structure present) and consistence. The texture criterion (a doubling in clay or a large absolute increase) is not strictly met in two of the three profiles. However, with the nevertheless strong textural contrast, abrupt transition and prismatic structure discretion with respect to the prismacutanic definition should be applied when classifying similar profiles.

Bonheim Form

A single cluster is present in the textural triangle diagrams of both horizons of the Bonheim Form (Figure 5.7). This occupies a portion of the clay to sandy clay classes and indicates a single natural soil body to be present in these profiles. Silt is relatively low but consistent with other soils formed on these parent materials (Table 5.2). Medium sands are dominant. The ratio of the clay percentages between the A1 and B1 horizons ranges from 0.8 to 1.1 giving Non-luvic properties. The Bonheim soils, in contrast to the Valsrivier soils, showed higher clay contents in the A and B horizons (Table 5.3).

Arcadia Form

There are only 3 soil profiles in this group, each within the clay textual class (Figure 5.8), but with silt values greater than 25%, together with low medium and coarse sand values (Table 5.3). Their texture distribution for all 5 particle size classes does not differ much from that of Arcadia Form soils formed from dolerite. The influence of basic igneous rock in the genesis of these soils should be suspected. In contrast, the silt values of the Valsrivier and Bonheim soils are lower (<20%, Table 5.3) while the medium and coarse sand values are higher (Table 5.3).

Shortlands Form

There are only 2 soil profiles in this group, with textures ranging from clay to sandy clay textual classes (Figure 5.9). These profiles have contrasting texture (Tables 5.2 and 5.3) and presence of free lime. Shortlands soils with the presence of free lime are not commonly encountered in KwaZulu-Natal. These profiles are included here since their genesis and parent materials are suspected to differ from those of Shortlands soils commonly formed from basic igneous rocks.

Hutton Form

Textural triangles for the A1 and B1 horizons of Hutton Form (Figure 5.9) indicate textures from loamy sand to sandy clay. Silt values are low (Table 5.2) while fine and medium sand values are higher. There are clearly similarities between these soils and the red sandy soils of the Quaternary Sediments (Chapter 4). The longer time for weathering would have resulted in higher clay contents as is evident here (Tables 5.2 and 5.3). However, it should be assumed that the loamy sand and sandy loam textured profiles belong to the natural body of Hutton soils of Quaternary Sediments. Those from the sandy clay loam to sandy clay textural class belong to the natural body of Hutton soils of the Cretaceous Sediments. There are thus 2 clearly defined natural bodies determined on the basis of texture, as illustrated in the textural diagrams (Figure 5.9) and the clay distribution histograms (Figure 5.10). The natural break is located at 15% clay in both the A1 and B1 horizons. The mean textural properties of the sandy clay natural soil body are presented in Table 5.3.

Table 5.3 Means and standard deviations of 5 textural classes for soils of the Cretaceous Sediments.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Valsrivier Form (Soils with Clay Content of B1 horizon 25-45%)												
A1	265	23.4	8.7	14.4	9.3	35.2	7.3	17.6	14.7	5.3	3.0	13
B1	746	30.5	7.9	14.5	10.1	31.2	8.7	18.2	16.5	4.2	2.0	14
B2	995	38.8	14.2	14.0	9.4	25.3	8.4	15.8	16.2	4.9	2.3	8
Form: Valsrivier Form (Soils with Clay Content of B1 horizon >45%)												
A1	400	49.3	5.2	14.3	3.3	21.0	3.0	7.0	1.0	6.0	3.0	3
B1	883	58.3	6.1	10.3	4.7	22.0	11.0	4.5	2.5	2.0	0	3
Form: Sterkspruit Form												
A1	298	18.5	7.9	11.8	9.9	31.8	2.2	28.0	17.7	7.8	1.9	4
B1	697	28.0	11.8	9.5	8.5	23.3	2.9	34.0	20.3	6.3	0.5	3
B2	1003	26.3	6.7	8.3	9.0	26.3	1.3	31.7	16.9	5.3	1.7	3
Form: Bonheim Form												
A1	500	48.1	6.9	12.3	3.7	21.5	8.5	8.5	5.5	6.0	1.0	7
B1	974	50.0	6.2	11.1	7.3	18.0	5.0	7.0	5.0	7.0	1.0	7
Form: Arcadia and Rensburg Forms												
A1	530	59.0	12.1	28.3	11.9	19.0	16.3	3.7	2.4	4.3	4.0	3
A2	905	67.0	1.0	20.5	3.5	8.5	1.5	2.0	0.0	1.5	0.5	2
Insufficient profiles for the C and or G horizons.												
Form: Shortlands Form												
A1	250	51.0	14.0	9.0	3.0	22.0	10.0	9.0	6.0	4.0	1.0	2
B1	750	44.0	4.0	16.5	5.5	25.5	5.5	8.0	4.0	3.0	1.0	2
Form: Hutton Form												
A1	227	26.5	8.2	8.3	5.2	46.0	3.0	15.4	5.4	3.3	1.3	6
B1	802	34.7	10.5	7.2	3.6	37.5	9.7	15.3	9.3	3.4	2.3	13
B2	1000	37.4	12.8	9.0	4.5	34.7	7.7	15.9	16.9	4.0	3.3	7

Dominant sand grades are fine and medium (Figure 5.11). The profiles of this natural soil body are luvic (Figure 5.11) and are a product of the longer times for profile weathering, clay formation and possible clay illuviation. Luvic properties are a feature of these red materials. Here it is evident close to the soil surface.

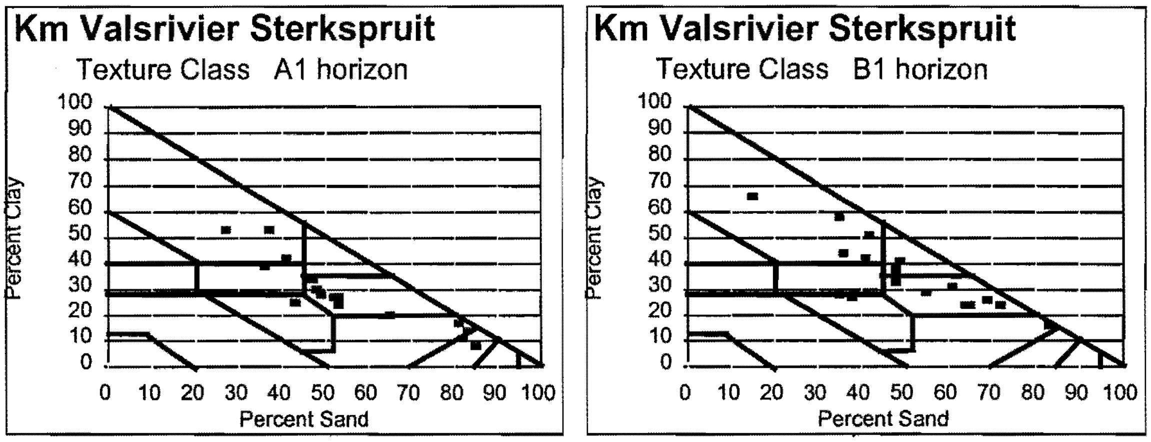


Figure 5.3. Distribution of soil textures within soils of the Valsrivier and Sterkspruit Forms.

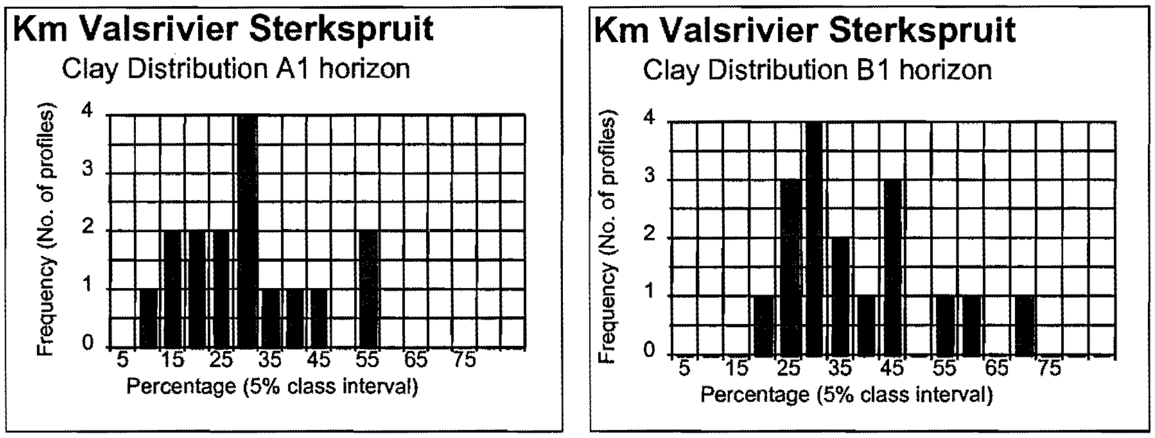


Figure 5.4. Distribution of clay within soils of the Valsrivier and Sterkspruit Forms.

