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SOILS OF KWAZULU-NATAL AND MPUMALANGA: RECOGNITION OF NATURAL SOIL BODIES

by

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Thesis submitted in partial fulfilment of the requirements of the degree of
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ABSTRACT

"Natural soil bodies can be identified with limited ranges of variation in soil properties and in the extent of their locations"

This hypothesis statement is central to the document. The information which follows sets out the extent to which this statement is true. It strives to do this in two main respects. The first is to document the soil forms that are regularly encountered in association with each of the major geology formations in KwaZulu-Natal and Mpumalanga. The second is to record the range of variation sampled from the length and breadth of these provinces. Each in its own right represents a statement of the natural soil bodies encountered from numerous observations and samples collected by soil scientists over the last thirty years. This document draws together these soil bodies, and it is hoped, provides new insights into the soils of KwaZulu-Natal and Mpumalanga and their properties.

The history of the soil series class, and their inclusion within the soil classification systems of the United States of America, South Africa and elsewhere are reviewed. The accent over the years placed on the soil series and its role within the scope of soil classification systems of their day reflects the changing emphasis and concepts of the soil series. Important in this regard are the recognition of soils as natural entities, initially with much emphasis placed on their morphological properties. Later the concepts as natural soil bodies, and of the soil series classes within classification systems held prominence. Increasingly emphasis is being placed on soil property values, and the distribution of these values over the landscape. Statistical manipulation of soil information within the framework of the electronic information systems places another emphasis on soil information. Each of these concepts and tools has brought understanding to our

knowledge of soils and of their distribution.

The study has collected the soil profile information from 4 000 sites over the provinces of KwaZulu-Natal and Mpumalanga. Each profile has been linked to a geographic co-ordinate, an underlying geological formation, and entered into computerised databases. After linking and verifying the information it was available for study and analysis. Soil textural information was extracted from the database for each soil form and for each geological formation. The hypothesis that natural soil bodies could be identified rests on the premise that geology formations could effectively be used as tools for separating soil bodies. Extensive use is made of the soil textural triangle and visual interpretation where actual soil profile data is plotted. The results of these separations are quoted in the text, in tables and in figures reported in chapters devoted to each of the major geological formations of KwaZulu-Natal and Mpumalanga. The text place emphasis on numerical soil values such that the central value can be comprehended and possible ranges in variation progressively visualised and determined. This information is reported for the soil textural properties, although the process could be repeated for other soil attribute values as well. For certain of the well sampled and studied soils the range of variation and central value can be clearly illustrated and comprehended. Other soils have been sampled only infrequently such that estimates of soil textural properties only can be gained. For many of the soils illustrated in this document the extent of available data lies between these two extremes.

In placing emphasis on numerical soil texture values the central role played by the soil form as an expression of natural soil bodies should not be overlooked. To this end the soil forms commonly encountered overlying a given geology formation are documented. These soil forms are condensed into Broad Soil Patterns based on the observations and views of soil survey specialists involved in the Natural Resources Survey of South Africa. They have been summarised from the extensive soil inventory database of this survey. Generalised climate information of the Broad Soil Patterns is included to give this perspective to the natural soil bodies.

A summary of the soils and their textural properties in KwaZulu-Natal and Mpumalanga is also presented as an independent chapter. Here the soil forms, and hence the natural soil bodies, associated with each geology formation are reported. Generalised sketches illustrating the range in soil textural properties from red apedal soils, through plinthic soils and duplex soils to red and black clay soils are presented. The information reported in each of these summary sketches is recorded in detail in the chapter dealing with that particular geology formation.

In conclusion it has been possible to show that natural soil bodies can be recognised on the basis of soil form classification and within a given geology formation. Much visual and analytical evidence is available to support this statement. In some soils the range in textural properties is limited with profile values clustering closely around a central value. Their definition into soil series classes with clear and limited boundaries could be considered. In other instances the range of soil textural properties, while exhibiting clearly defined boundaries, is much larger than we have chosen to expect within our formerly defined soil series classes. Some modification to our concepts of natural soil series, or some acceptance of arbitrary defined boundary limits should be considered. In still further instances, more than one natural body with respect to texture is illustrated. Additional criteria and sampling are often required to clearly define these soils into proposed soil series classes. Improvement in the understanding of the ranges in property values of soil series remains an important tool in developing our knowledge of soil. The electronic analysis of soil information is progressing together with the development of soil series and soil classification information. The construction of electronic information systems should be seen as an important complement to the information gained through the concepts of the soil series and soil classification. The information presented here strives to reinforce this complementary nature of natural soil bodies with the developing electronic information systems. Finally, some thoughts on the process of defining natural soil bodies, of collecting, administering and disseminating this information are considered.

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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

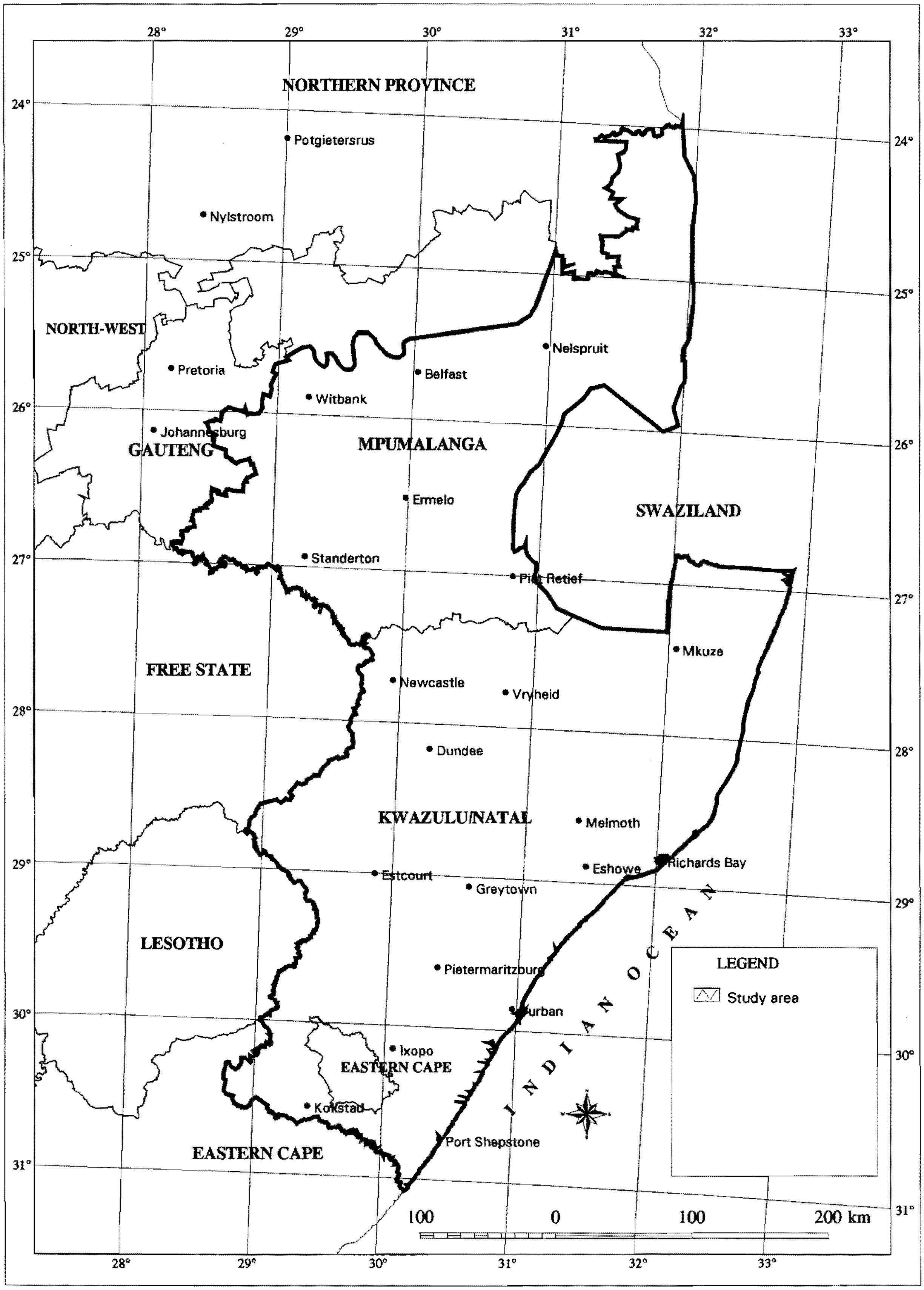


Figure 2.1. Location of the study area in KwaZulu-Natal and Mpumalanga.

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.

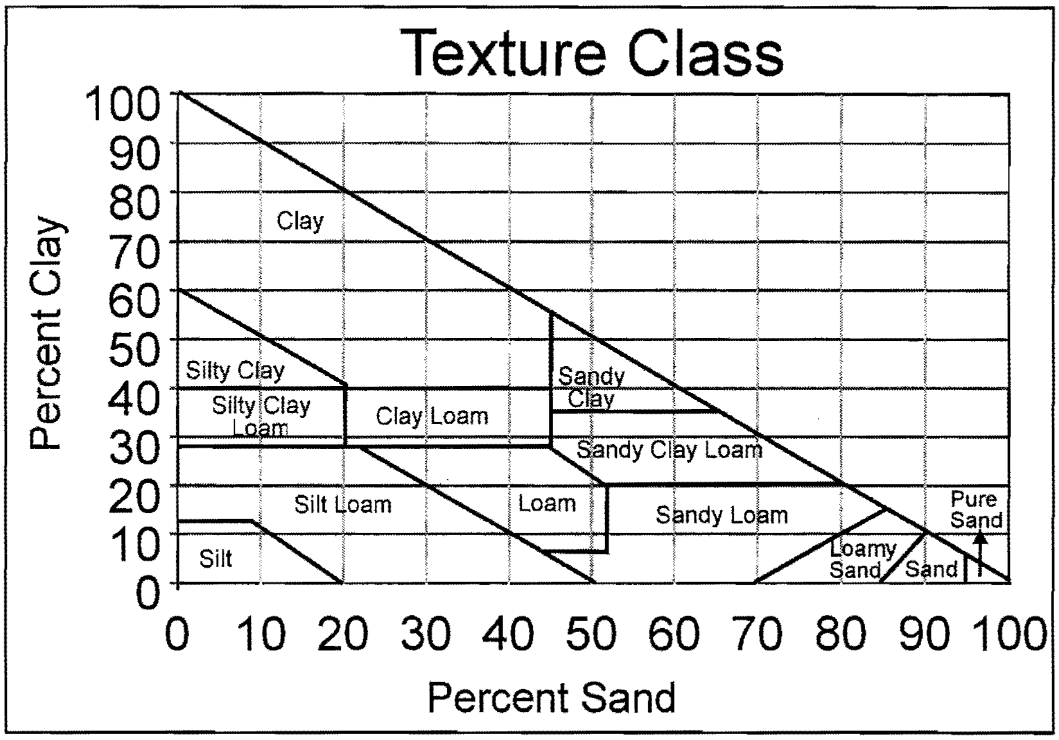


Figure 2.2 The texture triangle chart showing soil texture classes (Canada Soil Survey, 1978).

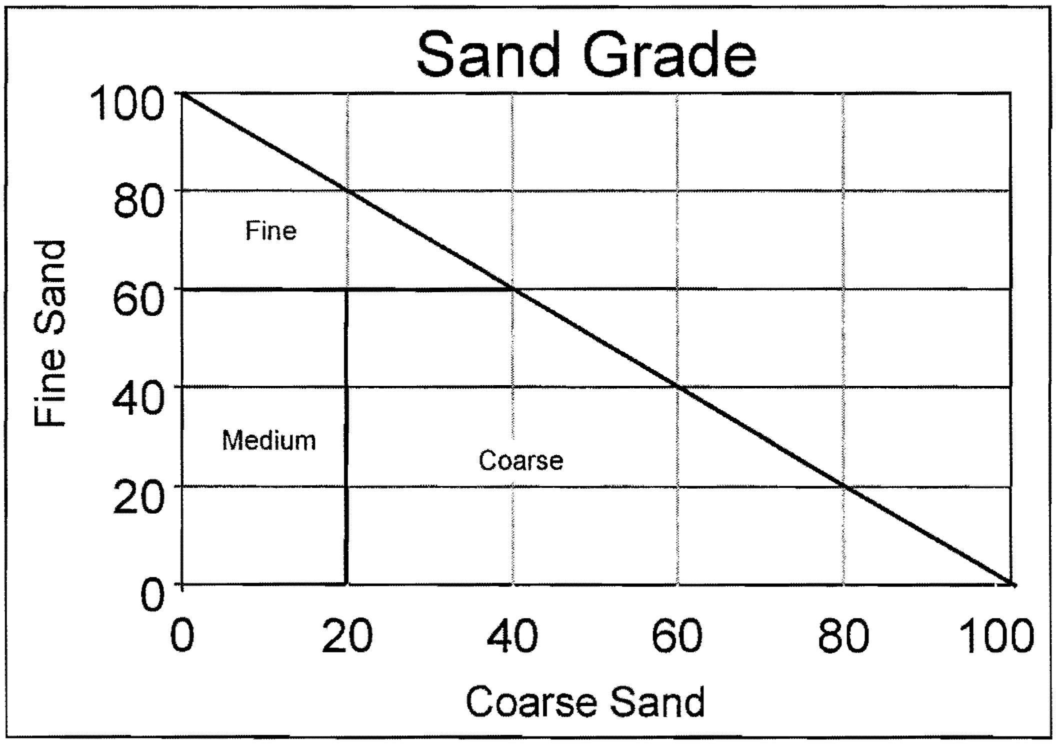


Figure 2.3 The dominant sand grade chart (Soil Classification Working Group, 1991).

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.

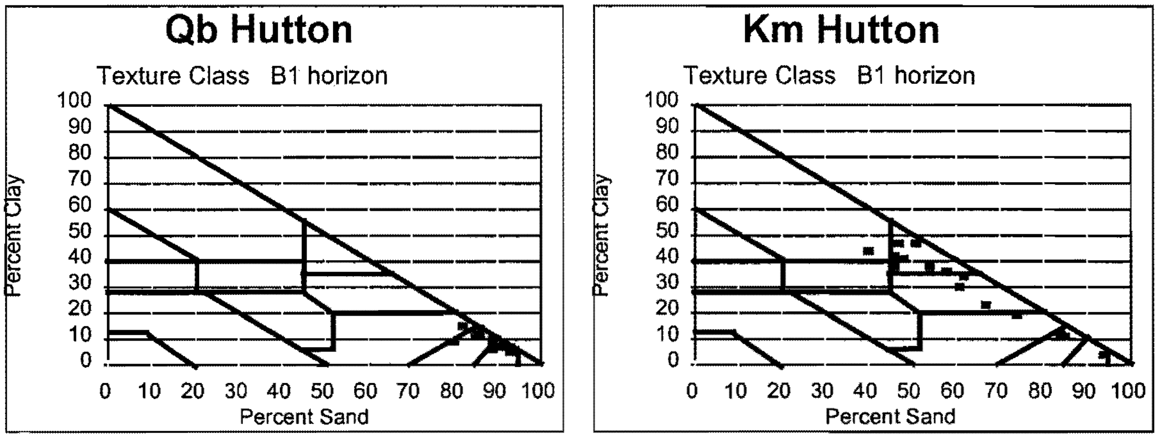
Soil classification has gained widespread acceptance in South Africa as a form of this stratification. The grouping of soils into classes to reduce the range of variability in a class to rational proportions has long been practised by soil scientists. In South Africa little attention has been paid to 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.

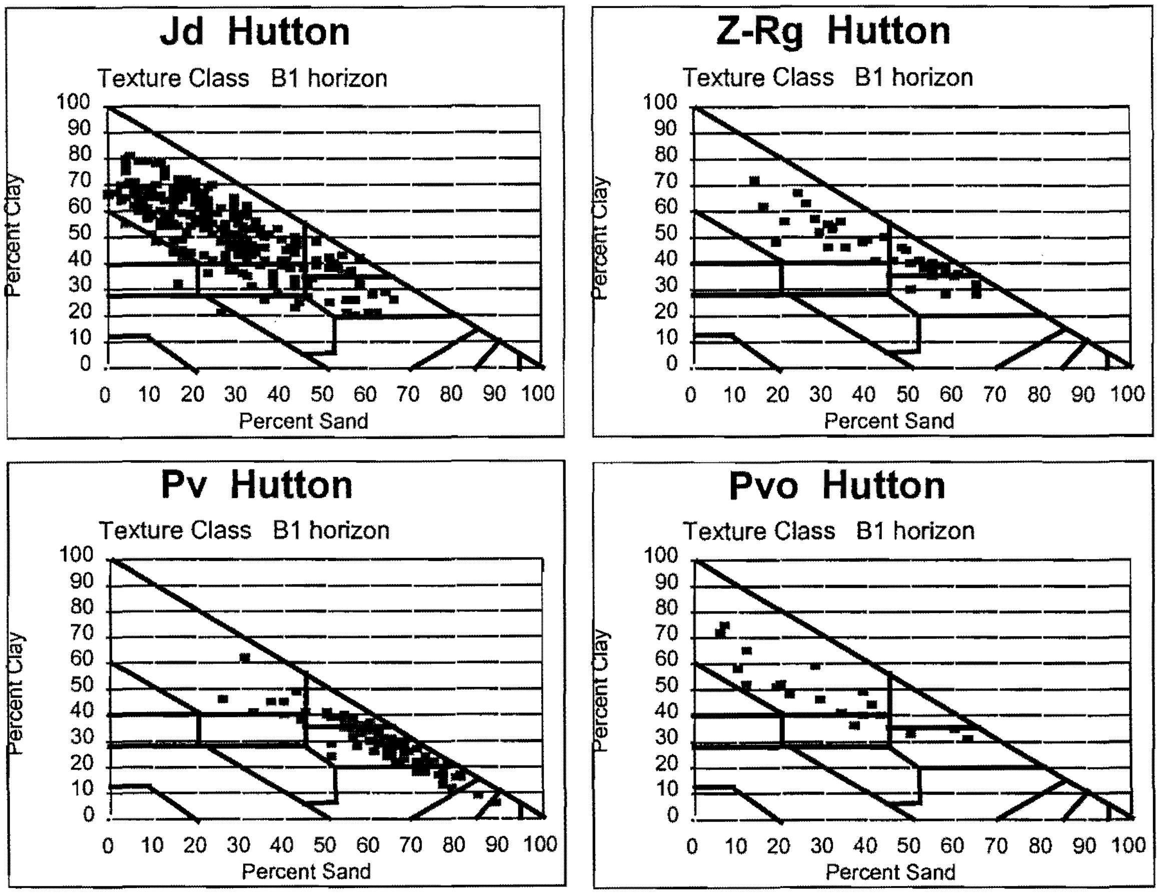


Figure 3.2 Distribution of soil textures for Hutton profiles from Jurassic dolerite (Jd), granite of the Piet Retief District (Z-Rg), and from the Vryheid (Pv) and Volksrust (Pvo) Formations, Ecca Group.

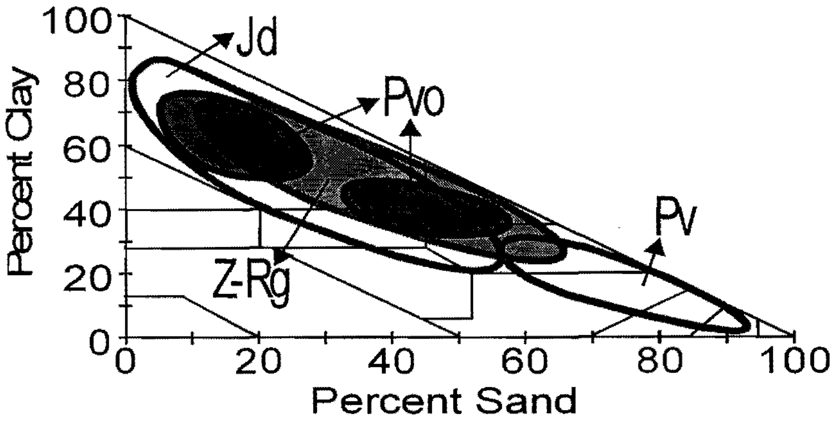


Figure 3.3 Soil texture distributions for four geology formations from KwaZulu-Natal and Mpumalanga.

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.

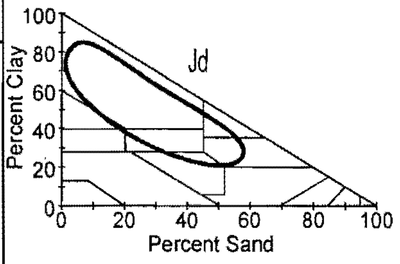
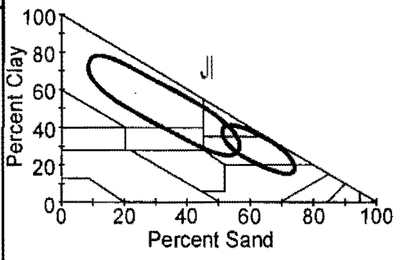
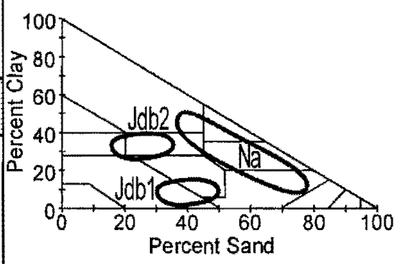
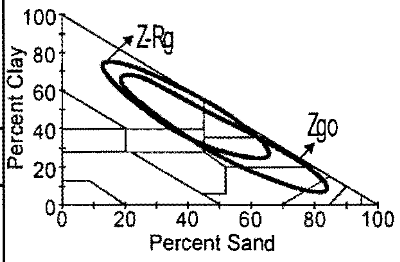
Igneous rocks	
Jurassic dolerite Jd	
* One natural soil body. * Distributed over clay textural class, extending into sandy clay loam in limited number of profiles. * Similar texture distributions in A1 and B1 horizons. * Soils extensively sampled that texture distribution can be described with confidence.	
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.

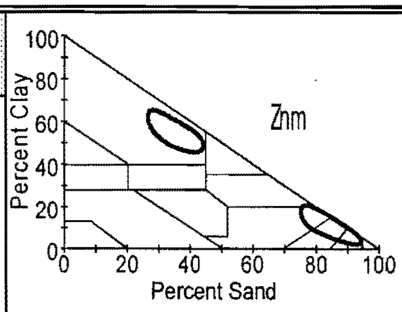
Nelspruit Suite Znm (Potassic gneiss and migmatite component of Nelspruit Suite)	
* Two texture clusters (loamy sand to sandy loam and clay) associated with high and low base status respectively. * Limited range in silt variability.	

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

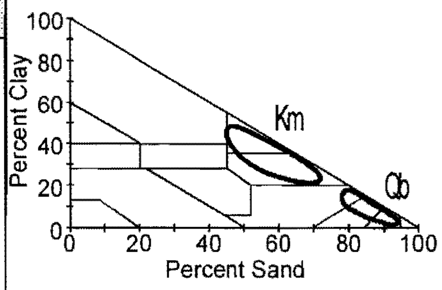
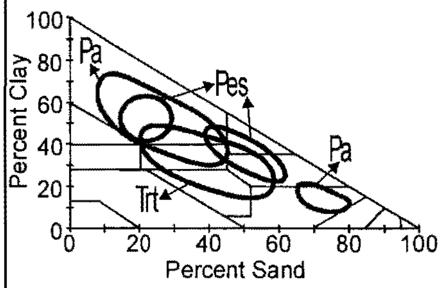
Sedimentary rocks	
Quaternary Sand Formations Qb and Cretaceous Sediment Formations Km (siltstone)	
* Single natural body in each group. * Qb: Sand and loamy sand textures. Medium and fine sand. Generally non-luvic properties between A1 and B1 horizons were determined, with commonly larger clay increases 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.

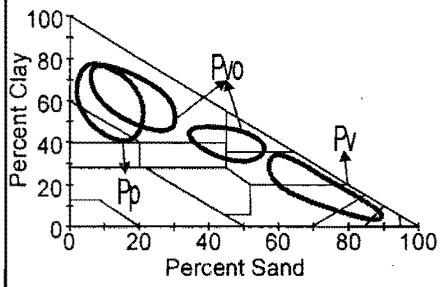
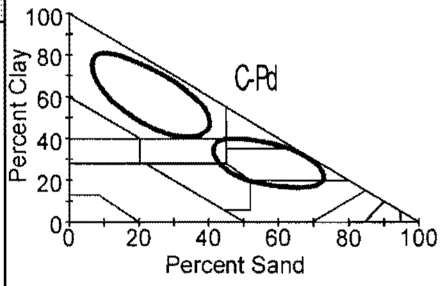
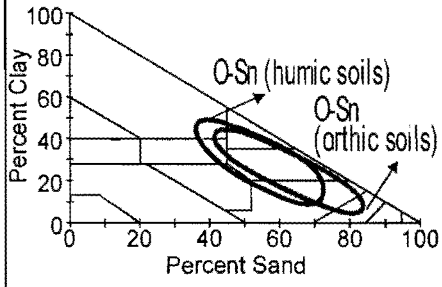
Sedimentary rocks	
Ecca Group	
Volksrust Formation Pvo (mudstone, shale) * Three natural bodies distinguished from all available soil profiles. A dominant feature is the clay textural class in Pvo. * Hutton soils are represented in only two natural bodies with clay and clay loam textures. * Fine sand 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.

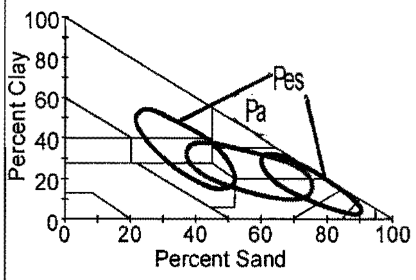
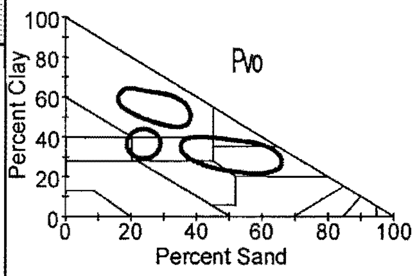
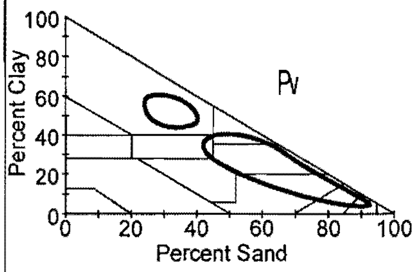
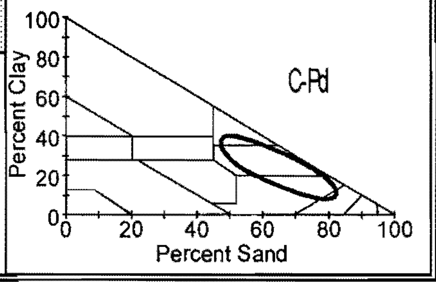
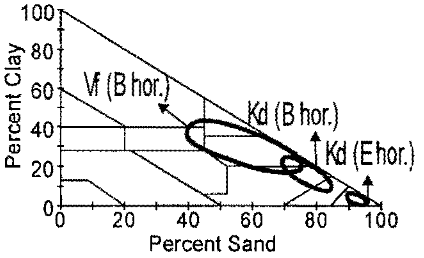
Sedimentary rocks	
Beaufort Group	
Adelaide Subgroup Pa (mudstone, shale) * Avalon (and Glencoe) profiles are represented in the sandy loam textural class. A single profile is from the clay loam textural class. Observations are made from a limited sample size. Estcourt Formation Pes (shale, sandstone) * 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

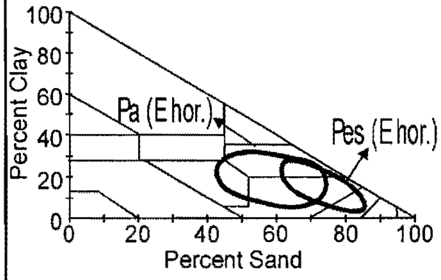
* Single natural body in each soil form (Fw, Ch, Vf, Kd) with regard to the E horizon. B1 horizons (where present) may have limited to larger clay accumulation.
* Sand and loamy sand textures in E horizons. Medium and fine sand. Silt values are less than 8%.
* Kroonstad (Kd) soils, profiles with limited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

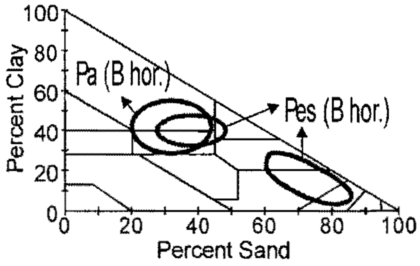


Table 3.6 (continued). Summary of textural properties of soils with an Eluvial (E) horizon.

Sedimentary and Igneous rocks

Ecca Group

Volksrust Formation Pvo (mudstone, shale)

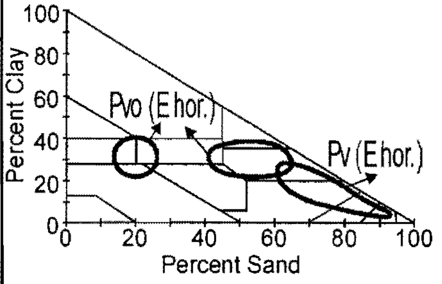
* Two natural soil bodies are represented in soils with an E horizon. A dominant feature is loam texture class.
* Longlands and Estcourt soils are represented in loam and in the sandy clay loam textural classes.
* Fine and coarse sand dominant.

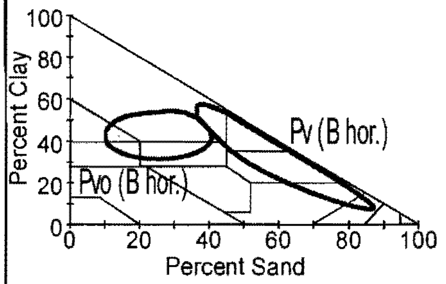
Vryheid Formation Pv (sandstone, shale)

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

Pietermaritzburg Formation Pp (shale)

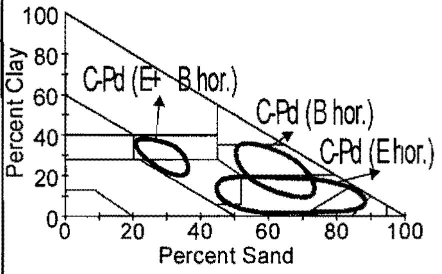
* Longlands and Estcourt soils (A1 and E1 horizons) have clay loam textural classes. (Observations are made from a limited sample size.)





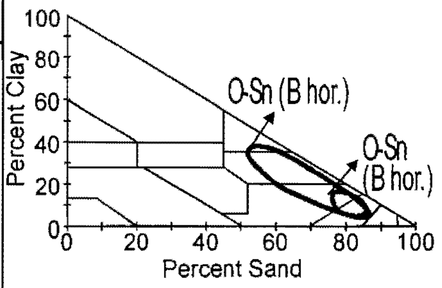
Dwyka Formation C-Pd (tillite)

* 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.)

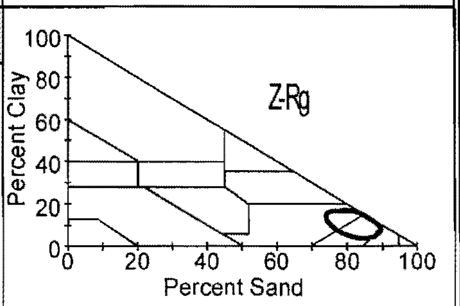


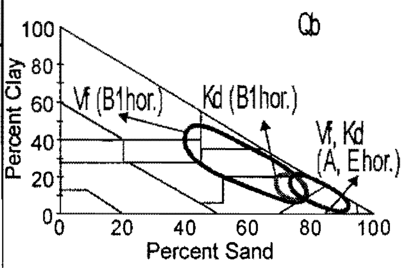
Table 3.7 Summary of textural properties of Swartland, Valsrivier, Estcourt and Kroonstad soils.

Igneous and Sedimentary rocks

Quaternary Sand Formations Qb of the KwaZulu-Natal Coastal Plain

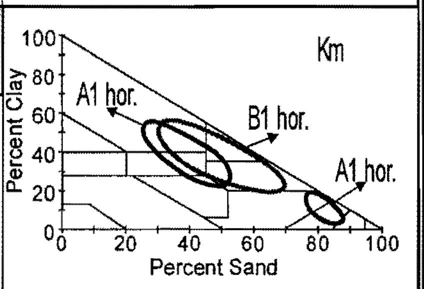
* Single natural body. Vilafontes(#) and Kroonstad Soils. Medium and find sand to loamy sand in A1 and E1 horizons. Vilafontes have a larger clay texture increase to B1 horizon spread over sandy loam through to clay loam. Kroonstad has smaller clay texture increase in the B1 horizon limited to sand and 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

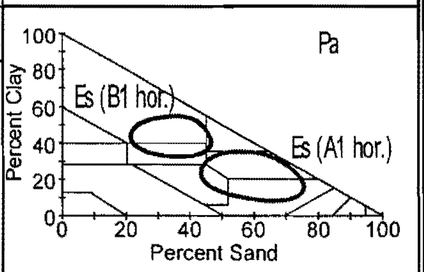
* Single natural body. Valsrivier and Sterkspruit soils. Textures in the sandy clay loam through clay loam and sandy clay to clay classes. Clusters show little difference between A1 and B1 horizons, but with clay increases in the B1 horizons of between 1.3 and 2.1 times that of the A1 horizons.



Beaufort Group

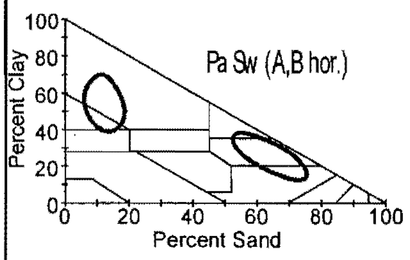
Tarkastad Formation TRt (sandstone, mudstone)

* 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)

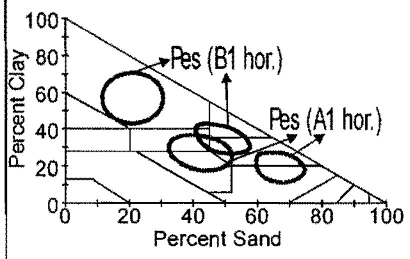


Adelaide Formation Pa (mudstone, sandstone)

* 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)

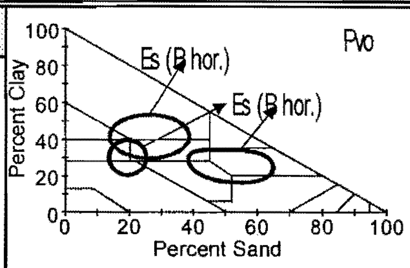
* Estcourt soils. Two indistinct natural bodies have been distinguished on basis of higher and lower silt values. Textures lie in the sandy clay loam through to clay loam classes (A1 and E1 horizons), and in the clay class (B1 horizons). B1 horizon clay percentages appear to be higher than those of the Estcourt soils of the Adelaide Formation.

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

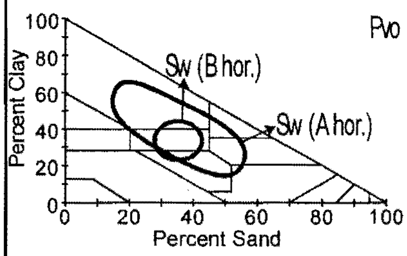
Ecca Group

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.

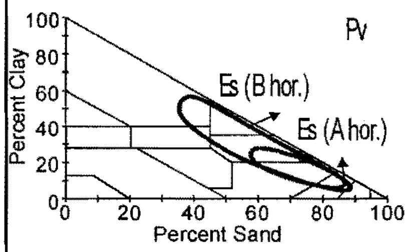


* Swartland soils: A single natural body has been recognised. Textures range from loam to clay loam, and from sandy clay loam and loam to clay for the A1 and B1 horizons respectively.



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.

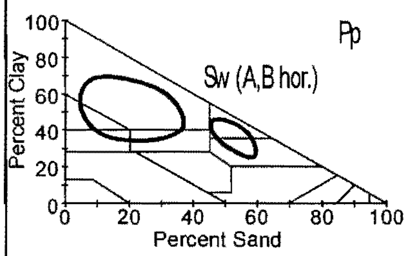


Table 3.7 (continued). Summary of textural properties of Swartland, Valsrivier, Estcourt and Kroonstad soils.

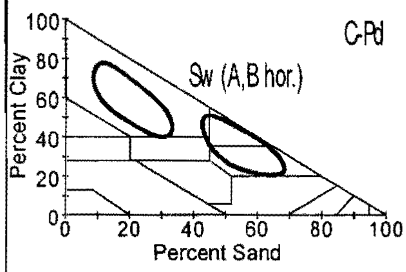
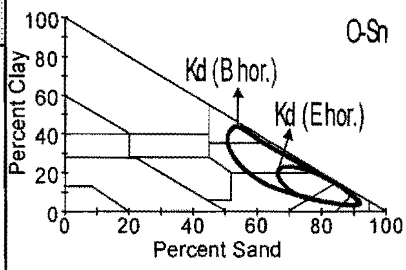
Dwyka Formation C-Pd (tillite)	
* Swartland soils. Show similarities to Swartland soils of the Pietermaritzburg Formation. Two natural soil bodies were determined in the sandy clay loam, and in the clay classes respectively (A1 and B1 horizons). Clusters show little differences between A1 and B1 horizons, 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.	
Natal Group O-Sn (sandstone)	
* Kroonstad soils. Textures are sand (A1 and E1 horizons) over sandy clay loam (B1 horizons). Show similarities to equivalent soils of the Vryheid Formation.	
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 3.8 . 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).

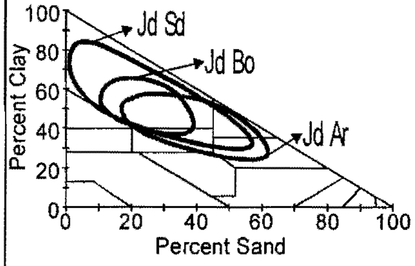
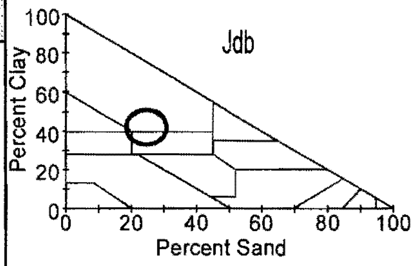
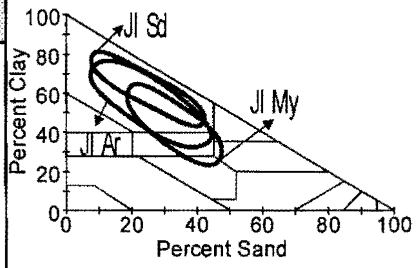
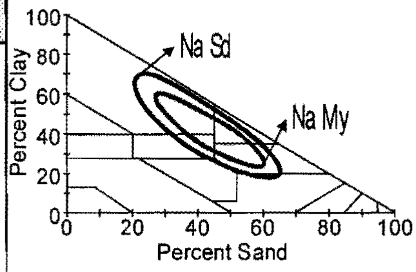
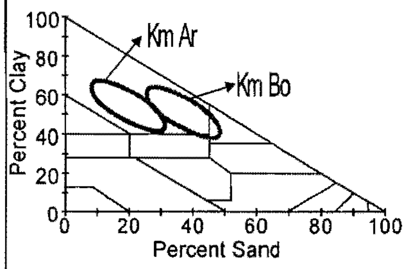
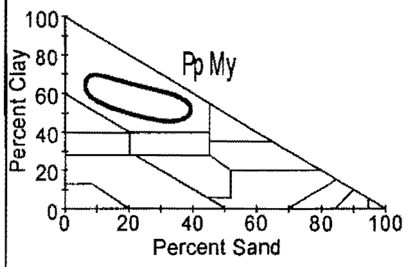
Igneous and Sedimentary rocks	
Igneous Rocks Karoo Dolerite Jd	
Shortlands (red soils) * Clay class (spread over whole class), extends into sandy clay class. * Silt value range (10 - 40%). * Dominantly (75%) non-luvic profiles. * Soils have been extensively sampled. Arcadia (vertic soils) * Clay class, 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.	
Drakensberg Formation Jdb (basalt)	
Mayo and Milkwood (melanic soils) * Clay loam A1 horizons from limited sampling.	
Letaba Formation Jl (basalt)	
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.	
Amphibolite of the Tugela Group and Mapumulo Metamorphic Suite Na	
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.	

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).

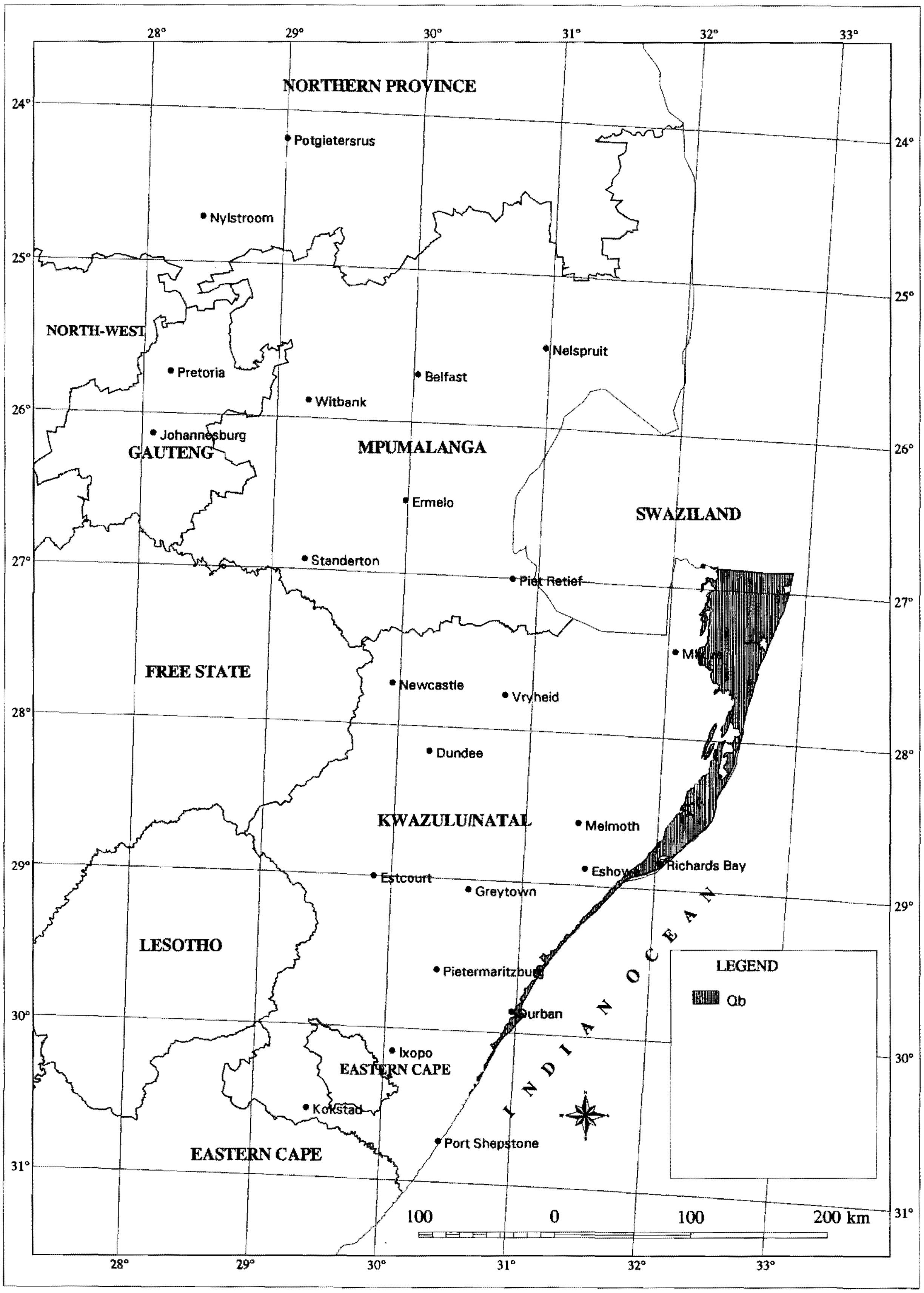


Figure 4.1. Location of Quaternary geology formations in the coast belt of KwaZulu-Natal (after Geological Survey, 1984).

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: Dominant Soils: Form	Series	Mean %	Sub-dominant Soils: Form	Series	Mean %	Climate Relationships (Annual Values): Statistic	Rainfall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red Apedal Sandy Soils (C oast 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

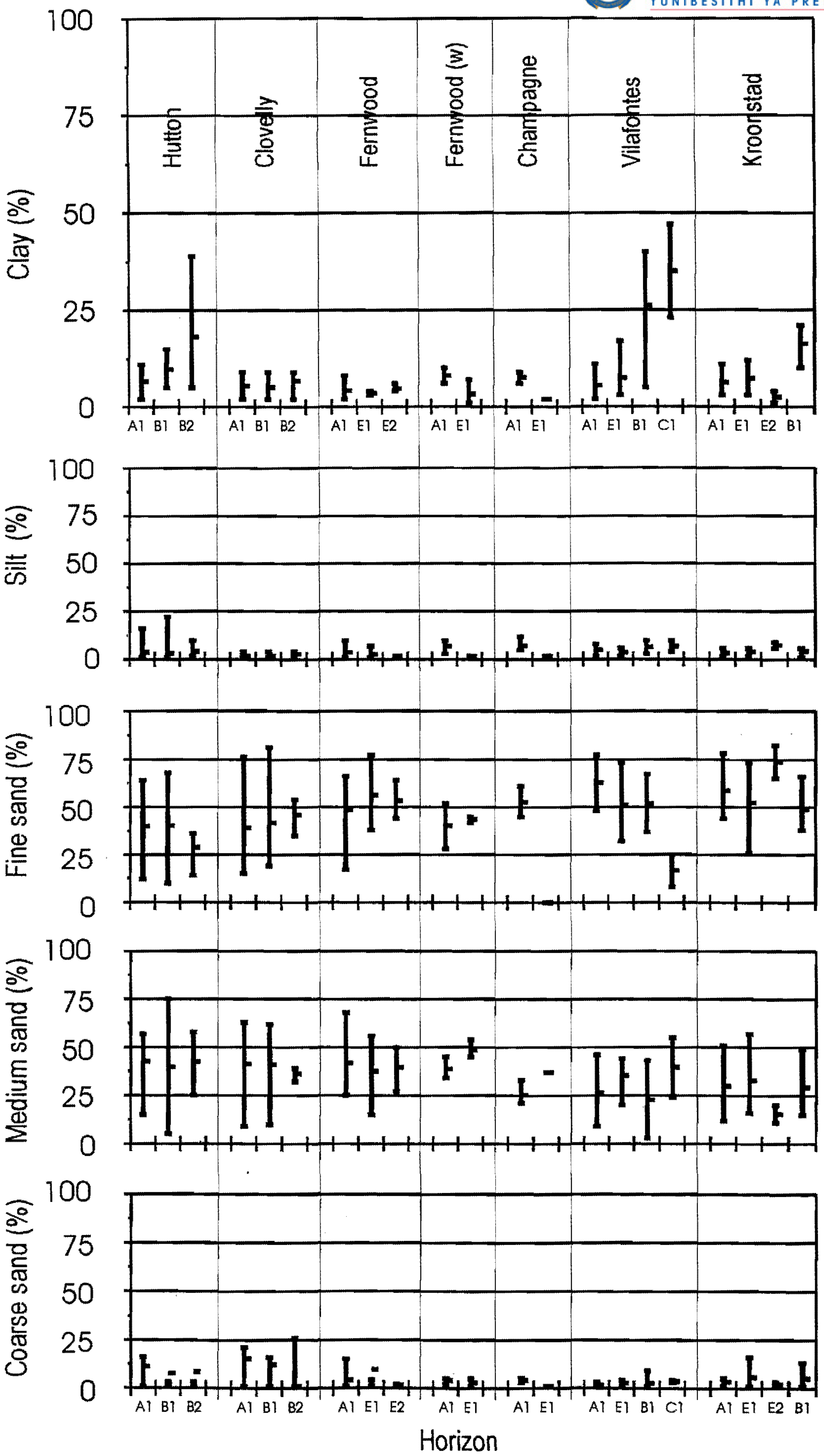


Figure 4.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Quaternary geology. Maximum, minimum and mean values are shown for each horizon.

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.

Horizon	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.

Horizon	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.

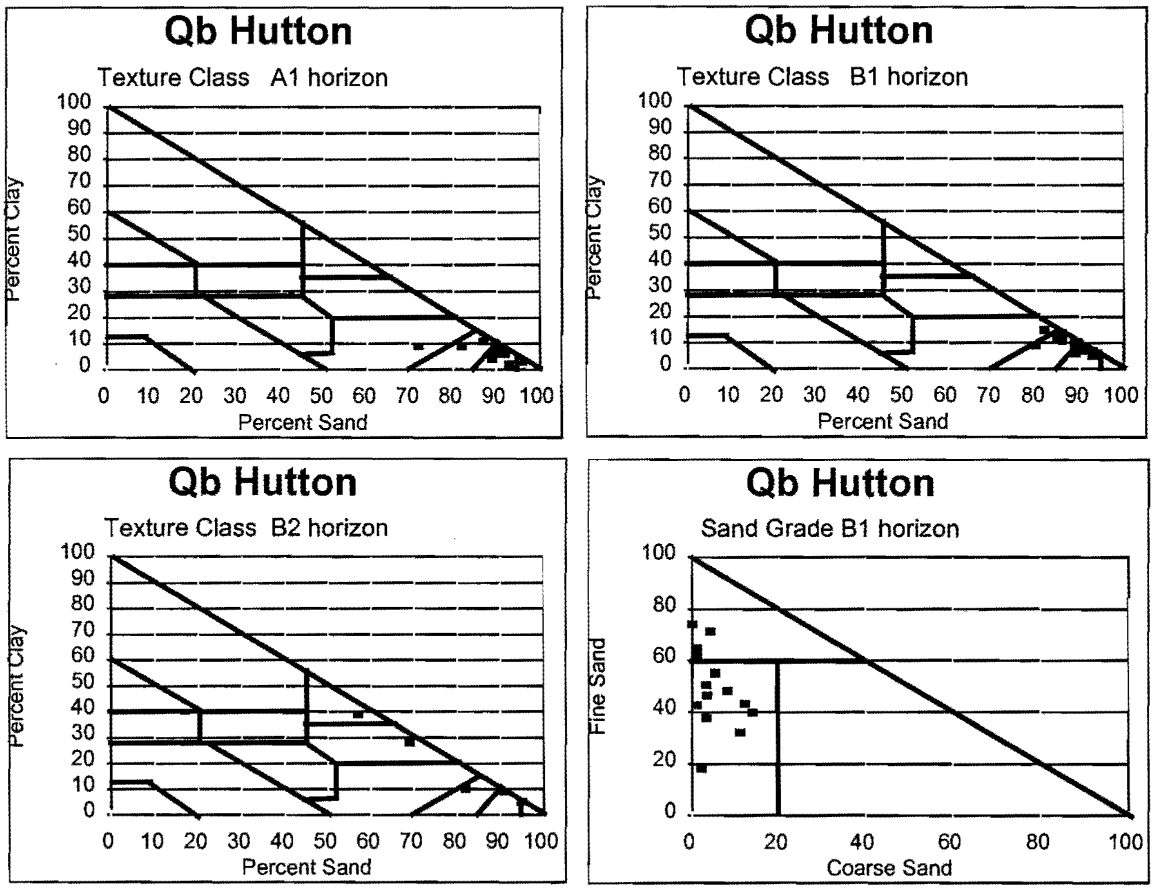


Figure 4.3 Distribution of soil textures, and sand grades, within soils of the Hutton Form.

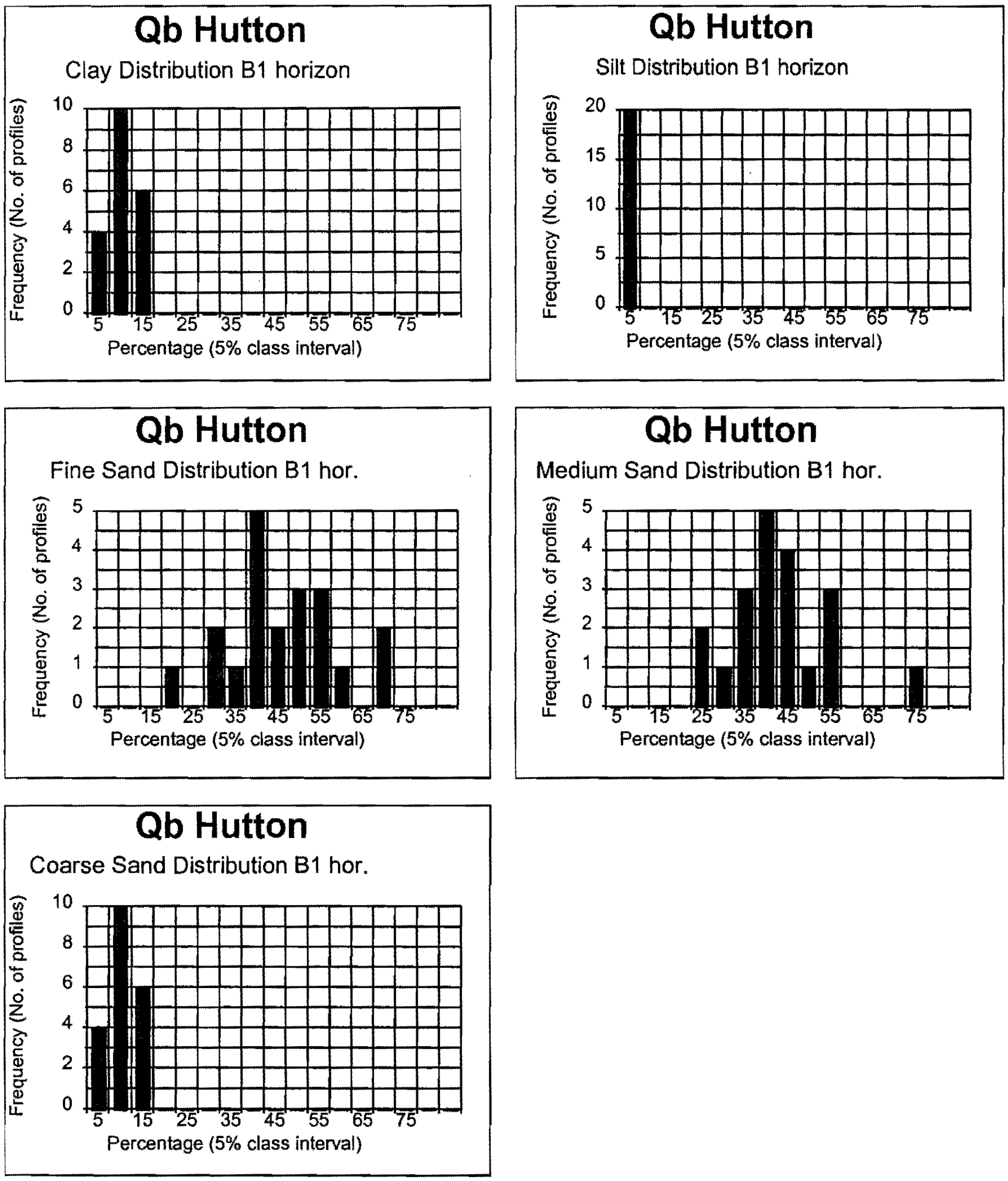


Figure 4.4 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

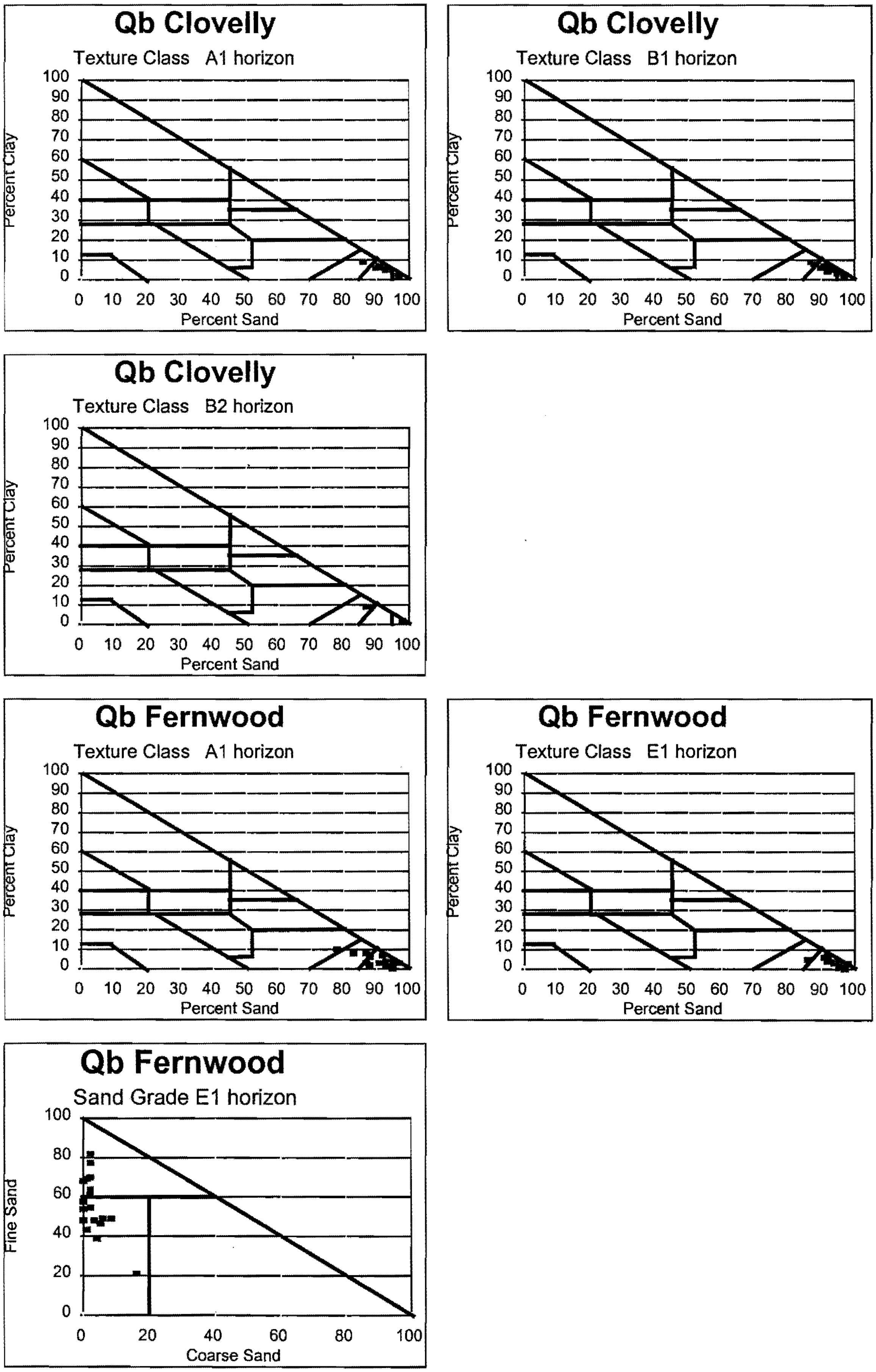


Figure 4.6 Distribution of soil textures, and sand grades, within soils of the Fernwood Form.

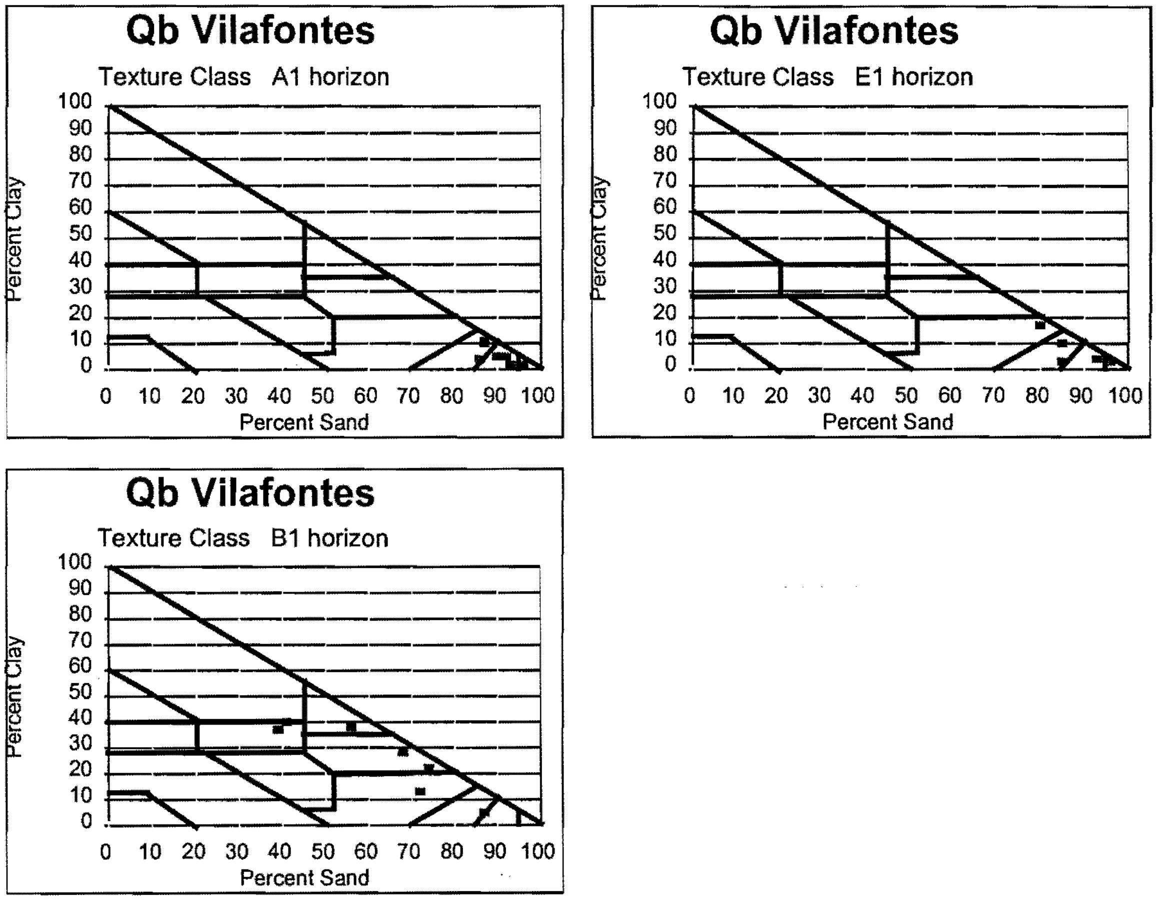


Figure 4.7. Distribution of soil textures within soils of the Vilafontes Form.

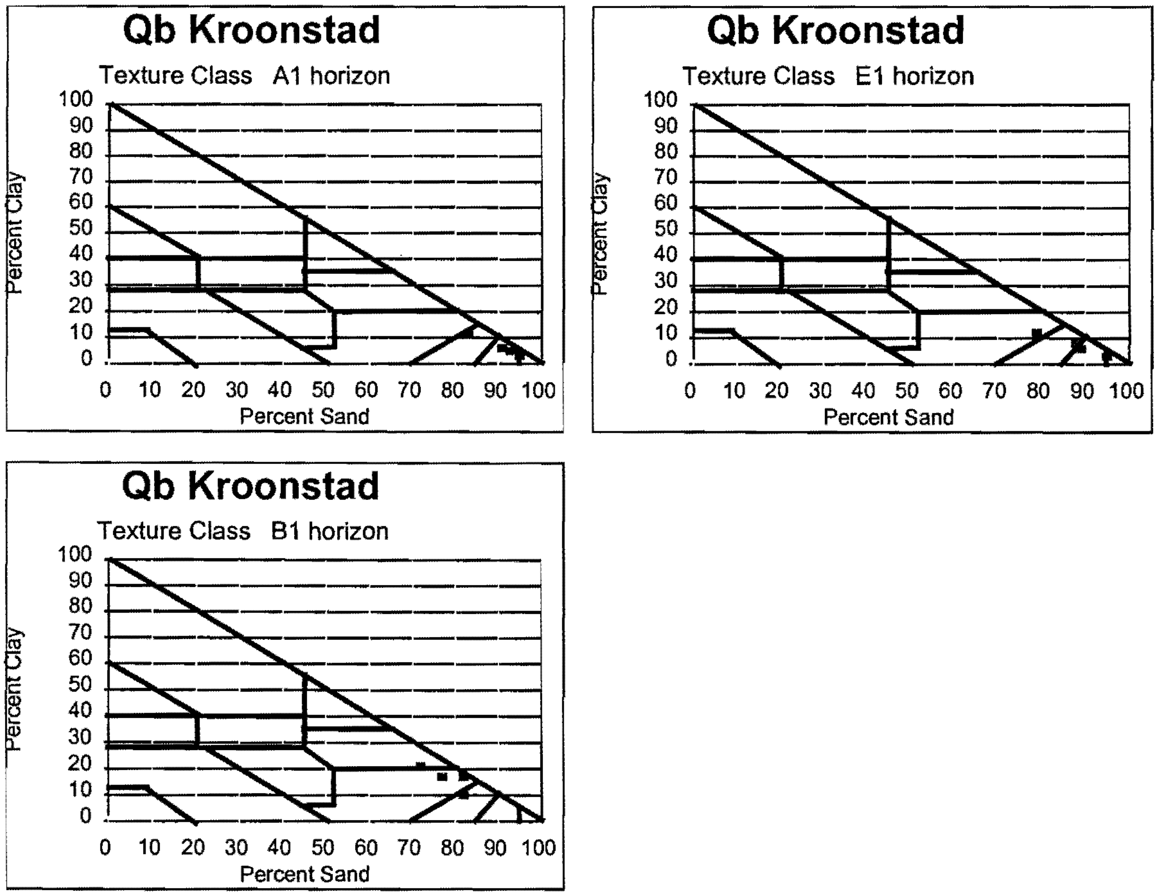


Figure 4.8 Distribution of soil textures within soils of the Kroonstad Form.

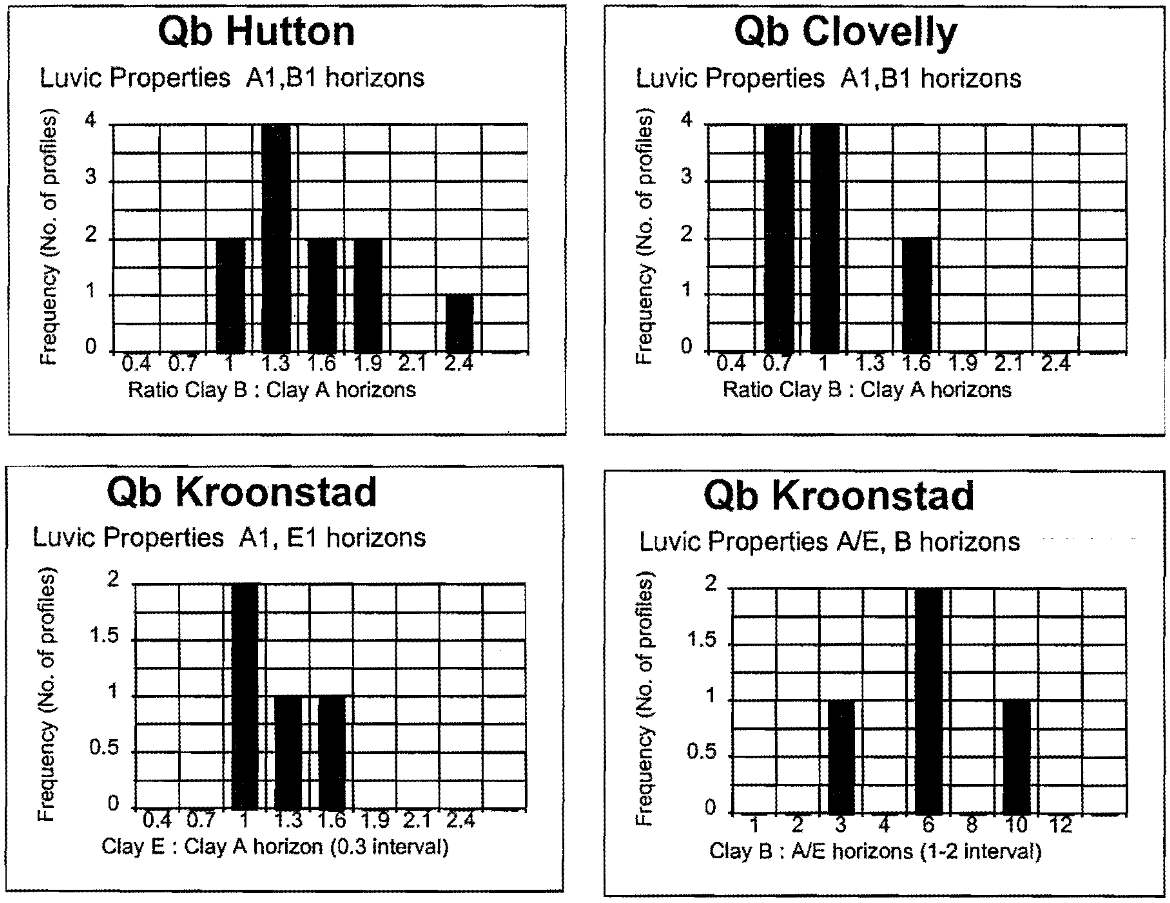


Figure 4.9 Luvic properties within soils Hutton, Clovelly and Kroonstad Forms.

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.

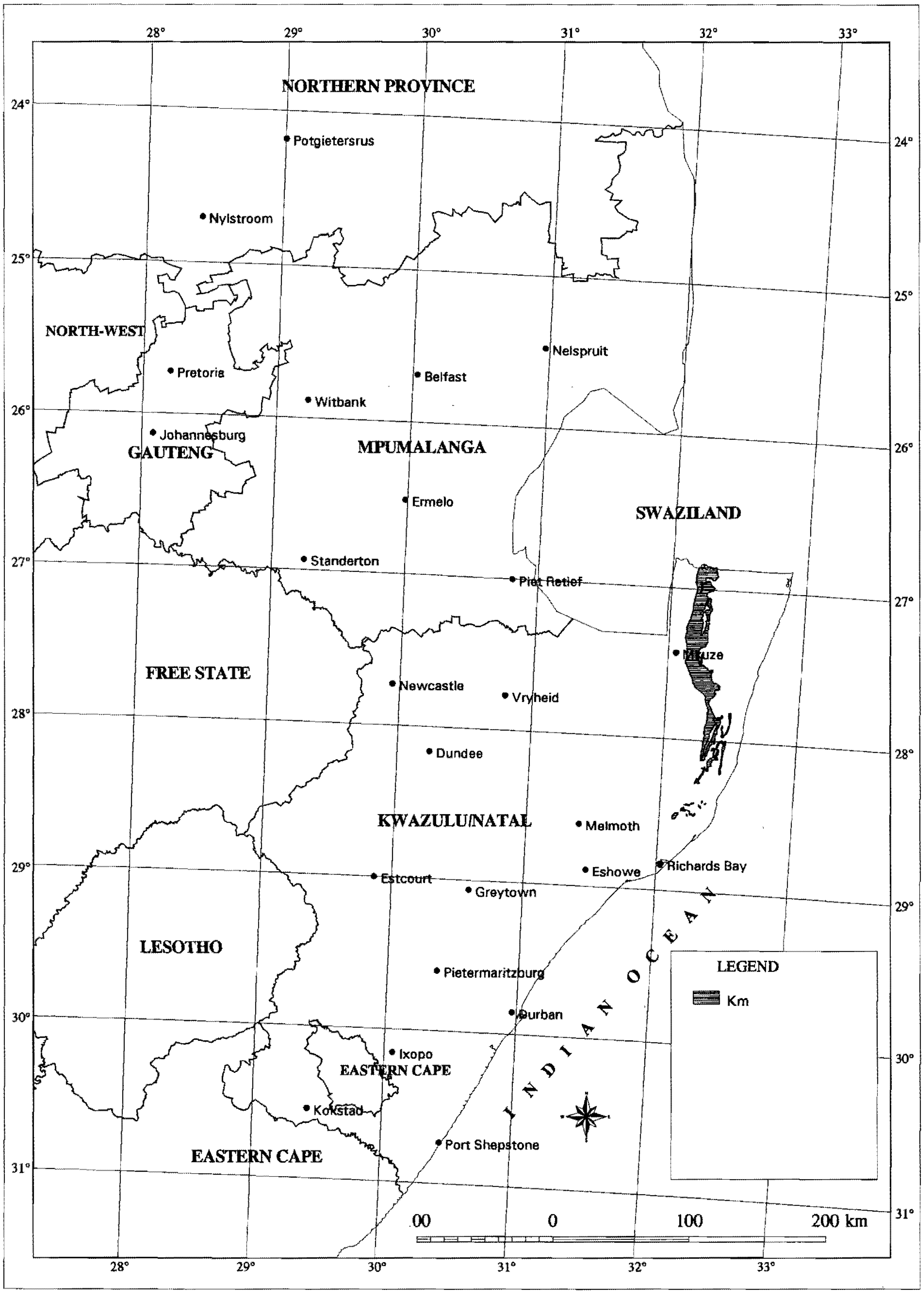


Figure 5.1. Location of Cretaceous geology formations in the coast belt of KwaZulu-Natal (after Geological Survey, 1984).

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

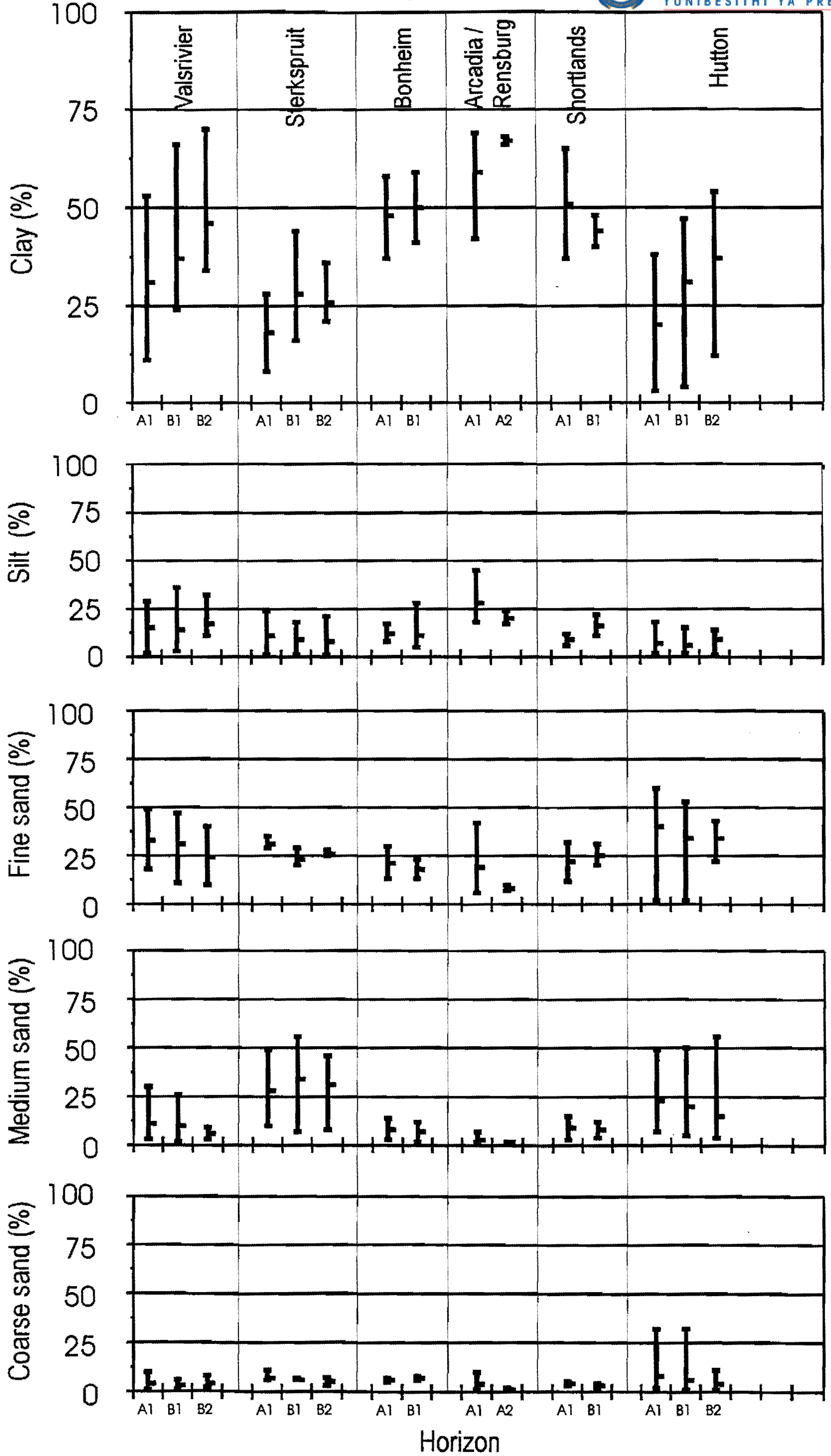


Figure 5.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Cretaceous geology. Maximum, minimum and mean values are shown for each horizon.

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.

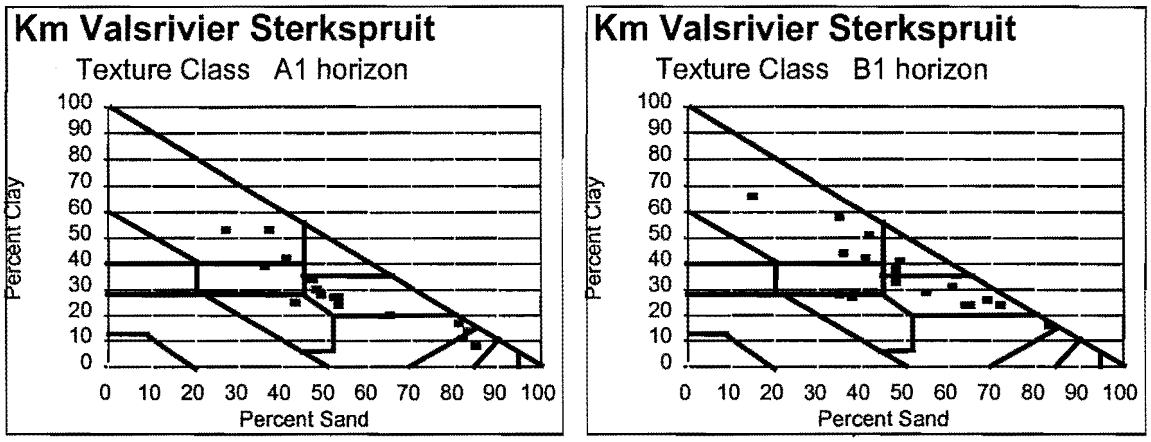


Figure 5.3. Distribution of soil textures within soils of the Valsrivier and Sterkspruit Forms.

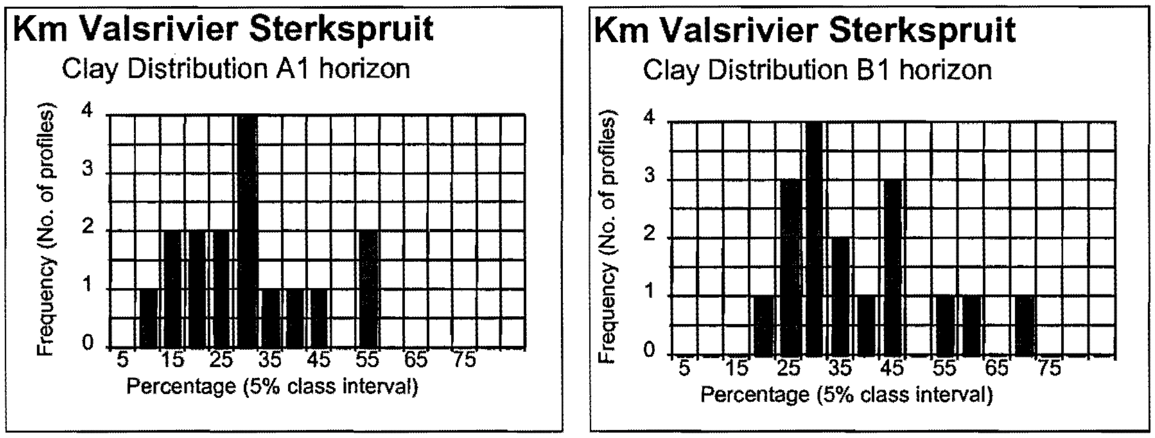


Figure 5.4. Distribution of clay within soils of the Valsrivier and Sterkspruit Forms.

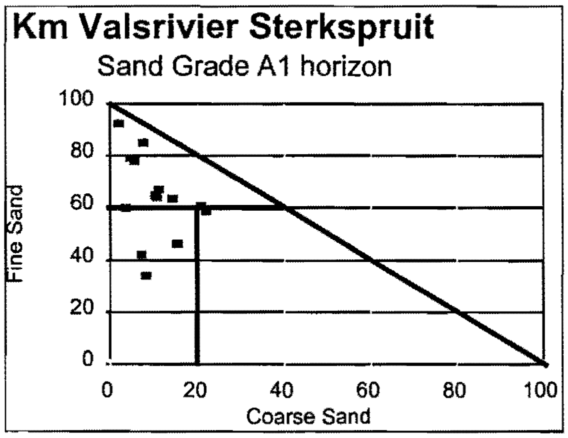


Figure 5.5. Distribution of sand grades within soils of the Valsrivier and Sterkspruit Forms.

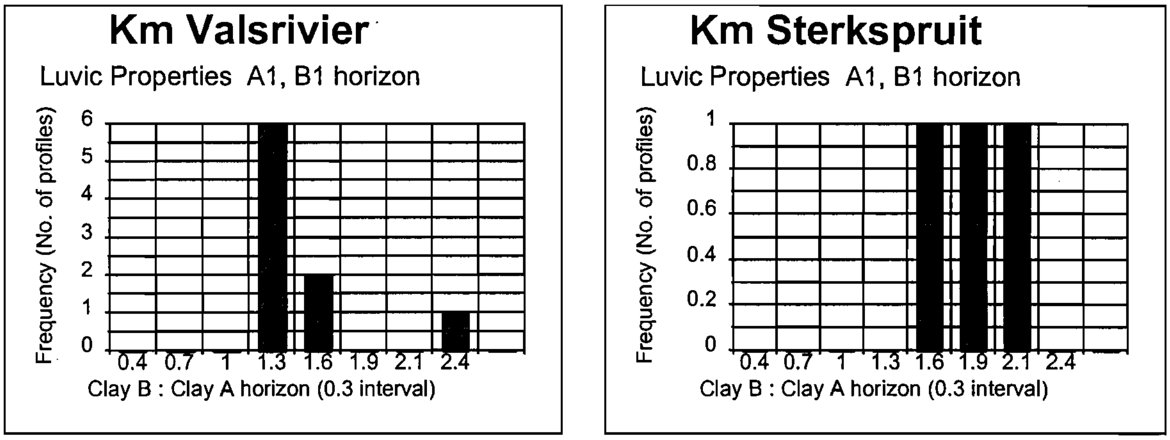


Figure 5.6. Luvic properties of the A1 and B1 horizons of soils of the Valsrivier and Sterkspruit Forms.

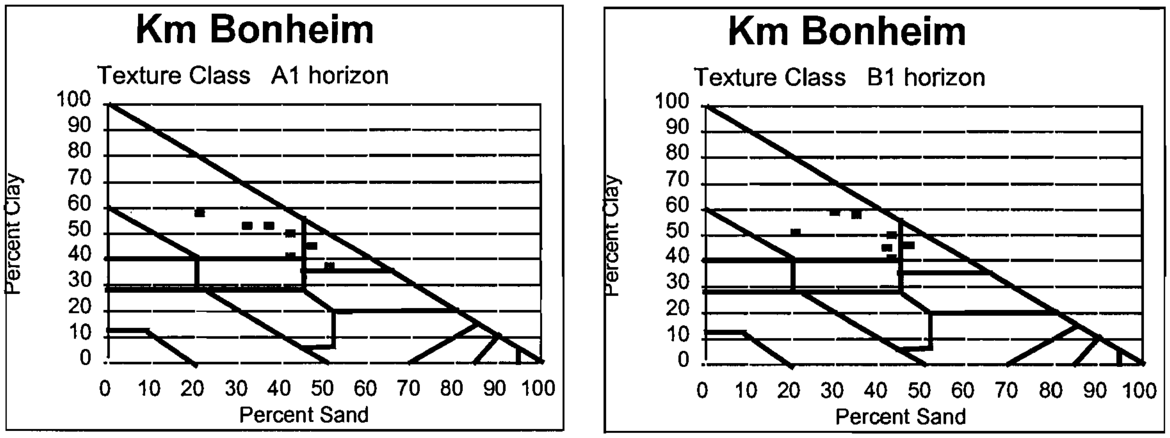


Figure 5.7. Distribution of soil textures within soils the Bonheim Form.

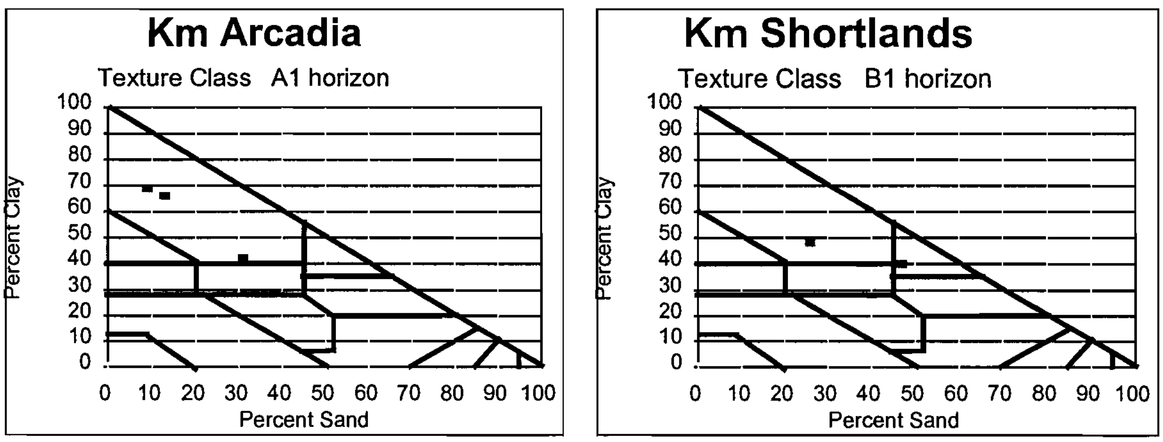


Figure 5.8. Distribution of soil texture within soils of the Arcadia and Shortlands Forms

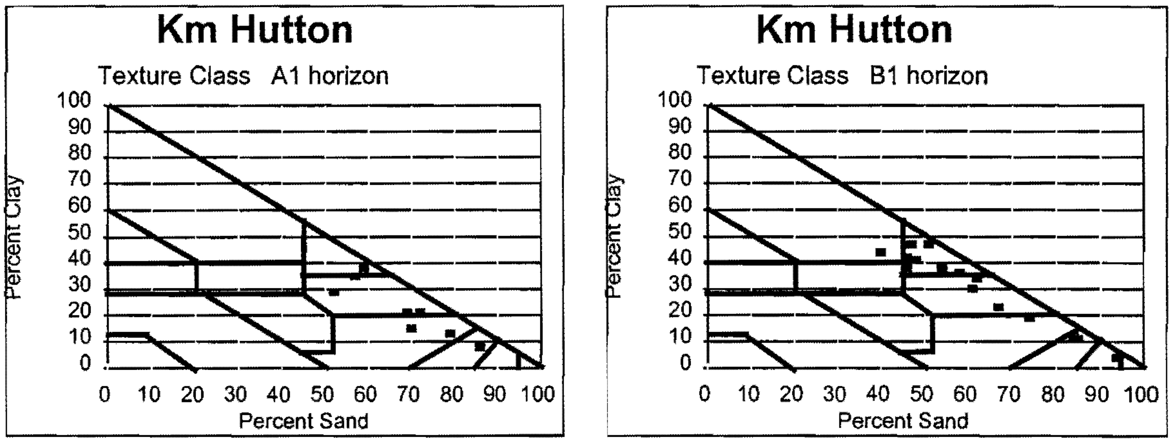


Figure 5.9. Distribution of soil texture within soils of the Hutton Form.

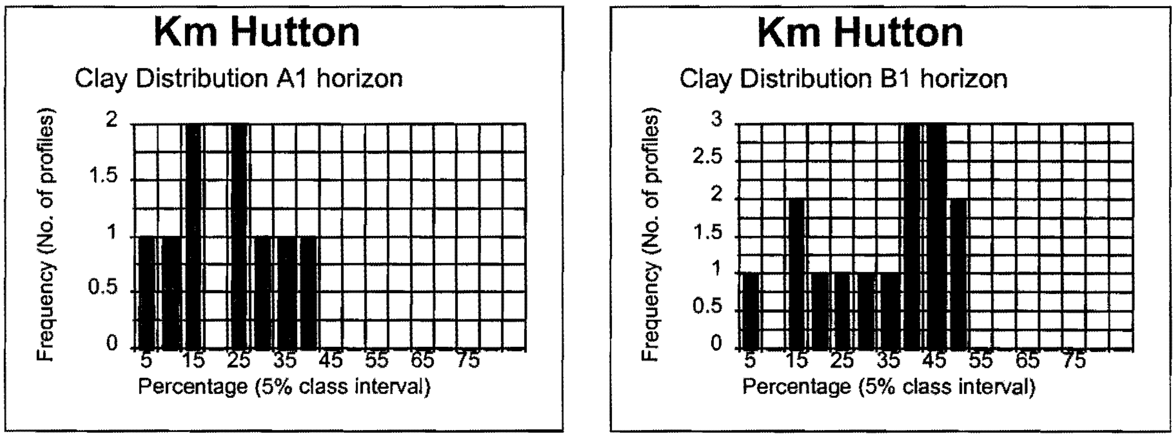


Figure 5.10. Distribution of clay within soils of the Hutton Form.

