An Analysis of Terracettes in a Region of Giant's Castle Game Reserve, KwaZulu - Natal Drakensberg, South Africa.

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Preface

The research reported herein was undertaken in the Department of Geography, University of Natal, Pietermaritzburg, and in the Giant's Castle Game Reserve, KwaZulu-Natal Drakensberg, from May 1995 to January 1998, under the supervision of Dr F. Ahmed.

These studies represent an original undertaking by the author. Where use has been made of the work of others it has been duly acknowledged in the text. This dissertation has not been submitted in any form for a degree to any other University.

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Abstract

Terracettes are a widely occurring form of micro-relief found throughout regions displaying various climatic and environmental conditions. Much speculation surrounds the processes responsible for their formation and development.

An investigation of these micro-forms, their associated soil physical properties, sustaining mechanisms, and their relationship to slope stability was undertaken in Giant's Castle Game Reserve, KwaZulu - Natal Drakensberg, South Africa. The study showed that relationships between terracette morphology and soil physical properties within the Reserve are few, and that current soil conditions cannot be used to infer process related to terracette formation. However dry bulk density data indicated that soil creep is the dominant formative mechanism within the Reserve. Throughflow at riser surfaces was the dominant sustaining mechanism, with needle ice growth, wind, surfacewash and animal disturbance contributing minor retreat at both treads and risers. Aspect played an important role in determining soil physical characteristics. It was inferred that terracettes imparted stability to the slopes on which they are found, and with continued retreat at both treads and risers the slope was again placed under conditions of instability.

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Table of Contents

List of Figures

Chapter Five

Chapter Six

List of Tables

Chapter Two

Chapter Three

Chapter Five

Chapter Six

Chapter 1

Introduction

1.1 Terracettes in Context

Step-like microrelief features known as terracettes are a common sight on hillslopes throughout the world (Figure 1.1). Due to their varied distribution, terracettes have been described in a number of different ways by various authors. Vincent and Clarke (1976) have referred to terracettes as geomorphic enigma, often observed but poorly

Figure 1.1 Terracettes in Giant's Castle Game Reserve.

understood. These microforms are a common hillslope feature and yet little research has been conducted on them locally or internationally. According to Day (1993) terracettes are not regarded as spectacular landscape features and consequently have been treated as minor, even trivial, geomorphic phenomena.

According to Vincent and Clarke (1976) the term was first used in the geomorphic literature by Ødum in 1922, where he described, in a morphological sense only, miniature valley side terraces. Since the inception of the term, terracettes have been described in a number of different ways by various authors. Terminology used includes, among others, sheep roads (Warming, 1906, cited in Vincent and Clarke, 1976), cat steps (Bennet, 1939), sheep tracks (Dury, 1959) and cattle steps (Boelhouwers, 1991). Terms such as these directly imply genesis and are thus far from satisfactory since various modes of formation and sustaining mechanisms have been proposed, most suggesting a geomorphic origin rather than origins related to animal disturbance.

Terracettes were first described In the KwaZulu-Natal Drakensberg by Troll (1944) and King (1944) who noted slip scars in the Mont aux Sources region and described them as terracettes. Subsequently terracettes in the Drakensberg have been described by various authors including Butzer (1973), Harper (1969), Hastenrath and Wilkinson (1973), Granger (1976), Verster *et al.* (1986), Boelhouwers (1988), Garland (1987), Watson (1988), and Day (1993). Most authors have only conducted vague morphometric analyses which have not given much insight into the formative and sustaining mechanisms of the microforms.

Garland (1987) maintains that local usage of the term 'terracette' is misleading and was employed to describe features slightly different to the features described in the international literature. Garland (1987) describes terracettes as steps in the surface soil either parallel or sub-parallel to the contour. Higgins (1982) describes them as small closely and regularly spaced benches or steps that more or less parallel the contour. By the preceding descriptions it seems that the authors are describing the same, if not similar features. Differences in morphology could be attributed to climate, aspect, soil type, vegetation cover, land use and soil properties to name but a few.

1.2 Aims and Objectives

A significant amount of confusion and speculation as to the mechanisms that initiate and sustain terracettes, their nomenclature and their stability, is evident in the literature. It is also evident that these features occur widely and are not confined to any one climatic zone. Terracettes are a common sight on hillslopes in the KwaZulu-Natal Drakensberg, yet little research has been conducted in order to better understand the landforms.

The aims and objectives of the present study are:

- To enhance insight into the formative and sustaining mechanisms of 'Drakensberg' terracettes,
- To determine active sustaining mechanisms of terracettes within Giant's Castle Game Reserve,
- To determine relationships between various soil physical properties and morphological aspects of terracettes,
- To determine the soil physical properties of slopes on which terracettes occur.