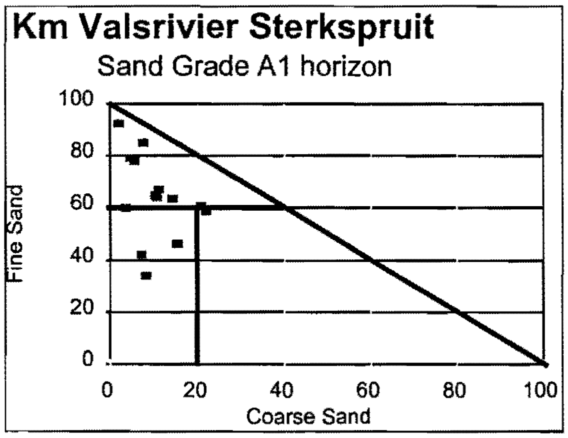


Figure 5.5. Distribution of sand grades within soils of the Valsrivier and Sterkspruit Forms.

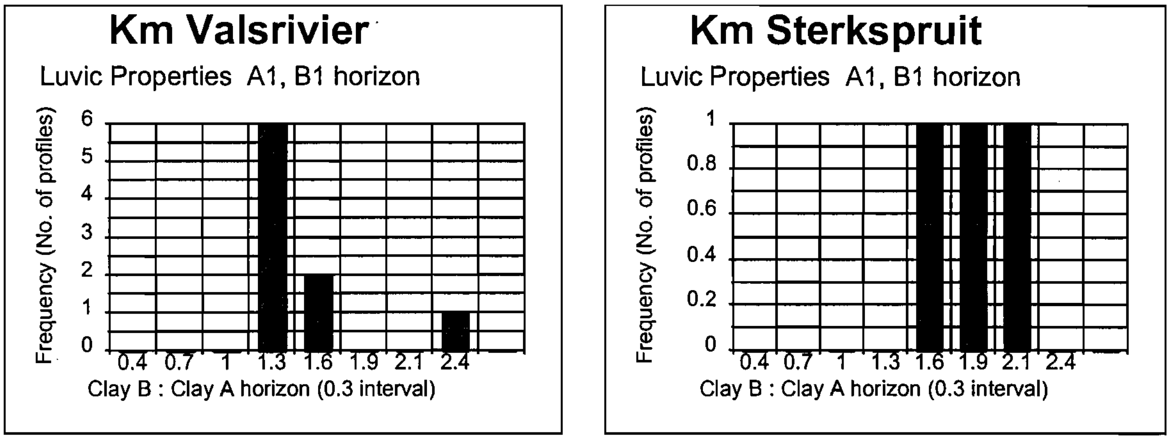


Figure 5.6. Luvic properties of the A1 and B1 horizons of soils of the Valsrivier and Sterkspruit Forms.

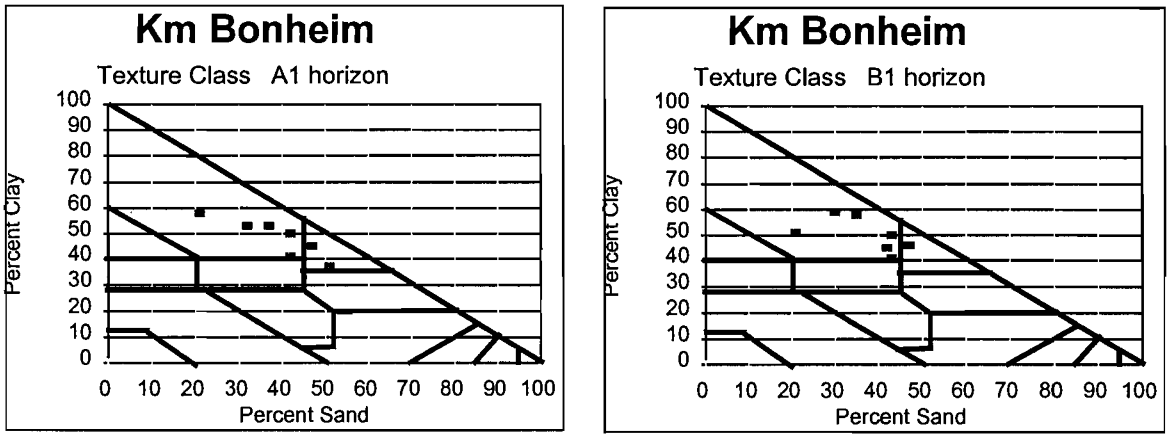


Figure 5.7. Distribution of soil textures within soils the Bonheim Form.

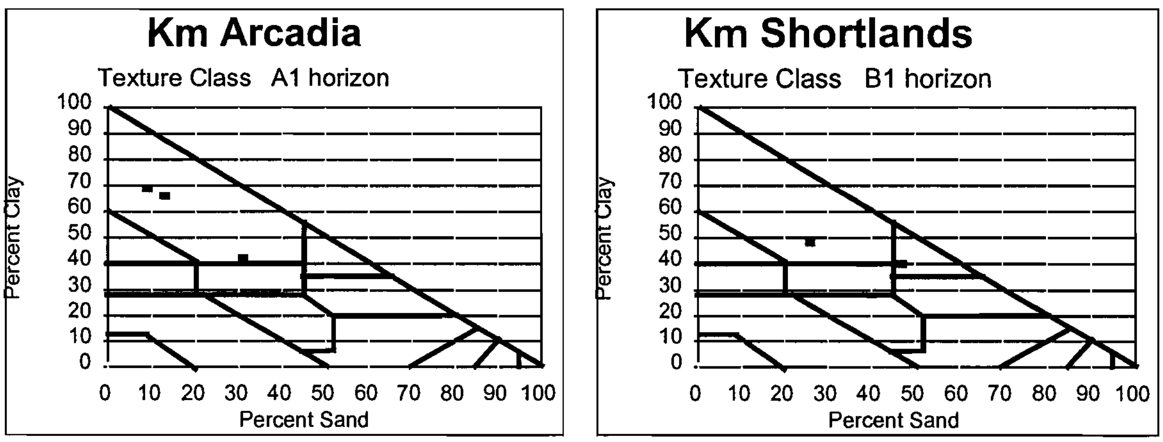


Figure 5.8. Distribution of soil texture within soils of the Arcadia and Shortlands Forms

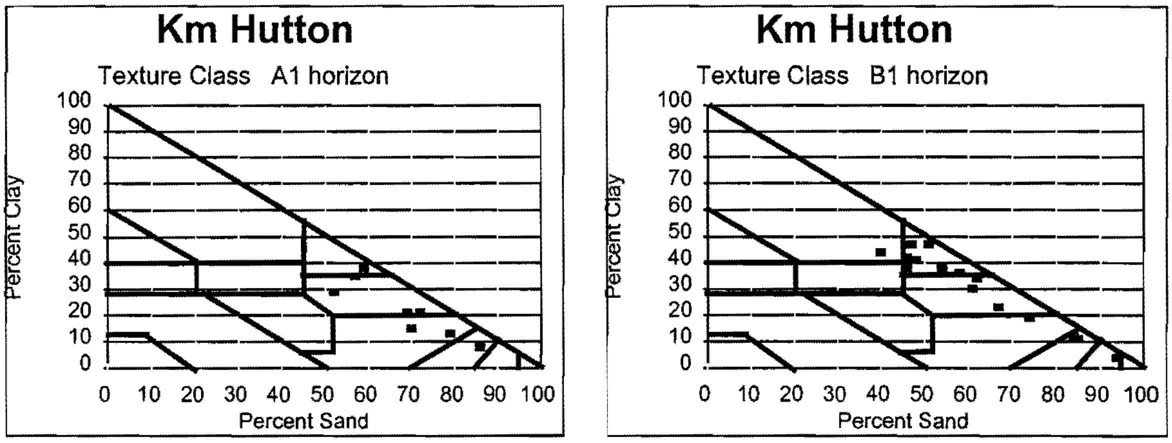


Figure 5.9. Distribution of soil texture within soils of the Hutton Form.