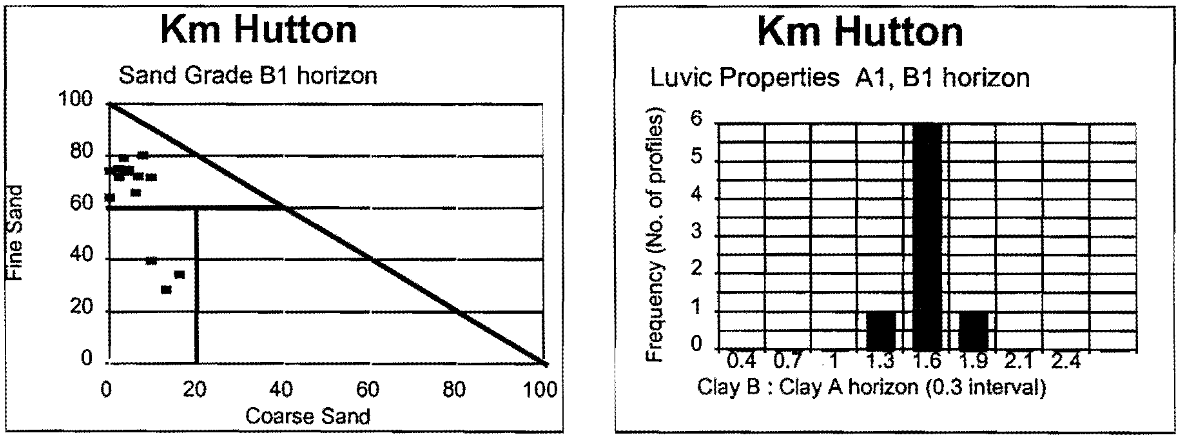


Figure 5.11. Sand grade and luvic properties of soils of the Hutton form.

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.

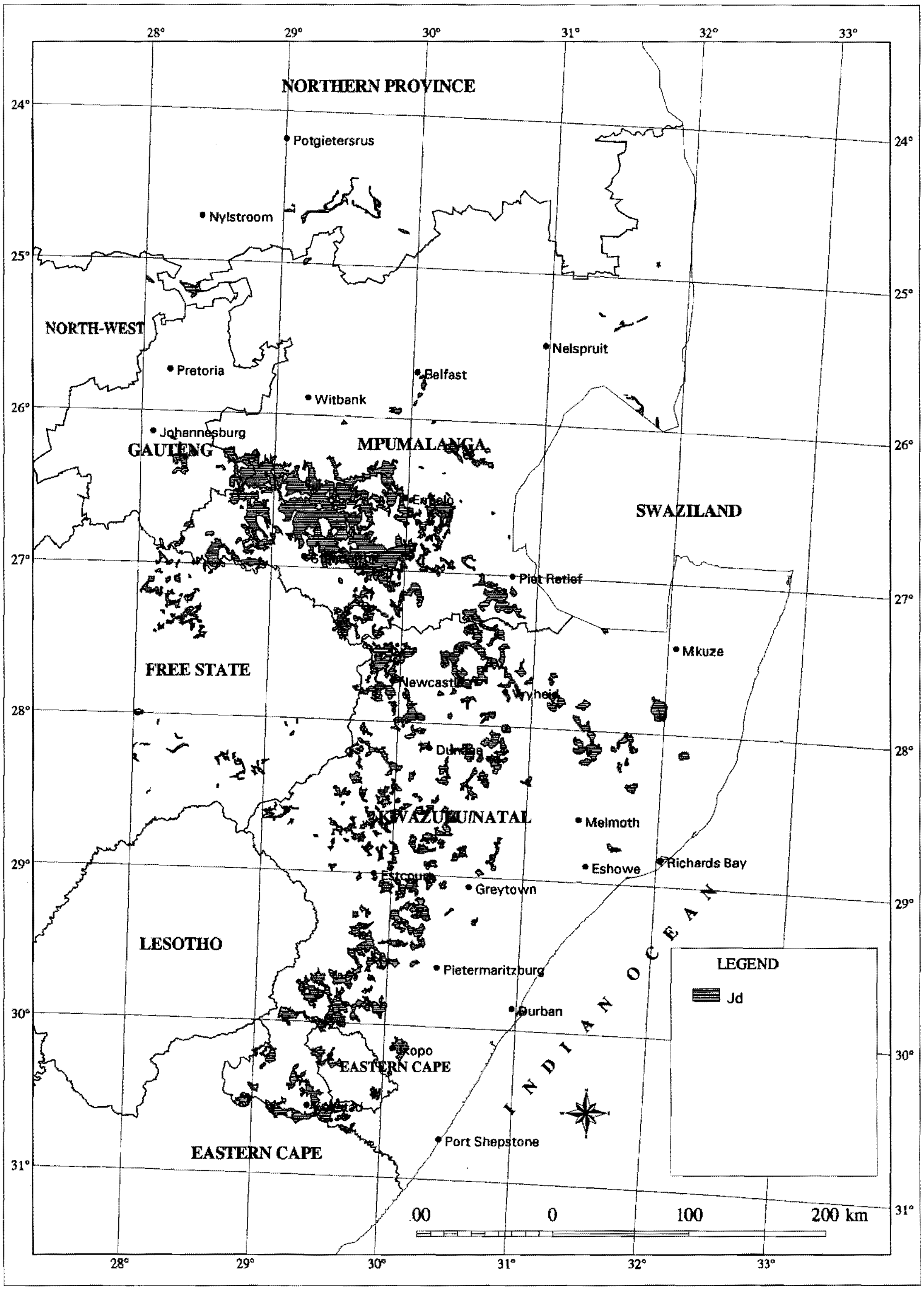


Figure 6.1. Location of the major occurrences of Jurassic dolerite in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

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 Soils			Ave	852	1527	2311	0.56
Glenrosa	Gs16	18				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

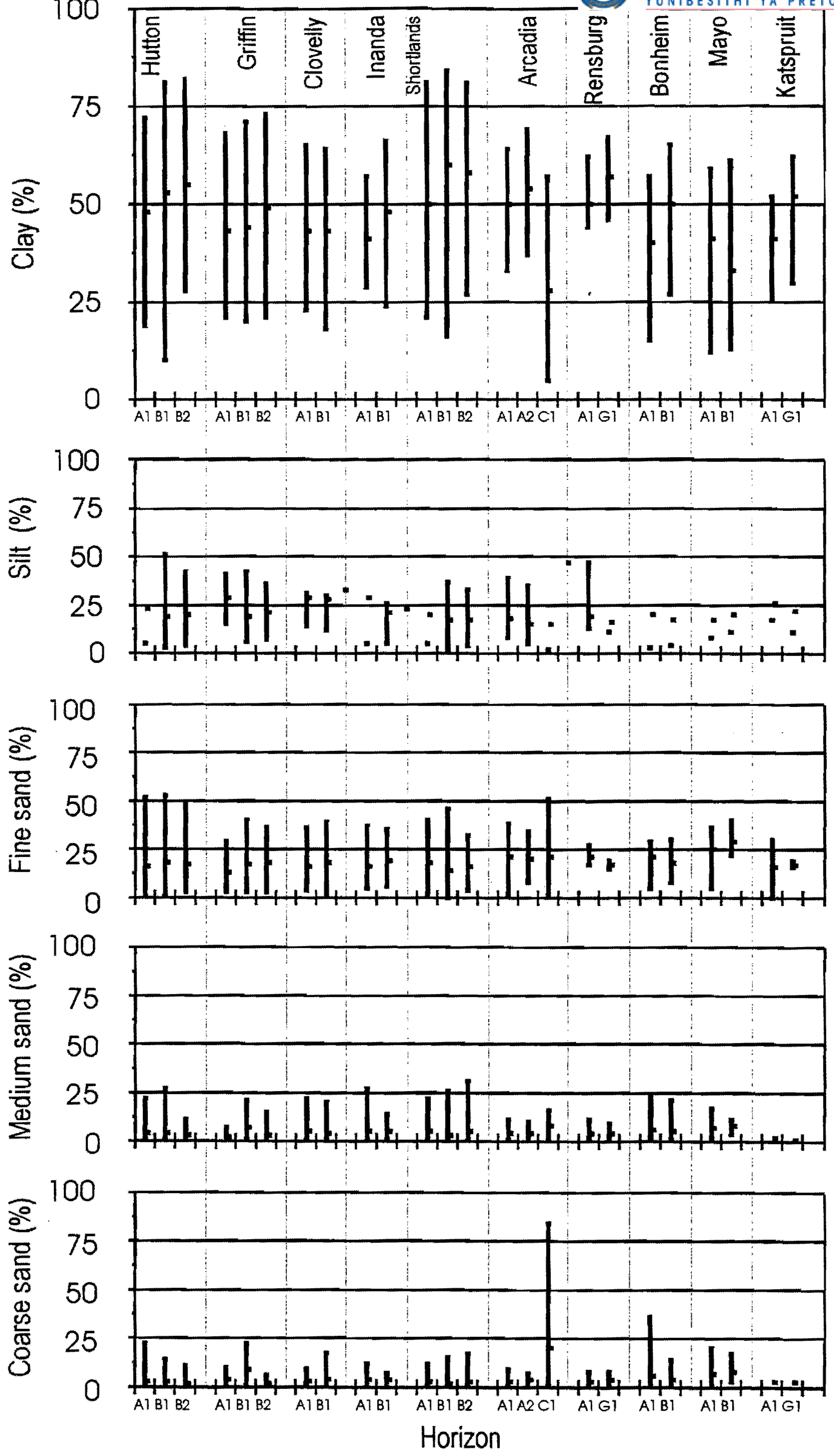


Figure 6.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Jurassic Dolerite geology. Maximum, minimum and mean values are shown for each horizon.

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.

Horizon	Depth mm	Clay Mean %	Clay SD %	Silt Mean %	Silt SD %	Fine Sand Mean %	Fine Sand SD %	Medium Sand Mean %	Medium Sand SD %	Coarse Sand Mean %	Coarse Sand SD %	Sample Size
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.

Horizon	Depth mm	Clay Mean %	Clay SD %	Silt Mean %	Silt SD %	Fine Sand Mean %	Fine Sand SD %	Medium Sand Mean %	Medium Sand SD %	Coarse Sand Mean %	Coarse Sand SD %	Sample Size
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.

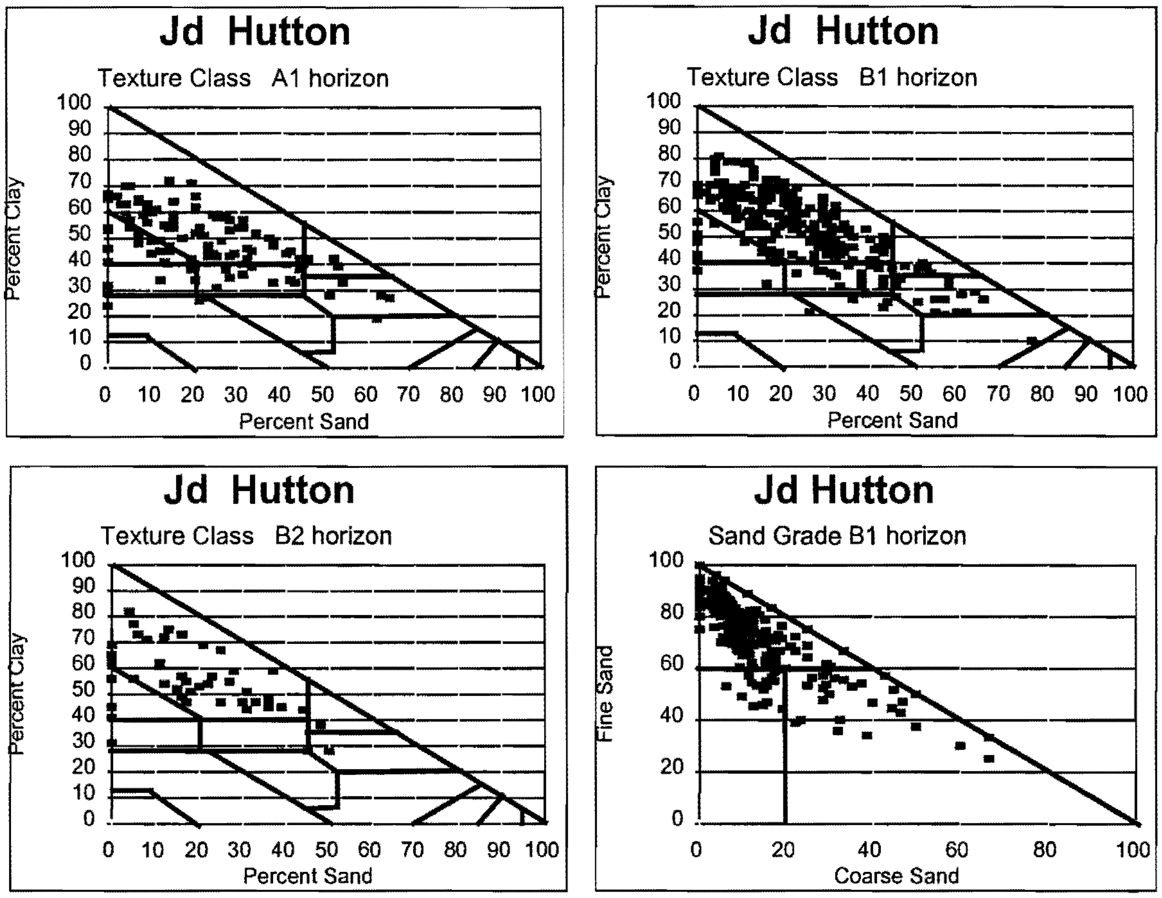


Figure 6.3 Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

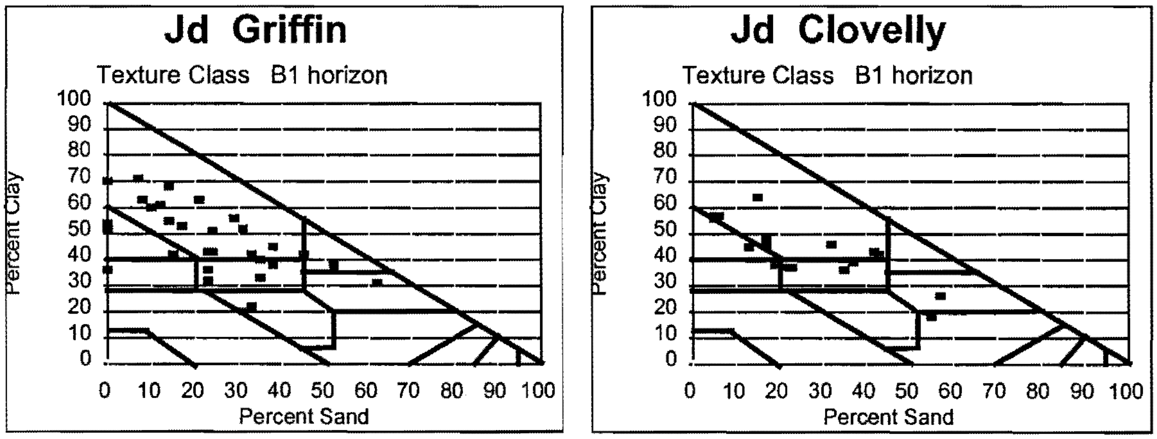


Figure 6.4 Distribution of soil textures within soils of the Griffin and Clovelly Forms.

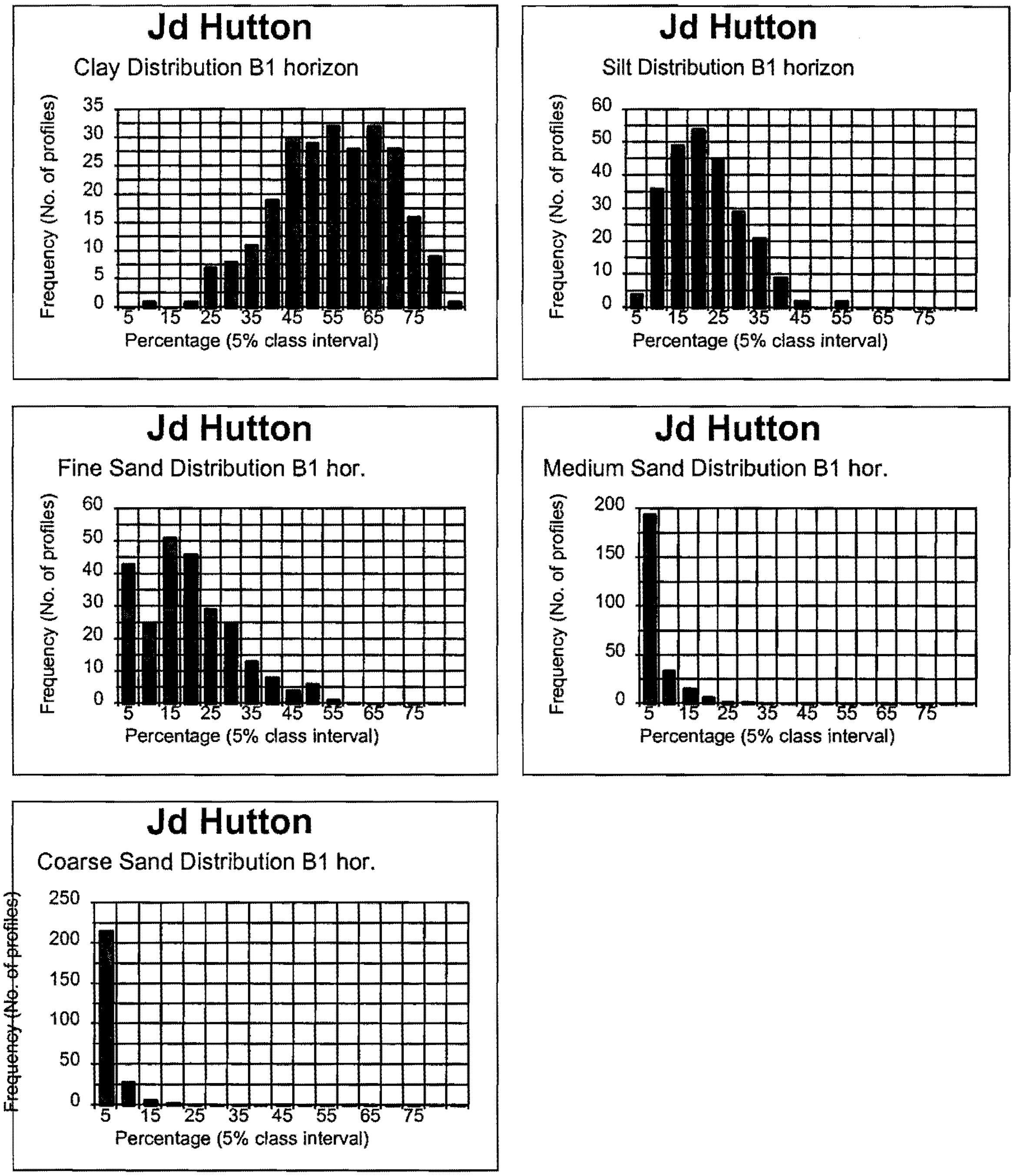


Figure 6.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

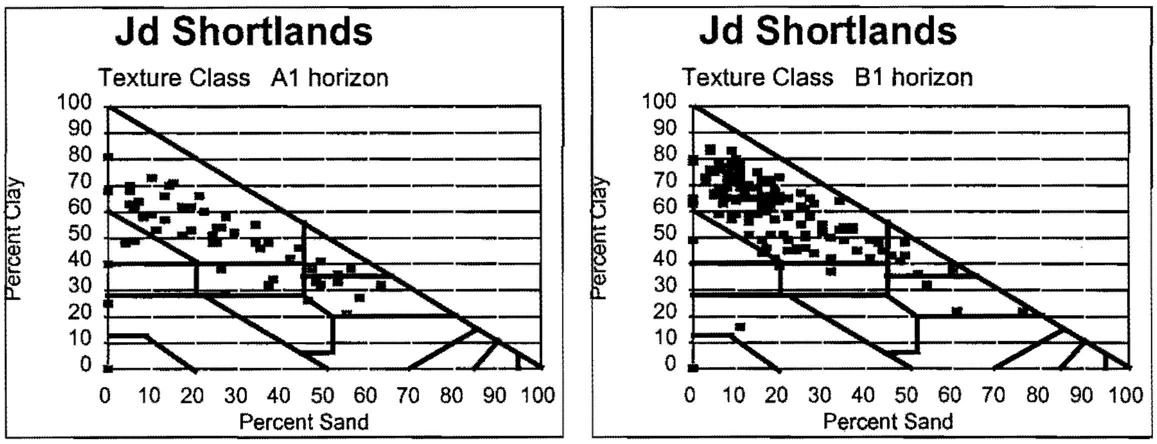


Figure 6.6 Distribution of soil textures within soils of the Shortlands Form.

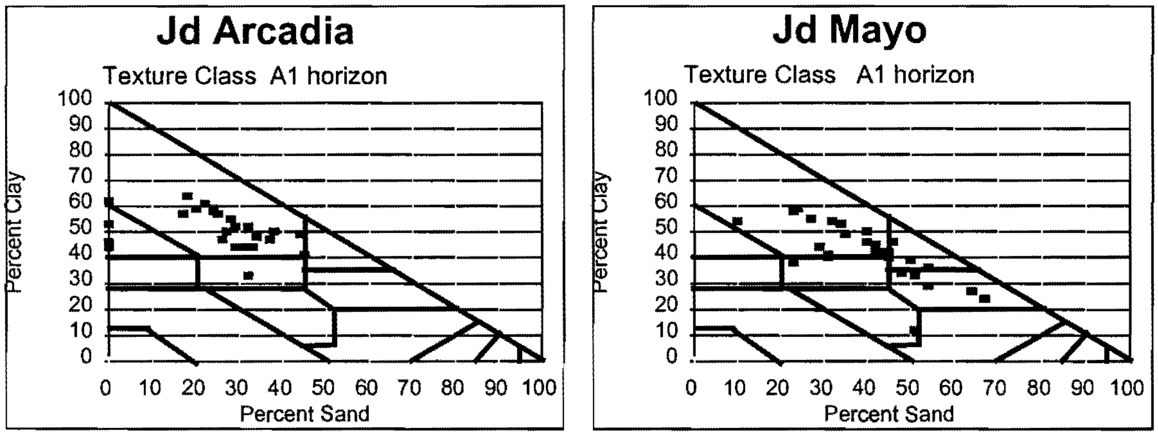


Figure 6.7 Distribution of soil textures within soils of the Arcadia and Mayo Forms.

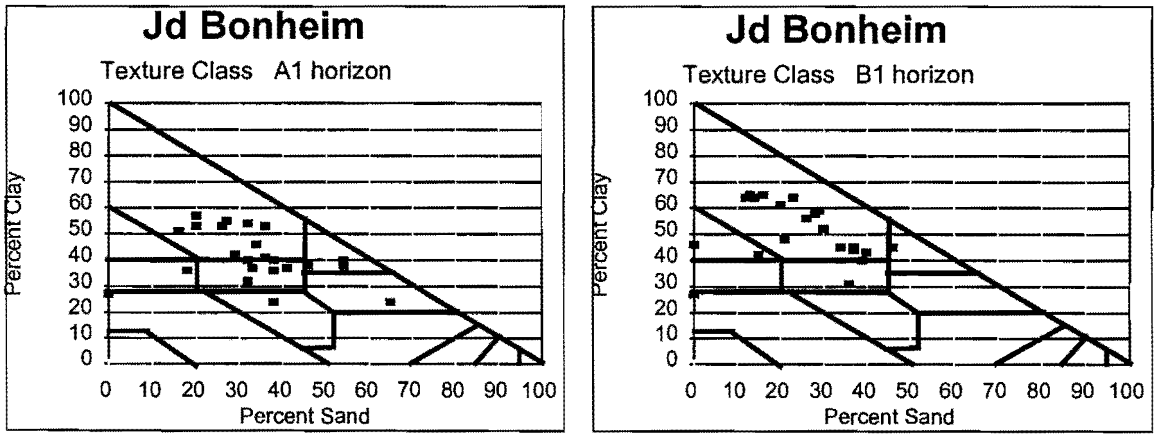
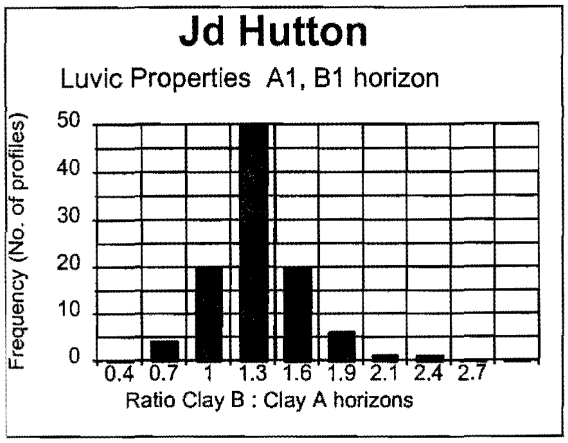


Figure 6.8 Distribution of soil textures within soils of the Bonheim Form.



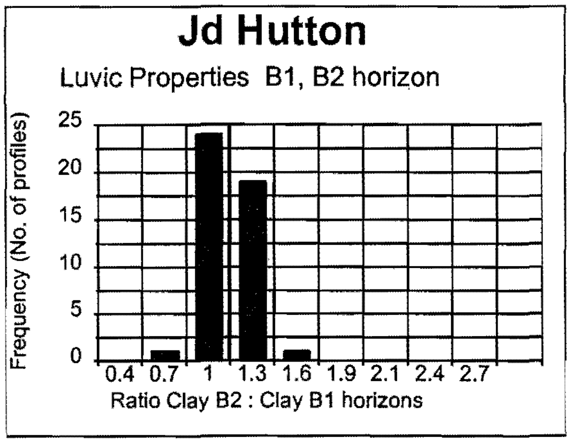
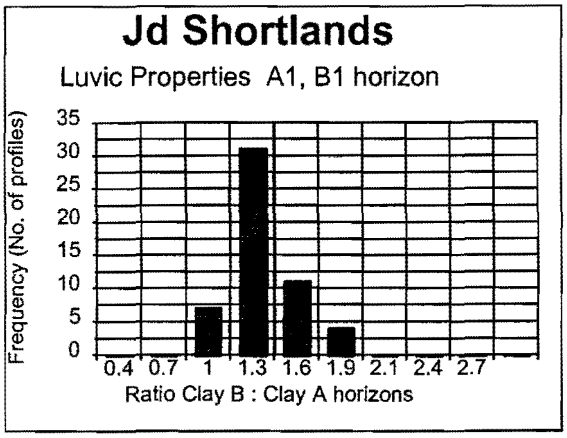


Figure 6.9 Luvic properties of soils of the Hutton Form.



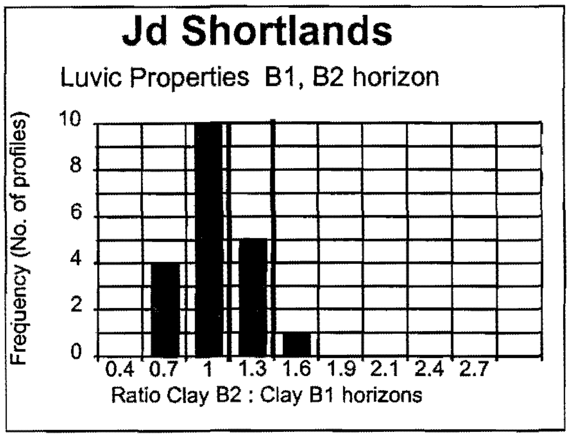


Figure 6.10 Luvic properties of soils of the Shortlands Form.

CHAPTER 7

SOILS OF THE BASALT OF THE DRAKENSBERG FORMATION IN KWAZULU-NATAL

Location and Extent

Within KwaZulu-Natal the Drakensberg Formation occupies a relatively narrow and steep belt along the high Drakensberg escarpment with altitudes often exceeding 3 000 metres. Beginning in the north from about the provincial boundary with the Free State, and with the Lesotho border in the west, it runs south east to the Giants Castle buttress where it attains its maximum width. It then turns south to Sani Pass and south west to Bushmans Neck. South of Sani Pass it occupies only a narrow stretch of the high escarpment. However, south of the southern Lesotho border the formation occupies relatively large areas of the Barkly East District. The formation also occupies extensive areas of the mountain Kingdom of Lesotho (Figure 7.1).

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

The Drakensberg Formation lies as the upper most strata of the Karoo Sequence and comprises basaltic lava. The early recognition of these lavas placed them in the Stormberg Beds (SACS, 1980), while the name Drakensberg Beds later replaced the Volcanic Beds of the Stormberg Series (SACS, 1980). In the main Karoo Basin the name, basic concept and boundaries of the original "Drakensberg Beds" remain unchanged with the name Drakensberg Formation being applied (SACS, 1980). The formation comprises basaltic lava, with subordinate fine-grained sandstone and agglomerate (Geological Survey, 1981a, 1981b).

The basaltic lavas capping the Karoo succession in the Springbok Flats, and the succession of volcanics of the Lebombo Mountain Range were also recognised in early geological reports. In the 1970 edition of the geological map of South Africa the lavas of the Lebombo Range and of the Springbok Flats were correlated with the lavas of the Drakensberg Group (SACS, 1980). In view of uncertainties in the correlation of these basic and acidic lavas independent formation names have now been assigned to the main lithological units of the Lebombo Group. The lava extending from the Lebombo Range to the Soutpansberg and the Springbok Flats is now named as the Letaba Formation and forms part of the Lebombo Group (SACS, 1980).

Partridge and Maud (1987) describe the geomorphology of the greater part of the basalt zone of the Drakensberg Formation within KwaZulu-Natal and the Eastern Cape Province as escarpment separating the elevated interior from the coastal hinterland. Further to the interior within Lesotho the mountainous areas are considered to be above the African Surface (Partridge and Maud, 1987). Remnants of the old Gondwanaland landsurface are preserved on the flat-crested mountains of Lesotho, while remnants of subsequent surfaces are evident as spurs protruding from the high Drakensberg (King and King, 1963). A detailed explanation of the geomorphology of KwaZulu-Natal is given in van der Eyk, MacVicar and de Villiers (1969).

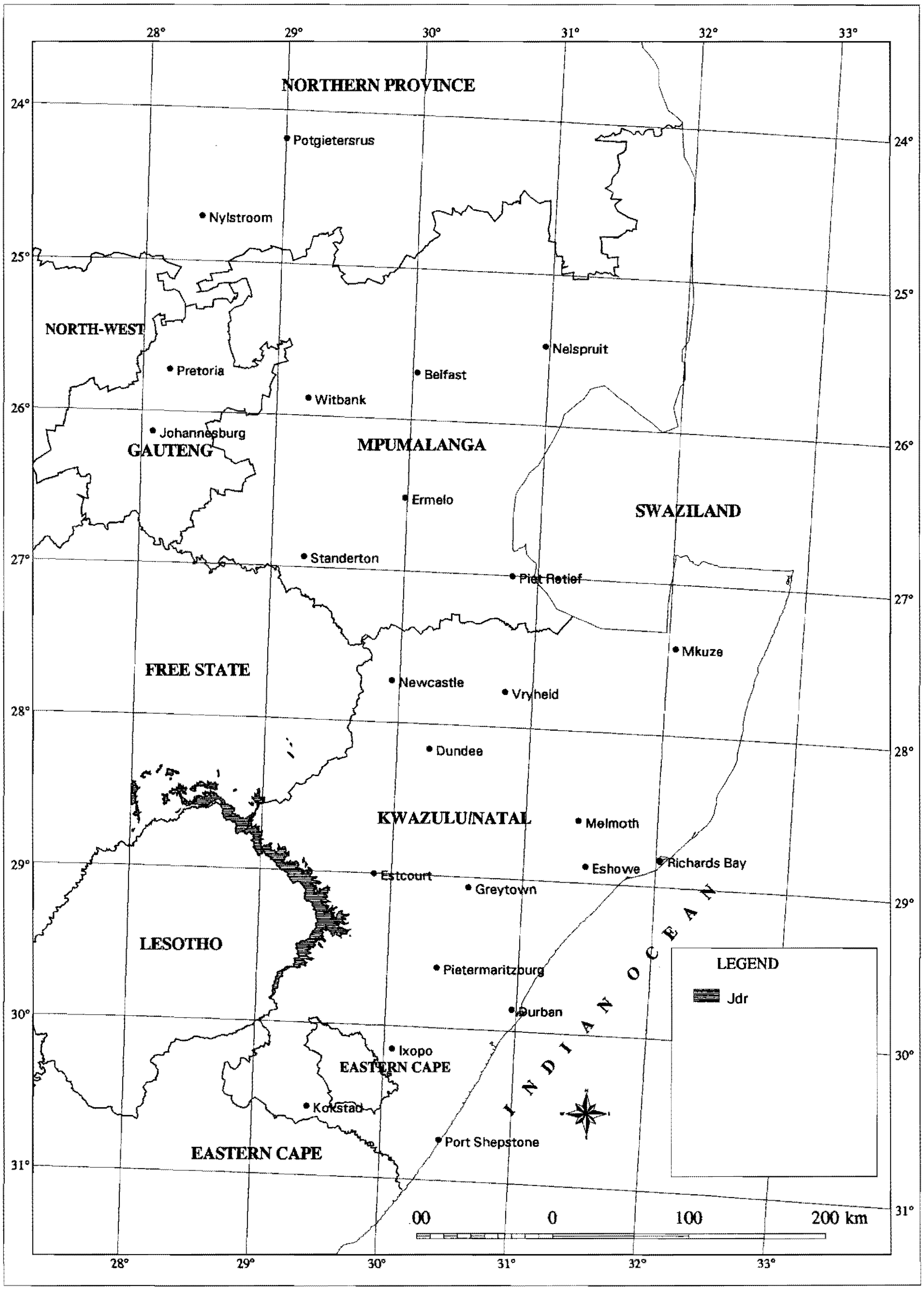


Figure 7.1. Location of the Drakensberg Formation in KwaZulu-Natal (after Geological Survey, 1984).

Physiography and Drainage Features

The basalt of the Drakensberg Formation occupies the narrow belt of steep land along the high escarpment. This area is described as comprising high mountains (Kruger, 1983) with high relief, and only very limited areas with slopes of less than 5 percent. Stream density is described as medium to high (Kruger, 1983) with drainage via the headwaters of streams and rivers feeding the Tugela, Mkomazi and Mzimvubu Rivers.

Vegetation

The vegetation is described at the high altitudes as Alti Mountain Grassland by Low and Rebelo (1996), while at the lower altitudes in the south of the zone it is described as Moist Upland Grassland, and in the north of the zone as Wet Cold Highveld Grassland.

Soils

Four major soil patterns are evident on the basalt of the Drakensberg Formation (Table 7.1). These are a yellow-brown and red apedal soil pattern with generally low base status, a red apedal pattern with high base status, black clays and lithosols.

The yellow-brown and red apedal soil pattern has a generally low base status, although intermediate to high base status soils are also present. These soils have developed from base rich basalt material in a cool to a cold climate, and with high rainfall. The weathering intensity is expected to be relatively high. However, in the incised and steep terrain of the high Drakensberg Mountains erosion from the soil mantle is relatively high. This erosion is reflected in the generally shallower soil depths of these yellow-brown and red apedal soils. However, interesting differences in the particle size distributions, base status variations and organic carbon values are evidence of the intense, but youthful weathering regimes. Furthermore, these soils differ from the highly weathered red and yellow-brown soils commonly encountered on the dolerite and other basic lavas. In the latter soils, depth can be much greater, clay contents greater and uniform throughout the profile, and low base statuses are properties reflected by a longer period of soil weathering. Mispah, Nomanci and Glenrosa soils, with rock is subdominant in this pattern.

Red apedal soils with high base status were recorded over a limited area (Table 7.1). In this pattern there is an absence of yellow-brown apedal soils, while Milkwood and Mayo soils are subdominant. Higher temperatures may be inferred form the absence of yellow soils, while the presence of melanic soils would indicate lower rainfall. This is confirmed from the climate information (Table 7.1). Regrettably heat units (a summation of temperatures) are not available for the yellow and red apedal soil pattern (Table 7.1). However, heat units for the red and yellow apedal soils of Karoo dolerite could be used as a reference value (Heat Unit = 2171 degree days for red and yellow apedal soil pattern). The heat unit values of the red apedal soils of high base status are then higher (Table 7.1). The location of this soil pattern in the upper reaches of the Mkomazi River Valley confirms the lower leaching status, lower rainfall and higher temperatures for this soil pattern.

Table 7.1 Dominant soils and selected climatic information for soil patterns occurring on Drakensberg Formation

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: Yellow and Red Apedal Soils (generally low base status)										
Clovelly	Cv16 Cv17 Cv23	23	Mispah	Ms10	18	Ave	1074	-	-	-
			Nomanci	No10		Std	106	-	-	-
Hutton	Hu16 Hu17 Hu23	22	Glenrosa	Gs16	17	Max	1260	-	-	-
Kranskop	Kp10	2	Rock	Rock	11	Min	900	-	-	-
Total Area: 65 580 Ha			Means of 11 Land Types							
Broad Soil Pattern: Red Apedal Soils (high base status)										
Hutton	Hu27 Hu37	48.31	Mispah	Ms10	15	Ave	834	-	2471	-
			Glenrosa	Gs19	8	Std	30	-	-	-
			Milkwood	Mw11 My11	6	Max	865	-	-	-
			Mayo			Min	804	-	-	-
			Rock	Rock	7					
Total Area: 8 830 Ha			Means of 2 Land Types							
Broad Soil Pattern: Black Soils										
Milkwood	Mw10 My10	22	Rock	Rock	42	Ave	842	-	-	-
Mayo						Std	158	-	-	-
Bonheim	Bo10 Bo11 Bo30 Bo31	19	Mispah	Ms10 Gs16	11	Max	1000	-	-	-
						Min	684	-	-	-
Inhoek	Ik10	2								
Total Area: 112 660 Ha			Means of 6 Land Types							
Broad Soil Pattern: Lithosols										
Rock	Rock	34	Hutton	Hu26 Hu36	12	Ave	1139	1512	816	0.75
Glenrosa	Gs14 Gs16	13	Clovelly	Hu16		Std	243	142	758	0.09
Mispah	Ms10	11		Cv26 Cv36	8	Max	1650	1714	1872	0.98
Nomanci	No10	3		Cv16		Min	698	1412	96	0.49
Total Area: 146 640 Ha			Means of 16 Land Types							

Milkwood, Mayo and Bonheim soils are dominant in the Black Clay Soil Pattern on the basalt of the Barkly East tableland of the North Eastern Cape. Located south of the southern Lesotho border and beyond the boundary of KwaZulu-Natal, these soils have been included for comparison purposes. The reason for this extensive area of melanic black clay soils is somewhat unexpected to the author. Mean annual rainfall of 842 mm (Table 7.1) is not that much lower than encountered in the KwaZulu-Natal Midlands. The terrain morphological patterns described as mountains and lowlands (Kruger 1983), with between moderate slopes (20 to 50% slopes of less than 5%) is duplicated in much of the KwaZulu-Natal Midlands. Mean annual temperatures are expected to be low for this soil pattern. Regrettably, no temperature stations could be located for comparative purposes between the Yellow and Red Apedal Soil Pattern of the Drakensberg Formation basalt, or the dystrophic soil patterns of Karoo dolerite. It is possible that the genesis and properties of these soils resemble those of the mollic horizons of Europe.

The Lithosolic soil pattern covers most of the main high Drakensberg escarpment. The high proportion of rock in this soil pattern is to be expected. The Glenrosa and Mispah soils probably have higher levels of organic carbon, while the presence of the Nomanci soil (No10, Table 7.1) is indicative of a thick humic A1 horizon. Hutton and Clovelly soils also occur in this soil pattern. The variable base status is ascribed to youthful nature of these soils. Leaching is to the extent that removal of bases has not taken place in the eutrophic and mesotrophic soils. However, the soil genesis is sufficiently intense that freely drained red and yellow apedal soils may form.

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for the Hutton, Clovelly, Mispah, Champagne and for the margalitic soils (Milkwood, Mayo and Bonheim) soils were extracted from the database. Two natural soil bodies are clearly evident for the Hutton and Clovelly soils (Table 7.2, Figure 7.2). This is supported by the range in texture properties (Table 7.2, Figures 7.3 and 7.4), their luvic properties (Figure 7.8), and in their base status values. These trends could be repeated in the Mispah and Champagne soils (Figure 7.6), but data is limited such that a clear picture does not emerge. It is probable that the genesis of the margalitic soils is so different that the textural properties of these two natural soils bodies are not necessarily repeated in data of the margalitic profiles (Figure 7.7).

The two natural soil bodies for the Hutton soils (labelled Hutton(1) and Hutton(2)) and Clovelly soils (labelled Clovelly(1) and Clovelly(2)) have been arbitrarily distinguished at a clay percentage value of 25% (Figure 7.2). The clay contents of the B1 horizons for soil profiles within the group Hutton(1) ranges from 11 to 14%, while those for Hutton(2) range from 35 to 41% (Table 7.2, Figure 7.4). Clay contents for the A1 horizons have a similar range clearly indicating two natural soil bodies. In the B1 horizon of the Clovelly soils this trend is repeated (Figure 7.3), while a plot of the A1 horizon textures shows the two soil bodies to merge about the 25% central value (Table 7.2, Figure 7.2, 7.3). The profiles within Hutton(1) and Clovelly(1) have higher silt, or higher silt plus fine sand values (Table 7.3), than those of Hutton(2) and Clovelly(2).

Exceptions, as measured by either the clay contents or the base status, in assigning profiles to either of the two groups is evident. This is a reflection that these soils (in this climate regime and in these terrain positions) must be undergoing rapid changes in mineral weathering and clay formation. One profile (data not shown) had a clay content for the A1 horizon of 27% (belonging to Hutton (2)) while that for the B1 horizon was 14% (belonging to Hutton (1)). The interpretation with respect to soil genesis, in these actively weathering soils, is that weathering of the A1 horizon has proceeded further than that of the B1 horizon. It may be postulated that weathering, leaching of bases, and clay formation could rapidly reach a near steady state position. If this were true, then the more common clay contents and base status, as commonly sampled for the dolerite derived soils should be attained.

Table 7.2 Textural properties of soils of the Drakensberg Formation derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton (Clay <25%)	A1 B1	Lm Lm-SiLm	12-19 11-14	38-49 18-57	24-31 23-35	4-9 3-12	3-7 2-5	fi fi	EL5 -
Hutton (Clay >25%)	A1 B1	SiClLm-ClLm SiClLm-ClLm	27-40 35-41	31-41 28-40	12-25 10-23	1-7 1-5	1-10 2-20	fi fi	NL2, L3 -
Clovelly (Clay <25%)	A1 B1	SiLm-Lm SiLm-Lm	14-31 5-20	28-50 13-51	12-31 11-66	3-6 4-9	2-10 2-11	fi, co fi, co	EL5 -
Clovelly (Clay >25%)	A1 B1	SiClLm-ClLm-Cl SiCl-ClLm	23-46 28-44	20-50 25-46	8-26 7-21	1-12 1-4	2-6 1-5	fi, co fi, co	NL2, L3 -
Mispah (All profiles)	A1	SiClLm-Lm	13-32	12-37	10-30	5-12	1-16	fi, co	-
Champagne (All profiles)	O1 G1	SiClLm-Lm SaClLm	25-30 23-23	18-42 15-15	16-24 43-43	2-10 14-14	2-7 5-5	fi	- -
Margalitic Soils (Milkwood, Mayo, Bonheim)	A1 B1	ClLm-Cl ClLm-Lm	29-44 38-62	29-42 23-31	17-21 10-19	2-6 1-4	3-4 3-7	fi	NL5 -

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).

The silt and fine sand fractions comprise the remaining dominant particle size classes (Table 7.2). While fine sand is the dominant sand grade (Figures 7.3, 7.4, 7.5) individual profiles do exhibit a dominance of coarse sand. This may be attributed to the remnants of physical weathering and colluviation.

The Hutton(1) and Clovelly(1) Group clearly shows a decrease in clay content between the A1 and B1 horizons(Figure 7.8), with a mean ratio Clay B1:Clay A1 of 0.59. These profiles are represented by the histogram bar 0.7 (Class interval 0.4 - 0.7, Figure 7.8). These profiles also have higher silt and fine sand fractions, and a higher base status in their B1 horizons. This is an indication of the youthful nature of these soils with more advanced weathering taking place in the A1 horizon. In contrast, the mean ratio of Clay B1:Clay A1 for the Hutton(2) and Clovelly is 1.14 (Figure 7.8) indicating clay illuviation or simply clay weathering and breakdown of some of the clay fraction of the A1 horizon has taken place. Clay values for the B2 horizon tend to be similar to those of the B1 horizon. These B1 horizons were originally not considered to qualify for the neocutanic B horizon on the basis of their morphology.

It is interesting that while weathering has proceeded to produce yellow and red soils, the B1 horizons do not qualify for the ferralic horizon of the World Reference Base System (ISSS, ISRIC, FAO, 1998). The higher CEC values should qualify for the cambic horizon. This implies that a wider range of profile weathering in the cambic horizon is permissible than would be recognised in the South African Soil Classification System.

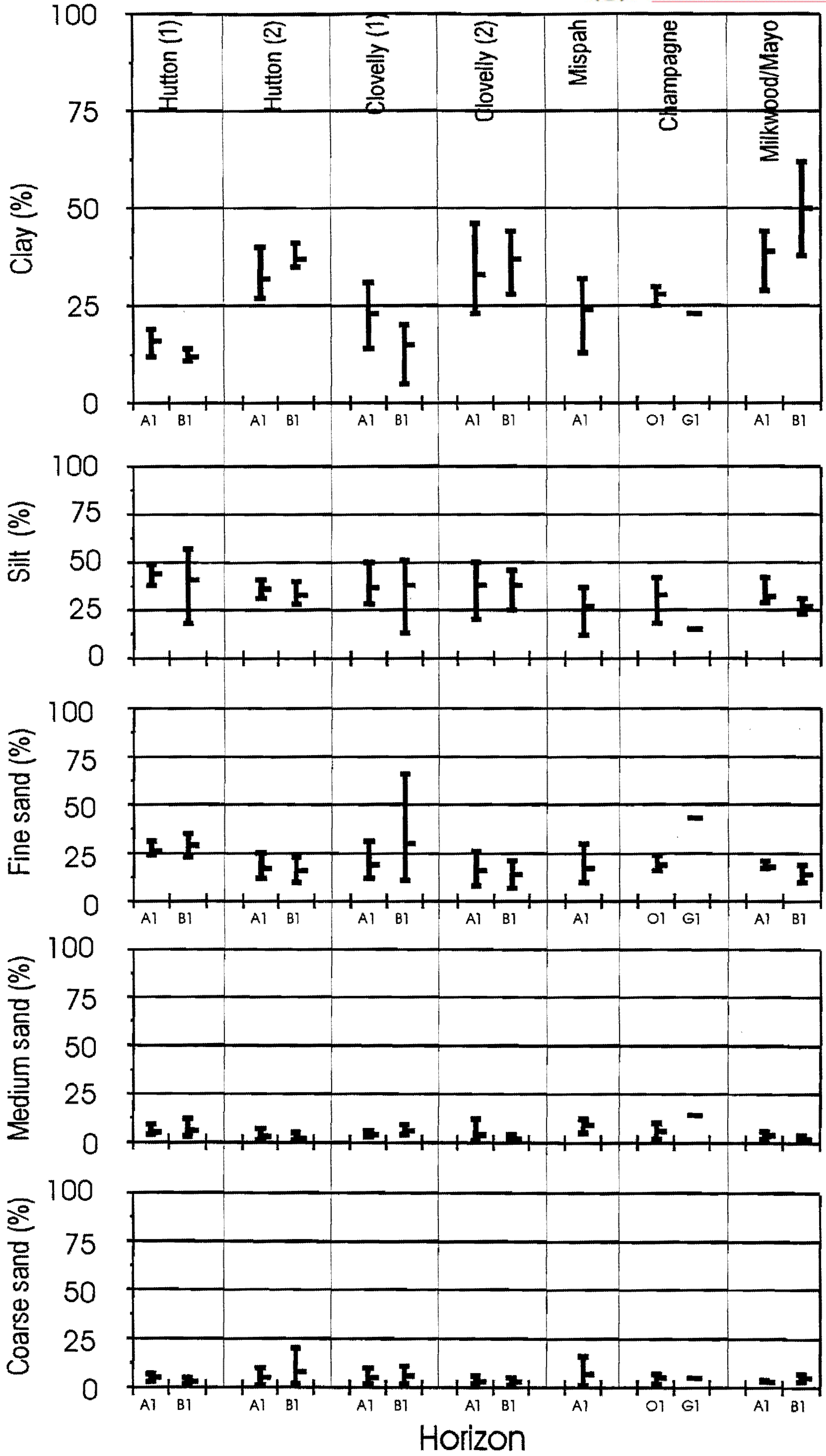


Figure 7.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Drakensberg Formation. Maximum, minimum and mean values are shown for each horizon.

The textural properties of the Mispah soils are similar to those of the Clovelly(1) soils (Table 7.2, Figure 7.2). The textures of the Champagne soils appear intermediate between those for the Hutton and Clovelly soils (Table 7.2, Figure 7.2). The existence of clay loam textures (30% clay) is confirmed for these organic horizon soils. There are a limited number of profiles for both soils in this group (Table 7.3).

The textures for the melanic soils are within the range determined for the Mayo soils of Jurassic dolerite and basalt of the Letaba Formation. There are a limited number of profiles in this group (Table 7.3).

Table 7.3 Means and standard deviations of five textural classes for soils of the Drakensberg Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton (Clay B1 horizon <25%)												
A1	303	16.3	3.1	44.3	4.6	26.7	3.1	5.7	2.4	5.0	1.6	3
B1	625	12.8	1.3	41.0	14.3	29.3	4.4	6.0	3.5	3.8	1.1	4
Form: Hutton (Clay B1 horizon >25%)												
A1	200	32.4	4.9	36.6	4.1	17.2	4.5	3.8	2.3	5.3	3.8	5
B1	437	37.8	2.4	33.5	5.5	16.3	5.8	2.5	1.5	8.0	8.5	4
Form: Clovelly (Clay B1 horizon <25%)												
A1	353	23.4	5.2	37.8	6.1	19.6	5.5	4.4	0.9	5.4	2.4	8
B1	746	15.5	4.9	38.9	11.8	30.3	17.0	6.4	1.5	6.0	2.7	8
Form: Clovelly (Clay B1 horizon >25%)												
A1	178	33.3	6.4	38.0	11.2	16.3	5.8	4.1	3.5	3.4	1.3	7
B1	566	37.0	6.0	38.4	8.1	14.8	4.8	2.4	1.0	3.2	1.3	5
Form: Mispah (All profiles)												
A1	157	24.5	7.2	27.0	9.5	17.3	7.7	9.0	2.7	7.8	6.1	4
Form: Champagne (All profiles)												
O1	633	28.3	2.4	33.7	11.1	19.7	3.3	6.0	3.3	5.0	2.2	3
G1	500	23.0	0.0	15.0	0.0	43.0	0.0	14.0	0.0	5.0	0.0	1
Form: Margalitic Soils (Milkwood, Mayo, Bonheim)												
A1	312	39.0	6.1	32.5	5.5	18.5	1.5	4.3	1.8	3.8	0.4	4
B1	750	50.0	12.0	27.0	4.0	14.5	4.5	2.5	1.5	5.0	2.0	2

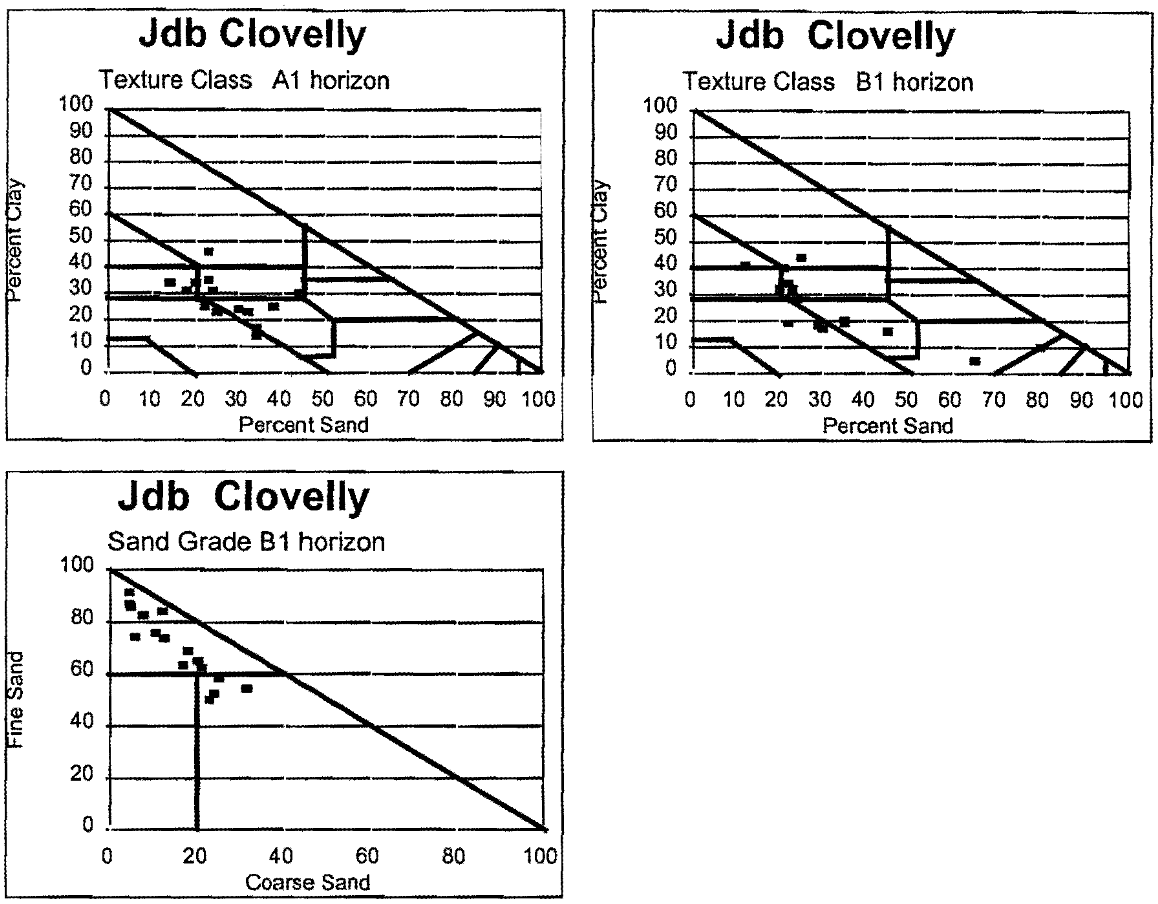


Figure 7.3. Distribution of soil textures, and dominant sand grade, within soils of the Clovelly Form.

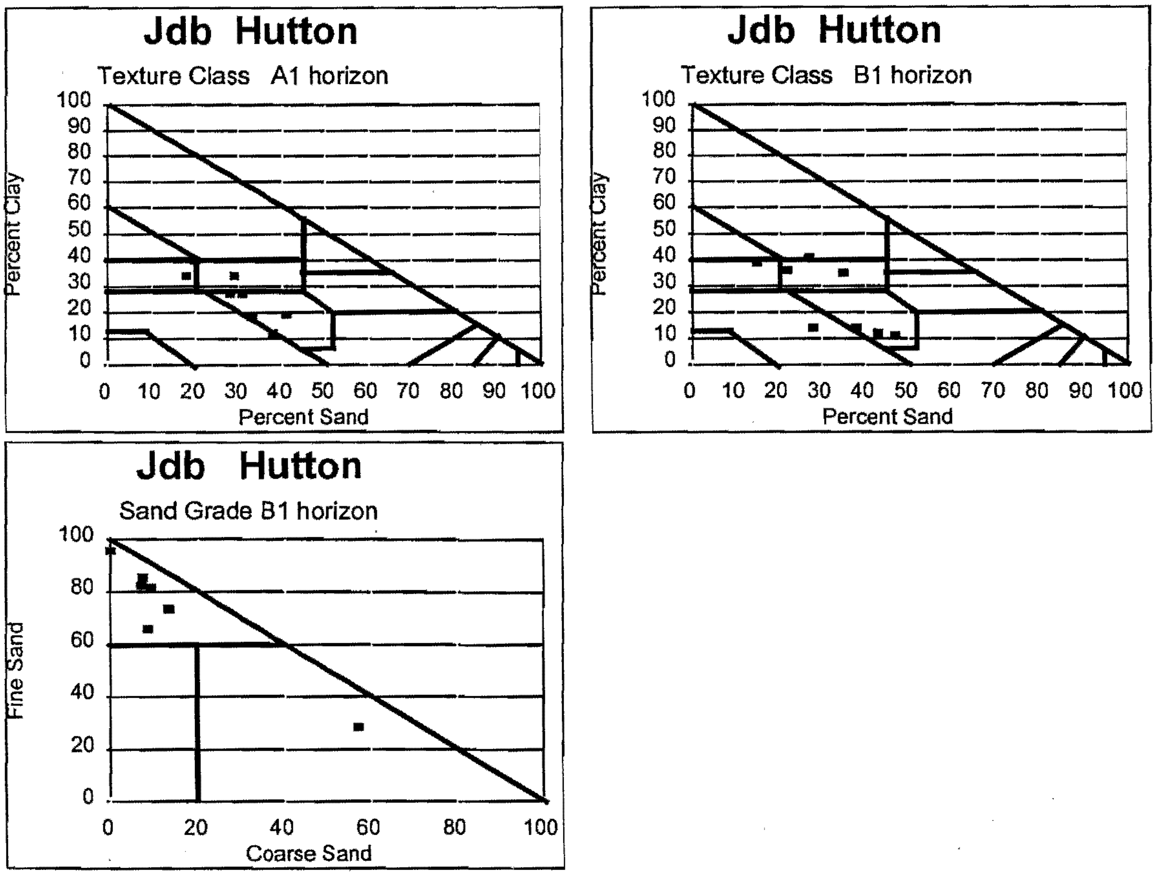


Figure 7.4. Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

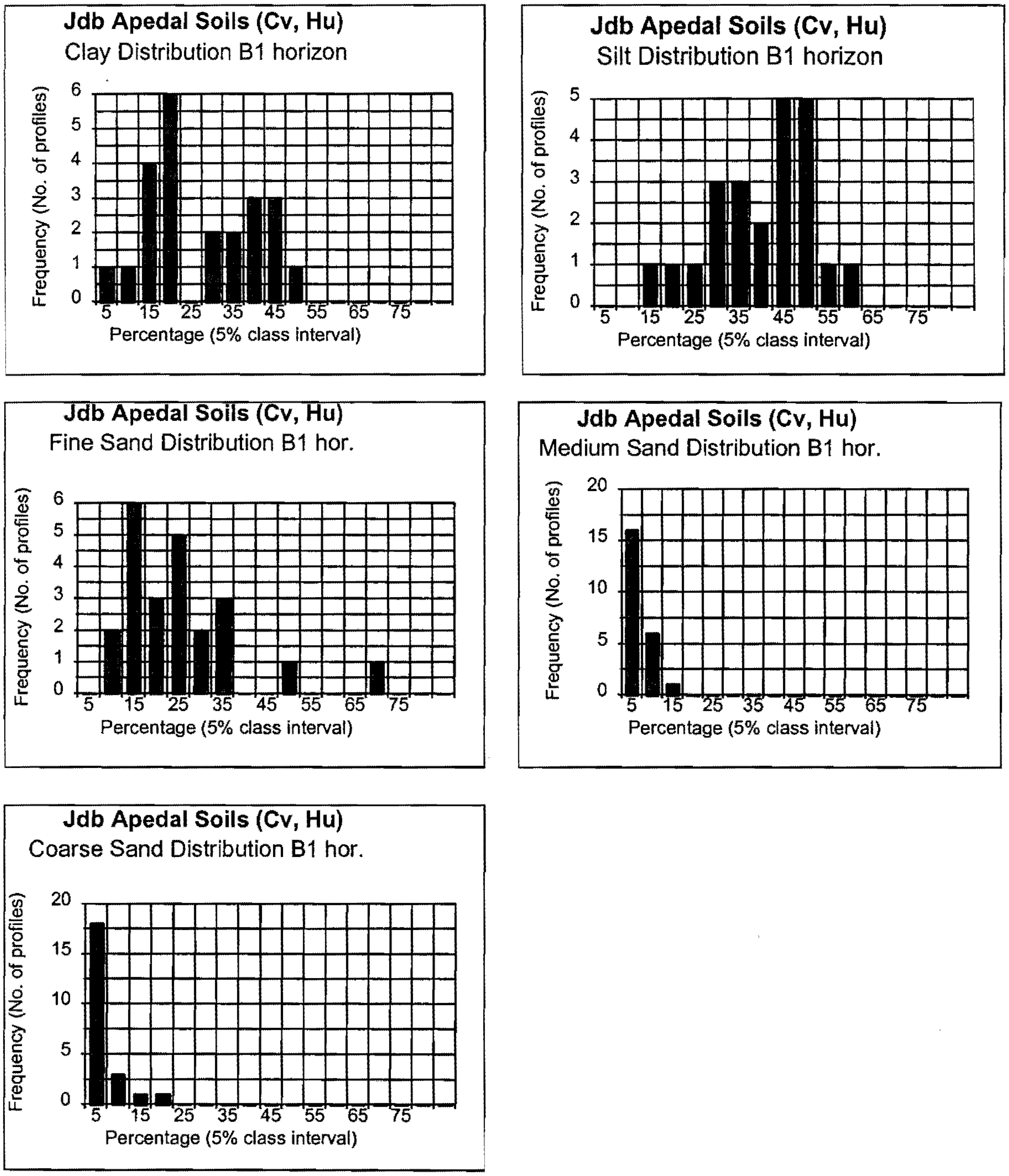


Figure 7.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Clovelly and Hutton Forms.

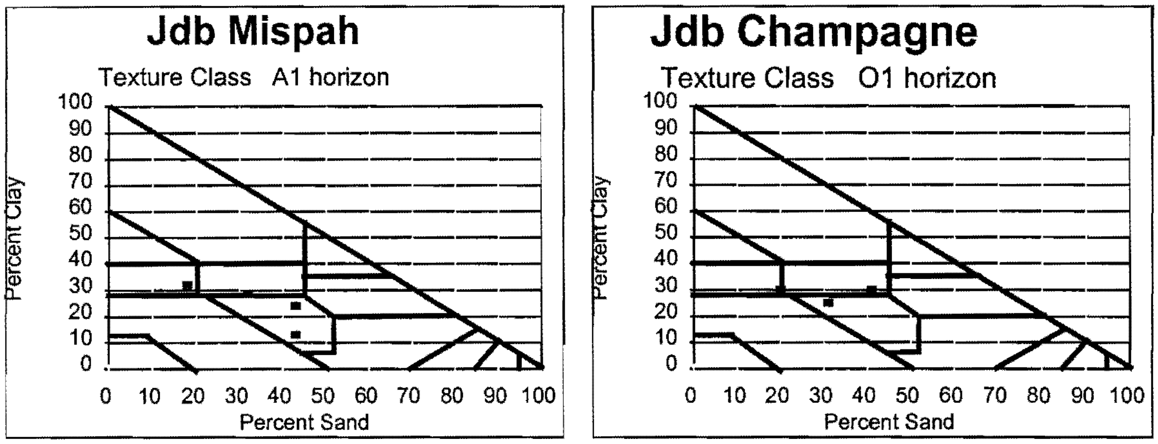


Figure 7.6 Distribution of soil textures within soils of the Mispah and Champagne Forms.

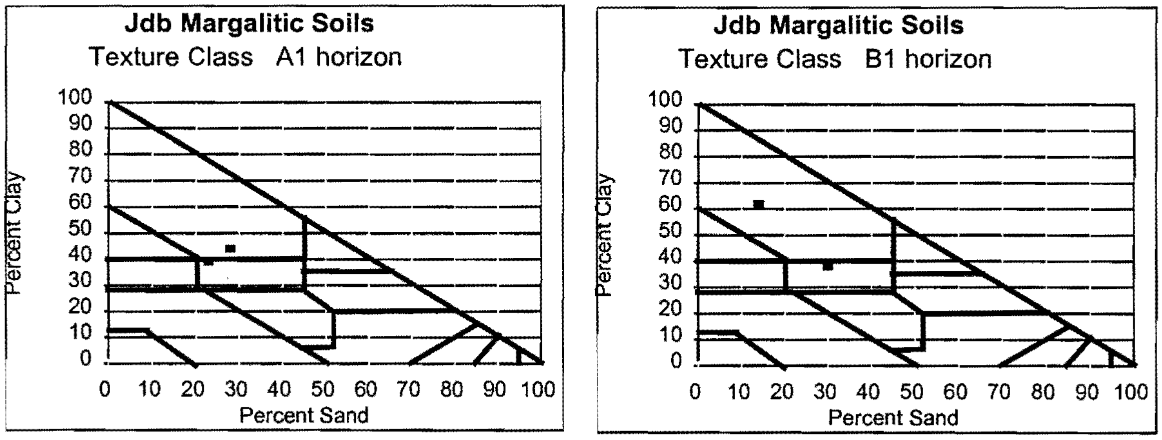


Figure 7.7 Distribution of soil textures within margalitic soils of the Milkwood, Mayo and Bonheim Forms.

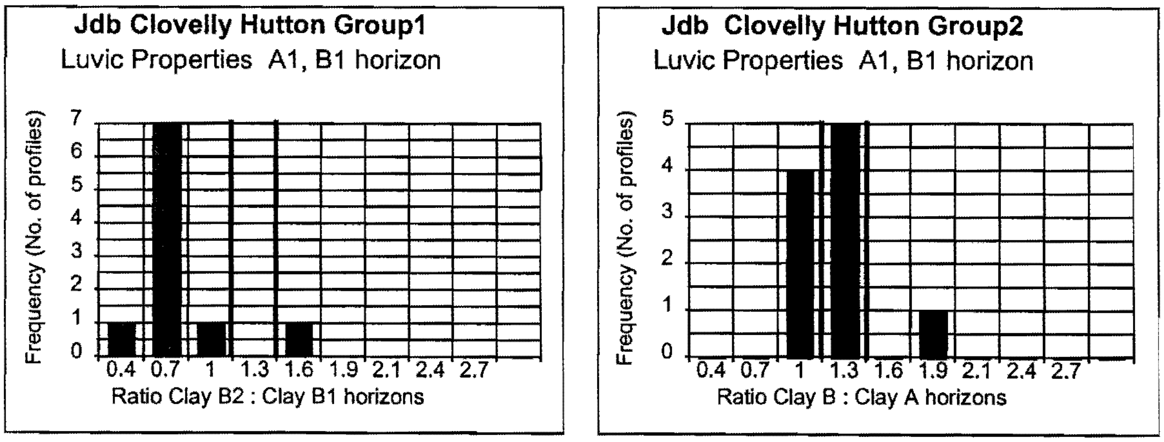


Figure 7.8 Luvic properties of two groups of soils within the Clovelly and Hutton Forms.

CHAPTER 8

SOILS OF THE BASALT OF THE LETABA FORMATION, LEBOMBO GROUP IN KWAZULU-NATAL AND MPUMALANGA

Location and Extent

The Letaba Formation runs in an extended belt from the Limpopo River in the north, stretching southwards through Mpumalanga and Swaziland. In KwaZulu-Natal it extends to form the common border with Swaziland southwards to the Mfolozi River. The formation is traceable well to the north of South Africa. The Letaba Formation, together with acid rhyolite volcanic member, forms the common border with Moçambique. The Letaba Formation also occupies extensive areas of the Springbok Flats in the Northern Province.

The formation covers an area of approximately 840 000 hectares, while within KwaZulu-Natal it covers an area of 197 600 hectares (Figure 8.1).

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

The Lebombo Group is a succession of basic and acidic lavas (SACS, 1980). The 1970 edition of the geological map of South Africa (Geological Survey, 1970) correlated these lavas with the Drakensberg Formation. However, uncertainties in their correlation have resulted in independent formation names being assigned for the three main lithological units of the Lebombo Group (SACS, 1980). The Letaba Formation comprises the lower basalt unit (SACS, 1980, Geological Survey, 1985a, Geological Survey, 1985b). The Jozini Formation is the name assigned to the rhyodacite acid unit (SACS, 1980; Geological Survey, 1985a; Geological Survey, 1985b). The third unit, the Movene Formation, is confined almost entirely to Moçambique. In this study soil profiles have only been sampled from the Letaba Formation. The remaining two units are hence not subsequently considered.

The basalt exposures of the Letaba Formation, east of the Lebombo Mountains is considered as of the Post African II surface which has become partly planed, and of Late Pliocene age (Partridge and Maud, 1987). The Lebombo Mountains themselves are descried as having exerted major structural control over this surface. The basalt exposures of the Springbok Flats are considered as part of a Post-African surface of Early Miocene age (Partridge and Maud, 1987).

Physiography and Drainage Features

The rhyolite of the Jozini Formation together with the basalt of the Letaba Formation forms the Lebombo Mountain Range stretching through north eastern Mpumalanga and KwaZulu-Natal. In Mpumalanga this range of hills comprising largely rhyolite has moderate relief. In KwaZulu-Natal the altitude difference between the basaltic plains to the west and the Lebombo Range is pronounced, forming low mountains. To the west of the Lebombo Range lies the basaltic plains with gentle slopes, low relief and low drainage density (Kruger, 1983). South of the Hluhluwe River to the Mhlatuze River the basalt plains become dissected giving rise to undulating hills and valleys. These plains are drained by sections of the major rivers the Sabie, the Crocodile and Komati, the Pongola and Mkuze and the Mfolozi Rivers. The basalt exposed on the Springbok

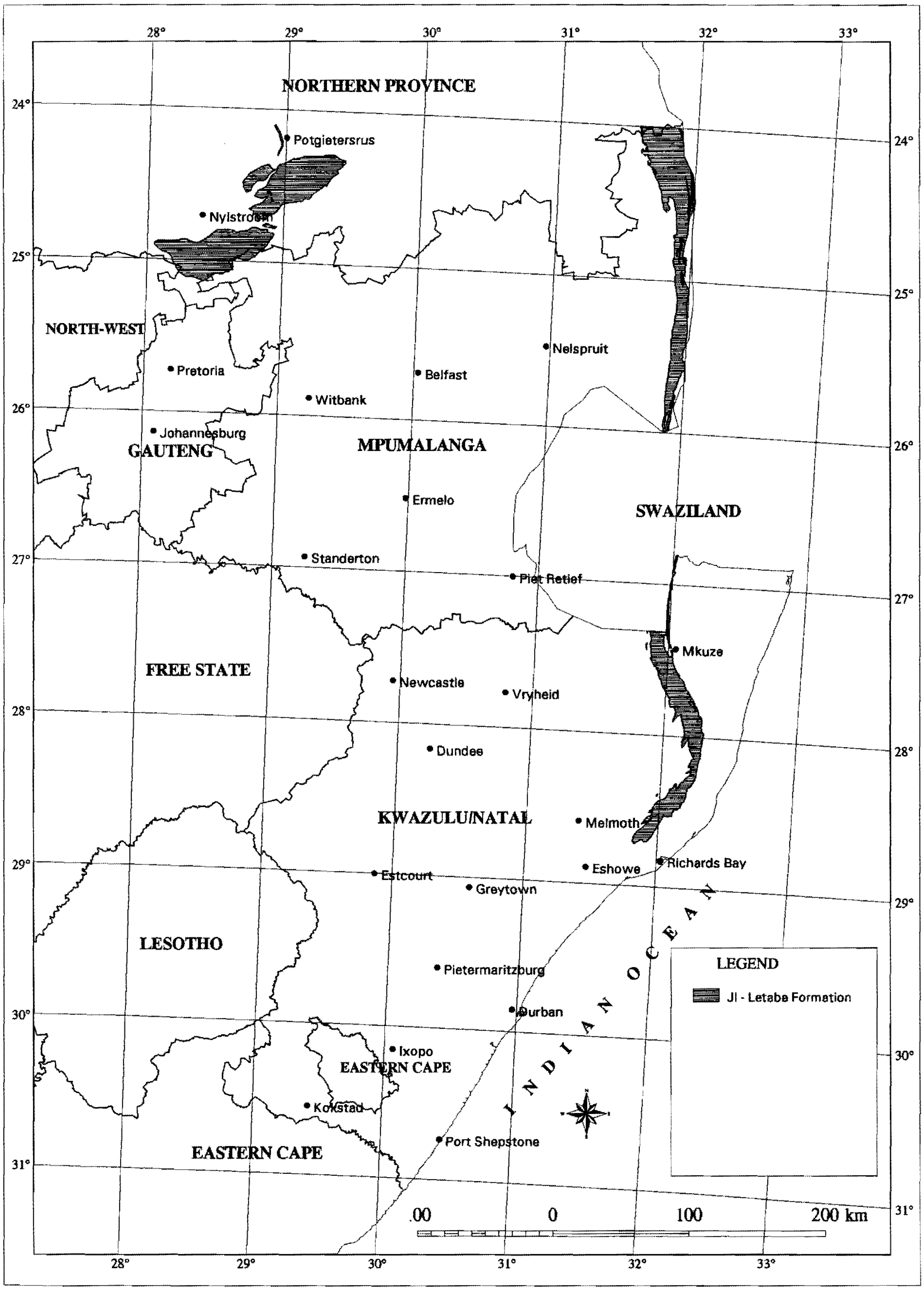


Figure 8.1. Location of the Letaba Formation, Lebombo Group in KwaZulu-Natal, Mpumalanga and Northern Province (after Geological Survey, 1984).

Flats forms an extensive plain of low relief and gentle slopes.

Vegetation

In Mpumalanga and stretching south to the Mkuze River the vegetation is described as Sweet Lowveld Bushveld (Low and Rebelo, 1996). South of the Mkuze River to the Mhlatuze river the vegetation is Natal Lowveld Bushveld (Low and Rebelo, 1996).

Soils

Two soil patterns are evident on the basalt of the Letaba Formation (Table 8.1). The first of these patterns is dominated by black clays of the Mayo, Milkwood, Bonheim and Arcadia soil forms. Other black clays may also be present. Red clays, Shortlands and Hutton soils, are also important components of this soil pattern. It is significant however, that the red soils of the Springbok Flats, which also overlie basalt of the Letaba Formation, have a significant component of red sandy loam to sandy clay loam soils (Land Type Survey Staff, 1987b). Judging by the sandy texture of these red soils, an external source of sand can be inferred. It is probable that this source of sand, in the red soils of the Springbok Flats, is from the sandstone of the Clarens Formation. A narrow band of the Clarens Formation is also present west of the Letaba Formation in KwaZulu-Natal and Mpumalanga. While sandier Hutton profiles are present in the sample set over basalt in KwaZulu-Natal and Mpumalanga, the extent of sandy material from the Clarens Formation east of the Lebombo Mountains appears much less.

The second soil pattern is a lithosolic one, associated with both basalt and rhyolite.

The pattern covering the largest area is that located on the plain west of the Lebombo Mountains. Mayo, Milkwood and Bonheim soils are dominant. Soils with both a non-calcareous and calcareous B horizons are indicated in the soil inventories (Land Type Survey Staff, 1986a; 1986b; 1987c; 1989a; 1989b). The calcareous soils are usually located in the lower midslope and valley bottom positions. Venter (1990) describes the presence of hardpan lime in bottomland sites in the Satara Land System, south of the Olifants River. Hardpan carbonate was also noticed south west of Komatipoort in Mayo soils on the Letaba Formation basalt. Similar occurrences of hardpan carbonates are not known to the author on basalt in KwaZulu-Natal. Arcadia soils are an integral component of this soil pattern. Rensburg soils were however estimated to cover only a limited area. The absence of Rensburg may be explained by the flat terrain with a few streambeds. There is only a limited area of bottomland soils, and in this relatively arid climate the extent of gleying is also limited. These observations seem to be confirmed in the descriptions given by Venter (1990).

Shortlands soils form an important component of this soil pattern, with both eutrophic and calcareous soils present (Table 8.1). The eutrophic Shortlands soils are present on the crest and midslope positions. Examples of the calcareous Shortlands were located on footslope positions.

Black clays, red and black clays, or lithosols are indicated to occur throughout this soil pattern (Table 8.1). There are zones within this soil pattern where the proportions of each of these components occurs to a greater or lesser extent (Land Type Survey Staff, 1986a; 1989b; Venter, 1990).

Table 8.1 Dominant soils and selected climatic information for soil patterns occurring on Letaba Formation.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Black and Red Clay soils (high base status)										
Mayo	My10 My11	12	Mispah	Ms10 Ms20	10	Ave	782	1707	4071	0.46
	My20 My21	2	Rock	Rock	5	Std	119	84	149	0.06
Milkwood	Mw10 Mw11	8				Max	918	1774	4078	0.52
	Mw20 Mw21	3				Min	608	1523	3842	0.36
Bonheim	Bo41	6								
	Bo31 Bo11 Bo21	6								
Arcadia	Ar40	9								
Shortlands	Sd21 Sd22	13								
	Sd31 Sd32	2								
Hutton	Hu37	4								
Total Area: 196 620 Ha			Means of 12 Land Types							
Broad Soil Pattern: Lithosolic soils										
Mispah	Ms10	50				Ave	600	1801	4150	0.33
Glenrosa	Gs16 Gs17	18				Std				
Rock		15				Max				
						Min				
Total Area: 900 Ha			Means of 1 Land Types							

The Lithosolic soil pattern is associated with basalt and rhyolite, the latter lithology giving rise to rockland with lithosolic soils. The area of this pattern is limited.

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles of the Hutton, Shortlands, Arcadia, Bonheim, Mayo, Glenrosa and Mispah 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 8.2. These ranges are also represented graphically in Figure 8.2. The figure allows for an overview comparison between different soil forms and over particle size classes. The majority of the profiles fall into the sandy clay loam to clay textural class (Table 8.2).

The maximum values for the Hutton (Cl1 clay textural class), Shortlands, Arcadia, Bonheim and Mayo soils do not differ much (Figure 8.2). The Arcadia soils have the highest mean values, but they also have the narrowest range of clay contents. The Hutton (Cl1), Shortlands and Bonheim soils have very similar mean values for clay percentage (Figure 8.2), but show a much larger range of values than the Arcadia soils. The implication is that these soils may have clay

Table 8.2 Textural properties of soils of the Jl Jurassic Lava-basalt derived from profile values.

Form	Hor izon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton(Cl1) (Lebombo)	A1 B1	SaCl-Cl ClLm-Cl	38-73 33-75	13-14 7-34	7-36 9-33	1-16 1-11	1-9 1-12	fi fi	- -
Hutton(Cl2) (Lebombo)	A1 B1	SaClLm Sa-LmSa-SaClLm	27 4-34	10 2-21	43 25-63	16 12-25	4-29 3-30	co co	- -
Hutton(Cl1) Nylstroom	A1 B1	ClLm-Cl ClLm-Cl	32-56 ??	7-29 ??	15-36 ??	4-14 ??	1-20 ??	fi fi	L3, N22 -
Hutton(Cl2) Nylstroom	A1	SaClLm-SaCl SaClLm-SaCl	18-38	3-20	25-43	13-27	3-23	fi, co fi, co	L3, NL2
Shortlands	A1 B1	SaClLm-ClLm-Cl SaClLm-ClLm-Cl	21-76 17-76	8-33 7-50	14-48 7-43	2-14 1-14	1-8 1-15	fi fi	NL4, L1 NL5
Arcadia	A1 A2 A3 C1	ClLm-Cl Cl Cl SaClLm-Cl	36-69 52-65 56-66 23-70	10-31 11-30 11-19 12-32	8-31 9-25 9-25 6-38	1-16 2-3 2-3 1-16	1-10 2-6 2-3 1-15	fi fi fi fi, co	NL5 NL5 NL3, EL2 -
Bonheim	A1 B1 B2	SaClLm-Cl SaClLm-Cl SaClLm-Cl	31-65 30-71 32-68	13-24 15-33 20-30	7-31 8-31 11-40	1-14 1-13 1-10	1-9 1-8 1-3	fi, co fi, co fi	NL5 NL2, EL3 EL5
Mayo	A1 B1	Lm-ClLm-Cl SaClFLm-SaCl-Cl	25-69 31-45	3-43 7-43	9-36 15-34	1-13 2-17	2-17 1-12	fi, co fi, co	EL -
Glenrosa	A1	SaLm-Lm-Cl	11-48	13-32	21-48	4-18	1-15	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).

percentages similar to, or lower than, those of the Arcadia soils. The mean clay percentages for the Mayo soils, and for the Glenrosa and Mispah soils respectively are lower than the others in this soil group (Figure 8.2).

The range of clay percentage values for the Shortlands are illustrated in Figures 8.2 and 8.5. It is common contention that the Shortlands soils should not have clay percentage values much below the sandy clay class (35 percent clay). In this sample set (Figure 8.5), and those from the dolerite soils (Chapter 6) there are profiles with these lower clay percentage values. Do Shortlands soils with loam textural classes really exist, and if so, should provision be made for them in any classification scheme? Alternatively, are these values simply the products of some form of error in either classification, analysis or data base construction? There is now only limited opportunity to detect such errors, and no opportunity to revisit these sites, or to re-analyse these soils. It seems probable that some form of provision for lower clay Shortlands soils will have to be made. However, these soils will probably be considered as exceptions, rather than part of the central concept of the Shortlands Form soils.

There is a small group of Hutton soils (labelled: Hutton (Cl2- Lebombo) which directly overlie the basalt of the Letaba Formation, but with sandy through loamy sand to sandy clay loam textures (Table 8.2). Coarse sand is dominant in these profiles. These profiles were sampled in the

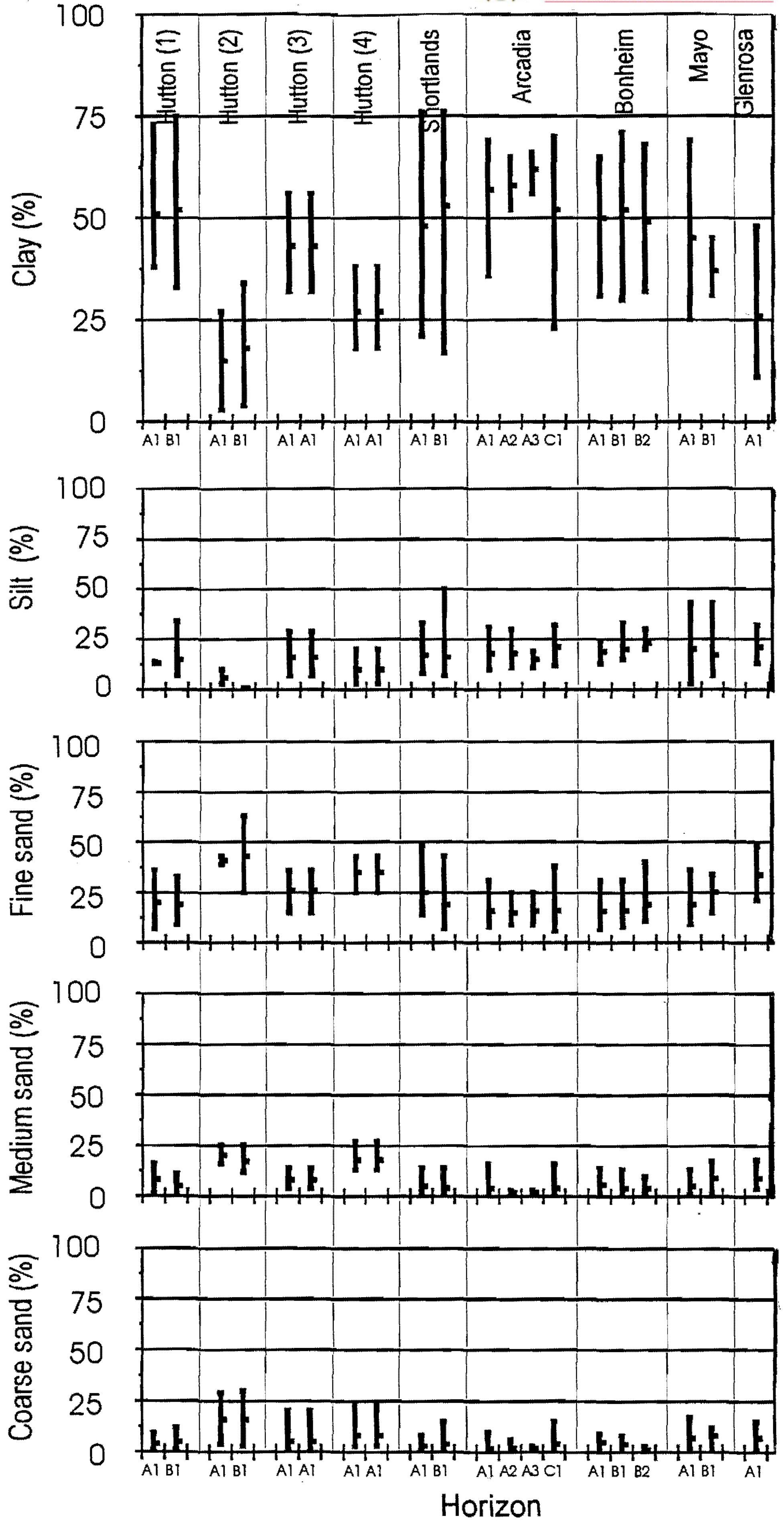


Figure 8.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Letaba Formation. Maximum, minimum and mean values are shown for each horizon.

Table 8.3 Means and standard deviations of five textural classes for soils of the Letaba Formation.

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 (Cl1) Lebombo: Profiles adjacent to Lebombo Mountain Range												
A1	216	51.3	15.5	13.7	0.5	20.0	12.0	8.0	6.2	4.3	3.4	3
B1	680	52.8	11.7	15.9	7.8	19.4	7.5	5.9	3.3	5.7	3.4	12
Form: Hutton (Cl2) Lebombo: Profiles adjacent to Lebombo Mountain Range												
A1	250	15.0	12.0	6.5	3.5	41.0	2.0	20.5	4.5	16.5	12.5	2
B1	530	18.2	11.4	7.2	7.1	43.6	12.7	17.4	6.2	16.8	9.8	5
Form: Hutton (Cl1) 2428 Nylstroom												
A1	-		-		-		-		-		-	
B1	725	43.4	6.4	16.0	7.7	26.4	7.0	8.6	2.6	5.5	6.3	14
Form: Hutton (Cl2) 2428 Nylstroom												
A1	-		-		-		-		-		-	
B1	583	27.1	6.1	10.3	4.0	35.3	5.3	18.8	3.7	8.2	5.2	18
Form: Shortlands												
A1	355	48.9	14.7	17.2	6.3	25.2	9.5	5.7	3.6	3.9	2.2	17
B1	679	53.2	16.0	16.3	8.6	19.8	8.6	4.7	3.1	4.4	3.5	38
Form: Arcadia												
A1	665	57.3	8.3	18.8	5.3	16.2	5.2	4.9	3.2	2.8	2.3	23
A2	665	58.3	5.7	18.8	6.3	15.3	5.5	2.5	0.5	2.8	1.5	6
A3	927	62.8	4.0	15.5	3.0	16.5	6.1	2.5	0.5	2.5	0.5	4
C1	1123	52.4	15.3	21.3	5.1	16.8	9.4	4.6	4.5	4.7	5.3	10
Form: Bonheim												
A1	393	50.1	10.0	19.7	3.4	16.0	6.5	6.2	3.8	5.6	2.5	10
B1	885	52.8	11.4	20.7	4.8	16.2	7.5	4.3	3.1	4.5	2.1	12
B2	1180	49.6	13.3	23.8	3.4	19.8	10.8	4.4	3.3	1.8	0.8	5
Form: Mayo												
A1	418	45.7	11.9	20.5	12.1	19.9	7.7	5.6	3.2	7.8	4.7	17
B1	638	37.3	5.1	17.3	12.8	25.0	7.6	9.6	6.0	8.0	4.3	6
Form: Glenrosa												
A1	253	26.1	13.7	21.8	7.3	34.0	9.8	9.0	5.0	7.8	4.4	8

Mpumalanga and Northern Provinces. No profiles with these texture classes were sampled from KwaZulu-Natal. To the west of the Letaba Formation basalt lies sandstone of the Clarens Formation. Colluvium or alluvium from this or other sources must be inferred as contributing to the sandy textures. Venter (1990) also notes the presence of these soils in the Vutome and Bulweni Land Systems within the Kruger National Park.