This will be achieved by analysing various morphometric properties, soil physical properties and site specific variables, in order to determine correlations between morphology and soil physical properties of the slopes on which the microforms are found. In order for this to be accomplished the following parameters will be investigated:

- Tread width, length and angle,
- Riser height, length and angle,
- Slope angle and aspect,
- Aggregate stability of the tread, riser and nearby control site,
- Bulk density of the tread, riser and nearby control site,
- Shear strength of the tread,
- Particle size,
- Atterberg limits for the tread, riser and control sites, and

- Field moisture content.

The above variables will be subjected to various statistical tests (discussed in Chapter 4) in order to determine relationships, and gain insight into terracettes found in the KwaZulu-Natal Drakensberg, South Africa. It is also intended to discuss possible formative and sustaining mechanisms of the terracettes found in the study site, and to determine their role in slope stability. Processes active on the terracettes in the region will also be discussed from field observations.

Chapter 2

Literature Review

2.1 Modes of Formation

Modes of formation commonly referred to in the literature include:

- solifluction
- gelifluction
- slumping or rotational slipping
- soil creep
- regolith control
- vegetation control
- surfacewash and deposition
- animal disturbance.

2.1.1 Solifluction

Several authors have ascribed solifluction to the formation of terracettes (Costin, 1950; Tivy, 1962; Tricart, 1970). Costin (1950) argued that the development of plant roots near to the soil surface restricted solifluction in the A_1 horizon, and the faster movement of the A_2 and B horizons resulted in a gradual backward movement of the ground, causing shearing in the turf. The tear in the turf was then left vulnerable to frost action, resulting in terracettes. Costin (1950) has noted that the formation of what he termed 'solifluction terracettes' was accompanied by minor slumping on steep, overgrazed slopes of the subalpine tract, and was sometimes accompanied by large slump movements. Vincent and Clarke (1976) however found problems with Costin's theory of formation. They argue that the scars often seen at the base of terracettes are long, horizontal features normal to the slope, and that it is therefore difficult to envisage a process whereby frost attacks the soil in such a regular pattern.

Tivy (1962) concluded that terracettes are in fact miniature turf bound solifluction lobes whose instability is often increased by sheep trampling and particularly by the vegetation cover downslope of them, either by sheep scars or by stream or gully undercutting.

Lother (1956, cited in Vincent and Clarke, 1976) and Tricart (1970) also advocated solifluction processes for the formation of terracettes. Lother in a study in le Pays de Herve, France, claimed that the slopes on which terracettes in the region are now found had only been active pasture lands for the preceding two hundred years. He considered this insufficient time for terracettes to form by under-hoof trampling. This argument has since been met with scepticism since Howard and Higgins (1986) found that terracettes could be formed within six weeks on slopes exposed to sheep trampling.

2.1.2 Gelifluction

Gelifluction is solifluction associated with frozen ground (Vincent and Clarke, 1976). Demangeot (1950, cited in Vincent and Clarke, 1976) recognised the contribution of gelifluction to the formation of terracettes. His study site in the cental Apennines revealed parallel steps in the vegetal carpet. Demangeot proposed that a special sequence of conditions is necessary in order for terracettes to form. The soil is first cracked by solifluction and the fissures enlarged by the joint *in situ* action of frost thaw, aeolian deflation, corrasion and cryoturbation. Finally, he suggests that the grass stripes are tilted over by gentle creeping. This theory however, can also be met with a certain amount of scepticism since terracettes can be found at low altitudes where frost processes are not active. If Demangeot is correct, it would suggest that all terracettes found in areas where frost is not active are fossil features and are only being sustained by processes associated with present day conditions. This would obviously require detailed palaeoenvironmental reconstruction in order to establish past climatic factors responsible for their formation.

Tricart (1970) maintains that terracettes are genetically related to earth hummocks and are thus a product of gelifluction activity.

2.1.3 Slumping and Rotational Slippage

Darwin (1904) observed lines of 'miniature cliffs' on steep, grass-covered slopes. He considered these forms to result from the sliding of the superficial, argillaceous earth, partially held together by roots of the grasses. In thus sliding had yielded and cracked in horizontal lines transversely to the slope. Ødum (1922) also reported parallel cracking of the earth surface associated with rotational slippage of superficial blocks. He also noted that on slopes where landslips occur, terracettes occur in the areas where no slips are visible. Sharpe (1938) described four types of landslip terracettes associated with:

- ❑ slippage of blocks on a major slip plane
- ❑ rotational slippage of blocks
- ❑ slumping on deep seated curved surfaces, and
- ❑ gravitational sliding where lithology consists of poorly consolidated material.

The above modes of formation all refer to slippage along a plane of weakness in the soil. Vincent and Clarke (1976) however point out that few such planes have been observed in the field to support the hypotheses.