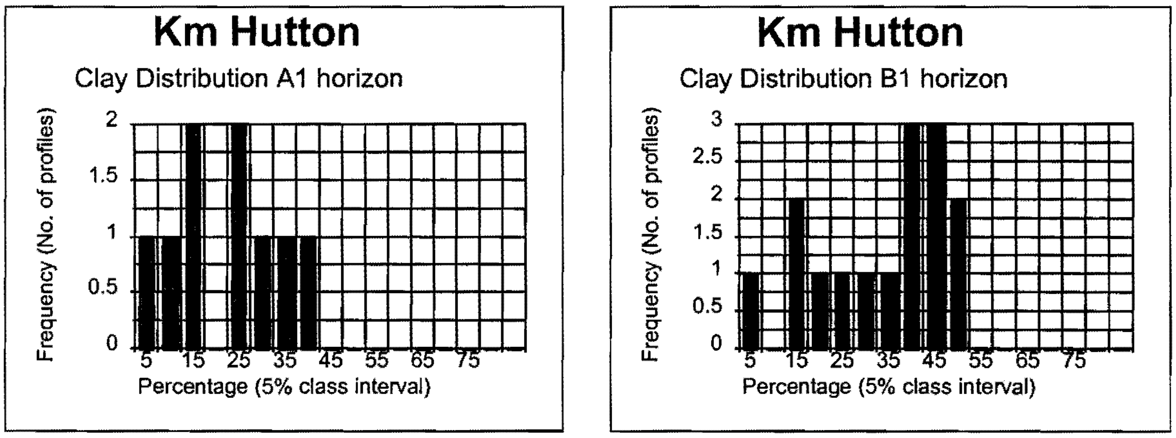


Figure 5.10. Distribution of clay within soils of the Hutton Form.

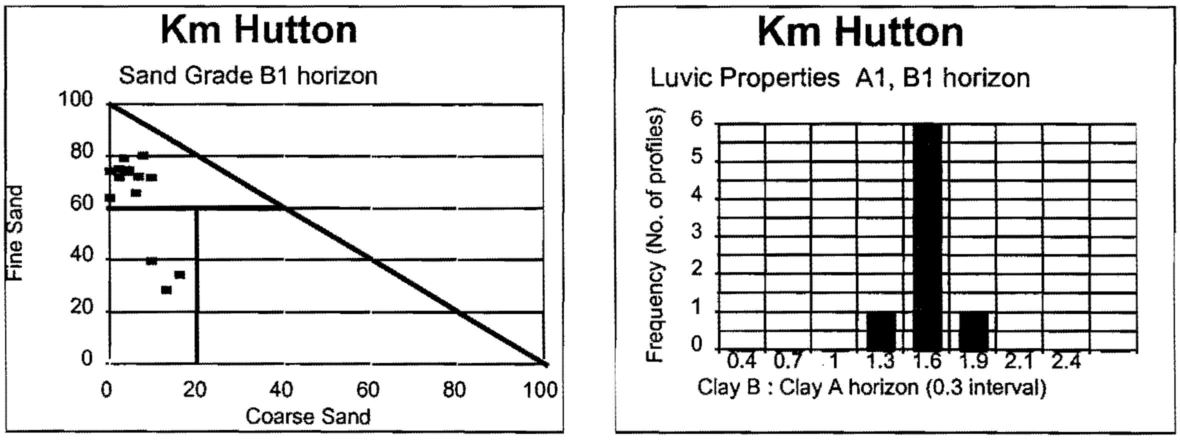


Figure 5.11. Sand grade and luvic properties of soils of the Hutton form.

CHAPTER 6

SOILS OF KAROO DOLERITE IN KWAZULU-NATAL AND MPUMALANGA

Location and Extent

The Jurassic dolerite is exposed throughout KwaZulu-Natal and Mpumalanga, with the main occurrences associated with intrusions into the Karoo sequence rocks. The larger occurrences are shown on the 1:1 million map geology of South Africa (Geological Survey, 1984) (Figure 6.1). Individual occurrences of dolerite are shown on the 1:250 000 geology series maps (Geological Survey, 1978-1992). It is from these maps that the geology association for the soil profiles (that have been sampled and entered into the soil profile database) has been established. This has been achieved by carefully examining the mapped location of soil profiles relative to occurrences of dolerite (Geological Survey, 1978-1992). This has been verified against soil form classification and profile description information. The dolerites are estimated to occur over an area of some 570 000 km^2 (44%) in South Africa (Du Toit, 1921; as quoted by SACS, 1980). The extent of those land types (Land Type Survey Staff, 1985-1997b) where dolerite is considered to be the dominant rock type (Geological Survey, 1984) is estimated to cover some 1 357 470 hectares. The dolerites occur over a wide range of terrain morphological positions and climates. The range of soils associated with dolerite is correspondingly large.

Geology and Geomorphology (Geology Symbol Abbreviation **Jd**)

Dolerite is a dark coloured crystalline igneous rock that abundantly intrudes the Karoo Sequence. It has given rise to many characteristic flat topped hills. The geologists of the Geological Commission of the Cape of Good Hope first decided to name this dark coloured rock dolerite; a name proposed for fine-grained igneous rock composed of augite and plagioclase in about equal amounts (SACS, 1980). The name dolerite has continued to be used in South Africa and elsewhere. The retention of the term dolerite is desirable as it immediately distinguishes the Karoo suite from the various older and commonly altered fine-grained mafic intrusions, consistently termed diabase in South Africa (SACS, 1980). They are almost entirely confined to the Karoo strata. The intrusions are generally horizontal, evenly inclined or undulating sheets. Dykes are also common (SACS, 1980).

Physiography and Drainage Features

Dolerite is commonly present in sloping to steep hill, mountain and escarpment landforms (ISSS-ISRIC-FAO, 1993). Slope gradients ranging from undulating (5-8%), through to rolling (8-15%) and moderately steep land (15-30%) are encountered. Dolerite sills and dykes often exert structural control in the landscape, and may be seen as present on flat topped hills, or as the crests of waterfalls. A description of the physiography of KwaZulu-Natal, and with reference to the role of the dolerite rocks is given by van der Eyk, MacVicar and De Villiers (1969). Examples of major structural control of the dolerite intrusions are on the Skurweberg, Biggarsberg and at Qudeni in the north of the province. With these steeper slopes the contributions of colluvial material to the soil parent materials become increasingly important.

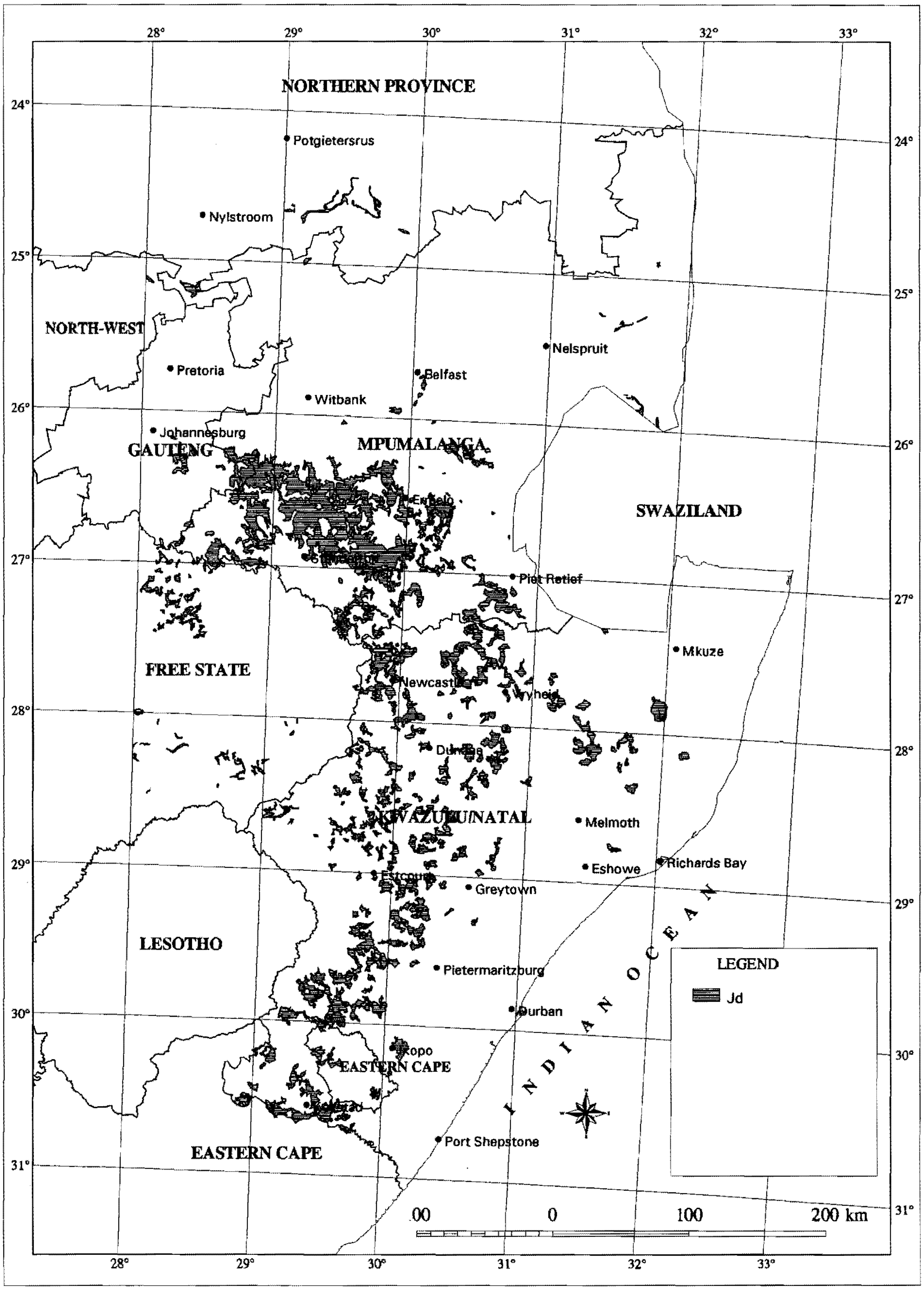


Figure 6.1. Location of the major occurrences of Jurassic dolerite in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Vegetation

Dolerite is associated with a variety of vegetation types. In KwaZulu-Natal and Mpumalanga it is in the Grassland Biome, as well as the Savannah and Thicket Biomes (Low and Rebelo, 1996).