There is however, a similar group of sandy loam to sandy clay loam soils occurring in the Nylstroom District of the Springbok Flats (labelled: Cl2-Nylstroom). These soils have been more intensively sampled so that the textural properties (Table 8.3, Figure 8.4) can be described with greater confidence. In this district, two soil bodies overlying basalt of the Letaba Formation can be recognised on the basis of their clay content and sand grade. The first soil body is of Hutton profiles (labelled: Hutton Cl1-Nylstroom) with clay textures suggesting a genesis directly form the basalt of the Letaba Formation. Their textural properties (Tables 8.2 and 8.3) do not differ much from Hutton soils (labelled: Hutton Cl1-Lebombo) derived from basalt west of the Lebombo Mountains. The second group of Hutton profiles has clay percentages about half of those derived from the basalt, while silt and fine sand values are similar to those of Hutton and Clovelly soils over sandstone of the Clarens Formation. In listing all the Nylstroom profiles the distinction between the two groups was placed at 50 percent total sand (about 35 percent clay), though this value is somewhat arbitrary (Figure 8.3 and 8.4). The relatively large number of sandy loam Hutton profiles in this geographic location would indicate difference in their genesis. This is supported by Oberholtser (1969a, 1969b), Taylor (1972) and Bühmann, Kirsten, Paterson and Sobczyk, (1993), although some of their data sets were relatively smaller and from restricted localities.

The Mayo profiles (17) have textures located in the clay and clay loam classes (Figure 8.7). These textures do not differ appreciably from those of the Bonheim soils (Figure 8.8). Profiles (8) from the Glenrosa and Mispah soils are located with textures in the clay, in the loam, and in the sandy loam texture classes (Figure 8.9). The implication appears to be that although clay texture profiles are possible for Mispah soils, sandier textures including those with intermediate silt values should be expected (Table 8.2, Figure 8.9).

Half of the Hutton profiles show luvic properties (Figure 8.10). These profiles are mostly from the Nylstroom District. A much smaller proportion (25%) of Shortlands profiles have luvic properties.

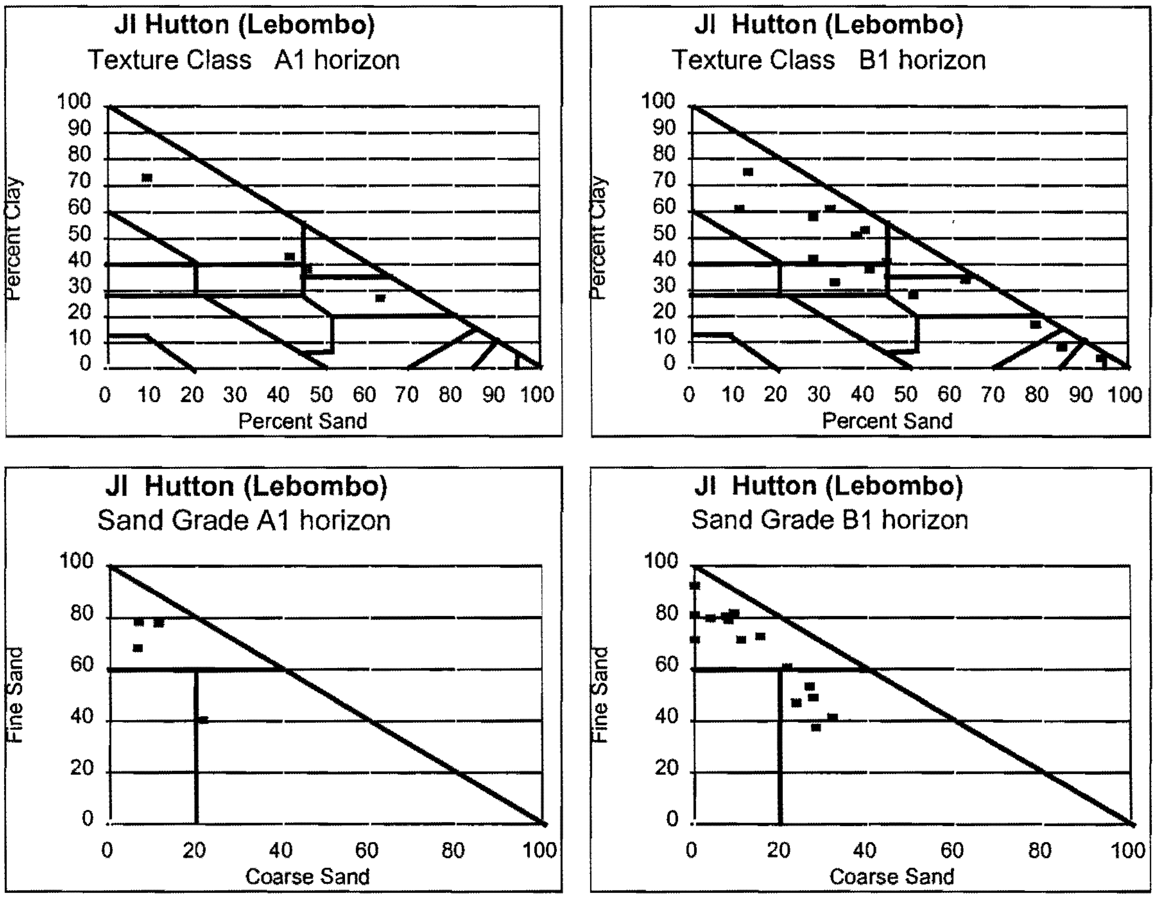


Figure 8.3 Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form (Lebombo Districts).

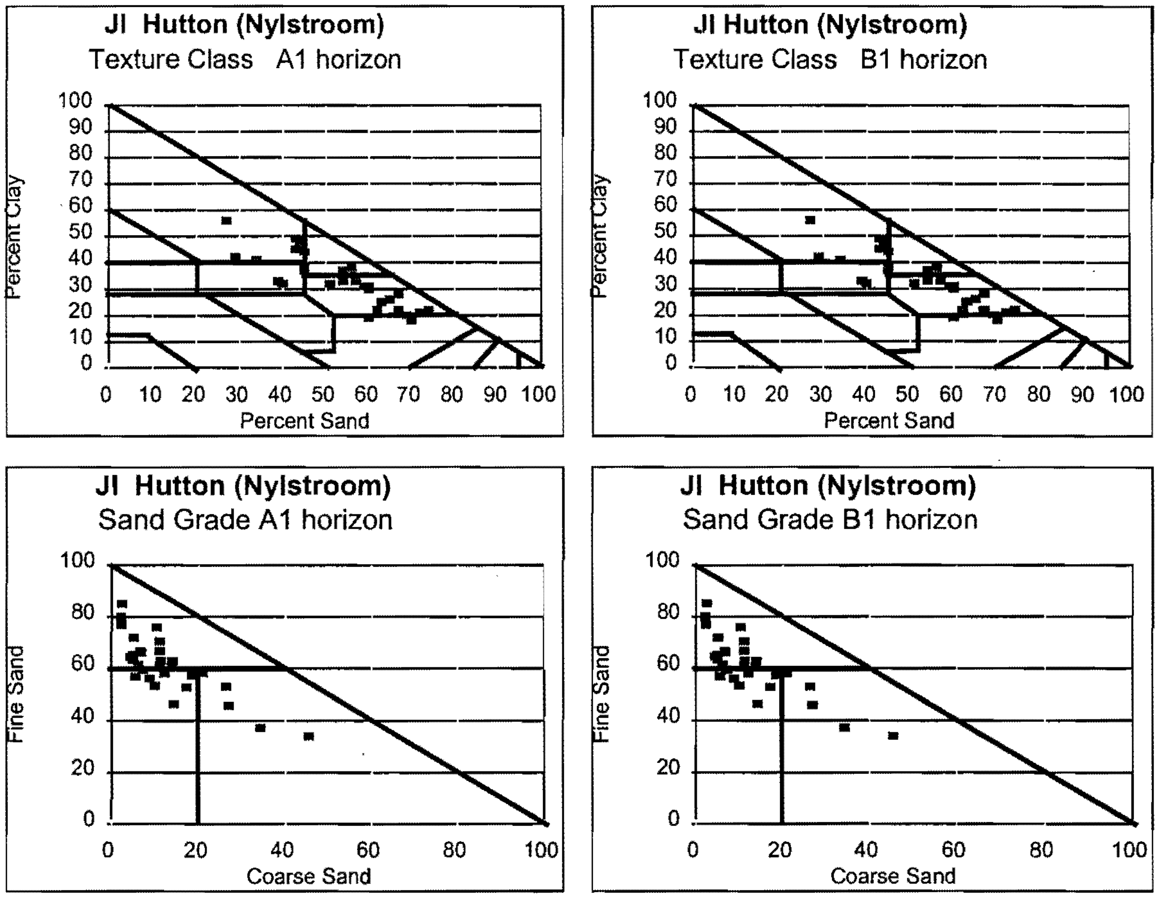


Figure 8.4 Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form (Nylstroom District).

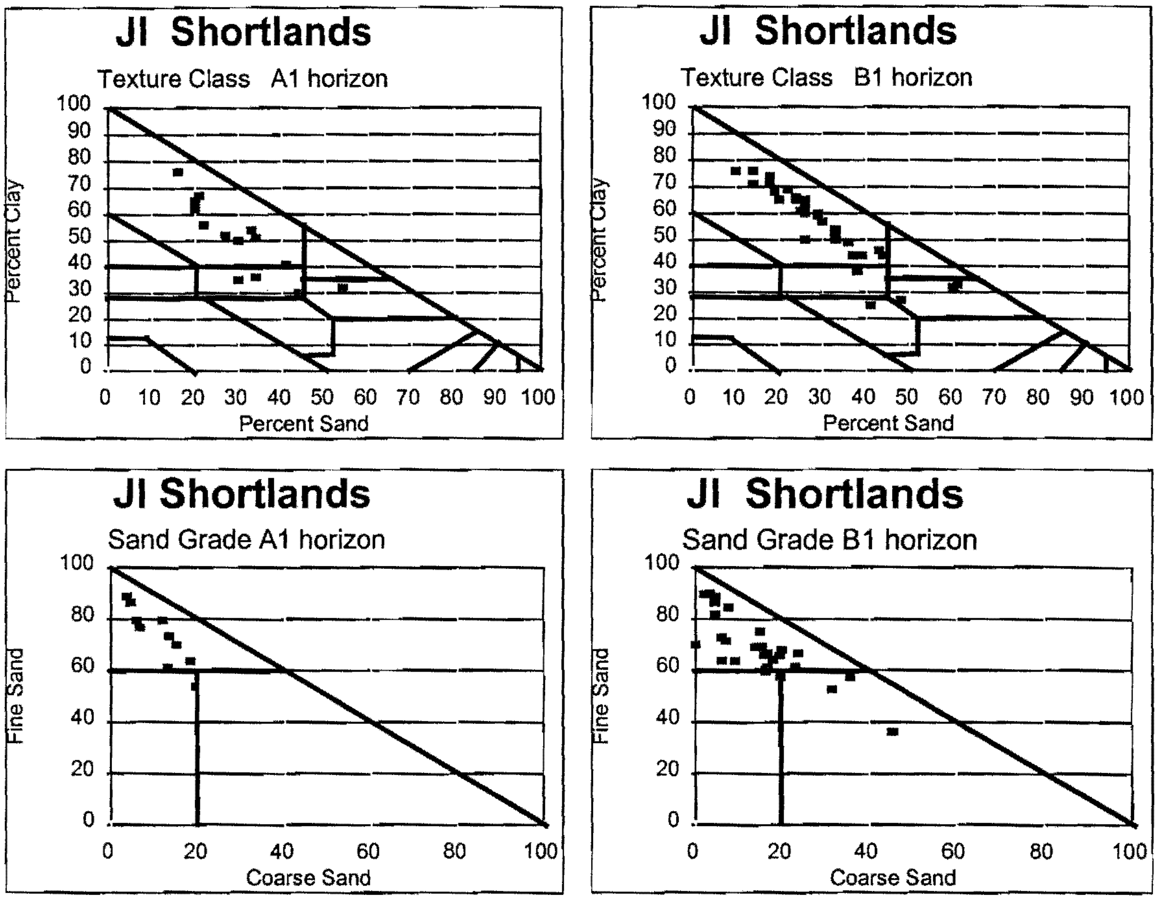


Figure 8.5 Distribution of soil textures, and dominant sand grade, within soils of the Shortlands Form.

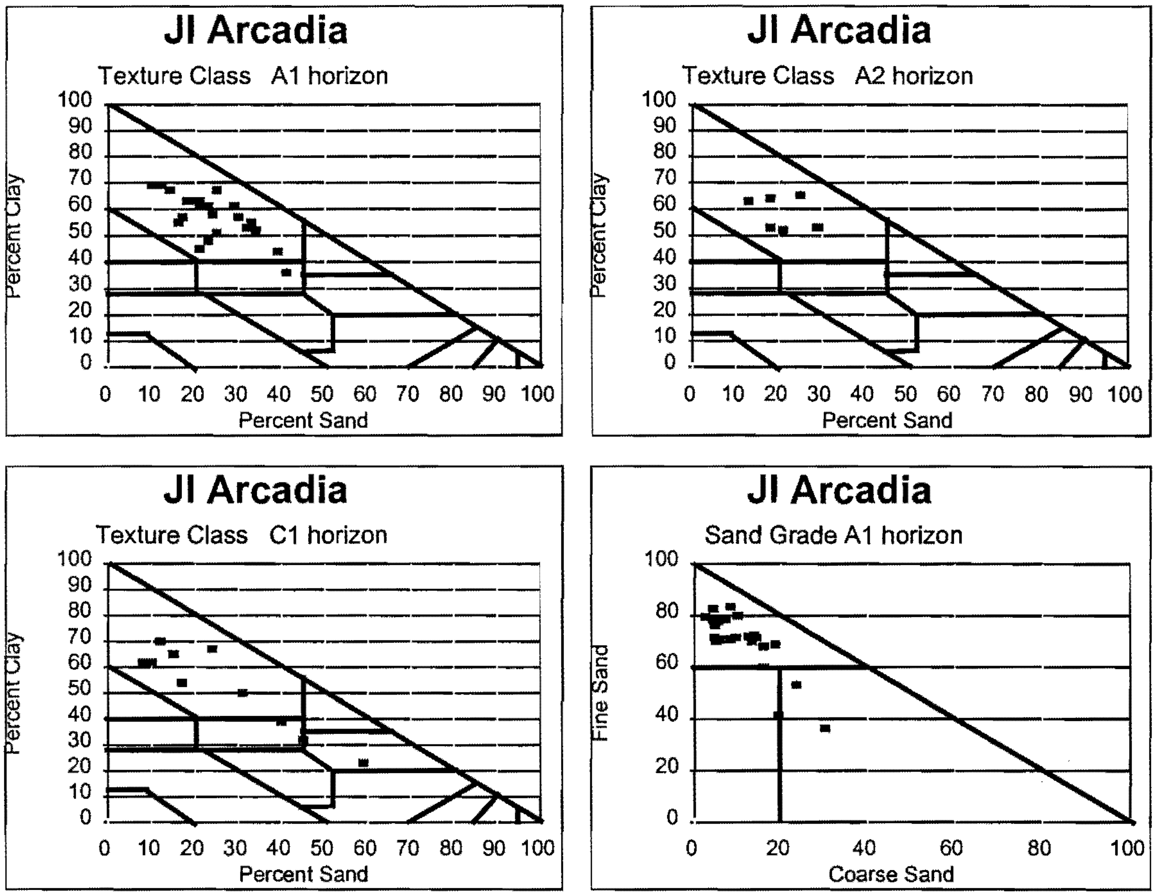


Figure 8.6 Distribution of soil textures, and dominant sand grade, within soils of the Arcadia Form.

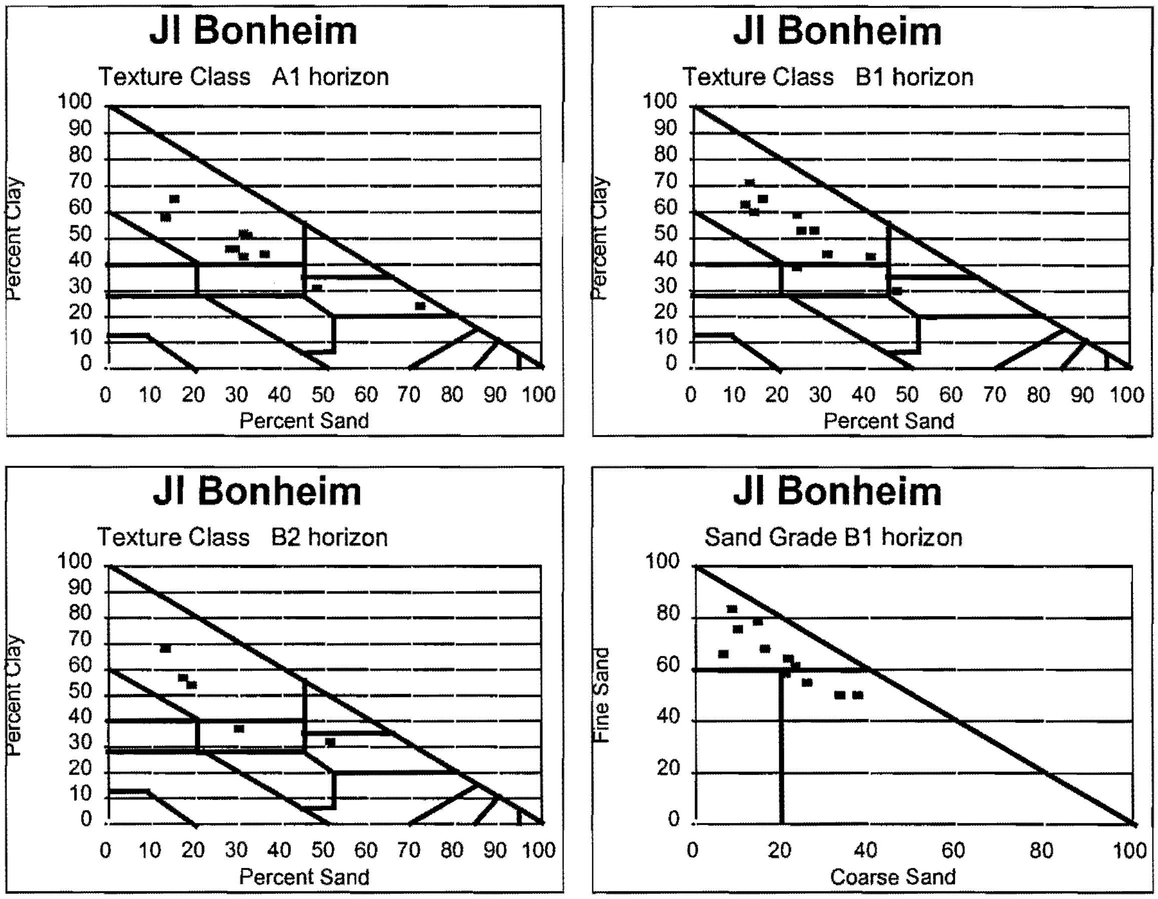


Figure 8.7 Distribution of soil textures, and dominant sand grade, within soils of the Bonheim Form.

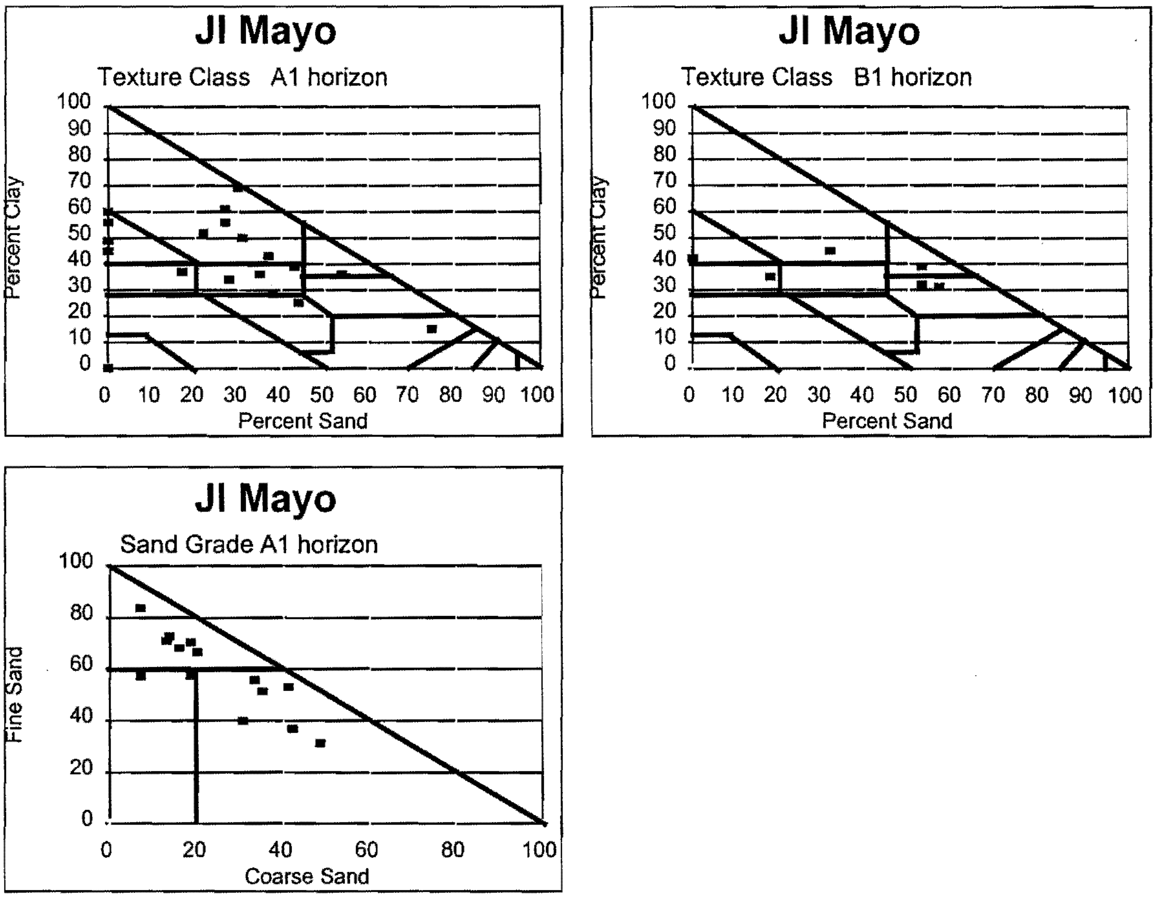


Figure 8.8 Distribution of soil textures, and dominant sand grade, within soils of the Mayo Form.

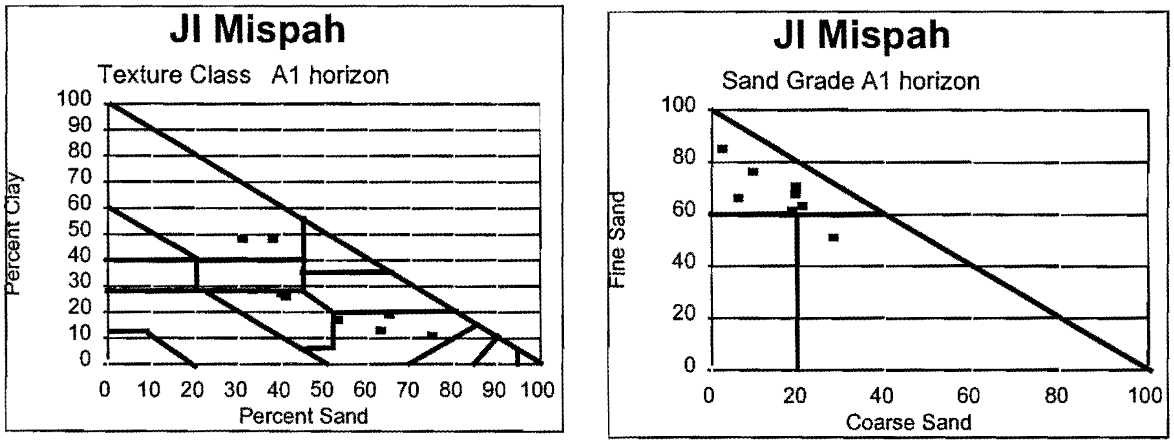


Figure 8.9 Distribution of soil textures within soils of the Mispah Form.

CHAPTER 9

SOILS OF THE AMPHIBOLITE OF THE TUGELA GROUP AND MAPUMULO METAMORPHIC SUITE IN KWAZULU-NATAL AND MPUMALANGA

Location and Extent

Amphibolites, together with basic and andersitic lavas are located in the Piet Retief District of Mpumalanga. The main occurrences are south and west of the town. Amphibolites are also located between 40 and 80 kilometres from the coast, in an area north and east of the Tugela River described as the Natal Structural and Metamorphic Province (Geological Survey, 1988c). Extensive faulting in this area has resulted in a complex geological pattern with a variety of other rocks including granite, gneiss, schist and diorite and others together with the amphibolites. Amphibolites are also present in the coast belt in the Ngoye Range and the escarpment located between the towns of Eshowe and Gingindlovu. There are further isolated occurrences of amphibolite in the Mgeni River Valley north east of Durban, and south of Durban in the Umzinto District (Figure 9.1).

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

Crystalline rocks intruded by granitoids in northern KwaZulu-Natal were recognised prior to 1900, and initially placed with the Swaziland Series of rocks (SACS, 1980). The rocks known variously as Nkandla, Nondweni, Mfongosi and Tugela Series comprise quartzites, schists, chert, limestone, amphibolite, gneiss, banded ironstone and others. They have been collectively grouped within the Natal Structural and Metamorphic Province (Geological Survey, 1984). Of particular interest in this study are the soils derived from amphibolites. These amphibolites are classified within eight formations of the Tugela Group, one formation each of the Matigulu Group, the Mapumulo and Empangeni Metamorphic Suites and one independent formation in the Port Shepstone District (Geological Survey, 1888b; Geological Survey, 1988c; Geological Survey, 1988d). Amphibolites also occur south and west of Piet Retief as part of the Barberton Sequence (Geological Survey, 1988a).

The exposures of the amphibolite east of the Eshowe Plateau have been considered (Partridge and Maud, 1987) as part of a lowered African Surface of Early Cretaceous age. Remnants of the surface are usually preserved on the interfluves.

Physiography and Drainage Features

The area in the Piet Retief District where amphibolite is exposed comprises undulating hills and low mountains with moderate relief. To the south, some of these amphibolite zones west of Melmoth in the Tugela River Valley also comprise undulating hills and valleys. However, most of the Tugela River Valley, where amphibolite is present comprises hills with moderate relief and low mountains. The areas are drained by tributaries of the Pongola and Tugela Rivers respectively.

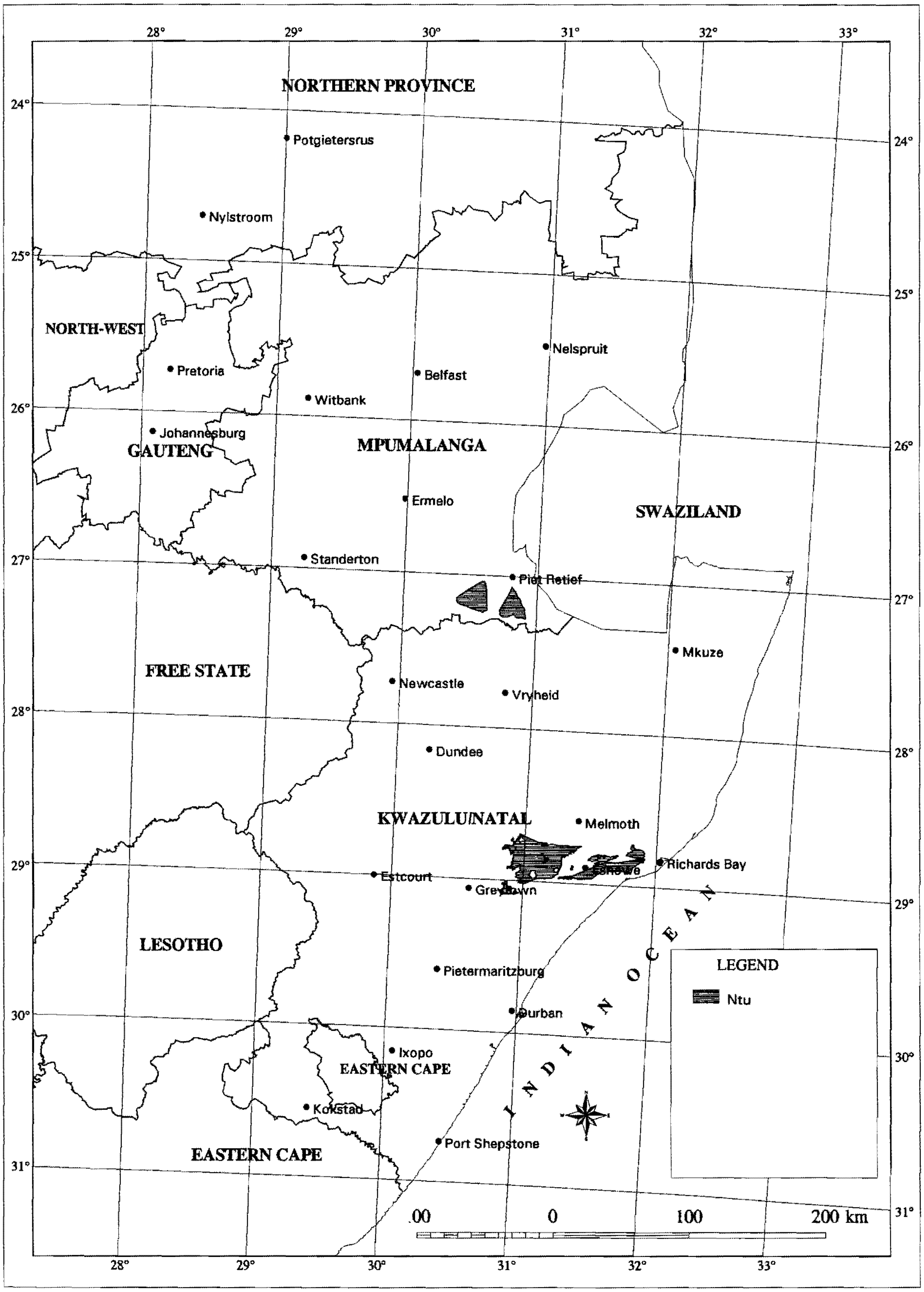


Figure 9.1. Location of the amphibolite rocks of the Tugela Group in KwaZulu-Natal (after Geological Survey, 1984).

Vegetation

The vegetation of these zones is North Eastern Mountain Grassland (Piet Retief District) and Coast Hinterland Bushveld (Tugela River Valley) (Low and Rebelo, 1996).

Soils

Four major soil patterns are evident on the amphibolites of the Tugela Group, Matigulu Group and Mapumulo Metamorphic Suite in KwaZulu-Natal. These are a red apedal pattern with dominantly mesotrophic base status, a pattern comprising of black and red clay soils, and lithosols with and without the presence of lime (Table 9.1). Information on the soils derived from amphibolite is somewhat limited. There are two reasons for this position. The amphibolite commonly occupies a limited surface extent. The separate recognition, at regional scales, of the soils derived from amphibolite, and those of other lithology has not been done. Furthermore, the amphibolite also occurs in steep and largely inaccessible land, such that accurate collection of soil information is not readily possible.

The red apedal soil pattern quoted (Table 9.1) is from the Tugela Valley where the base status and the proportions of Hutton and Shortlands soils have been recorded by field survey. Red soils, and probably of dystrophic base status, also occur in the Piet Retief District together with red soils derived from biotite granite. In this instance the soils derived from amphibolite have not been separated from those from granite. This information is not quoted in Table 9.1.

An area of dominantly Mayo, Bonheim and Shortlands soils is located in undulating land between Eshowe and Nkandla. The soils are moderately deep and have a sandy clay loam to clay texture.

The lithosolic soil patterns are located on steep land. Estimates of the soil distribution indicate the presence of Hutton, Shortlands, Mayo and Bonheim soils, in addition to those of Glenrosa and Mispah (Table 9.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles of the Hutton, Shortlands and Mayo 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 9.2. These ranges are also represented graphically in Figure 9.2. The figure allows for an overview comparison between different soil forms and over particle size classes.

The textures of the Mayo profiles derived from the amphibolite rocks of the Tugela Group are very similar to those from Karoo dolerite and the Letaba Formation basalt. Clay and sandy clay are the dominant texture classes with individual profiles extending to the sandy clay loam class (Figure 9.5). The B1 horizons too show these textures, indicating that weathering has proceeded in the case of these amphibolite rocks to at least 1 metre depth. Distinction between these Mayo soils derived from amphibolite, and those form dolerite and basalt, at series classification level

Table 9.1 Dominant soils and selected climatic information for soil patterns occurring on amphibolite.

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 Soils (mesotrophic base status)										
Hutton Shortlands	Hu27 Sd12 Sd21	52 30	Mispah	Ms10	10	Ave Std Max Min	850	1736	3514	0.48
Total Area: 1 640 Ha			Mean of 1 Land Type							
Broad Soil Pattern: Black and Red Clay Soils (high base status)										
Mayo Bonheim Shortlands	My11 Bo31 Bo11 Sd21 Sd22 Sd11 Sd12	36 21 18	Glenrosa	Gs16 Gs19	11	Ave Std Max Min	898 71 980 816	1549 38 1593 1505	3367 143 3533 3201	0.57 0.03 0.61 0.54
Total Area: 9 210 Ha			Means of 4 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa Hutton Shortlands Mayo	Gs16 Gs17 Hu26 Hu27 Sd11 Sd12 My10 My11	31 18 14 8	Cartref Bonheim Mispah Rock	Cf21 Cf31 Bo31 Bo11 Ms10 Ms11 Rock	3 3 4 4	Ave Std Max Min	953 109 839 1075	1707 110 1855 1546	3386 573 3874 2418	0.56 0.09 0.68 0.45
Total Area: 123 250 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime										
Glenrosa Mispah Hutton Shortlands	Gs16 Gs17 Gs26 Ms10 Hu34 Hu36 Hu44 Hu46 Sd21 Sd22	32 16 14 7	Rock	Rock	5	Ave Std Max Min	720 30 750 690	1724 52 1776 1672	3523 20 3543 3503	0.41 0.03 0.44 0.38
Total Area: 117 920 Ha			Means of 4 Land Types							

is probably not required with respect to texture. However, it is interesting that a greater proportion of Mayo soils, together with Shortlands and Hutton soils, have developed on the amphibolite. Bonheim, Arcadia and Rensburg Form soils have not been sampled on amphibolite rocks, and appear to be sub-dominant in these landscapes. The resultant weathering in the Mayo soils is to kaolinite and 2:1 chlorite minerals in the clay fraction. Quartz, feldspar, 2:1 chlorite and even kaolinite minerals are present in the silt fraction. Only a minor amount of smectite was present in one horizon (Land Type Survey Staff, 1987c; 1994a). The clay fraction has no (or only limited) swelling capacity for the Mayo soils. The absence of smectite was unexpected in these Mayo soils. (How does this compare with the Mayo from dolerite and basalt). Mineralogy is available for only three Mayo profiles to support this trend. It remains uncertain whether smectite

Table 9.2 Textural properties of soils of amphibolite derived from profile values.

Form	Hori zon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1	ClLm-Cl SaLm-SaClLm-ClLm-Cl	30-69 15-65	15-26 4-27	13-29 13-44	2-11 4-28	2-4 3-17	fi fi,me,co	- -
Shortlands	A1 B1	SaClLm-Cl SaClLm-Cl	25-66 30-83	8-30 8-26	14-32 8-42	4-30 1-15	2-11 1-6	fi,me fi,me	L3,NL2 -
Mayo	A1 B1	SaClLm-SaCl-Cl SaLm-SaClLm-Cl	22-58 17-65	9-25 7-28	18-55 14-52	5-31 3-26	1-15 1-22	fi,me,co fi,me,co	NL2,EL2,L1 -

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).

would be present in other Mayo profiles. Cation Exchange Capacities (CEC, expressed in cmol(+)/kg clay) range from 20 to 100 cmol(+)/kg clay and present a varied picture. The CEC values for the profiles where the mineralogy was determined, were placed centrally within this CEC range. This could indicate that smectite may not be expected in these Mayo soils. In the Shortlands and Hutton soils it is assumed that kaolin minerals together with the iron minerals are dominant. Cation Exchange Capacities (CEC) for the Shortlands and Hutton soils ranges from 13 to 70 cmol(+)/kg clay. No mineralogical analyses for these soils were available.

Table 9.3 Means and standard deviations of five textural classes for soils derived from amphibolite.

Hori zon	Depth mm	Clay % Mean	Clay % SD	Silt % Mean	Silt % SD	Fine Sand % Mean	Fine Sand % SD	Medium Sand % Mean	Medium Sand % SD	Coarse Sand % Mean	Coarse Sand % SD	Sample Size
Form: Hutton												
A1	0-290	49.5	19.5	20.5	5.5	21.0	8.0	6.5	4.5	3.0	1.0	2
B1	982	35.1	15.9	12.4	6.6	27.4	9.2	14.4	8.8	10.1	5.0	8
Form: Shortlands												
A1	488	39.2	15.4	18.7	8.1	23.8	6.7	12.7	8.5	5.3	2.8	6
B1	1011	55.7	14.7	16.3	6.9	18.1	11.1	7.1	4.0	3.8	1.7	7
Form: Mayo												
A1	524	40.1	10.2	14.9	4.6	28.0	10.1	12.7	6.3	6.3	4.5	15
B1	1025	42.5	14.8	17.2	5.7	25.9	12.5	10.9	7.6	6.8	6.0	10

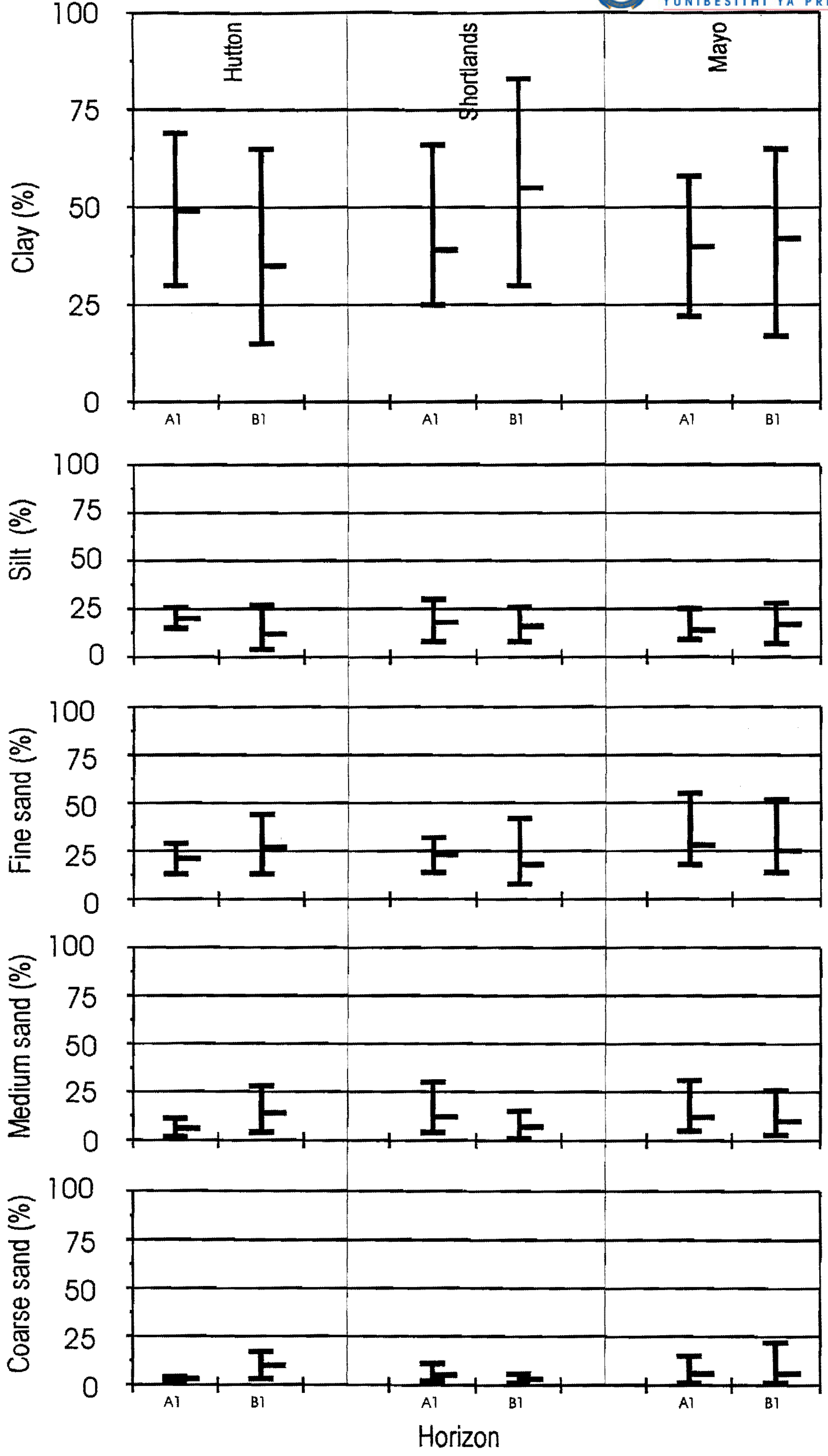


Figure 9.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the amphibolites of the Tugela Group. Maximum, minimum and mean values are shown for each horizon.

The texture of the A1 horizon of the Shortlands soils is dominantly sandy clay loam (Figure 9.4), while that for the B1 horizon rises to the clay class. This is clearly much lower than those soils derived from dolerite or basalt, which have clay texture classes throughout all horizons. This trend is more pronounced in the Hutton soils, where the textures of the B1 horizons range from sandy loam through to clay (Figure 9.3). Fine, medium and coarse sands are dominant within individual Mayo, Shortlands and Hutton profiles (Figures 9.3, 9.4, 9.5).

The Shortlands and Mayo soils have both luvic and non-luvic properties with respect to their A1 to B1 horizons.

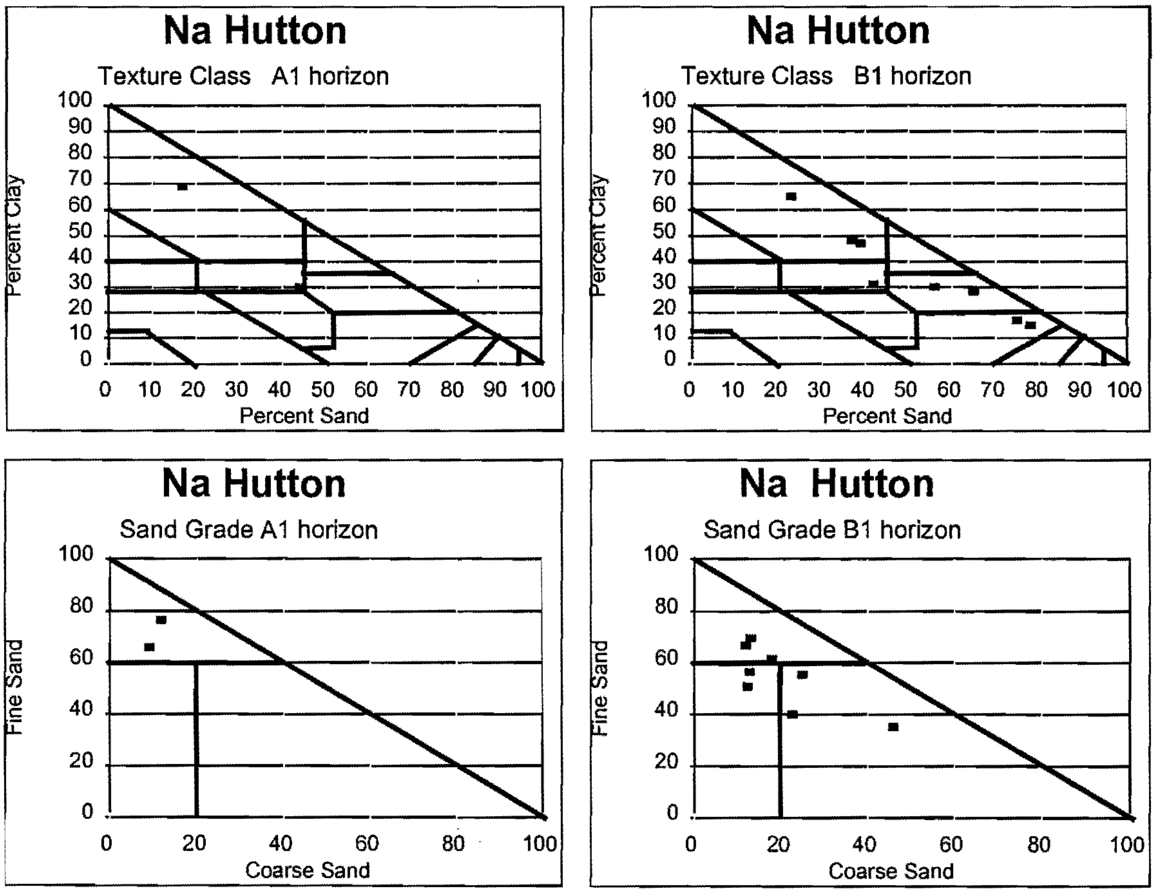


Figure 9.3. Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

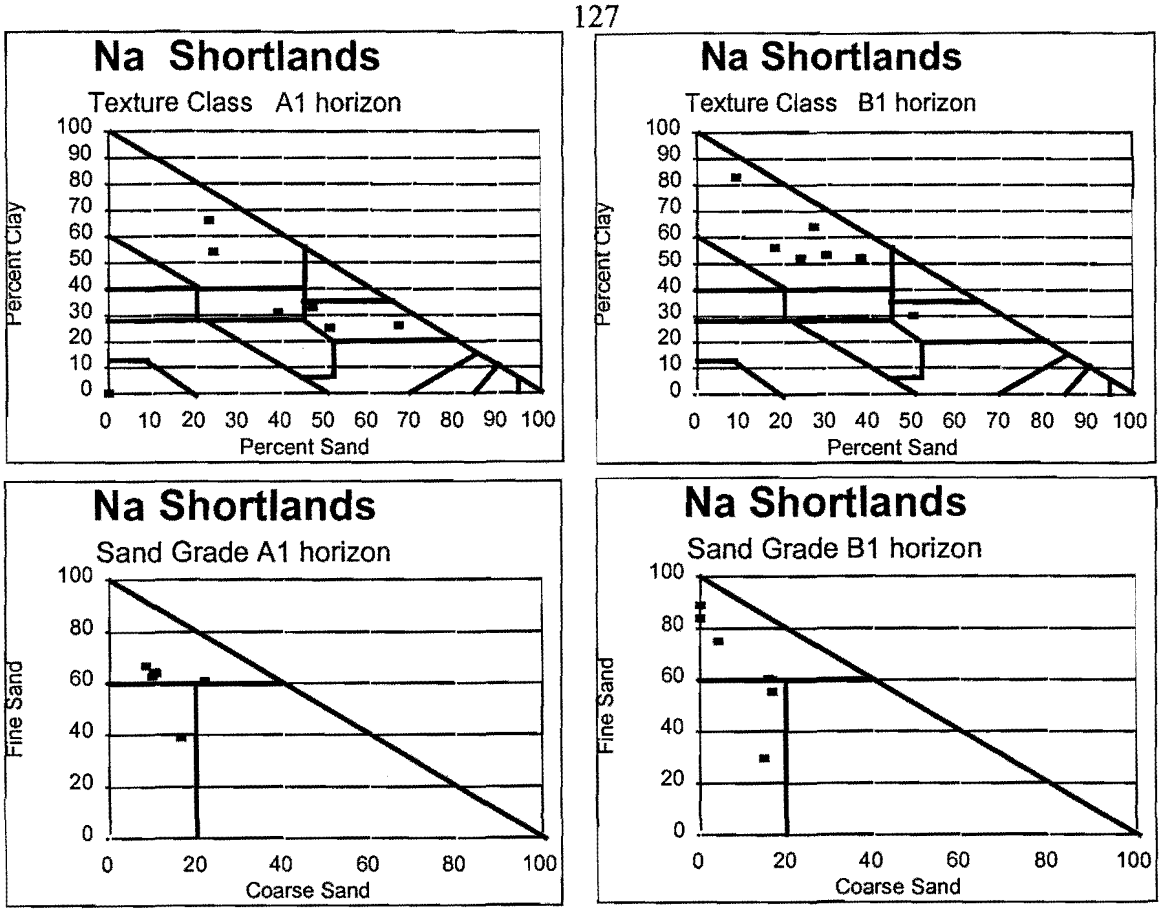


Figure 9.4. Distribution of soil textures, and dominant sand grade, within soils of the Shortlands Form.

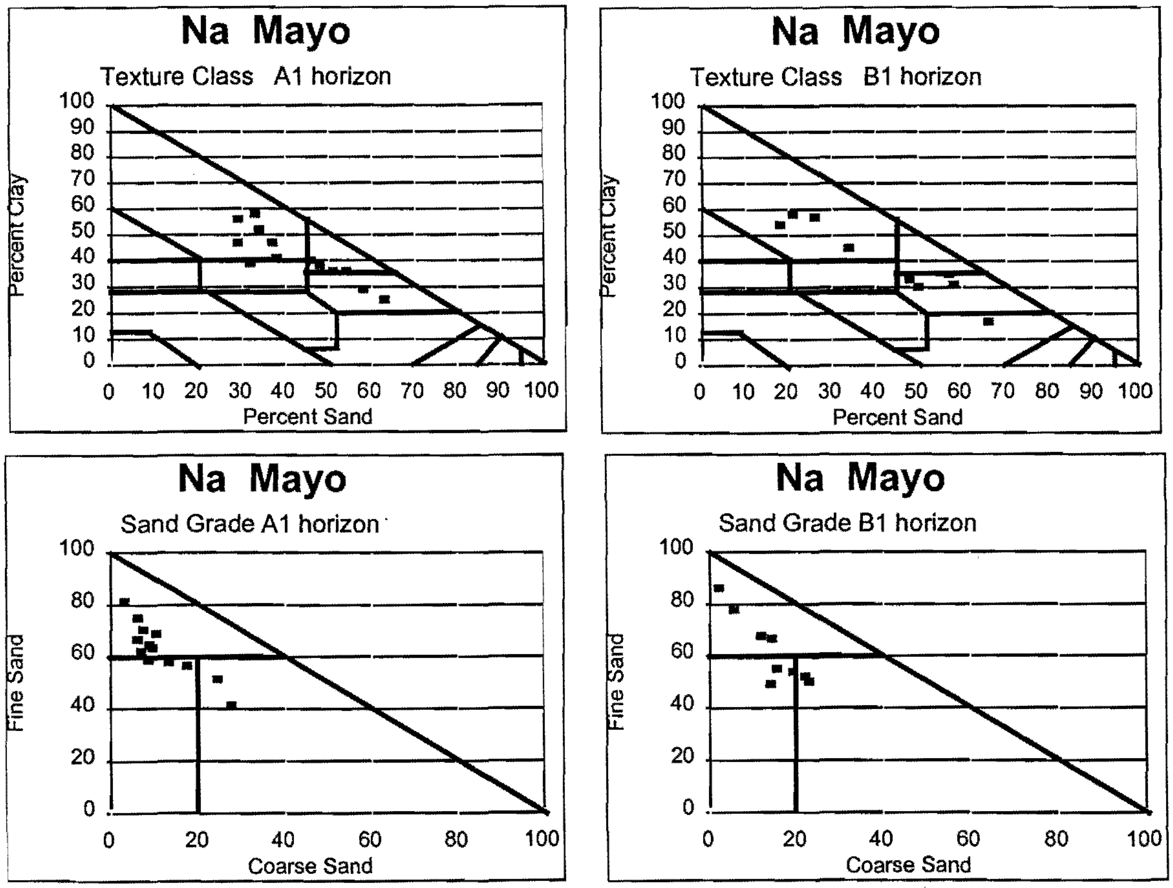


Figure 9.5. Distribution of soil textures, and dominant sand grade, within soils of the Mayo Form.

CHAPTER 10

SOILS OF THE SANDSTONE AND MUDSTONE OF THE TARKASTAD FORMATION, BEAUFORT GROUP IN KWAZULU-NATAL

Location and Extent

The Tarkastad Formation lies in a belt of between 15 and 30 kilometres wide, stretching from the source of the Klip River through southern KwaZulu-Natal. The formation is located in the foothills below the Drakensberg escarpment and the moist interior basins. In the west the formation is bounded by the Molteno and Elliot Formations. The eastern boundary is the Estcourt Formation in the north, while south of the Mkomazi River it bounded in the east by the Adelaide Formation (Figure 10.1). South of the Giants Castle buttress the area occupied by the Tarkastad Formation is intruded by extensive dolerite sheets.

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

The strata of the Beaufort Group can be readily subdivided into two geological mappable units, the upper Tarkastad Formation and the lower Adelaide Subgroup with the former possessing a greater proportion of sandstone and red mudstone (SACS, 1980). South of 31 degrees 30 minutes south (south of KwaZulu-Natal) two formations have been recognised, namely a lower arenaceous formation and an upper argillaceous formation. To the north it has not been possible to differentiate between the two formations and a single unit Tarkastad Formation is used. The Tarkastad Formation is described as comprising fine to medium grained yellow and grey sandstone and maroon (red) to green and blue mudstone (Geological Survey, 1981a; Geological Survey, 1981b).

Physiography and Drainage Features

The foothills of the Drakensberg Escarpment have undulating hills and low mountains with only limited land of flatter slopes. However, south of Giants Castle the proportion of land with slopes less than 5 percent increases significantly and lowlands and hills of moderate relief are encountered (Kruger, 1983). To the north drainage is via the Tugela, Bushmans and Mooi Rivers and their tributaries, while to the south drainage is via the Mkomazi, Mzimkulu and Mzimvubu Rivers.

Vegetation

The vegetation is largely North-eastern Mountain Grassland and Moist Upland Grassland (Low and Rebelo, 1996).

Soils

Four major soil patterns are evident on the sandstone and mudstone of the Tarkastad Formation (Table 10.1). The patterns include a red and yellow-brown apedal soil pattern where dystrophic sandy loam to sandy clay loam soils is dominant. The red clay soils (Hu18), while forming an integral part of this soil pattern, are probable derived from dolerite, and as such should be read in association with the sandier soils developed from the sandstones and mudstones of the

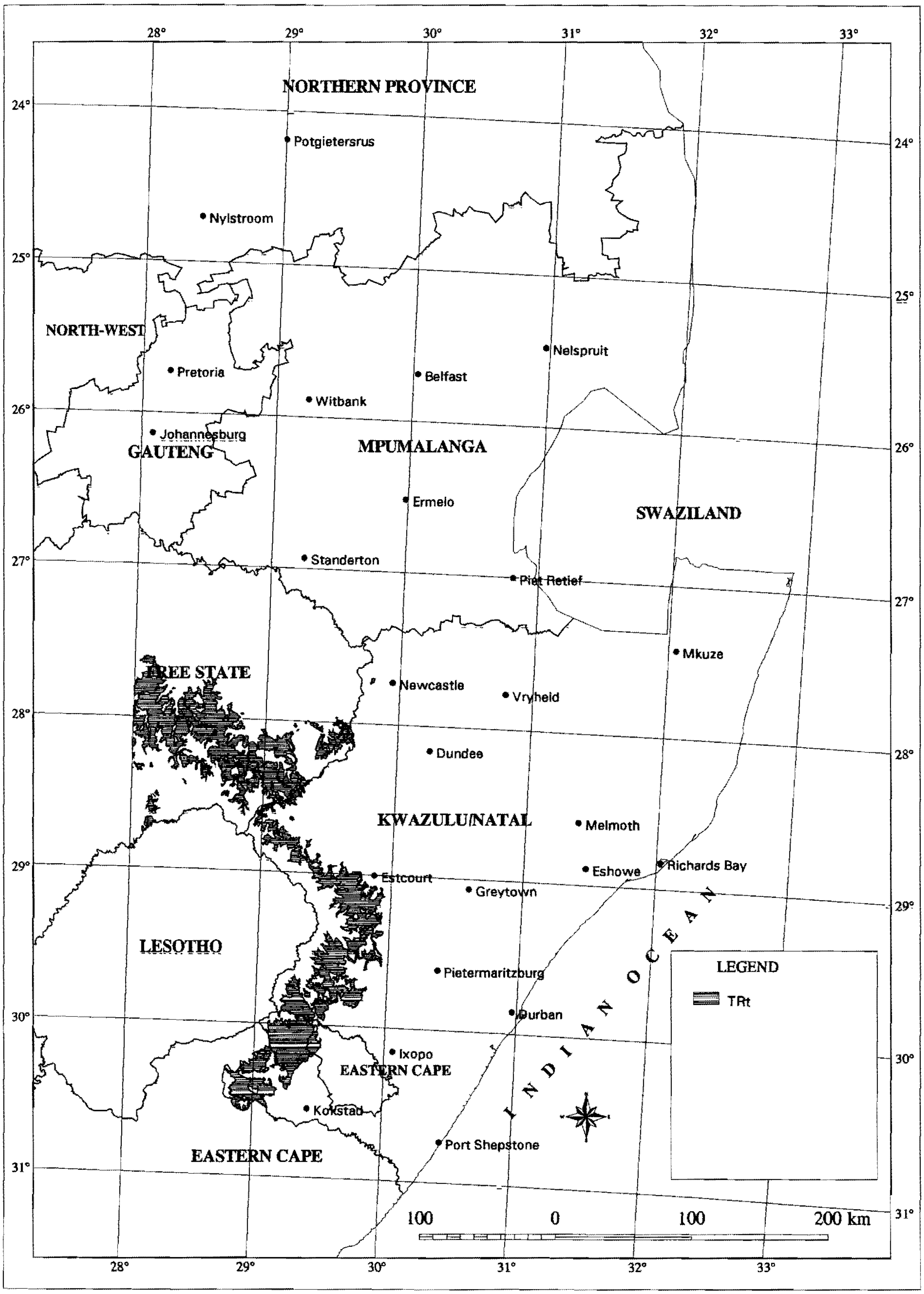


Figure 10.1. Location of the Tarkastad Formation, Beaufort Group in KwaZulu-Natal (after Geological Survey, 1984).

Table 10.1 Dominant soils and selected climatic information for soil patterns occurring on Tarkastad Formation.

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 Soils (dystrophic base status)										
Hutton	Hu16 Hu17 Hu26	20	Glenrosa	Gs16 Gs19	12	Ave	994	1716	1841	0.58
	(Hu18)	14	Mispah	Ms10	7	Std	151	286	361	0.11
Clovelly	Cv16 Cv17 Cv18	14				Max	1438	2951	3020	0.88
Griffin	Gf11 Gf12	8				Min	676	1230	1221	0.37
Oakleaf	Oa36	3								
Katspruit	Ka10	3								
Total Area: 324 370 Ha			Means of 99 Land Types							
Broad Soil Pattern: Plinthic Soils (mesotrophic base status) and Duplex Soils										
Avalon	Av23 Av24 Av26	33	Estcourt	Es13 Es16	8	Ave	753	1583	1459	0.48
Pinedene	Av16 Pn26 Pn16		Valsrivier	Va31 Va32	11	Std	47	28	82	0.03
Clovelly	Cv16 Cv26 Cv27	7		Va41 Va42		Max	800	1612	1541	0.50
Oakleaf	Oa36	3	Sterkspruit	Ss26	4	Min	706	1555	1377	0.45
			Swartland	Sw31 Sw32	2					
			Glenrosa	Gs16 Gs17	14					
			Mispah	Ms10						
			Rock	Rock	4					
Total Area: 162 680 Ha			Means of 5 Land Types							
Broad Soil Pattern: Duplex Soils										
Estcourt	Es33 Es34 Es36	17	Avalon	Av33 Av36	7	Ave	674	1718	2126	0.39
Valsrivier	Va31 Va41 Va21	27		Pn33		Std	25	50	632	-
Swartland	Sw31 Sw41 Sw11	11	Pinedene	Pn36		Max	710	1789	3008	0.40
	Sw21					Min	656	1682	1685	0.39
Sterkspruit	Ss23 Ss24 Ss26	12								
Glenrosa	Gs13 Gs16 Ms10	11								
Mispah										
Total Area: 32 350 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa	Gs16 Gs17 Gs19	19	Hutton	Hu16 Hu26	15	Ave	881	1811	1647	0.48
Mispah	Ms10	11		Hu27		Std	169	427	383	0.11
Cartref	Cf11 Cf12	3	Estcourt	Es13 Es16	4	Max	1260	2766	2217	0.78
Rock	Rock	16	Swartland	Sw31 Va31	4	Min	622	1319	784	0.31
			Valsrivier							
Total Area: 250 060 Ha			Means of 67 Land Types							

Tarkastad Formation. The plinthic soil pattern comprises dominantly of mesotrophic Avalon soils (Table 10.1). Pinedene, Clovelly and Oakleaf soils are also present, with a proportion of dystrophic soils. Duplex soils are sub-dominant in this soil pattern, having a relatively high proportion of Estcourt soils. The presence of an E horizon in the Estcourt soils reflects a higher level of soil profile wetness, and a slowly permeable prismacutanic horizon at generally shallow depths. This contrasts with the plinthic soil patterns of the Vryheid Formation where Longlands, Wasbank, Westleigh and on occasions Cartref soils are present (Chapter 14), and with the Volksrust Formation where in addition to plinthic soils, deeper Kroonstad soils are dominant (Chapter 13).

The duplex soil pattern is dominated by Valsrivier soils (Table 10.1). This soil form has unconsolidated material below the diagnostic pedocutanic horizon, and together with the Sterkspruit soils, could be evidence of transported material in the lower positions in these landscapes. Swartland, Sterkspruit and Estcourt soils, and the lithosolic soils Glenrosa and Mispah, also comprise significant proportions of the soil pattern. Avalon and Pinedene soils are sub-dominant in this pattern (Table 10.1). The presence again of a relatively larger proportion of Estcourt soils must be interpreted as giving an indication of the higher seasonal levels of profile wetness in bottomland positions. Two Estcourt profiles are included in the dataset (Tables 10.2, 10.3). Regrettably there are no Valsrivier, Swartland or Sterkspruit profiles sampled directly over the sandstone and mudstone of the Tarkastad Formation. Profiles of the Valsrivier, Sterkspruit and Estcourt Forms were noted overlying the Masotcheni Formation, the name given to the Quaternary lithology in the interior of KwaZulu-Natal. In this area the bottomland soils could be dominated by materials which comprise the Masotcheni Formation. An overview of the distribution and extent of the Masotcheni Formation is given by Botha, Scott, Vogel and Von Brunn (1992). The sediments are commonly located in the footslope and valley bottoms within the Ecca and Beaufort Group lithologies (Geological Survey, 1981a; 1981b; 1988a; 1988b; 1988c). Dramatic examples of deep gully erosion can be seen in many of the KwaZulu-Natal interior valley basins. The geomorphology and soil formation can be studied from the hillslope profiles and form the sediments within the gullies. Exposures in these gullies, which now commonly have Valsrivier and other duplex soils at their surface, often show a number of cycles of soil formation. Pictorial evidence of cycles of soil formation in these gullies and of the erosional landsurfaces is illustrated by photographs in Soils of the Tugela Basin (van der Eyk, MacVicar and de Villiers, 1969). The evidence of cyclic phases of soil formation within transported materials has been described by de Villiers (1962). Botha, *et al.* (1992) have dated examples of these soil erosional events.

A description of the erosional history and geomorphology of the KwaZulu-Natal Interior is given in Van der Eyk, *et al.* (1969). A review of the erosional history of the subcontinent is given by Partridge and Maud (1987).

The final lithosolic soil pattern has Glenrosa and Mispah soils dominant (Table 10.1). It is interesting that the clay and clay loam textural classes within the Glenrosa soils are recorded within this pattern. The sandy clay loam and sandier textural classes are those usually encountered. Hutton soils are subdominant in the high rainfall areas, while Estcourt, Swartland and Valsrivier soils are subdominant in the drier parts.

The summary information contained in Table 10.2 has been derived for the Land Type Survey (Land Type Survey Staff, 1994a; 1996; 1997a; 1997b).This survey focused on obtaining the soil distribution information by establishing the presence and estimated proportions of soils in any given area. Soil properties were estimated by the modal profile sampling program. Little attention could be directed at soil genesis and landscape evolution.

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles of the Hutton, Clovelly, Oakleaf, Estcourt, Mispah and Katspruit 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 10.2. These ranges are also represented graphically in Figure 10.2. The figure allows for an overview comparison between different soil forms and over particle size classes.

Table 10.2 Textural properties of soils of the Tarkastad Formation derived from profile values.

Form	Hori zon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1 B2	SaClLm-Lm-Cllm SaClLm-SaCl-ClLm-Cl Lm-SaClLm	4-47 4-54 17-40	2-42 3-39 4-30	19-73 6-61 30-55	1-15 1-15 2-6	1-4 1-12 1-2	fi fi fi	NL1,L1,EL3 NL1,L1,EL3 -
Clovelly	A1 B1 B2	SaClLm-SaCl-ClLm-Cl SaClLm-SaCl-ClLm-Cl SaClLm-ClLm-SiClLm	19-52 16-52 16-47	8-37 10-41 12-50	4-53 6-58 10-54	1-15 1-18 1-24	1-9 1-7 1-13	fi fi fi	NL1,L1,EL3 NL5 -
Oakleaf	B1	SaLm-SaClLm	12-24	10-25	43-58	2-18	1-2	fi	-
Eluvic Horizon Soils	A1	SaClLm-SaLm	4-50	6-38	8-54	1-14	1-8	fi	-
Estcourt	A1 E1 B1	SaLm SaLm SaLm	8-17 9-17 53-56	10-21 12-20 3-10	52-52 51-51 23-23	13-13 14-14 7-7	4-4 4-4 2-2	fi fi fi	NL L -
Mispah	A1	Lm-ClLm-Cl	4-50	30-32	13-33	1-4	1-5	fi	-
Katspruit	A1	Cl-SaLm	12-50	20-38	13-53	2-11	3-4	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).

The Hutton profiles are located in a single natural soil body clustered about the loam to sandy clay loam textural classes (Figure 10.3). Profiles with high clay contents extend into the clay loam and clay classes, while textures extending into the sandy loam class were also sampled. Within the Clovelly Form the spread of profile textures about the loam and sandy clay loam classes is similar to those of the Hutton Form. The clay profiles however are displaced with small increases in the silt and small decreases in the fine sand values. Two natural bodies with respect to texture can be recognised in the Clovelly profiles. This trend is extended into the A1 horizons of the remaining profiles (Oakleaf, Estcourt, Mispah, and Katspruit Forms) with orthic topsoils (Figure 10.6).

To retain a consistent pattern within the sediments of the Tarkastad Formation, two natural bodies have been selected. The threshold value for separation has been set at above and below 30 percent total sand. The means and standard deviations for five particle size classes centred around the sandy clay loam and clay loam respectively are given (Tables 10.3, 10.4). Fine sand is the dominant sand grade (Figures 10.3, 10.4, 10.6), silt values lie within a narrow range with means around 20 percent giving rise to the loam textural classes.

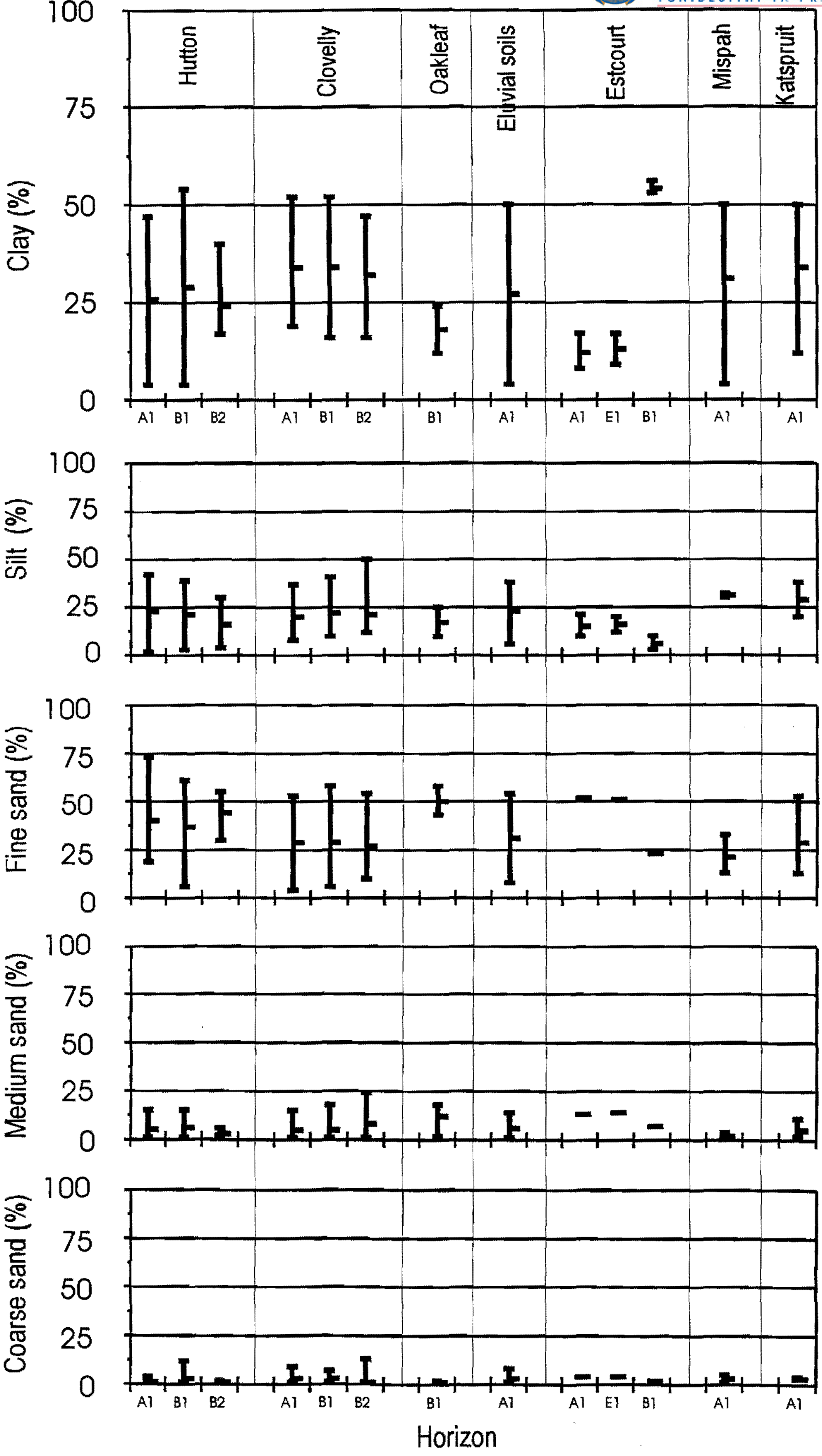


Figure 10.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Tarkastad Formation. Maximum, minimum and mean values are shown for each horizon.

Dominantly non-luvic profiles were measured for both the Hutton and Clovelly soils (Figure 10.7).

Duplex soils though widespread on the Tarkastad Formation cover only a limited area in KwaZulu-Natal (Table 10.1). No profiles of duplex soils were available in this sample set.

Table 10.3 Means and standard deviations of five textural classes for soils of the Tarkastad Formation.

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												
A1	288	26.6	9.6	23.3	12.4	40.0	11.2	5.8	3.5	1.6	1.0	43
B1	741	29.6	11.5	21.2	8.3	37.1	12.7	6.0	8.0	3.3	6.3	46
B2	1097	24.5	7.2	16.8	8.3	44.2	10.5	3.8	1.5	1.7	0.5	9
Form: Clovelly												
A1	275	34.3	8.9	20.9	8.1	29.3	12.4	5.9	4.1	3.3	2.5	24
B1	706	34.7	9.9	22.9	8.5	29.0	13.4	5.1	4.0	3.1	2.0	30
B2	1011	32.2	8.0	21.7	10.4	27.9	12.9	8.0	6.9	4.1	4.1	11
Form: Oakleaf												
B1	620	18.4	5.0	17.0	5.9	50.4	5.6	12.0	5.5	1.5	0.5	5
Form: Eluvic												
A1	341	27.5	16.1	23.9	10.5	31.6	17.1	6.5	5.1	3.1	2.1	13
Form: Estcourt												
A1	225	12.5	4.5	15.5	5.5	52.0	0.0	13.0	0.0	4.0	0.0	2
E1	340	13.0	4.0	16.0	4.0	51.0	0.0	14.0	0.0	4.0	0.0	2
B1	650	54.5	1.5	6.5	3.5	23.0	0.0	7.0	0.0	2.0	0.0	2
Form: Mispah												
A1	310	31.0	19.6	31.3	0.9	21.0	8.6	2.7	1.3	3.0	1.6	3
Form: Katspruit												
A1	522	34.5	14.5	29.5	8.1	29.3	17.1	5.3	4.0	3.3	0.5	4

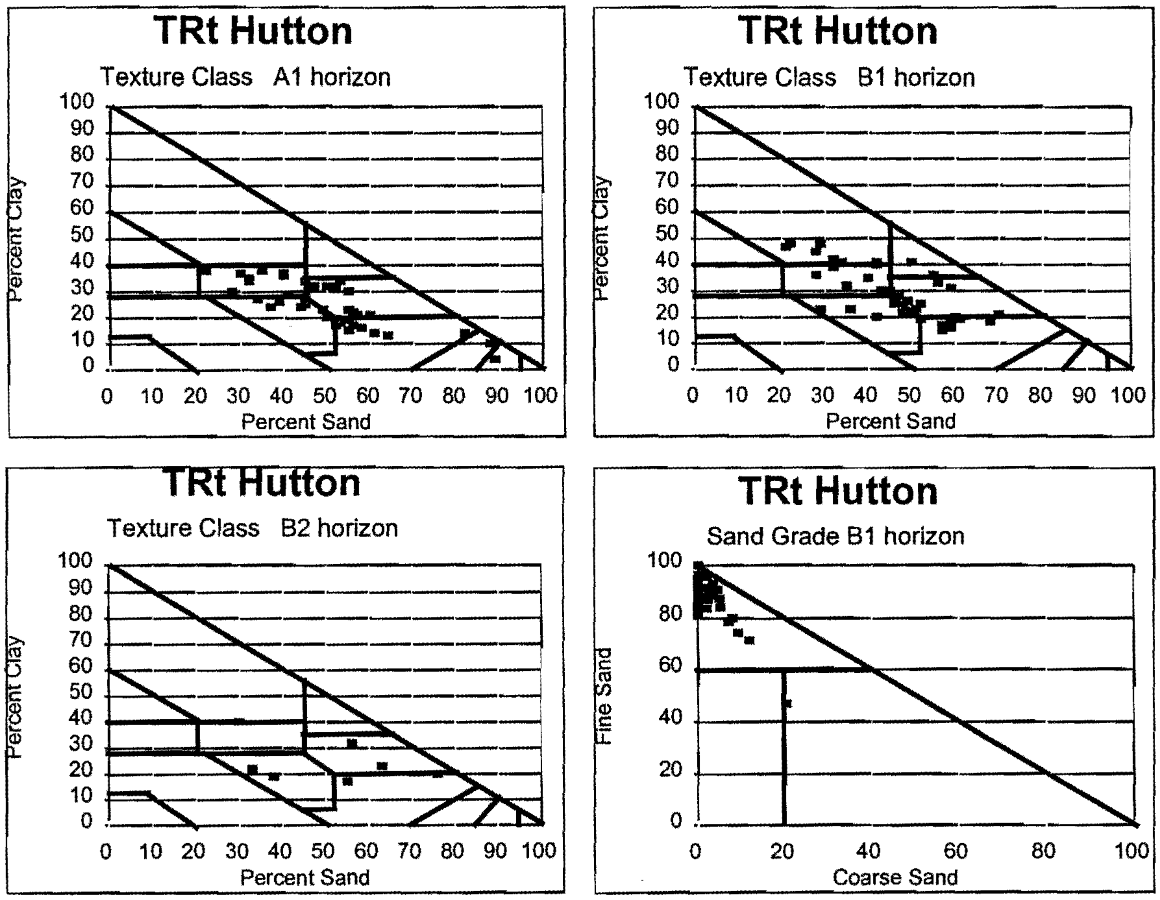


Figure 10.3. Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

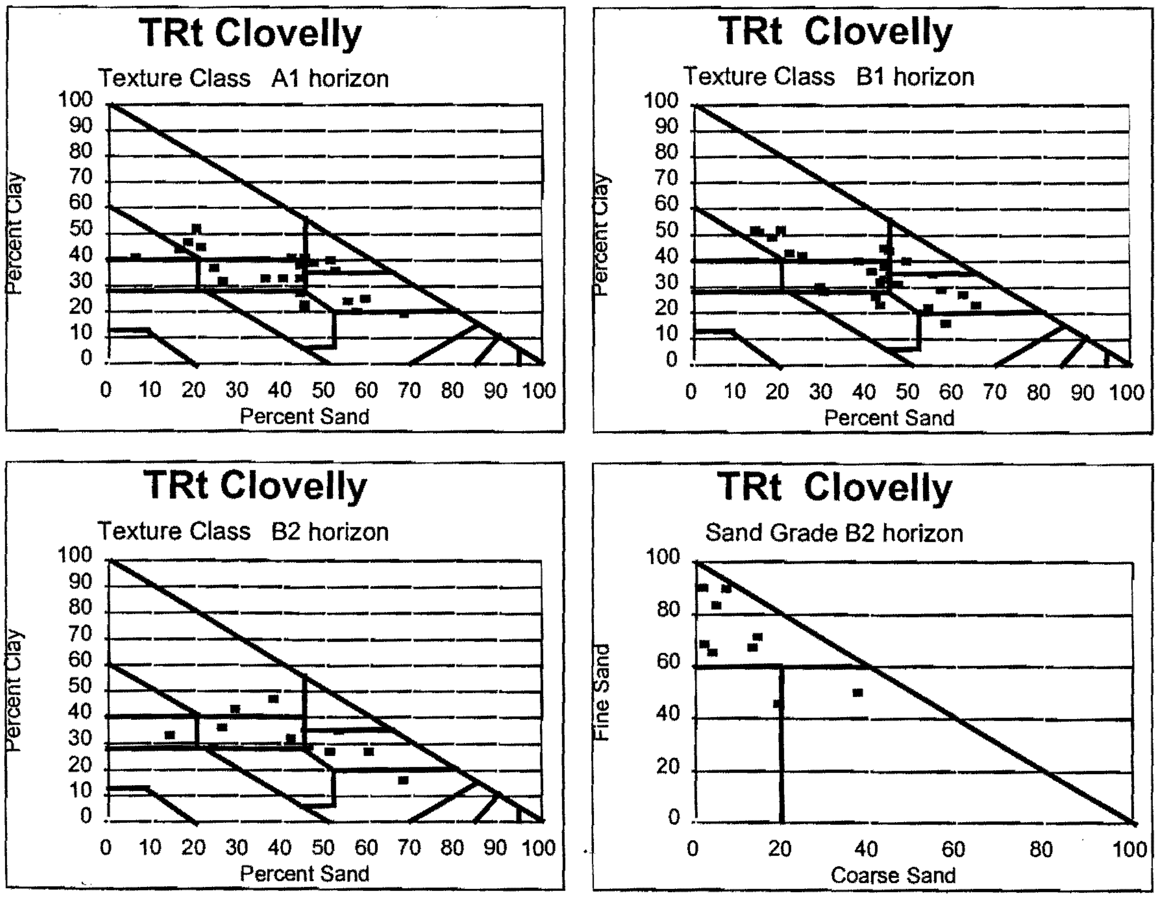


Figure 10.4. Distribution of soil textures, and dominant sand grade, within soils of the Clovelly Form.

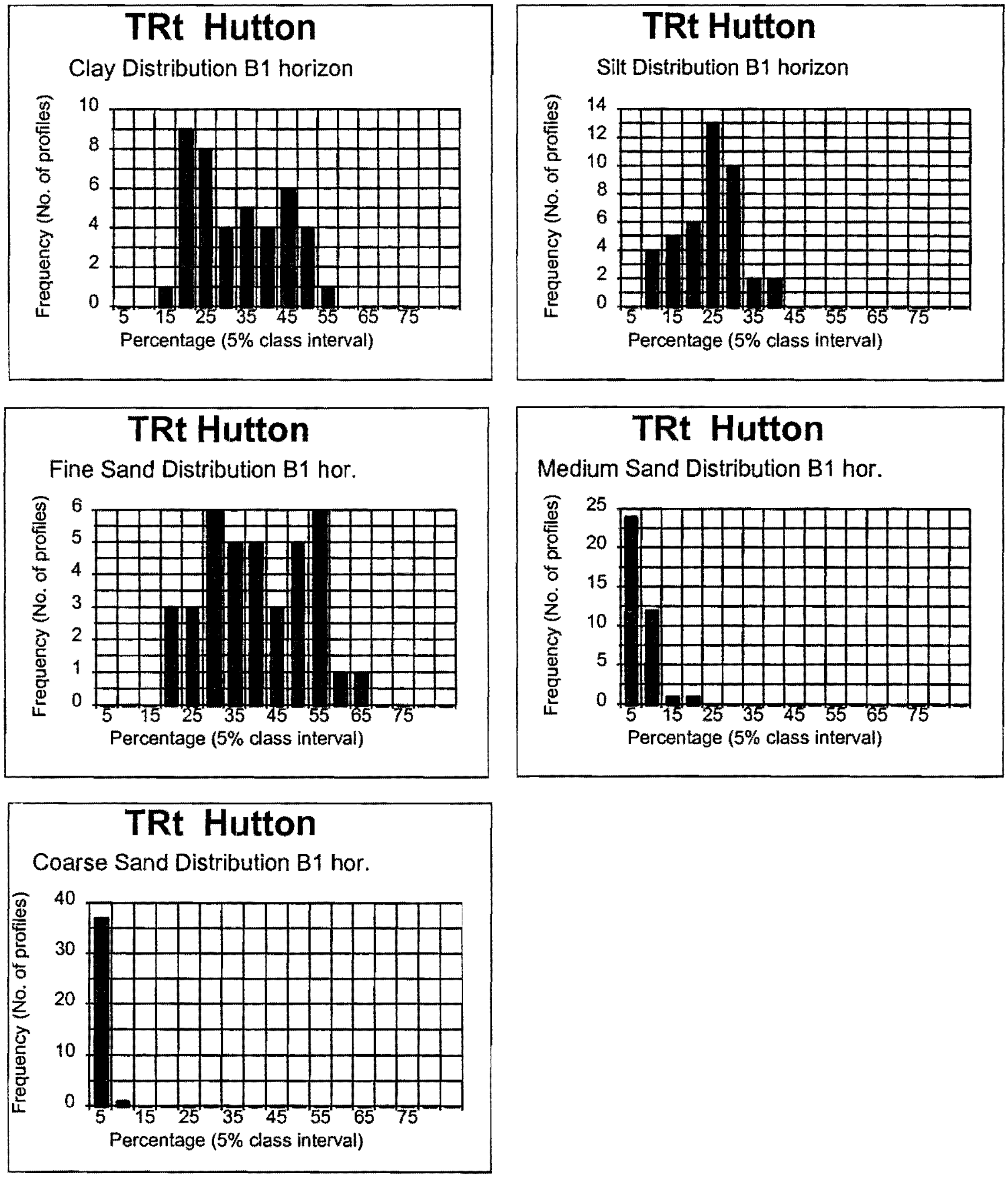


Figure 10.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

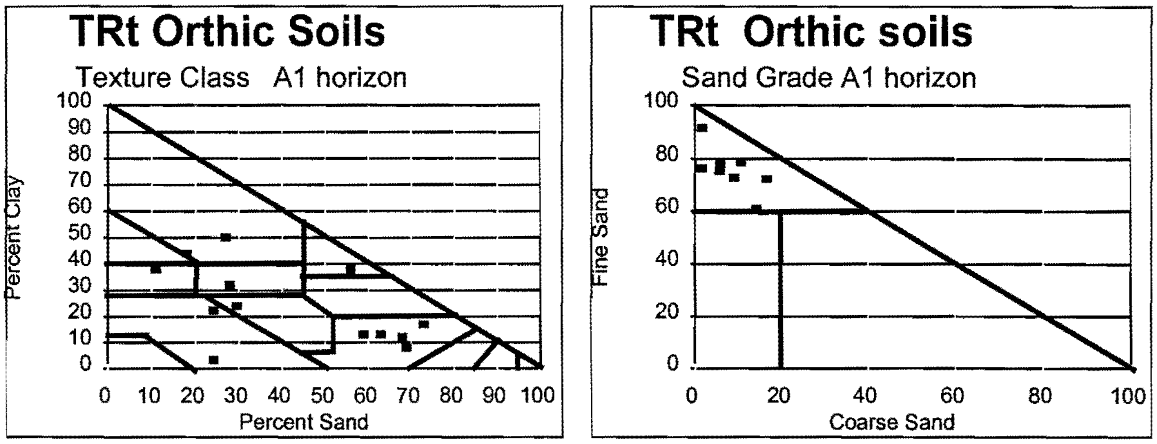


Figure 10.6 Distribution of soil textures, and dominant sand grade, within soils with an orthic horizon. Soils include profiles from the Estcourt, Longlands, Mispah and Katspruit Forms.

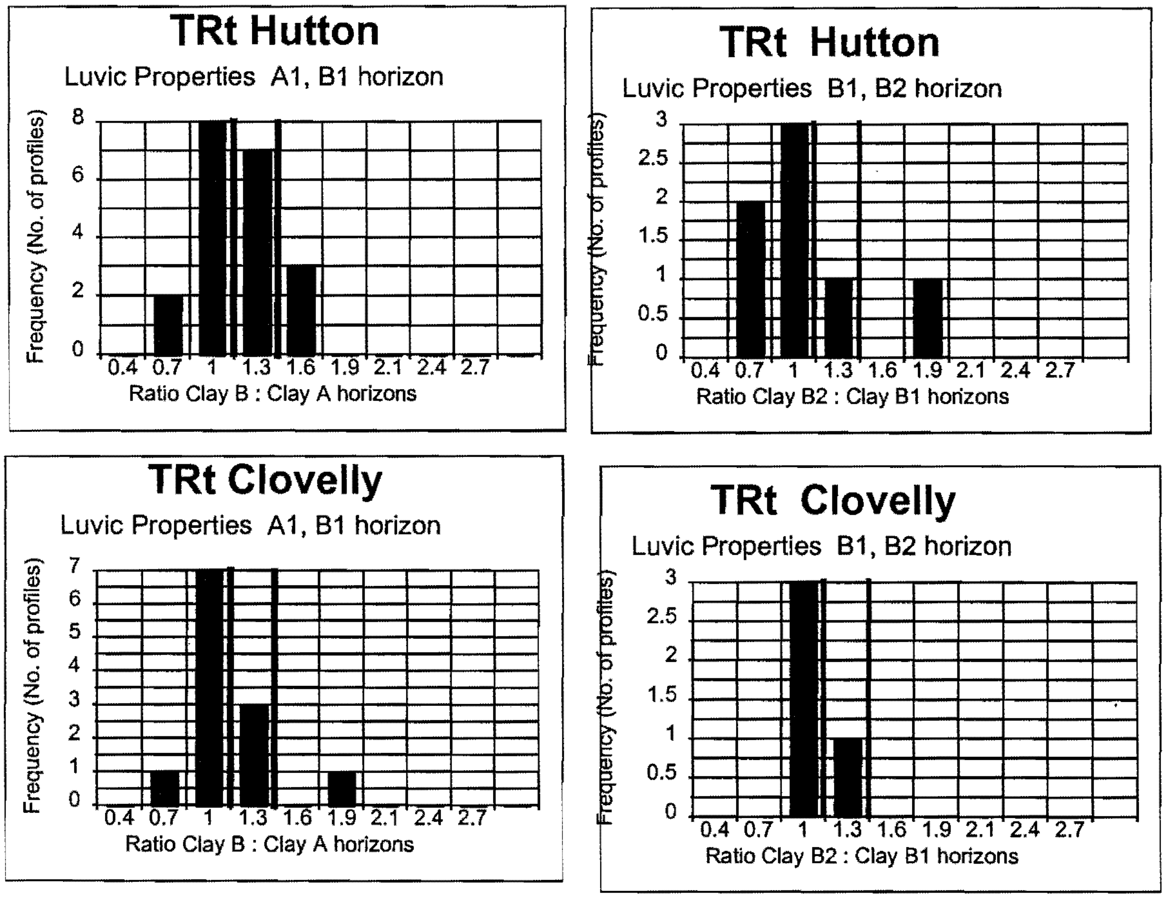


Figure 10.7 Luvic properties of soils of the Hutton and Clovelly Forms.

CHAPTER 11

SOILS OF THE MUDSTONE AND SANDSTONE OF THE ADELAIDE SUBGROUP, BEAUFORT GROUP IN KWAZULU-NATAL

Location and Extent

The Adelaide Subgroup stretches in a relatively broad belt of between 12 and 50 kilometres wide in the southern KwaZulu-Natal Interior Basins. It is located south of the Mkomazi River Valley between the Tarkastad Formation in the west and the shales and sandstones of the Ecca Group in the east. As with the Tarkastad Formation, the Adelaide Subgroup is locally intruded by relatively extensive dolerite intrusions (Geological Survey, 1981a; Geological Survey, 1981b). The Subgroup occupies approximately 356 110 hectares in extent (Figure 11.1). The equivalent parts of the Beaufort Group rocks in the northern KwaZulu-Natal basins are now recognised as the Estcourt Formation.