2.1.4 Soil Creep

Soil creep is defined by Sharpe (1938) as the slow downslope movement of superficial rock or soil debris, usually imperceptible accept to observations of long duration.

Clayton (1966) suggests that terracettes may be formed by creep while Taylor and Pohlen (1970) consider creep, only in it's accelerated form, to be a necessary requirement. Since moisture is necessary for any solifluction process to operate Vincent and Clarke (1976) contend that any general theory of terracette formation requires the experimentation of the role of soil moisture. Blong (1965) has observed the influence of sub-surface water in terracette formation. Williams (1973, cited in

Vincent and Clarke, 1976) argues that periodically high pore water pressure associated with fluctuating water tables can be the cause of terracette formation. However the increase in pore water pressure and soil moisture content, empirical in the above hypotheses, may explain the reduction in the shear strength of the soil, but on it's own does not qualify as a determinant of terracette formation and morphology (Vincent and Clarke, 1976).

2.1.5 Regolith Control

Terracette formation is of a superficial nature, therefore distinguishing it from landslides (Vincent and Clarke, 1976). Young (1963) observed terracettes on slopes between 44° and 33° where regolith was thin. Roberts (1964) did not consider the thickness of the regolith to be a determining factor in the formation of terracettes. However, Carson and Kirkby (1972) found the occurrence of terracettes to be closely linked to the thickness of the soil mantle. Where the mantle was thin, they observed terracettes and observed none where the soil was deep. Carson (1969) concluded that the shallowness of the soil mantle imparted extra strength to the slope and thus prevented mass failure but did not preclude the slope from small scale instability features such as terracettes. This was explained since the binding effect of vegetation is generally greater in thin soil mantles as opposed to a thick regolith cover. Young (1972) claims that the role of regolith strength is not known when considering the lower limiting angle of terracettes.

2.1.6 Vegetation Control

Young (1961) states that terracettes occurred on slopes with continuous soil, vegetation cover and limiting angles between 33° and 36°. Young (1960) showed that an increase in a slope angle increased the rate of soil movement - a view that is supported by Clarke (1965) who observed that slopes steeper than 32° and 33° show increasing signs of instability associated with well-marked terracettes, fractures in the turf cover and a thin soil mantle.

Dury (1959) found the presence of a root mat nonessential for the formation of terracettes since they can also occur on slopes with little or no vegetation. Brice (1958) displayed that terracette development is a function of slope angle and vegetation cover. He argues that breaks in the vegetation cover initiated the formation of terracettes and scarp retreat. According to Vincent and Clarke (1976), such breaks could be caused by drought, overgrazing, burrowing of rodents, or by the hoofs of grazing animals. Brice (1958) concluded that 'steps' are poorly developed on heavily sodded slopes because the sod cover reduces the impact of sheetwash and thus inhibits the development of low sod scarps.

2.1.7 Surfacewash and Deposition

Terracettes on steep loessic slopes in Nebraska are thought to have formed from sheetwash erosion where vegetation cover is interrupted. The process results from a short steep scarp being formed which retreats upslope as the process continues (Brice, 1958).

Selby (1970) proposes that sediment resulting from sheet erosion gradually builds up behind obstacles - such as rocks and grass tussocks - which create barriers to downhill flow. As the tread builds up the riser is eroded backwards resulting in step-like microrelief features.

2.1.8 Animal Disturbance

Central to the terracette discussion is the assertion by various authors such as Meynier (1951), Brice (1958), Gibbs (1962), Rahm (1962), Roberts (1964), Radcliffe (1968), and more recently Higgins (1982), and Howard and Higgins (1986), that terracettes are formed by the action of grazing animals on hillslopes. This view is contested by Vincent and Clarke (1976), who claim that it seems unlikely that the regularity of terracettes on a slope is fortuitous, or always attributable to grazing animals. Howard and Higgins (1986), assert that 'steps' are biogenic rather than purely physical in origin. Their data seems to indicate that grazing animals do in fact help in the formation of terracette like features. Higgins (1982), found that during 1977 one of two identical smoothed grass hillslopes in California was grazed by sheep. This slope developed distinct terracettes after a six week period, whereas the ungrazed slope showed no such features. The terracettes on the grazed slope were approximately 0.8m wide, with risers of about 0.4m high. The treads were bare and the risers vegetated. They formed only on slope segments greater than 15°, and showed a clear orientation sub-parallel to the contour.

There is little doubt that the terracettes described by Higgins (1982) were formed by sheep. The mechanism of formation however is unknown. Garland (1987) offers two possible explanations. Firstly, the added mass of the animals on the slope may have brought about an excess of shear stress over resistance, resulting in shear failure. Garland (1987) argues that this is in fact unlikely because the force exerted by the animals' body would be transferred to the slope through their hooves, resulting in high concentrations of stress at these points, and it is thus more likely that the hooves would have sunk into the soil rather than resulting in a coherent body of soil moving downslope. A more plausible argument according to Garland (1987) is that the soil trampled by the animals would compact and lose volume, thus being compressed into the shape of a terracette.