Soils

Five major soil patterns could be identified from Land Type information where dolerite was recorded as the dominant geological parent rock (Table 6.1). These include Red and Yellow-brown Apedal Freely Drained soil patterns located chiefly in the moist humid zones of the KwaZulu-Natal and Mpumalanga interior. Slopes range from undulating to moderately steep (Land type Survey Staff, 1985 -1997b). Red structured soils, with sub-dominant red apedal soils and with exposed rock, occur in the sub-humid zones. The range in base status of these soils is from the mesotrophic to eutrophic classes. Melanic and vertic soils are dominant in the sub-humid to semi-arid zones. Slopes are generally flatter than for the red apedal landscapes. They range from gently undulating to rolling slope classes. Extensive areas of soils with melanic topsoil horizons are present on the Highveld Plateau. Finally soil patterns dominated by Rockland and lithosols were identified (Table 6.1) with commonly rolling to steep slopes.

The Red and Yellow-brown Apedal Soil Pattern comprises moderately deep to deep clay soils of the Hutton, Griffin and Clovelly soil forms. Dystrophic soils are reported as occupying most of the land included in this class (Land Type Survey Staff, 1985-1997b). The area is reported to have fewer mesotrophic soils of the Hutton Form than dystrophic soils (Table 6.1). Katspruit is the dominant bottomland soil, while Glenrosa and Mispah soils are commonly also present. Soil-rock complexes, comprising shallow to deep soils of largely the Hutton Form, together with Mispah soils and remnant dolerite boulders are a feature of many landscapes.

Mixing of the parent materials in many of these highly weathered landscapes is common. This is particularly so where the clay forming parent materials of shales and mudstones of the Ecca and Beaufort Groups are present together with dolerite. In many of these landscapes it may become difficult to determine the exact origin of the parent material, such that a dolerite and shale or mudstone colluvium is suspected. However, dolerite has been mapped as comprising the major component (Geological Survey, 1984) of the parent rock in the information reported in Table 6.1.

Red structured soils consist of shallow to moderately deep clays (Table 6.1). Eutrophic soils are reported to occupy a slightly greater area than the mesotrophic soils (Land Type Survey Staff, 1985-1997b). Mesotrophic and Eutrophic soils of the Hutton Form, soils of the Mispah Form and rock are furthermore features of these landscapes.

Mayo and Milkwood Forms are dominant in the Melanic Soil Pattern (Table 6.1), together with soils of the Bonheim and Arcadia (vertic A horizon) Forms. A variety of other soils, including largely lithosols and duplex soils, may also be present where parent materials other than dolerite are present in the landscape.

The Vertic Soil Pattern is present on flat to gently undulating slopes, with soils of the Arcadia Form dominant (Table 6.1). A variety of other soils, including melanic soils may also be present.

Table 6.1 Dominant soils and selected climatic information for soil patterns occurring on Jurassic Dolerite within KwaZulu-Natal and Mpumalanga. Sub-dominant occurrences of soils derived from other geology rock types, notably those of the Karoo Sediments are included.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rainfall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow-brown Apedal Well Drained Soils										
Hutton	Hu17 Hu18	24	Katspruit	Ka10	4	Ave	989	1445	2171	0.69
	Hu27 Hu28	4	Glenrosa	Gs16 Gs17 Gs19	4	Std	180	140	451	0.17
Clovelly	(Cv17 Cv18)	12	Mispah	Ms10	3	Max	1551	1761	3257	-
Griffin	Gf12 Gf11	12				Min	703	1213	1040	0.47
Total Area: 268 090 Ha			Means of 58 Land Types							
Broad Soil Pattern: Red Structured Soils Dominant										
Shortlands	Sd11 Sd12	20	Hutton	Hu27 Hu37 Hu28	9	Ave	753	1592	2899	0.48
	Sd21 Sd22	27	Mispah	Ms10 Ms11	5	Std	60	168	572	0.07
			Rockland	Rock	18	Max	880	1967	4081	0.57
						Min	657	1396	2270	0.33
Total Area: 53 550 Ha			Means of 8 Land Types							
Broad Soil Pattern: Melanic Soils Dominant										
Mayo	My10 My11	17				Ave	711	1732	2951	0.41
	My21					Std	56	217	916	0.06
Milkwood	Mw10 Mw11	8				Max	807	2274	4822	0.53
	Mw21					Min	600	1500	1327	0.31
Bonheim	Bo31 Bo41	13								
Arcadia	Ar30 Ar40	13								
Total Area: 92 770 Ha			Means of 13 Land Types							
Broad Soil Pattern: Vertic Soils Dominant										
Arcadia	Ar30 Ar40	40				Ave	676	1962	2248	0.35
Rensburg	Rg10 Rg20	11				Std	30	180	365	0.05
						Max	720	2186	3002	0.44
						Min	638	1620	1772	0.29
Total Area: 834 160 Ha			Means of 9 Land Types							
Broad Soil Pattern: Lithosols										
Rockland	Rock	24	Other			Ave	852	1527	2311	0.56
Glenrosa	Gs16	18	Soils			Std	155	163	631	0.15
Mispah	Ms10	15				Max	1265	1967	3965	0.94
						Min	542	1267	1518	0.33
Total Area: 108 900 Ha			Means of 38 Land Types							

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Clovelly, Inanda, Shortlands, Arcadia, Rensburg, Bonheim, Mayo, and Katspruit Forms were extracted for the database. Their ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on their luvic properties are presented in Table 6.2.

Table 6.2 Textural properties of soils of the Jurassic dolerite derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1	Cl-SiCl-SaClLm	24-72	5-51	1-42	1-22	1-22	fi,me,co	NL3,EL1,L1
	B1	Cl-ClLm-SaClLm	21-81	3-51	1-53	1-27	1-60	fi,me,co	NL5
	B2	Cl-SaClLm	28-82	4-36	3-48	1-11	1-11	fi,me,co	-
Griffin	A1	Cl-ClLm	27-68	15-57	3-29	1-7	2-10	fi,co	EL3,NL1,L1
	B1	Cl-ClLm-SaClLm	31-71	6-43	3-40	1-21	1-22	fi,co	EL3,NL1,L1
	B2	Cl-ClLm-SaClLm	7-37	21-73	3-36	1-15	1-6	fi,co	-
Clovelly	A1	Cl-ClLm	28-65	16-38	4-36	1-8	2-4	fi,co	NL4,EL1
	B1	Cl-ClLm	26-64	12-41	2-39	1-20	1-12	fi,co	-
Inanda	A1	Cl-SaClLm-SiCl	29-57	5-51	5-37	1-27	1-12	fi	NL3,L2
	B1	Cl-SaClLm-SiCl	24-66	5-42	6-35	1-14	1-7	fi	-
Shortlands	A1	Cl-ClLm-SaClLm	26-81	5-41	2-40	1-22	1-12	fi,co	NL3,L2
		Cl-SaCl-SaClLm			1-45	1-22	1-15	fi,co	NL3,L2
	B1	Cl-SaCl-SaClLm	32-84	3-42	4-32	1-31	1-17	fi,co	-
	B2		27-81	4-36					
Arcadia	A1	Cl	41-64	8-26	2-38	1-11	1-9	fi	NL5
	A2	Cl-SaCl	37-69	5-30	8-34	2-10	2-7	fi	-
Rensburg	A1	Cl-SaCl	44-62	13-26	17-27	2-11	1-8	fi	-
	G1	Cl-SaCl	46-67	11-23	15-19	2-9	2-8	fi	-
Bonheim	A1	Cl-ClLm-SaCl	24-57	3-37	5-29	2-23	1-36	fi,me	NL4,L1
	B1	Cl	27-65	4-33	8-30	1-21	1-14	fi,me	NL5
Mayo	A1	Cl-SaCl-SaClLm	24-59	8-37	5-36	2-17	1-20	fi,co	EL5
	B1		13-61	11-35	22-40	4-11	3-17		-
Katspruit	A1	Cl-SaCl	26-52	17-47	-1-30	2-2	3-3	fi	-
	G1	Cl	30-62	11-47	16-19	1-2	3-3	fi	-

Luvic Properties: Explanation of symbols; L - Luvic, NL - Non-luvic, EL - Eluvic Properties. Numbers indicate relative dominance of property from occasionally (1) to dominantly(5).