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

The strata of the Beaufort Group can be readily subdivided into two geological mappable units, the upper Tarkastad Formation and the lower Adelaide Subgroup. The Adelaide Subgroup consists of essentially greenish (or bluish) grey, and greyish-red mudstones and sandstones (SACS, 1980). The Adelaide Subgroup is described as comprising grey and reddish-brown mudstone and yellow and grey fine grained sandstone (Geological Survey, 1981a; Geological Survey, 1981b).

Physiography and Drainage Features

The area where the Adelaide Subgroup is exposed comprises undulating to strongly undulating lowlands and hills (Kruger, 1983). Moderate slopes are encountered on much of the land drained by the Mzintlava River. To the south east and south west of the town of Kokstad lies the Ngele and Ngintsizwa Mountain Highlands with extensive dolerite intrusions.

Vegetation

The vegetation is Moist Upland Grassland with small occurrences of Mountain Forest (Low and Rebelo, 1996).

Soils

Five major soil patterns are evident for the soils derived from the mudstones and sandstones of the Adelaide Formation (Table 11.1). The first is a red and yellow-brown apedal soil pattern with Hutton, Clovelly and Griffin soils dominant. Glenrosa, Mispah and Katspruit soils are subdominant. A wide textural range has been measured for these soils. The plinthic soil pattern has Avalon, Glencoe, Longlands, Wasbank and Westleigh soil together with Clovelly, Pinedene and Hutton soils (Table 11.1). These dominantly mesotrophic soils are of the loamy sand to sandy clay loam textural classes, lacking the clay textural classes encountered in the red and yellow-brown apedal soils. Soils with an E horizon comprise one third of the soils within the

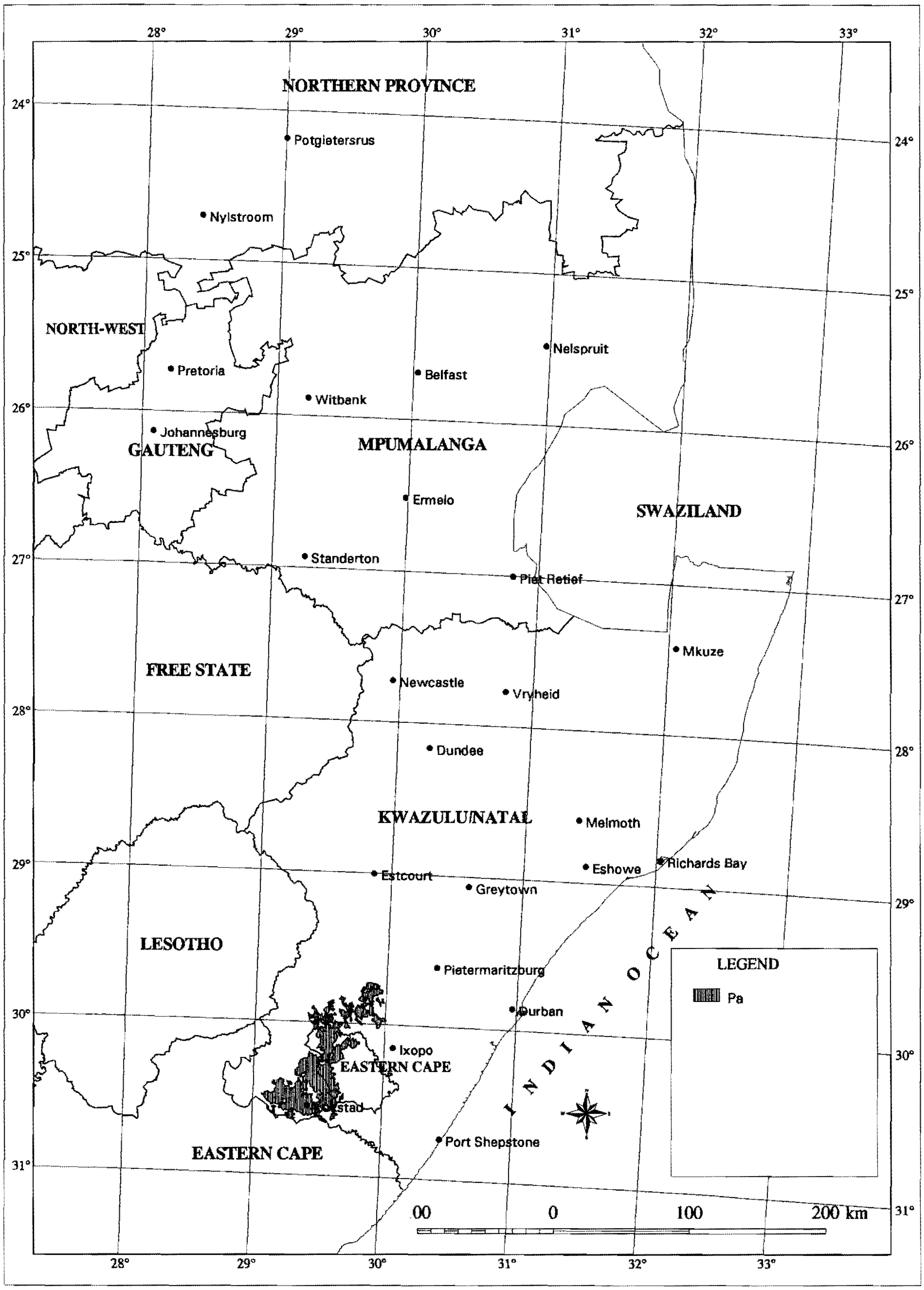


Figure 11.1. Location of the Adelaide Subgroup, Beaufort Group in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Table 11.1 Dominant soils and selected climatic information for soil patterns occurring on Adelaide Subgroup.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evapor ation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow-brown Apedal Soils (dystrophic and mesotrophic base status)										
Hutton	Hu17 Hu18	15	Glenrosa	Gs16 Gs19 Ms10	18	Ave	922	1350	1586	0.68
	Hu16	12	Mispah			Std	132	266	484	0.20
	Hu26 Hu27	5	Katspruit	Ka10	3	Max	1280	1737	2608	-
Clovelly	Cv16	10				Min	706	862	822	0.43
	Cv17	4								
Griffin	Gf11 Gf12	10								
Total Area: 186 166 Ha			Means of 54 Land Types							
Broad Soil Pattern: Plinthic and Apedal Soils (mesotrophic base status)										
Avalon	Av26 Av27 Gc26	6	Cartref	Cf11 Cf12	10	Ave	740	1321	843	0.56
Glencoe			Estcourt	Es13 Es16	4	Std				
Longlands	Lo11 Lo12 Wa11	10	Swartland	Sw31 Va31	5	Max				
Wasbank	Wa12		Valsrivier			Min				
Westleigh	We11 We12	7	Mispah	Ms10 Gs16	10					
Clovelly	Cv26 Cv27 Pn26	16	Glenrosa							
Pinedene										
Hutton	Hu26 Hu27	11								
Total Area: 11 720 Ha			Means of 3 Land Types							
Broad Soil Pattern: Duplex Soils										
Estcourt	Es33 Es36 Es16	9	Longlands	Lo11 Lo12 We11	4	Ave	709	1852	2472	0.38
Kroonstad	Kd16		Westleigh	We12		Std	54	114	604	0.05
Sterkspruit	Ss23 Ss26	4	Glenrosa	Gs16 Gs19 Ms10	10	Max	776	1967	3076	0.43
Valsrivier	Va31 Va32 Va41	13	Mispah			Min	654	1737	1868	0.33
	Va42									
Swartland	Sw31 Sw32	6								
	Sw41 Sw42									
Oakleaf	Oa16 Oa36 Oa46	14								
Total Area: 18 000 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa	Gs16 Gs19	14	Hutton	Hu17 Hu16 Hu27	20	Ave	799	1474	1573	0.54
Mispah	Ms10	10		Hu26		Std	99	179	258	0.11
Cartref	Cf12 Cf11 Cf21	5	Clovelly	Cv16 Cv17 Cv26	8	Max	999	1737	1868	0.77
	Cf22			Cv27		Min	649	1230	1040	0.43
Rock	Rock	16								
Total Area: 107 360 Ha			Means of 18 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime										
Glenrosa	Gs16 Gs19	17	Swartland	Sw30 Sw31	4	Ave	839	1700	2197	0.49
Mispah	Ms10	10	Valsrivier	Va30 Va31 Va41	5	Std	103	149	299	0.09
Cartref	Cf12 Cf11	3	Estcourt	Es16 Ss26	9	Max	1033	1976	2566	0.62
Rock	Rock	7	Sterkspruit			Min	668	1455	1566	0.37
			Hutton	Hu27 Hu28	14					
Total Area: 32 870 Ha			Means of 15 Land Types							

plinthic soil pattern. The duplex soil pattern has a range of soil forms and textures. Calcareous and non-calcareous soils are present (Table 11.1). Lithosols with and without the presence of lime comprise the remaining two soil patterns (Table 11.1). Dystrophic and mesotrophic Hutton and Clovelly soils are subdominant where lime is absent, while duplex soils are subdominant contributing to the soil pattern where lime is present (Table 11.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles of the Hutton, Griffin, Clovelly, Avalon, Longlands, Estcourt, Swartland and Glenrosa Forms were extracted from the database. Two natural bodies based on textural properties are evident (Figures 11.4 to 11.10) with a threshold for their separation set at 60 percent total sand. The ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade and information on their luvic properties are presented (Tables 11.2 and 11.3). These ranges are also represented graphically (Figures 11.2 and 11.3). Each figure allows for overview comparisons between different soil forms and over particle size classes. In the Estcourt soils only one natural body has been used as profile textures lie on either side of the 60 percent total sand value (Table 11.3).

Table 11.2 Textural properties of the clay loam to clay soils of the Adelaide Subgroup derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1	ClLm-SiCl-Cl	27-73	13-51	1-29	1-6	1-28	fi	NL2,EL2,L1
	B1	ClLm-SiCl-Cl	20-74	5-53	1-41	1-7	1- 4	fi	-
Griffin	A1	Cl	57-60	13-33	3-24	1-2	1-2	fi	NL3, L1,EL1
	B1	Cl	49-68	13-34	4-24	1-2	1-2	fi	-
Clovelly	A1	SaCl-ClLm-SiClLm-Cl	30-53	13-50	9-42	1-6	1-6	fi	NL4,EL1
	B1	ClLm-SiClLm-Cl	25-58	10-53	6-40	1-13	1-9	fi	NL5
	B2	Cl	51-60	12-29	7-7	1-1	5-5	fi	-
Swartland	A1	SiCl-Cl	32-60	11-40	8-12	1-3	1-3	fi	L5
	B1	SiCl-Cl	32-67	11-44	8-17	1-4	2-4	fi	-
Mispah	A1	Cl	41-50	18-33	11-20	1-4	2-2	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).

A striking feature of the soils is the wide range of textural classes determined from the database (Figures 11.4 to 11.10). All the textural classes, with the exception of the siltiest classes; silt and silt loam, and pure sand are represented in the Hutton, Clovelly and Griffin soils. Histogram distributions confirm the wide clay range of the Clovelly soils, two silt distribution peaks, and the dominance of fine sand (Figure 11.6). The Swartland soils too have clay and silty clay classes on the one hand, and with a second grouping around sandy clay loam (Figure 11.9). The Mispah soils show a similar trend (Figure 11.10). The Avalon soils (A1 and B1 horizons)(Figure 11.7), and the Longlands (Tables 11.3 and 11.5) and Estcourt soils (A1 and E1 horizons)(Figure 11.8) are dominantly sandy loam. Small increases in clay percentage for the soft plinthite horizon of the Avalon (Figure 11.7) and Longlands (Table 11.5) soils were determined. Much larger clay increases for the prismacutanic horizon of the Estcourt soils were determined (Figure 11.8). Means and standard deviations for five particle size classes for the two natural soil bodies are given (Tables 11.4, 11.5).

A small proportion of profiles showed luvic properties (Table 11.3), while clay decreases in the B1 horizon relative to the A1 are dominant in the Griffin and Clovelly soils. The mean clay increase ratios for the Swartland (A1 and B1 horizons) and Estcourt (E1 and B1 horizons) soils were 2.2 and 4.4 respectively (Reflected in Table 11.3).

Table 11.3 Textural properties of the loamy sand to sandy clay loam soils of the Adelaide Subgroup derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1	LmSa-SaClLm LmSa-SaClLm	12-26 9-16	4-13 4-10	37-53 53-73	13-25 5-20	1-12 1-4	fi fi	NL2, L1, EL2 -
Clovelly	A1 B1 B2	Sa-SaClLm LmSa-SaLm SaClLm	6-24 7-18 24-24	2-21 2-8 6-6	37-73 38-77 36-36	2-25 8-32 28-28	1-10 5-7 6-6	fi,co fi,co fi,co	NL3, EL2 - -
Avalon	A1 B1 B2	LmSa-SaClLm LmSa-SaLm LmSa-SaLm	8-23 8-36 7-18	3-10 2-11 3-12	48-70 32-73 43-71	15-17 14-19 16-20	1-4 1-8 1-5	fi, fi,me fi	NL2,L3 - -
Longlands	A1 E1 B1	SaLm SaLm-SaClLm SaLm-SaClLm	13-18 11-25 15-29	5-23 22-25 6-28	49-73 14-54 40-58	7-15 1-54 4-12	1-3 1-32 1-11	fi fi,me fi	EL L -
Estcourt	A1 E1 B1	SaLm-SaClLm PuSa-SaClLm SaCl-Cl	9-34 4-30 36-50	8-42 1-47 5-34	28-43 7-43 19-29	1-23 21-43 7-14	1-14 8-60 3-16	fi fi,me fi	EL4,NL1 L5 -
Swartland	A1 B1	SaLm-SaClLm Lm-SaClLm	19-33 12-24	8-13 6-38	39-49 48-56	8-18 15-15	1-2	fi fi	L -
Mispah	A1	SaLm	8-8	14-14	44-44	24-24	8-8	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).

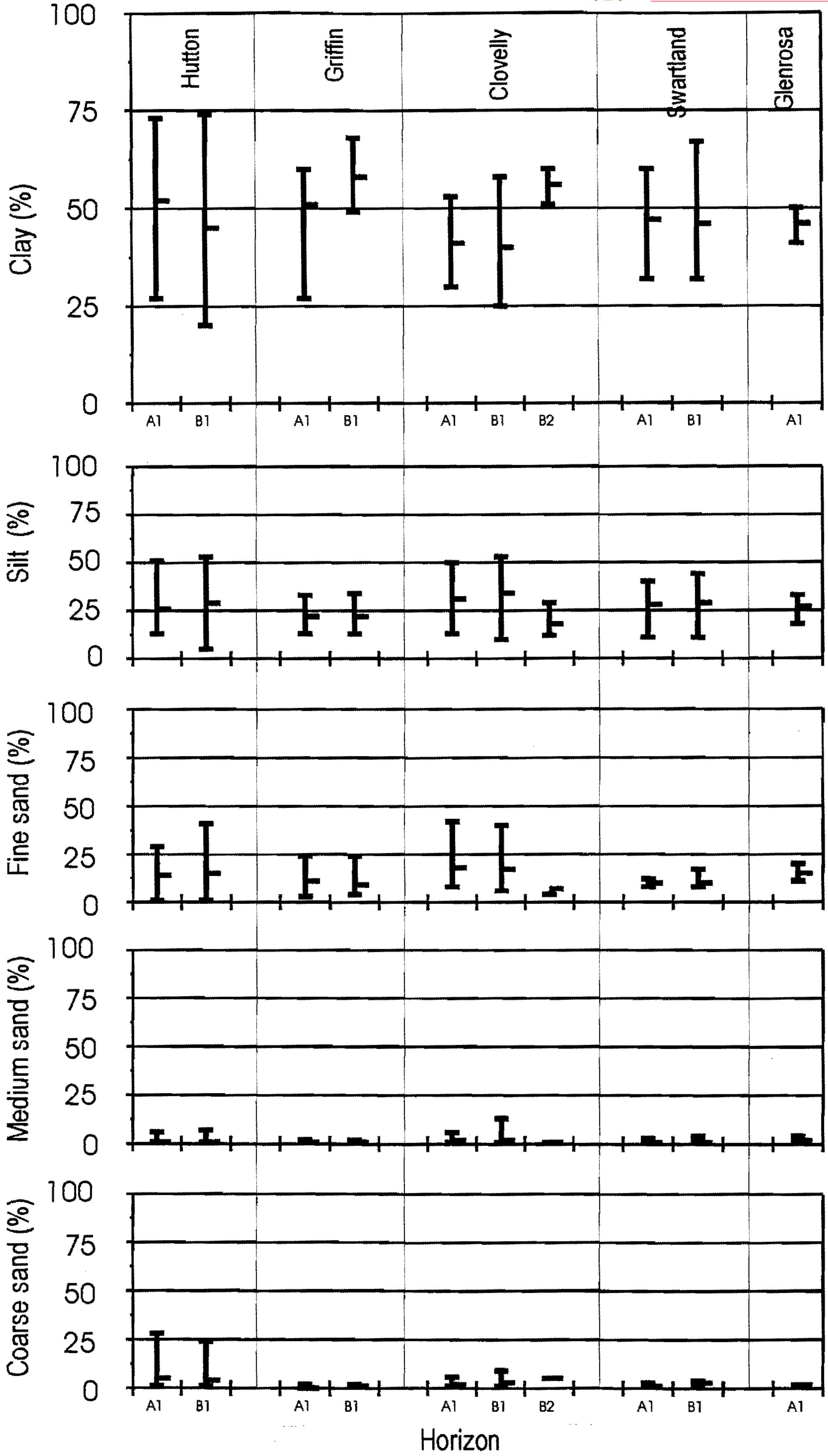


Figure 11.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Adelaide Subgroup with a clay loam to clay texture. Maximum, minimum and mean values are shown for each horizon.

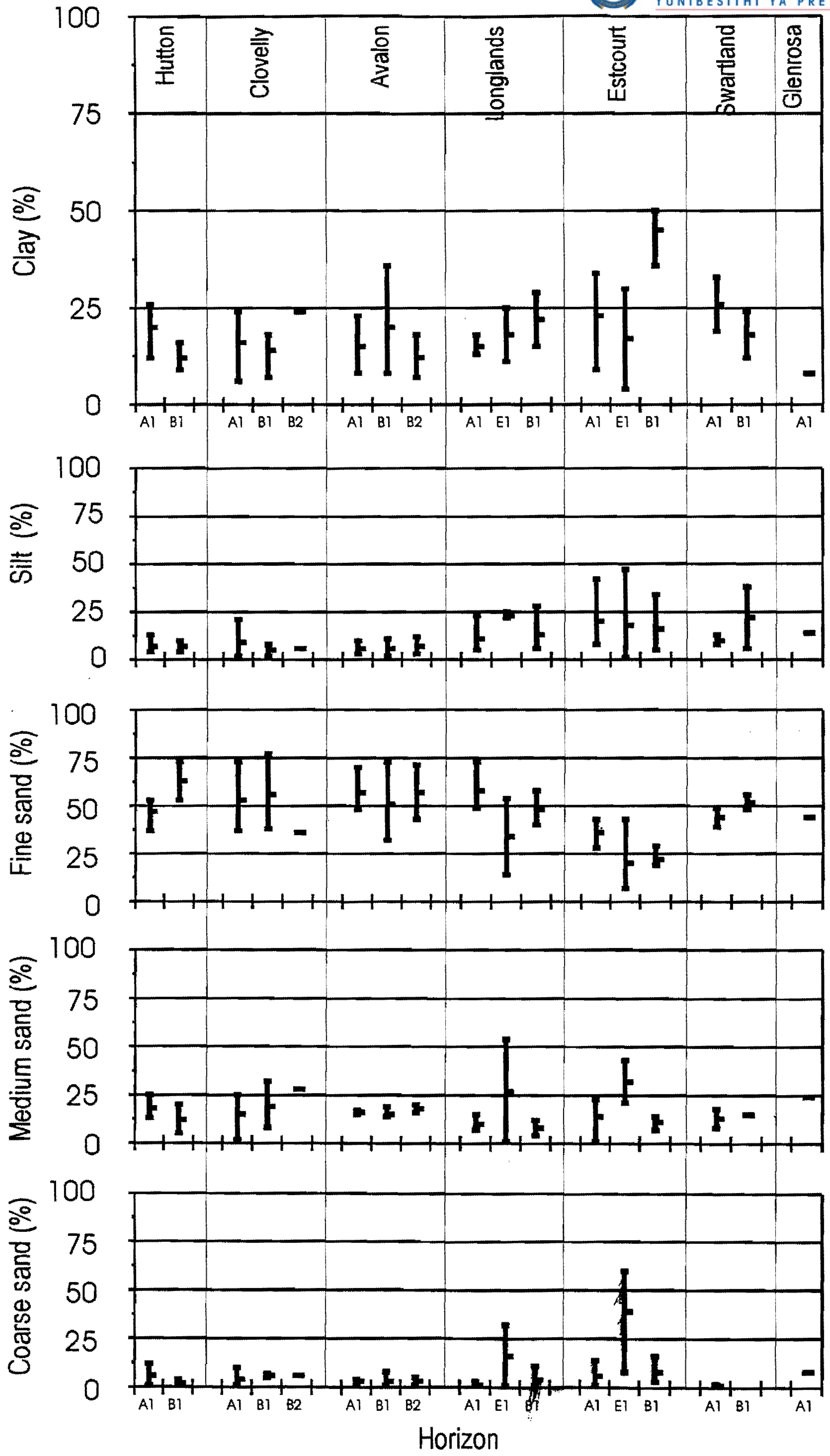


Figure 11.3 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Adelaide Subgroup with aloamy sand to sand clay loam texture. Maximum, minimum and mean values are shown for each horizon.

Table 11.4 Means and standard deviations of five textural classes of the clay loam to clay soils of the Adelaide Subgroup.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
A1	323	52.0	14.5	26.4	12.3	14.3	8.1	1.6	1.4	5.0	7.4	13
B1	689	45.4	15.0	29.0	12.6	15.9	9.2	1.8	1.5	4.2	5.1	23
Form: Griffin												
A1	280	51.5	14.2	22.3	9.3	11.0	9.3	1.3	0.5	0.7	1.3	4
B1	680	58.8	6.1	22.8	8.0	9.8	8.3	1.3	0.5	1.7	0.5	5
Form: Clovelly												
A1	320	41.2	6.3	31.3	10.9	18.8	10.3	2.1	1.4	2.5	1.8	15
B1	695	40.4	8.7	34.0	10.9	17.4	8.3	2.6	3.2	3.2	2.3	24
B2	970	56.3	3.9	18.0	7.8	7.0	0.0	1.0	0.0	5.0	0.0	3
Form: Swartland												
A1	376	47.2	8.9	28.4	10.3	10.5	1.5	1.8	0.8	1.8	0.8	5
B1	606	46.8	11.6	29.8	11.4	10.6	3.4	1.8	1.2	3.0	0.9	6
Form: Mispah												
A1	320	46.0	3.7	27.7	6.8	15.5	4.5	2.5	1.5	2.0	0.0	3

Table 11.5 Means and standard deviations of five textural classes loamy sand to sandy clay loam soils of the Adelaide Subgroup.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
A1	410	20.0	5.9	7.7	3.9	47.0	7.1	18.0	5.1	6.0	4.5	3
B1	1050	12.5	3.5	7.0	3.0	63.0	10.0	12.5	7.5	2.5	1.5	2
Form: Clovelly												
A1	346	16.0	5.9	9.2	6.6	53.6	12.5	15.2	7.9	4.0	3.4	5
B1	683	14.0	5.0	5.3	2.5	56.3	16.0	19.7	9.8	6.0	1.0	3
B2	920	24.0	0.0	6.0	0.0	36.0	0.0	28.0	0.0	6.0	0.0	1
Form: Avalon												
A1	450	15.3	5.5	6.0	2.5	57.0	8.5	16.3	0.8	3.0	1.4	4
B1	897	20.3	10.1	6.3	3.3	51.8	15.1	15.8	1.9	3.8	2.6	4
B2	1325	12.5	5.5	7.5	4.5	57.0	14.0	18.0	2.0	3.0	2.0	2
Form: Longlands												
A1	277	15.0	2.1	11.8	6.8	58.0	10.7	10.7	3.3	1.7	0.9	4
E1	450	18.0	7.0	23.5	1.5	34.0	20.0	27.5	26.5	16.5	15.5	2
B1	687	22.5	5.0	13.3	8.8	48.3	7.4	8.3	3.3	4.7	4.5	4
Form: Estcourt												
A1	285	23.3	9.0	20.3	10.7	36.0	5.6	14.5	8.7	6.5	4.8	6
E1	577	17.3	11.8	18.3	17.5	20.0	14.8	32.3	9.0	39.3	22.5	4
B1	738	45.0	4.8	16.6	9.9	22.5	3.8	11.0	2.9	8.0	5.7	5
Form: Swartland												
A1	340	26.0	7.0	10.5	2.5	44.0	5.0	13.0	5.0	1.5	0.5	2
B1	940	18.0	6.0	22.0	16.0	52.0	4.0	15.0	0.0			2
Form: Mispah												
A1	400	8.0	0.0	14.0	0.0	44.0	0.0	24.0	0.0	8.0	0.0	1

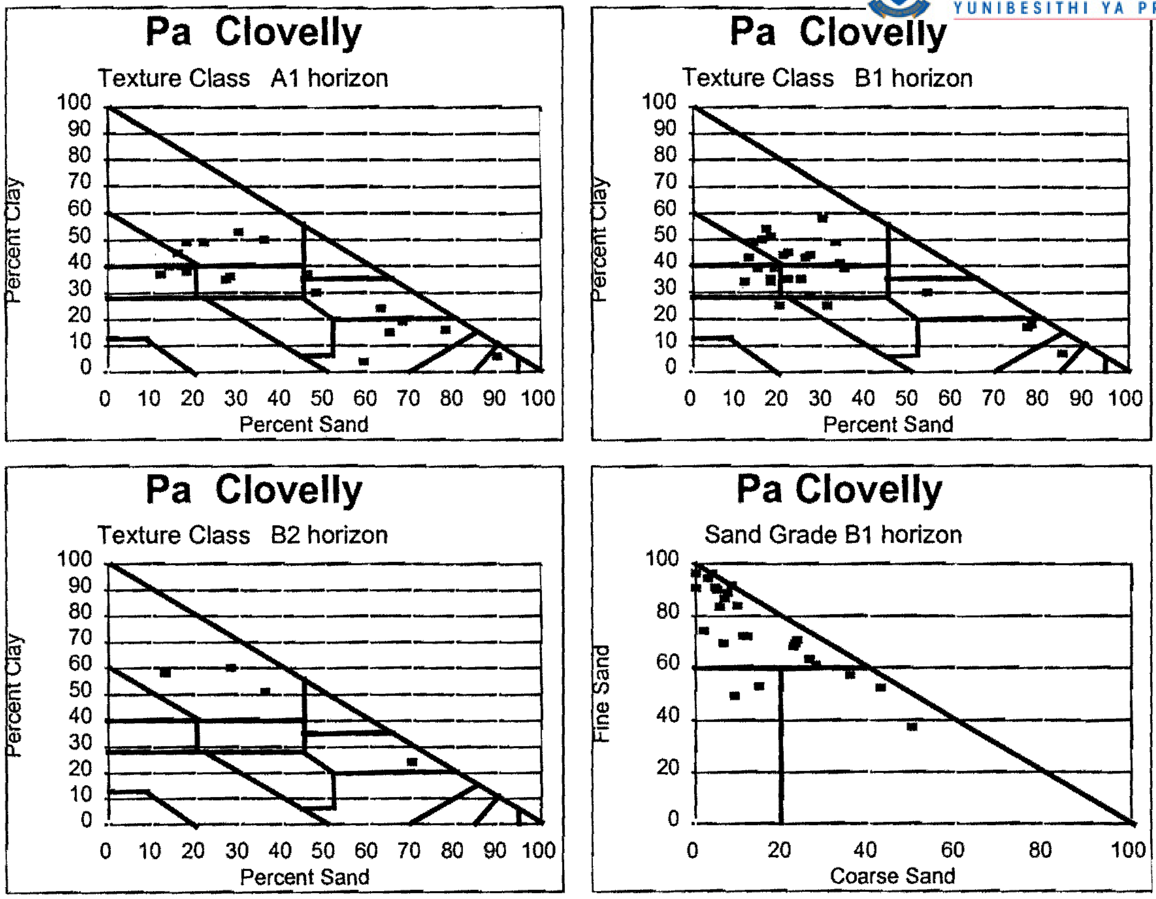


Figure 11.4. Distribution of soil textures, and dominant sand grade, within soils of the Clovelly Form.

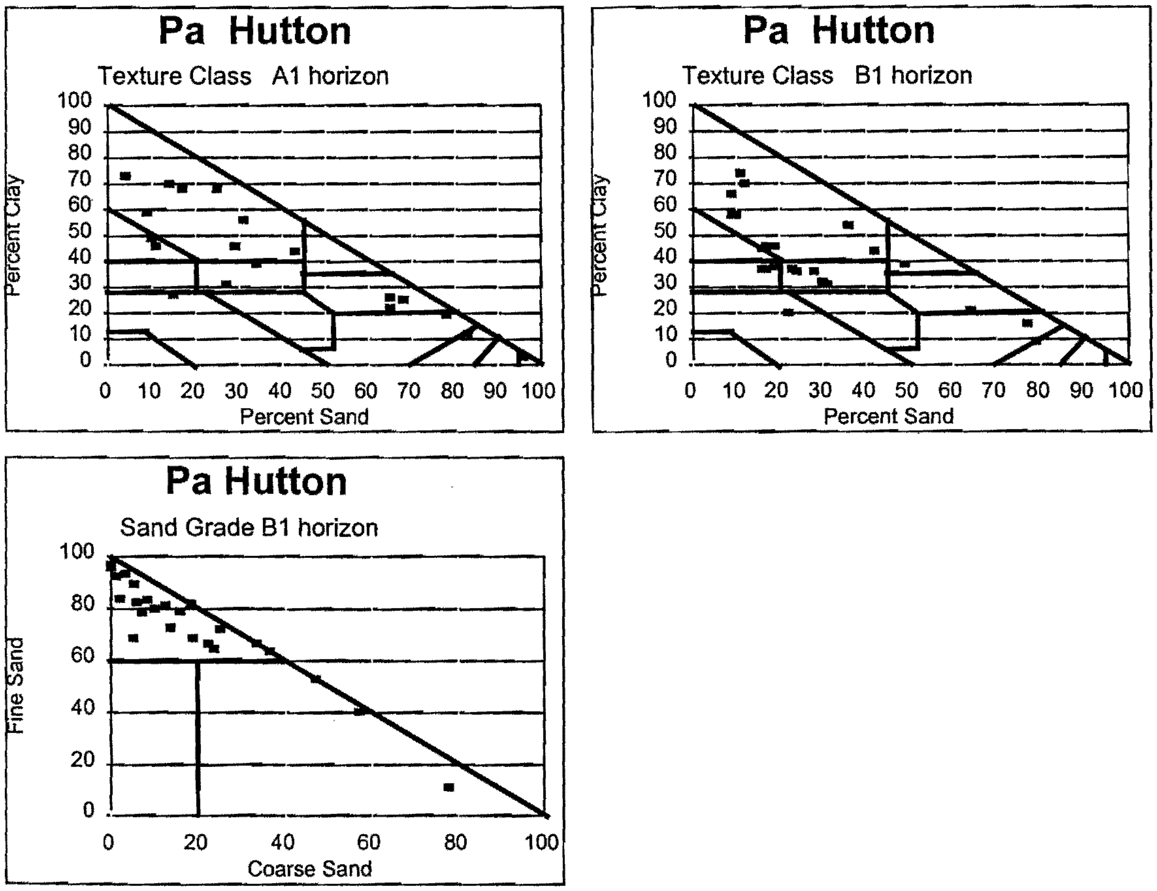


Figure 11.5 Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

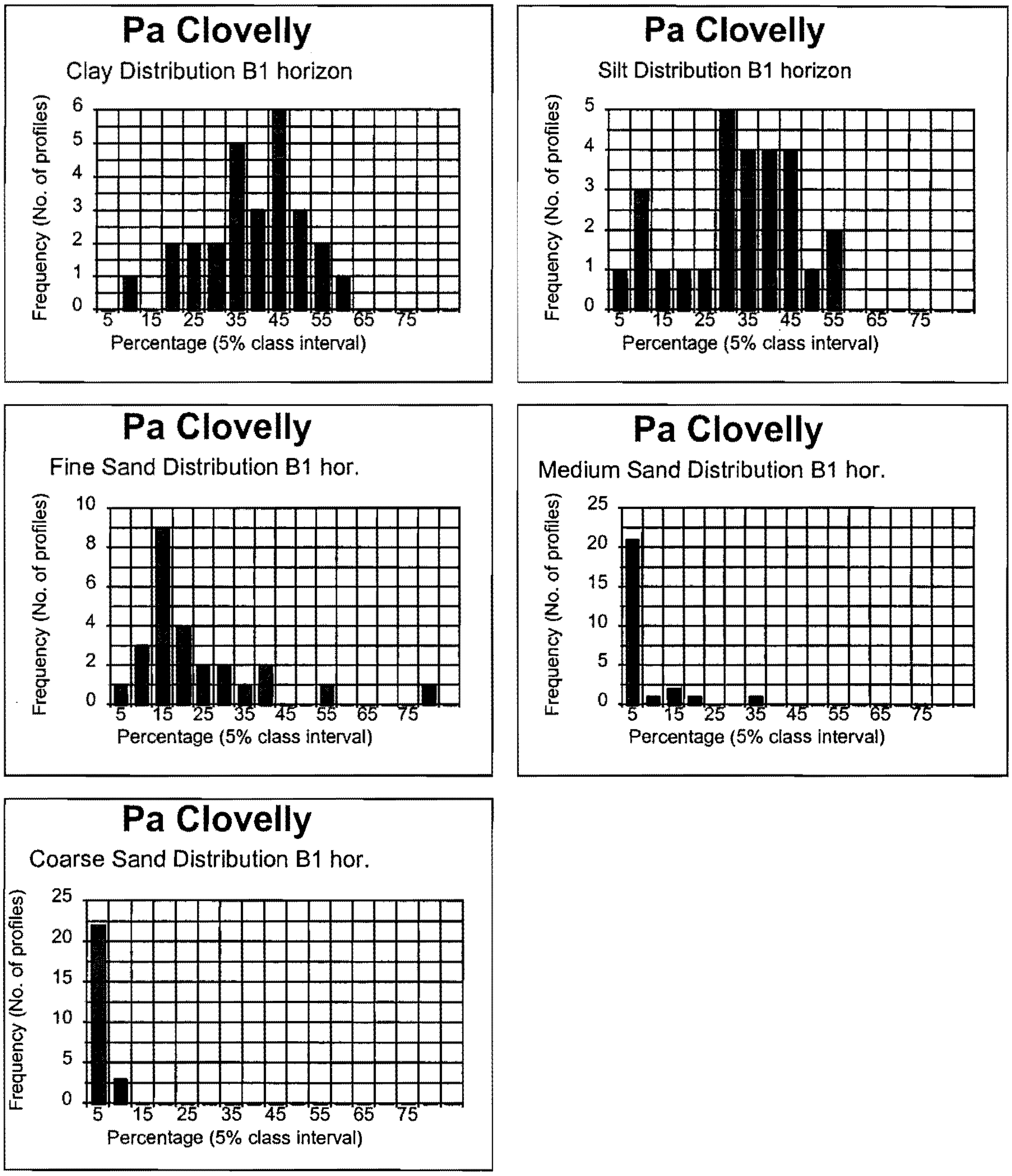


Figure 11.6 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Clovelly Form.

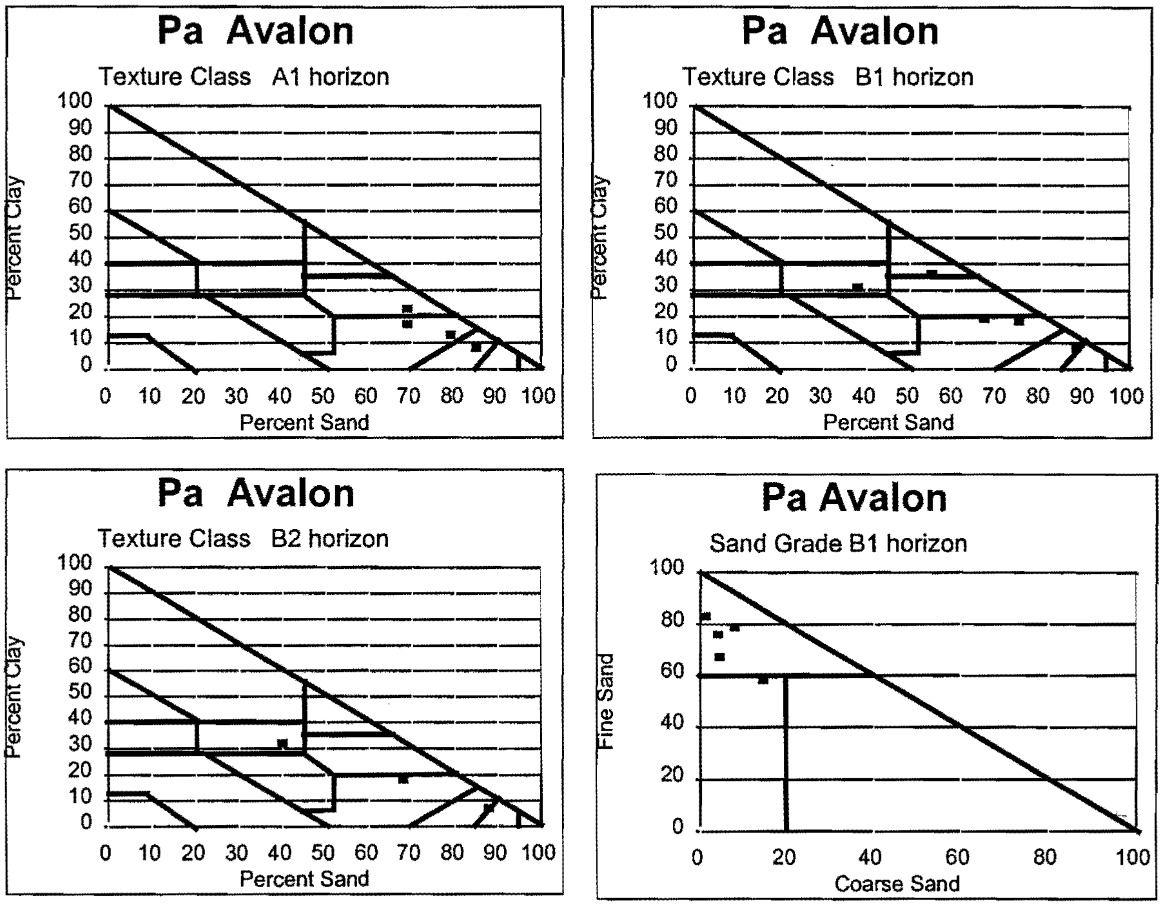


Figure 11.7. Distribution of soil textures, and dominant sand grade, within soils of the Avalon Form.

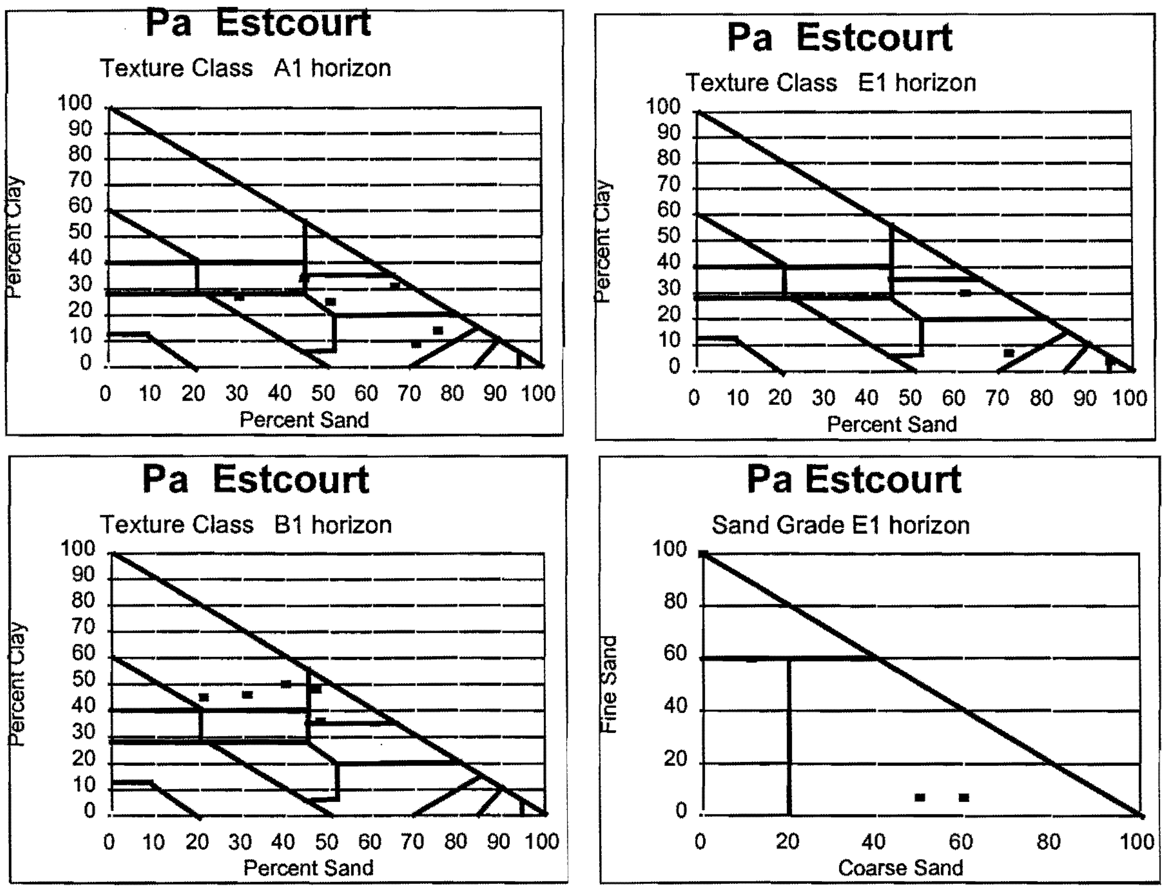


Figure 11.8. Distribution of soil textures, and dominant sand grade, within soils of the Estcourt Form.

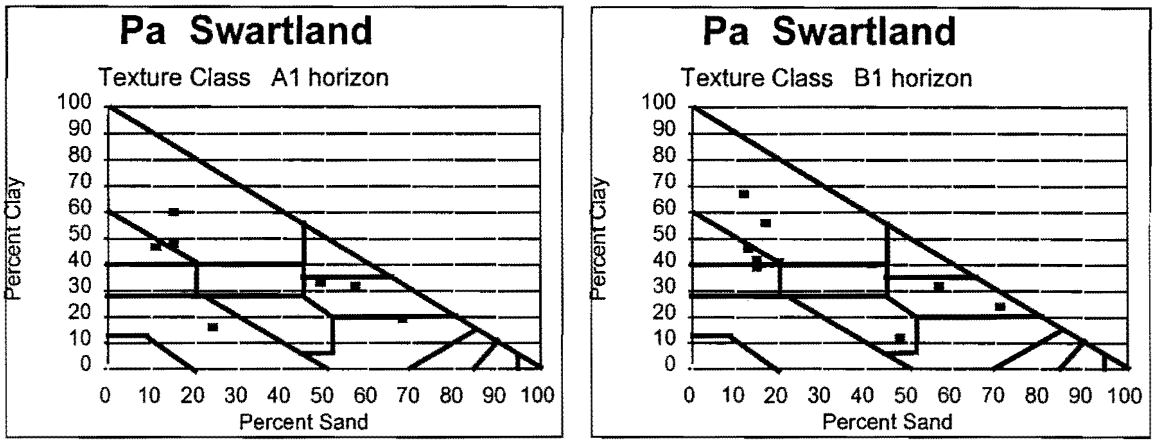


Figure 11.9 Distribution of soil textures within soils of the Swartland Form.

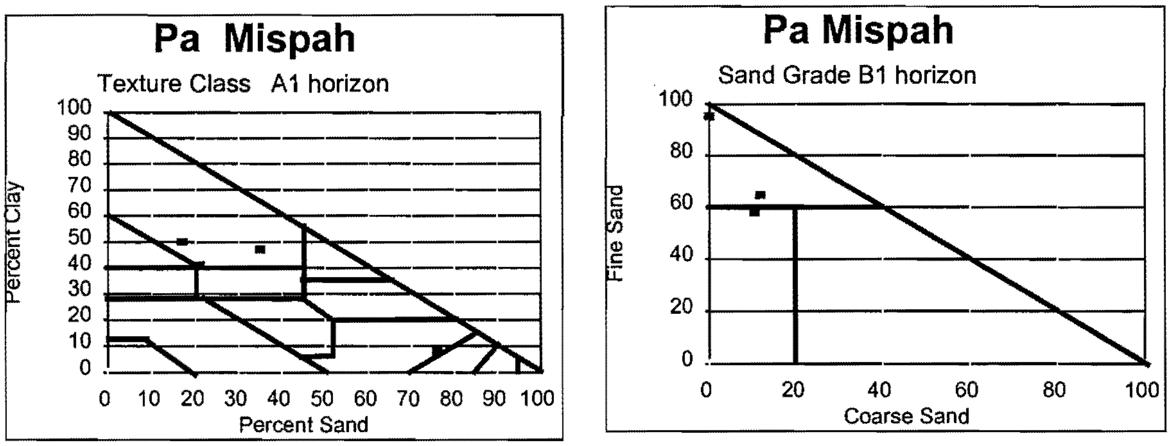


Figure 11.10 Distribution of soil textures, and dominant sand grade, within soils of the Mispah Form.

CHAPTER 12

SOILS OF THE SHALE AND SANDSTONE OF THE ESTCOURT FORMATION, BEAUFORT GROUP IN KWAZULU-NATAL

Location and Extent

The Estcourt Formation occurs at isolated locations on the Mpumalanga Highveld and in northern KwaZulu-Natal. The largest of these exposures forms the crest lands of the Ballesberg Highlands. To the south and west it occupies a narrow belt of between three and ten kilometres wide stretching along the KwaZulu-Natal and Free State boundary (Geological Survey, 1984, 1992) located between the Volksrust Formation of the Ecca Group, and the Tarkastad Formation of the Beaufort Group (Figure 12.1). The formation covers extensive areas of the north eastern Free State Province. South of the Klip River the formation widens to cover extensive areas in the KwaZulu-Natal Interior Basin and of the Highland Sourveld (Geological Survey, 1981a). The extent of the dark grey shale, siltstone and sandstone of the formation is recognised southwards to the Mkomazi River. South of this locality the mudstones and sandstones are considered as forming part of the Adelaide Subgroup, Beaufort Group.

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

Overlying the Volksrust Formation in the Estcourt and Mooi River area is a mappable unit consisting of laminated carbonaceous shale and an often coarse grained sandstone with a few thin coal seams (SACS, 1980). The South African Committee for Stratigraphy (SACS, 1980) noted that because of the similarities in the lithology of the Ecca and Beaufort Groups in this area it proved difficult in assigning the formation to either group. However, since the formation is laterally equivalent to the Adelaide Subgroup in the south, it may be more convenient to include it with the Beaufort Group. The Estcourt Formation is described as comprising dark-grey shale (often carbonaceous), siltstone and fine and medium to coarse grained sandstone (Geological Survey, 1981a; Geological Survey, 1988b; Geological Survey, 1988c).

Physiography and Drainage Features

The physiography of the northern and central zones where the Estcourt Formation is exposed range from strongly undulating land to low mountains (Kruger, 1983), with only limited areas of gentle slopes. In the KwaZulu-Natal Interior Basin irregular undulating lowlands and hills are encountered with slopes commonly less than five percent. To the south the proportion of steeper slopes increase. Undulating hills and lowlands and in places low mountains are encountered (Kruger, 1983).

Vegetation

In the north the vegetation is described as Moist Cool Highland Grassland, or as Wet Cold Highland Grassland (Low and Rebelo, 1996). The central zone of the KwaZulu-Natal Interior Basin has a drier climate where the dominant vegetation covering the rocks of the Estcourt Formation is described as Natal Central Bushveld. In the south the vegetation is recorded as dominantly Moist Upland Grassland (Low and Rebelo, 1996).

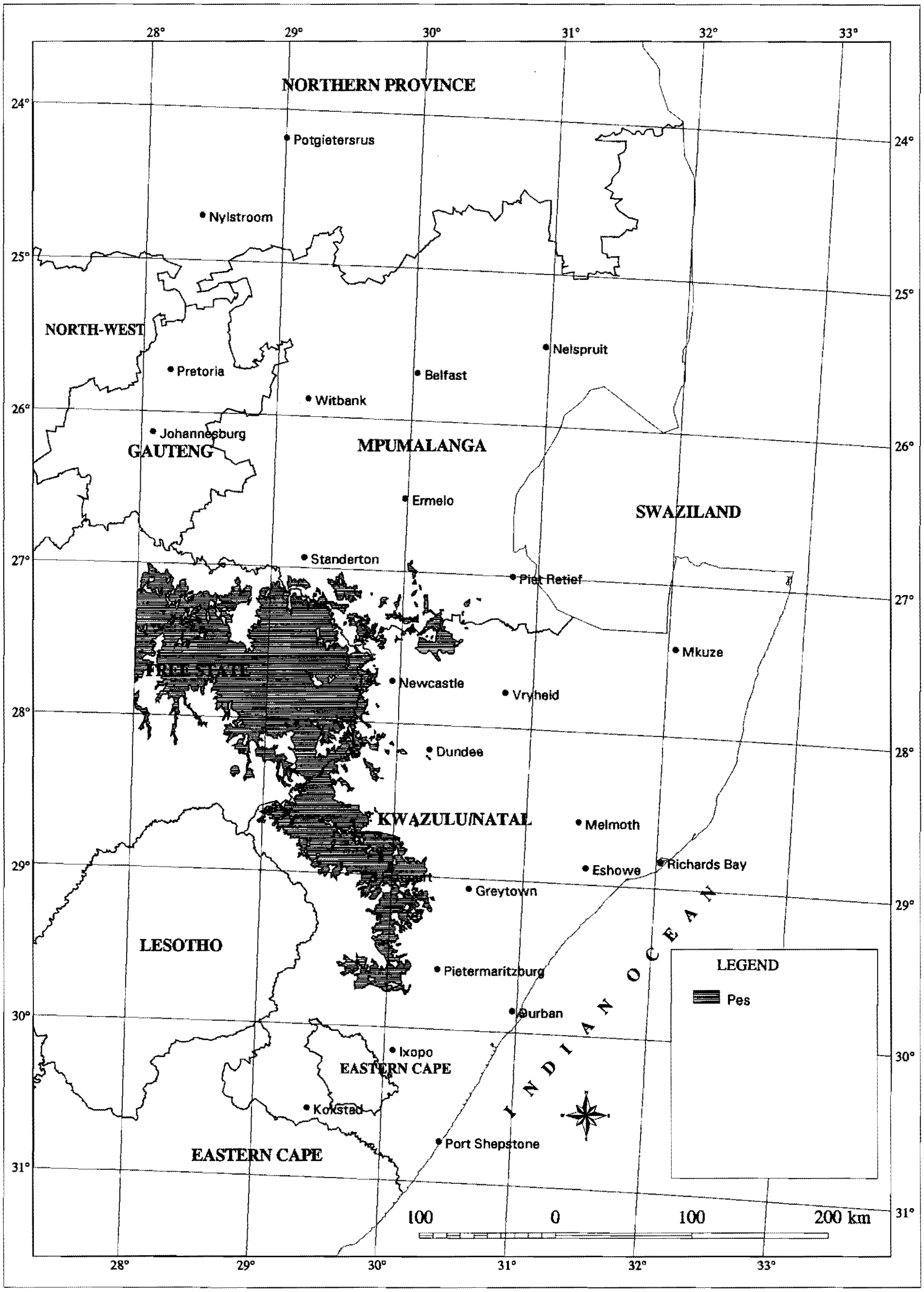


Figure 12.1. Location of the Estcourt Formation, Beaufort Group in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Soils

Seven major soil patterns are evident in the soils derived from the dark grey shale, silt stone and sandstone of the Estcourt Formation (Table 12.1). The first is a red and yellow apedal soil pattern with Hutton, Griffin and Clovelly soils dominant. Katspruit, Mispah and Glenrosa soils are subdominant. A variant of this soil pattern has sandy to sandy loam and sandy clay loam, dystrophic yellow apedal soils occurring in the soil pattern (Table 12.1). Cartref soils with an E horizon are also present in the moist, yet younger landsurfaces than where the apedal soils are dominant. In the plinthic soil pattern Avalon, Glencoe, Longlands, Wasbank and Westleigh soils are present together with Mispah, Glenrosa, Cartref soils and rock land. Rainfall decreases in this soil pattern to that encountered in the apedal soil patterns (Table 12.1). The plinthic and duplex soil pattern has Longlands, Wasbank and Westleigh soils together with the duplex soils of the Swartland, Valsrivier and Estcourt Forms as dominant soils. Here the recorded rainfall is again lower and aridity indexes higher than where duplex soils are absent. The proportion of Avalon and Glencoe soils are also lower than where duplex soils are absent (Table 12.1). Duplex soils occur over extensive areas of the KwaZulu-Natal Interior Basin. Lithosolic soil patterns with and without the presence of lime are located throughout the zone. While Mispah and Glenrosa soils may contain lime, free calcium carbonate is generally located in the lower horizons of the duplex soils (Table 12.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles of the Hutton, Griffin, Clovelly, Avalon, Longlands, Estcourt, Swartland and Glenrosa forms were extracted from the database. Two natural soil bodies are evident (Figures 12.4 to 12.8) with the threshold for their separation set at 60 percent total sand. The subdivision reflects a group of soils with the dominant textural classes in the clay, clay loam and loam classes, and despite a relatively wide spread these profiles are retained within one group. The other, more sandy group, has textures clustering in the sandy clay loam and sandy loam classes. Within the more extensively sampled clay grouping additional subdivision could be envisaged, particularly of those profiles falling towards the loam class with higher silt proportions. The ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade and information on their luvic properties are presented (Tables 12.2 and 12.3). These ranges are represented graphically (Figures 12.2 and 12.3). Each figure allows for overview comparisons between different soil forms and over particle size classes.

Within the clay group of soils the Clovelly soils (B1 horizons) have ranges in clay and silt of between 19 and 55% clay and 12 and 52% silt respectively. These values are representative of the red and yellow apedal soils and Avalon soils (Table 12.2, Figures 12.3, 12.5, 12.6). There does appear a tendency for the yellow soils (Cv, Gf, Av) to have higher silt values than the Hutton soils although the reason for this observation is not apparent. These ranges in textural classes show similarities to the soils derived from the Adelaide Subgroup (Pa), Beaufort Group, and the Volksrust Formation (Pvo), Ecca Group. However, the equivalent clay textural class for the Pa and Pvo soils appear to have slightly higher clay and silt values than those of the soils from the Estcourt Formation. The apedal soils derived from the Estcourt Formation show relatively clear differences from the soils derived from the Tarkastad Formation (TRt, dominantly clay loam to sandy clay loam), and clear differences from the sandier soils derived from the Vryheid Formation (Pv), Ecca Group, and the Natal Group (O-Sn).

Table 12.1 Dominant soils and selected climatic information for soil patterns occurring on Estcourt Formation.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evapor ation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow-brown Apedal Soils (dystrophic base status)										
Hutton	Hu17 Hu16	39	Katspruit	Ka10	3	Ave	877	1388	1856	0.63
Griffin	Gf12 Gf13	17	Mispah	Ms10 Gs17	10	Std	65	80	124	0.06
Clovelly	Cv17	17	Glenrosa	Gs19		Max	973	1568	1991	0.74
						Min	789	1321	1574	0.55
Total Area: 50 036 Ha			Means of 8 Land Types							
Broad Soil Pattern: Yellow-brown Apedal Soils (dystrophic base status)										
Clovelly	Cv16 Cv17	17	Cartref	Cf10 Cf11	18	Ave				
	Cv13 Cv14 Cv10	17	Mispah	Ms10	14	Std				
	Cv11					Max				
						Min				
Total Area: 16 290 Ha			Means of 2 Land Types							
Broad Soil Pattern: Plinthic Soils (mesotrophic and dystrophic base status)										
Avalon	Av26 Av27 Av16	4	Hutton	Hu26 Hu27	17	Ave	732	1428	2050	0.52
	Av27		Clovelly	Cv26 Cv27	8	Std	55	87	132	0.06
Glencoe	Gc16 Gc17	2				Max	825	1561	2207	0.62
						Min	676	1321	1843	0.46
Longlands	Lo11 Lo12 Lo22	7								
Wasbank	Wa12									
Westleigh	We12 We22	7								
Mispah	Ms10 Ms11	13								
Glenrosa	Gs16 Gs17	12								
Cartref	Cf12	10								
Rock	Rock	4								
Total Area: 15 093 Ha			Means of 4 Land Types							
Broad Soil Pattern: Plinthic and Duplex Soils										
Longlands	Lo11 Lo12	12	Hutton	Hu36 Hu37	11	Ave	673	1427	2154	0.47
Wasbank	Wa11 Wa12	4		Hu26		Std	4	17	74	-
Westleigh	We11 We12	10	Clovelly	Cv36 Cv37	5	Max	676	1439	2207	0.48
	We13			Cv26		Min	667	1403	2049	0.47
Avalon	Av26 Av27 Gc26	5								
Glencoe	Gc27									
Swartland	Sw30 Sw31	9								
Valsrivier	Va41	3								
Estcourt	Es33 Es36	5								
Mispah	Ms10 Ms11	6								
Glenrosa	Gs16 Cf12	12								
Cartref										
Total Area: 11 560 Ha			Means of 3 Land Types							

Table 12.1 continued. Dominant soils and selected climatic information for soil patterns occurring on Estcourt Formation.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evapor ation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Duplex Soils										
Valsrivier	Va41 Va42 Va31 Va32	15	Glenrosa	Gs14 Gs16 Gs17	10	Ave	676	1544	2336	0.44
						Std	62	214	401	0.08
Swartland	Sw41 Sw42 Sw31 Sw32	15	Mispah	Ms1 Ms20	7	Max	765	1967	3076	0.55
			Rock	Rock	4	Min	596	1385	1966	0.33
Sterkspruit	Ss26 Ss27	4								
Estcourt	Es33 Es36	8								
Total Area: 19 980 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Mispah	Ms10	13	Clovelly	Cv16 Cv17	13	Ave	838	1354	1863	0.62
Glenrosa	Gs16 Gs19	14	Hutton	Hu27	12	Std	99	69	327	0.11
Cartref	Cf12	14				Max	989	1455	2316	0.79
Rock	Rock	15				Min	720	1251	1441	0.51
Total Area: 42 410 Ha			Means of 7 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime										
Mispah	Ms10 Ms20	38	Swartland	Sw31 Sw32 Sw41 Sw42	7	Ave	704	1729	2823	0.41
Glenrosa	Gs16 Gs17 Gs26	11				Std	97	278	680	0.11
			Valsrivier	Va41 Va42	5	Max	1052	2274	4822	0.71
Rock	Rock	12	Estcourt	Es34 Es36	2	Min	635	1403	1966	0.31
Total Area: 59 770 Ha			Means of 15 Land Types							

There are also differences in the dominant textures of profiles from the Griffin, Clovelly and Avalon soils. The Griffin soils have textures dominantly in the clay class (Figure 12.4), the Clovelly soils in a portion of the clay and clay loam classes (Figure 12.3), and the Avalon soils in the loam class (Figure 12.6).

There are textural differences too between the apedal soils (Hu, Gf, Cv, Av) and those of the Longlands and Estcourt soils derived from shale and siltstone of the Estcourt Formation. The lower clay contents of the Longlands and Estcourt soils can be explained by clay eluviation from the E horizons. The A1 horizons too show various degrees of bleaching, and eluviation for these horizons could also be expected. Texture similarities exist within the A1 and E1 horizons of the Longlands and Estcourt soils (Table 12.2, Figures 12.7, 12.8). A feature of the textures of these soils (Lo, Es) is the relatively high silt values present in many of the soils derived from the Estcourt Formation. Whilst there are commonly increases in the clay content of the B1 horizons of the Longlands soils, there are markedly large clay percentage increases for the B1 horizons of the Estcourt soils (Table 12.4, Figure 12.7, 12.8). Fine sand is dominant in all soils developed from the Estcourt Formation (Tables 12.2 and 12.3).

Table 12.2 Textural properties of the clay loam to clay soils of the Estcourt Formation derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1	SaClLm-Cl SaClLm-Cl	39-49 29-59	6-16 8-38	20-41 16-42	9-10 1-9	1-3 1-5	fi fi	NL5 -
Griffin	A1 B1 B2	ClLm-Cl ClLm-Cl Cl	34-48 30-67 39-63	14-38 11-43 12-34	7-30 4-40 3-28	1-3 1-5 1-1	3-5 1-5 1-6	fi fi fi	NL3,L2 NL3,EL2 -
Clovelly	A1 B1	Lm-SaClLm-Cl SaClLm-ClLm-Cl	18-50 19-55	12-39 12-52	5-39 4-51	1-11 1-11	1-4 1-6	fi fi	NL3,EL2 -
Avalon	A1 B1 B2	Lm -ClLm-Cl Lm-ClLm-Cl Lm-ClLm-Cl	17-49 18-51 20-54	8-35 7-34 10-27	21-45 17-44 22-39	1-7 1-6 2-5	1-4 1-6 1-7	fi fi fi	- - -
Longlands	A1 E1 B1	SaClLm SaClLm ClLm-Cl	18-33 19-41 16-48	12-38 8-31 5-32	30-58 32-53 19-35	2-5 2-11 4-4	1-9 1-11 3-12	fi fi fi	NL5 NL3,L2 -
Estcourt	B1	Lm-ClLm Lm-ClLm Cl	17-32 14-38 48-71	3-32 28-45 8-23	2-48 33-42 13-20	1-24 1- 4 1- 5	4-29 6-6 4-10	fi, co	-
Swartland	B1	SaCl-Cl	44-58	3-19	25-28	1-19	3-8	fi, me	-
Mispah	A1	ClLm-Cl	13-47	4-31	7-30	2-35	1-18	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).

Table 12.3 Textural properties of the sandy loam to sandy clay loam soils of the Estcourt Formation derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	B1	SaClLm	20-31	8-14	27-47	13-22	2-12	fi	-
Avalon	A1 B1	Lm-ClLm Lm-ClLm	14-20 10-26	4-10 4-12	57-82 48-73	7- 7 2-11	6-6 1-13	fi fi	- -
Longlands	A1 E1 B1	LmSa-SaClLm LmSa-SaClLm SaClLm	9-28 9-9 10-29	5-18 4-4 4-18	40-79 74-74 54-74	7-10 10-10 6-9	2-13 2-2 1-6	fi fi fi	- -
Estcourt	A1 E1	SaLm SaClLm	16-25 11-39	10-15 8-16	41-64 7-52	5-16 3-14	3-7 4-7	fi 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).

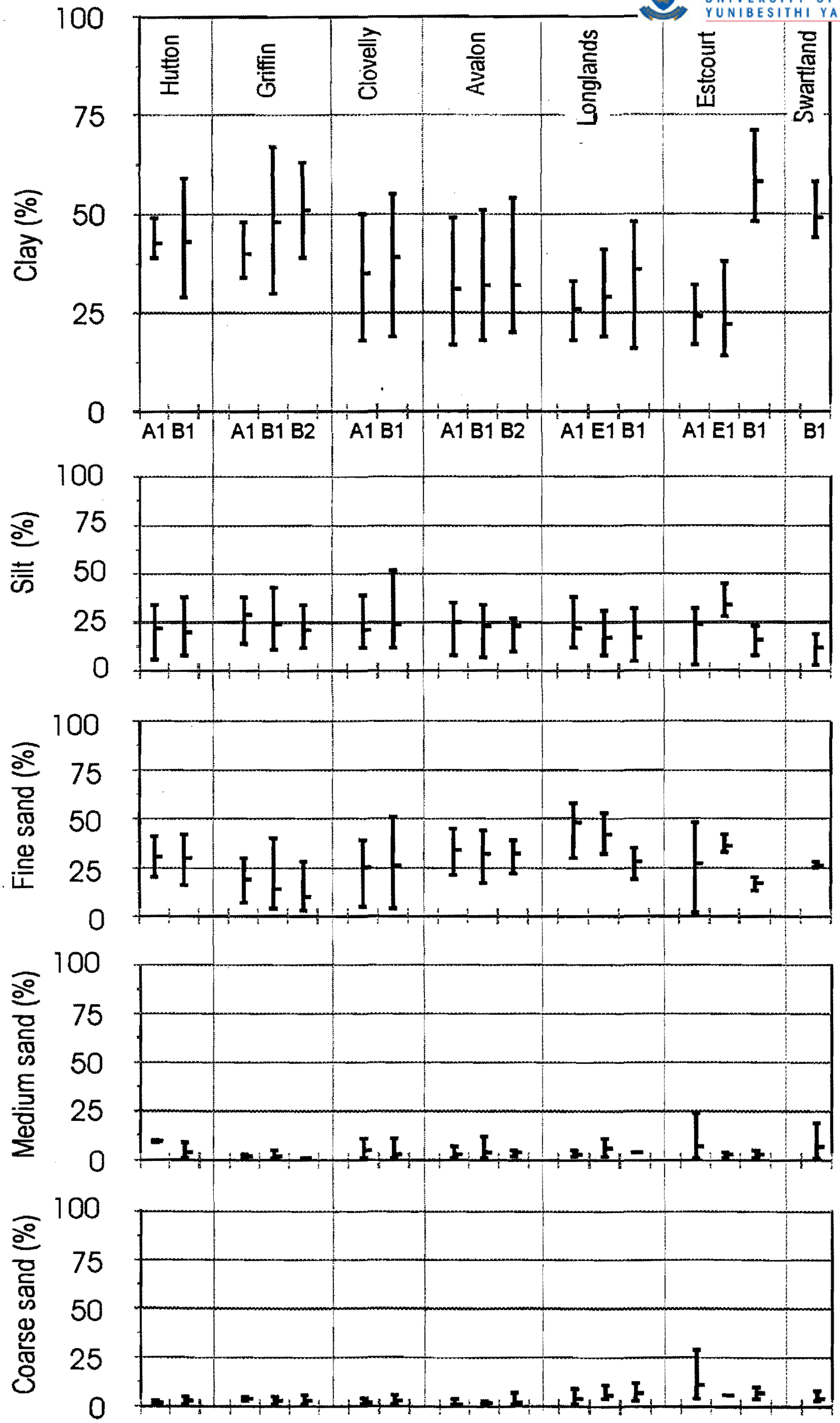


Figure 12.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Estcourt Formation with a clay loam to clay texture. Maximum, minimum and mean values are shown for each horizon.

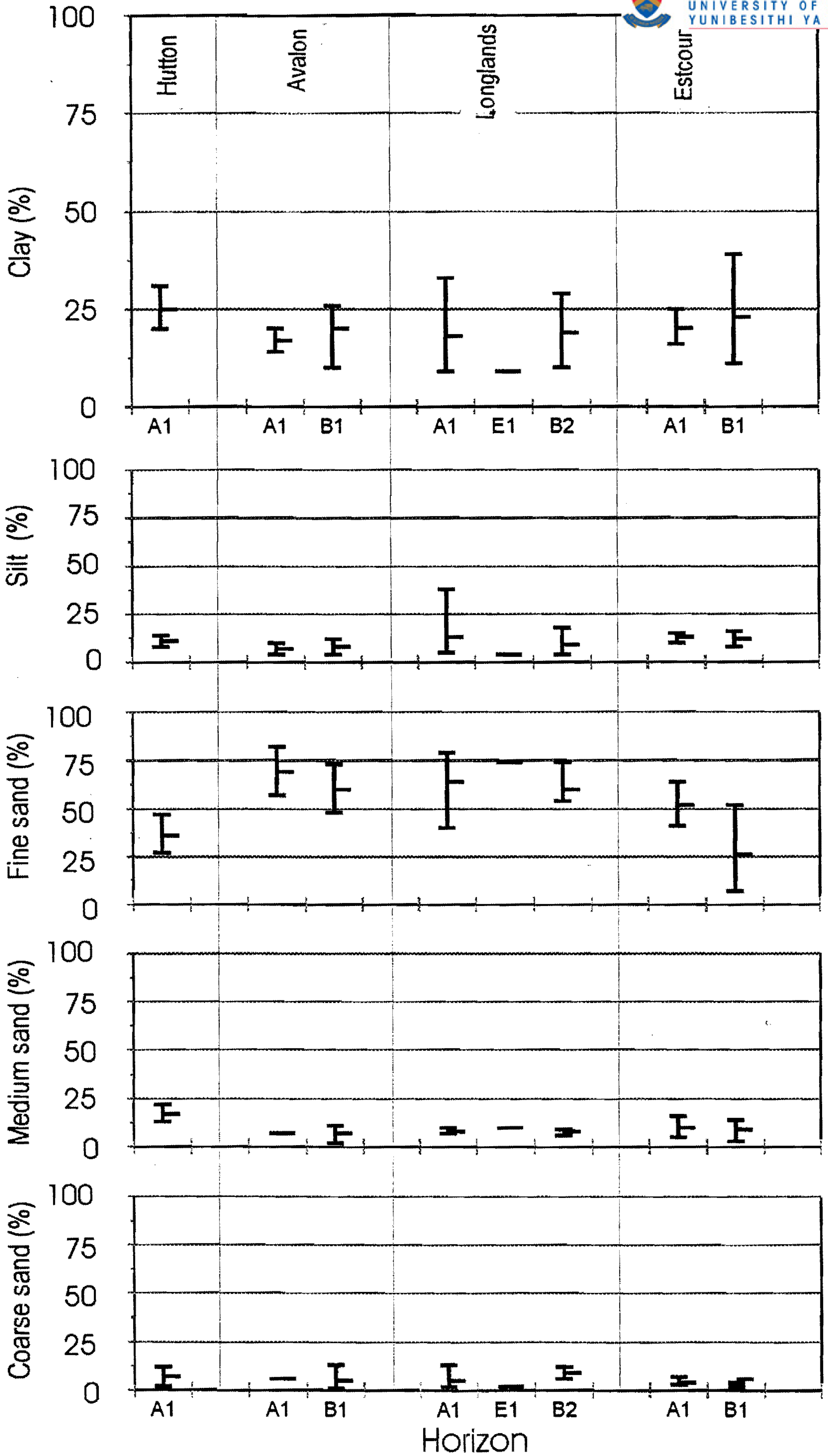


Figure 12.3 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Estcourt Formation with a sandy loam to sandy clay loam texture. Maximum, minimum and mean values are shown for each horizon.

Table 12.4 Means and standard deviations of five textural classes for the clay loam to clay soils of the Estcourt Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
A1	276	42.7	4.5	21.7	11.7	30.5	10.5	9.5	0.5	2.0	1.0	3
B1	765	43.0	8.5	19.8	7.3	29.9	8.4	3.8	2.9	2.7	1.3	12
Form: Griffin												
A1	298	40.4	6.0	28.6	8.7	19.0	9.4	1.7	0.9	3.7	0.9	5
B1	568	47.2	9.3	24.0	11.6	14.4	11.1	2.0	1.3	3.4	1.5	11
B2	1157	50.6	8.1	21.3	8.0	10.0	9.1	1.0	0.0	3.2	1.6	7
Form: Clovelly												
A1	324	34.8	10.0	20.9	7.8	25.1	11.6	4.9	3.5	2.4	1.3	11
B1	646	38.9	9.1	24.1	8.9	25.9	10.5	3.3	2.8	2.5	1.5	29
Form: Avalon												
A1	309	31.2	9.8	25.0	7.8	34.1	7.5	3.1	2.0	1.4	1.0	10
B1	506	32.7	8.6	23.3	7.8	32.1	6.1	4.0	3.0	2.8	1.7	23
B2	685	51.5	2.5	23.0	4.0	22.5	0.5	3.0	0.0	1.5	0.5	2
Form: Longlands												
A1	314	26.0	4.5	21.9	7.5	48.2	9.1	3.3	1.3	4.5	3.0	9
E1	576	28.8	7.1	17.9	7.2	42.0	9.1	6.5	3.2	6.3	2.9	8
B1	841	36.3	10.5	17.7	10.4	28.0	6.7	4.0	0.0	7.3	3.7	7
Form: Estcourt												
A1	312	23.6	5.2	24.0	11.0	27.6	15.8	7.4	8.5	11.5	10.2	5
E1	470	22.3	11.1	34.7	7.4	36.7	3.9	2.7	1.3	6.0	0.0	3
B1	628	58.2	8.4	16.0	5.6	17.2	2.6	3.0	1.4	7.3	2.4	5
Form: Swartland												
B1	503	49.0	6.4	12.0	6.7	26.7	1.3	7.0	8.5	4.7	2.4	3
Form: Mispah												
A1	221	32.3	12.8	21.3	8.4	20.2	7.5	10.2	12.8	6.0	6.2	6

Table 12.5 Means and standard deviations of five textural classes for sand loam to sandy clay loam soils of the Estcourt Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
B1	766	25.0	4.5	11.0	2.5	36.7	8.2	17.7	3.7	7.3	4.1	3
Form: Avalon												
A1	250	17.0	3.0	7.0	3.0	69.5	12.5	7.0	0.0	6.0	0.0	2
B1	600	19.5	6.5	8.3	2.9	60.0	8.9	7.5	3.8	5.0	4.7	4
Form: Longlands												
A1	307	18.4	7.5	13.3	10.3	64.7	10.3	8.2	1.2	5.4	4.2	9
E1	500	9.0	0.0	4.0	0.0	74.0	0.0	10.0	0.0	2.0	0.0	1
B1	687	18.8	6.8	9.5	5.6	60.3	8.1	7.8	1.3	3.5	1.8	4
Form: Estcourt (no data available for E horizons)												
A1	226	20.0	3.7	12.7	2.0	52.7	9.4	10.0	4.5	4.3	1.9	3
B1	722	23.0	11.9	11.5	3.0	26.5	18.4	8.8	5.3	26.0	21.5	2

There are relatively few samples of Swartland soils. Textures of the B1 horizons are of the sandy clay to clay class (Table 12.2). The textures of the Mispah soils (Figure 12.3) are in the same range (loam through clay loam to clay) as those measured for other soils of the Estcourt Formation. A common perception that the Mispah soils will exhibit lower clay percentages, is inaccurate.

The sandy loam group contained profiles from the Hutton, Avalon, Longlands and Estcourt Form (Table 12.3, 12.5), although data is limited. It must be assumed that these profiles are derived from the sandstone source of the Estcourt Formation. Sand grades are fine (Table 12.3). A feature to distinguish this group from the clay group is the sandier textures and the lower silt values (Figures 12.4, 12.6, 12.7, 12.8). Clay contents range from about 10 to 30 percent and silt values from 4 to 20% (Table 12.3).

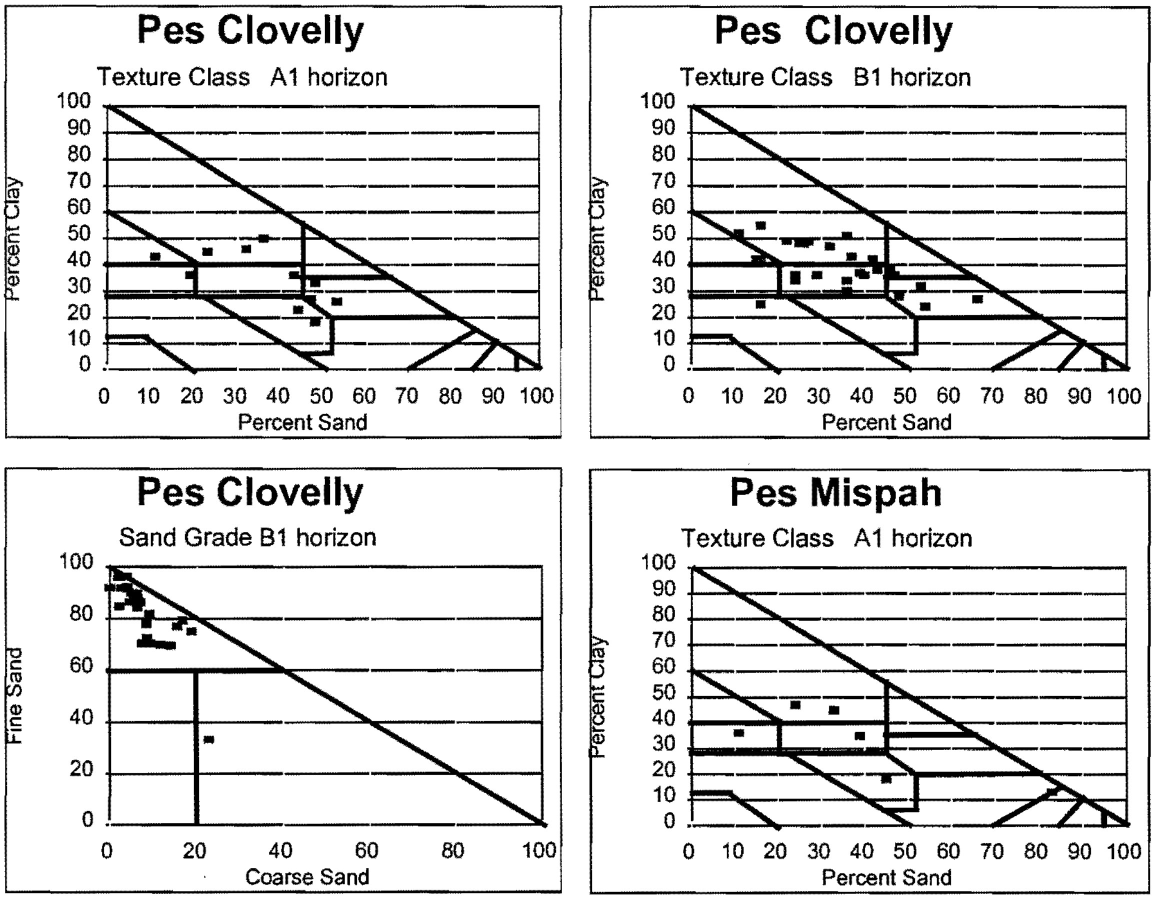


Figure 12.4 Distribution of soil textures, and dominant sand grade, within soils of the Clovelly and Mispah Forms.

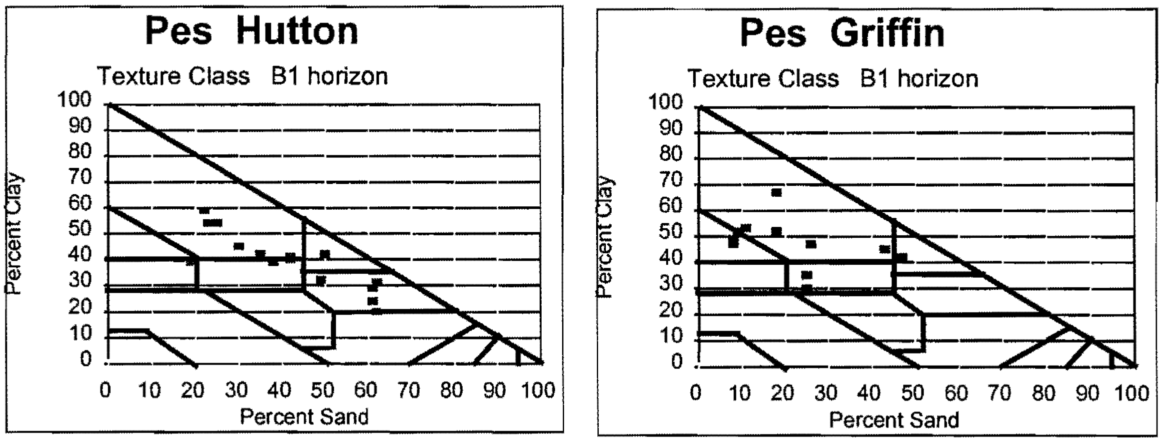


Figure 12.5 Distribution of soil textures within soils of the Hutton and Griffin Forms.

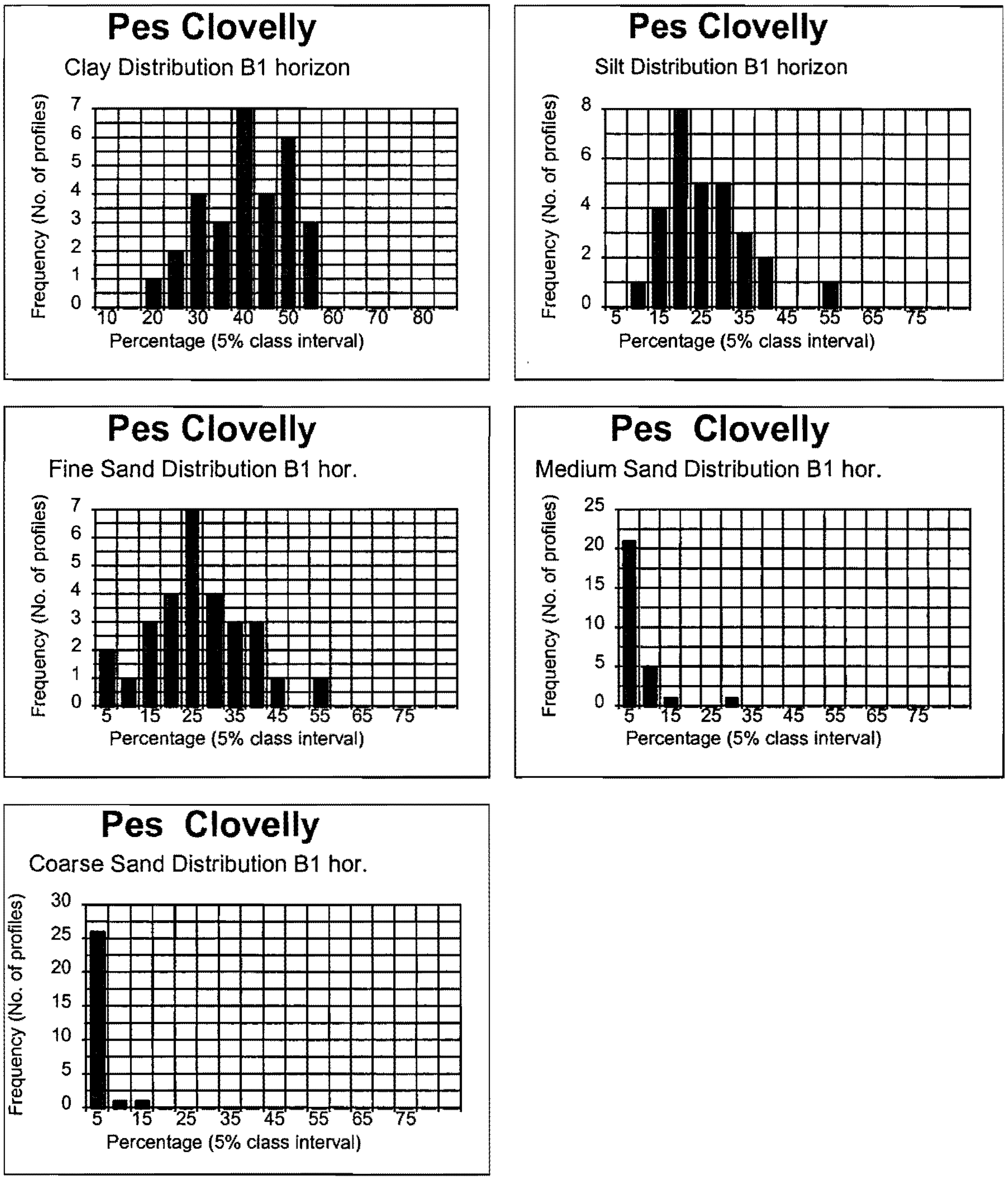


Figure 12.6 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Clovelly Form.

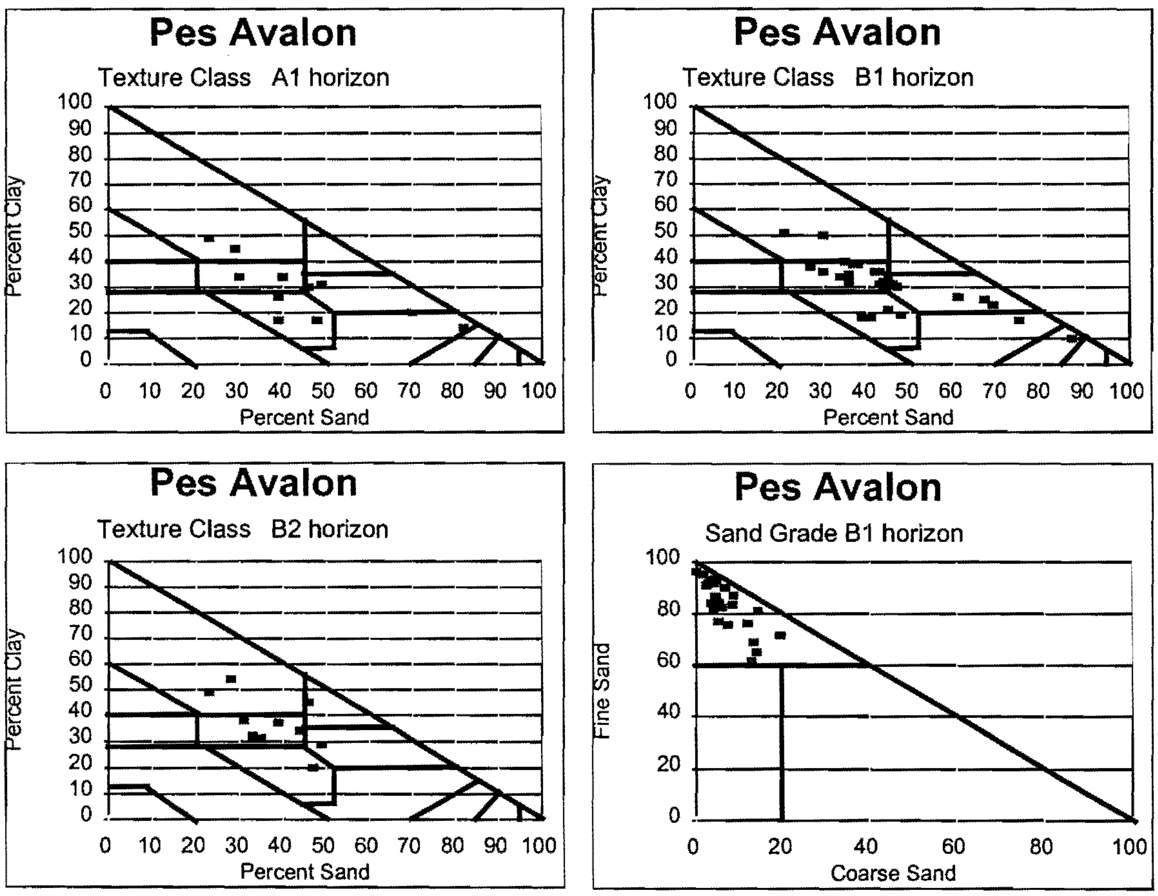


Figure 12.7 Distribution of soil textures within soils of the Avalon Form.

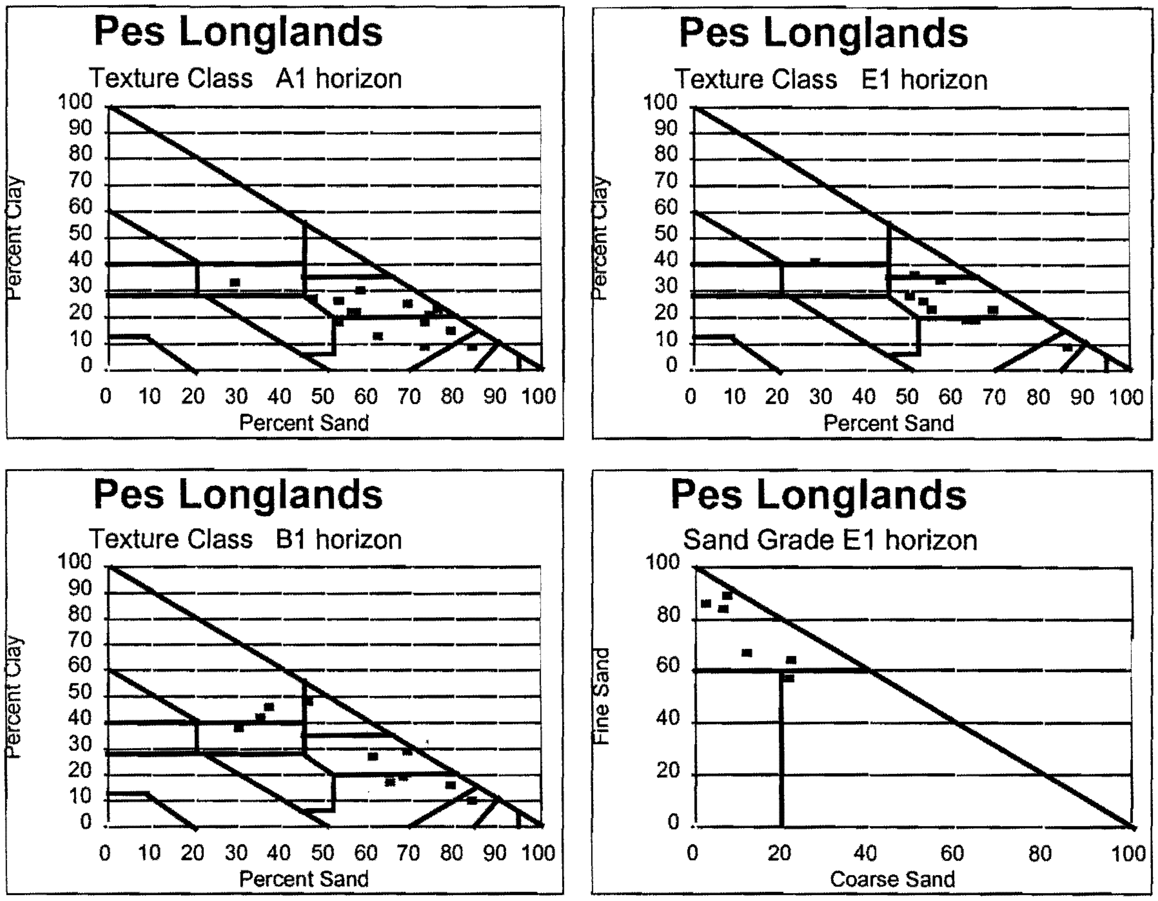


Figure 12.7. Distribution of soil textures, and dominant sand grade, within soils of the Longlands Form.