From Garland's (1987) argument it can be deduced that animal induced 'terracettes' are not in fact terracettes at all, but rather 'grazing steps' that take on a similar appearance to terracettes. Selby (1982) claims that animal treading is almost certainly primarily responsible for continuous terracette systems which may have been built upon natural forms, developed beneath forests and by irregular soil creep. In the field it would be difficult to distinguish between the two phenomena and past land use would thus become a necessary criterion for distinguishing between the two microforms.

2.1.9 Summary

It is impossible to envisage an environment in which the above formative mechanisms act alone and in which only one mechanism operates. It must be considered that mechanisms act both in series and in parallel in order for terracettes to form. It can be deduced that the various formative mechanisms proposed are dependant on four general factors:

- Climate - rainfall type and intensity, temperature
- Topography - aspect and gradient
- Soils - type and thickness, physical properties and moisture, and
- Vegetation - type and extent.

Furthermore it also becomes important to look at mechanisms that sustain the landforms. Day (1993) divides formative mechanisms into two distinct groups (Figure 2.1):

- Primary factors directly responsible for terracette initiation, and
- site-specific secondary mechanisms responsible for sustaining or accentuating terracette forms.

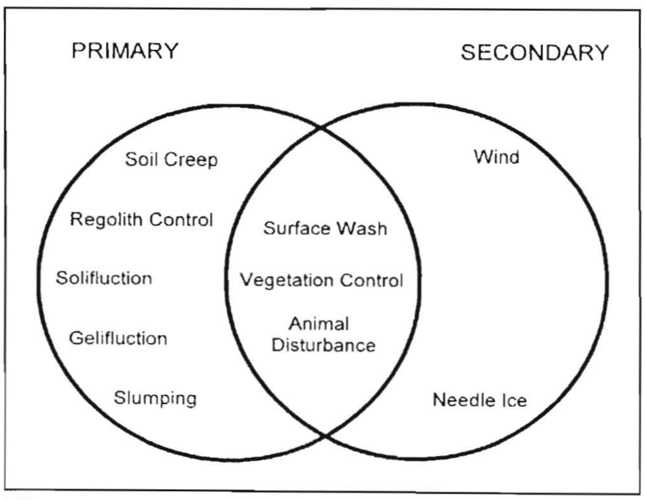

Figure 2.1 Geomorphic mechanisms suggested for terracette initiation and development. (After Day, 1993).

The results of several studies undertaken by various authors are summarised in Table 2.1. Discrepancies and disagreement regarding virtually all aspects of terracette morphology and genesis are evident, and clearly reflect the varied nature of these features and the controversy surrounding their origin. Although differences in terracette morphology cannot provide all the necessary explanations in terms of genesis, the variety of forms reported in the literature suggests that morphology may play an important role in determining process. The ubiquitous nature of terracettes would suggest that different processes may well give rise to similar features under varying environmental conditions.

2.2 Secondary Mechanisms

As discussed in section 2.1.9 above, secondary mechanisms are important to consider when examining terracette morphology.

2.2.1 Needle Ice

Needle ice plays an important role in continuing terracette retreat (Harper, 1969, Killick, 1963, Boelhouwers, 1988). The processes by which this occurs are explained by Taber (1929, 1930). Briefly, when air temperature is at freezing point and the soil temperature is slightly above freezing point, water segregates just below the soil surface and freezes. Vertically orientated frost crystals, commonly known as needle-ice, are formed and grow downwards drawing water towards the freezing front through soil capillaries by molecular cohesion. The growth of frost crystals results in the uplift of soil. On thawing, the base of the crystals melt first, causing the loose soil to fall away from it's original position. Soil loss due to needle ice disturbance can be fairly extensive and Boelhouwers (1988) recorded soil losses of between 4.5g and 2.4g in a site 406cm^2 over a 6 day period. In a more detailed experiment carried out on the banks of the River Ilston, West Glamorgan in the United Kingdom, Lawler(1993) recorded sediment losses of 4.02kg m^{-2} over a 2.25 year period. Although Boelhouwers (1988) carried out his tests on the 'riser' of a footpath and Lawler (1993) conducted his research on a river bank, the erosive potential of needle

Table 2.1: Summary of data obtained by various authors.