These ranges are represented graphically in Figure 6.2. The Figure and Table allow for overview comparison between different soil forms and over particle size classes. Whilst the majority of profiles fall into the clay texture class (pipette method)(Table 6.2, and Figures 6.3-6.8) and parts of the clay loam and sandy clay classes, there are values for clay percentage recorded that are much lower than expected. This is particularly the case within the Hutton, Griffin and Clovelly Forms. Despite these somewhat lower clay percentages silt and fine sand values remain high, while medium and coarse sand values are consistently low (Table 6.2). This would suggest that the soils could well be derived from dolerite, since these basic igneous rocks give rise to clay soils with higher silt and fine sand values, and consistently low values for medium and fine sand. However, certain of the Ecca and Beaufort Sediments may also give rise to soils with similar

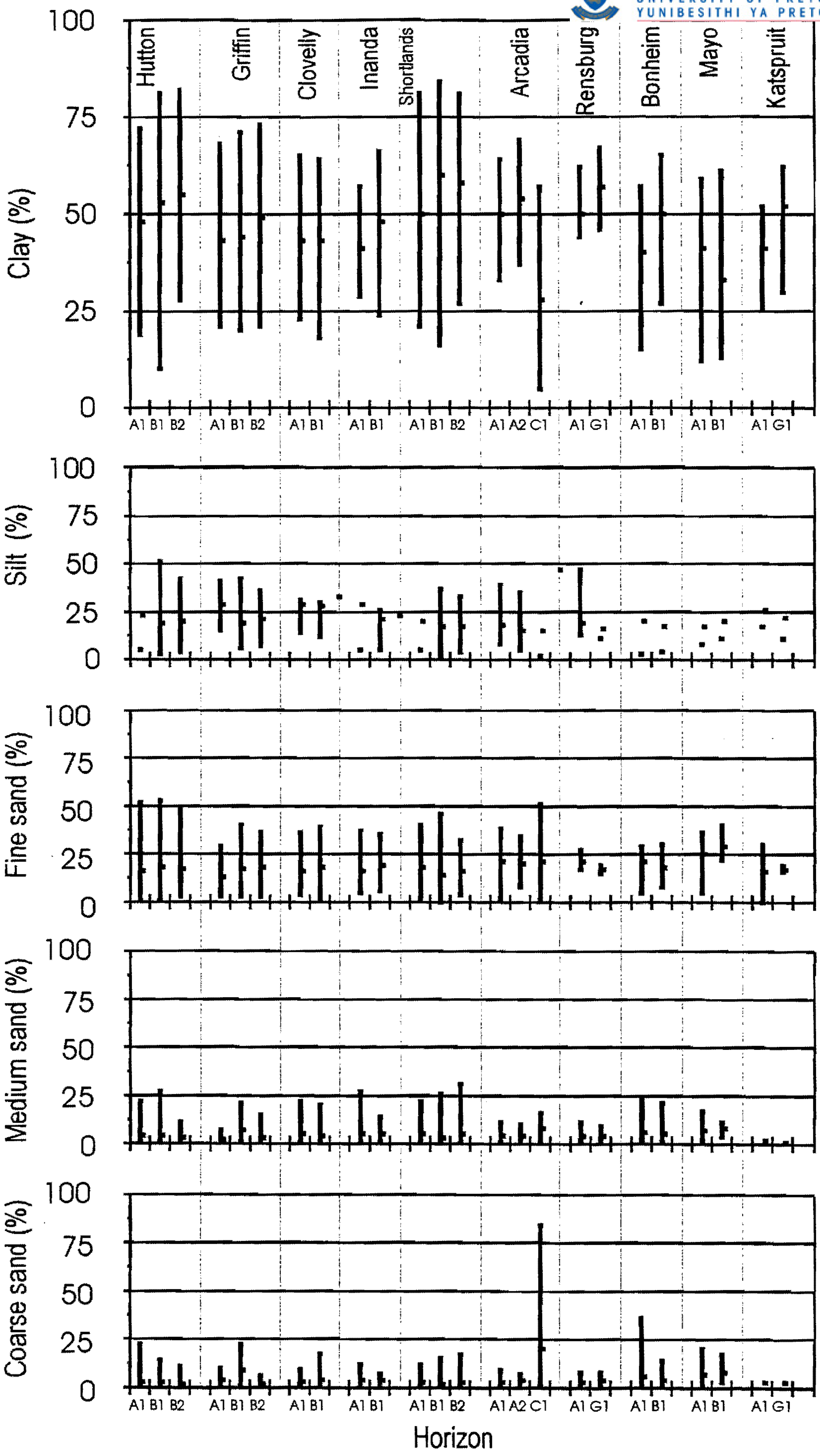


Figure 6.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Jurassic Dolerite geology. Maximum, minimum and mean values are shown for each horizon.

textures. The range in clay contents for the Arcadia and Rensburg Forms are narrower and belong essentially to the clay class. This is in line with the expected values for clay percentage. The range in clay for the Bonheim and Mayo soils is lower than that for the Arcadia soils (Table 6.2, Figures 6.7 and 6.8). Soils with lower clay textural classes, and which do not directly overlap those of the Arcadia soils are evident. These textural classes would appear to be regularly present in the Bonheim and Mayo soils.

The textural values for the Katspruit soils are quoted for information purposes despite the limited sample size (Table 6.2). While dolerite has been identified as the underlying rock, mixing with alluvial and colluvial materials should be expected.

Hutton Form

The Hutton Form Soils formed on dolerite are probably the most commonly sampled soils in the database. The information contained in this data set presents an opportunity to evaluate the properties and their range of variation for this important soil group from a relatively large sample set.

The textural class is concentrated in the clay and clay loam classes, with individual profiles located in the sandy clay and sandy clay loam classes in the A1 horizon and B1 horizon (Figure 6.3). Despite a relatively large sample size for the B2 horizon, only the clay texture class is represented (Figure 6.3). Within the clay textural class profiles have more than 10% silt, and seldom exceed the boundary at 40% silt (the diagonal line).

In examining the textural triangle and histogram figures (Figures 6.3 and 6.5) for the A1, B1 and B2 horizons of the Hutton Form there appears to be only one (1) natural body. For the B1 horizon the range in clay percentage is commonly from 35% to 75%, with clay percentages in excess of 80% also being measured. Since the sample size is large, the mean value for an important property such as clay percentage will probably not be appreciably affected by low or high outlier values. However, what is an acceptable measure of the range in the property values, in this case clay percentage? The maximum value of 81% (Table 6.2) appears acceptable, since high clay contents have come to be expected for soils derived from dolerite. The minimum value of 20% seems less acceptable. It is commonly thought that mixing of dolerite derived soils with those from Karoo sediments could easily give rise to low clay percentages. However, various pieces of evidence do suggest that the lower clay percentages are possible on dolerite derived soils. The mean clay percentage for the B1 horizon of 53.4% (Table 6.3) gives a central value, with one standard deviation (SD) above and below this mean accounting for approximately 67% of the range of variation. This range could then be defined as from 39.6 to 67.2% (53.4% plus and minus 13.8%). The mean plus and minus two standard deviations better approaches the range shown in Figures 6.3 and 6.5. Statistically this accounts for 95% of the variation. The values of 25.8 to 81.0% correspond more closely with the range in Figures 6.3 and 6.5, and appear acceptable. The median for clay percentage is 54.0% which does not differ much from the mean value. Similarly, lower and upper quartile values appear not to adequately define the range in clay percentage, accounting for the central 50% of observation values.

The mean and median values for many of the soils (with smaller or larger sample sizes) and soil properties (e.g. clay percentage) are very similar. Median values are superior where the central value of a population is strongly influenced by very high or very low values. This does not appear

Table 6.3 Means and standard deviations of five particle size classes for soils of the Jurassic Dolerite.