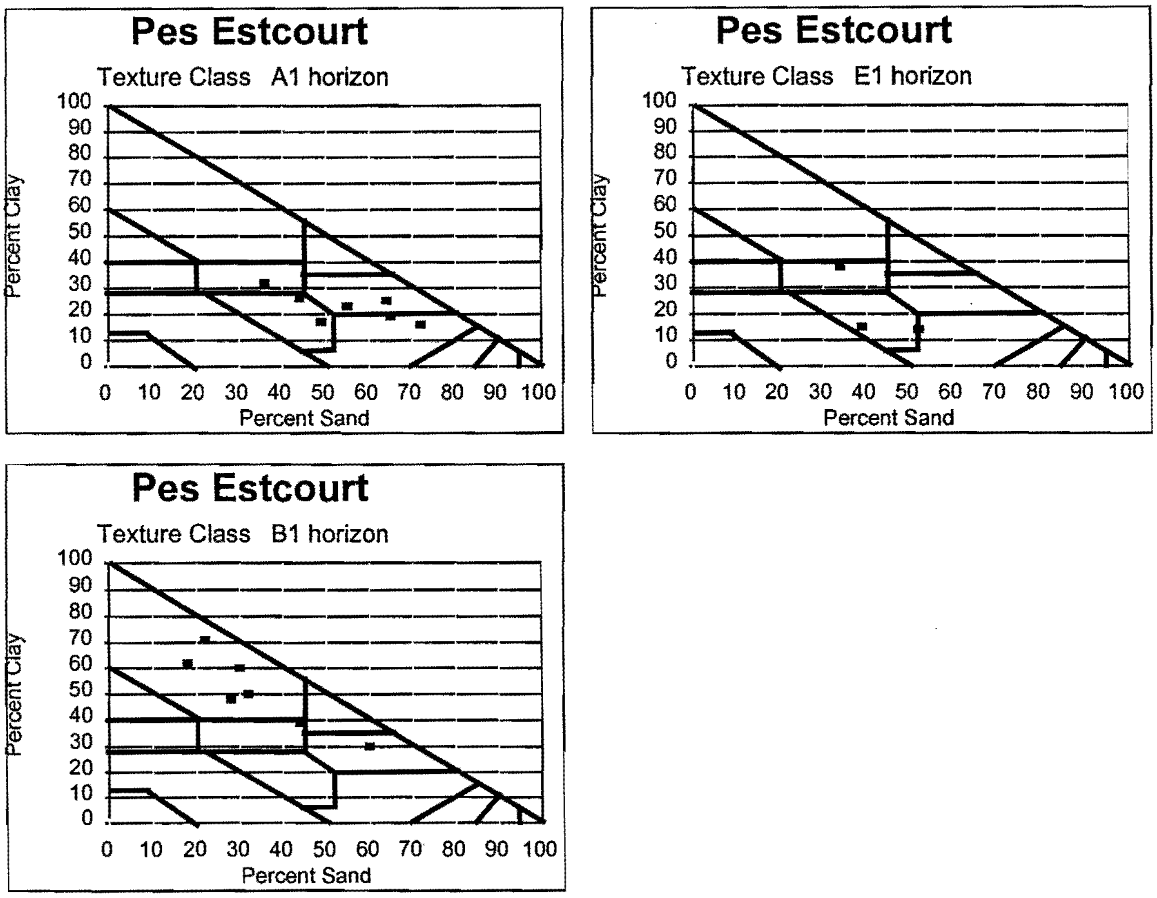


Figure 12.8. Distribution of soil textures, and dominant sand grade, within soils of the Estcourt Form.

CHAPTER 13

SOILS OF THE MUDSTONE AND SHALE OF THE VOLKSRUST FORMATION, ECCA GROUP IN KWAZULU-NATAL AND MPUMALANGA

Location and Extent

The Volksrust Formation covers extensive areas of the Highveld Plain south of the Vaal River extending eastwards to the town of Volksrust from which the formation derives its name. Southwards the formation occupies a narrow belt east of the main Drakensberg Escarpment, on the western parts of the KwaZulu-Natal Interior Basin. South of the Klip and Tugela Rivers the formation is more extensive, being located between the Vryheid Formation in the east and the Estcourt Formation, Beaufort Group in the west. The southern extent of the formation is near the southern KwaZulu-Natal boundary (Figure 13.1). The formation covers some 690 000 hectares in the study area.

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

The Volksrust Formation is the name applied to the old Upper Ecca beds, comprising 150 to 250 m of shale which overlies the Vryheid Formation (SACS, 1980). The formation is described as bluish-grey or dark grey mudstone and shale with subordinate siltstone (Geological Survey, 1992) and as shale and siltstone (Geological Survey, 1988a, 1988b). As with the Pietermaritzburg Formation, the Volksrust formation is limited by a lateral cutoff coinciding with the pinch-out of the Vryheid Formation. In southern KwaZulu-Natal this occurs just south of the Mzimkulu River.

Physiography and Drainage Features

The physiography of the zones where the Volksrust Formation is exposed range from slightly undulating plains (slopes 2 - 5%) to irregular undulating land (slopes 2 - 8%) (Kruger, 1980). It is in these zones that plinthic and duplex soil patterns are present. The Highveld Plain is drained by the Vaal River and its tributaries. The portions where the Volksrust Formation is exposed on the northern Drakensberg Escarpment is largely low mountains. In the central and southern KwaZulu-Natal areas the terrain varies between undulating lowland with hills (slopes 2-8%), undulating hills (slopes 5-15%) to low mountains (slopes 8-30%) (Kruger, 1980). The drainage is via the Tugela River and its southern tributaries and the Mgeni, Mkomazi and Mzimkulu Rivers.

Vegetation

On the Highveld the vegetation is largely the Moist Clay Highveld Grassland and Wet Cold Highveld Grassland (Low and Rebelo, 1986). In central and southern KwaZulu-Natal the vegetation comprises the Moist Upland and Short Mistbelt Grasslands. There are areas covered by Valley Thicket.

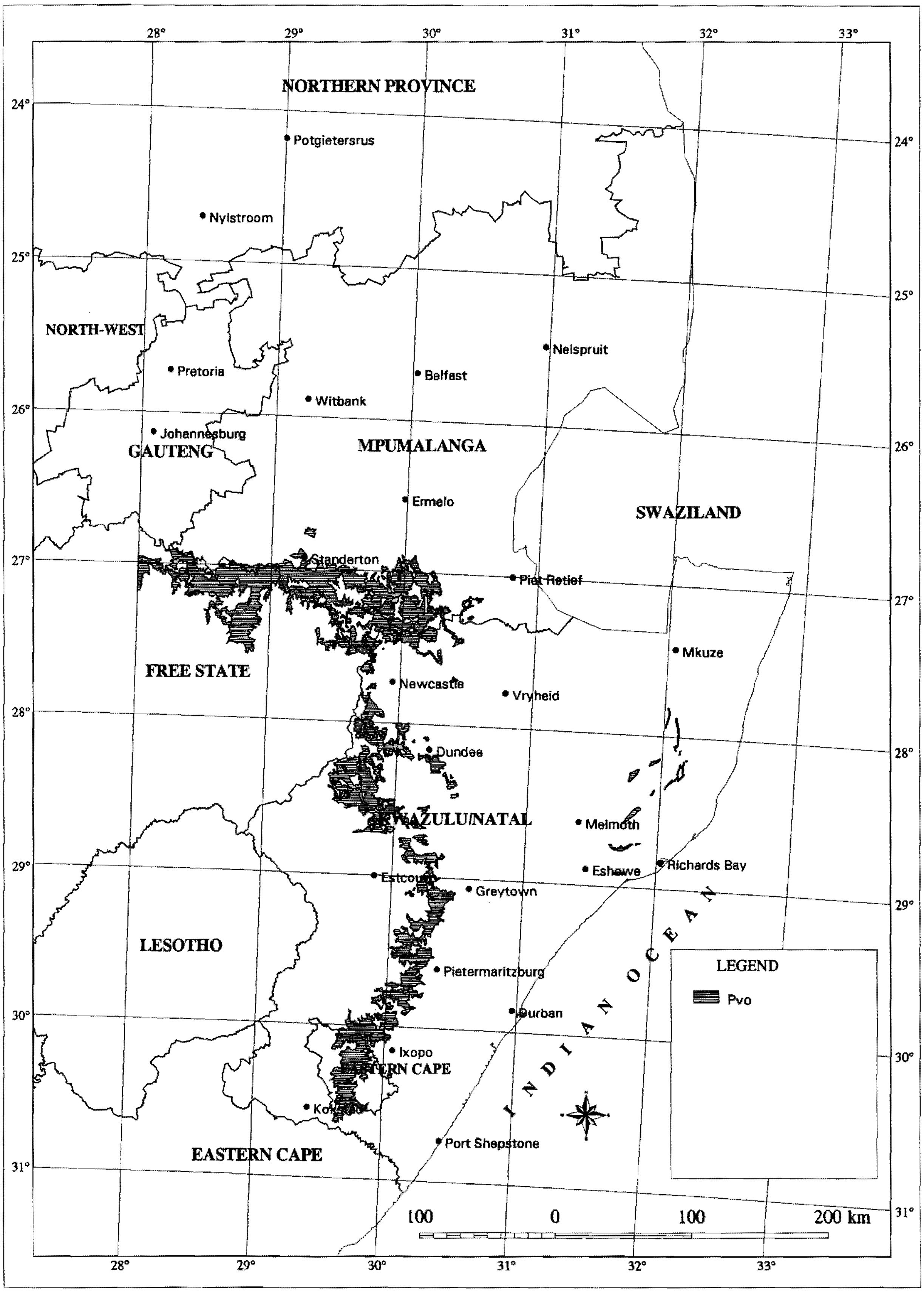


Figure 13.1. Location of the Volksrust Formation, Ecca Group in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Soils

Six major soil patterns are evident on the materials of the Volksrust Formation (Table 13.1). These include a red and yellow apedal soil pattern where dystrophic soils are dominant and a plinthic pattern which has together with the plinthic soils, red and yellow apedal soils of dominantly mesotrophic base status. There is also a plinthic pattern where plinthic soils, soils with E horizons and duplex soils dominate. In the duplex soil pattern soils of the Swartland Form are dominant. Lithosols, with and without the presence of lime makes up the remaining two patterns. Here Mispah and Glenrosa soils are dominant, while respectively Hutton and Swartland soils are sub-dominant (Table 13.1).

The red and yellow apedal soil patterns on rocks of the Volksrust Formation are only present in southern KwaZulu-Natal. Hutton, Griffin and Clovelly soils occur over a range of slopes and terrain positions. These range from gently undulating (2 - 5%) and undulating slopes (5 - 8%) through to moderately steep land (15 - 30% slopes). Dystrophic soils are dominant over the mesotrophic soils. Glenrosa, Mispah and Katspruit soils are also present in smaller proportions. While dystrophic soils are dominant in the red and yellow apedal soil patterns, they may also be present in other soil patterns, notably in the plinthic soil pattern.

Sandy loam to sandy clay loam Avalon and Glencoe soils form an important component of the plinthic soil pattern with red and yellow apedal soils. Other soils include the Clovelly, Hutton and Griffin Forms with mesotrophic and dystrophic base status (Table 13.1). The profile analyses indicate that the clay contents of these soils can be higher than those quoted in the source data used to compile Table 13.1. Longlands, Wasbank and Westleigh soils are also important in this soil pattern. These soils are commonly located on gently undulating slopes (2 - 5% slope).

Plinthic soils with E horizons and duplex soils occur regularly together in the same landscape. On the shales and mudstones of the Volksrust Formation fine sandy loam to sandy clay Kroonstad and Cartref soils are dominant (Table 13.1). Other duplex and plinthic soils are present (Table 13.1). However, mesotrophic and dystrophic Clovelly soils are also present (Table 13.1). In these shales and mudstones which occur at generally high altitudes, and in cool climates, weathering to kaolinitic apedal soils could be expected. Their presence together with duplex soils is unusual, and is associated with the parent material and the cooler climate.

In the duplex pattern Swartland soils with sandy clay to clay subsoils are dominant (Land Type Survey Staff, 1985 -1997). Valsrivier, Estcourt, Mispah and Glenrosa are also present (Table 13.1).

In the more youthful landscapes, where either the slopes are greater or effective rainfall is less, lithosols are dominant. Time for soil formation must be assumed to be short. In those zones where effective rainfall is lower the proportion is in favour of Mispah, Glenrosa and Swartland soils (Table 13.1), while where effective rainfall is higher the proportion is in favour of Glenrosa, Mispah and Hutton soils (Table 13.1). Leaching to the extent that loss of calcium carbonates has taken place.

Table 13.1 Dominant soils and selected climatic information for soil patterns occurring on shale and siltstone of the Volksrust Formation, Ecca Group. Subdominant 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 Soils (Dominantly dystrophic)										
Hutton	Hu17 Hu18	25	Glenrosa	Gs16 Gs19	10	Ave	977	1479	2243	0.66
	Hu16	3	Mispah	Ms10	8	Std	149	300	299	0.15
	Hu27 Hu28	5	Katspriut	Ka10	3	Max	1408	2980	2948	-
Clovelly	Cv16	7				Min	760	1117	1599	0.41
	Cv17	4								
Griffin	Gf11 Gf12	9								
Total Area: 192 410 Ha			Means of 44 Land Types							
Broad Soil Pattern: Plinthic Soils with Red and Yellow Apedal Soils (Mesotrophic and Dystrophic Base Status)										
Avalon	Av16 Av17	14	Mispah	Ms10	6	Ave	826	1469	2239	0.56
Glencoe	Gc16 Gc17	2				Std	48	319	305	0.11
						Max	886	1988	2657	0.77
Clovelly	Cv16 Cv17	5				Min	706	1026	1755	0.43
	Cv26 Cv27	4								
Hutton	Hu27 Hu28	6								
	Hu17 Hu18	5								
Griffin	Gf12	5								
Longlands	Lo22 Lo13	8								
Wasbank	Wa22 Wa21	3								
Westleigh	We12 We13 We22	4								
Total Area: 85 080 Ha			Means of 13 Land Types							
Broad Soil Pattern: Plinthic (with E horizons) and Duplex Soils										
Kroonstad	Kd13 Kd16	25	Clovelly	Cv26 Cv16	20	Ave	791	1884	2588	0.42
Estcourt	Es16 Es36	4				Std	86	389	1349	0.17
Other	Va41 Sw31	4				Max	964	2274	4822	0.65
Duplex						Min	710	1494	1518	0.31
Wasbank	Wa12 Wa13	4								
Westleigh	We13	4								
Cartref	Cf12 Cf13	10								
Total Area: 224 510 Ha			Means of 10 Land Types							
Broad Soil Pattern: Duplex Soils										
Swartland	Sw31 Sw32	19				Ave	809	1674	2661	0.48
Valsrivier	Va31 Va32	7				Std	78	262	322	0.12
Estcourt	Es36 Es37	6				Max	929	1881	3188	0.77
						Min	694	1026	2316	0.37
Mispah	Ms10	11								
Glenrosa	Gs16 Gs19	7								
Total Area: 49 260 Ha			Mean s of 17 Land Types							

Table 13.1 continued. Dominant soils and selected climatic information for soil patterns occurring on shale and siltstone of the Volksrust Formation, Ecca Group. Subdominant 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	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Lithosols (without the presence of lime)										
Glenrosa	Gs16 Gs17	12	Hutton	Hu17 Hu27	15	Ave	852	1590	2186	0.54
Mispah	Ms10	9				Std	100	205	396	0.09
						Max	1045	1887	2918	0.69
Rockland	R	18				Min	649	1212	1122	0.37
Total Area: 84 060 Ha			Means of 29 Land Types							
Broad Soil Pattern: Lithosols (with the presence of lime)										
Mispah	Ms20 Ms10	19	Swartland	Sw31 Sw32	10	Ave	693	1701	2781	0.41
Glenrosa	Gs16 Gs17 Gs26	17		Sw41 Sw42		Std	53	216	432	0.07
	Gs27					Max	840	1967	3965	0.52
Rockland	R	10				Min	635	1361	2071	0.33
Total Area: 55 900 Ha			Means of 16 Land Types							

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Clovelly, Avalon, Longlands, Estcourt, Swartland, Katspruit, Mispah, Arcadia and Mayo Forms were extracted form the database. The ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented in Table 13.2.

These ranges are presented graphically in Figure 13.2. The figure allows for an overview comparison between different soil forms and over particle size classes. It shows the clayey and silty nature of many of these soils derived from shale and mudstone of the Volksrust Formation (Table 13.2). The clay contents of the Clovelly soils (B1 horizons) range between 21 and 67 percent. The silt contents for these soils range between 9 and 46 percent. These values are representative of the red and yellow-brown apedal soils. Similarly, the soils with E horizons have large ranges in clay and silt contents. Examples are in the E horizons of soils of the Estcourt Form. Ranges in clay content are between 8 and 39 percent, while ranges in silt content are between 6 and 53 percent (Table 13.2). Fine sand is the dominant sand grade, while medium and coarse sand values are low.

These textural values contrast sharply with the soils derived from the Vryheid and Dwyka Formations, and the Natal Group sandstone. However they do show similarities and differences

Table 13.2 Textural properties of soils of the Volksrust Formation derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1	ClLm-SaClLm Cl-ClLm	21-61 31-75	6-34 5-35	4-38 3-34	1-21 1-10	1-11 1-8	fi,co fi,co	EL2,NL2,L1 -
Griffin	A1 B1 B2	Cl-SaClLm Cl-SaCl Cl-SiCl-SaCl	34-68 27-70 31-58	11-46 8-51 7-39	4-37 5-38 18-44	1-9 1-14 2-10	1-7 1-12 1-7	fi fi fi	EL3,NL2,L1 EL4,NL1 -
Clovelly	A1 B1	Cl-SaClLm Cl-SaClLm	26-58 21-67	10-35 9-46	6-50 3-54	1-13 1-13	1-8 1-10	fi fi,co	EL3,NL2 -
Avalon	A1 B1 B2	Cl-SaLm Cl-SaLm Cl-SaClLm	16-57 22-57 26-63	6-40 6-41 9-33	15-55 11-51 11-47	1-22 1-17 1-17	1-12 1-20 2-23	fi fi,co fi,co	NL5 El2 -
Longlands	A1 E1 B1	Lm-SaLm Lm-SaClLm Lm-SaCl	18-27 22-41 24-42	15-44 16-41 14-44	12-48 7-50 11-32	2-16 2-10 1-12	1-21 2-19 4-30	fi,co fi,co	EL3,NL2 - -
Estcourt	A1 E1 B1	ClLm-SaLm SiClLm- SaClLm SiCl-Cl	8-37 8-39 20-50	8-56 6-53 9-46	3-55 6-57 2-48	2-18 1-17 1-12	1-15 2-17 2-11	fi fi,co fi	EL4,NL1 L5 -
Swartland	A1 B1	SiClLm-ClLm Cl-Lm-SaClLm	27-43 22-80	15-43 9-38	9-36 7-27	3-13 1-6	1-23 1-43	fi,co fi,co	NL3,L2 -
Katspruit	A1	Cl-SiCl-Lm	20-64	23-45	3-37	1-9	1-4	fi	-
Mispah	A1	Cl-SiCl- SaClLm	20-47	14-34	7-48	2-11	2-13	fi	-
Arcadia Mayo	A1	Cl-ClLm	35-47	26-33	5-24	5-9	2-8	fi,co	-

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).

to soils derived from the sedimentary rocks of the Beaufort Group.

The range in texture values is relatively large and subdivision of this range could have advantages towards understanding the soil properties and in land use applications. The A1, E1 and B1 horizons of all the soil forms were extracted from the database and plotted onto texture diagram graphs. A selection of these graphs is shown in Figures 13.3 to 13.9. Examination of these texture graphs allows the postulation of a number of natural clusters for soils of the Volksrust Formation. A number of possibilities were examined. Limiting the number of clusters to three, appears to be useful. Each of these clusters, with regard to texture class, could be considered as a natural soil body. The threshold values are given in Table 13.3. The values are somewhat arbitrary, but appear to apply over all soils sampled from within the Volksrust Formation. The original composite file was subdivided to prepare three files using these threshold values, and means and standard deviations determined from these files for each natural soil body. These data for texture are reported in Tables 13.4 to 13.6 respectively.

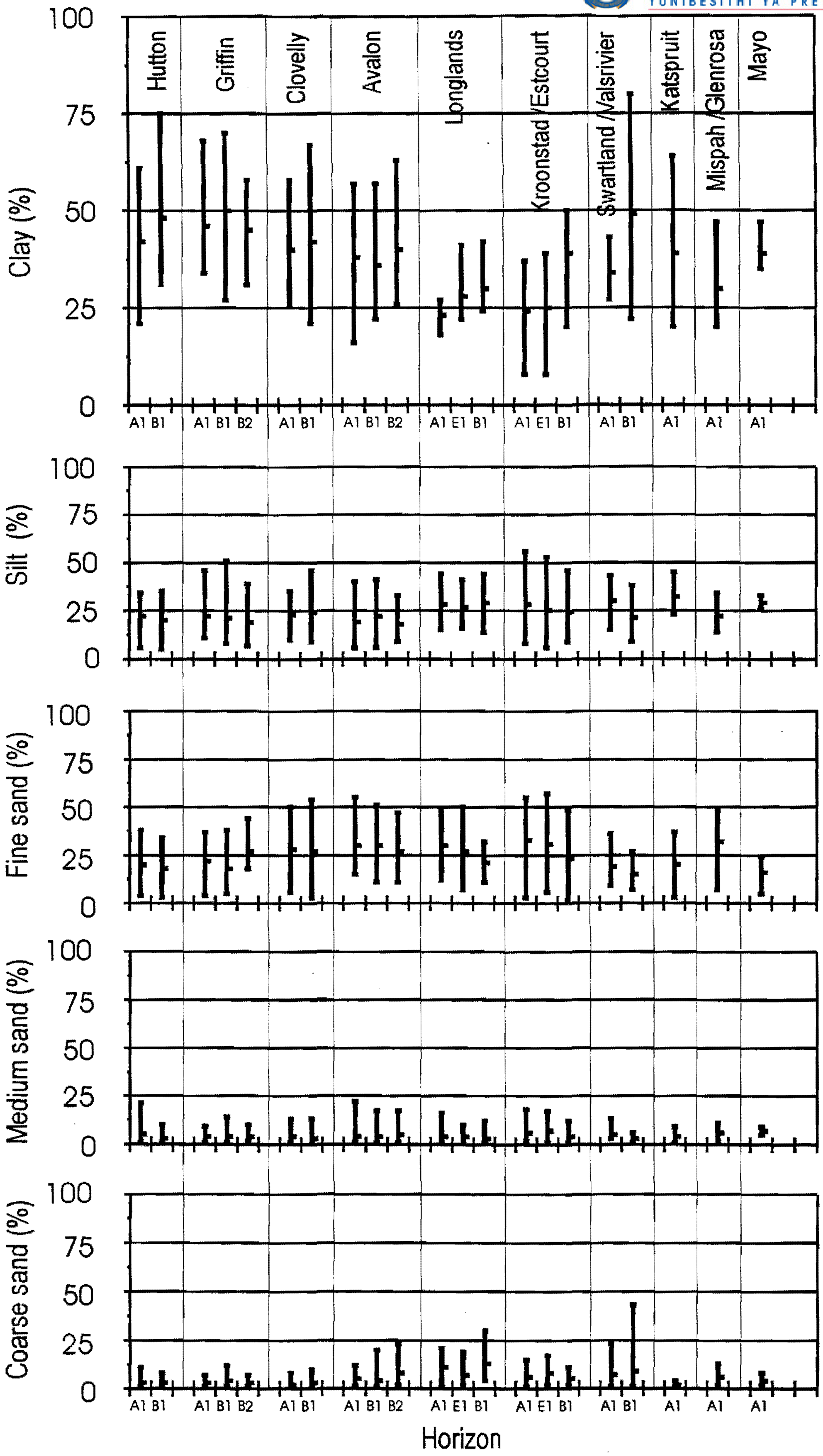


Figure 13.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Volksrust Formation. Maximum, minimum and mean values are shown for each horizon.

Table 13.3 Threshold values for three natural soil bodies within the Volksrust Formation.

Natural body based on texture	Threshold Value	Natural Body present in samples of the following soils:	Dominant Texture Class	Data referenced in:
1	>40% clay	Hutton A1, B1 Clovelly A1, B1 Griffin B1 Katspruit A1 Avalon B1 Swartland B1 Kroonstad B1	Clay	Table 13.4
2	<40%clay and >30% total sand	Clovelly A1, B1 Katspruit A1 Avalon B1 Kroonstad A1, B1 Swartland A1, B1	Clay Loam, Sandy Clay, Sandy Clay Loam	Table 13.5
3	<40% clay and <30% total sand	Griffin B1 Avalon A1, B1 Kroonstad A1, E1, B1 Swartland A1	Clay Loam, Silty Clay Loam, Silty Loam	Table 13.6

There is surprising little difference between the means within each natural body. In considering Table 13.4 there is little difference between the corresponding A1 and B1 horizons for the apedal soils, with similarities extending to the duplex and gleyed soils. It should be noted that while the clay values are higher the silt values and their standard deviations are also higher (Table 13.4) than the corresponding apedal soils (Hutton, Griffin, Clovelly and Avalon) within the (second) sandy to sandy loam natural body (Table 13.5).

In the sandy to sandy loam natural body similarities exist within the apedal soils (Hutton, Griffin, Clovelly and Avalon) (Table 13.5). There are similarities within the corresponding horizons of the Longlands and Kroonstad soils, although their clay values are lower and silt values higher than the apedal soils (Table 13.5). The classical concept of reduction (verified by the E horizon colours) and loss of CBD iron applies (Table 13.7). However, there is an increase in clay from the A1 to the E1 and to the B1 horizons (Table 13.5). This appears to be a feature of the soils of this geology formation. It is unusual and will require additional sampling for confirmation. However, it may be partly explained by the higher silt contents commonly encountered on this geology formation. In the presence of these silt values incomplete reduction of iron and loss of clay during pedogenesis could provide some explanation for their properties. Profile descriptions give grey matrix colours and an E horizon classification.

There are relatively few soils with the unusually high silt values (Table 13.6) and relatively low clay values. These soils with rather high silt values are somewhat unusual in South Africa. There are sufficient profile analyses to recognise that soils with these properties do exist and should be accommodated at the soil series level of classification.

Table 13.4 Means and standard deviations of five particle classes from the clay natural soil body for soils of the Volksrust Formation.

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	310	48.6	11.6	24.3	9.2	10.3	5.8	2.3	1.8	2.7	1.1	8
B1	896	55.9	9.7	22.5	7.3	12.5	7.0	1.8	1.1	2.6	1.6	12
Form: Griffin												
A1	291	51.5	9.3	19.7	7.0	20.6	9.3	4.6	2.9	2.8	1.6	6
B1	718	56.8	6.7	19.0	5.9	16.6	7.2	3.4	2.6	2.8	1.6	12
B2	1118	52.6	3.8	15.6	5.0	24.8	3.1	4.5	3.3	3.0	2.4	5
Form: Clovelly												
A1	233	50.7	4.9	29.3	3.7	14.8	5.8	2.3	1.3	1.8	0.8	6
B1	619	52.0	6.8	28.5	7.8	13.3	8.3	1.8	1.7	3.6	2.8	24
Form: Avalon and Glencoe												
A1	304	51.0	3.3	16.4	3.5	25.5	6.0	2.3	2.2	3.0	2.1	5
B1	776	51.2	4.0	18.2	5.3	22.2	5.7	2.5	1.7	4.3	3.0	6
Form: Swartland and Valsrivier												
A1	164	34.1	5.8	30.0	9.7	19.6	8.8	5.4	3.3	7.3	7.2	7
B1	632	55.6	10.2	20.2	8.6	15.8	6.2	2.7	1.5	4.5	3.3	10
Form: Katspruit												
A1	346	55.0	7.3	36.3	6.2	5.5	2.5	1.0	0.0	1.0	0.0	3

Table 13.5 Means and standard deviations of five particle classes from the sandy to sandy loam natural soil body for soils of the Volksrust Formation.

Horizon	Depth mm	Clay Mean %	Clay SD %	Silt Mean %	Silt SD %	Fine Sand Mean %	Fine Sand SD %	Medium Sand Mean %	Medium Sand SD %	Coarse Sand Mean %	Coarse Sand SD %	Sample Size
Form: Hutton												
A1	250	30.8	6.8	17.5	2.6	35.3	3.3	10.3	6.6	5.3	3.5	4
B1	670	38.0	3.0	20.8	4.9	30.4	5.3	6.2	2.7	4.0	2.6	5
Form: Griffin												
A1	370	36.0	2.0	17.5	0.5	36.5	0.5	7.0	2.0	3.0	1.0	2
B1	720	35.0	4.2	14.7	6.2	32.3	4.5	10.0	3.3	7.3	1.9	3
B2	1275	32.5	1.5	19.5	9.5	38.0	6.0	6.5	1.5	3.5	0.5	2
Form: Clovelly												
A1	260	32.9	4.0	18.6	7.8	35.1	8.6	6.1	3.5	3.1	2.4	8
B1	704	32.4	4.6	18.7	7.3	40.6	7.7	5.0	3.8	2.7	1.7	21
Form: Avalon												
A1	370	27.5	6.7	18.3	8.7	36.5	9.6	7.2	7.1	6.7	3.2	6
B1	696	32.1	5.3	19.6	8.3	36.3	7.5	5.5	4.7	4.8	4.1	20
B2	1028	31.9	3.4	19.6	9.2	31.1	9.8	7.0	5.2	9.9	6.7	7
Form: Longlands												
A1	369	23.6	3.1	28.0	10.7	30.7	12.2	4.8	4.2	11.0	6.2	10
E1	546	28.3	5.5	27.5	9.6	27.6	13.2	4.9	2.4	7.6	5.1	8
B1	732	30.9	7.0	29.2	9.2	21.6	8.2	3.8	3.3	13.3	8.3	9
Form: Kroonstad and Estcourt												
A1	256	16.8	7.7	21.8	10.6	44.6	9.2	8.6	4.8	7.0	5.4	5
E1	410	23.0	7.3	18.2	7.0	39.5	11.3	8.8	3.8	8.2	5.0	6
B1	718	44.3	3.8	20.7	3.7	22.8	4.1	4.7	1.7	4.8	2.3	6
Form: Swartland												
B1	603	28.3	7.6	25.0	8.3	13.3	4.5	5.0	0.8	24.0	13.7	3
Form: Katspruit												
A1	422	30.0	6.1	31.8	6.4	28.3	5.6	5.3	3.3	3.0	0.7	5
Form: Mispah/Glenrosa												
A1	112	26.5	4.7	19.0	7.0	38.5	7.3	7.5	2.1	8.0	4.1	4
Form: Mayo												
A1	366	36.3	1.9	28.7	2.0	20.7	4.7	6.7	1.7	4.7	2.5	3

Table 13.6 Means and standard deviations of five particle classes from the clay loam to loam natural soil body for soils of the Volksrust Formation.

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: Avalon and Griffin												
A1	300	36.0	0.0	43.0	3.0	10.5	4.5	2.0	0.0	6.0	1.0	2
B1	758	35.2	4.0	40.3	5.9	14.8	5.6	1.6	0.5	7.2	4.1	6
Form: Kroonstad and Estcourt												
A1	205	33.0	4.2	36.8	13.2	15.0	8.6	2.7	0.9	4.7	4.5	4
E1	300	31.0	8.0	46.5	6.5	8.0	2.0	3.0	2.0	9.0	1.0	2

Table 13.7 Means of CBD-Iron values for soils of the Volksrust Formation. Horizon notation is given.

Hutton		Clovelly		Griffin		Avalon		Kroonstad Estcourt		Swartland	
Horizon	%	Horizon	%	Horizon	%	Horizon	%	Horizon	%	Horizon	%
A1	2.8	A1	2.4	A1	5.4	A1	3.5	A1	0.9	A1	2.3
B1	2.8	B1	3.0	B1	5.4	B1	3.1	E1	1.1	B1	2.4
B2		B2		B2		B2		B1	1.4	B2	

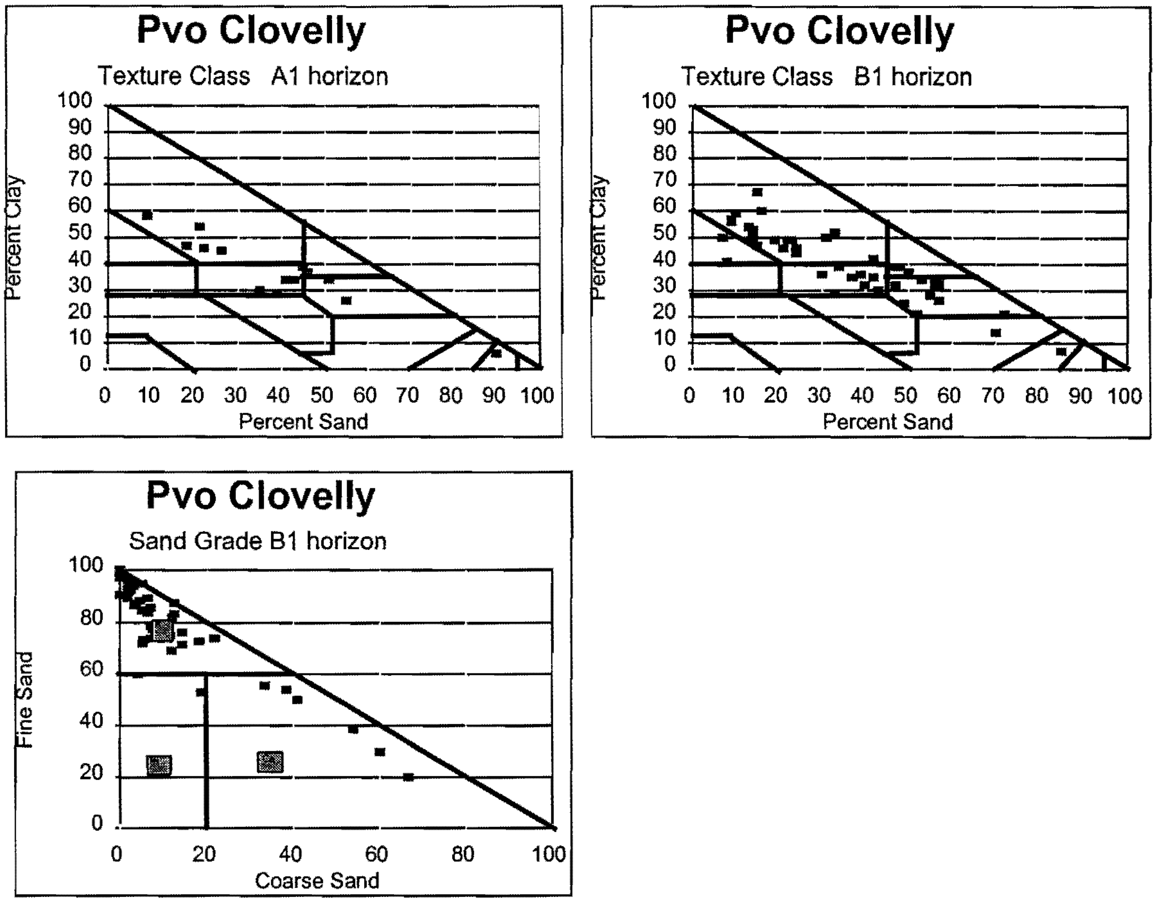


Figure 13.3 Distribution of textures, and dominant sand grades, within soils of the Clovelly Form.

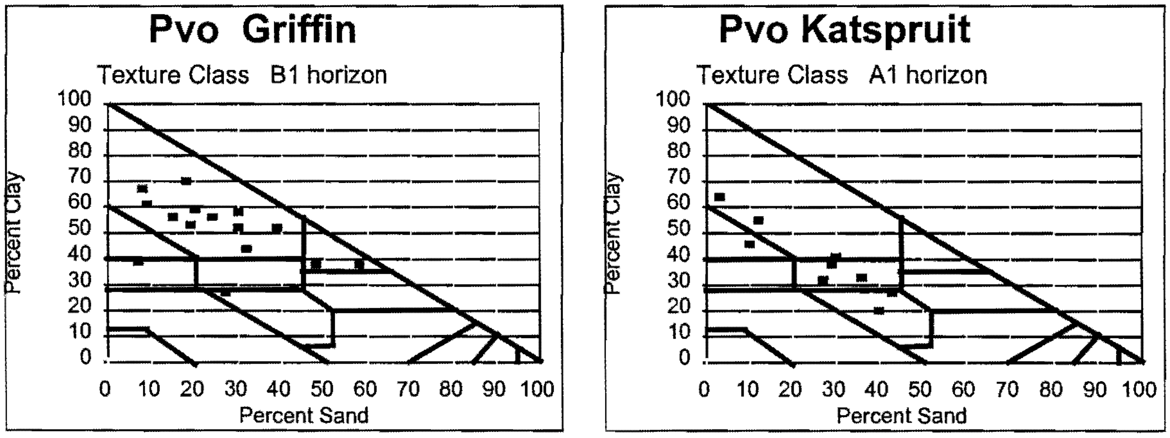


Figure 13.4 Distribution of soil textures within soils of the Griffin and Katspruit Forms.

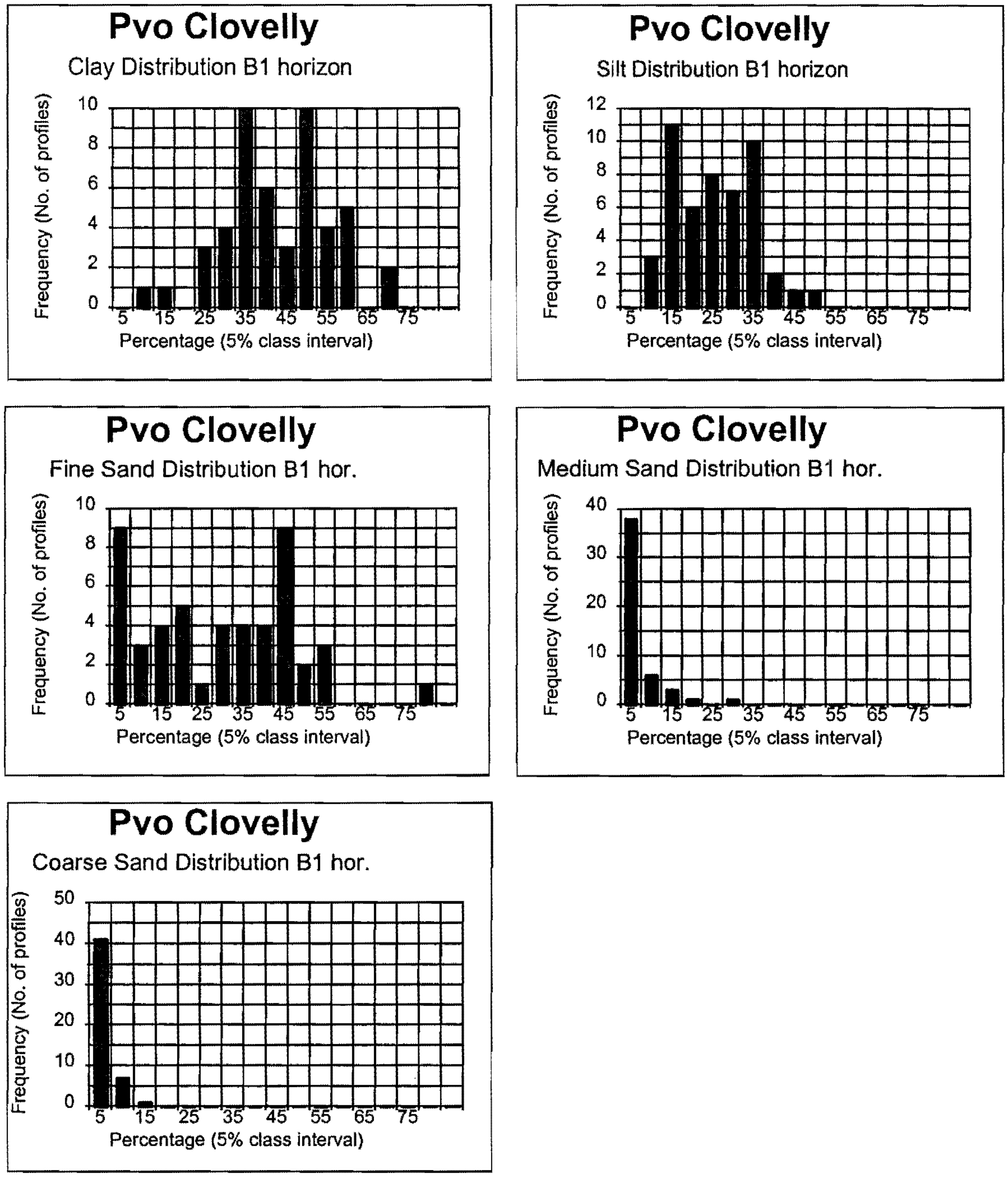


Figure 13.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Clovelly Form.

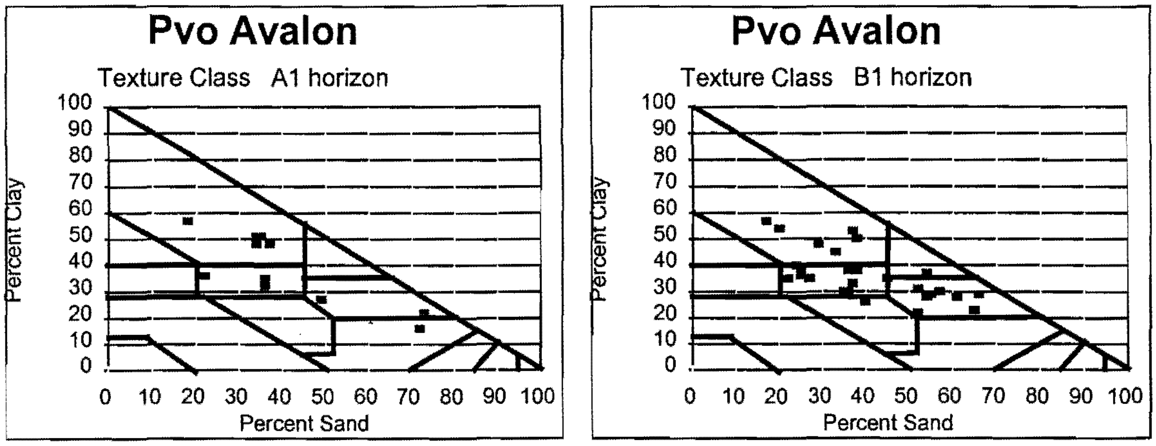


Figure 13.6 Distribution of soil textures within soils of the Avalon Form.

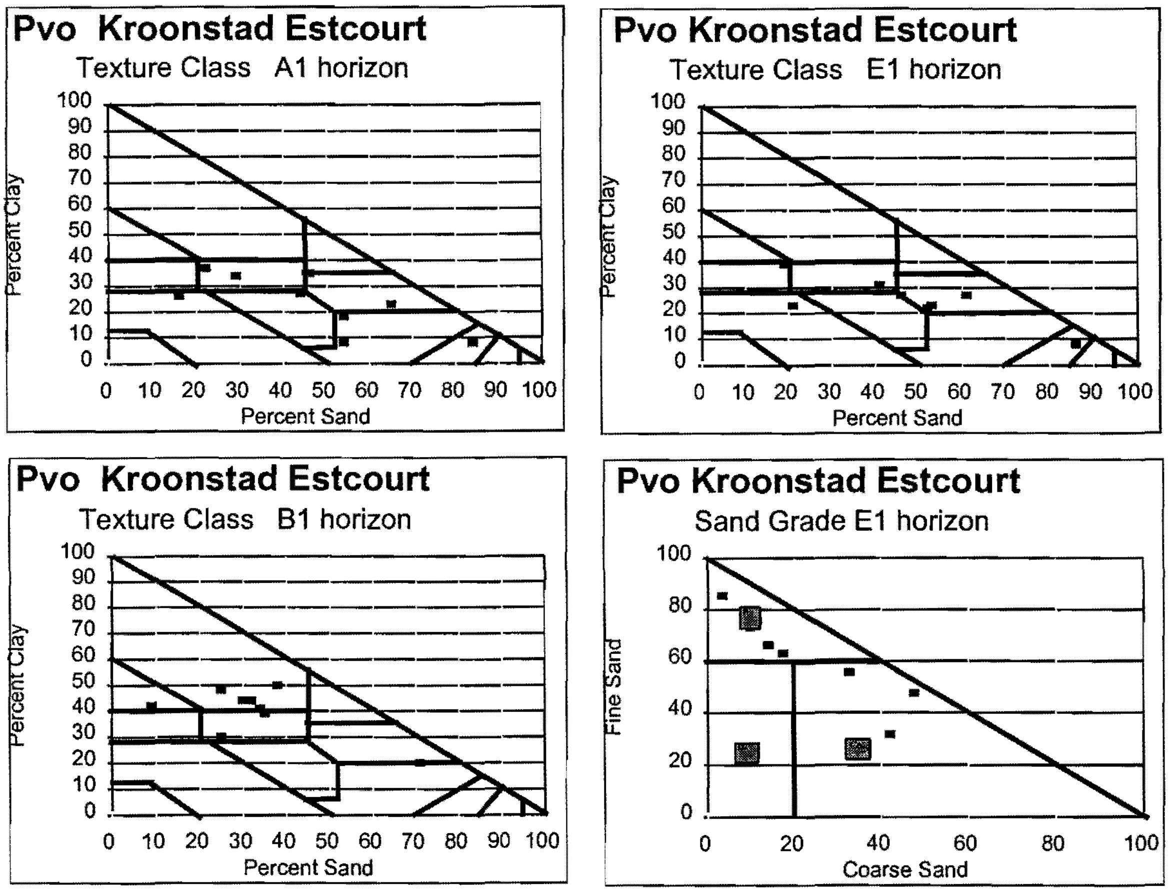


Figure 13.7 Distribution of soil textures, and dominant sand grade, within soils of the Kroonstad and Estcourt Forms.

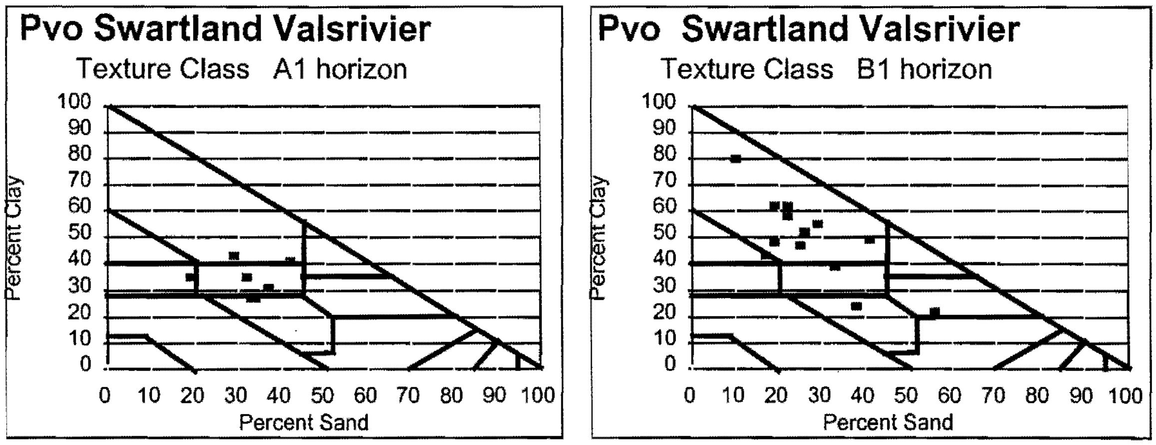


Figure 13.8 Distribution of soil textures within soils of the Swartland and Valsrivier Forms.

CHAPTER 14

SOILS OF THE SANDSTONE AND SHALE OF THE VRYHEID FORMATION, ECCA GROUP KWAZULU-NATAL AND MPUMALANGA

Location and Extent

The Vryheid Formation covers extensive areas of the Highveld Plain and the Interior Basins of KwaZulu-Natal. Within the study area it is located from Benoni on the East Rand stretching north east to the edge of the Highveld Plain at the towns of Witbank and Middelburg in the Mpumalanga Province (Geological Survey, 1984). To the north are rocks of the Transvaal Sequence and the Bushveld Igneous Complex. Further to the east exposures of the Vryheid Formation are bounded by the Archaean Granites. The southern boundary is located near the Vaal River at the contact with the Volksrust Formation. Interspersed over much of the area covered by the formation are intrusions of dolerite. One such extensive intrusion is located in the south western Highveld zone around the town of Standerton. Stretching southwards into KwaZulu-Natal the Vryheid Formation covers large areas of the KwaZulu-Natal Interior Basin. It is bounded in the west by the Volksrust Formation and in the east by the Dwyka Formation (Geological Survey 1984). Further to the east the formation is extensively exposed in the Mfolozi River Basin bounded in the west by various geological formations, including tillite of the Dwyka Formation, and in the east by basalt of the Letaba Formation. South of the Tugela River the extent of the formation is limited to a narrow strip of the KwaZulu-NatalMidland Escarpment. The formation pinches out south of the Mzimkulu River near the southern KwaZulu-Natal boundary (Figure 14.1). The formation covers some 3.964 million hectares in the study area.

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

The distinguishing features and boundaries of this formation are those of the Middle Ecca. It consists of sandstone, shale and subordinate coal beds, and has a maximum thickness of 500m (SACS, 1980). The formation is described as medium to coarse grained sandstone, grey micaceous shale, with subordinate grit and coal beds (Geological Survey, 1988a, 1988b; Geological Survey, 1992)

Physiography and Drainage Features

The physiography of the zones where the Vryheid Formation is exposed on the Highveld Plain range from slightly undulating plains (slopes 2 - 5%) to strongly undulating land (slopes 2 - 8%) (Kruger, 1980). It is in these zones that red and yellow-brown apedal and plinthic soil patterns are common. The Highveld Plain is drained by in the north by the Wilge, Olifants and Klein Olifants Rivers and their tributaries. To the south the exposures of the Vryheid formation are drained by the Vaal River and its tributaries. In the KwaZulu-Natal Interior Basin the terrain varies between undulating lowland plains with hills (slopes 2-8%) to undulating hills (slopes 5-15%). It is from these chains of hills in the District of Vryheid that the formation takes its name. Soils range from red and yellow apedal, through plinthic to duplex soil patterns (Land Type Survey Staff, 1984-1997). Here the drainage is via the Buffalo, Tugela and Mooi Rivers and their tributaries. In the Tugela River valley the slopes are steeper with the presence of low mountains (slopes 8-30%) (Kruger, 1980). Duplex and lithosolic soil patterns are present.

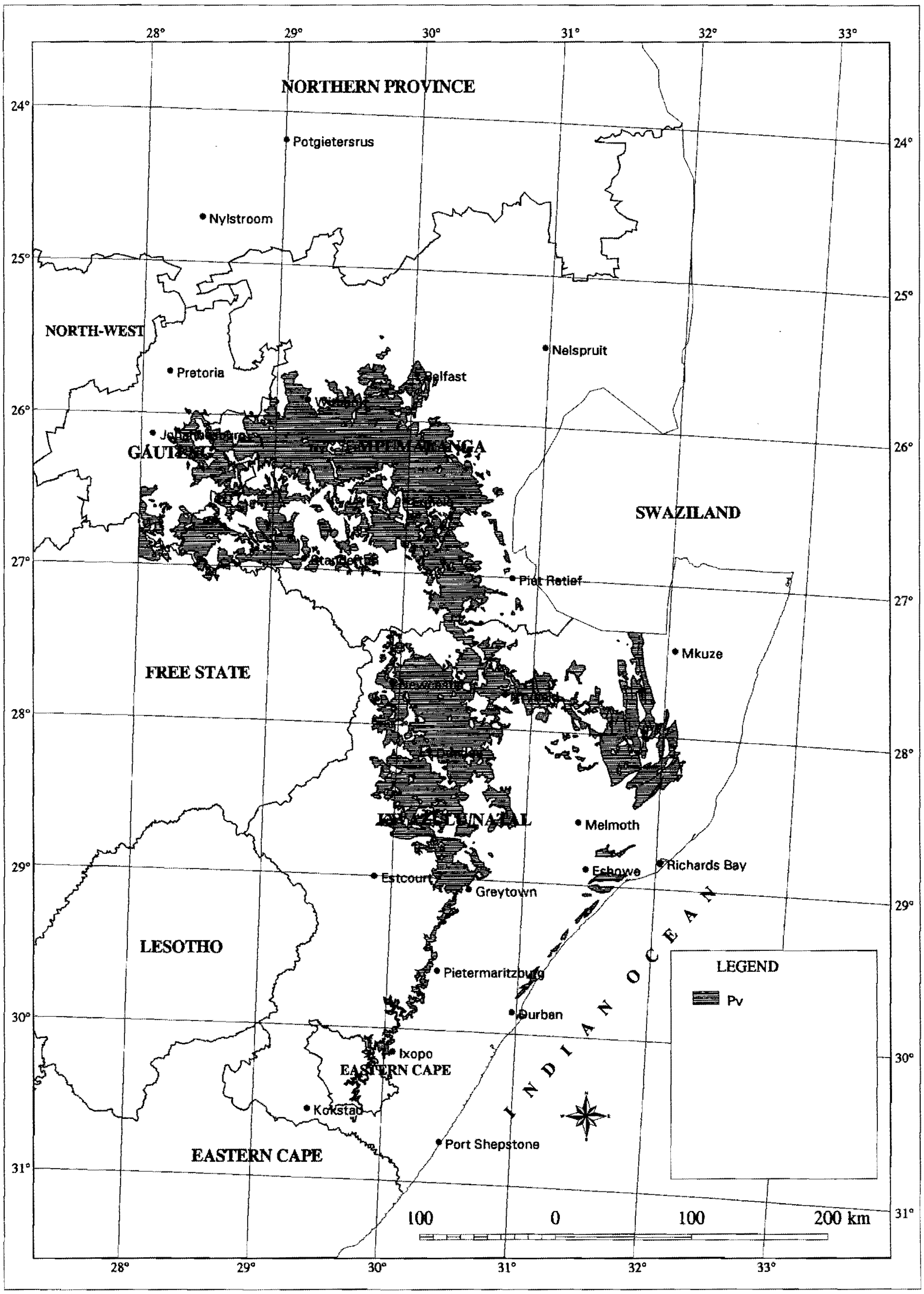


Figure 14.1. Location of the Vryheid Formation, Ecca Group in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Vegetation

On the Highveld the vegetation on the soils of the Vryheid Formation is dominated by the Moist Sandy Highveld Grasslands (Low and Rebelo, 1996). The vegetation where dolerite intrusions are common into the sandstones and shales is described as Moist Clay Highveld Grassveld. To the east the vegetation is North Eastern Mountain Grassveld. Vegetation covering much of the KwaZulu-Natal Interior Basin is described as the Natal Central Bushveld of the Savanna Biome (Low and Rebelo, 1996).

Soils

Six major soil patterns are evident on the sandstones and shales of the Vryheid Formation (Table 14.1). These include a red and yellow apedal soil pattern where dystrophic soils are dominant and a plinthic soil pattern which has together with the plinthic soils, red and yellow apedal soils of dystrophic and mesotrophic base status. There is also a plinthic pattern where plinthic soils, soils with E horizons and duplex soils dominate. In the duplex soil pattern soils of the Swartland, Valsrivier and Sterkspruit Forms are dominant. Lithosols with, and without the presence of lime make up the remaining two patterns. Here Mispah and Glenrosa soils are dominant, while respectively Cartref and Swartland soils are sub-dominant (Table 14.1).

The red and yellow apedal freely drained soil patterns on sandstones and shales of the Vryheid Formation occur on the moist eastern regions of the Highveld Plain and the highlands of north eastern KwaZulu-Natal. Located at the foot of the Skurweberg and at Nkambula are undulating (slopes 5 - 8%) to rolling (slopes 8 - 15%) areas of dystrophic red and yellow apedal soils. The soils of the Vryheid Formation characteristically have a sandy to sandy clay loam texture. Occasionally soils of a clay texture have been sampled and are associated with the shales present within the formation. The dystrophic and mesotrophic Clovelly, Griffin soils, and the sandy loam Hutton (Hu16) soils (Table 14.1) are derived from sedimentary rocks of the Vryheid Formation. The clay Hutton soils (Hu17, Hu18, Hu27, Hu28 of Table 14.1) are likely derived from the numerous dolerite intrusions into the Vryheid Formation. Glenrosa, Mispah and Katspruit soils are also present in smaller proportions.

The plinthic soil pattern covers extensive areas of the Highveld Plain and Interior Basins of KwaZulu-Natal (Table 14.1). With the gently undulating (slopes 2 - 5%) to undulating (slopes 5 - 8%) and favourable climate they form important areas for crop production. There are characteristic zones of dystrophic and of mesotrophic soils. Eutrophic soils are also present together with mesotrophic soils where there is decreasing effective rainfall. As the rainfall decreases further Longlands and Wasbank soils become dominant to the exclusion of the freely drained apedal soils.

Plinthic soils with E horizons and duplex soils occur regularly together in the same landscape. On the sandstones and shales of the Vryheid Formation a variety of soils may occur (Table 14.1). Plinthic soils and those with an E horizon (Longlands, Wasbank, Westleigh and Cartref) are common. A range of duplex soils are commonly present, while Avalon, Glencoe, Clovelly and Hutton soils may be present to varying proportions (Table 14.1). Each of these soils have a characteristic range of textures. The soils are present on younger land surfaces and within zones where there is diminishing effective rainfall (Table 14.1).

Table 14.1 Dominant soils and selected climatic information for soil patterns occurring on sandstone and shale of the Vryheid Formation, Ecca Group. Subdominant occurrences of soils derived from other geology formations, notably Jurassic dolerite are included.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow Apedal Freely Drained Soils										
Clovelly	Cv16 Cv14	10	Mispah	Ms10	7	Ave	964	1492	2401	0.65
	Cv17	7	Glenrosa	Gs16	5	Std	166	378	437	0.17
Griffin	Gf12	8				Max	1514	3210	3683	-
Hutton	Hu16	11				Min	620	1038	1327	-
	Hu17 Hu18	21								
	Hu27 Hu28									
Total Area: 355 190 Ha			Means of 53 Land Types							
Broad Soil Pattern: Plinthic Soils										
Avalon	Av16 Av14	12	Mispah	Ms10	9	Ave	740	1759	2192	0.42
	Av26 Av24	6				Std	79	260	479	0.09
	Av36 Av34	1				Max	882	2186	3020	0.68
Glencoe	Gc16 Gc14 Gc26	8				Min	580	1306	1350	0.29
Hutton	Hu16 Hu26	17								
	Hu27	4								
Clovelly	Cv16 Cv14 Cv26	6								
Longlands	Lo21 Lo20	6								
Wasbank	Wa21 Wa20	3								
Westleigh	We22 We13	3								
Total Area: 2 161 260 Ha			Mean of 53 Land Types							
Broad Soil Pattern: Plinthic (with E horizons) and Duplex Soils										
Longlands	Lo21 Lo20	10	Avalon	Av36 Av26	8	Ave	735	1673	2683	0.44
Wasbank	Wa21	3	Glencoe	Gc26	3	Std	63	217	303	0.08
Westleigh	We13 We22	2				Max	909	2186	3002	0.58
Cartref	Cf20 Cf21	5	Hutton	Hu36 Hu26	6	Min	620	1385	2063	0.29
			Clovelly	Cv26	6					
Kroonstad	Kd14 Kd13 Kd21	6								
Estcourt	Es34	6	Mispah	Ms10	5					
Valsrivier	Va31 Va41	7	Glenrosa	Gs14 Gs16	5					
Swartland	Sw31	4								
Sterkspruit	Ss24	3								
Total Area: 389 560 Ha			Means of 25 Land Types							
Broad Soil Pattern: Duplex Soils										
Swartland	Sw30 Sw31 Sw41	17	Mispah	Ms10	4	Ave	755	1730	3242	0.44
Valsrivier	Va40 Va41 Va42	13	Glenrosa	Gs16 Gs17	4	Std	131	136	659	0.08
Sterkspruit	Ss24 Ss26 Ss21	14				Max	900	1924	4255	0.63
Estcourt	Es34 Es36	9	Bonheim	Bo41	3	Min	580	1346	1772	0.34
Kroonstad	Kd14	4	Mayo	My21	3					
Total Area: 201 350 Ha			Means of 27 Land Types							

Table 14.1 continued. Dominant soils and selected climatic information for soil patterns occurring on sandstone and shale of the Vryheid Formation, Ecca Group. Subdominant occurrences of soils derived from other geology formations, notably Jurassic dolerite are included.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Lithosols (Without the presence of lime)										
Glenrosa Mispah Rockland	Gs16 Gs17 Gs14 Ms10 Rock	22 18 20	Cartref	Cf21	4	Ave Std Max Min	858 179 1495 638	1504 204 2274 1194	2599 719 4822	0.57 0.17 - 0.29
Total Area: 278 160 Ha			Means of 48 Land Types							
Broad Soil Pattern: Lithosols (With the presence of lime)										
Glenrosa Mispah Rockland	Gs16 Gs17 Gs26 Ms10 Ms20 Rock	25 17 10	Swartland	Swf31 Sw41	7	Ave Std Max Min	692 93 991 557	1708 201 2274 1394	3296 661 4822 1889	0.41 0.09 0.59 0.26
Total Area: 579 470 Ha			Means of 60 Land Types							

In the duplex pattern Swartland, Valsrivier, Sterkspruit, Estcourt, and Kroonstad soils with characteristic sandy topsoil textures are present (Land Type Survey Staff, 1985 -1997). Mispah and Glenrosa are also present (Table 14.1). The Bonheim soils, commonly in bottomland and eroded positions is associated with dolerite.

In the more youthful landscapes, where either the slopes are greater or effective rainfall is less, lithosols are dominant. Time for soil formation must be assumed to be shorter. In those zones where effective rainfall is higher Cartref soils are dominant (Table 14.1). Higher rainfalls result in the formation of soils with an E horizon. Where rainfall is lower calcareous and non-calcareous Swartland soils dominate (Table 14.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Clovelly, Avalon, Longlands, Cartref, Estcourt, Swartland, Sterkspruit, Mispah and Katspruit were extracted form the database. It is apparent that the soils derived from the sandstone of the Vryheid Formation have a characteristic loamy sand to sandy clay loam texture. Silt contents are low and have fairly constant values. On plotting the range of textures in histograms and in textural triangle graphs there is a strong dominance in these textural classes. However, there is also a smaller group of soils with sandy clay to clay textures that could be clearly distinguished from the more sandy group. These soils are likely to be derived from the shales of the Vryheid Formation. The ranges in textural properties are reported separately (Table

Table 14.2 Textural properties of soils from the loamy sand to sandy loam natural soil body of the Vryheid Formation, Ecca Group derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1	me-fiSa-SaCl	5-42	1-19	16-56	6-35	3-41		L3,NL2
	B1	me-fiSa-SaCl	3-49	1-30	18-63	3-38	1-41	fi,me,co	NL4,EL1
	B2	meSa-SaCl	4-42	2-15	17-42	9-29	4-40	fi,me	-
Griffin	A1	SaLm-SaCl	13-41	4-22	23-48	12-37	2-14	fi,me	NL4,EL1
	B1	SaLm-SaCl	4-44	2-22	12-75	6-38	3-43	fi,me	NL4,EL1
	B2	SaClLm-SaCl	26-44	1-20	21-36	5-24	3-16	fi,me,co	-
Clovelly	A1	me-fiSa-SaCl	5-39	2-53	4-59	1-39	1-20	fi,me,co	NL3,L2,E1
	B1	me-fiSa-SaCl	4-44	1-23	1-63	5-40	2-39	fi,me	NL4,L1
	B2	me-fiSa-SaClLm	4-44	1-36	1-63	1-40	2-39	fi,me	-
Avalon	A1	LmSa-SaClLm	2-30	1-27	5-64	7-44	2-47	fi,me,co	L3,NL1,EL1
	B1	LmSa-SaCl	1-41	1-34	8-65	1-45	1-39	fi,me,co	NL2,L2,EL1
	B2	SaLm-SaCl	13-39	1-30	6-61	6-31	2-40	fi,me,co	-
Longlands	A1	me-fiSa-SaClLm	5-23	2-25	26-57	6-48	2-30	fi,me,co	EL3,L2
	E1	me-fiSa-SaClLm	2-34	1-25	14-60	5-44	1-45	fi,me,co	L4,NL1
	B1	SaClLm-SaCl	24-42	14-44	11-32	1-12	4-30	fi,me,co	-
Cartref	A1	me-fiSa-SaClLm	6-21	2-3	54-58	14-36	2-3	fi,me	-
	E1	me-fiSa-SaClLm	2-28	2-9	27-58	11-43	2-26	fi,me,co	-
Estcourt	A1	me-fiSa-SaLm	4-35	1-32	10-62	3-39	2-40	fi,me,co	EL3,NL2
	E1	me-fiSa-SaClLm	3-34	2-37	9-67	3-50	1-44	fi,me,co	L5
	B1	LmSa-SaCl	5-46	1-20	15-51	8-33	2-46	fi,me,co	-
Swartland	A1	me-fiLmSa-SaCl	11-43	3-30	5-61	3-35	3-24	fi,me,co	L4,NL1
	B1	SaLm-SaCl	16-42	3-21	9-54	7-30	1-30	fi,me,co	L3,NL2
	B2	SaClLm-SaCl	27-58	3-18	12-70	10-30	4-21	fi,me,co	-
Sterkspruit	A1	me-fiSa-SaClLm	6-29	2-18	20-67	4-41	2-20	fi,me,co	L5
	B1	SaClLm-SaCl	24-39	4-18	20-45	3-25	1-17	fi,me	-
	B2	SaClLm	33	8	20	19	19	fi,me	-
Mispah	A1	me-fiSa-SaCl	10-41	2-37	10-61	4-29	2-30	fi,me,co	-
Katspruit	A1	me-fiSa-SaCl	10-32	14-31	15-42	4-8	2-6	fi,me	-

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).

14.2 and Table 14.3) for these two groups of soils. The ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented in Tables 14.2 and 14.3.

Table 14.3 Textural properties of soils from the clay natural soil body of the Vryheid Formation, Ecca Group derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades
Griffin	A1	Cl-SiCl	47-56	5-32	5-33	1-5	5-5	fi,me
	B1	Cl	58-67	14-25	3-13	1-1	1-11	fi,me
	B2	Cl	54-54	28-28	6-6	1-1	11-11	fi,me
Clovelly	A1	Cl-SiCl	46-69	16-32	7-20	1-4	1-7	fi,me
	B1	Cl-SiCl	50-65	8-45	3-20	1-10	1-7	fi,me
Avalon	A1	Cl	46-48	19-20	21-25	2-3	3-3	fi,me
	B1	Cl	45-53	11-21	23-29	2-6	1-4	fi,me
	B2	Cl	46-51	6-16	27-36	3-13	2-4	fi,me
Estcourt	B1	Cl	52-65	1-25	11-23	1-15	2-16	fi,me
Swartland	A1	Cl	48-56	10-10	25-26	3-12	2-3	fi,me
	B1	Cl	46-60	6-26	10-30	1-10	2-5	fi,me

These ranges are presented graphically in Figure 14.2 and 14.3. The figures allow for overview comparisons between different soil forms and over particle size classes. Figure 14.2 shows the range in clay contents for the red and yellow-brown apedal soils (Hutton, Griffin, Clovelly and Avalon) from 2% to about 45% clay. Silt values are low, commonly less than 20% and seldom exceed 30% (Table 14.2). Fine, medium and coarse sand grades are present in varying proportions. There are similarities between the soils with E horizons (Longlands, Cartref, Estcourt Forms) and those of the red and yellow-brown apedal soils, although clay contents are slightly lower in the A1 and E1 horizons (Table 14.2). The duplex soils (Swartland and Sterkspruit Forms) have properties between these two soil groups.

The textural properties of the soils of the Vryheid Formation (formerly known as Middle Ecca) show some similarities to those of the tillites of the Dwyka Formation and sandstone of the Natal Group. With erosion and faulting these geological formations are often located near to the Vryheid Formation. However, soils derived from the Vryheid Formation show striking textural differences to the soils derived from the Pietermaritzburg and Volksrust Formations (formerly known as Lower and Upper Ecca respectively) and to the soils derived from dolerite.

Figure 14.3 shows the clay nature of the group of soils assumed to be derived from shale within the Vryheid Formation. Silt values are somewhat higher(Tables 14.3 and 14.5) than the sandy group (Tables 14.2 and 14.4), but generally lower than those soils derived from the Volksrust Formation (Chapter 13) where mean silt values of between 20 and 30% were commonly measured. Fine sand is the dominant sand grade with low values for medium and coarse sand respectively (Table 14.3).

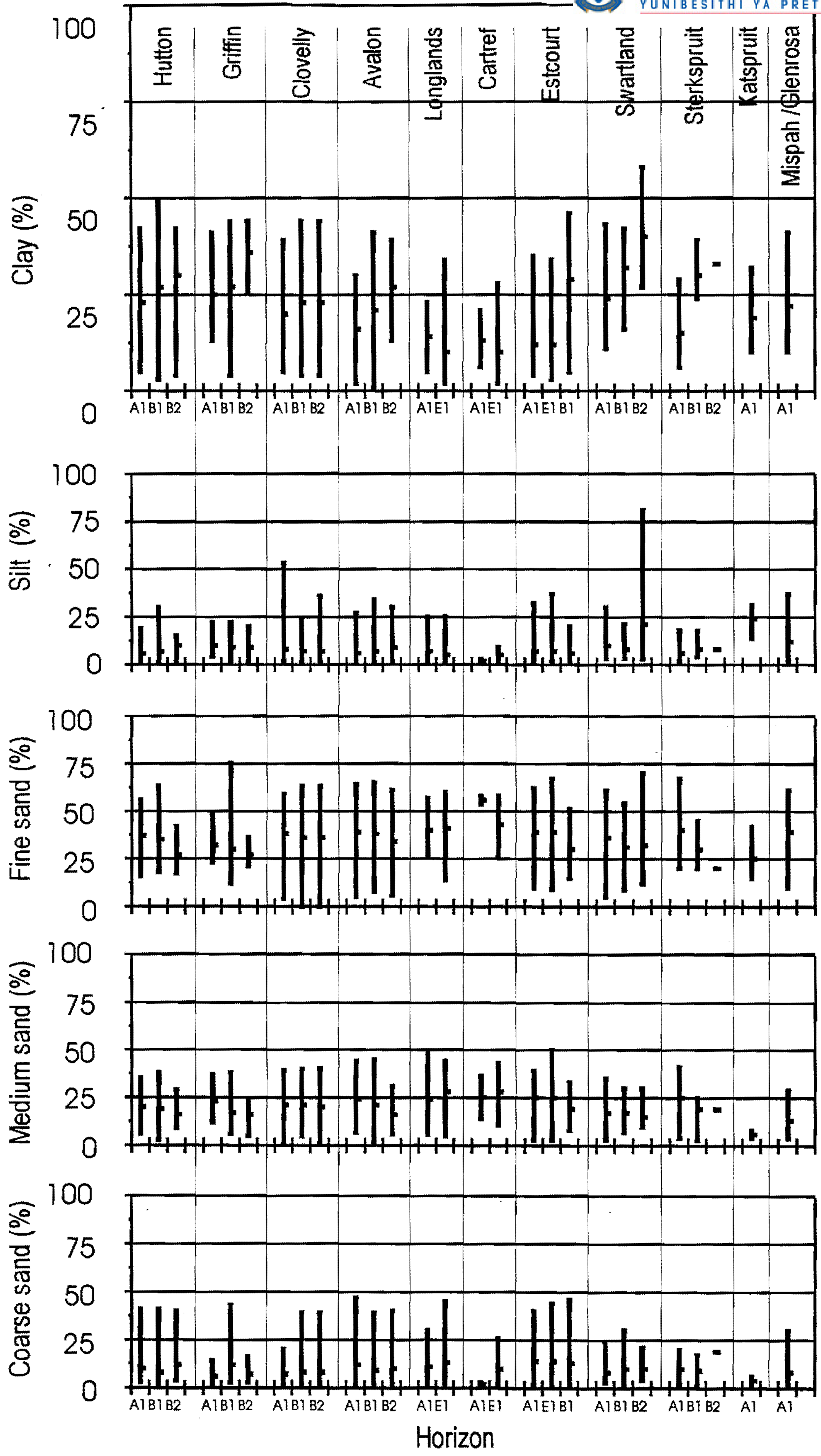


Figure 14.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Vryheid Formation with a sand to sandy loam texture. Maximum, minimum and mean values are shown for each horizon.

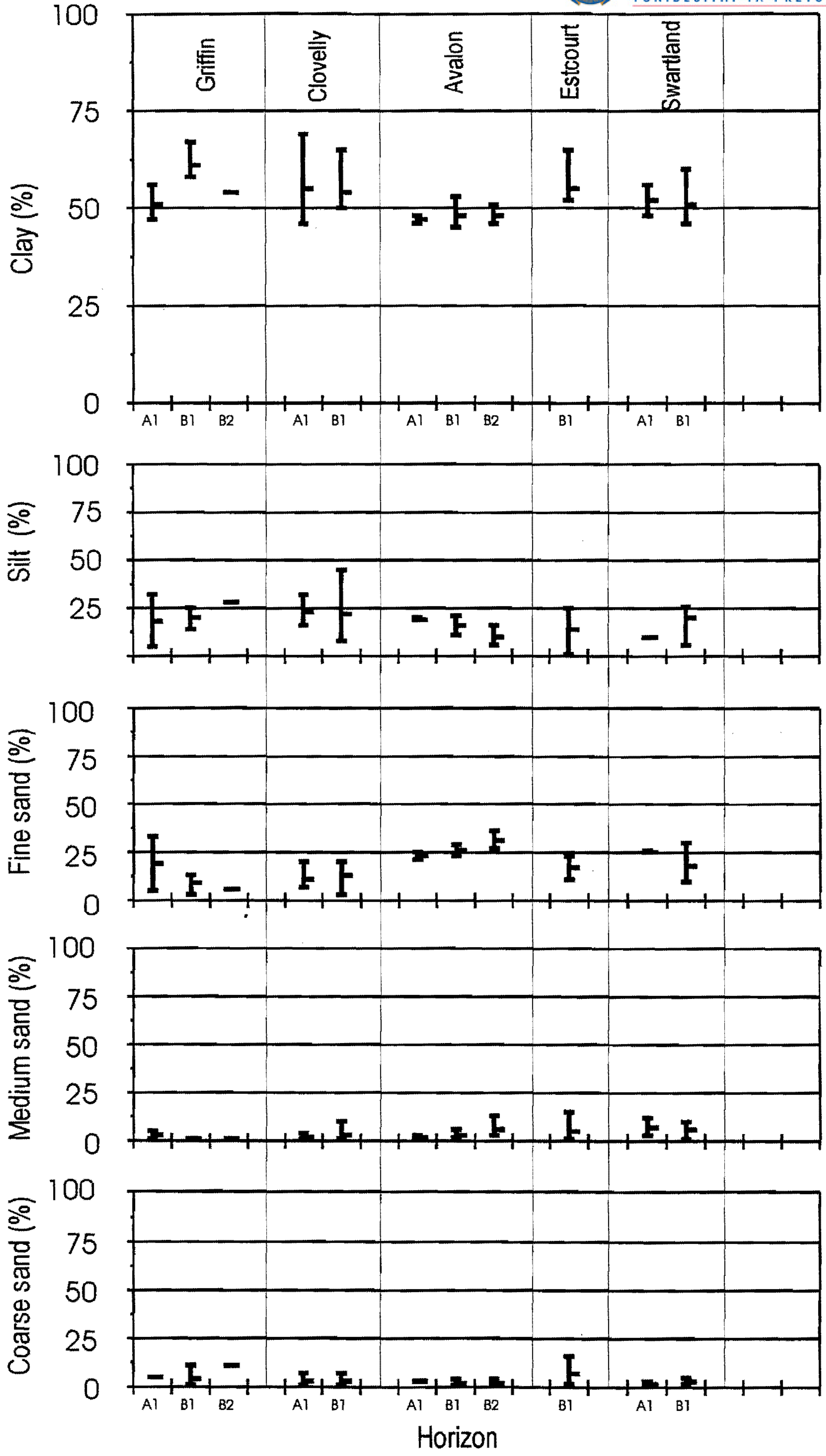


Figure 14.3 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of Vryheid Formation with a sandy clay to clay texture. Maximum, minimum and mean values are shown for each horizon.

Table 14.4 Means and standard deviations of five textural classes for soils of the Vryheid Formation from the sand to sandy clay loam natural soil body.

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	304	23.1	8.9	6.8	4.7	37.9	10.0	20.3	7.3	10.3	7.5	35
B1	757	27.1	10.0	7.4	5.4	35.2	8.4	19.2	6.7	8.7	6.3	80
B2	1333	30.8	12.7	10.0	5.4	27.8	8.3	16.5	6.2	12.7	12.4	6
Form: Griffin												
A1	360	25.1	8.0	10.7	5.8	32.0	7.2	23.0	8.7	6.7	4.0	10
B1	719	27.9	11.3	14.9	2.4	30.5	12.9	17.8	8.6	12.5	11.3	19
B2	1114	36.8	6.1	17.3	2.5	27.8	4.8	16.3	6.4	7.4	4.1	9
Form: Clovelly												
A1	334	20.1	8.2	8.8	9.3	38.1	12.4	21.7	8.5	7.3	4.5	32
B1	761	23.7	8.9	7.3	4.2	36.8	10.1	21.2	7.6	8.8	6.3	82
B2	763	23.8	8.9	7.7	5.2	36.6	10.2	20.9	7.9	8.8	6.3	83
Form: Avalon												
A1	314	16.0	6.2	6.0	4.1	39.4	11.3	24.6	8.0	12.0	8.6	60
B1	746	21.5	9.4	7.5	5.9	38.9	10.2	21.4	8.7	9.2	5.9	148
B2	1014	27.1	7.4	9.5	6.4	34.6	10.0	16.9	7.1	10.7	7.8	32
Form: Longlands												
A1	314	14.7	4.8	7.4	5.5	40.6	8.3	24.5	9.8	11.7	6.4	21
E1	675	10.1	6.8	5.1	4.8	41.5	11.1	28.8	9.1	13.6	10.3	32
B1	732	30.9	7.0	29.2	9.2	21.6	8.2	3.8	3.3	13.3	8.3	9
Form: Cartref												
A1	300	13.5	7.5	2.5	0.5	56.0	2.0	25.0	11.0	2.5	0.5	2
E1	650	10.7	8.3	5.0	2.2	43.0	10.8	28.9	10.0	10.7	8.2	10

Table 14.4 continued. Means and standard deviations of five textural classes for soils of the Vryheid Formation from the sand to sandy clay loam natural soil body.

Horizon	Depth mm	Clay %		Silt %		Fine Sand %		Medium Sand %		Coarse Sand %		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Form: Estcourt												
A1	264	12.3	6.8	7.4	7.9	39.0	11.1	25.2	9.5	14.6	8.9	23
E1	589	12.9	9.2	7.4	6.5	39.8	14.2	25.5	10.4	14.2	10.1	36
B1	850	29.9	12.5	6.6	4.6	30.4	10.1	19.2	7.3	13.9	10.8	23
Form: Swartland												
A1	302	24.5	9.2	10.9	8.5	36.5	12.8	17.7	8.3	8.8	5.7	24
B1	641	23.8	2.7	32.1	7.8	31.1	11.1	17.1	6.5	10.8	7.1	18
B2	993	28.9	2.7	40.5	10.9	32.8	20.1	15.2	7.2	10.8	6.0	6
Form: Sterkspruit												
A1	249	15.9	8.1	6.3	4.4	40.3	10.6	25.4	10.6	10.1	5.7	12
B1	687	30.9	5.1	8.8	4.7	30.7	6.5	19.3	6.2	9.1	4.2	9
B2	700	33.0	0.0	8.0	0.0	20.0	0.0	19.0	0.0	19.0	0.0	1
Form: Katspruit												
A1	313	19.7	9.2	24.7	7.6	25.7	11.7	6.0	1.6	4.0	1.6	3
Form: Glenrosa												
A1	264	22.3	7.9	12.2	8.6	39.7	13.5	13.7	7.9	8.3	7.4	20

Table 14.5 Means and standard deviations of five textural classes for soils of the Vryheid Formation from the sand clay to clay natural soil body.

Horizon	Depth mm	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
		%		%		%		%		%		
Form: Griffin												
A1	225	51.5	4.5	18.5	13.5	19.0	14.0	3.0	2.0	5.0	0.0	2
B1	633	61.3	4.0	20.3	4.6	9.3	4.5	1.0	0.0	4.3	4.7	3
B2	1500	54.0	0.0	28.0	0.0	6.0	0.0	1.0	0.0	11.0	0.0	1
Form: Clovelly												
A1	312	55.3	8.6	23.8	6.9	11.8	5.1	2.8	1.3	3.5	2.2	4
B1	733	54.7	4.3	22.9	11.1	13.0	5.8	3.7	3.3	3.2	2.0	9
Form: Avalon												
A1	225	47.0	1.0	19.5	0.5	23.0	2.0	2.5	0.5	3.0	0.0	2
B1	791	48.2	2.6	16.5	3.3	26.6	2.6	3.2	1.5	2.4	1.0	6
B2	1100	25.1	0.9	48.7	2.0	31.3	3.7	6.3	4.7	2.7	0.9	3
Form: Estcourt												
B1	766	55.8	4.7	14.0	8.4	17.8	4.1	5.3	5.1	7.0	5.1	6
Form: Swartland												
A1	445	52.0	4.0	10.0	0.0	25.5	0.5	7.5	4.5	2.5	0.5	2
B1	655	51.0	4.4	20.3	7.2	18.8	6.9	6.0	3.1	3.5	1.0	6

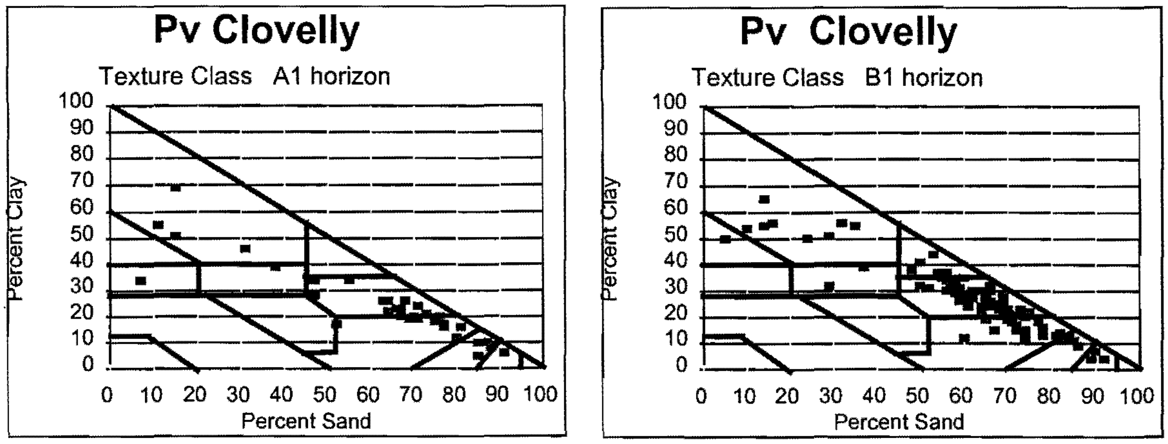


Figure 14.4 Distribution of soil texture within soils of the Clovelly Form.

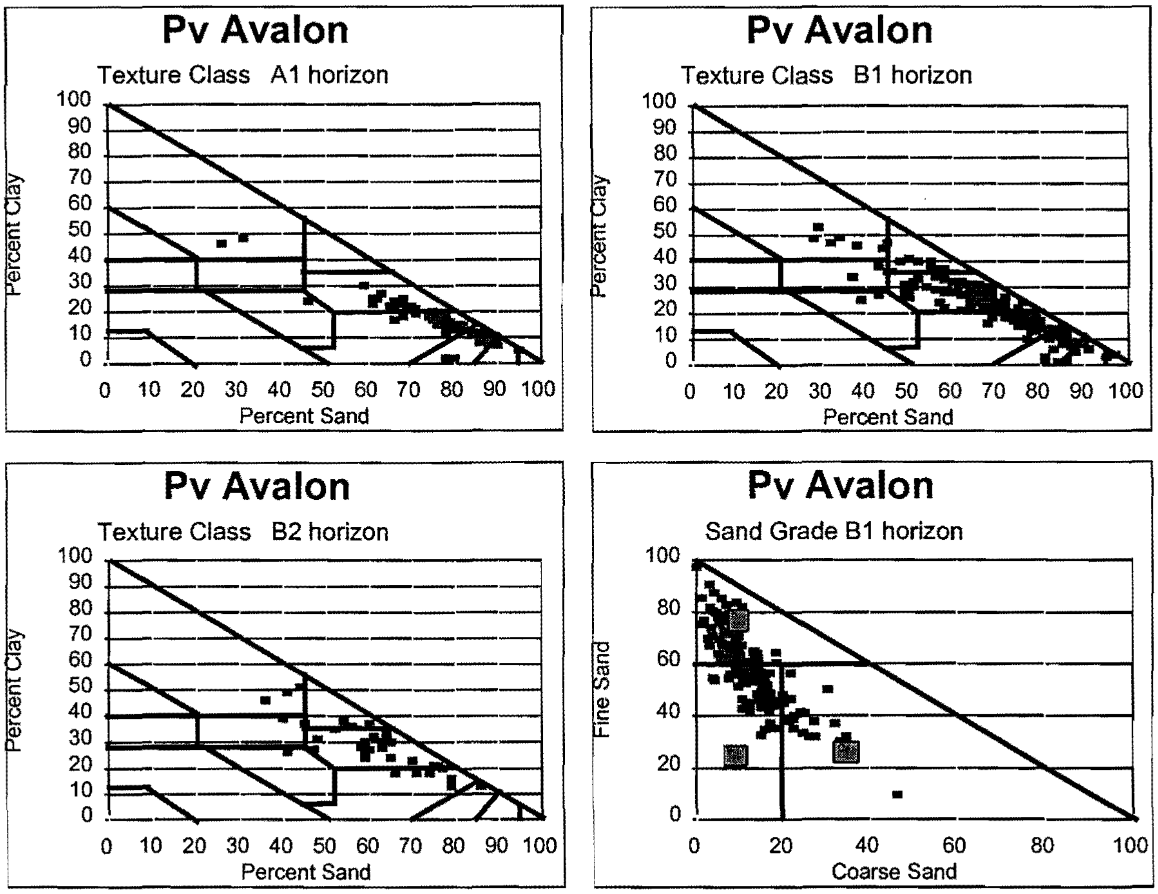


Figure 14.5 Distribution of soil texture, and dominant sand grade, within soils of the Avalon Form.