AUTHOR	LENGTH (m)	WIDTH (cm)	HEIGHT (cm)	SLOPE ANGLE (degrees)	VEGETATION ON TREAD	PRIMARY	SECONDARY
Dury (1959)			"A foot or two"	steep		soil creep	
Harper (1969)	< 6	90	30 - 60			surface wash	needle ice, wind
Kirkby (1972)					bare	soil creep	
Carson and Kirkby (1972)		50	50		bare	soil creep	animal disturbance
Higgins (1982)	continuous	80	40	15 - 31	vegetated	animal disturbance	slope wash, needle ice
Hastenrath and Wilkinson (1972)						animal disturbance	needle ice
Verster *et al* (1986)		<200 >300				mechanical failure	
Watson (1988)	5.12	270	330	12 - 20	bare	polygenetic	animal disturbance
Moeyersons (1989)				28	bare	slow sliding	
Garland (1987)	14.16	369	550	18 - 90		polygenetic	rainsplash and runoff
Boelhouwers (1988)	0.1 - 0.5		5 - 25	15	bare	surface wash	needle ice
Boelhouwers (1991)	0.4 - 6	90	5 - 130	30	bare	animal disturbance	needle ice
Hall and Boelhouwers (1990)	4 - 10		10 - 20	22	diminishes towards riser	soil creep, soil flow, runoff	animal disturbance

ice can clearly be seen and thus inferred to terracettes, provided the temperature, moisture and soil conditions are met.

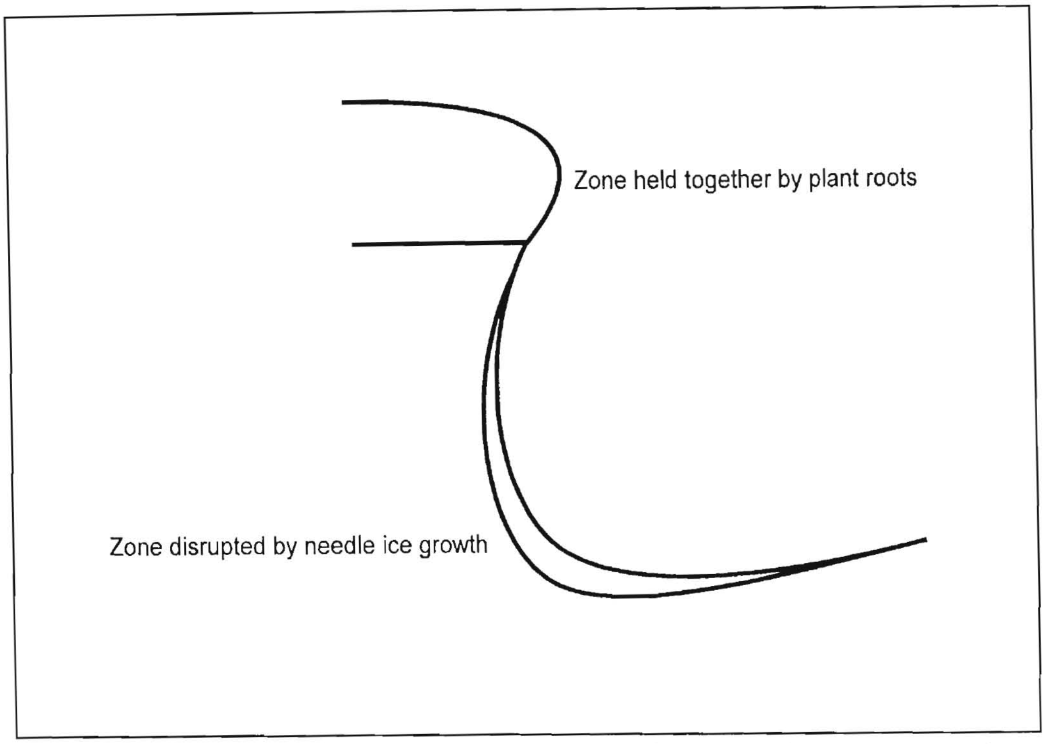

Figure 2.2 Zone of disturbance by needle ice growth on a terracette tread and riser.

2.2.2 Wind

The geomorphic influence of winds is little known since few data are available to assess the influence of wind on soil movement. However it cannot be discarded as an unimportant variable when considering soil loss on terracettes with bare treads and risers. Wherever unvegetated surfaces occur it is likely that wind erosion will occur if threshold limits are exceeded. Factors influencing and facilitating soil erosion by wind include soil type, soil moisture content, particle size and wind velocity (Cooke and Doornkamp, 1974).

Boelhouwers (1988) does not consider deflation as a major geomorphic agent in the Drakensberg since vegetation cover is thick and bare soils are rare, however bare risers and treads are abundant in the study area. The effect of veld burning on soil loss due to wind may be more significant and Sumner (1995) estimates a loss of 152 tons/ha per annum near the Escarpment south of Kamberg. Garland (1987), however, downplays the role of wind erosion on terracette morphology even after veld burning has taken place. Since no effective study on the role of wind has taken place with reference to terracettes in the study region, it cannot be regarded as a non-entity with regards to sustaining mechanisms.