Hori zon	Depth mm	Clay %		Silt %		Fine Sand %		Medium Sand %		Coarse Sand %		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Form: Hutton												
A1	340	48.6	11.5	23.7	10.7	16.2	10.1	4.7	4.5	3.5	3.0	107
B1	782	53.4	13.8	19.8	9.1	17.9	10.6	4.3	4.3	3.6	4.9	250
B2	1146	55.0	12.7	20.4	8.5	17.5	10.9	3.1	2.8	2.8	2.2	44
Form: Griffin												
A1	304	45.1	12.4	30.6	11.6	13.4	7.5	2.6	1.6	4.1	3.0	17
B1	725	45.8	13.1	18.2	10.9	17.4	9.1	8.3	7.9	9.3	8.1	37
B2	1229	49.6	17.3	21.8	9.6	18.9	12.6	3.6	4.7	2.9	1.6	10
Form: Clovelly												
A1	312	45.6	11.8	31.9	7.0	14.6	11.5	2.6	2.4	2.4	0.7	8
B1	715	44.5	9.4	28.1	9.8	18.4	12.3	3.6	4.8	3.6	2.7	17
Form: Inanda, Magwa, Kranskop												
A1	522	41.8	9.3	29.9	15.5	16.2	10.8	5.8	8.5	4.0	3.5	11
B1	933	48.5	13.0	21.5	11.9	19.2	9.1	5.5	4.3	4.0	2.7	6
Form: Shortlands												
A1	327	51.9	13.8	20.2	8.0	18.5	11.0	5.0	4.9	3.3	2.7	54
B1	792	61.1	12.0	17.8	8.2	14.4	8.7	3.6	4.0	2.6	2.5	136
B2	1196	58.8	16.4	17.2	9.2	16.6	8.9	5.2	7.5	3.3	4.0	20
Form: Arcadia												
A1	492	51.5	11.7	18.4	4.7	21.1	8.2	4.7	2.6	3.5	2.2	25
A2	600	54.2	8.0	15.6	5.8	20.1	7.3	4.3	2.1	4.1	1.9	14
Form: Rensburg												
A1	686	50.3	7.0	19.5	4.8	21.9	4.0	4.6	3.0	3.4	2.1	8
G1	1140	57.9	7.0	16.6	4.1	17.5	1.4	4.8	2.4	4.3	2.0	7
Form: Bonheim												
A1	360	41.4	9.7	19.8	8.4	21.8	6.2	6.3	5.1	6.6	7.0	23
B1	719	50.7	11.1	17.5	6.3	18.0	6.4	5.1	4.6	4.0	3.4	21

Table 6.3 continued. Means and standard deviations of five particle size classes for soils of the Jurassic dolerite.

Hori zon	Depth mm	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
		%		%		%		%		%		
Form: Mayo												
A1	334	43.0	9.0	16.2	7.3	24.6	6.7	7.6	4.4	7.5	4.8	27
B1	812	33.6	16.6	20.6	9.1	29.0	6.1	8.0	2.8	8.0	5.0	5
Form: Katspruit												
A1	310	41.8	9.7	26.8	11.8	16.0	12.8	2.0	0.0	3.0	0.0	4
G1	997	52.0	12.9	22.8	14.4	17.5	1.5	1.5	0.5	3.0	0.0	4

to be the case for particle size properties and a number of other soil properties as well. The mean values have been subsequently chosen and are reported. Standard deviation above and below the mean value gives a good measure of the range of variation where sample populations are normally distributed (Burrough, 1991). From a visual inspection of the histogram for Hutton soils derived from dolerite, the population appears to be reasonably normally distributed (Figure 6.5). However, for the silt values for many soils (Figure 6.5) this is commonly not the case. The highest silt values are measured for the lowest value classes (commonly less than 10-20% for many soils) with a tail representing the few higher values. Examples of this type of distribution are given here for the medium and coarse sand (Figure 6.5). Here the standard deviation values give limited insight into the range of variation. Pedologists would probably still wish to opt for maximum and minimum values, and choose to ignore those high or low values. Explanation for such high or low values may be given in terms of the inferred soil pedogenesis.

The clay percentages of the B2 horizons range from 45 to 75% (Figure 6.3). The mean value is 55.0%, with a standard deviation of 12.7%. One (1) standard deviation above and below the mean gives a range of between 42.3% and 67.7%, while that for two (2) standard deviations are between 29.6% and 80.4%. This latter range is more applicable to the range shown in Figure 6.5.

There are a number of profiles with clay percentages less than 35% in their B2 horizons. Reasons for this observation could be advanced:

* Soils derived from dolerite may contain lower clay percentages (<35% clay) and weathering to clay sized particles is incomplete. Higher silt and fine sand fractions would be expected.

  However, it is interesting that the silt and fine sand percentages are higher (each commonly greater than 25%) and of similar values to those profiles of the remainder of the dolerite data set. This would suggest that at least some of these profiles could be derived from dolerite.

* Colluviation has taken place in these profiles and the soil parent material is not only derived from dolerite. Additions from other parent materials may have taken place. If this

were true, the particle size distribution should reflect sand and silt grades commonly present in the surrounding Karoo Sediments (commonly the Vryheid Formation with medium grade sands in KwaZulu-Natal). This does not appear to be the case with low proportions of medium sand (commonly less than 10%) and coarse sand (commonly less than 6%).

Sandy loam to sandy clay loam soils (<35% clay) derived from the Vryheid Formation have higher medium and coarse sand fractions than those evident here. Those soil profiles sampled from contact between dolerite and other geological formations have not been included in this part of the study.

* That laboratory analysis of the silt and sand fraction could be incorrect. Whilst this is possible, the analyses have been performed by the pipette method where a direct measure of the silt fraction is obtained. Calgon has been used as a dispersing agent to promote dispersion. Calgon reduces the flocculating action of calcium and aluminium, and promotes dispersion by adding sodium. Highly to moderately weathered red soils derived from dolerite are characteristically impregnated with free iron oxides, derived from the weathering of augite, an iron containing mineral forming a major part of dolerite. Free iron oxides have very strong aggregate stabilization properties, preventing dispersion of clay. Special measures are required to obtain complete clay dispersion in such soils.

Dolerite is a base rich medium to fine grained rock. Higher clay contents are expected in the soils derived from dolerite. However, the analyses also show higher silt and fine sand particle size classes as well. The range in silt values is from 3 to 51% (Table 6.2, Figure 6.5) with a mean of 19.8% and a standard deviation of 9.1% (Table 6.3) in the B1 horizon. Approximately half the profiles sampled have silt values in excess of 20%. The range in fine sand values is from 1 to 53% (Table 6.2, Figure 6.5) with a mean of 17.9% and a standard deviation of 10.6% (Table 6.3) in the B1 horizon. Fine sand is the dominant sand grade (Figure 6.3). Medium and coarse sand comprises only a small proportion of the particle size distribution classes (Table 6.2).

Hutton soils derived from dolerite are dominantly non-luvic. Soils with luvic properties are indicated where the vertical bars have a value greater than 1.3. Half the profiles have a similar clay content in the A1 and B1 horizons, expressed as a ratio of between 1.0 and 1.3. Only one quarter (27%) of the Hutton soils on dolerite has a clay increase in the B1 horizon sufficient to qualify for luvic B horizons. Soils with a luvic B horizon were sampled over all the range of clay content to a maximum of 60%. Luvic properties would be expected to be most strongly expressed in the sandier soils. However, examples of luvic soils in the Hutton Form on dolerite were recorded over the full range of clay contents up to a maximum of about 60%. Thereafter the criterion of 1.3 times the clay content of the A1 horizon requires a relatively large clay percentage increase in the B1 horizon to qualify for luvic families. Higher ESP values do not appear to be present in the luvic B horizons. Approximately one quarter of the profiles has less clay in the B1 than in the A1 horizon. Clay contents between the B1 and B2 horizons commonly are similar (Table 6.2, Figure 6.9) or show a small decrease.

The low degree of eluviation in the Hutton soils from dolerite is not surprising. Only water-dispersible clay can undergo eluviation. As indicated earlier, the high free iron oxide content of these soils stabilizes the clay against dispersion.

Griffin and Clovelly Form

There appear little differences in the textural distribution between the Griffin and Clovelly soils and the Hutton soils. In the Griffin Form only 20% of the profiles were luvic. However, half of these profiles had a lower clay content in the yellow-brown B1 horizon, than in the A1 horizon. It must be postulated that an eluvial process operates in these Griffin soils. This trend extends to most Griffin soils sampled in the database. In the Clovelly soils, no profiles were noted to be luvic. The sample size was limited.

Shortlands Form

The texture classes of the Shortlands Form differ little from those of the Hutton Form (Tables 6.2 and 6.3, Figure 6.6). There are a few profiles which have a sandy clay loam texture in the A1 horizon, but none have this texture class in the B1 horizon. The series classes with less than 35% clay (MacVicar *et al.*, 1977) would only rarely be necessary for red structured soils derived from materials other than basic igneous rocks.

Luvic properties were present in 30% of the Shortlands profiles.

Arcadia and Rensburg Forms

Soils of the Arcadia and Rensburg Forms only had a clay texture class. They exhibit a narrow range in all particle size classes (Table 6.2, Figure 6.7). In contrast to the Hutton and Shortlands Forms, high clay percentages (greater than 60%) are rather surprisingly absent (Figure 6.7). Means and standard deviations for particle size classes are presented in Table 6.3.

Bonheim and Mayo Forms

The A1 horizons of the Bonheim and Mayo Forms have textures in the clay, through clay loam and sandy clay to sandy clay loam classes (Table 6.2, Figure 6.7 and 6.8). This is similar to those of the Hutton and Shortlands Forms, although the high clay percentages (greater than 60%) are absent (Figure 6.7 and 6.8). The majority of Bonheim profiles are non-luvic (Table 6.2). Means and standard deviations for particle size classes are presented in Table 6.3.