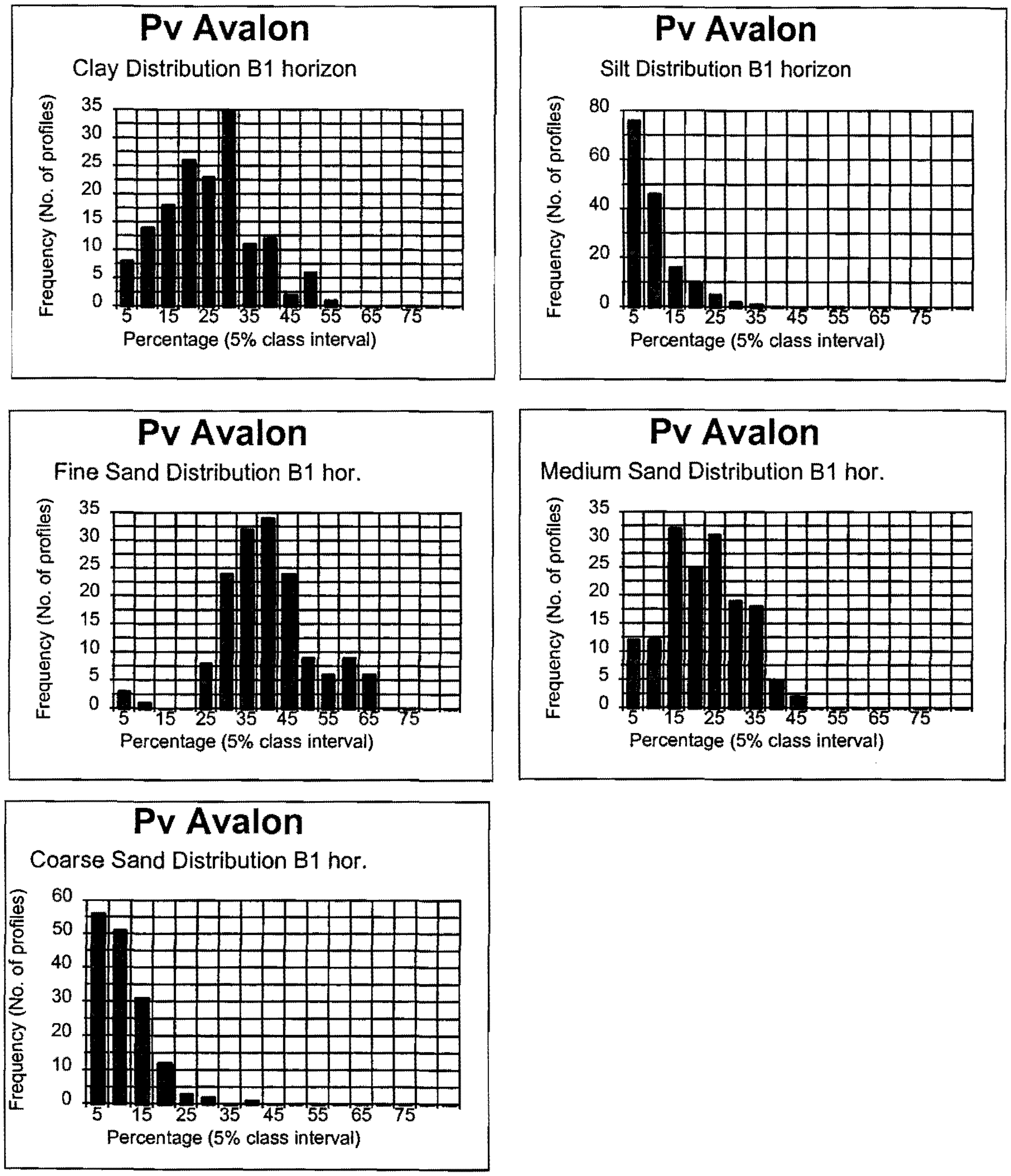


Figure 14.6 Distribution of clay and silt, fine sand, medium sand and coarse sand within soils of the Avalon Form.

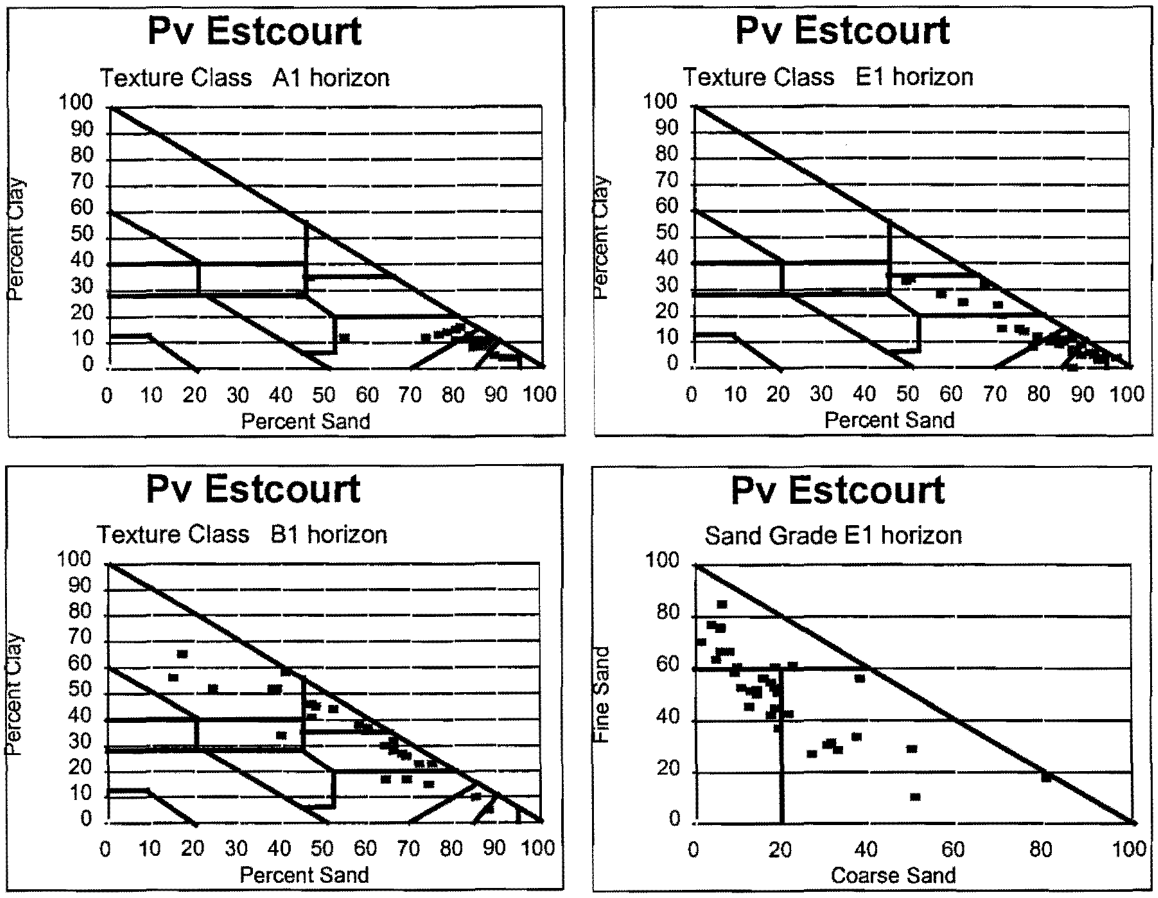


Figure 14.7 Distribution of soil textures, and dominant sand grade, within soils of the Estcourt Form.

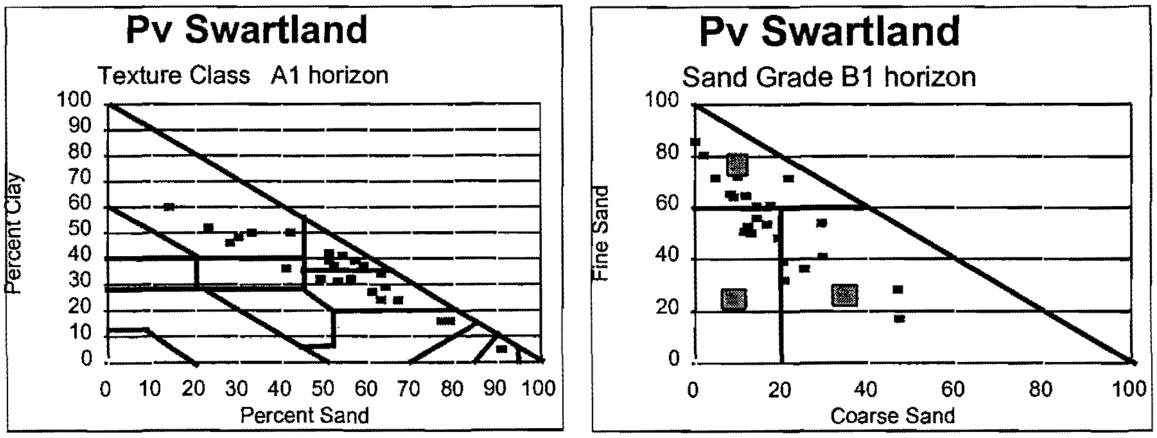


Figure 14.8 Distribution of soil textures, and dominant sand grade within soils of the Swartland Form.

CHAPTER 15

SOILS OF THE SHALE OF THE PIETERMARITZBURG FORMATION, ECCA GROUP IN KWAZULU-NATAL

Location and Extent

The Pietermaritzburg Formation covers parts of northern and central KwaZulu-Natal. It is exposed south of Vryheid and in the Mfolozi and Mkuze valleys (Geological Survey, 1984)(Figure 15.1). South of the Tugela River the Pietermaritzburg Formation is located in two north-south stretching belts (Figure 15.1). For convenience of description these belts may be considered as lying on either side of the reported axis of the Natal monocline (King, 1940). The western boundary of this interior belt is determined by Ecca Group rocks of the Vryheid Formation. To the east lies the tillite of the Dwyka Formation. The boundaries of the Pietermaritzburg Formation are commonly determined by the numerous faults present within the monoclinal structure of the coastal hinterland (Geological Survey, 1988b, 1988c, 1988d). The eastern belt lies within the coastal belt at altitudes of between 50 and 300 metres. With the extensive faulting in the coast belt, the shales of the Pietermaritzburg Formation are bounded by the sandstones of the Vryheid Formation and the Natal Group, sands of the Berea Formation, and tillite of the Dwyka Formation. These changes in geology have important local influences of the soils, their classification and properties. The tillite occupies an area of approximately 908 650 hectares.

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

In the north eastern area of the Karoo basin the soft blue Pietermaritzburg shales have long been recognised (SACS, 1980). They have also been known as the Lower Ecca Beds. However, the name Pietermaritzburg Formation has been assigned by the South African Committee for Stratigraphy (SACS, 1980). The unit consists almost entirely of shale and attains a maximum thickness of over 400m. The upper boundary is gradational and is probably best defined as a horizon above which the sand: shale ratio is greater than 0.5 (SACS, 1980). The name ceases to apply beyond the point in southern KwaZulu-Natal where the overlying Vryheid Formation pinches out (SACS, 1980). Here it is no longer distinguishable from the Volksrust Shale. This occurs in the areas of southern KwaZulu-Natal, (south of 30° 30') where the name Ecca Shale Formation is preferred.

The formation is described as dark grey shale, carbonaceous shale, siltstone and subordinate sandstone (Geological Survey, 1981; Geological Survey, 1988a, 1988b, 1988c, 1988d;).

Physiography and Drainage Features

In the KwaZulu-Natal northern interior basin exposures together with other Ecca Group rocks give rise to undulating lowlands and hills (Kruger, 1983). Exposures of the Pietermaritzburg Formation in the Mkuze, Mfolozi and Tugela River Valleys commonly occur on steep valley sides. However, south of the Tugela River are open undulating hills and valleys with many slopes being less than 5 percent. South of Pietermaritzburg undulating hills of moderate relief are again present, while in the Mzimkulu River Valley low mountains are present (Kruger, 1983). The

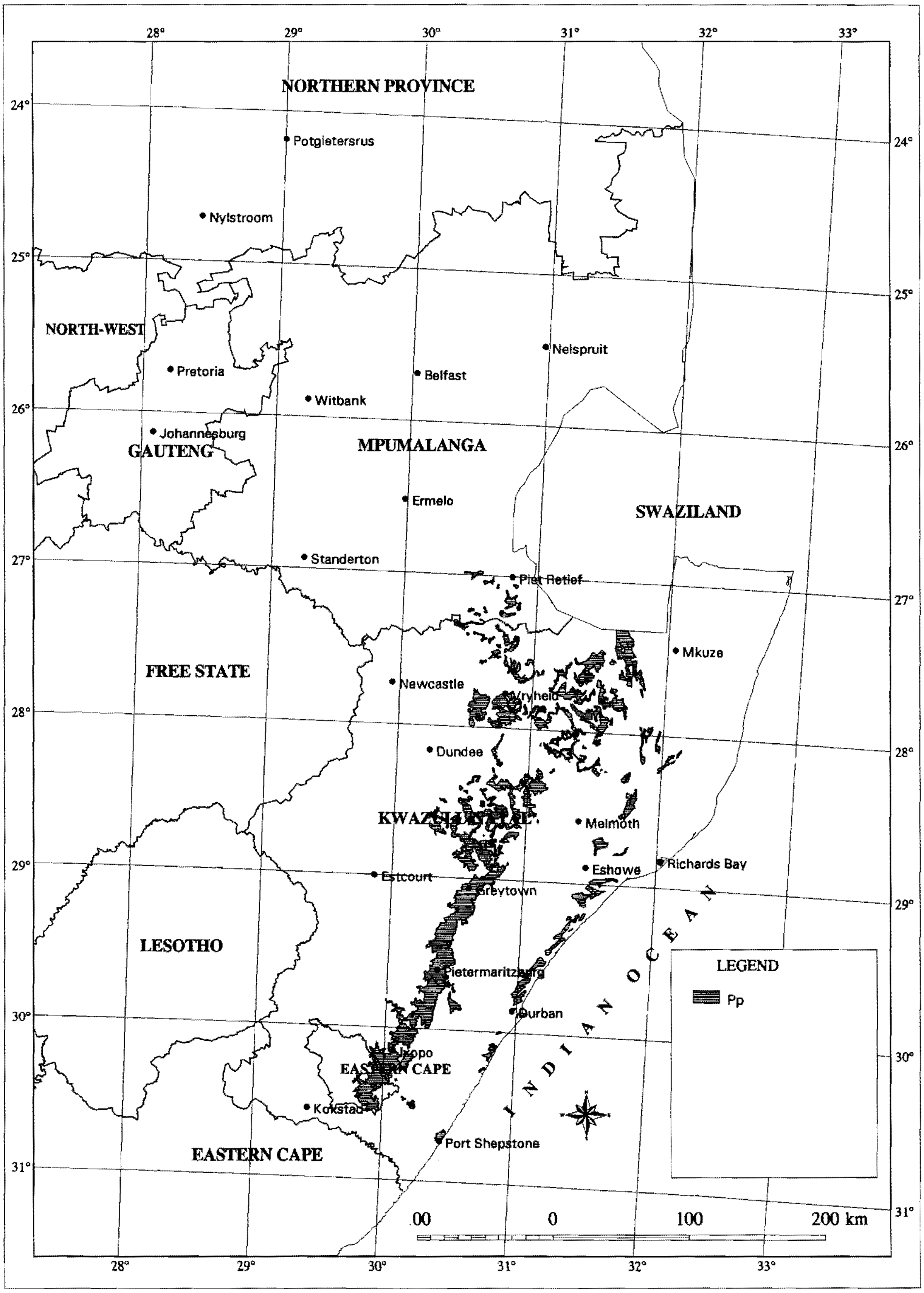


Figure 15.1. Location of the Pietermaritzburg Formation, Ecca Group in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

exposures of the Pietermaritzburg Formation along the entire coastal belt occur in highly dissected landscapes with limited flatter slopes.

Vegetation

In the northern KwaZulu-Natal Interior Basin the vegetation is dominated by Natal Central Bushveld with Natal Lowveld Bushveld in east of these interior basins (Low and Rebelo, 1996). The Tugela Valley has Valley Thicket, while Short Mistbelt Grassland covers the southern zones.

Soils

Eight major soil patterns are evident on the shales of the Pietermaritzburg Formation (Table 15.1). In three of these soil patterns red soils are dominant. In a further two soil patterns plinthic and duplex soils respectively are dominant. Lithosols comprise the major soils of two patterns, while margalitic black clays form the last pattern. It is interesting that each of these reflects in a uniquely different way the properties of the shale from which soil formation has taken place. The shales give rise to clay soils, and hence the freely drained red and yellow-brown soils of the apedal soil patterns. These soils are similar to those derived from the sedimentary rocks with a greater clay forming potential, and to those derived from dolerite. Iron and manganese concretions and iron coatings on stones and shale chips are characteristic of the plinthic landscapes, and contrast in morphology to the plinthite horizons of the interior basins developed from sandstone. The lithosols differ too, in that higher clay contents are recorded, often overlying hard horizontal shales, or the fractured and inclined shales with soil movement into the fractures. Finally, the margalitic soil pattern of Milkwood, Mayo and Bonheim soils, with the vertic soil forms of Arcadia and Rensburg, differs significantly from the soil patterns derived from other sedimentary rocks in KwaZulu-Natal and Mpumalanga Provinces. While margalitic and vertic soils are present on the sedimentary rocks they are usually directly associated with dolerite, or are located in bottomland positions where base materials and silica can accumulate. These soils show similarities to those of the basalts of the Letaba (Jl) and Bivane (Zb) Formations. The soils of the Pietermaritzburg Formation derived from shale thus show similarities to both the sedimentary rocks, particularly those of greater clay forming potential, as well as to the basic igneous rocks. This makes the soils developed from the shales of the Pietermaritzburg Formation rather unique.

The soil patterns derived from shale of the Pietermaritzburg Formation are listed below (Table 15.1). These include a red and yellow-brown apedal soil pattern where dystrophic soils are dominant, or occur together with mesotrophic soils. Another pattern has red apedal and red structured soils with dominantly eutrophic base status. In this pattern there are also calcareous Hutton soils, black clays (Bonheim, Mayo and Milkwood), duplex soils and lithosols. The plinthic soil pattern has Avalon, Westleigh, Longlands soils with mesotrophic and eutrophic base status. However, Hutton, Clovelly, Griffin and Shortlands soils comprise an appreciable component of the soils in this pattern. Plinthic soils commonly occur with duplex soils and lithosols where a lower effective rainfall is present. This is evident in the fourth soil pattern which is derived from the combination of seven land types (Table 15.1). The duplex soil pattern is dominated by Swartland and Valsrivier soils. A small proportion of the soils belong to the Estcourt form, having an E horizon, showing signs of soil wetness. The melanic black clay soil pattern is somewhat unique with dominant black clay soils lying directly over the shale. Examples where margalitic soils are dominant are located at Verulam and inland of

Table 15.1 Dominant soils and selected climatic information for soil patterns occurring on shale of the Pietermaritzburg Formation.

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 Dystrophic and Mesotrophic Apedal Soils										
Hutton	Hu17 Hu18	28				Ave	883	1483	2676	0.60
	Hu27 Hu28	7				Std	128	137	436	0.10
Clovelly	Cv16 Cv17 Cv18	13				Max	1284	1913	3916	0.90
Griffin	Gf12 Gf13	11				Min	606	1123	1674	0.39
Glenrosa	Gs16 Gs19	12								
Mispah	Ms10	9								
Total Area: 190 240 Ha			Means of 56 Land Types							
Broad Soil Pattern: Red Apedal and Red Structured Eutrophic Soils										
Hutton	Hu37 Hu38	35	Valsrivier	Va41 Va42	5	Ave				
	Hu36	6		Va12 Va22	4	Std				
	Hu47	3	Swartland	Sw31 Sw41	2	Max				
Shortlands	Sd21 Sd22	8	Bonheim	Bo41	4	Min				
	Sd31 Sd32		Mayo	My11Mw11	3					
			Milkwood							
			Mispah	Ms10	4					
Total Area: 39 330 Ha			Means of 10 Land Types							
Broad Soil Pattern: Red and Yellow-brown Apedal and Plinthic Soils (Dominantly Mesotrophic Base Status)										
Hutton	Hu27 Hu28 Hu17	15	Westleigh	We12 We13	4	Ave	794	1534	2467	0.52
	Hu37 Hu38 Hu36	3	Longlands	Lo12	2	Std	51	81	509	0.05
Clovelly	Cv27	13	Shortlands	Sd 21 Sd22	7	Max	845	1679	3016	0.58
Griffin	Gf22	3	Glenrosa	Gs16 Gs19	6	Min	684	1427	1146	0.42
Avalon	Av26 Av27 Av24	6	Mispah	Ms10 Ms11	8					
	Av36 Av37 Av34	4								
	Av16 Av17	2								
Total Area: 381 300 Ha			Means of 52 Land Types							
Broad Soil Pattern: Plinthic and Duplex Soils										
Avalon	Av26 Av16	7	Hutton	Hu27 Hu37	14	Ave	713	1495	2931	0.48
Westhleigh	We12 We13 We22	6	Shortlands	Sd11 Sd12	7	Std	60	128	166	0.06
Longlands	Lo12 Lo13 Lo22	5				Max	842	1576	3192	0.59
Swartland	Sw31 Sw32 Sw41 Sw42	8				Min	650	1158	2739	0.42
Valsrivier	Va31 Va31	4								
Estcourt	Es33 Es34 Es36	4								
Glenrosa	Gs16 Gs17	17								
Mispah	Ms10	7								
Total Area: 46 550 Ha			Means of 7 Land Types							

Table 15.1 continued. Dominant soils and selected climatic information for soil patterns occurring on shale of the Pietermaritzburg Formation.

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: Duplex Soils										
Swartland	Sw31 Sw32	18				Ave	754	1519	3503	0.50
	Sw41 Sw42	8				Std	95	162	684	0.05
Valsrivier	Va31 Va32 Va41	15				Max	922	1729	4292	0.56
	Va42					Min	634	1251	2678	0.43
Estcourt	Es34 Es36	3								
Glenrosa	Gs16 Gs17 Gs19	14								
Mispah	Ms10	4								
Total Area: 35 290 Ha			Means of 5 Land Types							
Broad Soil Pattern: Melanic Black Clay Soils										
Milkwood	Mw11	18	Swartland	Sw31 Sw41	6	Ave	835	1566	3272	0.54
Mayo	My11	4	Valsrivier	Va31 Va41	6	Std	150	162	546	0.08
Bonheim	Bo11 Bo21	12				Max	1055	1878	4230	0.66
	Bo31 Bo41					Min	620	1259	2415	0.37
Other	Ar30 Ar40	5								
Black	Rg10 Rg20									
Clays.										
Glenrosa	Gs16 Gs17 Gs19	17								
Mispah	Ms10	3								
Total Area: 59 570 Ha			Means of 15 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa	Gs16 Gs17 Gs19	19	Hutton	Hu17 Hu22	11	Ave	781	1565	3018	0.50
	Gs10			Hu28		Std	97	169	543	0.07
Mispah	Ms10	17		Hu37 Hu38	4	Max	1043	1967	4300	0.61
Cartef	Cf12 Cf21	3	Shortlands	Sd12 Sd22	6	Min	657	1251	2373	0.33
Rock		9								
Total Area: 58 750 Ha			Means of 18 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime										
Glenrosa	Gs16 GS17	19	Swartland	Sw31 Sw32	8	Ave	695	1678	3198	0.41
	Gs19 Gs29	1		Sw41 Sw42		Std	101	238	500	0.10
Mispah	Ms10	16	Valsrivier	Va31 Va41	3	Max	-	-	-	-
	Ms20	5				Min	615	1245	2415	0.33
Rock	Rock	8								
Total Area: 97 620 Ha			Means of 24 Land Types							

Scottborough, while similar margalitic soils are present in the Mpushini River valley, east of Pietermaritzburg. The lithosols can form in higher rainfall zones with correspondingly higher rates of soil formation. However, higher rates of erosion are also to be expected, as would be likely in steeper landscapes. The lithosols on Pietermaritzburg shale without the presence of lime, are associated with dystrophic (higher rainfall) through to eutrophic (lower rainfall) Hutton soils, and where correspondingly higher rates of ferralitic weathering can to be expected. They are also associated with Cartref soils. The inference is that the lithosols and Cartref soils are formed in a higher rainfall regime (Table 15.1), sufficient to give rise to an E horizon with soil wetness above slowly permeable shales. Effective rainfall is usually lower than is the case where ferralitic weathering to form Hutton or Shortlands soil is observed to be operative. The appropriate combinations of landsurface, relief and topography should also be operative to give rise to the E horizons or the ferralitic soils. Lithosols with the presence of lime were also noted. Lime was present in the Glenrosa, Mispah, Swartland and Valsrivier soils. Rainfall is lower than where either Hutton or Cartref soils are present (Table 15.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Clovelly, Longlands, Estcourt, Swartland, Glenrosa, Mispah, Mayo, Milkwood, Rensburg and Shortlands were extracted from the database. The ranges in textural properties, (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented (Table 15.2). These ranges are also presented graphically (Figure 15.2). The figure allows for overview comparison between

Table 15.2 Textural properties of soils of the Pietermaritzburg Formation derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1	ClLm-SiCl-Cl ClLm-SiCl-Cl	30-58 33-74	13-43 5-49	3-34 1-38	1-11 1-16	1-9 1-40	fi,co fi,co	NL5 -
Griffin	A1 B1 B2	ClLm-SiCl-Cl ClLm-SiCl-Cl SaClLm-SiCl-Cl	29-60 35-65 26-70	9-53 11-50 14-38	3-27 1-32 3-40	1-16 1-13 1-11	2-11 1-14 3-8	fi,co fi,co fi,co	NL4,EL1 NL2,L2,EL1 -
Clovelly	A1 B1	SiCl -Cl SaCl-Cl	48-72 38-70	19-39 9-42	2-15 1-37	1-2 1-22	1-4 1-18	fi,me,co fi,co	EL3,NL1,L1 EL3,NL2
Longlands	E1 B1	Sa-SaLm-Lm SaClLm-ClLm-Cl	24-24 22-47	36-36 17-32	19-19 7-41	2-2 3-20	19-19 1-25	fi,me,co fi,co	EL5 L5
Estcourt	A1 E1 B1	SaLm-Lm LmSa-SaLm-Lm Lm-Cl	26-26 24-26 23-51	36-41 37-38 10-38	25-27 24-26 16-27	8-8 7-9 6-14	2-3 2-3 2-12	fi fi,me fi,me,co	EL3,NL2 L5 -
Swartland	A1 B1	SaLm-Cl SaClLm-SiCl-Cl	1-56 28-69	4-37 8-51	4-51 3-46	1-26 1-19	1-57 1-7	fi,co fi	NL3,L2 NL5
Glenrosa/ Mispah	A1	SaClLm-ClLm-Cl	17-54	8-39	6-43	2-13	1-16	fi,co	-
Mayo	A1 B1	SiCl-Cl	36-65 25-64	9-42 5-34	3-34 4-31	1-10 2-12	1-8 1-13	fi,co fi,co	EL5 -
Rensburg	A1	Cl	70-70	16-20	8-11	1-1	1-2	fi	-
Shortlands	B1	Cl	47-75	18-27	1-15	1-10	1-5	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).

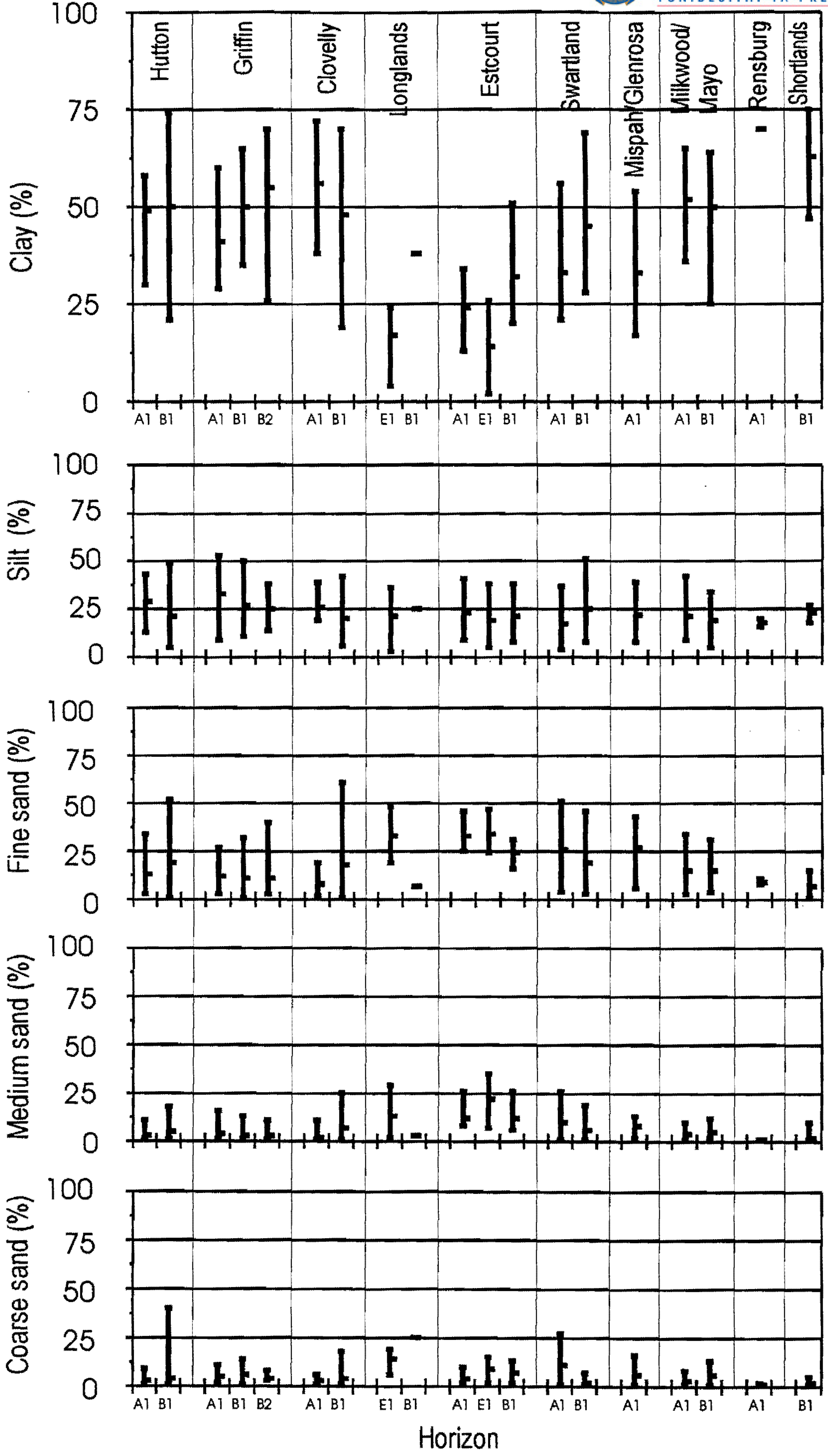


Figure 15.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Pietermaritzburg Formation. Maximum, minimum and mean values are shown for each horizon.

different soil forms over the particle size classes. It shows the clay nature of the red and yellow-brown apedal soils (Hutton Griffin, Clovelly), and of the melanic and vertic soils (Mayo, Rensburg) and red structured soils (Shortlands), and the sandy clay to clay nature of the Swartland and Mispah soils (Table 15.2, Figure 15.2). Maximum values for silt and fine sand values can be relatively high (Figure 15.2). Mean silt values generally are greater than those for fine sand. It is common to note fine gravel size shale chips in many of the soil profiles developed in semi-arid areas. These gravel chips are also reflected here in a small coarse and medium sand component (Table 15.2, Figure 15.2).

A review of the texture graphs (Figures 15.3 to 15.7) indicates that the textures of the majority of profiles are located in the clay class. Within this clay class however, there does appear to be a clustering of profiles with lower sand values (data reported in Table 15.4) and higher sand values (data reported in Table 15.5). These two natural clusters can be observed in the Griffin soils (Figure 15.3), in the B1 horizon of the Mayo soils (Figure 15.6), and in the Mispah soils (Figure 15.6). In the Clovelly soils (Figure 15.5) and in the Swartland soils (Figure 15.7) these clusters appear to merge together. It could be argued that these two clusters could be considered separately. This option has been chosen with data for the higher clay and silt values reported separately in Table 15.4, and for the somewhat lower clay and silt values reported in Table 15.5. In the Mispah and Swartland soils (Figures 15.6, 15.7) there is also a cluster of profiles with textures in the sandy clay loam class. Means and standard deviations of profiles are reported in Table 15.6. Threshold values for the separation of these data are reported in Table 15.3.

Table 15.3 Threshold values for the separation natural textural classes for the soils of the Pietermaritzburg Formation.

Natural Body based on texture	Threshold value	Natural Body represented in profiles of the following soils:	Dominant texture class	Data referenced in:
1 Clay texture, low sand	Total sand <25% (Corresponds to clay percentage >35%)	Hutton Griffin Clovelly Swartland Glenrosa / Mispah Mayo/Milkwood Rensburg Shortlands	Clay Silty clay loam	Table 15. 4
2 Clay texture, higher sand	Total sand between 25 and 50% (Corresponds to clay percentage >35%)	Hutton Griffin Clovelly Longlands Estcourt Swartland Glenrosa/Mispah Mayo/Milkwood	Clay	Table 15.5
3 Sandy clay loam texture	Total sand >50%	Swartland Mispah	Sandy clay loam	Table 15.6

Within the first clay group the Rensburg soils (Vertic A1 horizons, Table 15.4) have the highest clay percentage. The Mayo soils (Melanic A1 horizons) have, as expected, slightly lower clay percentages than the vertic soils. There is little difference between the Hutton, Griffin and Clovelly soils (Table 15.4), while the Mispah and Swartland (B1 horizons) have only slightly lower clay contents. There is thus limited variation over different soil forms within the single lithology.

Within the second clay grouping, the clay and silt percentages values are displaced slightly lower for the Hutton, Griffin, Clovelly, Swartland and Mispah soils (Table 15.5). Increases in the fine sand values are evident. The Longlands and Estcourt soils show interesting, but similar properties (Table 15.5). Mean clay percentages are around 25 percent, while mean silt values are around 35 percent. The clay values are about half the value of the red and yellow-brown apedal soils, and the Mispah soils (Table 15.4 and 15.5). This can be assumed to be a reflection of the presence of the E horizon in these soils. It is also interesting that the clay percentages are lower than those for the Mispah soils. These clay and silt values are similar to those determined for Longlands, Kroonstad and Estcourt soils of the Volkrust Formation. It serves to confirm the important existence of these higher clay content E horizon soils which have not been extensively sampled. These clay and silt contents are about 1.5 to 2 times greater than those for the Longlands soils derived from the sandstone of the Vryheid Formation. The latter soils cover extensive areas of the KwaZulu-Natal interior basins and could be considered as the "expected and typical" Longlands soil. The Longlands and Estcourt soils from the Pietermaritzburg and Volksrust Formations serve to confirm the departure from the sandy Longlands and Estcourt soils (Table 15.5).

Mispah, Glenrosa and Swartland soils also have sandy clay loam texture (Table 15.6). Here silt values tend to be low, with higher values for fine, medium and even coarse sand.

The Hutton, Griffin and Clovelly soils, with high clay contents, have in general non-luvic B1 horizons (Table 15.2, Figure 15.8). The Griffin and Clovelly soils have a significant proportion of the profiles with the clay content in the B1 lower than that of the A1 horizon. The clay increases are as expected for the Longlands and Estcourt soils (Table 15.2) although derived from limited data sets. The clay increases for the Swartland soils, while being the largest within this group of soils, are less than initially expected (Figure 15.8).

Fine sands are generally dominant (Table 15.2, Figures 15.3 and 15.6). The presence of coarse sand (and probably also fine gravel fragments) in Figures 15.3 and 15.5 is indicative of fine shale derived gravel fragments, often with a hard iron coating, common in many of the soils derived from the shale of the Pietermaritzburg Formation.

Table 15.4 Means and standard deviations of five textural classes for soils of the clay and silty clay group of the Pietermaritzburg Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
A1	378	52.9	4.2	32.4	9.8	8.2	6.0	1.3	0.4	3.6	1.9	7
B1	856	60.1	8.1	27.1	9.6	6.8	5.2	1.5	0.7	3.5	2.2	16
Form: Griffin												
A1	411	46.7	8.1	41.2	10.6	5.2	2.7	1.0	0.0	4.0	2.0	6
B1	638	54.7	7.5	29.7	8.8	7.2	5.2	1.5	1.0	6.3	4.0	13
B2	930	60.8	9.0	26.8	8.5	6.0	2.8	1.0	0.0	4.8	1.9	5
Form: Clovelly												
A1	297	58.6	6.8	26.6	6.2	6.9	4.5	1.1	0.4	3.0	0.9	7
B1	666	56.9	8.2	29.7	7.9	7.5	4.8	1.1	0.3	3.1	1.8	11
Form: Swartland												
A1	240	49.5	5.4	26.5	10.7	16.0	8.5	3.8	1.9	5.8	4.0	4
B1	240	49.5	5.4	26.5	10.7	16.0	8.5	3.8	1.9	5.8	4.0	4
Form: Glenrosa/Mispah												
A1	400	49.0	5.0	33.0	6.0	6.5	0.5	2.0	0.0	3.5	2.5	2
Form: Mayo/Milkwood												
A1	440	55.6	5.8	25.0	6.1	8.9	4.9	2.5	1.0	2.9	1.6	12
B1	666	53.7	8.9	21.0	9.2	7.3	3.3	2.3	0.4	4.0	2.1	6
Form: Rensburg												
A1	425	70.0	0.0	18.0	2.0	9.5	1.5	1.0	0.0	1.5	0.5	2
Form: Shortlands												
B1	937	63.4	9.2	23.4	3.1	7.9	5.3	2.5	3.4	2.3	1.4	8

Table 15.5 Means and standard deviations of five textural classes for soils of the clay and sandy clay group of the Pietermaritzburg Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton												
B1	820	47.1	11.3	17.3	8.2	25.5	10.5	5.6	4.8	6.7	10.5	12
Form: Griffin												
A1	370	35.8	7.7	24.6	11.6	21.2	5.8	8.4	4.9	7.6	3.1	5
B1	610	42.4	5.2	20.2	6.4	23.6	4.8	7.2	3.7	4.6	2.1	5
Form: Clovelly												
B1	987	47.6	6.1	14.3	4.7	23.4	6.3	9.3	6.5	4.0	2.1	8
Form: Longlands												
E1	500	24.0	0.0	36.0	0.0	19.0	0.0	2.0	0.0	19.0	0.0	2
B1	1290	37.8	8.6	23.6	5.3	19.5	14.0	7.0	6.5	16.0	8.8	5
Form: Estcourt												
A1	350	26.0	0.0	38.5	2.5	26.0	1.0	8.0	0.0	2.5	0.5	2
E1	450	25.0	1.0	37.5	0.5	25.0	1.0	8.0	1.0	2.5	0.5	2
B1	840	35.0	12.3	24.8	12.8	23.3	4.3	9.3	3.0	6.5	4.2	4
Form: Glenrosa/Mispah												
A1	366	40.3	4.8	26.7	2.6	22.0	1.4	6.7	0.9	2.0	0.8	3
Form: Mayo/Milkwood												
A1	295	46.6	8.2	15.1	4.5	24.6	6.9	6.7	1.8	5.0	1.8	7
B1	650	50.8	7.4	17.0	8.3	20.5	3.5	6.0	0.7	6.8	0.8	4

Table 15.6 Means and standard deviations of five textural classes for soils of the sandy clay loam group of the Pietermaritzburg Formation.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Swartland												
A1	0-296	20.4	11.3	9.8	4.5	34.8	16.1	15.6	6.3	16.0	20.7	5
B1	296	20.4	11.3	9.8	4.5	34.8	16.1	15.6	6.3	16.0	20.7	5
Form: Glenrosa/Mispah												
A1	168	26.3	5.2	18.4	7.9	35.5	3.5	9.3	3.3	9.1	5.1	8

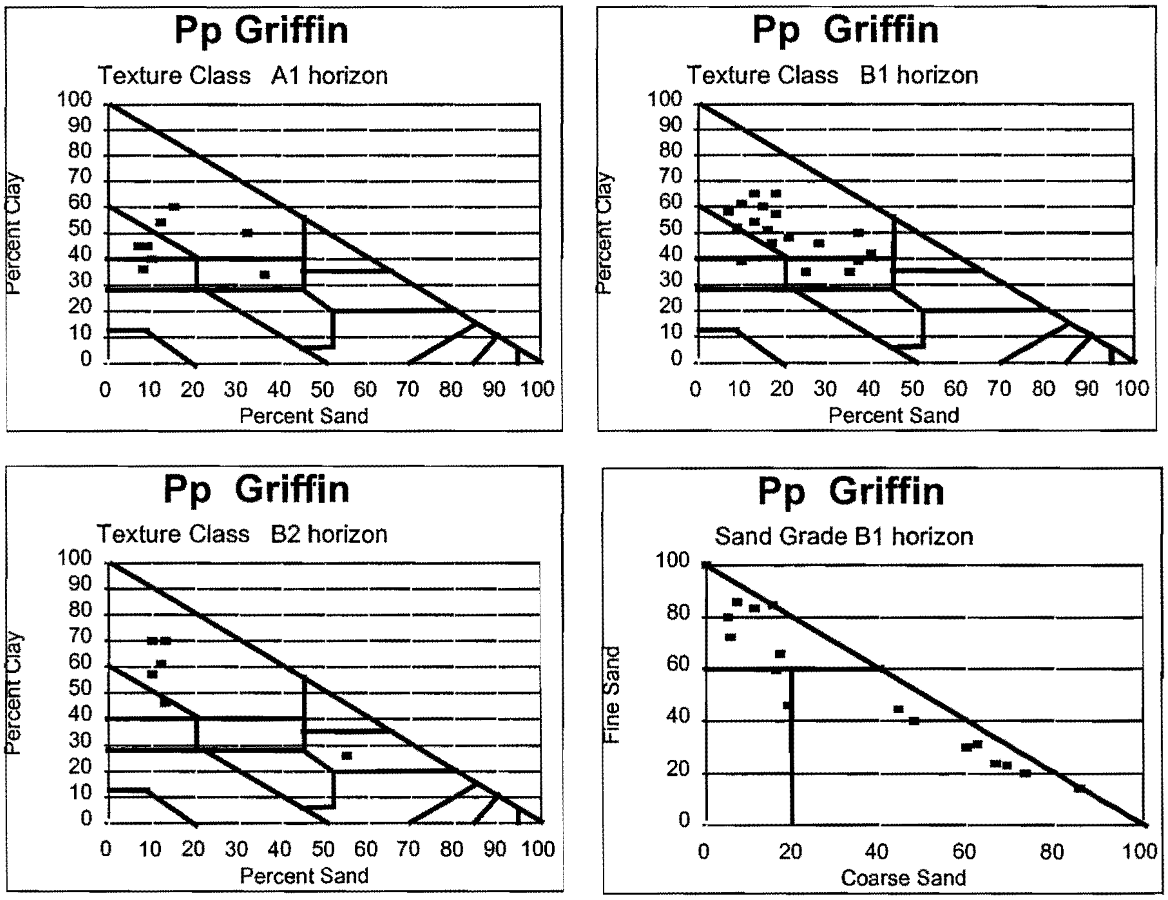


Figure 15.3 Distribution of soil textures, and sand grades, within soils of the Griffin Form.

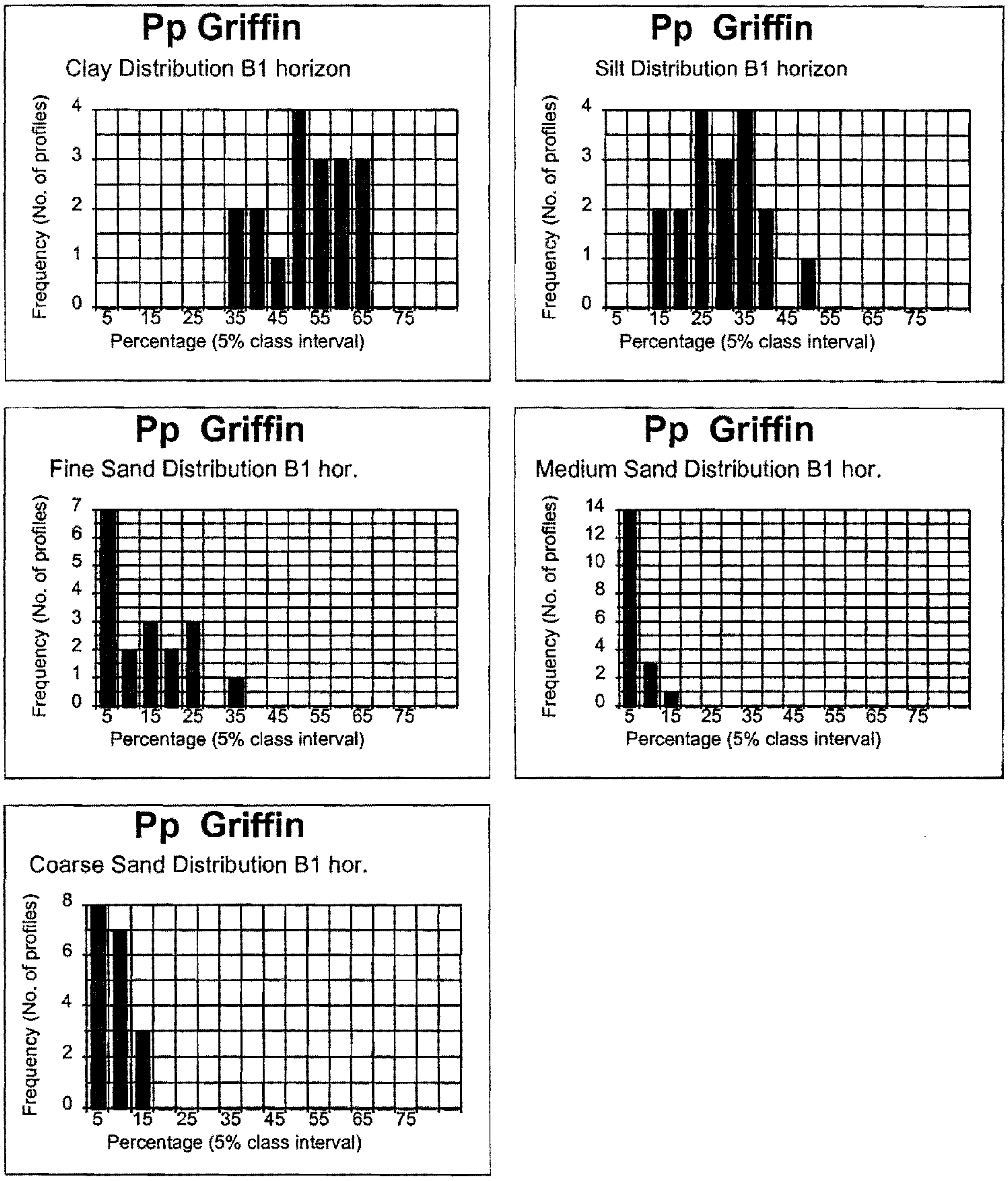


Figure 15.4 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Griffin Form.

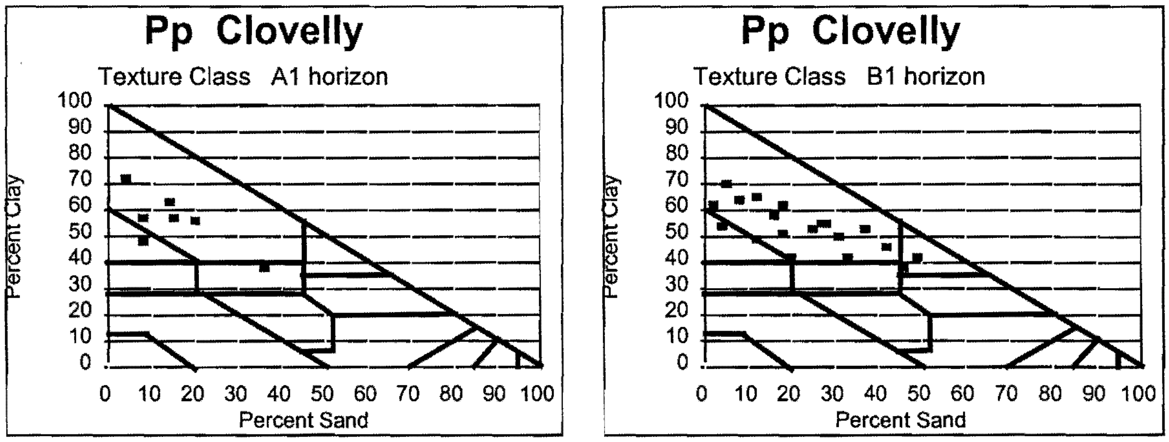


Figure 15.5 Distribution of soil textures within soils of the Clovelly Form.

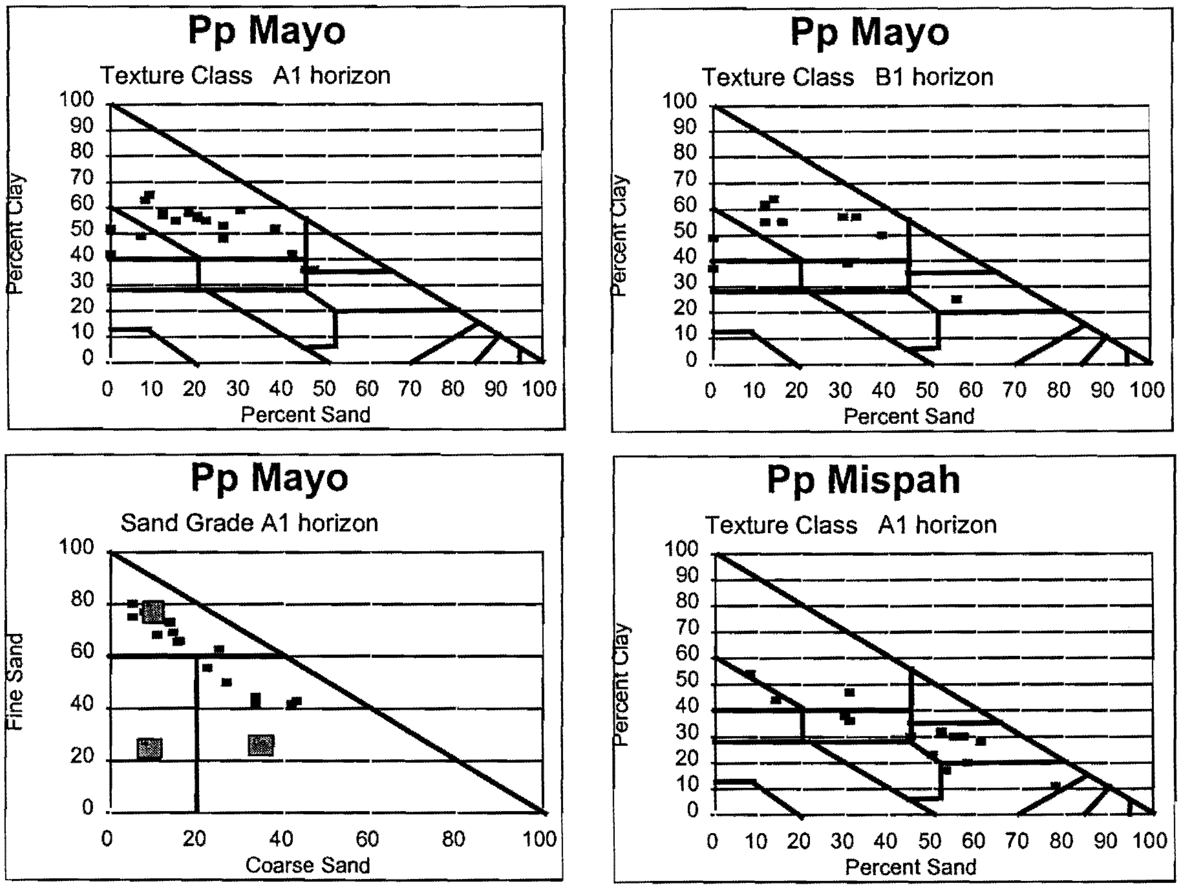


Figure 15.6 Distribution of soil textures, and sand grades, within soils of the Mayo and Mispah Forms.

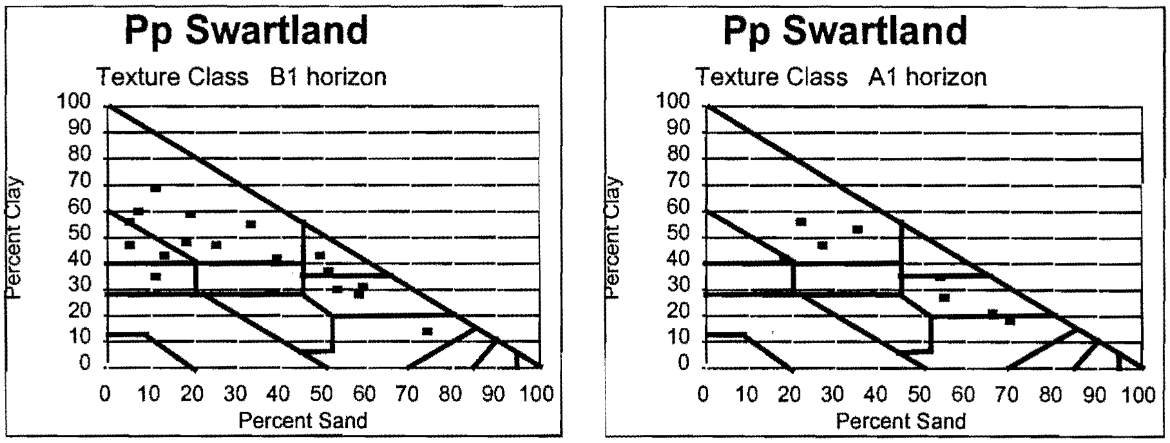


Figure 15.7 Distribution of soil textures within soils of the Swartland Form.

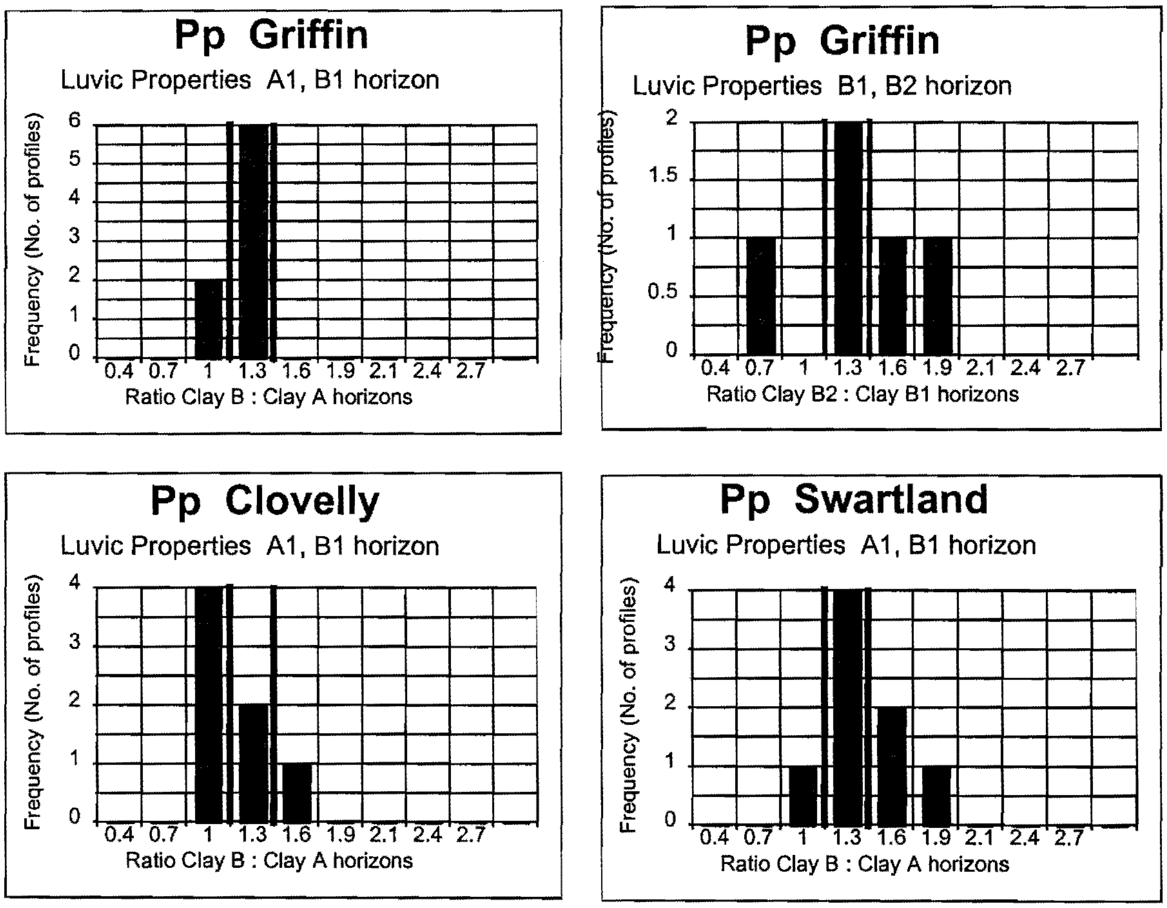


Figure 15.8 Luvic properties within soils Griffin, Clovelly and Swartland Forms.

CHAPTER 16

SOILS OF THE TILLITE OF THE DWYKA FORMATION IN KWAZULU-NATAL AND MPUMALANGA

Location and Extent

The Dwyka Formation covers extensive areas of north eastern KwaZulu-Natal stretching from the upper reaches of the Mkuze River and covering extensive areas of the interior valley basins of the Mfolozi and Buffalo River valleys (Geological Survey, 1984)(Figure 16.1). South of the Tugela River the Dwyka Formation is located in two north-south stretching belts (Figure 16.1). For convenience of description these belts may be considered as lying on either side of the reported axis of the Natal monocline (King, 1940). The western boundary of this interior belt is determined by Ecca Group rocks of the Pietermaritzburg Formation. To the east lies the sandstones of the Natal Group, and in some instances even the basement granites. The boundaries of the tillite are commonly determined by the numerous faults present within the monoclinal structure of the coastal hinterland (Geological Survey, 1988b; Geological Survey, 1988c; Geological Survey, 1988d). This belt of tillite occupies altitudes of between 700 - 900 metres. The eastern belt lies within the coastal plain at altitudes of between 50 and 300 metres. To the west lies sandstone of the Natal Group. The eastern boundary, often determined by faulting, comprises of shales, sandstones or red sands of the Pietermaritzburg, Vryheid and Berea Formations. These changes in geology have important local influences on the soils, their classification and properties. The tillite of the Dwyka Formation is also located in northern fringes of the Mpumalanga Highveld (Geological Survey, 1984). Soil profiles sampled from this area appear to have properties somewhat different to those of the main KwaZulu-Natal zone. The tillite occupies an area of approximately 834 500 hectares.

Geology and Geomorphology (Geology Symbol Abbreviation **C-Pd**)

The Dwyka Formation is the product of glaciation and is reported by Truswell (1977) as occurring throughout the former Gondwanaland continent. These glaciers were competent to carry fragments of any size, and much glacial sediment has been dumped as ill-sorted till, that has consolidated to form tillite. Since similar rocks may form as a result of landslides and submarine mudflows, the term diamictite is now commonly used in a non-genetic way for such ill-sorted sediment. Much of the Dwyka material is ill-sorted diamictite, a greenish or blueish rock with a dense argillaceous matrix in which coarse fragments of various sizes are set. Other materials in the overall unit include sandstones, conglomerates, argillaceous rocks, and some shales (Truswell, 1977). The Dwyka diamictite is locally up to 1 000 m thick in the south of the Karoo Basin. This thickness decreases rapidly northwards and in Mpumalanga the unit is preserved only in thin, erratically developed pockets.

The Dwyka Formation is described variously as comprising tillite, minor shale, dropstone-bearing shale, varved shale and sandstone (Geological Survey, 1981b; Geological Survey, 1988a; Geological Survey, 1988b; Geological Survey, 1988c).

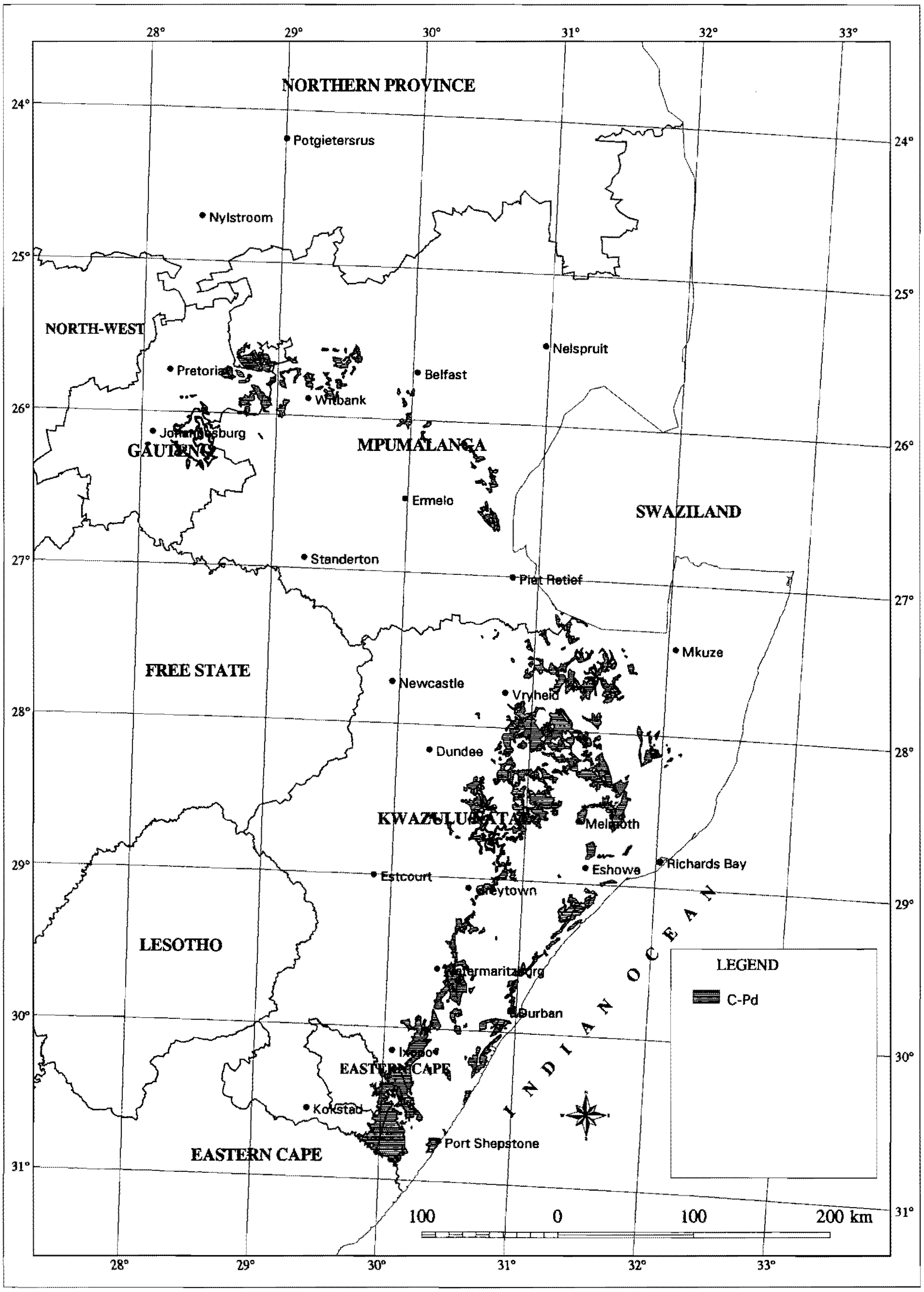


Figure 16.1. Location of the Dwyka Formation in KwaZulu-Natal and Mpumalanga (after Geological Survey, 1984).

Physiography and Drainage Features

The Dwyka Formation is exposed in a number of terrain morphological classes. In the KwaZulu-Natal Interior Basin undulating hills and lowlands are encountered with a relatively high proportion of slopes less than 5 percent (Kruger, 1983). These terrain classes commonly support plinthic and lithosolic soil patterns. Undulating hills and valleys of moderate relief are encountered in the Mistbelt Zone, commonly with red and yellow apedal soils located on these surfaces. The Dwyka Formation is extensively exposed in many of the river valleys. In the Mkuze, Mfolozi and Mkomazi River Valleys the terrain could be described as low mountains (Kruger, 1983), where lithosolic and duplex soil patterns are commonly present. Along the Coast Belt the Dwyka Formation is exposed, often with Basement Granites, in highly dissected hills and valleys. The Formation is also exposed on the northern fringe of the Highveld Plain where gentle to moderate slopes are present.

Vegetation

The vegetation over the greater part of the zones where tillite is exposed is described by Low and Rebelo (1996) as Coast Hinterland Bushveld. Natal Central Bushveld is present in the northern KwaZulu-Natal Interior, while Short Mistbelt Grassland occurs in the Mistbelt.

Soils

Six major soil patterns are present on the tillite of the Dwyka Formation (Table 16.1). These include a red and yellow apedal dystrophic soil pattern, a pattern comprising plinthic soils with red and yellow apedal soils, and a plinthic soil pattern. The remaining soil patterns comprise duplex soils and plinthic soils, and lithosols with and without the presence of lime.

The red and yellow dystrophic soil pattern is located on moist, undulating tablelands (Table 16.1). These tablelands are remnants of old landsurfaces and show deep weathering of the underlying material to give rise to a soft, friable to crumbly saprolite. Evidence of the original structure of the tillite material is preserved as sand and stone erratics within this saprolite material. These erratics, which have also undergone weathering, may range in size from the very fine whitish sand size particles to larger remnants of pebble, stone and boulder sizes. The data source (Land Type Survey Staff, 1986b; 1987a; 1988c; 1994a; 1994b; 1997b) gives dystrophic Hutton soils as dominant within this pattern (Table 16.1). However, Griffin and Clovelly soils are present as important components. Many Griffin profiles developed on tillite of the Dwyka Formation could be considered as modal benchmark sites for those soils exhibiting the sequence of horizons comprising of dark brown topsoils, over a bright yellow-brown horizon, over a red horizon. Topsoils commonly have elevated levels of organic carbon (>2%). It is significant that many of the Hutton profiles also show the yellow to red horizon sequence within the soil colours. Colours could range from yellowish red to dark reddish brown within the 5YR and 2.5YR hues. Similarly the Clovelly soils exhibit reddening of the third horizon, but within the yellow-brown colour ranges of 7.5YR and 10YR hues. The clear association of these characteristic highly weathered Hutton, Griffin and Clovelly profiles with the tillite can be readily established. Weathered remnants of stone sized erratics can be traced from the saprolite through the red apedal B horizon in many profiles. The uniform morphology and texture could be used to infer the associations between the red horizon and the surface horizons.

Table 16.1 Dominant soils and selected climatic information for soil patterns occurring on tillite of the Dwyka Formation.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow Apedal Soils										
Hutton	Hu17 Hu18	27	Glenrosa	Gs16 Gs17	9	Ave	954	1493	2593	0.64
	Hu16 Hu27 Hu28	5		Gs19		Std	179	210	200	0.16
Griffin	Gf12 Gf13	11	Mispah	Ms10	4	Max	1495	2141	3619	-
	Gf11	3	Katspruit	Ka10	3	Min	750	1201	1662	0.38
Clovelly	Cv17 Cv18	7								
	Cv16	4								
	Cv26 Cv27	1								
Total Area: 86 640 Ha			Means of 19 Land Types							
Broad Soil Pattern: Plinthic soils with Red and Yellow Apedal Soils										
Avalon	Av26	18	Clovelly	Cv26 Cv27	8	Ave	784	1544	2901	0.51
	Av27	2	Hutton	Hu17 Hu27	5	Std	24	6	81	0.01
Longlands	Lo12 Lo21	4	Griffin	Gf12 Gf22	3	Max	805	1552	3020	0.52
Westleigh	We22 We32	9	Oakleaf	Oa36	5	Min	750	1537	2824	0.49
Glenrosa	Gs16 Gs17 Gs19	19								
Mispah	Ms10	8								
Total Area: 5 480 Ha			Means of 3 Land Types							
Broad Soil Pattern: Plinthic Soils										
Longlands	Lo12 Lo22	9	Estcourt	Es33 Es34	5	Ave	698	1561	2959	0.45
	Lo11 Lo21	5		Es30 Es40		Std	58	36	313	0.04
Wasbank	Wa12 Wa22 Wa11	3	Valsrivier	Va30 Va40	3	Max	768	1620	3486	0.50
	Wa21		Sterkspruit	Ss23 Ss24	3	Min	606	1521	2678	0.39
Westleigh	We12 We22	4								
	We11 We21									
Avalon	Av36	4								
Glenrosa	Gs16 Gs17 Gs14	20								
Mispah	Ms10 Ms11	12								
Total Area: 28 850 Ha			Means of 5 Land Types							
Broad Soil Pattern: Duplex Soils and Plinthic Soils										
Swartland	Sw30 Sw31	10	Avalon	Av26	4	Ave	686	1551	2969	0.44
	Sw40 Sw41	3	Cartref	Cf12 Cf21	5	Std	42	108	372	0.05
Estcourt	Es34 Es36	5				Max	758	1786	3886	0.54
Sterkspruit	Ss24 Ss26	5				Min	650	1385	2610	0.37
Valsrivier	Va31 Va41	4								
Longlands	Lo12 Lo22	4								
	Lo11 Lo21	2								
Westleigh	We12 We22	6								
Glenrosa	Gs16 Gs17 Gs14	17								
Mispah	Ms10	7								
Total Area: 37 960 Ha			Means of 9 Land Types							

Table 16.1 continued. Dominant soils and selected climatic information for soil patterns occurring on tillite of the Dwyka Formation.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa Mispah Cartref	Gs16 Gs17 Gs19 Ms10 Cf11 Cf12	43 10 9	Swartland Oakleaf	Sw31 Sw30 Oa36 (Soft B horizons)	5 4	Ave Std Max Min	827 132 1100 570	1543 217 2768 1229	3212 483 4230 2102	0.53 0.10 0.82 0.27
Total Area: 374 890 Ha			Means of 75 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime										
Glenrosa Mispah Rockland Swartland Valsrivier	Gs16 Gs17 Ms10 Rock Sw31 Sw41 Va31 Va41	31 17 8 6 6	Swartland Valsrivier Sterkspruit	Sw31 Sw41 Va31 Va41 Ss24 Ss26	6 6 3	Ave Std Max Min	683 60 940 575	1640 91 1762 1342	3339 492 4081 2102	0.42 0.05 0.55 0.35
Total Area: 300 680 Ha			Means of 44 Land Types							

Subtle, but observable differences between the soils of the tillite of the Dwyka Formation and those of the Natal Group, and the Vryheid Formation are evident in the profile morphology and in the geomorphology. These differences closely follow the geological boundary and can be traced over all the soil patterns. The differences between the tillite of the Dwyka Formation and the shale of the Pietermaritzburg Formation are less evident in the highly weathered environments. However, soil differences are more evident in the subhumid environments with difference in dominant soil forms and properties. Differences below the soil solum are also noticeable with the tillite commonly giving rise to a crumbly, moderately weathered aggregate, which contrasts to the commonly hard horizontal shale plates.

Plinthic soils in association with red and yellow apedal soils occur on the fringes of the subhumid KwaZulu-Natal Interior Basins. This soil pattern occupies a relatively small area (Table 16.1). The higher effective rainfall could account for the formation of red and yellow soils in an environment where otherwise plinthic soils would be expected.

The plinthic soil pattern is located in the subhumid zone of the KwaZulu-Natal Interior Basins (Table 16.1). Plinthic soils with an E horizon (Longlands, Wasbank and Westleigh) are dominant, while the Avalon soils comprise on average only 4 percent of the plinthic soil unit. The Glenrosa and Mispah soils with characteristic profile morphology and properties are common on tillite in many of the KwaZulu-Natal Interior Basins. Duplex soils of the Estcourt, Valsrivier and Swartland Forms are subdominant to the plinthic soils and generally occupy the bottomland positions.

The duplex soil pattern comprises both calcareous and non-calcareous soils of the Swartland, Estcourt, Sterkspriut and Valsrivier Forms (Table 16.1). Glenrosa and Mispah soils are again dominant within the pattern, while Longlands, Westleigh and Cartref soils are also present. The duplex soils occupy a greater proportion of the upland and bottomland sites. It is probable that the shallower Swartland, Sterkspruit and Estcourt soils are derived directly from tillite. The deeper Valsrivier and Sterkspruit are probably derived from tillite colluvium, or from colluvium from adjacent soil zones. The properties of these soils are documented for implementation in land use applications. The formation of duplex as opposed to plinthic soils could to some extent be explained by their occurrence in a zone with a lower rainfall and greater evaporation and heat unit values (Table 16.1).

The lithosolic soil patterns are dominated by Glenrosa and Mispah soils (Table 16.1). In the pattern without the presence of lime, the higher rainfall regime is reflected in the E horizons of the Cartref soils, while the presence of Oakleaf soils (in upland topographic positions) is a reflection of a longer and more intense weathering regime. These Oakleaf soils may well be classified to the family of soils with a soft B1 horizon within the Glenrosa Form (Soil Classification Working Group, 1991). The rainfall at some of these localities with lithosolic soils is comparable to those of the red and yellow apedal soil patterns. It must be inferred that these are younger soil landscapes.

The lithosolic soil pattern with the presence of lime is dominated by Glenrosa and Mispah soils, with a greater proportion of rock. Lime is generally present in the bottomlands of the Swartland, Valsrivier and Sterkspruit soils (Table 16.1).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Clovelly, Avalon, Longlands, Estcourt, Swartland, Inhoek, Glenrosa and Mispah Forms were extracted from the database. The data was plotted on textural triangle graphs (Figures 16.4 to 16.10) to establish the range of variation and any possible natural soil bodies. It was evident that the range stretches over a number of texture classes from sandy loam to clay. For the apedal soils (Griffin, Figure 16.4; Hutton, Figure 16.5) the cluster of profile points spans the whole range with no clear natural breaks. Within the profiles of Avalon (Figure 16.5), Glenrosa (Figure 16.6), Longlands (Figure 16.7), and Swartland (Figure 16.9) soils clearer evidence of clustering is apparent. It was also apparent that the textural properties of profiles derived from the tillite of the Interior Basins of KwaZulu-Natal differed from those on the northern fringes of the Mpumalanga Highveld. It was evident that a number of soil bodies could be drawn out from the dataset. Consequently the data were divided into three natural soil bodies as evident in the textural triangle graphs and their threshold values (Table 16.2) determined. These three textural groups are reflected in subsequent tables and figures. The first two textural groups are well represented by profiles from the dataset. However, the loam textural class is represented by only a limited number of profiles. The ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented for the three natural soil bodies (Tables 16.3, 16.4 and 16.5). These ranges are also presented graphically (Figures 16.2 and16.3). The figures allow for overview comparisons between different soil forms over the particle size classes.

(Continued on page 222)

Table 16.2 Threshold values for the separation natural textural classes for the soils of the Dwyka Formation.

Natural Body based on texture	Threshold value	Natural Body as represented in profiles of the following soils:	Dominant texture class	Data referenced in:
1	Clay percentage >35% (Corresponds to Total sand<45%)	Hutton Griffin Clovelly Longlands Swartland Glenrosa / Mispah Inhoek	Clay Clay loam Sandy clay	Table 16.3
2	Clay percentage <35% (Corresponds to Total sand>45%)	Hutton Griffin Clovelly Avalon Longlands Estcourt Swartland Glenrosa/Mispah	Sandy loam Sandy clay loam	Table 16.4
3	Clay <35% Silt <30%	Longlands Glenrosa/Mispah	Loam	Table 16.5

Table 16.3. Textural properties of soils of the Dwyka Formation with clay loam to clay textural classes as derived from profile values.

Form	Hori zon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1 B1 B2	Cl SaCl-ClLm-Cl ClLm-Cl	38-68 36-81 27-79	8-41 7-37 7-33	3-30 4-35 1-28	1-6 1-10 1-9	1-12 1-10 2-10	fi,me,co fi,me,co fi,co	NL - -
Griffin	A1 B1 B2	ClLm-Cl SaCl-ClLm-Cl Cl-ClLm	36-59 39-66 39-66	11-34 8-32 8-32	11-30 9-29 9-29	3-11 2-16 2-16	1-3 1-7 1-7	fi,me fi,me fi,me	NL4,L1 NL5 -
Clovelly	A1 B1 B2	Cl Cl-SaCl Cl	41-50 36-56 41-45	12-20 3-17 15-18	22-31 21-39 25-38	6-10 5-23 5-9	1-3 1-4 1-3	fi,me,co fi,me.cof i,co	NL5 - -
Longlands	A1 E1 B1	SaLm-SaClLm LmSa-SaLm-Lm Cl	16-29 12-39 44-59	32-35 29-39 21-26	21-34 19-39 11-15	7-8 5-7 2-3	5-7 5-5 1-4	fi,me,co fi,me,co fi,me,co	EL L -
Swartland	A1 B1	Cl ClLm-Cl	49-49 38-72	25-28 7-32	13-15 8-20	4-5 1-7	2-3 1-5	fi,me,co fi,me,co	L3,NL2 -
Glenrosa	A1 B1	Cl Cl	45-45 45-47	24-24 13-25	25-25 23-28	2-2 1-5	3-3 1-4	fi,me fi,me	- -
Inhoek	A1 B1	ClLm-Cl Cl	30-54 41-58	8-31 7-30	6-18 6-19	1-6 1-4	1-3 1-2	- -	- -

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).

Table 16.4 Textural properties of soils of the Dwyka Formation with sandy loam to sandy clay loam textural classes as derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Hutton	A1	SaLm-SaClLm	12-27	4-33	32-52	10-26	4-17	fi,me,co	L5
	B1	SaLm-SaClLm	14-34	3-26	26-47	3-46	1-26	fi,me,co	-
Griffin	A1	LmSa-SaClLm	9-24	6-20	32-59	7-38	3-14	fi,me,co	L5
	B1	SaLm-SaClLm	10-25	5-23	29-61	6-20	3-30	fi,me,co	L3,NL2
	B2	SaLm-SaClLm	10-25	5-23	29-61	6-20	3-30	fi,me,co	-
Clovelly	A1	LmSa-SaClLm	7-25	6-22	29-58	9-33	2-16	fi,me,co	L3,NL2
	B1	SaLm-SaClLm	8-32	2-22	27-56	8-30	6-30	fi,me,co	L3,NL2
	B2	SaLm	17-20	12-20	29-41	12-18	9-21	fi,me,co	-
Avalon	A1	LmSa-SaClLm	7-31	3-46	12-58	4-36	1-15	fi,me,co	L5
	B1	SaLm-SaClLm-SaCl	12-41	2-54	13-55	2-40	2-26	fi,me,co	NL3,L2
	B2	SaLm-SaClLm	15-35	9-19	35-52	6-19	3-15	fi,me,co	-
Longlands	A1	LmSa-SaLm	6-18	6-28	36-66	9-34	4-16	fi,me,co	EL3,NL1,L1
	E1	LmSa-SaLm	8-20	2-29	32-78	5-37	5-18	fi,me,co	NL2,L3
	B1	SaLm-SaClLm	12-32	7-28	22-46	6-24	5-18	fi,me,co	-
Estcourt	A1	LmSa-SaClLm	6-25	2-24	19-62	6-29	2-26	fi,me,co	EL3,NL2
	E1	LmSa-SaClLm	2-14	6-17	38-53	12-29	6-21	fi,me,co	L5
	B1	SaLm-SaCl	12-37	4-24	33-46	8-24	2-15	fi,me,co	-
Swartland	A1	SaLm-SaClLm	11-37	4-15	26-54	5-17	1-12	fi,me,co	L5
	B2	SaClLm-SaCl	22-43	7-20	26-47	6-18	1-11	fi,me,co	-
Glenrosa	A1	LmSa-SaLm-SaCl	10-39	4-25	27-72	3-26	1-26	fi,me,co	L4,NL1
	B1	SaLm-SaCl	13-39	11-27	25-63	4-20	1-15	fi,me,co	-

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).

Table 16.5. Textural properties of soils of the Dwyka Formation with loam texture class as derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Longlands	A1	Lm	13-29	31-35	21-37	7-13	4-7	fi,me	-
	E1	Lm	12-23	36-45	23-39	7-8	3-8	fi,me	-
	B1	Lm	25-25	41-41	26-26	4-4	4-4	fi,me	-
Glenrosa	A1	Lm	15-20	33-37	12-33	7-12	2-50	fi,me	-

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).

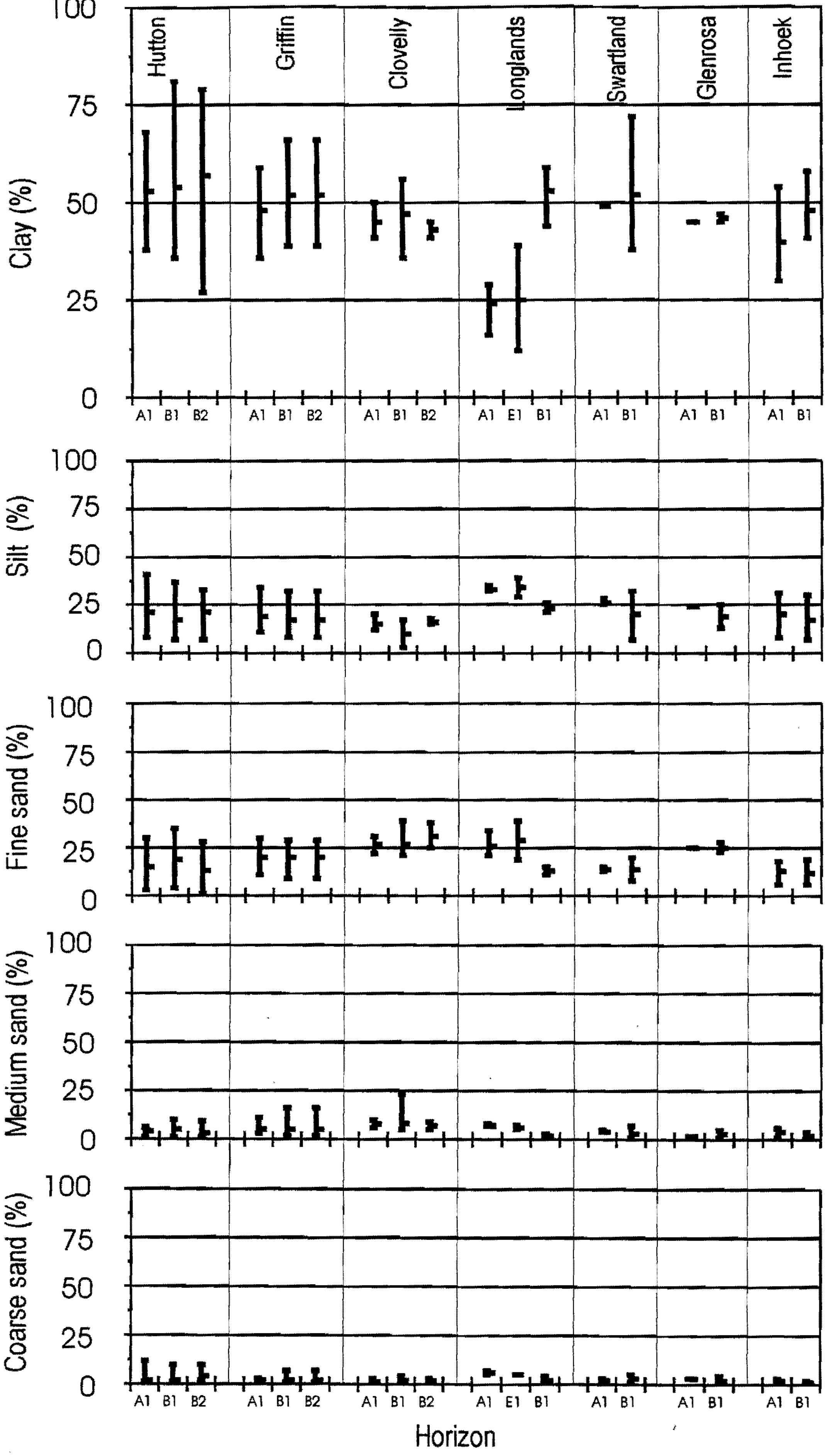


Figure 16.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Dwyka Formation with a sandy clay to clay texture. Maximum, minimum and mean values are shown for each horizon.

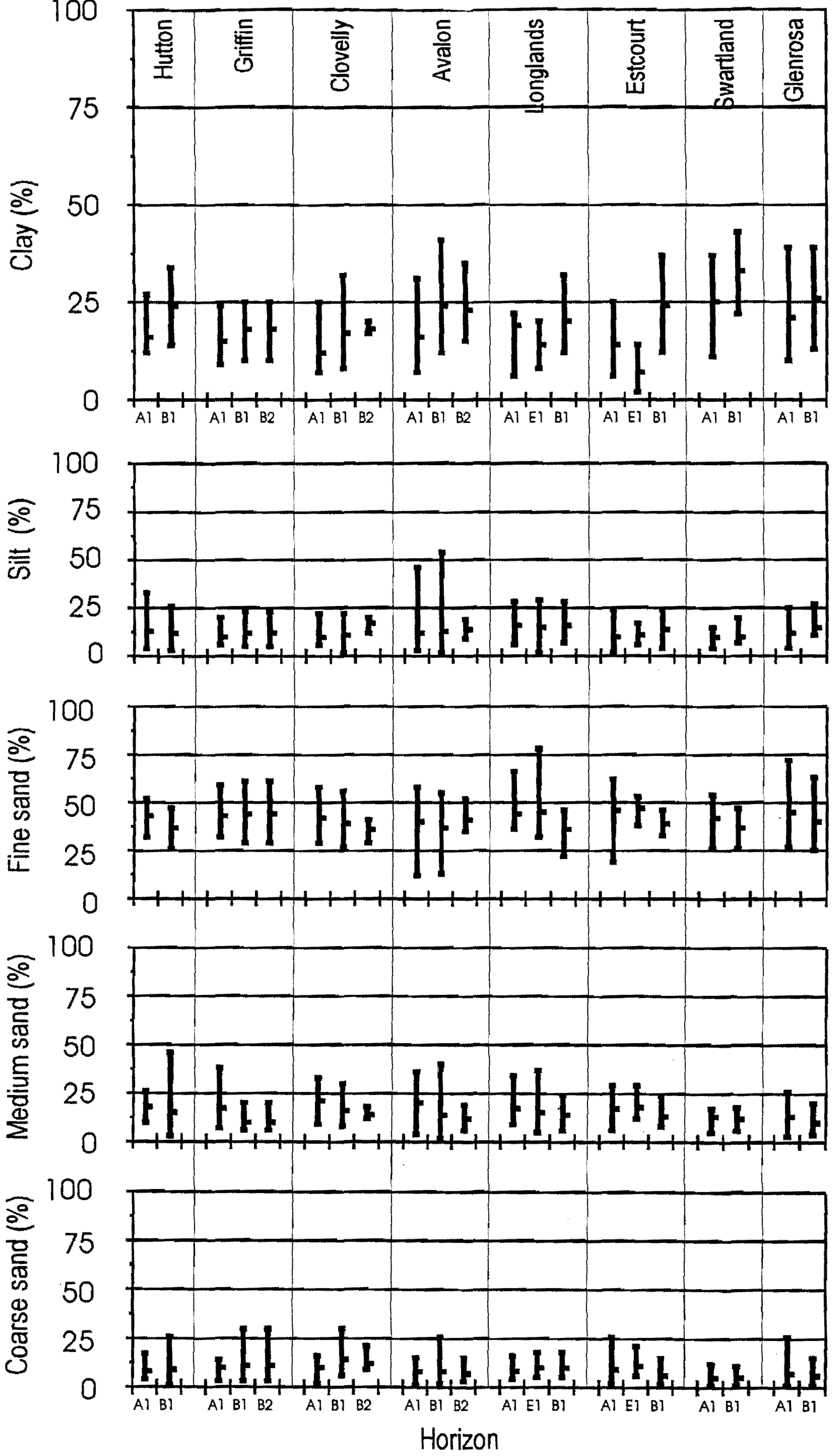


Figure 16.3 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Dwyka Formation with a sandy loam to sandy clay loam texture. Maximum, minimum and mean values are shown for each horizon.

Table 16.6 Means and standard deviations of five particle size classes for soils of the tillite of the Dwyka Formation with a clay loam to clay textural class.

Horizon	Depth mm	Clay % Mean	Clay % SD	Silt % Mean	Silt % SD	Fine Sand % Mean	Fine Sand % SD	Medium Sand % Mean	Medium Sand % SD	Coarse Sand % Mean	Coarse Sand % SD	Sample Size
Form: Hutton												
A1	0-443	53.8	8.6	21.1	9.4	15.0	6.1	4.0	1.4	2.5	2.9	13
B1	822	54.9	11.1	17.1	7.6	19.0	8.9	5.0	2.7	2.7	2.4	29
B2	894	29.0	57.3	29.0	21.8	29.0	13.3	29.0	3.5	29.0	4.8	4
Form: Griffin												
A1	401	48.7	7.4	19.6	7.0	20.2	7.8	5.6	2.6	2.0	0.7	9
B1	715	52.6	7.1	17.4	6.8	20.4	7.2	5.5	3.5	2.1	1.4	16
B2	715	52.6	7.1	17.4	6.8	20.4	7.2	5.5	3.5	2.1	1.4	16
Form: Clovelly												
A1	366	45.7	3.7	15.0	3.6	27.0	3.7	8.0	1.6	1.7	0.9	3
B1	860	47.7	6.6	10.5	3.6	28.7	5.8	8.4	5.1	2.2	0.9	10
B2	1200	43.0	2.0	16.5	1.5	31.5	6.5	7.0	2.0	2.0	1.0	2
Form: Longlands												
A1	400	24.3	5.9	33.0	1.4	26.0	5.7	7.3	0.5	6.0	0.8	3
E1	450	25.5	13.5	34.0	5.0	29.0	10.0	6.0	1.0	5.0	0.0	2
B1	1201	53.8	5.8	23.7	2.0	13.7	1.9	2.5	0.5	2.7	1.3	4
Form: Swartland												
A1	300	49.0	0.0	26.5	1.5	14.0	1.0	4.5	0.5	2.5	0.5	2
B1	809	52.8	10.7	20.4	8.7	14.0	4.6	3.9	1.7	3.0	1.6	11
Form: Glenrosa												
A1	200	45.0	0.0	24.0	0.0	25.0	0.0	2.0	0.0	3.0	0.0	1
B1	755	46.0	1.0	19.0	4.3	25.3	2.0	3.7	1.9	2.7	1.3	4
Form: Inhoek												
A1	446	40.2	8.3	20.0	8.8	13.3	5.3	4.3	2.4	2.0	0.8	6
B1	642	48.2	5.6	17.0	9.9	12.5	6.5	2.5	1.5	1.5	0.5	5

Table 16.7 Means and standard deviations of five particle size classes for soils of the tillite of the Dwyka Formation with a sandy loam to sandy clay loam textural class.