2.3 Classification Systems

Various authors have proposed classification systems for terracettes. These range from classifying according to modes of formation to purely morphometric classifications. Not only does classification lead to confusion regarding the landforms but offers little in their overall explanation and interpretation. According to Anderson (1972) commonly accepted definitions are vague and tentative and do nothing to clarify the position.

Anderson (1972) distinguished two basic types of terracettes:

- normal terracettes with wide risers at a similar angle to that of the slope, and long, unbroken treads parallel to each other and normal to the slope, and,
- tear terracettes with narrow, steep risers generally lacking in vegetation, and short treads which are rarely parallel or normal to the slope.

Anderson (1972) found morphometric differences between 'normal' and 'tear' terracettes.(Table 2.2). Four factors were used by Anderson (1972) in order to classify terracettes in his study:

- riser angle,
- tread angle,
- riser height, and
- tread width.

Although the above classification was carried out statistically and in some detail, only four morphometric parameters were used. Anderson (1972) neglected to consider riser and tread length, macroslope angle and failed to consider other factors such as climate, soil type, vegetation cover and land use - both past and present. A system that attempts to classify terracettes should thus not make generalisations on such few variables and should take all factors into account. It is through such general classifications and definitions that so much confusion exists in the terracette realm. It would be far more helpful to the discipline if terracettes were not classified according to morphology, but rather according to formative mechanisms. However since many authors disagree on formative mechanisms this would also be a difficult task and detailed process studies would have to be undertaken.

Table 2.2: Morphometric differences between 'normal' and 'tear' terracettes. (After Anderson, 1972).

	NORMAL	TEAR
TREAD ANGLE	10.5°	16.8°
RISER ANGLE	39.9°	68.0°
TREAD WIDTH (cm)	54.5	36.0
RISER HEIGHT (cm)	90.5	25.9

2.4 Terracettes in a Periglacial Context

Terracettes have been used as periglacial indicators and cold climate features both in international and local literature (Harper, 1969; Tricart, 1970; Butzer, 1973 Hastenrath and Wilkinson, 1973; Dardis and Granger, 1986; Boelhouwers, 1988, 1991; Hall and Boelhouwers, 1990; Hanvey and Marker, 1992). They have been used, especially in the South African context, as indicators of past and present periglacial climates. However, if generally accepted formative mechanisms are considered the only mechanism restricted to periglacial zones is gelifluction, for without ground ice the process cannot occur.

Thorne (1992, p. 24) defines periglacial geomorphology as:

> ".....that part of geomorphology which has as it's primary object physically based explanations of the past, present and future impacts of diurnal, seasonal, and perennial ground ice on landform and landscape initiation and development. Additional components of the subdiscipline include similar investigations of the geomorphic roles of snowpacks (but not glaciers) and fluvial, lacustrine, and marine ice."

From the above definition we can infer that if terracettes are periglacial phenomena that they would only be found in periglacial regions - or those regions where ground ice has played a significant role in landscape initiation and development. If this were so, there are vast implications for palaeoenvironmental reconstruction.

Killick (1963) suggests that terracettes are formed by needle ice action alone. From the preceding review it is clear that terracettes cannot form from needle ice action alone, and that other fluvial and aeolian processes act in series with formative mechanisms. It is clear that terracettes are not periglacial landforms and to infer past and present climatic conditions from there occurrence is a misnomer. Terracettes can only be referred to as periglacial if a distinct type, based on morphology and process, is found to only occur in periglacial regions. To date no such unique form of terracette has been observed or reported in the literature. The question then arises whether such a feature should in fact be called a terracette, or even a periglacial terracette. Since the only proposed formative mechanism for terracettes that operates solely in periglacial regions is gelifluction, what could be of significance is the rate at which the formative mechanisms act in periglacial and marginally periglacial zones.

A possible reason for terracettes in the KwaZulu-Natal Drakensberg being described as periglacial in origin is King's (1944) definition where he relates their formation to rotational slumping once soil had become saturated due to seasonal snow melt. A similar mechanism has been proposed by Costin (1950) in regions devoid of snow, thus the process described by King (1944) could well be accelerated in a periglacial environment. Similarly soil creep occurs in many varied environments and could be accelerated by frost heave as opposed to wetting and drying alone. Kirkby (1972) measured creep in cold regions at a rate of 5cm - 10cm per annum. This rate is faster than rates measured in non-periglacial regions where surface rates of 0.3mm y^{-1} to 6mm y^{-1} were recorded by Day (1977) in temperate maritime environments, and rates of 3mm y^{-1} to 4.6mm y^{-1} were recorded by Lewis (1974) in a tropical savannah environment. If the rate of seasonal creep is faster in periglacial environments, the vegetation is more likely to be disrupted, and terracettes more likely to form by needle ice action at breaks in the turf mat. Troll (1944) favoured such a process for terracette formation in the KwaZulu-Natal Drakensberg at elevations above 2000m.