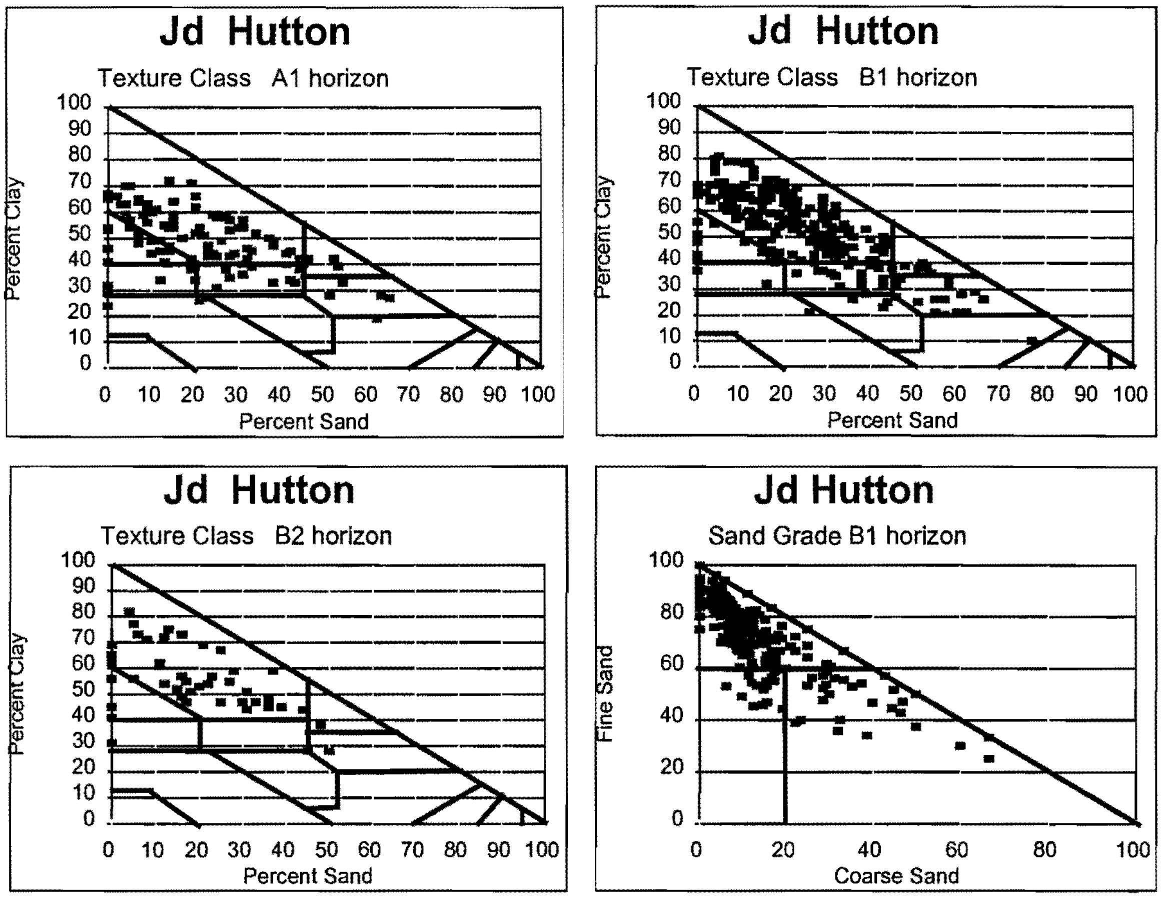


Figure 6.3 Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

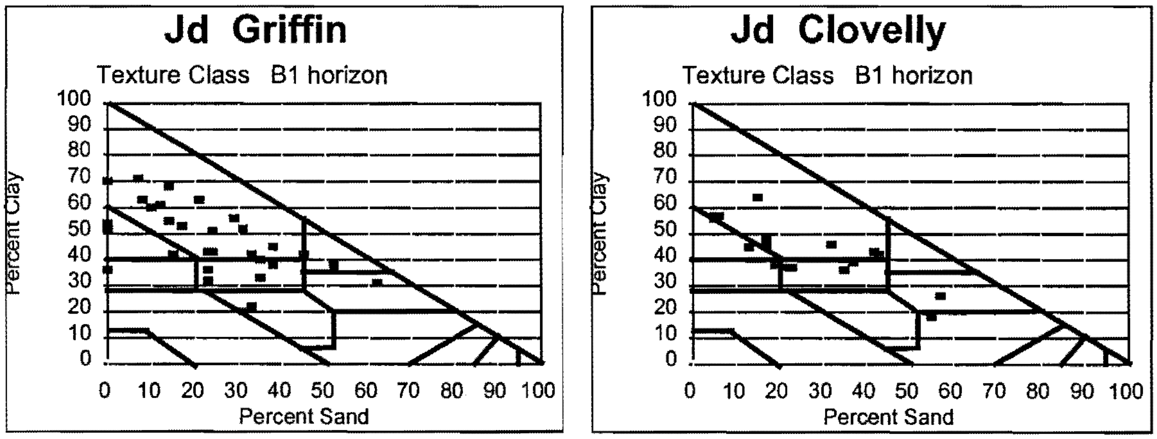


Figure 6.4 Distribution of soil textures within soils of the Griffin and Clovelly Forms.