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												
A1	343	16.2	5.6	13.1	7.8	43.2	6.2	18.9	5.3	8.1	3.7	9
B1	819	24.6	5.5	12.4	7.1	37.2	6.3	15.7	9.2	9.0	6.8	20
Form: Griffin												
A1	346	15.5	5.4	10.6	4.3	43.8	8.4	17.4	9.5	10.5	4.2	8
B1	816	18.9	5.0	12.2	5.0	44.1	9.7	10.9	4.4	11.6	8.5	9
B2	816	18.9	5.0	12.2	5.0	44.1	9.7	10.9	4.4	11.6	8.5	9
Form: Clovelly												
A1	277	12.8	5.0	10.3	4.1	42.8	6.5	21.8	6.5	10.6	3.1	21
B1	754	17.5	7.0	11.3	5.1	39.0	8.2	16.8	6.2	14.2	6.7	27
B2	1180	18.5	1.1	17.3	3.1	36.5	4.6	14.0	2.5	12.5	4.9	4
Form: Avalon												
A1	316	16.9	6.1	12.1	10.9	40.7	11.1	20.3	9.1	8.9	4.1	15
B1	686	24.5	8.1	13.1	10.1	40.7	11.1	20.3	9.1	8.9	4.1	15
B2	1381	23.6	7.8	14.7	3.6	41.0	5.7	12.8	4.7	7.5	4.2	7
Form: Longlands												
A1	270	19.6	26.4	16.1	7.4	44.4	8.0	17.1	6.3	8.4	3.6	14
E1	584	14.2	4.5	15.6	9.1	45.9	13.3	15.8	7.9	10.3	4.3	20
B1	972	20.7	6.8	16.6	5.7	36.0	7.0	14.2	5.8	10.8	4.7	9
Form: Estcourt												
A1	335	14.2	5.4	10.7	5.3	46.5	11.9	17.9	6.5	9.0	6.9	13
E1	482	7.6	3.9	11.8	4.5	47.2	5.7	18.8	7.6	11.8	5.3	5
B1	822	24.6	.5	4.4	6.8	39.2	3.5	13.9	5.2	6.6	4.1	11
Form: Swartland												
A1	318	25.9	8.5	10.1	3.3	42.7	10.4	13.0	3.7	5.6	3.3	9
B1	620	33.1	7.1	10.8	3.9	37.4	6.2	12.3	4.0	5.2	2.6	10
Form: Glenrosa												
A1	323	21.3	6.8	12.7	5.2	45.1	10.5	13.3	5.8	7.6	5.7	31
B1	707	26.4	8.8	15.4	4.3	40.3	12.2	10.6	4.2	6.4	5.0	12

Table 16.8 Means and standard deviations of five particle size classes for soils of the tillite of the Dwyka Formation with a loam textural class.

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: Longlands												
A1	425	21.2	6.0	32.8	1.6	30.2	6.1	8.3	2.1	5.5	1.0	6
E1	525	15.0	4.6	39.3	3.5	32.5	5.9	7.3	0.4	5.5	1.8	4
B1	1000	25.0	0.0	41.0	0.0	26.0	0.0	4.0	0.0	4.0	0.0	1
Form: Glenrosa												
A1	283	17.7	2.0	34.7	1.7	25.7	9.7	8.7	2.4	18.7	22.2	3

Examination of the textural properties of the Hutton, Griffin and Swartland soils gives a range of clay contents from between 10 to 70 percent (Figures 16.4, 16.5 and 16.9). The silt values commonly range from between 5 and 30 percent. Then there are a small number of profiles in the loam textural class (Figures 16.7 and 16.9). The separation of the clay and the sandy clay to sandy clay loam classes is clear in the Swartland B1 horizon (Figure 16.9). This separation is less apparent in the case of the B1 horizons of the Hutton (Figure 16.5) and Griffin soils (Figure 16.4). Since the range of variation is relatively large, threshold values for their separation at 35 percent clay and 45 percent total sand divide this range at a central point. For the Hutton, Griffin and Clovelly soils the clay textural class is encountered largely in KwaZulu-Natal, while the sandy loam class is largely present in Mpumalanga. However, there is some overlap to this general observation such that localities alone could not be effectively used in any separation of natural soil groupings.

In keeping with the format adopted elsewhere, the ranges in textural properties (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented for each of the three natural soil bodies (Tables 16.3, 16.4 and 16.5). This information is presented graphically (Figures 16.2, 16.3). The figures allow for an overview comparison between different soil forms and over particle size classes. The irregularities in textural properties in tillite are to be expected. In the selection of the three groupings the range of variation is reduced. The means and standard deviations of five particle size classes, and for each of the textural groupings is presented (Tables 16.6, 16.7 and 16.8). When examining the textural data of soils derived from tillite of the Dwyka Formation, and when viewed in general terms, the range of variation is not much larger than that encountered in certain of the other sedimentary materials.

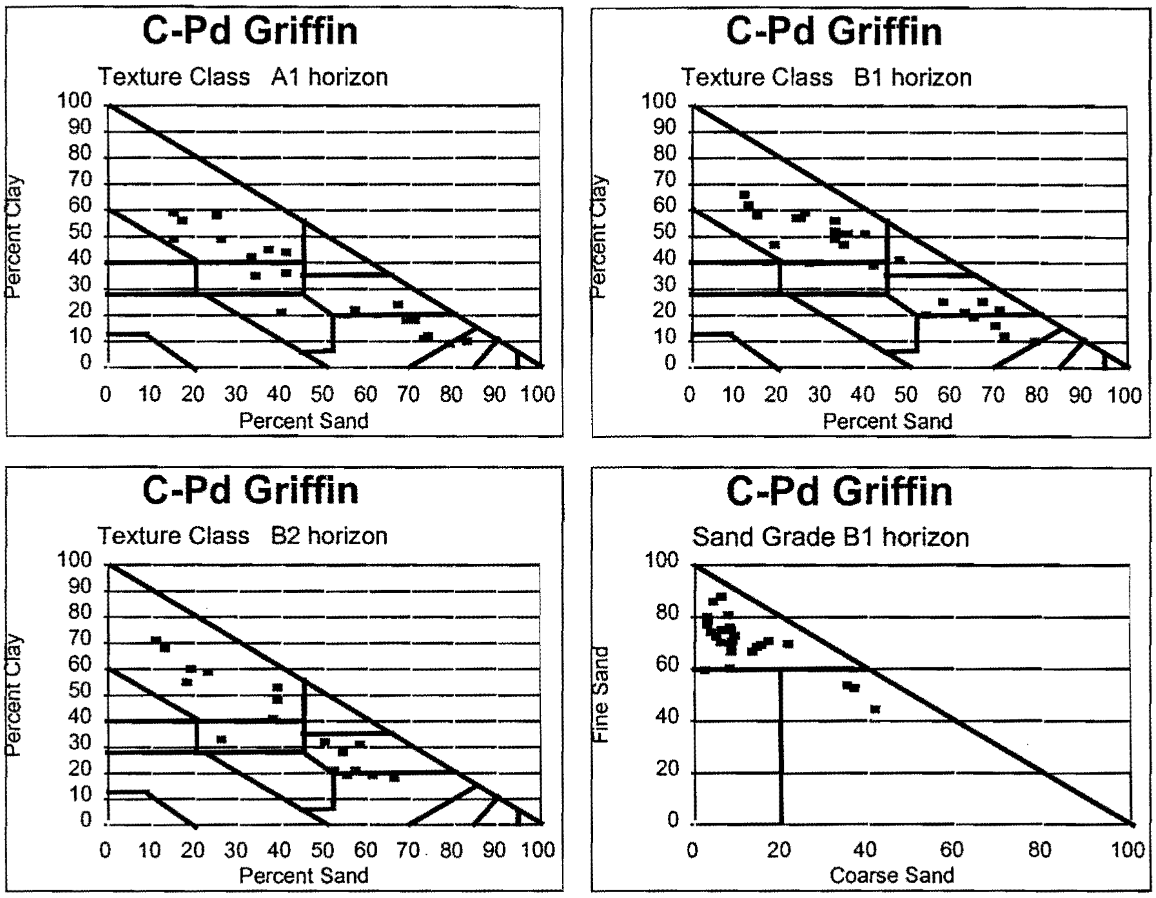


Figure 16.4 Distribution of soil textures, and dominant sand grade, within soils of the Griffin Form.

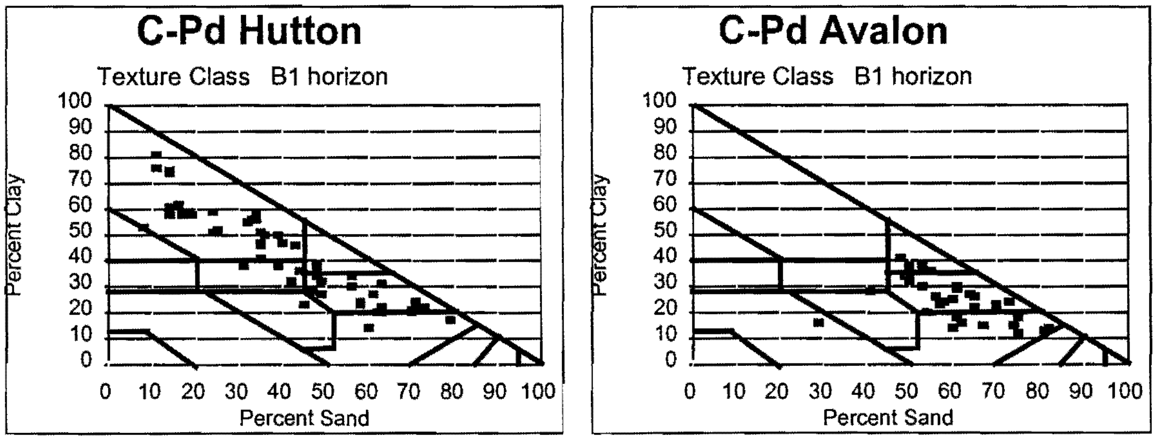


Figure 16.5 Distribution of soil textures within soils of the Hutton and Avalon Forms.

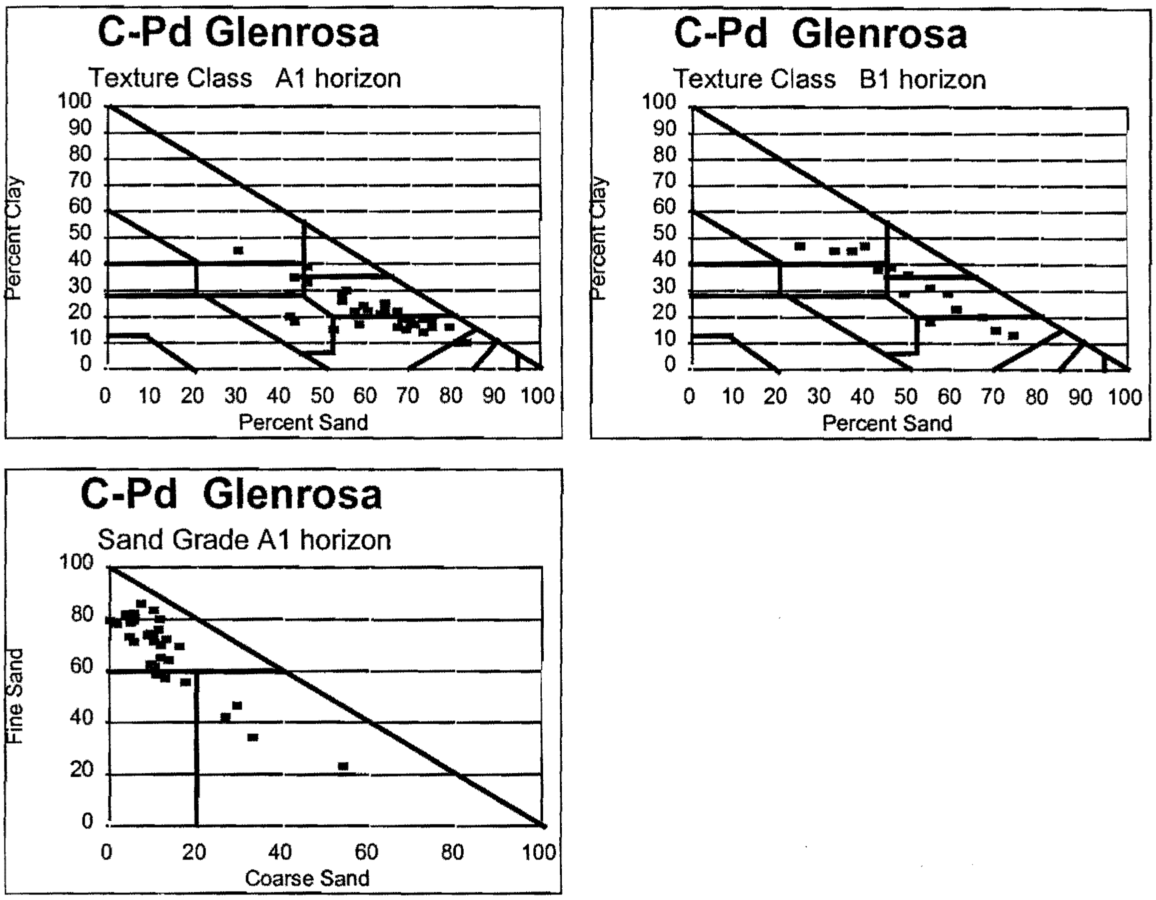


Figure 16.6. Distribution of soil textures, and dominant sand grade, within soils of the Glenrosa Form.

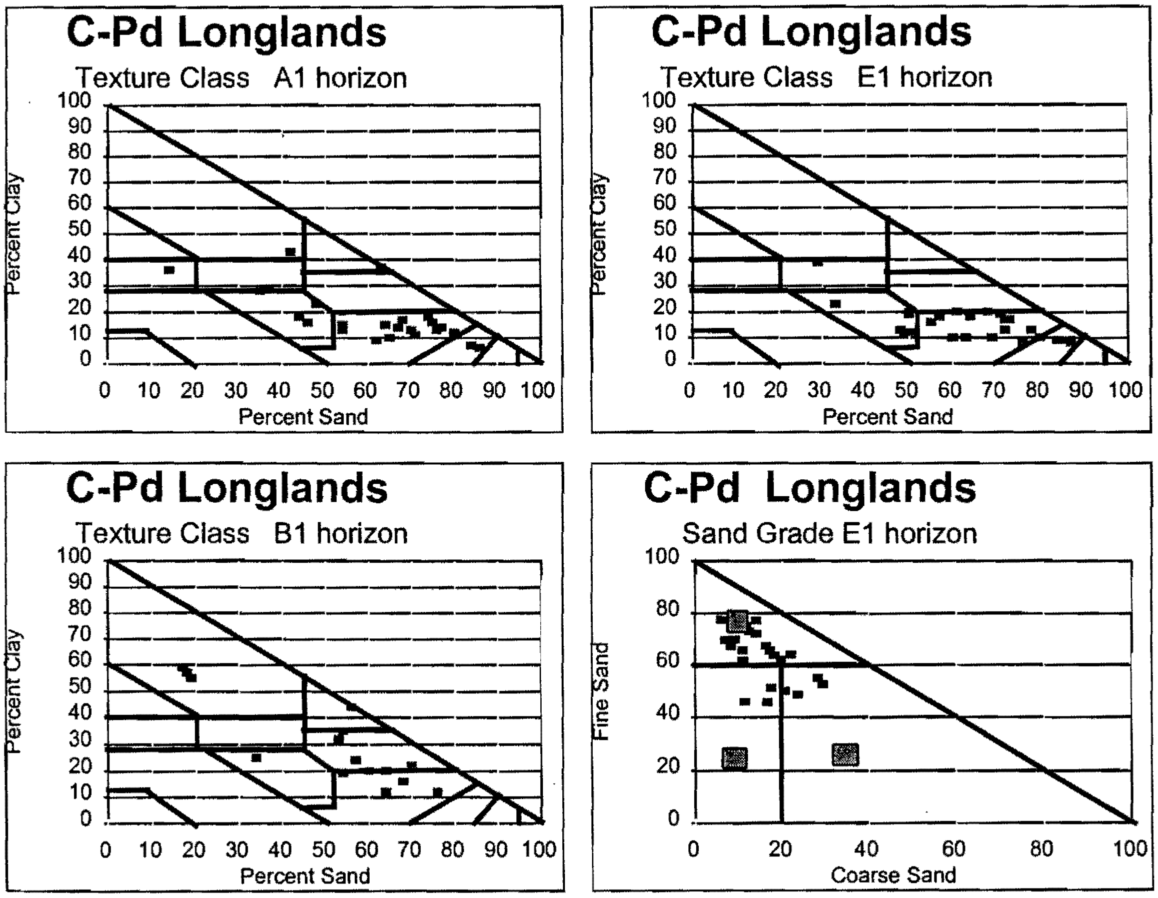


Figure 16.7. Distribution of soil textures, and dominant sand grade, within soils of the Longlands Form.

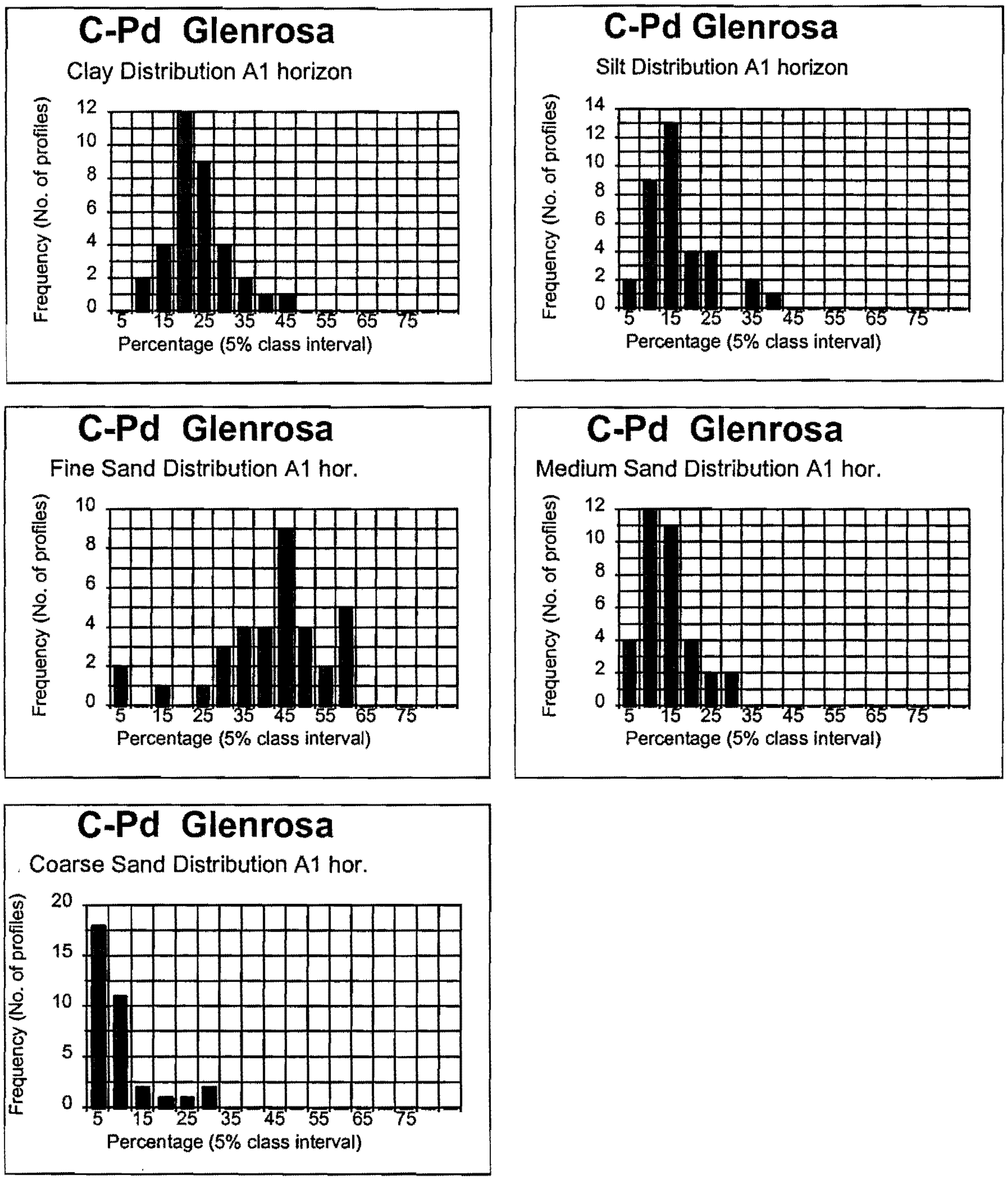


Figure 16.8 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Glenrosa Form.

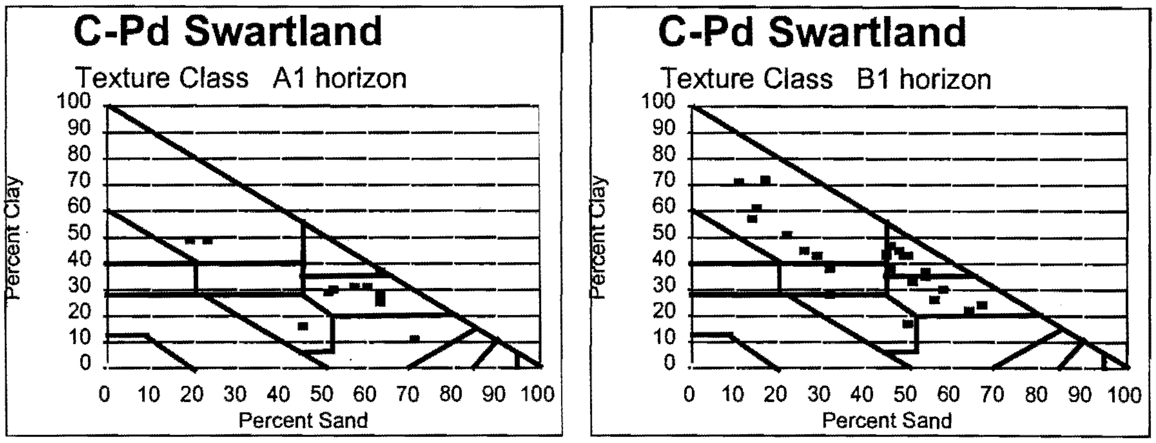


Figure 16.9 Distribution of soil textures within soils of the Swartland Form.

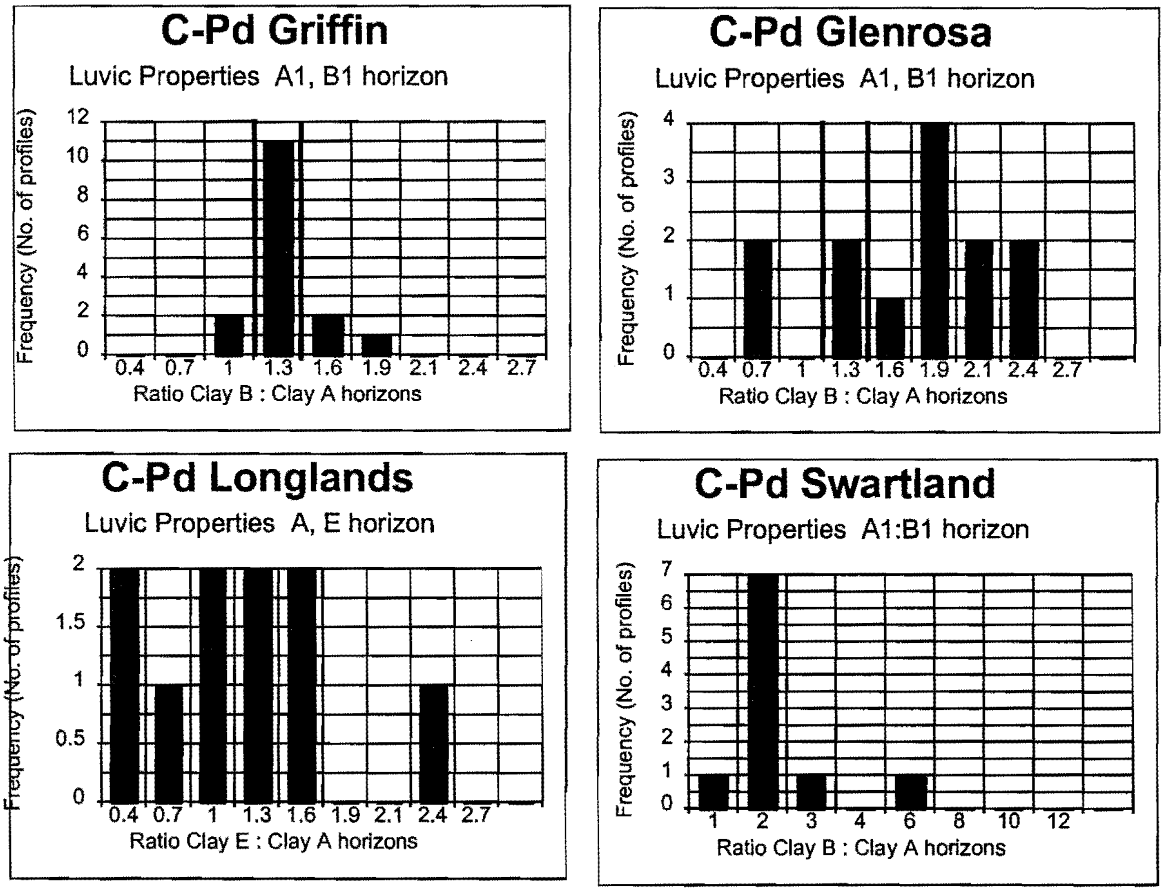


Figure 16.10 Luvic properties of soils of the Griffin, Glenrosa, Longlands and Swartland Forms.

CHAPTER 17

SOILS OF THE SANDSTONE OF THE NATAL GROUP IN KWAZULU-NATAL

Location and Extent

The Natal Group sandstones can be envisaged as lying in two essentially parallel belts in the coast belt and coast hinterland (Geological Survey, 1984). In the stratigraphic column the Natal Group rests on the basement granites, and below the tillites of the Dwyka Formation. Extensive faulting and down warping of the coast (Maud, 1968) has taken place giving rise to the sharp, but commonly irregular boundaries with these geological strata. Sandstones of the Natal Group are commonly exposed as flat to undulating tablelands, bounded by steep escarpments. The apparent uplifting of the geological stratigraphy of the province, and the reported monoclinal structure of the coastal belt, may be helpful in visualising the distribution and properties of soils derived from sandstones of the Natal Group. A clear description of this geomorphology is given by Van der Eyk, *et al.* (1969). The boundaries of these sandstones are thus strongly influenced by the resultant faulting and down weathering of the resultant strata. The northern extent of the Natal Group lies in the Mfolozi River valley north of Mtubatuba. The coastal extent of the Natal Group stretches southwards over the tablelands of Melmoth, Eshowe and Ndwedwe, through Durban to southern KwaZulu-Natal. In the interior stretching southwards from Kranskop through to the Oribi and Maringa Flats and into northern Pondoland are further occurrences of these sandstones. The eastern margins of these tablelands are often in elevated positions and experience a cool, misty climate with deeply weathered soils.

Geology and Geomorphology (Geology Symbol Abbreviation **O-Sn**)

The Natal Group rocks are predominantly greyish-white generally flat laying sandstones resting on the basement granite and gneiss (Geological Survey, 1980). They extend southwards from near the Mfolozi River into Pondoland. The Natal Group has been correlated with the Table Mountain succession in the South Western Cape, while associations with the Waterberg sandstone have also been suggested (SACS, 1980).

In the main outcrop area, which stretches from Hibberdene in the south to Eshowe in the north, five formations have been recognised (SACS, 1980). Three of these formations (Inanda, Mlazi and Eshowe Formations) contain largely felspathic and micaceous sandstone (SACS, 1980). They represent approximately 85% of the total reported thickness of the Natal Group and should dominate their surface extent. Their influence on the sandy through to sandy clay texture of the soils formed from Natal Group sandstone rocks is thus of important significance. The remaining two formations (Hibberdene and Mkunya Formations) are relatively thin and consist of white quartz sandstone. Should these formations be located on flat terrain, base poor and sandy Mispah, Cartref and Fernwood soils could be expected. South of Hibberdene the Natal Group is not known to be divisible into distinct lithostratigraphic units (SACS, 1989). The establishment of mappable lithostratigraphic units consisting essentially of a single rock type has proved difficult across the main outcrop area (SACS, 1980). Published maps give only the Natal group as a single unit.

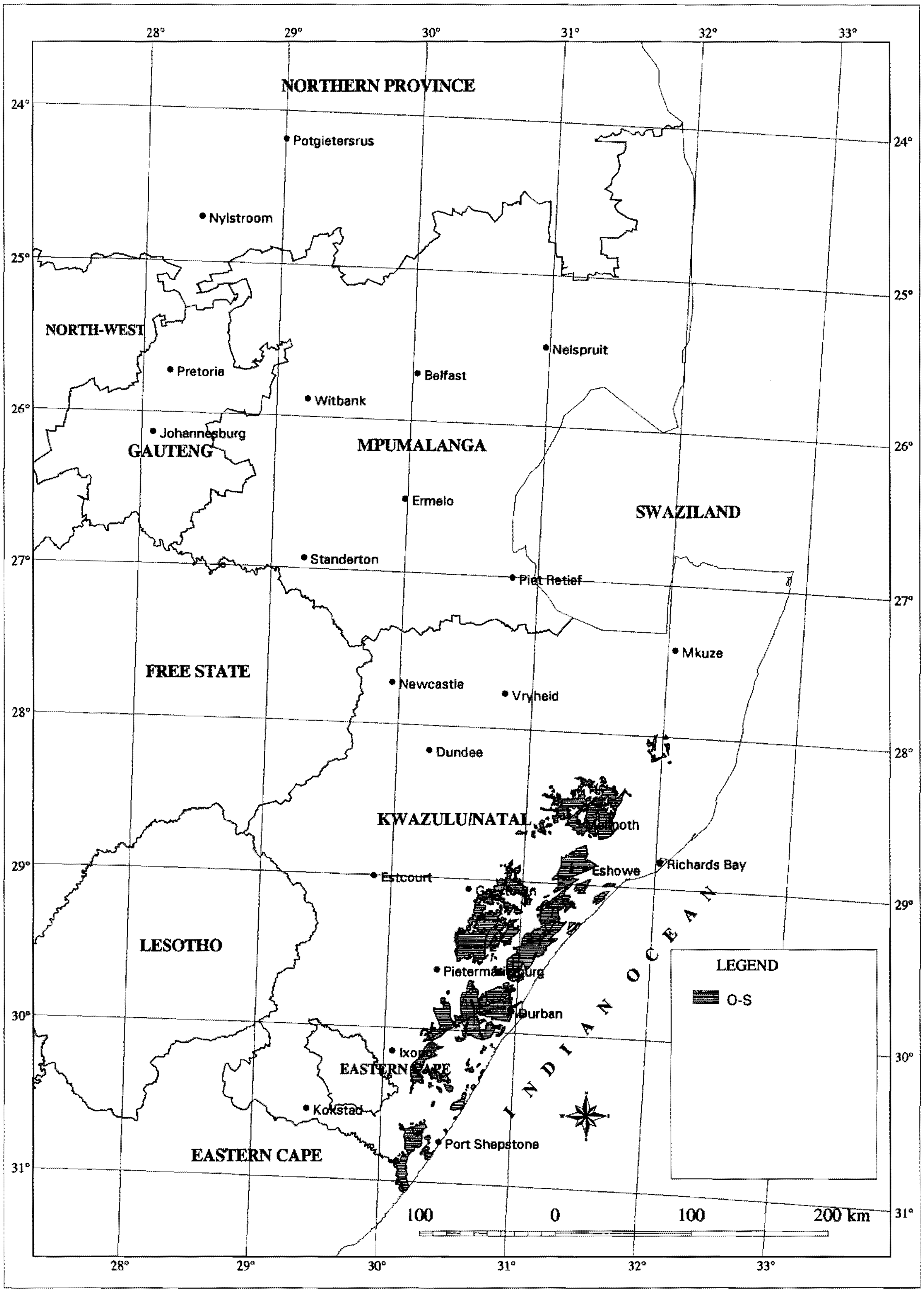


Figure 17.1. Location of the Natal Group in KwaZulu-Natal (after Geological Survey, 1984).

The Natal Group is described as comprising red-brown course to fine-grained arcosic sandstone, light-grey quartz arenite, micaceous sandstone, small pebble conglomerate, grit, subordinate siltstone and mudstone (Geological Survey, 1988c; Geological Survey, 1988d). In the northern Eshowe district the Natal Group sandstone assumes a maroon colour (Geological Survey, 1988b).

Many of the zones supporting thick humic soils are considered as of the African Surface (Partridge and Maud, 1987).

Physiography and Drainage Features

The terrain morphology of the exposures of the sandstones of the Natal Group varies from zones of relatively level land to steep low mountains. There are numerous examples of tablelands in the coast belt, the coast hinterland and in the interior where slopes of the order of 2 to 8 percent are common. These gentle sloping surfaces, usually with a favourable climate, form zones of high agricultural activity. Examples are the Eshowe and Ntumeni Plateaux in the north, the Sipepho Plateau in the central coastal zone, and the Oribi and Maringa Flats in the south. Incision of these sandstone surfaces has also given rise to undulating land of moderate relief, as encountered in the Melmoth and Kranskop Districts, in the interior at Bruyns Hill and Glenside, and in the south at Umbumbulu. The greater extent of the Natal group sandstones occurs on terrain of this nature. The level plateaux are usually bounded by steep escarpments zones. Examples of these escarpments are at Fields Hill west of Durban, and at Mtonjaneni over the Mfolozi Valley.

Vegetation

Vegetation of the plateaux is described as Short Mistbelt Grassland (Low and Rebelo, 1996). The vegetation of many of coast hinterland plateaus could be expected to support similar grassland, although it has been altered by agricultural activity. The vegetation of the drier river valleys is described as Coast-Hinterland Bushveld (Low and Rebelo, 1996).

Soils

Five major soil patterns are evident on the arcosic, micaceous and quartzitic sandstones of the Natal Group (Table 17.1). These include a red and yellow-brown apedal soil pattern where humic dystrophic soils predominate. Similar red and yellow-brown apedal soil pattern zones, but with orthic A horizons, are commonly located adjacent to but inland of these humic zones. Plinthic soils are not widespread on sandstones of the Natal Group. They do however, occur in a relatively narrow belt in the interior, in the Wartburg District (Land Type Survey Staff, 1994a), where E horizon soils are dominant. This is in contrast to other geology formations, notably the Vryheid Formation, where plinthic soils occupy relatively larger areas of the interior basins. Lithosols, comprising Glenrosa, Mispah and Cartref soils, without lime cover extensive areas of the interior valleys and of the coast belt. Lastly lithosols with duplex soils with the presence of lime are located in the drier interior valleys (Table 17.1).

The Natal Group sandstone commonly formed tablelands elevated above the surrounding countryside, and bounded by fairly steep scarps. Humic soils are widespread on those cool, moist and elevated tablelands that are first exposed to the easterly rain-bearing winds. Erosional

Table 17.1 Dominant soils and selected climatic information for Soils Patterns of the Natal Group.

Soil Patterns						Climate Relationships (Annual Values)				
Dominant Soils			Sub-dominant Soils							
Form	Series	Mean %	Form	Series	Mean %	Statistic	Rain fall mm	Evaporation mm	Heat Unit deg. day	Aridity Index
Broad Soil Pattern: Red and Yellow-brown Dystrophic Soils with a humic horizon										
Inanda	Ia10 Ia11	20	Glenrosa	Gs14 Gs17	21	Ave	1028	1515	3187	0.68
Kranskop	Kp10 Kp11	7	Mispah	Ms10		Std	129	109	367	0.08
Magwa	Ma10 Ma11	4				Max	1257	1789	4061	0.84
Nomanci	No10 No11	20				Min	760	1281	2534	0.52
Hutton	Hu16 Hu17	9								
Griffin	Gf11 Gf12	4								
Clovelly	Cv16 Cv17	3								
Total Area: 75 300 Ha			Means of 18 Land Types							
Broad Soil Pattern: Red and Yellow-brown Dystrophic Soils with an orthic horizon										
Hutton	Hu16 Hu17	36	Inanda	Ia10 Ia11	4	Ave	967	1536	3129	0.63
Griffin	Gf11 Gf12	8	Kranskop	Kp10 Kp11	2	Std	128	103	339	0.10
Clovelly	Cv16 Cv17	9	Magwa	Ma10 Ma11		Max	1156	1738	3859	0.76
			Nomanci	No10 No11	4	Min	640	1292	2469	0.37
Glenrosa	Gs14 Gs17	23								
Mispah	Ms10	4								
Total Area: 122 660 Ha			Means of 21 Land Types							
Broad Soil Pattern: Plinthic Soils with an E horizon										
Longlands	Lo21 Lo22	21				Ave	864	1550	2737	0.56
Wasbank	Wa21 Wa22	4				Std	54	135	226	0.07
Westleigh	We21 We22	9				Max	940	1787	3051	0.65
Avalon	Av24 Av26	6				Min	799	1421	2366	0.48
Glencoe	Gc24 Gc26									
Glenrosa	Gs14 Gs17	17								
Cartref	Cf21 Cf22	14								
Mispah	Ms10	8								
Kroonstad	Kd14 Kd17	3								
Total Area: 34 040 Ha			Means of 6 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime										
Glenrosa	Gs14 Gs15 Gs16 Gs17	33	Hutton	Hu16	6	Ave	938	1556	3457	0.61
			Oakleaf	Oa16	4	Std	160	133	447	0.12
Cartref	Cf20 Cf21 Cf11 Cf31	23	Kroonstad	Kd14	3	Max	1409	1813	4456	-
						Min	570	1266	2469	0.37
Mispah	Ms10	10								
Total Area: 363 700 Ha			Means of 101 Land Types							
Broad Soil Pattern: Lithosols with duplex soils with the presence of lime										
Glenrosa	Gs14 Gs15 Gs16 Gs17	29	Swartland	Sw31 Sw41	4	Ave	724	1693	3808	0.43
			Valsrivier	Va31 Va41	4	Std	111	50	166	0.08
Cartref	Cf20 Cf21 Cf31	16	Kroonstad	Kd14	3	Max	980	1738	4081	0.62
Mispah	Ms10	19	Sterkspruit	Ss24 Ss26	1	Min	640	1592	3529	0.37
Rock	Rock	7								
Total Area: 33 320 Ha			Means of 9 Land Types							

stripping of the humic soils should also not have occurred to expose fresh to poorly weathered sandstone. These humic soils have very characteristic thick humic A horizons. Significant darkening of the A horizon to depths in excess of 600 mm, and even to 1 metre have been recorded. Inanda form soils dominate, (Table 17.1) where red apedal B horizons are present below the A horizons. Since it has been the usual practice not to give prominence to intergrades, the field pedologist must determine the lower boundary of the darkened A horizon. Increasing reddening of the profile over a diffuse boundary is commonly noted. Associated with this reddening are dark brown to yellow-brown colours in a transitional A/B horizon. This somewhat yellowish transitional horizon has usually not been assigned prominence and the diagnostic sequence of Humic A Horizon over Red Apedal B Horizon has been used. Where the thickness of the yellow horizon is greater, Kranskop and Magwa soil forms have been recognised (Table 17.1).

The thick humic A horizon soils occupy cooler, moist climate zones. The elevated levels of organic carbon of between 1.8 and 6 percent reflect these present climate features. They are considered as occupying the Early Tertiary erosion surfaces (Partridge and Maud, 1987). The deep weathering, low base status and the unusually thick A1 horizons with high organic carbon levels are considered as evidence of a long period of soil formation of these soils (MacVicar, Fitzpatrick and Sobczyk, 1984). Similar red and yellow-brown dystrophic apedal soils but with orthic A horizons are thought to occupy the Later Tertiary erosional land-surfaces (Partridge and Maud, 1987). It may be speculated that some measure of erosional stripping of the soil surface has taken place with removal of the organic matter rich soil horizons. The subsequent extent of accumulation of organic matter may be assumed to have been insufficient to develop the elevated levels of organic carbon over the larger A horizon depths.

The orthic A soil zones are located in slightly drier climates or at altitudes a little lower than corresponding humic zones. This may be illustrated below. At Melmoth the orthic soil group is located inland of the humic zones at Eshowe (and hence has a lower effective rainfall) and lower in altitude to an adjacent humic soil zone at KwaMagwaza. At Bruyns Hill and Glenside (north east of Pietermaritzburg) orthic topsoils are located in adjacent landscapes below the crest ridges which bear humic soils. Humic soils are not widespread on the Natal Group sandstones in the Kranskop area, although it is from this area that the thick humic Kranskop soil takes its name. Here orthic topsoils dominate. The orthic topsoil group has formed in the moist, humid climate capable of sustaining intensive arable cropping. The climate is nevertheless slightly drier than that of the humic zones. Casual observation would indicate that the humic soils are located where mist is frequently experienced. The fact of this drier climate is not well illustrated in Table 17.1 where climate statistics are derived over a wide geographical extent and with inherent variation. The differences could be better explained by referring to climate statistics of selected humic and orthic soil zones.

Within the humic soil zones Inanda, Kranskop, Magwa and Nomanci soils dominate (Table 17.1). Glenrosa and Mispah soils occupy subdominant proportions and are usually present on the steeper slopes, or associated with exposures of fresh sandstone, where erosional soil loss may be assumed to have taken place.

The red and yellow-brown apedal soil patterns with an orthic horizon show many similarities to those of the humic soils. Hutton, together with Griffin and Clovelly soils dominate (Table 17.1). Humic soils may occupy isolated remnant crest or lowland colluvial positions. These Hutton,

Table 17.2 Textural properties of soils of the Natal Group derived from profile values.

Form	Horizon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Humic Soils	A1	SaLm-SaClLm-ClLm-Cl	12-57	6-47	8-61	1-36	1-24	fi,me,co	NL3, L2
	A2	SaLm-SaClLm-ClLm-Cl	12-47	6-33	19-40	5-35	1-18	fi,me,co	-
	B1	SaLm-SaClLm-ClLm-Cl	6-73	3-34	6-44	1-32	1-50	fi,me,co	NL3, L1,EL1
	B2	SaLm-SaClLm-ClLm-Cl	10-64	8-9	14-73	5-35	2-18	fi,me,co	-
Inanda	A1	SaLm-SaClLm-ClLm-Cl	13-57	6-33	18-61	3-36	2-24	fi,me,co	NL3,L2
	A2	SaLm-SaClLm-ClLm-Cl	17-47	7-33	19-32	7-35	1-18	fi,me,co	-
	B1	SaLm-SaClLm-ClLm-Cl	6-51	3-33	16-34	2-32	1-23	fi,me,co	-
	B2	SaLm-SaClLm-ClLm-Cl	10-55	5-14	16-73	5-35	4-18	fi,me,co	-
Kranskop	A1	SaLm-SaCl-ClLm	12-36	6-47	8-43	4-26	2-17	fi,me,co	NL3,L2
	A2	SaLm-SaCl-ClLm	12-38	6-30	23-37	6-30	4-13	fi,me,co	-
	B1	SaLm-SaCl-Cl	13-73	5-34	6-44	1-26	1-20	fi,me,co	NL3,L2
	B2	SaLm-Cl	23-64	4-21	14-42	7-23	2-15	fi,me,co	-
Magwa	A1	SaLm-SaCl	18-40	6-19	18-44	5-34	2-21	fi,me,co	L3, NL2
	A2	SaClLm-SaCl	31-39	15-17	22-30	5-29	2-6	fi,me,co	-
	B1	SaClLm-SaCl	22-42	5-19	15-31	6-31	3-50	fi,me,co	-
Orthic Soils	A1	Sa-LmSa-SaClLm-Lm	6-45	2-41	8-54	1-34	1-30	fi,me,co	NL3, L2
	B1	Sa-SaClLm-Cl	7-65	1-97	6-50	1-38	1-27	fi,me,co	-
Hutton	A1	LmSa-SaCl-ClLm-Lm	9-45	2-41	8-54	1-31	1-24	fi,me,co	NL3,L2
	B1	LmSa-SaLm-SaCl-Cl	10-65	1-97	6-50	1-38	1-18	fi,me,co	-
Griffin	A1	SaLm-ClLm-Cl	17-42	9-40	15-37	7-33	2-15	fi,me,co	NL1,L1,EL3
	B1	SaLm-ClLm-Cl	15-60	9-31	16-40	8-32	1-14	fi,me,co	L5
	B2	SaCl-ClLm-Cl	36-47	16-24	15-23	10-21	3-11	fi,me,co	-
Clovelly	A1	SaLm-SaCl	6-36	6-24	19-41	16-34	5-30	fi,me,co	NL3, L2
	B1	SaLm-SaCl-Cl	7-63	8-19	16-38	5-31	2-27	fi,me,co	-
Oakleaf	A1	SaLm-SaCl	19-37	6-11	19-24	18-30	10-24	fi,me,co	-
	B1	Sa-SaClLm-Cl	4-75	5-14	13-53	3-31	1-21	fi,me,co	-
Eluvic Horizon Soils	A1	Sa-SaLm	3-17	2-23	22-46	16-46	7-38	fi,me,co	NL3, L1,EL1
	E1	Sa-SaClLm	3-27	1-13	19-77	21-47	2-38	fi,me,co	-
	B1	Sa-SaLm-SaCl-Cl	5-50	3-12	20-33	15-46	7-46	fi,me,co	-
Cartref	A1	Sa-SaLm	3-17	4-23	24-46	16-46	7-26	fi,me,co	EL3,NL1,L1
	E1	Sa-SaLm	3-17	3-13	28-44	24-47	2-31	fi,me,co	L3,NL2
	B1	Sa-SaLm	5-21	5-12	25-32	25-46	13-18	fi,me,co	-
Kroonstad	A1	Sa-SaLm	7-10	2-9	22-32	36-40	12-38	fi,me,co	EL4,NL1
	E1	Sa-SaClLm	5-27	1-10	19-77	21-41	3-38	fi,me,co	L5
	B1	LmSa-Cl	13-50	3-9	20-33	15-37	7-46	fi,me,co	-
Nomanci	A1	SaLm-SaClLm-Cl	12-51	6-38	9-40	1-31	1-24	fi,me,co	NL3,EL2
	A2	SaLm-SaCl	16-37	6-12	28-40	23-26	2-12	fi,me,co	-
Glenrosa Mispah	A1	LmSa-SaLm-SaCl-Cl	7-52	6-25	18-89	11-42	3-25	fi,me,co	-
	B1	LmSa-SaLm-SaCl-Cl	4-51	6-17	16-51	7-35	1-11	fi,me,co	-

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).

Griffin and Clovelly soils, while having dystrophic base status, will commonly have lower organic carbon levels and a thinner A horizon depth. Textural properties are similar, although mean clay percentages for the orthic group of soils are between five and ten percent lower than the humic group.

Soils of the plinthic pattern are located over a limited surface extent in the Wartburg District.

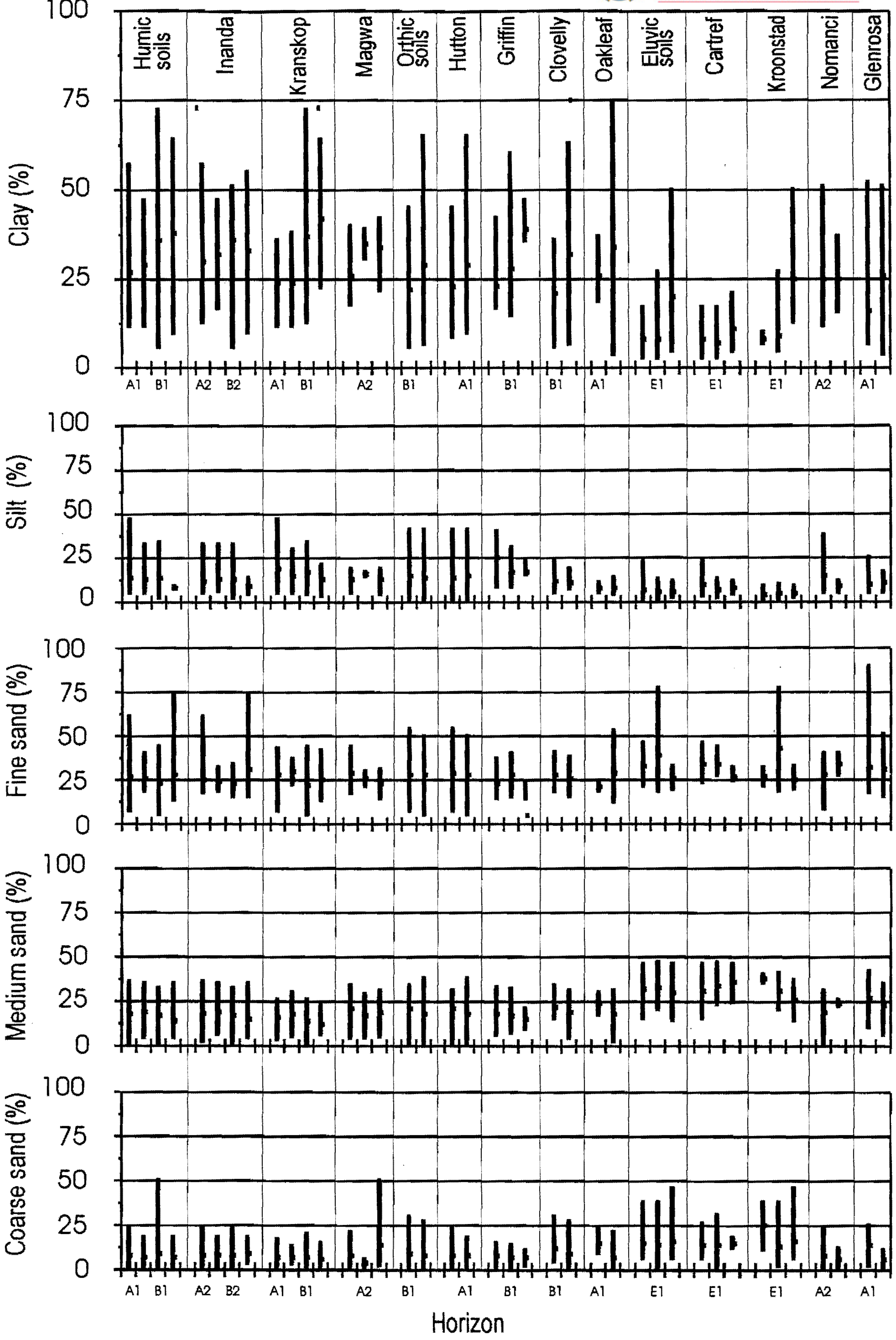


Figure 17.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of the Natal Group. Maximum, minimum and mean values are shown for each horizon.

Longlands, Wasbank and Westleigh soils are dominant (Table 17.1), together with other E horizon soils including Cartref and Kroonstad. Glenrosa and Mispah soils are also subdominant. Avalon and Glencoe soils with yellow-brown B1 horizons are estimated to occupy only small proportions of the landsurface (Table 17.1). This is somewhat in contrast to the soil pattern sequences of other sandstone geology formations where yellow-brown apedal soils occupy the moist subhumid zones, and E horizon soils occupy the drier subhumid zones. Furthermore, plinthic soils with maximal accumulation of iron and manganese oxides are widespread within the KwaZulu-Natal Interior Basins, and the Mpumalanga Highveld. Plinthic soils, and occurrences of ferricrete, are somewhat isolated in soils of the Natal Group sandstone (Land Type Survey Staff, 1988c; 1994a; 1994b). Occurrences of ferricrete, possibly of a relic nature, are present at the base of soil profiles at Wilsons Cuttings, Oribi Flats.

Grey coloured Glenrosa, Cartref and Mispah soils are dominant in the lithosolic soil patterns of the Natal Group sandstones. These soils have similar morphology and textural properties. Bleaching of the surface horizons, often not noted in the early profile descriptions, are common soil features. The transition from the A to E horizons is commonly gradual to diffuse and their classification is often subjectively based on the limited organic matter accumulation and on soil depth. In this soil pattern Kroonstad and Katspruit soils may occupy bottomland positions. An Oakleaf soil, possibly indicative of the initial stages of ferralitic weathering is sometimes present in certain upland sites.

In the semi-arid areas of the Mfolozi Valley similar lithosols are present, together with a greater proportions of rock. In addition, the bottomlands are occupied by duplex soils of the Swartland, Valsrivier and Sterkspruit forms. Lime is present in some of these duplex soils.

Physical Properties of Natural Soil Bodies: Textural Properties

The textural properties for soil profiles with thick humic A horizons, with orthic A horizons, and with Eluvial (E) horizons have been collectively extracted from the database and grouped by soil form. Their attribute values are given (Tables 17.2, 17.3). The textural properties of soil profiles from the Inanda, Kranskop and Magwa forms with thick humic A horizons have been reported separately after this Humic grouping. Textural properties of soil profiles from the Hutton, Griffin, Clovelly and Oakleaf forms are reported in the Orthic soil group. Similarly Cartref, and Kroonstad soils are reported in the Eluvial (E) horizon soil group. Finally textural properties for Nomanci, Glenrosa and Mispah are reported (Table 17.2 and 17.3). The trends for the respective individual soil forms within the Humic (Inanda, Kranskop and Magwa), Orthic (Hutton, Griffin, Clovelly and Oakleaf) and E horizon (Cartref, Longlands and Kroonstad) soil groups are similar. For brevity only the textural triangle graphs (Figures 17.3 to 17.6) for the Humic, Orthic and E horizon soils have been presented.

The ranges in textural properties, (maximum and minimum values) for five particle size classes, dominant sand grade, and information on the luvic properties are presented. (Table 17.2). These ranges are also presented graphically (Figure 17.2). The figure allows for overview comparisons between different soil forms over the particle size classes.

Soils with a humic A horizons have sandy loam through sandy clay loam to the lower end of the clay textural class as dominant in the A1 through to B2 horizons (Figure 17.3). There is little change in the minimum values for soils with a thick humic horizon (Table 17.2), with a

Table 17.3 Means and standard deviations of five textural classes for soils of the Natal Group.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Humic Soils												
A1	562	27.8	9.9	14.7	8.6	27.5	8.1	18.7	8.0	8.4	5.4	76
A2	612	29.9	8.7	13.9	6.9	26.8	5.1	19.3	7.8	7.5	4.6	31
B1	1091	36.3	12.0	14.2	7.5	23.4	7.5	17.0	8.2	9.1	8.7	38
B2	1321	38.1	15.9	8.5	0.5	28.7	15.2	14.8	8.4	7.9	4.9	13
Form: Inanda												
A1	494	30.9	10.0	12.5	5.9	25.9	7.3	18.7	7.5	8.5	5.5	34
A2	607	32.0	8.1	13.9	7.2	24.5	3.3	19.0	7.3	8.1	5.1	19
B1	1153	36.2	10.2	13.1	7.3	23.7	4.7	17.6	8.0	8.0	5.6	21
B2	1283	33.2	16.4	9.0	2.9	31.8	19.1	15.8	10.1	9.8	5.0	6
Form: Kranskop												
A1	442	24.9	7.4	19.8	12.0	28.1	8.1	16.1	6.9	7.6	4.6	13
A2	564	24.7	8.4	15.4	7.2	30.1	4.5	18.7	8.4	7.6	2.8	7
B1	963	37.7	17.3	17.1	8.0	22.6	12.0	14.3	8.2	7.5	6.4	10
B2	1270	42.6	15.4	13.0	7.0	25.8	11.7	12.8	6.3	6.0	4.7	5
Form: Magwa												
A1	596	26.4	7.2	13.4	4.6	29.4	9.1	21.3	8.3	8.7	6.0	8
A2	630	35.0	4.0	16.0	1.0	26.0	4.0	17.0	12.0	4.0	2.0	2
B1	1091	34.6	6.5	13.0	5.7	23.6	5.8	19.1	7.6	14.6	14.9	7
Form: Orthic Soils												
A1	497	22.9	8.2	15.9	9.8	28.0	8.8	21.0	6.6	9.8	6.1	57
B1	900	29.6	12.1	14.9	13.1	28.0	8.1	18.8	7.2	8.8	4.8	67
Form: Hutton												
A1	479	23.3	9.6	14.4	10.1	29.7	9.9	21.2	7.3	8.7	6.1	29
B1	928	29.1	11.6	15.4	16.6	28.8	9.2	18.8	7.9	8.7	4.9	37
Form: Griffin												
A1	504	23.4	6.3	25.0	8.7	23.4	7.0	18.0	6.1	8.0	3.8	11
B1	842	28.4	12.7	17.8	7.5	28.0	5.9	17.8	6.1	7.9	3.8	14
B2	1292	39.0	4.2	17.6	2.8	20.3	3.3	15.1	3.4	7.6	2.2	7

Table 17.3 continued. Means and standard deviations of five textural classes for soils of the Natal Group.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Clovelly												
A1	522	21.7	6.1	12.8	5.2	28.2	6.6	22.6	5.0	12.7	6.2	17
B1	886	32.0	12.2	11.4	3.7	26.1	6.6	19.6	6.1	9.9	5.3	16
Form: Oakleaf												
A1	356	26.3	7.7	8.7	2.0	21.7	2.0	24.0	4.9	15.3	6.2	3
B1	983	34.1	20.7	8.3	2.9	29.7	11.2	18.4	7.7	7.8	5.8	9
Form: Soils with an Eluvic Horizon												
A1	347	8.6	3.1	7.3	5.1	33.3	7.7	32.8	7.5	15.9	8.7	16
E1	818	8.5	6.0	6.1	3.7	39.4	14.4	33.2	7.9	14.0	9.6	15
B1	961	20.9	13.3	6.5	2.8	26.0	5.2	30.0	9.5	16.1	11.8	11
Form: Cartref												
A1	392	8.4	4.3	10.3	6.0	34.0	6.7	31.0	8.9	14.9	6.9	7
E1	907	7.6	4.7	7.3	3.8	34.4	5.2	34.9	8.7	14.3	8.6	7
B1	983	11.0	7.1	8.0	2.9	27.3	3.3	36.3	8.7	15.7	2.0	3
Form: Kroonstad												
A1	358	8.4	1.4	4.0	2.5	27.0	5.0	38.0	2.0	25.0	13.0	5
E1	740	9.3	6.9	5.1	3.3	43.8	18.0	31.8	6.8	13.8	10.4	8
B1	953	25.1	13.0	5.9	2.4	25.2	6.0	26.2	7.9	16.4	14.8	8
Form: Nomanci												
A1	733	25.3	10.7	15.5	9.5	28.8	8.3	19.5	8.7	8.5	5.5	21
A2	743	25.7	8.7	9.3	2.5	34.3	4.9	24.3	1.3	6.0	4.3	3
Form: Glenrosa/Mispah												
A1	369	16.6	10.1	10.2	4.9	32.3	14.6	27.4	7.3	14.1	6.9	20
B1	575	26.5	16.6	11.5	3.9	31.8	12.7	23.0	10.2	6.0	5.0	4

minimum value of around six to ten percent. There is however a progressive increase in the mean clay content with depth in the profile (Table 17.3) (for soils with a thick humic A horizon). This increase in clay content is substantially greater than in soils derived from the Vryheid Formation which shows similar patterns and properties for the corresponding textural triangle graphs. Silt values remain fairly constant down the profile, with maximum silt values around 35 percent (Table 17.2, Figure 17.3). Fine, medium and coarse sand fractions are represented in all soils (Figure 17.3) with about equal dominance of each of these fractions in humic soil profiles (Table

17.2, Figure 17.3). There are a few profiles with a loam to clay loam textural class (silt values greater than 30 percent). In view of the strong dominance of low to intermediate silt values, this observation was not expected.

The soils with an orthic A horizon show similar properties to those with a humic A horizon. Clay contents of the A1 horizon seem to be slightly lower than the corresponding humic soils (Table 17.3, Figure 17.5) with individual profiles within the loamy sand class. Silt values are also seldom in excess of 30 percent although individual profiles are within the loam class. Mean clay contents for the Hutton, Griffin and Clovelly soils do not show much difference with small increases down the profile (Table 17.3). There are a number of interesting Oakleaf profiles with slightly higher clay contents (and higher SD, Table 17.3) than the corresponding Clovelly soils which they closely resemble. The Oakleaf soils occur within a ferralitic weathering regime, but appear to have a youthful morphology. It is uncertain whether they have a greater reserve of weatherable minerals derived from variations in the parent sandstone.

The Cartref, Longlands and Kroonstad soils have substantially lower clay contents in the A1 and E1 horizons than the ferralitic soils (Table 17.2, Figure 17.2). Their clay contents are also lower than those of the Nomanci and Glenrosa soils (Tables 17.2, 17.3) although in a morphological sense they appear very similar. Cartref and Kroonstad soils are seldom present together with the red and yellow-brown apedal soils in the same landscape (Table 17.1). There is commonly a clear boundary between the Cartref and Kroonstad soils, and the ferralitic soils (Land Type Survey Staff, 1988c; 1994a; 1994b). They are invariably present on an erosional landsurface below the apedal soils. Rainfall is lower than in the red and yellow apedal soil zones, but may well be sufficient to sustain arable cropping. The reasons that weathering has proceeded to give rise to E horizons, with losses of iron and clay, from a parent material which has otherwise given rise to red and yellow freely drained sandy clay loams to sandy clays is uncertain. While the higher clay contents for the Nomanci soils are similar to that for the other humic soils, the higher mean clay contents for the Glenrosa soils were not expected. It would point to more intense eluvial horizon processes in the Cartref and Kroonstad soils than in the Glenrosa soils. Given their similarities in topsoil colour this speculation would require verification.

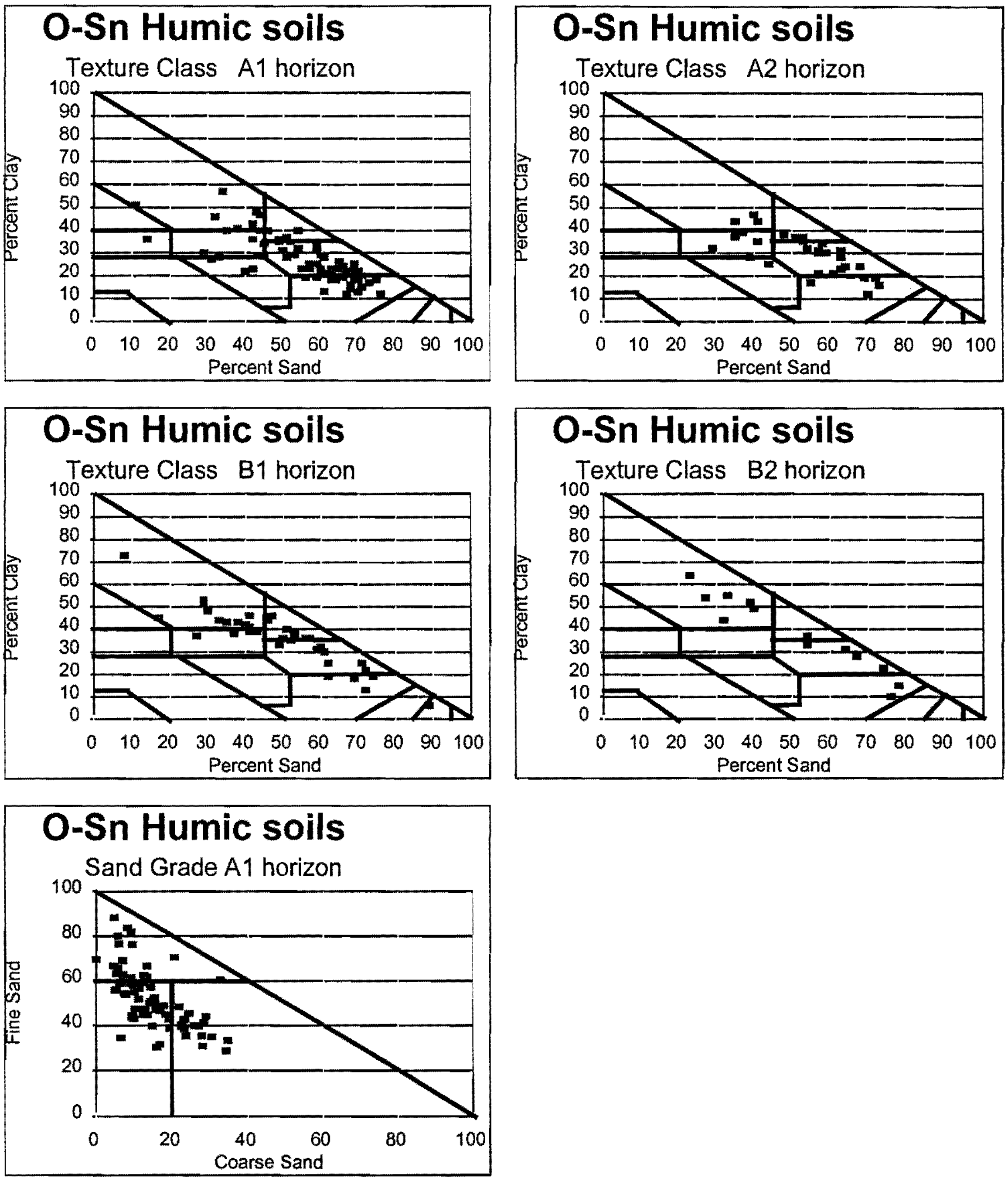


Figure 17.3 Distribution of soil textures, and dominant sand grade, for soils with humic A1 horizons, namely the Inanda, Kranskop and Magwa Forms.

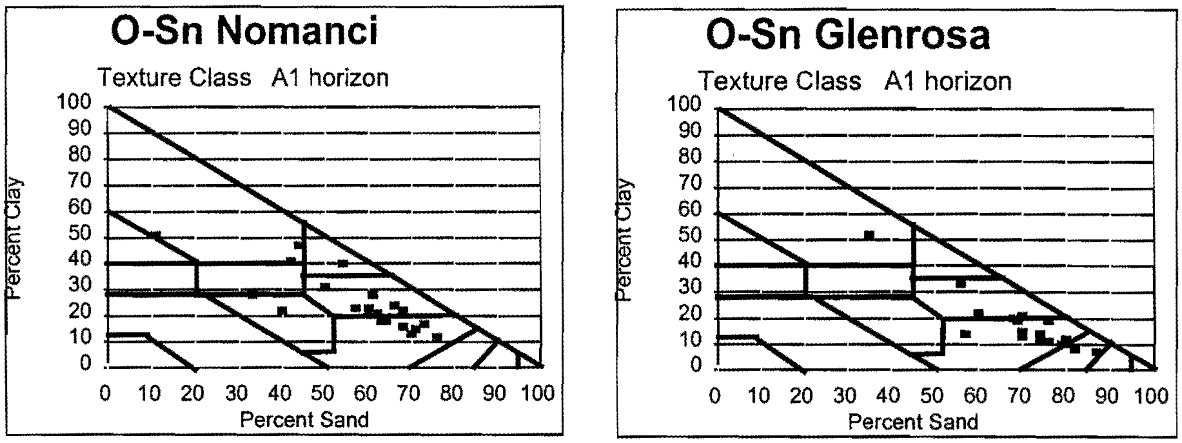


Figure 17.7. Distribution of soil textures within soils of the Nomanci and Glenrosa Forms.

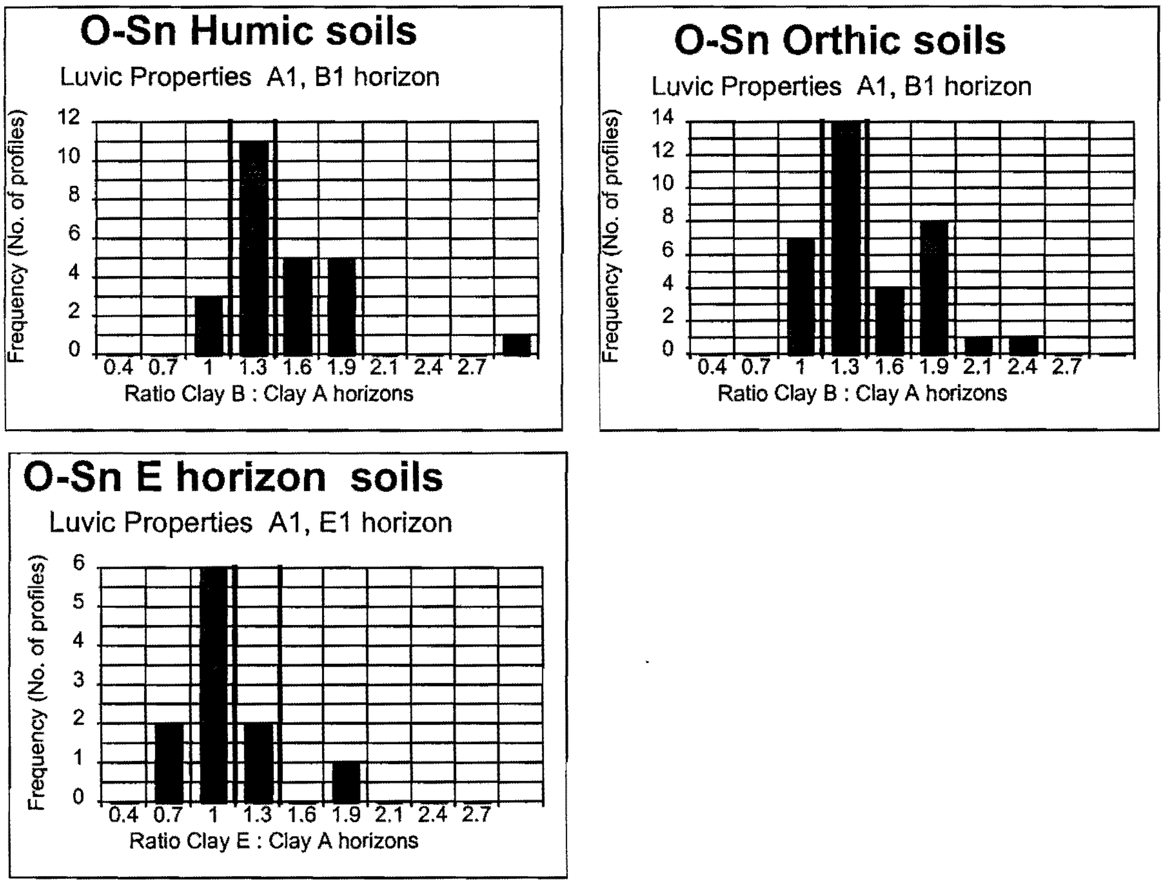


Figure 17.8 Luvic properties of soils with humic A1, orthic A1 and eluvial E1 horizons.

CHAPTER 18

SOILS OF GRANITIC ROCKS IN KWAZULU-NATAL AND SOUTHERN MPUMALANGA

Location and Extent

Granites in Southern Mpumalanga and in KwaZulu-Natal are essentially located in five broad zones and are of Swazian, Swazian to Randian, and Namibian ages (Geological Survey, 1984). The first three of these zones are located in the north of the study area and comprises an unnamed potassic granite of Swazian or Swazian-Randian age. Occurrences have been identified in the Piet Retief district, the Mfolozi River valley, and the Nkandla District (Figure 18.1). The remaining two major occurrences of granitic rocks in the study area have been collectively called the Mapumulo Metamorphic Group (Geological Survey, 1984) and are located in two north-south stretching belts in the KwaZulu-Natal Coast Hinterland (Figure 18.1). The first stretches from the Tugela River in the north to the Mgeni River in the south. The second lies to the south of the Mgeni River covering much of the Coast Hinterland of southern KwaZulu-Natal.

Granites occur over extensive areas of the Lowveld of Mpumalanga and the Northern Province (Figure 18.1) and have given rise to a range of soils complementary to those encountered in KwaZulu-Natal. To draw comparisons between the granitic soils in KwaZulu-Natal and that occurring elsewhere soil profiles from two additional granitic zones have been chosen. These are from the Goudplaats Gneiss located over large parts of the Northern Province (Figure 18.1), and a migmatite and gneiss of the Nelspruit Suite (Geological Survey, 1986) occurring in Mpumalanga.

The locations of the main granitic zones within KwaZulu-Natal are described below. The unnamed potassic granite (Symbol Z-Rg) is located in the southern parts of Mpumalanga and the northern interior basins of KwaZulu-Natal. The first of these exposures occurs from south of the Ngwempisi River in Mpumalanga, and stretches southwards into northern KwaZulu-Natal through the upper reaches of the Assegai, Pongola and Bivane River Basins. The towns of Piet Retief and Paulpietersburg are central in this zone. This region experiences a warm, and yet moist climate and is located at altitudes of between 800 and 1400 metres.

The second of these occurrences stretches over undulating terrain from the Nondweni River in the northern KwaZulu-Natal Interior Basin to south of the White Mfolozi River where undulating to steep terrain is encountered. Ulundi is located to the east of this granitic zone. The altitudes here range from 1100 metres in the interior to 550 metres in the Mfolozi River Valley. A sub-humid to a semi-arid climate is encountered. The symbol Zg has been used for this granitic zone in this text.

The third occurrence of potassic granite (Zg) is located in a steep zone east of Nkandla within the upper reaches of the Mhlatuze River. This zone is largely inaccessible with only limited soil information.

The northern exposures of the Mapumulo Metamorphic Suite, and its associated units, stretches over the coast hinterland basins of the Tugela, Mvoti and Mgeni Rivers (Geological Survey, 1984). They are described as comprising of gneiss and granulite. This zone could be described

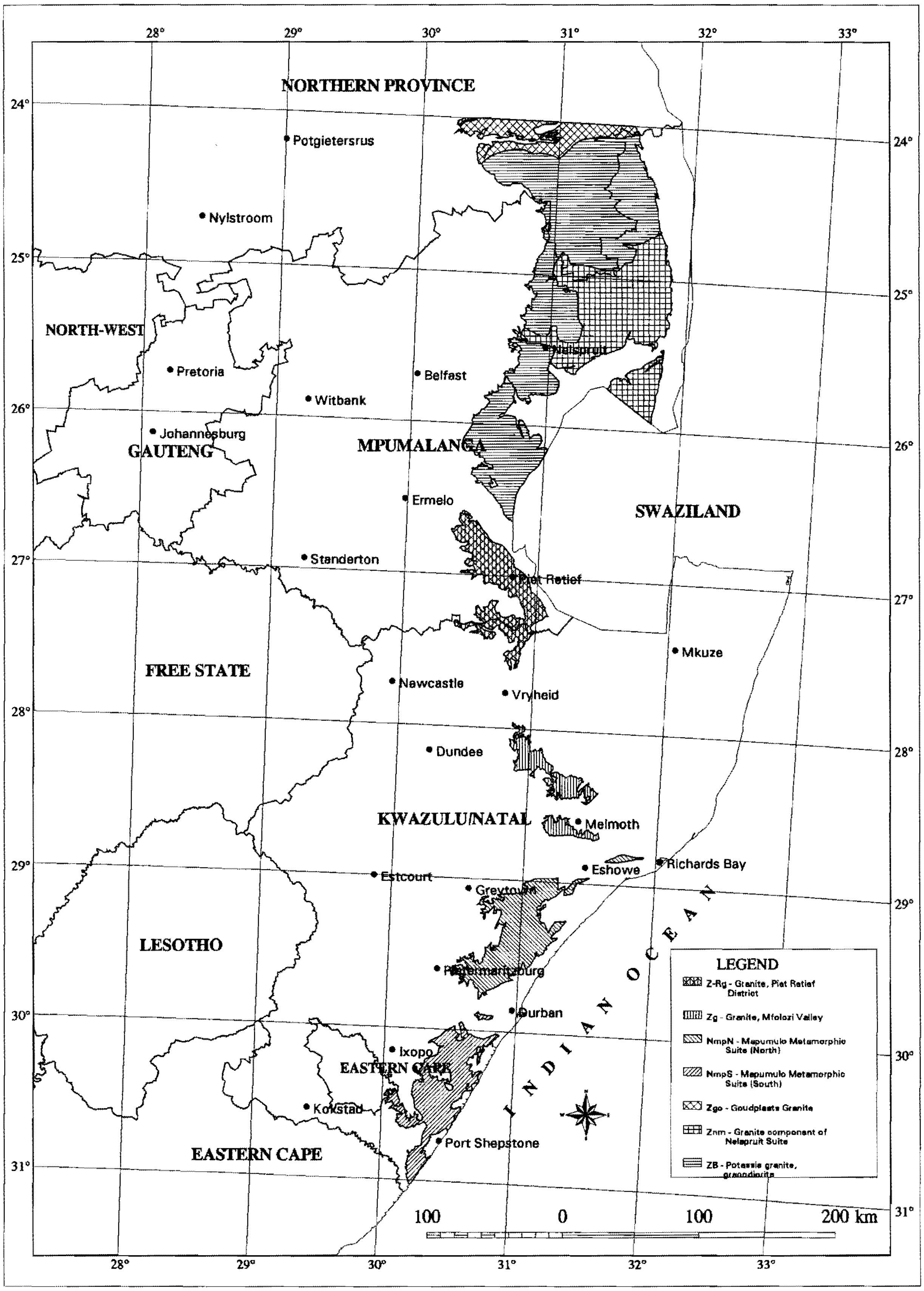


Figure 18.1. Location of granitic rocks in KwaZulu-Natal, Mpumalanga and Northern Province (after Geological Survey, 1984).

as experiencing a moist to a sub-humid climate within undulating to steep terrain. This granitic area is bounded in both the east and the west by sandstones of the Natal Group. There is a break in the exposures of these granitic rocks over an axis between Durban and Pietermaritzburg. To the south of this break granitic rocks are exposed in the Lovu, Mkomazi, Mtwalume and Mzimkulu River Valleys. Here the granites stretch right up to the coast, or are bounded by Quaternary sands, tillite of the Dwyka Formation and sandstone of the Natal Group. The granites are not exposed south of the KwaZulu-Natal border at the Mtamvuna River.

Geology and Geomorphology (Geology Symbol Abbreviation **Z-Rg**)

The 1970 Edition of the Geology map of South Africa (Geological Survey, 1970) records an extensive belt of migmatite, gneiss and ultrametamorphic rocks stretching from south of the Soutpansberg, and east of the Great Escarpment into Mpumalanga and Swaziland. The southern most occurrence of this unit (labelled AG2, Geological Survey, 1970) extends to Nondweni in the Mfolozi River Valley of KwaZulu-Natal. This zone was known as the Northern Cape and Transvaal Belt of metamorphism and granitization. South of the Mfolozi River the migmatite, gneiss and ultrametamorphic rocks were described in a single unit as the Natal Zone of metamorphism and granitization (labelled AG7: Geological Survey, 1970). Subsequent construction of the map legends on the 1984 Edition of the Geological Map of South Africa records a potassic granite and granodiorite (labelled ZB; Geological Survey, 1984) occurring over Central Mpumalanga and stretching further south in Northern KwaZulu-Natal to the Mfolozi and Mhlatuze Rivers. The Tugela Group was defined separately. The Mapumulo Metamorphic Suite now covered the greater part of the former Natal Belt of metamorphism and granitization and was now defined as comprising gneiss and granulite (Geological Survey, 1984). The location of the Mapumulo Metamorphic Suite is that shown in Figure 18.1. The Goudplaats Gneiss unit was also defined separately in the Northern Province (labelled Zgo) and comprises migmatite, gneiss and leucogranite (Geological Survey, 1984).

Mapping at the more detailed 1:250 000 scale records a number of granitic units. The medium to coarse grained biotite granite of Piet Retief District, labelled Z-Rg, is considered to be of Swazian to Randian age (Geological Survey, 1986c, Geological Survey, 1988a). The soils developed from this unit have been fairly extensively sampled and provide the most detailed soil information for this study area. To the south map legends (Geological Survey, 1988b) describe the units as granite and of Swazian age. The symbol Zg is used for recognition purposes. Specific descriptive or place names have not been recognised by the South African Committee for Stratigraphy (1980). Independent units within the Mapumulo Metamorphic Suite have been recognised from within the northern and southern zones (Geological Survey, 1988c, 1988d). Regrettably the number of soil profiles sampled from any single unit is limited and soil profiles have been collectively grouped as the Northern (NmpN) and Southern (NmpS) occurrences of the Mapumulo Metamorphic Suite (Nmp)(Figure 18.1). The profiles are derived largely from biotite gneiss (NmpN) (Geological Survey, 1988c) and coarse-grained porphyritic granite (NmpS) (Geological Survey, 1988d).

The unit of the Nelspruit Suite, labelled Znm, consists of potassic gneiss and migmatite (Geological Survey, 1986a, 1986b) (Figure 18.1).

Physiography and Drainage Features

Within the granitic areas of southern Mpumalanga Province moderately undulating plains are encountered. To the south the slopes of the Pongola Valley become steeper and undulating hills and lowlands are encountered (Kruger, 1983). This the only region within the study area on granite which has gentle to moderate slopes and consequently higher agricultural land use potentials. East of the town of Paulpietersburg the Pongola and Bivane Rivers fall into steeply incised valleys, where the terrain can be described as low mountains with only limited flatter land.

In the Nondweni District irregular undulating lowlands with hills are present, with slopes dominantly between 5 and 8 percent. However, these moderate slopes comprise only a limited area of generally shallow soils. Within the Mfolozi River Valley undulating hills and lowlands are encountered, with limited flatter slopes (Kruger, 1983).

The granitic areas of the Nkandla District comprise highly dissected low undulating mountains, drained by the Mhlatuze River. Similar highly dissected terrain with low undulating mountains are present in the valleys of the Tugela, Mvoti and Mgeni Rivers (Kruger, 1983). The dissection of the granitic areas to the south of Durban is less intense than to the north, although limited land with flatter slopes is present. Drainage is via the Lovu, Mkomazi, Mtwalume and Mzimkulu Rivers, and via numerous other smaller rivers and tributaries.

Vegetation

The vegetation of the granites exposed in the Piet Retief District is North-eastern Mountain Grassland, while in the Tugela Valley and of the Mapumulo Metamorphic Suite is Thicket and Coast-Hinterland Bushveld. In the south the vegetation where granite is exposed is Coastal Bushveld and Grassland (Low and Rebelo, 1996).

Soils

Three major soil patterns are evident on the granitic rocks of KwaZulu-Natal and southern Mpumalanga (Table 18.1). The first is a red and yellow apedal soil pattern with dominantly dystrophic soils. Recognisable within this dominantly red and yellow apedal soil pattern are similar, largely red apedal soil patterns where yellow soils are subdominant or absent, or where there are increasing proportions of lithosols, chiefly of the Glenrosa Form. Lithosols without the presence of lime occupy relatively large areas of the undulating to steep interior basin and coast hinterland. Lithosols with the presence of lime occupy restricted zones within the arid interior basins and on the dolomite and marble rocks of the Mzimkulu River Valley at Oribi Gorge.

Soil patterns with respectively red apedal Hutton soils with a sandy loam texture, plinthic soil patterns with Avalon, Longlands and Westleigh Forms, and duplex soil patterns comprising Sterkspruit, Valsrivier, Swartland and Estcourt Forms occur over extensive areas of north eastern Mpumalanga and Northern Province. They are generally located in geographic zones between the red and yellow apedal soil patterns and those of the lithosolic soil patterns. Their absence in KwaZulu-Natal can be attributed to differences in weathering intensity and weathering duration, and to differences in geomorphology and topography factors.

Table 18.1 Dominant soils and selected climatic information for soil patterns occurring on granitic rocks of the Piet Retief District (Z-Rg), Mfolozi District (Zg) within KwaZulu-Natal.

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 Soils (Piet Retief Granite Z-Rg1)										
Hutton	Hu17 Hu18	50	Glenrosa	Gs17 Gs18	7	Ave	900	1622	2961	0.55
	Hu27 Hu28	7				Std	124	164	440	0.08
Griffin	Gf12 Gf13	11				Max	1073	1479	2632	0.45
Clovelly	Cv17 Cv18	6				Min	701	1853	3584	0.63
Total Area: 52 160 Ha			Means of 6 Land Types							
Broad Soil Pattern: Red and Yellow-brown Apedal Soils with Lithosols (Piet Retief Granite Z-Rg2)										
Hutton	Hu17 Hu27	39	Avalon	Av16 Av17	12	Ave	850	1949	2166	0.43
Griffin	Gf12 Cv17	6	Glencoe	Gc16		Std	20	135	784	0.03
Clovelly						Max	873	241	3584	0.45
Glenrosa	Gs15 Gs18	16				Min	821	1853	1500	0.38
Cartref	Cf31	4								
Mispah	Ms10 Ms11	4								
Rock	Rock	8								
Total Area: 53 870 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols without the presence of lime (Piet Retief Granite Z-Rg3)										
Glenrosa	Gs15 Gs18 Gs16	43				Ave	781	1720	2673	0.45
	Gs17					Std	59	137	299	0.02
Cartref	Cf31 Cf32	8				Max	838	1853	3152	0.49
Mispah	Ms10	3				Min	700	1539	2418	0.43
Rock	Rock	17								
Total Area: 27 880 Ha			Means of 4 Land Types							
Broad Soil Pattern: Lithosols with the presence of lime (Mfolozi Granite Zg1)										
Glenrosa	Gs15 Gs18	30	Estcourt	Es15 Es34	8	Ave	737	1560	2924	0.47
	Gs14 Gs16 Gs17	9	Kroonstad	Kd15 Kd14		Std	179	81	382	0.05
Mispah	Ms10 Ms11	11	Swartland	Sw40 Va40	5	Max	1150	1710	3777	0.53
Cartref	Cf30 Cf31	8	Valsrivier			Min	594	1473	2721	0.39
Rock	Rock	6								
Total Area: 50 820 Ha			Means of 7 Land Types							

The red and yellow apedal soil pattern comprises dominantly sandy clay to clay dystrophic soils (Table 18.1, Piet Retief Zone, Z-Rg1). Soils are commonly deeply weathered where the solum grades to a soft red to pink saprolite. Stonelines of fine quartz gravel are commonly present within the solum, usually between the A and B horizons. The gravel may also be somewhat

Table 18.2 Dominant soils and selected climatic information for soil patterns occurring on granitic rocks of the Mapumulo Metamorphic Suite (NmpN, NmpS).

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 soils (dystrophic and mesotrophic) (Mapumulo Metamorphic Suite, NmpN1)										
Hutton	Hu17 Hu27 Hu26	53	Glenrosa	Gs15 Gs18	17	Ave	883	1571	3246	0.56
Oakleaf	Oa16 Oa17 Oa36	9				Std	-	-	-	-
						Max	1145	1628	3759	0.73
						Min	740	1534	2924	0.47
Total Area: 30 170 Ha			Means of 6 Land Types							
Broad Soil Pattern: Broad Soil Pattern: Lithosols with Red Apedal Soils of eutrophic base status (Mapumulo Metamorphic Suite, NmpN2)										
Glenrosa	Gs15 Gs17 Gs18	40	Hutton	Hu36 Hu37	25	Ave	840	1605	3452	0.53
Cartref	Cf31 Cf21	5	Oakleaf	Oa16 Oa17 Oa36	9	Std	112	118	480	0.08
Rock	Rock	6		Oa37		Max	1030	1813	4318	0.66
						Min	635	1473	2924	0.38
Total Area: 188 840 Ha			Means of 21 Land Types							
Broad Soil Pattern: Red Apedal Soils (dystrophic and mesotrophic base status) (Mapumulo Metamorphic Suite, NmpS1)										
Hutton	Hu17 Hu18 Hu27 Hu28	42				Ave	1027	1558-	3692	0.66
						Std	-	-	-	-
Glenrosa	Gs15 Gs18 Gs19	28				Max	-	-	-	-
						Min	-	-	-	-
Total Area: 26 230 Ha			Means of 5 Land Types							
Broad Soil Pattern: Lithosols with Red Soils of mesotrophic and eutrophic base status (Mapumulo Metamorphic Suite, NmpS2)										
Glenrosa	Gs15 Gs17 Gs18 Gs19	66	Hutton	Hu26 Hu27 Hu34 Hu35 Hu36	19	Ave	942	1500	3681	0.63
			Oakleaf			Std	184	83	204	0.14
Cartref	Cf31 Cf32	5		Oa34 Oa35 Oa36	5	Max	1231	1606	3958	0.82
						Min	647	1281	2938	0.41
Total Area: 323 530 Ha			Means of 48 Land Types							
Broad Soil Pattern: Lithosols with Red Soils of eutrophic base status (Mapumulo Metamorphic Suite, NmpS3)										
Glenrosa	Gs18 Gs28	45	Hutton	Hu36 Hu37 Hu46 Hu47	17	Ave	790	1441	3197	0.54
						Std	-	-	-	-
						Max	878	1466	3222	0.47
						Min	703	1417	3173	0.61
Total Area: 22 990 Ha			Means of 2 Land Types							

dispersed through the profile and is usually attributed to physical weathering and fracturing of quartz veins within the granitic rocks. The proportion of yellow apedal soils derived from granitic rocks is at its highest values in the Piet Retief District (Table 18.1, Piet Retief Zone, Z-Rg1). Griffin soils are dominant over the Clovelly soils. The genesis of these yellow soils is probably the result of a high (> 950 mm per annum) rainfall and misty rainfall pattern and a moderate temperature regime. The proportion of yellow apedal soils on granitic rocks decreases in the escarpment zones of northern Mpumalanga and Northern Province.