Surface wash is also more likely to operate more efficiently in periglacial regions, particularly in regions where snowfalls are frequent and melt out accelerated. According to Boelhouwers (1988) surface wash causes step formation by the removal of soil which is consequently deposited behind and in between grass tussocks.

Tricart (1970) describes small benches 30cm - 80cm wide, separated by steep risers 20cm - 1m in height. He claims they occur entirely on steep grassy slopes, of at least 20°, and are related to earth hummocks, into which they pass as the slope flattens. It seems unlikely that this type of formative mechanism would result in such regular and distinct parallel features on hillslopes.

From the above discussion it is clear that terracettes can be periglacial features due to the nature of some proposed formative mechanisms. However terracettes cannot be used as climatic indicators due to their widespread occurrence and thus can certainly not be used as evidence of periglacial or past periglacial environments.

2.5 Terracette Stability

Some authors conclude that terracettes are features that add to the stability of the slopes on which they are found. Ødum (1922) claimed that after the formation of terracettes no new formation, disintegration or downward movement of earth would take place. Pissart (1964, Cited in Vincent and Clarke, 1976) confirmed this theory by showing that terracettes stabilise slopes reaching an angle of 43°. Vincent and Clarke (1976) point out that, if terracettes stabilise slopes, conditions may have changed so that the features are fossil - as in the Gelifluction Hypothesis above.

Figure 2.3 Instability features possibly initiated by terracette movement.

They conclude therefore that it is then difficult to determine the conditions necessary for the formation of terracettes and that present environmental conditions and measurements may be inadequate or irrelevant.

Garland (1987) claims that the question of terracette stability is crucial to erosion hazard assessment in areas where they occur. Once they have formed it is important to know whether the formation process will continue to form more, or modify existing terracettes, and if once formed they contribute to, or hinder further erosional processes on the slope.

By terracettes forming on a slope they have adjusted the original set of conditions that were active on the slope and thus render the original set of conditions unstable.

Garland (1987) considers this as an attempt by the slope system to regain equilibrium between forces causing soil movement and those resisting it. Since terracettes take a relatively long time to form and the process is not therefore instantaneous - estimates ranging from 6 weeks (Higgins, 1982) to greater than 200 years (Lothar, 1956; cited in Vincent and Clarke, 1976) - it is reasonable to assume that most observed terracettes have not developed through to an equilibrium stage. The presence of terracettes where none occurred before also creates different conditions which might allow other erosional processes to become more active.

Previous authors have noted instability resulting from the initiating process. Thomas (1959) showed downhill motion of terracettes, on a 13° slope, of 0.6m over a four year period near Chichester, England. Moeyersons (1989) recorded a mean downslope movement of 145mm in a year on Rwaza Hill, Rwanda. Clarke (1965) also observed downhill advance of terracettes at Edale and Bowland, England, although no measurements were recorded. Pissart (1964, cited in Vincent and Clarke, 1976), in contrast, showed that some terracettes in the French Alps remain stable for long periods of time. Verster and van Rooyen (1988) recorded soil movement both upslope and downslope of terracettes. Upslope movement was recorded at 0.57 mm per annum and downslope movement as 3.25mm per annum. These measurements were recorded in the Cathedral Peak area of the KwaZulu-Natal Drakensberg, South Africa. Verster and van Rooyen (1988) claim that terracette formation is an indication of downslope soil movement, and advocate slope instability and soil creep as formative mechanisms.

Erosional processes active on terracettes, other than those responsible for their initiation, is not well documented. Higgins (1982) observed a number of landslips and slumps on slopes featuring terracettes in California after high rainfall events. He noted that similar slopes that were devoid of terracettes were only affected by sheet and rill erosion.

It seems that some terracettes lend stability to the landscape while others do not (Garland, 1987). Why this is so is not always evident. Garland (1987) claims that in the case of stable features the development of terracettes may have created a new landform in complete equilibrium with driving forces, or the conditions causing mobility in the upper soil layers may have disappeared.

Chapter 3

Environmental Setting of Giant's Castle Game Reserve

3.1 The Study Site

Giant's Castle Game Reserve is situated in the Central KwaZulu - Natal Drakensberg, South Africa (Figure 3.1) and was set aside as a Reserve Area in 1903, covering 34638 hectares (Sumner, 1995). It forms part of a protected area known as the Drakensberg Park, and is bordered by Lesotho to the west, Injasuthi to the north and the Natal Parks Board Highmoor and Mkhomazi areas to the south. To the east lies the area formerly known as the Drakensberg Location, which now forms part of the Province of KwaZulu - Natal. The Reserve can be accessed via Estcourt, Mooi River or Nottingham Road/Rosetta on secondary roads.