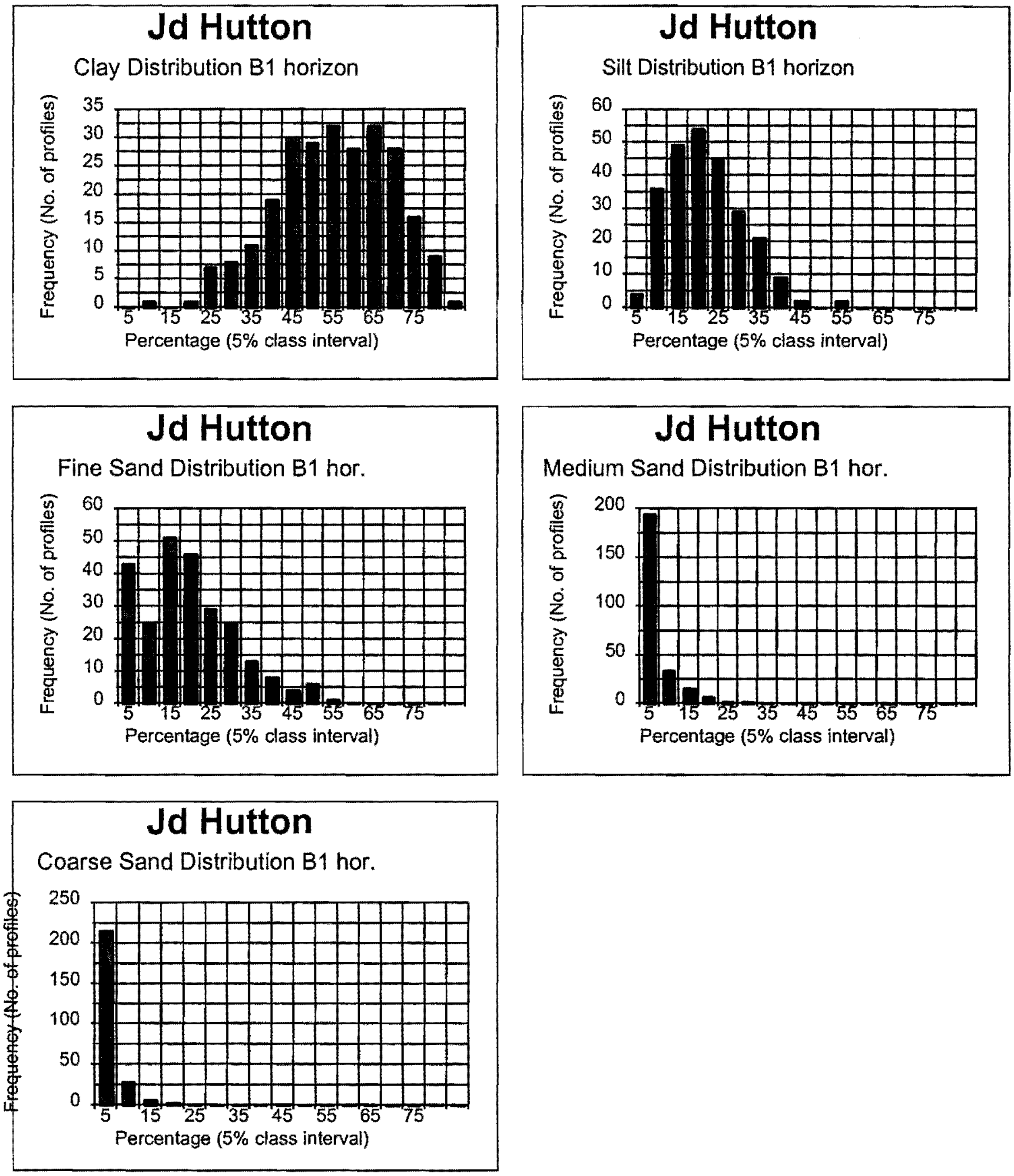


Figure 6.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

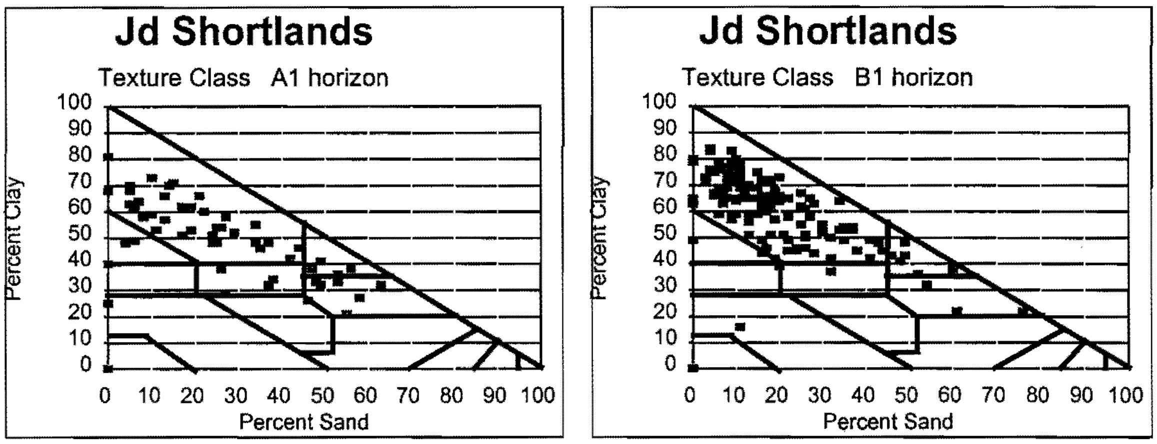


Figure 6.6 Distribution of soil textures within soils of the Shortlands Form.

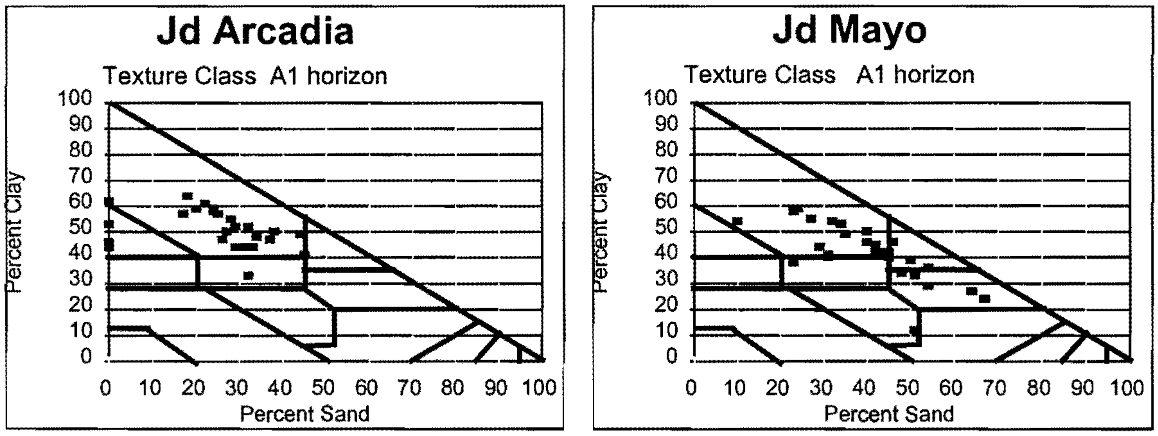


Figure 6.7 Distribution of soil textures within soils of the Arcadia and Mayo Forms.

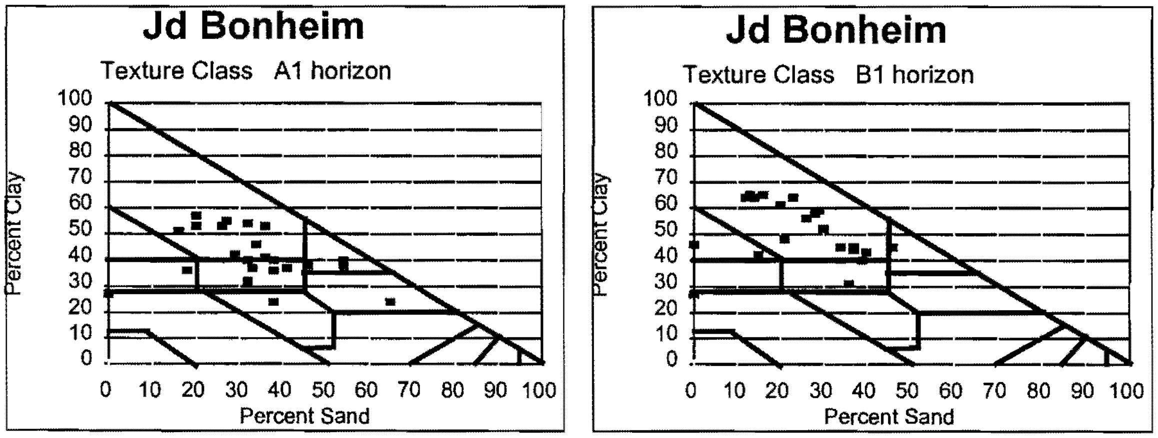


Figure 6.8 Distribution of soil textures within soils of the Bonheim Form.

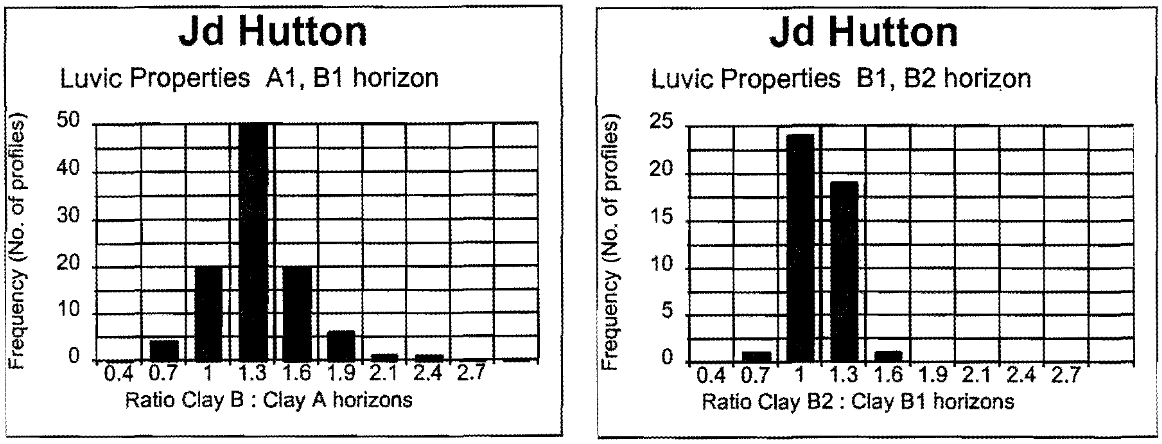


Figure 6.9 Luvic properties of soils of the Hutton Form.

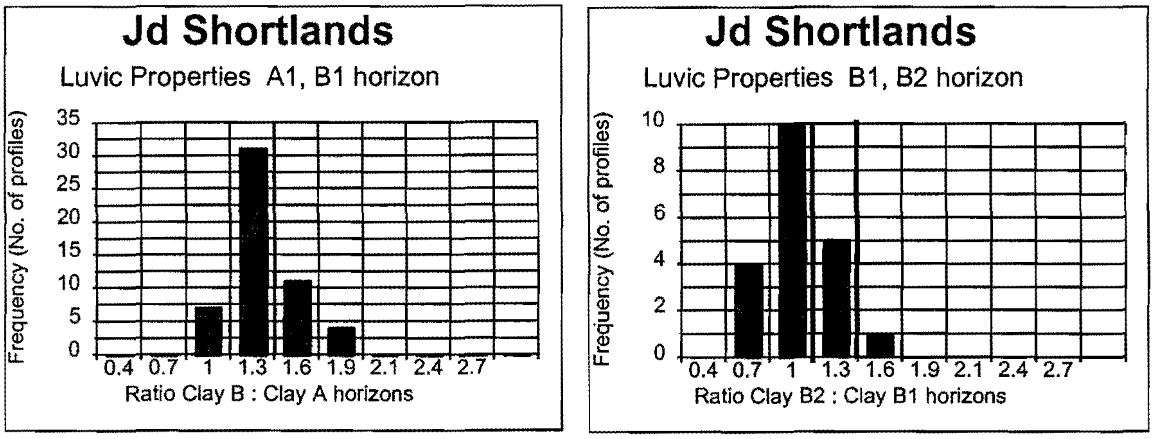


Figure 6.10 Luvic properties of soils of the Shortlands Form.