Variants of the red and yellow apedal soil pattern in the Piet Retief District have Avalon and Glencoe soils as subdominant components (Table 18.1, Piet Retief Zone, Z-Rg2). Glenrosa and Cartref soils are also estimated to occupy subdominant proportions. Other variants occupying the crestland in the Mgeni and Mvoti Valleys (Table 18.2, NmpN1) have mesotrophic red apedal soils together with the dystrophic soils, while Oakleaf and Glenrosa soils are present in subdominant proportions. The presence of mesotrophic soils could be expected with a lower effective rainfall, and a possible shorter duration of weathering. Similarities to these soil patterns derived from granitic rocks in the Mzumbe and Oribi Gorge Districts are also evident (Table 18.2, Oribi Gorge Zone, NmpS1). Distinctions derived from differences in the geological naming and mineralogy of these largely biotite granites have given rise to only limited differences in the composition of the major soil patterns developed from these rocks. Indeed the ranges and means for textural properties of the Hutton and Glenrosa profiles also shows close similarities (Tables 18.3 and 18.4).

Glenrosa soils without the presence of lime are dominant in the lithosols soil patterns (Table 18.1). Cartref soils (Table 18.1, Piet Retief Z-Rg3), and eutrophic sandy loam Hutton and Oakleaf soils, and Cartref soils (Table 18.2, NmpN2, NmpS2) are subdominant.

Lithosols with the presence of lime occur in two Broad Soil Patterns. In the Mfolozi Zone lime is generally absent in the lithosolic soils of the upland terrain positions, but is present in Swartland, Valsrivier and Estcourt soils of the lowland positions (Table 18.1, Mfolozi Zone, Zgl). However, in the marble and dolomite rocks of the Oribi Gorge Zone lime is present in soils in both upland and bottomland positions (Table 18.2, NmpS3).

Physical Properties of Natural Soil Bodies: Textural Properties

Soil profiles for Hutton, Griffin, Avalon, Longlands, Estcourt and Glenrosa Forms were extracted from the database for the granitic rocks of southern Mpumalanga and KwaZulu-Natal. The ranges in textural properties (maximum and minimum values) for five particle classes, dominant sand grade, and information on the luvic properties are presented (Table 18.3). These ranges are also presented graphically (Figure 18.2). The figure allows for an overview comparison between different soil forms and over particle size classes.

The textural properties, expressed as maximum and minimum values (Table 18.3), and mean values (Table 18.4) for the Hutton and Griffin soils in the Piet Retief district show similar ranges. The profile textures lie dominantly in the sandy clay loam, through sandy clay to clay classes (Table 18.3, Figures 18.3 and 18.4). Silt values of the A1 and B1 horizons are less than 20 percent, showing a small increase in the B2 horizon where weathering may be assumed less intense (Table 18.4). The Piet Retief granite represents a relatively large uniform body of medium to coarse grained biotite granite (Geological Survey, 1988a, symbol Z-Rg). Soil formation has taken place in a warm, moist environment, giving rise to deeply weathered kaolinitic sandy

Table 18.3 Textural properties of soils of the granitic rocks of KwaZulu-Natal derived from profile values.

Form	Hori zon	Texture Class	Clay %	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Sand Grades	Luvic Properties
Granite of the Piet Retief District (Z-Rg)									
Hutton	A1 B1 B2	SaLm-SaClLm-Cl SaClLm-SaCl-Cl Lm-SaClLm-ClLm-Cl	13-63 28-72 19-59	6-23 2-42 12-42	9-38 6-37 11-28	4-22 1-25 4-17	2-22 1-21 2-16	fi,me,co	NL2,L3 NL1,EL4 -
Griffin	A1 B1 B2	SaClLm-Cl SaClLm-SaCl-Cl Cl	30-52 28-59 41-53	10-24 6-29 10-46	11-22 12-34 6-18	5-20 1-21 1-10	2-14 1-27 1-10	fi,me,co	NL3, L1, EL1 NL5 -
Avalon	B1	SaClLm-Cl	35-51	7-13	20-40	8-11	6-6		-
Longlands/ Estcourt	A1 E1 B1	LmSa LmSa SaLm-Lm	10-12 4-12 8-35	9-14 8-9 12-21	25-26 9-25 23-28	16-16 15-16 6-18	31-38 36-62 11-32	co co	EL L -
Glenrosa	A1 B1	SaLm-SaClLm-Cl SaLm-SaClLm-Lm	17-54 17-46	6-40 14-24	6-43 15-39	11-23 9-15	1-19 8-17	me, co fi, co	-- -
Mapumulo Metamorphic Suite (NmpN)									
Hutton	A1 B1	SaLm-Lm-Cl SaLm-ClLm-Cl	13-58 34-65	10-38 10-30	9-36 11-25	7-25 2-18	7-13 4-14	co me, co	L4,NL1 -
Mapumulo Metamorphic Suite (NmpS)									
Hutton	A1 B1 B2	Lm-SaClLm-Cl Lm-ClLm-Cl SaClLm-Cl	12-51 15-61 29-61	6-35 14-34 20-25	4-73 3-32 6-26	3-15 2-14 2-11	1-21 2-17 6-15	fi, co fi, co co	NLl3, L1, EL1 -

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).

clay to clay soils. The sample set of the Hutton and Griffin soils (comprising 55 analyses from the B1 horizons) could represent central reference values for soil textures derived from biotite granite in moist, highly weathered environments. It is interesting to note that the textures are dominantly of the sandy clay to clay classes. Despite the presence of quartz in the parent rock, the high component of weatherable biotite mica provides the higher potential for clay formation. The sand grades are clustered with medium and coarse sand dominant (Table 18.3, Figures 18.3 and 18.4). Despite this dominance of coarse and medium sand, the percentage values of these sand grades are generally less than 10 and 15 percent respectively (Table 18.4). Hutton soil profiles with luvic and non-luvic properties were analysed in approximately equal proportions (Table 18.3).

The Hutton profiles sampled from the Mapumulo Metamorphic Suite of both northern and southern KwaZulu-Natal have very similar properties to those from the granite of the Piet Retief District (Z-Rg). Profiles from the Mapumulo Metamorphic Suite in northern KwaZulu-Natal have been sampled from two unnamed units comprising megacrystic biotite granite and biotite gneiss (Symbol NmpN, Geological Survey, 1988c). In southern KwaZulu-Natal Hutton profiles have been sampled from six units including those described as comprising medium to coarse grained granite, biotite gneiss, hornblende gneiss, and quartz feldspar gneiss and migmatite

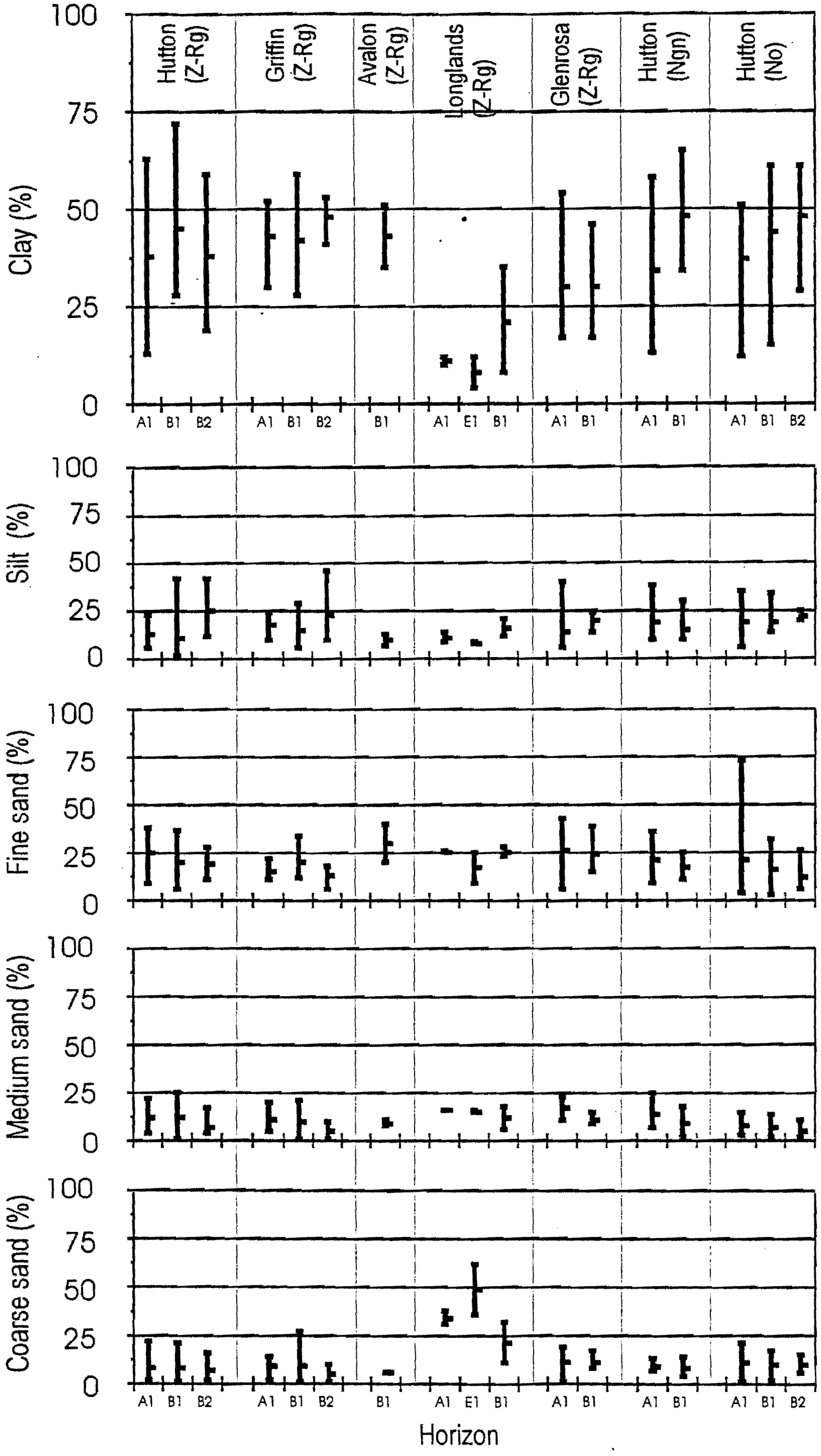


Figure 18.2 Ranges in clay, silt, fine sand, medium sand and coarse sand for soils of granite from KwaZulu-Natal. Maximum, minimum and mean values are shown for each horizon.

Table 18.4 Means and standard deviations of five textural classes for soils of the granite from KwaZulu-Natal.

Horizon	Depth	Clay		Silt		Fine Sand		Medium Sand		Coarse Sand		Sample Size
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	mm	%		%		%		%		%		
Form: Hutton (Granite of the Piet Retief District, Z-Rg)												
A1	270	38.2	14.5	13.7	4.6	25.4	8.3	12.4	5.1	8.4	4.9	12
B1	696	45.4	10.5	11.3	8.1	20.4	6.1	12.3	6.6	8.9	4.6	40
B2	942	38.8	12.4	25.0	9.4	19.2	5.1	7.8	4.2	7.8	4.2	9
Form: Griffin (Granite of the Piet Retief District, Z-Rg)												
A1	340	43.8	8.4	18.2	5.0	15.2	4.3	11.0	5.2	9.2	4.1	6
B1	660	42.9	9.7	15.1	6.7	20.2	7.0	10.6	5.9	9.5	6.3	15
B2	1025	48.8	4.7	23.0	14.0	13.3	4.5	5.5	3.6	5.8	4.3	4
Form: Avalon (Granite of the Piet Retief District, Z-Rg)												
B1	625	43.0	8.0	10.0	3.0	30.0	10.0	9.5	1.5	6.0	0.0	2
Form: Longlands/Estcourt (Granite of the Piet Retief District, Z-Rg)												
A1	325	11.0	1.0	11.5	2.5	25.5	0.5	16.0	0.0	34.5	3.5	2
E1	595	8.0	4.0	8.5	0.5	17.0	8.0	15.5	0.5	49.0	13.0	2
B1	1455	21.5	13.5	16.5	4.5	25.5	2.5	12.0	6.0	21.5	10.5	2
Form: Glenrosa (Granite of the Piet Retief District, Z-Rg)												
A1	275	30.4	12.2	14.7	10.9	26.7	11.8	17.0	4.2	11.3	5.2	7
B1	780	30.6	9.8	20.0	2.8	24.4	9.0	11.3	2.2	11.7	2.5	7
Form: Hutton (Mapumulo Metamorphic Suite, NmpN)												
A1	500	34.0	18.5	19.7	13.0	21.0	11.2	14.0	7.9	9.3	2.6	3
B1	1011	48.6	9.0	15.7	6.1	17.4	3.8	9.3	4.8	8.0	3.4	9
Form: Hutton (Mapumulo Metamorphic Suite, NmpS)												
A1	460	37.4	11.7	19.4	7.2	21.4	17.4	8.5	3.4	11.4	5.7	14
B1	915	44.5	13.2	19.5	5.8	16.6	10.1	7.5	3.9	10.7	3.7	13
B2	1112	48.8	11.9	22.5	2.5	12.5	8.0	5.8	3.6	10.8	3.5	4

(Symbol NmpS, Geological Survey, 1988d). Generally there are insufficient profiles sampled from each geological unit (Geological Survey, 1988c, 1988d) to list these texture data separately. The texture values of component units of the Mapumulo Metamorphic Suite (Tables 18.3 and 18.4) are grouped to give composite mean values. The sampled profiles are all of the Hutton Form and of dystrophic or mesotrophic base status and with kaolinitic weathering. The soil forming factors of climate and time are assumed reasonably constant. There does not appear to be differences in textural properties resulting from these differences in geological materials.

The texture properties of the Avalon soils sampled from this area fall within the same textural range as determined for the Hutton profiles (Tables 18.3 and 18.4). As the sample size is small, these data should not be extrapolated to other plinthic zones on granitic rocks.

The textural properties of the Longlands and Estcourt soils (those soils with an E Horizon) are sharply different to those of the Hutton soils (Tables 18.3 and 18.4). Although the sample size is limited (the reason for grouping of Longlands and Estcourt soils) the textures of the A1 and E1 horizons are of the loamy sand class. Coarse sand is dominant. The texture class for the B1 horizons of the Longlands and Esctourt soils are loamy sand and clay loam respectively (Table 18.3).

The texture range of the Glenrosa soils is relatively large (Table 18.3). Whilst the central class is sandy clay loam, profiles with clay and with sandy loam classes were also determined (Figure 18.6). Sand grades are both medium and coarse.

The range of soil forms that have been sampled is somewhat limited, with sampled profiles drawn largely from only the Hutton, Griffin and Glenrosa Forms. Profile values are grouped per soil form and district on the assumption of there being relative uniformity within a restricted locality with respect to parent material, weathering intensity and topography. This is reflected in the texture and base status data. The Hutton and Glenrosa profiles from the Piet Retief District (Z-Rg), and those of the Mapumulo Metamorphic Suite (NmpN, NmpS) have developed essentially clay and sandy clay textures (Table 18.3). The very limited sample set of soils having an E horizon have coarse loamy sand textures (Table 18.3). While this data is characteristic of the granite soils of KwaZulu-Natal, it does not represent the broader picture. The range of soil forms and textural properties is known to be greater than this.

Granites and granodiorites cover extensive areas of the Lowveld of Mpumalanga and Northern Province. Granitic rocks extend from the Crocodile River in southern Mpumalanga to the Soutpansberg in Northern Province. Their extent is bounded in the east by the Lebombo Mountain Range and approximately by the escarpment in the west. The 1: 1 million geological map of South Africa (Geological Survey, 1970) describes this map unit as the Transvaal Belt of granitization and metamorphism. Subsequent editions (Geological Survey, 1984) describe a number of units including the Nelspruit, Kaap Valley and Mpulusi Granites in the south, an unnamed granite in the central belt, and the extensive Goudplaats Granite in the north. Soil profiles sampled from this extensive granitic body include red and yellow apedal soils, plinthic soils, duplex soils and lithosols. A selection of Hutton and Glenrosa profiles from this sample set has been chosen to reflect the greater range of soil textures in these two soil forms. The Hutton soils from the Goudplaats Granite (Symbol Zgo) (Geological Survey 1985c, Geological Survey, 1986a) have a textural range from loamy sand through to clay (Table 18.5, Figure 18.8), while those for the Glenrosa soils are dominantly sand through sandy loam to sandy clay loam. Two Glenrosa profiles were measured to have a clay texture (Figure 18.8). Sand grades range from fine to coarse. The range for the Hutton and Glenrosa soils on the gneiss component of the Nelspruit Suite (Symbol Znm) (Geological Survey, 1986b) is much narrower (Table 18.5, Figure 18.8), and reflects essentially soil texture clusters in the sand to sandy loam classes. Individual profiles of the Hutton Form were recorded in the clay class (Table 18.5, Figure 18.8).

Table 18.5 Textures of Hutton and Glenrosa soils derived from granitic rocks of the Goudplaats Granite and Nelspruit Suite.

Form	Horizon	Texture Class	Sand Grades
Goudplaats Granite (Zgo)			
Hutton	A1	LmSa - Cl	fi, me, co
	B1	LmSa - Cl	me, co
Glenrosa	A1	Sa - Cl	fi, me, co
	B1	LmSa - Cl	fi, me, co
Nelspruit Suite (Znm)			
Hutton	A1	Sa - Cl	co
	B1	Sa - SaLm, Cl	co
Glenrosa	A1	Sa - LmSa	co

The Hutton soils in the Piet Retief District have developed in a humid climate, while those from the Nelspruit District have developed in a semi arid climate. Soils from the Goudplaats Granite occur over a wider range of climatic conditions. This would suggest a relationship between estimates of climate and soil texture properties. The sum of exchangeable cations (S/clay Ratio) or the cation exchange capacities (CEC/clay Ratio) expressed as a ratio of the clay content are commonly measured parameters expressing weathering intensity and climate (Soil Classification Working Group. 1991, ISSS, ISRIC, FAO. 1998, Soil Survey Staff. 1999). Graphs of the clay percentage against S/clay Ratio reveals an interesting trend (Figure 18.9). The graphs are for Hutton soils derived from granitic rocks from KwaZulu-Natal, Mpumalanga and Northern Province. The dystrophic soils (S/clay Ratios < 5) are concentrated in the clay region, with an absence of sandy textures. S/clay ratios of greater than 15 (eutrophic soils) have clay percentages less than 35 percent (sandier than sandy clay loam), while S/clay ratios of greater than 40 have textures sandier than sandy loam. The trend for the CEC/clay ratio plotted against clay percentage is very similar.

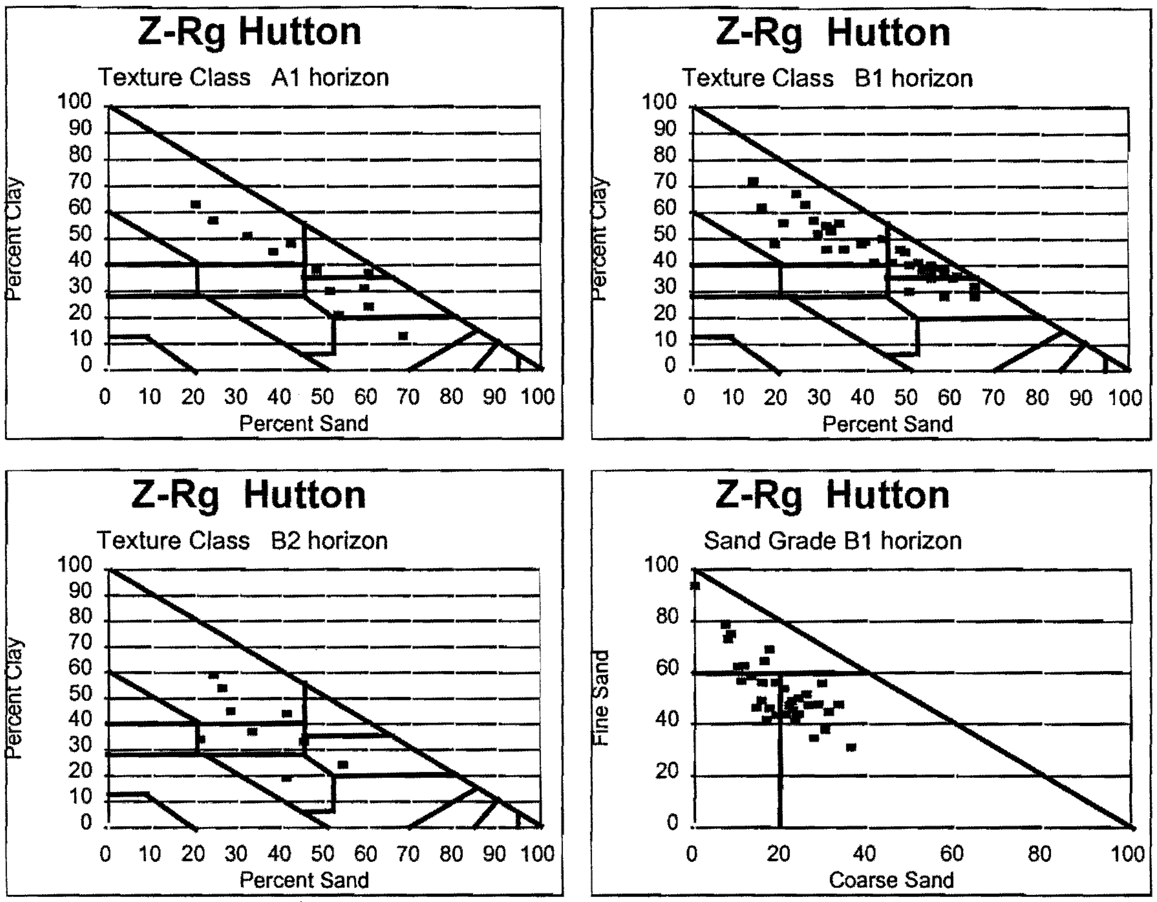


Figure 18.3. Distribution of soil textures, and dominant sand grade, within soils of the Hutton Form.

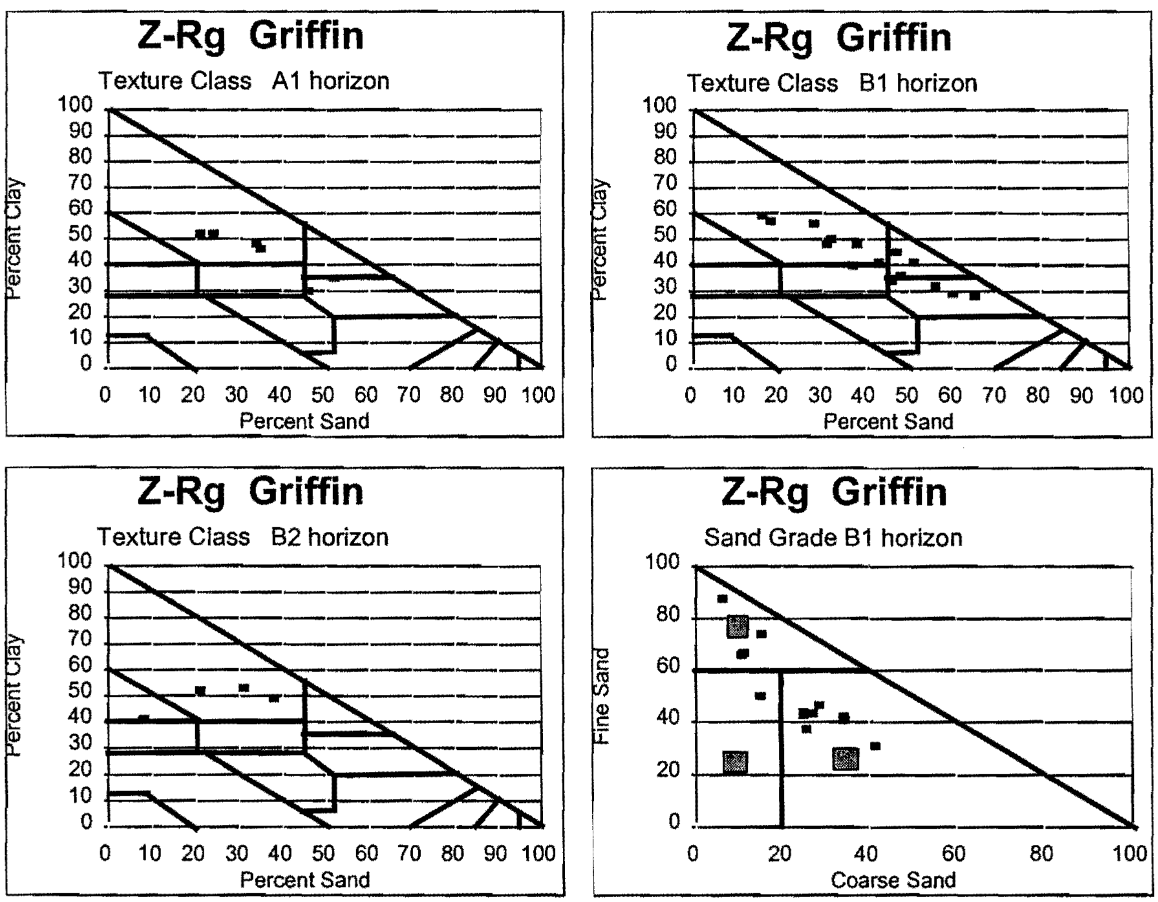


Figure 18.4. Distribution of soil textures, and dominant sand grade, within soils of the Griffin Form.

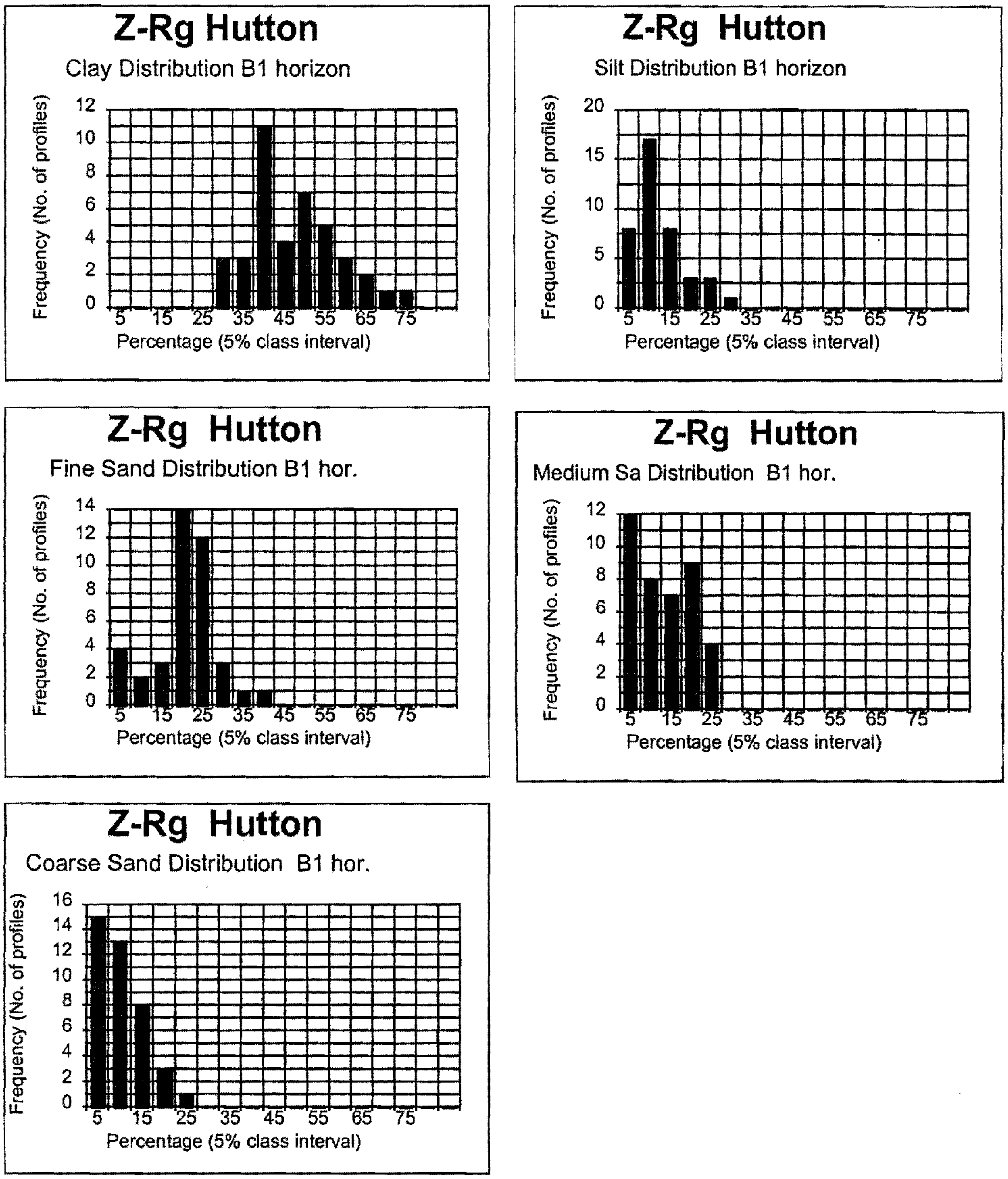


Figure 18.5 Distribution of clay, silt, fine sand, medium sand and coarse sand within soils of the Hutton Form.

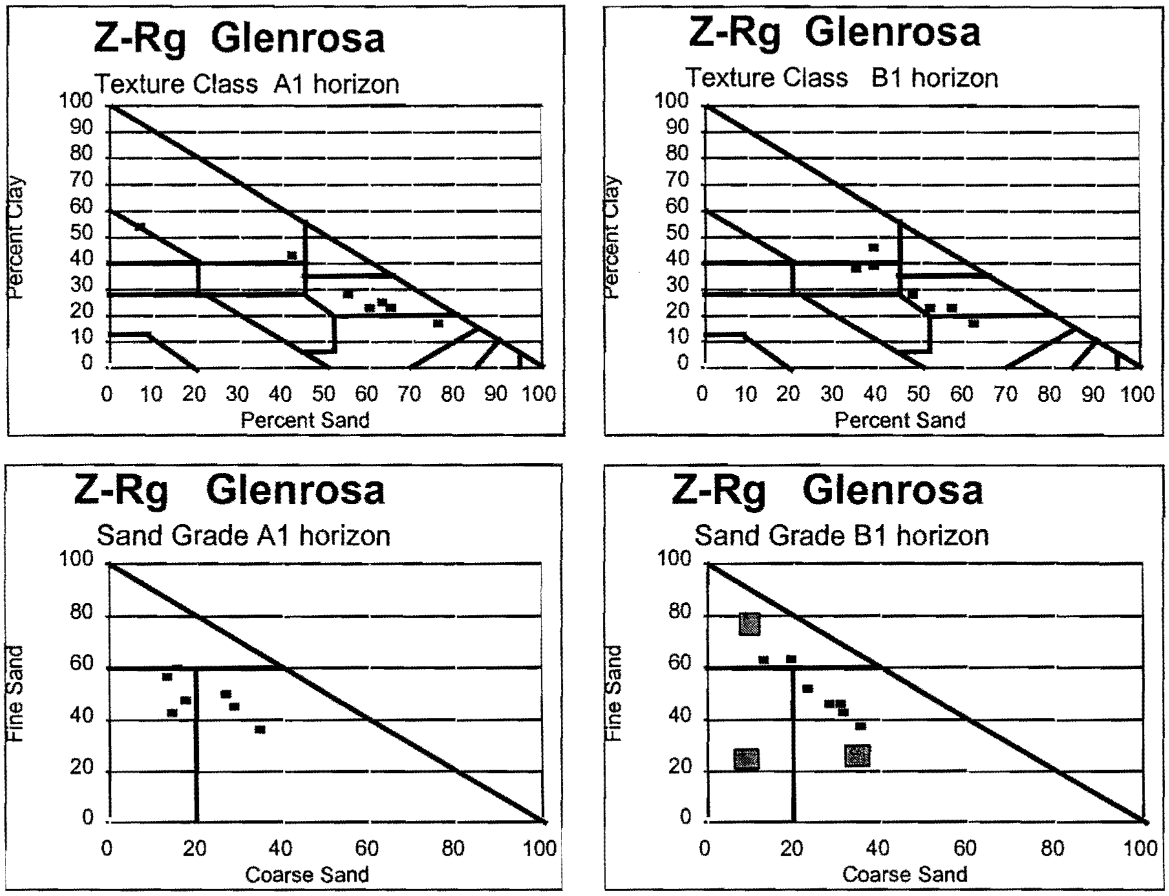


Figure 18.6 Distribution of soil textures, and dominant sand grade, within soils of the Glenrosa Form.

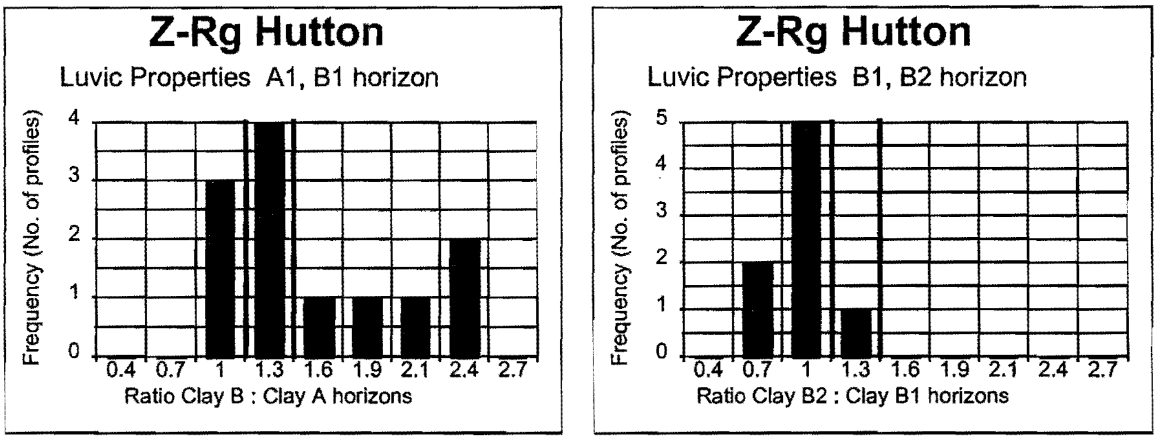


Figure 18.7 Luvic properties of soils of the Hutton, Griffin and Glenrosa Forms.

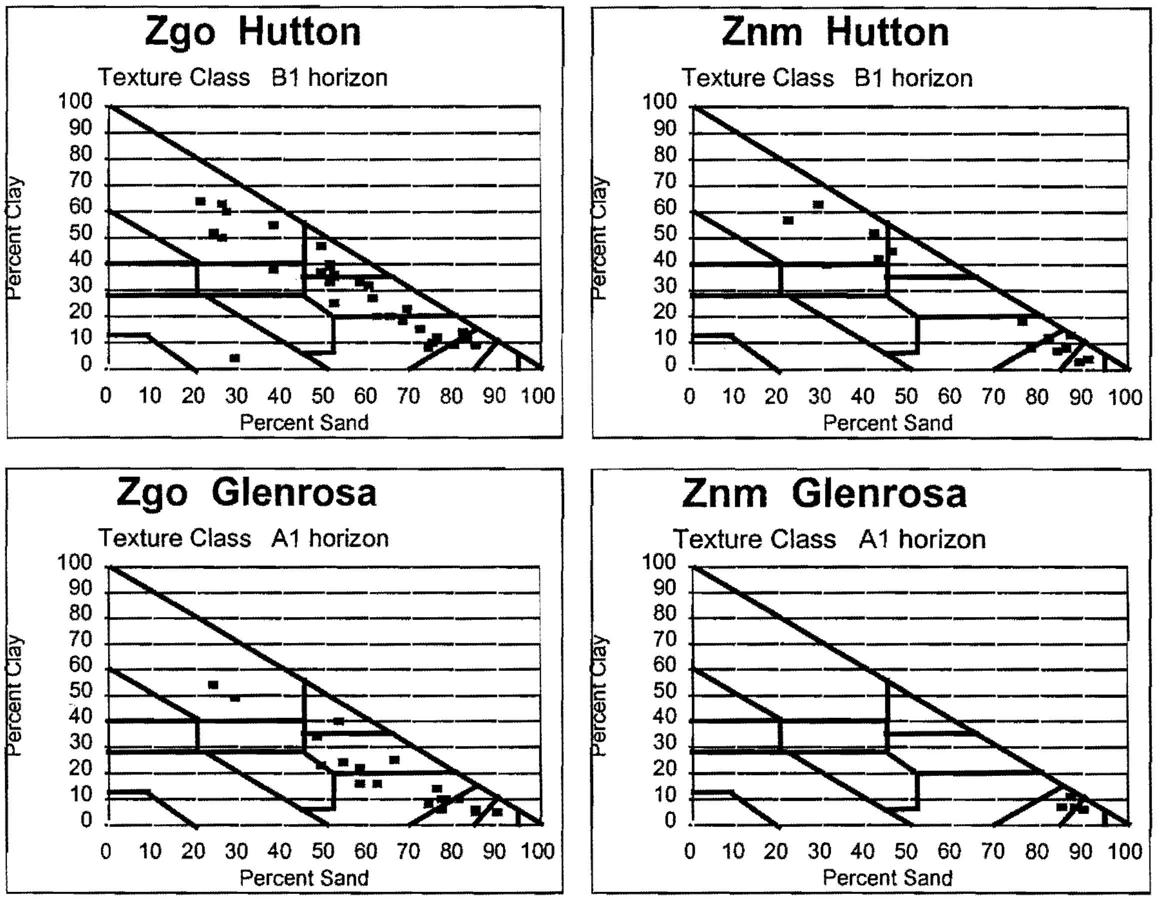


Figure 18.8 Distribution of soil textures within soils of the Hutton and Glenrosa Forms derived from Goudplaats Granite and from a omponent of the Nelspruit Suite.

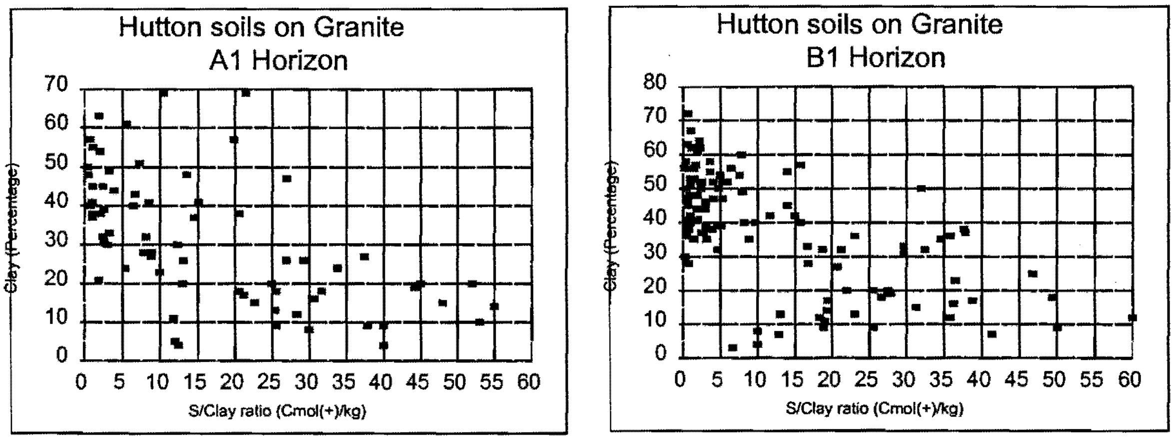


Figure 18.9 Distribution of clay percentages relative to S/clay ratios of Hutton soils derived from granitic rocks in KwaZulu-Natal, Mpumalanga and Northern Province.

CHAPTER 19

APPROACHES FOR THE RECOGNITION OF NATURAL SOIL BODIES

Recognition of natural soil bodies within the soil form classification class

A natural body could be defined as a collection of soil individuals that are more similar to each other than to the soils that border them. This is also the basis of soil classification. The debate concerning natural soil bodies would seem to centre around creating close fitting soil groupings that generally reflect sharp changes in soil landscapes. These groupings should be perceived as representing useful groups of like soil individuals by those who study and use soils.

Soil profiles currently classified to soil form, family or series represent groupings within a classification class. They should also become recognised as natural soil bodies reflecting the influences of natural factors on their formation, properties and position in the landscape. Finally they should also be recognised for their interpretative and administrative value. They often have an acceptably narrow range of variation and demonstrate similar measurable properties. The soil form classification class provides a common basis upon which interpretations for land use decisions can be made. They also reflect strong similarities in our understanding of the processes that have given rise to their genesis.

There is a need to recognise soil forms as natural soil bodies in addition to their taking on the general properties of the soil form. This recognition as natural soil bodies implies beginning to associate the soil forms with defined locations, geology formations, geomorphological positions and climate properties. In addition this will imply that the range of variation of soils classified to a single soil form and falling within a given natural soil body will be more limited than all soils classified to that soil form. Glenrosa soils derived from coarse grained granite have strong similarities with one another but differ from Glenrosa soils derived from tillite of the Dwyka Formation. Each should become recognised as a natural soil body by virtue of the identifiable changes in boundary conditions at the soil form and at the subordinate soil classification classes. It could also imply using soil forms and appropriate family or series classification levels in administrative functions. The characteristic relationship between soil forms and geology formations is documented in this thesis. Detailed information is presented in Chapters 4 to 18 with summary information collected in Chapter 3.

Natural soil bodies and point soil information sources

The approaches to recognising natural soil groupings, particularly with regard to soil texture has followed two courses. The first has been to group soils about a central concept or range of properties. This grouping could be described as a grouping from within. The extremities of the range of a property were commonly defined by a sharp change in that property or from the extent of sampling. Conceivably the boundary could progressively change as additional information is gained. The boundary values appear to be strongly influenced by location and extent of sampling. Examples are probably the early soil series of the United States of America. The early soil series of the KwaZulu-Natal Coastal Belt did not have boundaries defined as much by property values, but by the extent of the underlying geology formation. This approach has undoubtedly conveyed much valuable information and facilitated soil and land management practices. Traditionally these valuable classification tools have been structured and interpreted by a relatively small group of specialist researchers. The major limitations in this approach are that the information may not be specific enough to meet all the current information needs. The range of property values may be large or the boundary values may lack clear or reproducible values. Classes that are established must be clearly defined to promote their consistent application by all soil users.

Alternatively, when viewed from a broader national perspective the approach to soil classification has been to determine acceptable threshold limits to a soil property. Classes at the family and series levels may cut across natural soil bodies, but would provide classes that can be consistently applied by a wide range of persons. It must be assumed that these limits are set with a specific purpose in mind.

The future strategy would seem to lie in a progressively improved understanding the range of variation of soil properties. Classification forms an integral part of this understanding. Soil scientists should however recognise that procedures to account for ranges in property values, or alternatively for point data sources, will also become necessary to meet future information needs. The understanding of the range in variation of soil properties is central to the future definition of natural soil bodies. Consideration should be given to all soil properties, not necessarily only those chosen to represent threshold values in soil classification classes. In this way the range of properties within a natural soil body (or even within arbitrary defined classes where these are retained) will become known. Programs aimed at establishing natural soil bodies will be beneficial. They should be supported by a full spectrum of persons who could supply expertise and information. The programs should also focus on progressively documenting point soil profile information. Efficient storage and retrieval of this point information are also essential if a program to define natural soil bodies were to be effective. It would seem that natural bodies must be stratified according to some criteria restricting locations. The geology formation has been shown to be one criterion that is effective. Other criteria may also be used. A defined range in variation in individual soil properties would then represent the further subdivisions giving rise to natural soil bodies.

The natural body concept, or soil taxonomy classes with defined though arbitrary limits, represent effective ways of transferring soil information in a qualitative and semi-quantitative manner. Where the need for more precise information is indicated, qualitative assessment followed by quantitative modelling approaches will be required. However, detailed distributions of point data and precise models capable of handling quantitative soil response functions will be required. The soil information needs will range from those requiring useful descriptive classes through to precise soil response functions. The information on soil property values of natural soil bodies will provide an integral part of these information needs.

The interpretation of soil attribute values in natural soil bodies

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 is 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 those 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 class. This places limitations on the practical usefulness of natural soil bodies when interpretations using a class interval approach is 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. 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. 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. 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.

Threshold values for soil properties

Objections to the arbitrary, but practically useful, textural limits adopted in Soil Classification: A Binomial System for South Africa (MacVicar *et al.*, 1977) became an important consideration in not formally defining soil series in the revised soil classification system (Soil Classification Working Group, 1991). The notion that a limited range in soil variability, in this case soil textural variability, existed in natural soil bodies was a further consideration. The concept that a soil property value should not extend beyond the defined class limit implied that soil series as previously defined (MacVicar *et al.*, 1977) often divided natural soil bodies. This type of artificial subdivision was much less evident at the soil form level. The class limits set for the soil form level generally exhibited sharp changes in property values that are accepted as separating different soils. The concept of a soil property value extending beyond the class limits has been addressed only informally in South Africa. Strictly the definition of any class should apply. However, the classification has recognised morphological properties (which do not always lend to precise measurement) to be important in the classification process and placed emphasis on infield decision making to determine classes. This is one of the strengths of the South African soil classification system and it should be retained as far as possible. This does not imply that laboratory analyses should not be used. They should rather fulfill a supporting role. Furthermore, persons classifying soils should be urged to use their judgement in placing soils in classes, particularly where intergrades are apparent. The classification class that is chosen should reflect the best information message that can be conveyed to land users. This should best reflect the dominant features that are exhibited in the profile morphology and any soil analysis. The need for these persons to classify soils to the appropriate classes is indeed important where only limited soil correlation is possible.

In defining natural soil bodies the concept of the control horizon would need review. This concept is extensively used in Soil Taxonomy for recognition of the family and series classification classes (Soil Survey Staff, 1999). It is specified for the soil properties under review as being the depth below the mineral soil surface, or the depth to the upper boundary of a root-limiting layer. Keys define the control section classes for family and series differentiae routinely used in Soil Taxonomy (Soil Survey Staff, 1999). Particle size and mineralogy classes are listed first and second respectively, indicating their relative importance in defining soils to these taxa. The concept of a control section has precedent in Soil Classification: A Binomial System for South Africa (MacVicar *et al.*, 1977). The control horizon gives prominence to the properties of a defined horizon. It would seem important in evaluating which properties should be considered diagnostic. Where numerical differences between properties of horizons indicate that the soil may be placed in more than one classification class, preference should be assigned to the defined horizon. In defining natural soil bodies attention should be directed at whether the properties are measured in the A, E or B horizons. The Soil Classification Working Group (1991) has defined the surface horizon to be important in describing soil texture. In this study prominence has been assigned to the B and the E horizons. They are recommended to retain significance as control horizons. However, the decision to use these horizons in this study has largely been a pragmatic one. There was simply more data available for B and E horizons, than their corresponding A horizons.

The problem of soils having measured soil property values beyond the defined limits will increase as natural soil bodies are defined. There are many examples of soils within a restricted geographical area having dominantly fine and medium sands without there being clear distinctions between soils exhibiting these sand grades. Similarly, soils within a natural entity having base status values extending on either side of base status class limits have been reported. In these cases the class limits (dominant sand grade, base status) has shown their practical usefulness and do not necessarily require alteration. Clearly, guidelines to accommodate these situations should be established. The concepts of limiting the number of natural soil bodies to those which can be clearly defined and which are dominant in the South African soil mantle seems to hold promise.

Accommodation of silt in natural soil bodies

The distribution of silt (0.02 to 0.002 mm) for the soils of each geological formation of KwaZulu-Natal and Mpumalanga has been summarized in Chapter 3. Silt values have generally been recognised as low, with values of between approximately 2 and 45 percent being measured. The silt values for the soils derived from the sediments of the Vryheid Formation, Ecca Group; the Natal Group (formerly Table Mountain Sandstone) and the Quaternary and Cretaceous Sediments are generally low. The silt values for soils derived from granite are similarly low. The values range from less than 10 percent in the sand texture class to about 15 to 20 percent in the sandy clay loam class. Soils in the sand to loamy sand texture class seldom contain more than approximately 10 percent silt. The portion of the texture triangle with silt values greater than 10 percent silt is not representative of the soils of KwaZulu-Natal and Mpumalanga. The description sand or loamy sand is misleading as it also includes silt values considerably higher than were regularly determined. In the sandy loam texture class silt values of commonly less than 15 percent, and in the sandy clay loam texture class less than about 20 percent were determined. Profile textures are consistently located in only a small portion of the sandy loam class making the use of these texture descriptions misleading as well.

Soils derived from sediments of the Beaufort Group had textures located through the sandy clay loam, loam, clay loam and clay texture classes. Soils derived from these sediments are represented by intermediate clay contents (20 to 75 percent) and by higher silt contents (15 to 45 percent). Clay contents of red and yellow-brown apedal soils ranged from 20 to 45 percent in the Tarkastad Formation and from 30 to 75 percent in the Estcourt Formation and Adelaide Subgroup respectively. The clay contents for soils with an E horizon were lower.

Soils derived from Jurassic dolerite and basalt fills the clay texture class. Ranges in clay content are from about 30 to 80 percent were recorded. Silt values range up to about 40 percent making this boundary (40 percent silt) between the clay and silty clay classes relevant. The 40 percent silt value could however, be extended into the clay loam class. Soil textures in the sandy clay class were recorded, but tend to be better associated with the textures of natural soil bodies from the clay or from the sandy clay loam classes. The sandy clay texture description appears of limited significance for these soils.

A modified textural triangle (Figure 19.1) is proposed that may provide useful textural descriptions for the soils of KwaZulu-Natal and Mpumalanga. Subdivisions of clay percentage

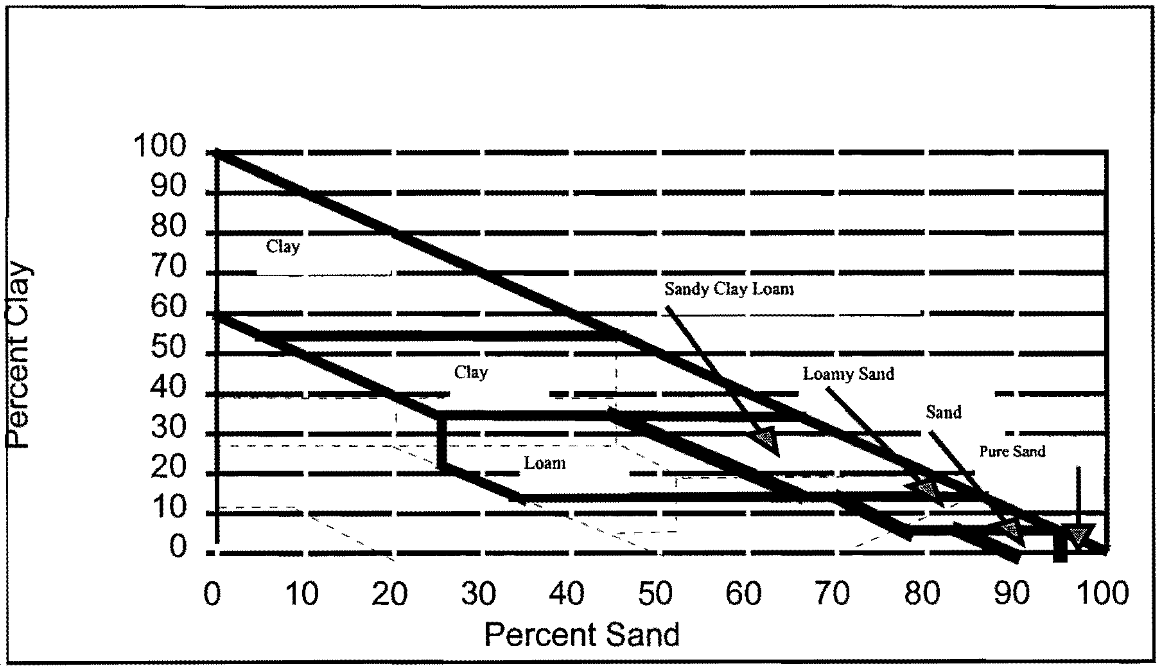


Figure 19.1 A practical textural diagram to describe the soils of KwaZulu-Natal and Mpumalanga.

have been widely used (MacVicar *et al.*, 1977) in soil survey reports in South Africa. These arbitrary subdivisions have been retained in view of their regular use and familiarity to soil surveyors. Silt boundaries are set to accommodate the soil textural analyses determined for these provinces. The classes accurately reflect particle size compositions from soil analyses. They may also bring a level of simplicity to practical soil surveys by combining silt threshold values with the widely used clay percentage subdivisions. Textures outside these classes were rarely encountered and could largely be ignored.

Summary statements concerning natural soil bodies

* Natural soil bodies at the soil form level of classification can be regularly identified for defined geological formations.

* Natural soil bodies according to soil texture could be identified using geology and soil form as selection criteria. Such natural soil bodies appear reasonably unique and consistent for a given geological formation.

* Stratification of some kind would appear necessary if the natural body concept is to have practical significance. This stratification would be to limit the extent of the locations from which soil profiles may be drawn in order to qualify for inclusion in that natural soil body.

* Boundary values for natural soil bodies expressed on a textural basis are not mutually exclusive. The boundaries regularly overlap when considered over different geology formations. This overlap in textural boundaries is less apparent when considered over different soil forms but still within the same geological formation.

* These boundaries tend not to coincide with the arbitrary, but convenient to use clay only boundaries applied in the 1977 definition of soil series.

* Ranges in maximum and minimum values for texture have been identified. They provide a basis for recognition of natural soil bodies at this level of soil classification.

* The classical boundaries for soil textural classes as traditionally established in the literature appear to hold only limited significance for the actual boundaries determined from soil analyses for this study area. This is particularly apparent for the sand to sandy loam textural classes. Modifications to these classes could be useful for South African soils.

* An administrative procedure should be established to recognise natural soil bodies. The procedure should be fully supported by all persons who could supply expertise and information. The procedure should also focus on progressively documenting point soil profile information in electronic and standard formats.

* The nature of the underlying materials of soils has traditionally been considered important in agriculture, forestry and engineering. Presently there is no formal treatment of underlying materials by the classification, although an indication of underlying materials is given in certain soil forms. The nature of the underlying materials may be incorporated into the classification via their influence on soil texture within the natural body concept.

Procedures for the collection of information on natural soil bodies

The concept would be to promote the description in scientific terms of natural soil bodies making up the South African soil mantle. Description would be at roughly the series level of abstraction. The defined natural soil bodies should also lend themselves to a large number of land use interpretations. They may be derived from existing data or new data. The examples quoted in this document are strongly associated with geological formations or place defined localities. The essential information and procedures should include:

* Profile descriptions including site information (usual position in the landscape, probable parent material) and horizon information.
* An indication of the spatial extent of the natural soil body and geographic location of type sites.
* A classification of the natural soil body within the South African Soil Classification Systems (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991), the USDA Soil Taxonomy (Soil Survey Staff, 1999) and the World Reference Base for Soil Resources (ISSS, ISRIC, FAO, 1998). Classification to other international systems may also be useful.
* Comprehensive soil analyses using recognised standard analytical methods should be applied (Non-Affiliated Soil Analysis Work Group, 1990; Soil Survey Staff (USDA), 1996c; Brunt and Van Reeuwijk, 1995).
* Data storage in electronic or paper formats is recommended.
* Publication and distribution of material are recommended. Contribution of information on natural soil bodies should add to our public information sources.
* Central and Regional Administering Authorities is recommended.

While textural considerations have received most attention in recognising natural soil bodies, other criteria could also be considered. These criteria could include the following:

* Nature of the underlying geological formation,
* Coarse fragments,
* Duration of soil water saturation,
* Signs of wetness,
* A narrower range of those soil properties used at higher levels of classification. These properties could include thickness of horizons, organic carbon content, base status, plasticity index, colour and others. The classes would be chosen to give improved interpretative properties.
* Mineralogy properties,
* Measured values of certain chemical elements that differ appreciably from a standard value or ranges and beneficially of adversely affect plant growth or human and animal health.

REFERENCES

AUSTIN, M.E. 1965. Land Resource Regions and Major Land Resource Areas of the United States (exclusive of Alaska and Hawaii). Agriculture Handbook 296. Soil Conservation Service, United States Department of Agriculture, Washington DC.

BEATER. B.E. 1957. Soils of the Sugar Belt I. Natal North Coast. Oxford University Press, Cape Town (for University of Natal).

BEATER. B.E. 1959. Soils of the Sugar Belt II. Natal South Coast. Oxford University Press, Cape Town (for University of Natal).

BEATER. B.E. 1962. Soils of the Sugar Belt III. Zululand. Oxford University Press, Cape Town (for University of Natal).

BEATER, B.E. 1970. Soil series of the Natal Sugar Belt. The South African Sugar Association, Durban.

BECKET, P.H.T. and WEBSTER, R. 1971. Soil variability: A review. Soils Fert. 34:1-15.

BESTER, H.C. 1993. Mobility and phytotoxicity of boron in two Highveld soils. M. Sc. thesis. Dept. of Agronomy, Univ. of Natal, Pietermaritzburg.

BESTER, H.C. and LIENGME, D.P. 1993. Irrigation suitability survey of a portion of the grounds of the Drakensberg Sun Hotel, Estcourt District, Natal. ISCW Report No. GW/A/93/33. Institute for Soil, Climate and Water, Pretoria.

BEYTELL, J.F. and SCHOONWINKEL, D. 1993. Grond opname van die plaas Bloupoort, Bronkhorstspruit. ISCW Report No. GW/A/93/33. Institute for Soil, Climate and Water, Pretoria.

BRUNT, J. AND VAN REEUWIJK, L.P. 1995. SOILIMS: Laboratory Information and Management System for Soil and Plant Laboratories. Manual and Tutor. Version 1.3. International Soil Information and Reference Centre. Wageningen, The Netherlands.

BÜHMANN, C., KIRSTEN, W.F.A., PATERSON, D.G. and SOBCZYK, M.E. 1993. Pedogenic differences between two different adjacent basalt derived soil profiles 1. Textural and chemical characteristics. S. Afr. J. Plant Soil 10:155-161.

BURGESS, T.M. and WEBSTER, R. 1980a. Optimal interpolation and isarithmic mapping of soil properties: 1 The semi-variogram and punctual kriging. J. Soil Sci. 31:315-331.

BURGESS, T.M. and WEBSTER, R. 1980b. Optimal interpolation and isarithmic mapping of soil properties: 2 Block kriging. J. Soil Sci. 31:333-341.

BURROUGH, P.A. 1991. Sampling Designs for quantifying map unit composition. In Spatial Variabilities of Soils and Landforms. Mausbach, M.J. and Wilding, L.P. (Eds.) SSSA Special

Publication No. 28. Soil Sci. Soc. Am., Madison, Wisconsin.

BURROUGH, P.A., MACMILLIAN, R.A. and VAN DEUSEN, W. 1992. Fuzzy classification methods for determining land suitability from soil profile observations and topography. J. Soil Sci. 43:193-210.

BURROUGH, P.A., VAN GAANS, P.F.M. and HOOTSMAN, R. 1997. Continuous classification in soil survey: spatial correlation, confusion and boundaries. Geoderma 77:115-135.

BORLAND dBASE IV. 1993. dBASE IV Version 2.0 for DOS. Borland International Inc. Scotts Valley, California.

BORLAND QUATTRO PRO. 1993. Quattro Pro Version 5.0 for Windows. Borland International Inc. Scotts Valley, California.

BOTHA, G.A., SCOTT, L., VOGEL, J.C. and VON BRUNN, V. 1992. Palaeosols and palaeoenvironments during the Late Pleistocene hypothermal in Northern Natal. S. Afr. J. Sci. 88:508-512.

CANADA SOIL SURVEY COMMITTEE, 1978. Soil Family and Series. In The Canadian System of Soil Classification. Canada Dept. Agric. Publ. 1646, Supply and Services, Ottawa, Ontario.

COREL CORPORATION LIMITED, 1997. Corel Draw 8, Corel Corporation Limited, Ottawa, Canada.

DEKKER, D.A., JEFFREY, R.A. and SCOTNEY, D.M. 1980. Soil survey of the Tala Valley area. Report No. 11/1980. Natal Region, Dept. of Agriculture and Fisheries, Pietermaritzburg.

DEMAREST, M. 1992. Grond opname van die plaas Roodekopjies. ISCW Report No. GW/A/92/5. Institute for Soil, Climate and Water, Pretoria.

DENT, M.C., LYNCH, S.D. and SCHULZE, R.E. 1988. Mapping mean annual and other rainfall statistics over Southern Africa. WRC Report No. 109/89 (plus maps). Water Research Commission, Pretoria.

DE VILLIERS, J.M. 1962. A study of soil formation in Natal. PhD Thesis, Univ. of Natal, Pietermaritzburg.

DE VILLIERS, J.M. 1964. The genesis of some Natal soils. I. Clovelly, Kranskop and Balmoral series. S. Afr. J. Agric. Sci. 7:417-438.

DE VILLIERS, J.M. 1965. The genesis of some Natal soils. II. Estcourt, Avalon, Bellevue and Rensburgspruit series. S. Afr. J. Agric. Sci. 8:507-524.

DOHSE, T.E. 1970. Pedology of selected soils in the central Orange Free State. M.Sc. Agric. Thesis. Univ. of the Orange Free. State, Bloemfontein.

DRENNAN, MAUD AND PARTNERS. 1988a. A soil survey of the Macekane Irrigation Scheme. Drennan, Maud and Partners, Durban.

DRENNAN, MAUD AND PARTNERS. 1988b. A soil survey of the Mtengu Irrigation Scheme. Drennan, Maud and Partners, Durban.

DUVENHAGE, A.J., LAKER, M.C. and TURNER, D.P. 1992. 'n Vergelyking tussen twee gronde van die Avalon Grondvorm met die oog op seriedifferensieasie. Proc. 17th Soil Sci. Soc. S. Afr.Congress. Stellenbosch.

ENGLUND, E. and SPARKS, A. 1988. GEO-EAS users guide. Environmental Monitoring Systems Lab., Office of Research and Development, EPA, Las Vegas, NV. (See Burrough, 1991. Statistical system for use in soils attributes.)

FAO-UNESCO. 1988 Soil Map of the World: Revised Legend. FAO World Soil Resources Report 60, Rome, Italy.

GEERS, B.C. and DOHSE, T.E. 1980. Reconnaissance soil survey of parts of the Mfolozi River Catchment. SIRI Report No. 954/154/80. Soil and Irrigation Research Institute, Pretoria.

GEERS, B.C., DOHSE, T.E. and SCHOEMAN, J.L. 1981. Verkenningsgrondopname van die Laër Krokodilvallei. SIRI Report No. 903/21/79. Soil and Irrigation Research Institute, Pretoria.

GEOLOGICAL SURVEY. 1970. Geological map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland. (1: 1 000 000) Geological Survey S. Afr., Pretoria.

GEOLOGICAL SURVEY. 1978. 1:250 000 Geological Series 2528 Pretoria. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1981a. 1:250 000 Geological Series 2928 Drakensberg. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1981b. 1:250 000 Geological Series 3028 Kokstad. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1984. Geological map of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland. (1: 1 000 000) Geological Survey S. Afr., Pretoria.

GEOLOGICAL SURVEY. 1985a. 1:250 000 Geological Series 2632 Kosibaai. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1985b. 1:250 000 Geological Series 271/232 St. Lucia. Geological

Survey, Pretoria.

GEOLOGICAL SURVEY . 1985c. 1:250 000 Geological Series 2330 Tzaneen. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1986a. 1:250 000 Geological Series 2430 Pilgrims Rest. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1986b. 1:250 000 Geological Series 2530 Barberton. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1986c. 1:250 000 Geological Series 2630 Mbabane. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1986d. 1:250 000 Geological Series 2628 East Rand. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1988a. 1:250 000 Geological Series 2730 Vryheid. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1988b. 1:250 000 Geological Series 2828 Dundee. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1988c. 1:250 000 Geological Series 2930 Durban. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1988d. 1:250 000 Geological Series 3030 Port Shepstone. Geological Survey, Pretoria.

GEOLOGICAL SURVEY. 1992. 1:250 000 Geological Series 2728 Frankfort. Geological Survey, Pretoria.

GRUNDLING, H., GORDON, D.H and SMITH-BAILLIE, A.L. 1986. Verkennings grondopname van die Pongolariviergebied tussen Lachkraal en Bendor. SIRI Report No. GB/A/86/32. Soil and Irrigation Research Institute, Pretoria.

HALLMARK, C.T., WEST, L.T., WILDING, L.P. and DREES, L.R. 1986. Characterization data for selected Texas soils. Texas Agricultural Experiment Station, College Station, Texas.

HARTUNG, S.L., SCHEINOST, S.A. and AHRENS, R.J. 1991. Scientific method of the National Cooperative Soil Survey. In Spatial Variabilities of Soils and Landforms. Mausbach, M.J. and Wilding, L.P. (Eds.) SSSA Special Publication No. 28. Soil Sci. Soc. Am., Madison, Wisconsin.

HEWITT, A.E. and VAN WAMBEKE, A. 1985. The error taxadjunct and its application in soil taxonomic assignment. Soil Sci. Soc. Am. J. 49:952-956.

IDESSA-ISRIC. 1994. Soil reference profiles of Cote d' Ivoire. Field and analytical data. Country Report 4. (van Kekem A. and van de Ven, T. Compilers) International Soil Information and Reference Centre, Wageningen, The Netherlands and Idessa Institut des Savannes, Bouake, Cote d' Ivoire.

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE (ISRIC). 1993. Global and National Soils and Terrain Digital Databases (SOTER): Procedures Manual. (van Engelen, V.W.P. et al. Eds.) ISRIC, Wageningen, The Netherlands.

ISRIC. 1994. Soil reference profiles of Zambia. Field and analytical data. Country Report 13. (van Baren J.H.V. and Spaargaren, O.C. Compilers.) International Soil Information and Reference Centre, Wageningen, The Netherlands.

INTERNATIONAL SOCIETY OF SOIL SCIENCE, INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE, FOOD AND AGRICULTURE ORGANIZATION (ISSS, ISRIC, FAO) 1998. World Reference Base for Soil Resources. FAO. Rome.

JEFFREY, R.A. and SCOTNEY, D.M. 1979. Soil survey of the Muden irrigation area. Report No. N13/1979. Natal Region, Dept. of Agriculture and Fisheries, Pietermaritzburg.

JEFFREY, R.A., DEKKER, D.A. and SCOTNEY, D.M. 1981. Soil survey of the False Bay-Hluhluwe area. Report No. N6/1981. Natal Region, Dept. of Agriculture and Fisheries, Pietermaritzburg.

KAUFFMAN, J. H. 1995. Progress of national soil reference collections and databases (NASREC) 1980-1995. In Proceedings of Workshop on National Soil Reference Collections and Databases (NASREC), 6-17 November 1995. (Volume 1, Spaargaren, O.C. Ed). International Soil Information and Reference Centre, Wageningen, The Netherlands.

KAUFFMAN, J. H., MANTEL, S. and SPAARGAREN, O.C. 1995. Soils of the humid and seasonally dry (sub)tropics: a correlation of reference data and their assessment for agriculture using the ISIS database. In Proceedings of Workshop on National Soil Reference Collections and Databases (NASREC), 6-17 November 1995. (Volume 2, Spaargaren, O.C. Ed). International Soil Information and Reference Centre, Wageningen, The Netherlands.

JENNY, H.F. 1941. Factors of soil formation. McGraw Hill, New York.

KING, L.C. 1940. The monoclinal coast of Natal. J. Geomorph. 3:144-153.

KING, L.C. and KING, L.A. 1959. A reappraisal of the Natal monocline. S. Afr. Geogr. J. 41:15-30.

KRUGER, G.P. 1983. Terrain morphological map of Southern Africa. Soil and Irrigation Research Institute, Pretoria.

LAND TYPE SURVEY STAFF. 1972-1991. Land Type Survey: Soil analyses reports for the soil series identification profiles in KwaZulu-Natal and Mpumalanga. Institute for Soil, Climate and Water, Pretoria.

LAND TYPE SURVEY STAFF. 1985. Land types of the map 2628 East Rand and 2630 Mbabane. Mem. agric. nat. Resour. S. Afr. No. 5. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1986a. Land types of the map 2632 Mkuze. Mem. agric. nat. Resour. S. Afr. No. 6. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1986b. Land types of the map 2730 Vryheid. Mem. agric. nat. Resour. S. Afr. No. 7. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1987a. Land types of the maps 2526 Rustenburg and 2528 Pretoria. Mem. agric. nat. Resour. S. Afr. No. 8. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1987b. Land types of the maps 2426 Thabazimbi and 2428 Nylstroom. Mem. agric. nat. Resour. S. Afr. No. 10. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1987c. Land types of the map 2830 Richards Bay. Mem. agric. nat. Resour. S. Afr. No. 11. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1989a. Land types of the maps 2330 Tzaneen and 2430 Pilgrims Rest. Mem. agric. nat. Resour. S. Afr. No. 12. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1989b. Land types of the map 2530 Barberton. Mem. agric. nat. Resour. S. Afr. No. 13. Department of Agriculture and Water Supply, Pretoria.

LAND TYPE SURVEY STAFF. 1991. A procedure for describing soil profiles. SIRI Report No GB/A/ 91/67. Soil and Irrigation Research Institute, Pretoria.

LAND TYPE SURVEY STAFF. 1994a. Land types of the map 2930 Durban. Mem. agric. nat. Resour. S. Afr. No. 17. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF. 1994b. Land types of the map 3030 Port Shepstone Mem. agric. nat. Resour. S. Afr. No. 21. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF. 1996. Land types of the map 2928 Drakensberg. Mem. agric. nat. Resour. S. Afr. No. 25. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF. 1997a. Land types of the maps 2728 Frankfort and 2828 Harrismith. Mem. agric. nat. Resour. S. Afr. No. 28. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF. 1997b. Land types of the map 3028 Kokstad. Mem. agric. nat. Resour. S. Afr. No. 31. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF. 1998a. Land types of the maps 3026 Aliwal North and 3126 Queenstown. Mem. agric. nat. Resour. S. Afr. No. 27. Institute for Soil, Climate and Water, Agricultural Research Council, Pretoria.

LAND TYPE SURVEY STAFF, 1998b. Land Type Survey Database for KwaZulu-Natal and Mpumalanga; Electronic version. Institute for Soil, Climate and Water, Pretoria.

LE ROUX J. and SCOTNEY D.M. 1970. A key to the Soils of Natal. Department of Agricultural Technical Services. Pretoria.

LOW, A.B. and REBELO, A.G. (Eds.) 1996. Vegetation of South Africa, Lesotho and Swaziland. A companion to the vegetation map of South Africa, Lesotho and Swaziland. Department of Environment Affairs and Tourism, Pretoria.

LOXTON, R.F. 1962. Soil survey of Kroonstad. Technical Communication No. 15. Dept. Agric. Tech. Serv., Pretoria.

LOXTON, R.F., HUNTING AND ASSOCIATES. 1967. Soil Classification Project: Eastern Transvaal Highveld. Classification and Description of Soil Series. (First Edition). R.F. Loxton, Hunting and Associates, Johannesburg.

LOXTON, R.F., HUNTING AND ASSOCIATES. 1970a. Soil Classification Project: Eastern Transvaal Highveld. Classification and Description of Soil Series. (Revised Edition). R.F. Loxton, Hunting and Associates, Johannesburg.

LOXTON, R.F., HUNTING AND ASSOCIATES. 1970b. Soil Classification Project: North Western Orange Free State. Classification and Description of Soil Series. R.F. Loxton, Hunting and Associates, Johannesburg.

LOXTON, R.F., HUNTING AND ASSOCIATES. 1970c. Soil Classification Project: Western Transvaal Highveld. Classification and Description of Soil Series. R.F. Loxton, Hunting and Associates, Johannesburg.

LOXTON, R.F., HUNTING AND ASSOCIATES. 1981. Mahlabatini Rural Development Project: Soils and land capability legend. R.F Loxton Hunting and Associates. Johannesburg.

LOXTON, R.F. and MACVICAR, C.N. 1965. The soil series in relation to agricultural research and land use planning. Proc. 37th Annual Congress, South African Sugar Technologists'

Association, Mount Edgecombe, South Africa.

LUDICK, B.P. 1992. Voorgestelde handeling vir die omskrywing van grondliggame asook gewas- en veldekotope in die landtipes van die Hoëveldstreek. Technical Communication No. 236. Dept. of Agricultural Development, Pretoria.

LUDORF, R. and SCOTNEY, D.M. 1975. Soils of the Lions River and Mooi River Soil Conservation Districts. Tech. Communication No. 94. Dept. of Agric. Tech. Serv., Pretoria.

MACVICAR, C.N. 1965. The constitution and genesis of four soil series from dolerite in the Natal Midlands. S. Afr. J. Agric. Sci. 8:979-990.

MACVICAR, C.N. 1969. A basis for the classification of soil. J. Soil Sci. 20:141-152.

MACVICAR, C.N. 1973. Soils of the sugar industry. Bull. No. 19. S. Afr. Sugar Experiment Station, Mount Edgecombe.

MACVICAR, C.N. 1978. Advances in soil classification and genesis in Southern Africa. 8th Congress Soil Sci. Soc. S. Afr. Technical Communication No. 165, Dept. Agric. Tech. Serv., Pretoria.

MACVICAR, C.N., DE VILLIERS, J.M., LOXTON, R.F., VERSTER, E., LAMBRECHTS, J.J.N., MERRYWEATHER, F.R., LE ROUX, J., VAN ROOYEN, T.H. AND HARMSE, H.J. VON M. 1977. Soil Classification: A Binomial System for South Africa. Dept. of Agricultural Technical Services, Pretoria.

MACVICAR, C.N., FITZPATRICK. R.W. and SOBCZYK, M.E. 1984. Highly weathered soils in the east coast hinterland of Southern Africa with thick, humus-rich A1 horizons. J. Soil Sci. 35:103-115.

MACVICAR, C.N. and LOXTON, R.F. 1967. Soils of the Langkloof. Tech. Comm. No. 59, Dept. Agric. Tech. Serv., Pretoria.

MACVICAR, C.N., LOXTON, R.F. and VAN DER EYK, J.J. 1965a. South African Soil Series. Part I: Definitions and key. Dept. of Agricultural Technical Services, Pretoria.

MACVICAR, C.N., LOXTON, R.F. and VAN DER EYK, J.J. 1965b. South African Soil Series. Part II: Profile descriptions and analytical data. Dept. of Agricultural Technical Services, Pretoria.

MACVICAR, C.N. and PERFECT, G.A. 1971. The soils of the Eastern Transvaal sugar industry. Proc. 42nd Annual Congress, South African Sugar Technologists' Association, Mount Edgecombe, South Africa.

MACVICAR, C.N. and SOBCZYK, M.E. 1984. Humic-melanic investigation. SIRI Report No. GW/A/99/123. Soil and Irrigation Research Institute, Pretoria.

MAUD, R.R. 1968. Quaternary geomorphology and soil formation in coastal Natal. Z. Geomorph. N.S. Suppl. 7 :155-199.

MAZAHERI, S.A., KOPPI, A.J. and MCBRATNEY, A.B. 1995. A fuzzy allocation scheme for the Australian Great Soil Groups classification system. Eur. J. Soil Sci. 46:601-612.

MAZAHERI, S.A. MCBRATNEY, A.B. and KOPPI, A.J. 1997. Sensitivity of membership to attribute variation around selected centroids and intergrades in the continuous Australian Great Soil Groups classification system. In Fuzzy Sets in Soil Science. De Gruijter, J.J., McBratney, A.B. and McSweeney, K. (Eds.), Geoderma 77:155-168.

MCBRATNEY, A.B. and ODEH, I.O.H. 1997. Application of fuzzy sets in soil science: fuzzy logic, fuzzy measurement and fuzzy decisions. In De Gruijter, J.J., McBratney, A.B. and McSweeny, K. (Eds.), Fuzzy Sets in Soil Science. Geoderma 77:85-113.

MEYER, J.H., VAN ANTWERPEN, R. and MEYER, E. 1996. A review of soil degradation and management research under intensive sugarcane cropping. Proc. S. Afr. Sug. Technol. Ass. 70:22-28.

NATURAL RESOURCE CONSERVATION SERVICE STAFF. 1993. Field Office Technical Guide; Howard County, Indiana. United States Department of Agriculture, Indiana.

NETTLETON, W.D., BRASHER, B.R. and BORST, G. 1991. The taxadjunct problem. Soil Sci. Soc. Am. J. 55:421-427.

NIELSEN, D.R.. BIGGER, J.W. and ERH, K.T. 1973. Spatial variability of field-measured soil water properties. Hilgardia 42:215-259.

NON-AFFILIATED SOIL ANALYSIS WORKING GROUP (NASAWG). 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Pretoria.

OBERHOLSTER, R.E. 1969a. Genesis of two different soils on basalt 1. Mineralogical characteristics. Agrochemphysica 1:53-62.

OBERHOLSTER, R.E. 1969b. Genesis of two different soils on basalt 2. Contribution of transported material. Agrochemphysica 1:73-78.

ORCHARD, E.R. 1965. Pedological patterns of soil fertility. Proc. S. Afr. Sugar Technol. Assoc. 39:247-249.

PARTRIDGE, T.C. and MAUD, R.R. 1987. Geomorphic evolution of southern Africa since the Mesozoic. S. Afr. J. Geol. 90:179-208 (plus maps).

PATERSON, D.G. 1991a. Soil survey of a portion of the farm Bankfontein 216 near Witbank. ISCW Report No. GW/A/91/63. Institute for Soil, Climate and Water, Pretoria.

PATERSON, D.G. 1991b. Soil survey of a portion of the farm Nooitgedacht 300JS, near Witbank. ISCW Report No. GW/A/91/64. Institute for Soil, Climate and Water, Pretoria.

PATERSON, D.G. 1992a. Soil survey of Balmoral Colliery. ISCW Report No. GW/A/92/1. Institute for Soil, Climate and Water, Pretoria.

PATERSON, D.G. 1992b. Grondopname van Towoomba Proefplaas, Warmbad. ISCW Report No. GW/A/92/7. Institute for Soil, Climate and Water, Pretoria.

PIENAAR, M. 1998. Program listing of computer programs, Project GW50/008. ISCW Report No. GW/A/99/124. Institute for Soil, Climate and Water, Pretoria.

PLATH,.B.L., VIVIAN, L.J. GRUNDLING, H.,SMITH-BAILLIE, A.L. and DOHSE, T.E. 1982. Grondopname van die Nkwalini-, Mfuli- en Heatonvillebesproeiingsdistrikte, Eshowe-Empangeni, Natal. SIRI Report No. 967/430/80. Soil and Irrigation Research Institute, Pretoria.

POTGIETER, L.J.C. and WILKE, C. 1991. Grondopname van die plaas Elandsfontein, Bronkhorstspruit. ISCW Report No. GW/A/91/51. Institute for Soil, Climate and Water, Pretoria.

RIJKSUNIVERSITEIT UTRECHT. 1988. PC Geostat Manual. Internal Publication. Dept Physical Geography, The Netherlands.

ROBERTS, V.E. 1969. Soil survey of Bethlehem. Technical Communication No. 58. Dept. Agric. Tech. Serv., Pretoria.

SCHOEMAN, J.L. 1973. Die pedologie van die Grootspruit-opvanggebied, distrik Fouriesburg. M.Sc. Thesis. Univ. of Potchefstroom for CHE, Potchefstroom.

SCHOEMAN. J.L. 1989. Natural soil bodies of the Lichtenburg, Bothaville, Viljoenskroon and Wesselsbron areas and estimates of their water holding characteristics as derived from land type data. Technical Communication No. 219. Department of Agriculture and Water Supply, Pretoria.

SCOTNEY, D.M., JEFFREY, R.A. and DEKKER, D.A. 1978. Soil survey of the Kokstad-Cedarville area. Natal Region, Dept. of Agric. Tech. Serv., Pietermaritzburg.

SIMONSON, R.W. 1959. Outline of a generalized theory of soil genesis. Soil Sci. Soc. Am. Proc. 23:152-156.

SIMONSON, R.W. 1978. Soil survey and soil classification in the United States. Proc. 8th Congr. Soil Sci. Soc. S. Afr. Pietermaritzburg. Tech. Comm. No. 165. Dept. Agric. Tech. Serv., Pretoria.

SIMONSON, R.W. 1997. Evolution of Soil Series and Type Concepts in the United States. Advances in GeoEcology 29: 79-108. Catena Verlag, Reiskirchen, Germany.

SMITH, G.D. 1986. The Guy Smith Interviews: Rationale for Concepts in Soil Taxonomy. Soil Management Support Services Technical Monograph No.11, Soil Conservation Service, United States of Agriculture, Washington DC.

SMITH-BAILLIE, A.L., 1986a. Reconnaissance soil survey of the Lower Pongola River west of the J.G. Strijdom dam. SIRI Report No. GB/A/86/33. Soil and Irrigation Research Institute, Pretoria.

SMITH-BAILLIE, A.L., 1986b. Reconnaissance soil survey report of the Kamberg Nature Reserve. SIRI Report No. GB/A/86/35. Soil and Irrigation Research Institute, Pretoria.

SMITH-BAILLIE, A.L., BESTER, H.C. and LIENGME, D.P. 1991. Natal Soil Tour. ISCW Report No. GW/A/95/95. Institute for Soil, Climate and Water, Pretoria.

SMITH-BAILLIE, A.L. and DOHSE, T.E. 1975. Detail grondopname van die plase Bronkhorstfontein en Kogelfontein, Moeketsiegebied. SIRI Report No. 833/144/75. Soil and Irrigation Research Institute, Pretoria.

SMITH-BAILLIE, A.L., SNYMAN, K. PALLETT, R.N. GRUNDLING, H.G. and TURNER, D.P. 1989. Soil survey report of the Magudu, Lelieshoek and Nooitgedacht areas, Ngotshe District, Natal. SIRI Report No. GB/A/89/10. Soil and Irrigation Research Institute, Pretoria.

SNYMAN, K. 1987. The micromorphology of selected diagnostic horizons of the binomial system for soil classification. M. Sc thesis. Univ. of Natal, Pietermaritzburg.

SOHAN LAL, DESHPANDE, S.B. and SEHGAL, J. 1994. Soil Series of India. Soils Bulletin 40, National Bureau of Soil Survey and Land Use Planning. Nagpur, India.

SOIL CLASSIFICATION WORKING GROUP. 1991. Soil Classification: A Taxonomic System for South Africa. Dept. of Agricultural Development, Pretoria.

SOILSCAPES 93 ORGANISING COMMITTEE. 1993. Soil profiles of the Soilscapes 93 Tour. ISCW Report No. GW/A/93/95. Institute for Soil, Climate and Water, Pretoria.

SOIL SURVEY STAFF. 1960. Soil Classification, A Comprehensive System. 7th Approximation. U.S. Dept. Agric. Soil Cons. Serv., Washington, D.C.

SOIL SURVEY STAFF. 1972. Soil series of the United States, Peurto Rico, and the Virgin Islands: Their Taxonomic Classification. (August, 1972). Soil Conservation Service, United States Department of Agriculture.

SOIL SURVEY STAFF. 1975. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agriculture Handbook No.436. Soil Conservation Service, U.S. Dept. Agric. Washington, D.C.

SOIL SURVEY STAFF. 1980. Soil Survey Manual. USDA-SCS Handbook 18. U.S. Govt.

Printing Office Washington, DC.

SOIL SURVEY STAFF. 1992. Keys to Soil Taxonomy, Fifty Edition, SMSS Technical Monograph No. 19, Pocahontas Press, Blacksburg, Virginia, USA.

SOIL SURVEY STAFF. 1996a. Keys to Soil Taxonomy, Seventh Edition. Natural Resources Conservation Service, United States Department of Agriculture. Washington DC.

SOIL SURVEY STAFF. 1996b. National Soil Survey Manual, Title 430-VI. Natural Resources Conservation Service, United States Department of Agriculture. Washington DC.

SOIL SURVEY STAFF. 1996c. Soil Laboratory Methods Manual, Soil Survey Investigations Report No. 42. Version 3.0. Natural Resources Conservation Service, United States Department of Agriculture. Washington DC.

SOIL SURVEY STAFF. 1998. Keys to Soil Taxonomy, Eighth Edition. Natural Resources Conservation Service, United States Department of Agriculture. Washington DC.

SOIL SURVEY STAFF. 1999. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Second Ed. Agriculture Handbook No 436. Natural Resources Conservation Service, United States Department of Agriculture, Washington DC.

SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS). 1980. Stratigraphy of South Africa. Part 1 (Comp. L.E. Kent). Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda: Handb. geol. Surv. S. Afr. 8. Geological Survey, Pretoria.

STEENEKAMP, PI 1989. Detail grondopname van die plaas Sterkfontein 495JR. ISCW Report No. GW/A/91/46. Institute for Soil, Climate and Water, Pretoria.

TAYLOR, K.P. 1972. An investigation of the clay fraction of soils from the Springbok Flats, Transvaal. M.Sc. Thesis. Univ. of Natal. Pietermaritzburg.

TRUSWELL. J.F. 1977. The geological evolution of South Africa. Purnell. Cape Town.

TURNER, D.P. 1976. A study of water infiltration into soils. Dept. of Soil Science and Agrometeorology, Univ. of Natal, Pietermaritzburg.

VAN DER BANK, W.J. 1968. Bodemopname van Lichtenburg. Technical Communication No. 58. Dept. Agric. Tech. Serv., Pretoria.

VAN DER BANK, W.J., VERSTER, E., ROBERTS, V.E., MACVICAR, C.N. 1978. Soil survey of Grootvlei. Technical Communication No. 145. Dept. Agric. Tech. Serv., Pretoria.

VAN DER EYK, J.J. 1965. Climate as a Soil forming factor in Natal. Proc. S. Afr. Sugar Technol. Assoc. 39:234-241.

VAN DER EYK, J.J., MACVICAR, C.N. and DE VILLIERS, J.M. 1969. Soils of the Tugela Basin. NTRP Planning Reports Vol. 15, Natal Town and Regional Planning Commission, Pietermaritzburg.

VAN MEIRVENNE, M., SCHELDEMAN, K. BAERT, G. HOFMANG. 1994. Quantification of Soil texture of Bas-Zaire using Soil map polygons and/or point observations. Geoderma 62:69-82.

VAN REEUWIJK, L.P. 1967. Pedogenic and clay mineralogical studies : I. Genesis of textural lamella in some subtropical sand soils. II. Properties of synthetic and natural amorphous aluminosilicates. M.Sc(Agric) thesis, University of Natal, Pietermaritzburg.

VAN WAMBEKE, A. and FORBES, T.R. 1986. Guidelines for using "Soil Taxonomy" in the names of soil map units. Soil Management Support Services Technical Monograph No.10, Soil Conservation Service, United States of Agriculture, Washington DC.

VENTER, F.J. 1990. A Classification of Land for Management Planning in the Kruger National Park. PhD Thesis. Univ. of South Africa. Pretoria.

VENTER, G.H.C., FOLSCHER, W.J. and OBERHOLSTER, R.E. 1969. Gronde van die Nooitgedacht-navorsingstasie. Tech. Communication No. 61. Dept. of Agric. Tech. Serv., Pretoria.

VERSTER, E. 1971. Soil survey of Makwassie. Technical Communication No. 56. Dept. Agric. Tech. Serv., Pretoria.

VERSTER, E. 1972. Konsepte, tegnieke en prosedures vir die globale hulpbronopname (grond). Report No. 154/73/784. Soil and Irrigation Research Institute, Pretoria.

VERSTER, E. 1973. Bodemopname van Rustenburgomgewing. Technical Communication No. 103. Dept. Agric. Tech. Serv., Pretoria.

WEBSTER, R. 1985. Quantitative spatial analysis of Soil in the field. Adv. Soil Sci. 3:1-70.

WEBSTER, R. 1994. The development of Pedometrics. Geoderma 62:1-15.

WEBSTER, R. and OLIVER, M.A. 1990. Statistical methods in Soil and land resource survey. Oxford University Press, Oxford.

WILDING L.P., and DREES, L.R. 1983. Spatial Variability and Pedology. In Wilding, L.P., Smeck, N.E. and Hall, G.F. (Eds.) Pedogenisis and Soil Taxonomy. I. Concepts and Interactions. Elsevier Science Publishers, Amsterdam. pp 83-116.

YOUNG, F.J., MAATTA, J.M. and HAMMER, R.D. 1991. Confidence intervals for Soil properties within map units. In Spatial Variabilities of Soils and Landforms. Mausbach, M.J. and Wilding, L.P. (Eds.) SSSA Special Publication No. 28. Soil Sci. Soc. Am., Madison, Wisconsin.