The Reserve is a popular tourist retreat and has cottage facilities which can house up to 80 guests. Attractions include scenic hiking trails, a wealth of Bushman art which can be viewed at the Main Caves Museum, and serves as a popular access route to the Main Escarpment and Lesotho for more energetic hikers. No camping facilities are available at present. The extensive footpath network within the Reserve makes the area popular to both day visitors and overnight visitors who can make use of three self catering huts situated on the contour path at approximately 2250m above sea level.

Reasons for choosing the Reserve as a study area include:

- Easy access from the University, in Pietermaritzburg,
- Accommodation within the Reserve, and nearby Hillside Camp, which was made available by the Natal Parks Board,
- Equipment left in the field for long periods of time is secure and the likelihood of tampering and theft is minimal, (sites included in Figure 3.2).

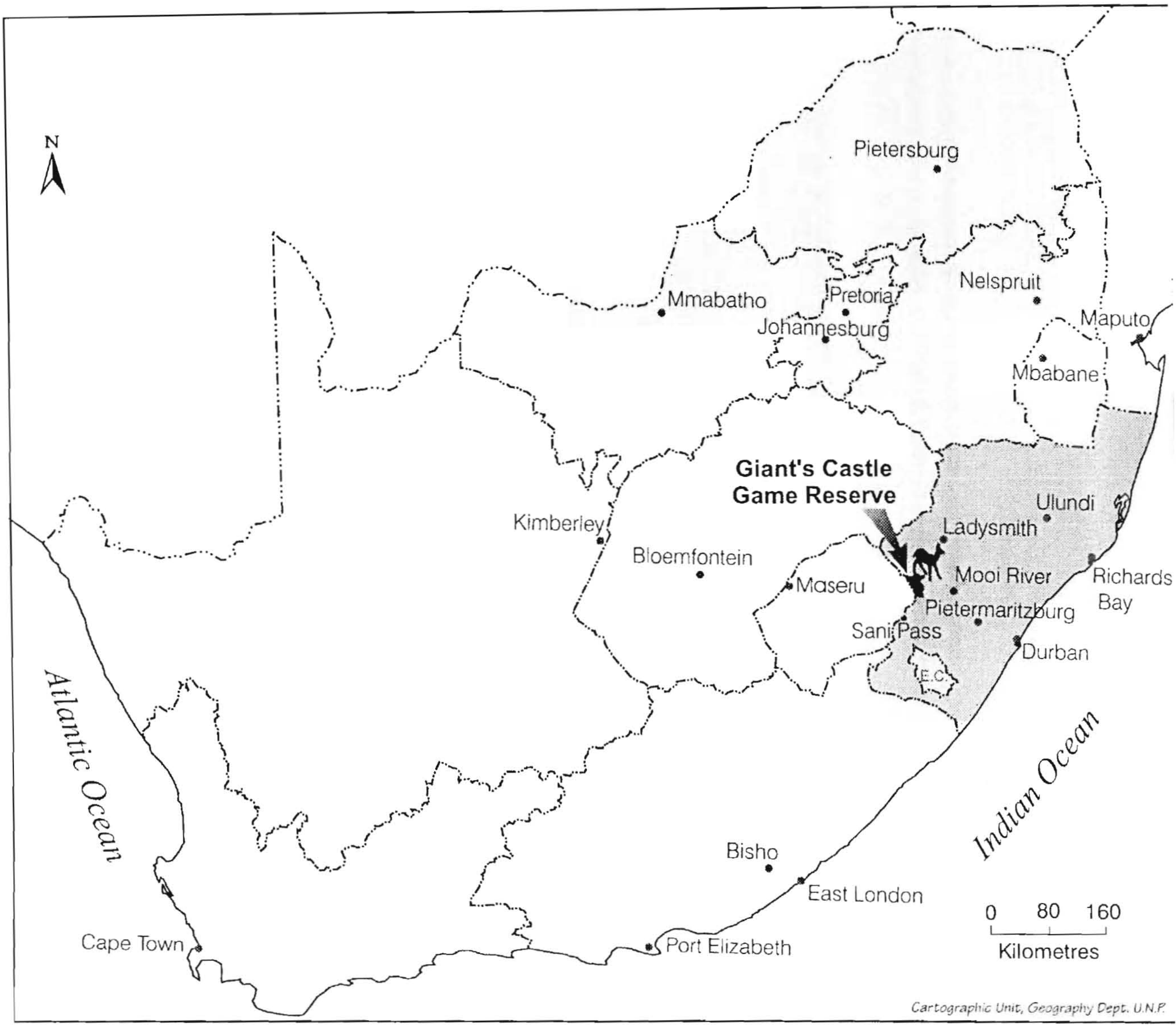

Figure 3.1 Location map of Giant's Castle Game Reserve.

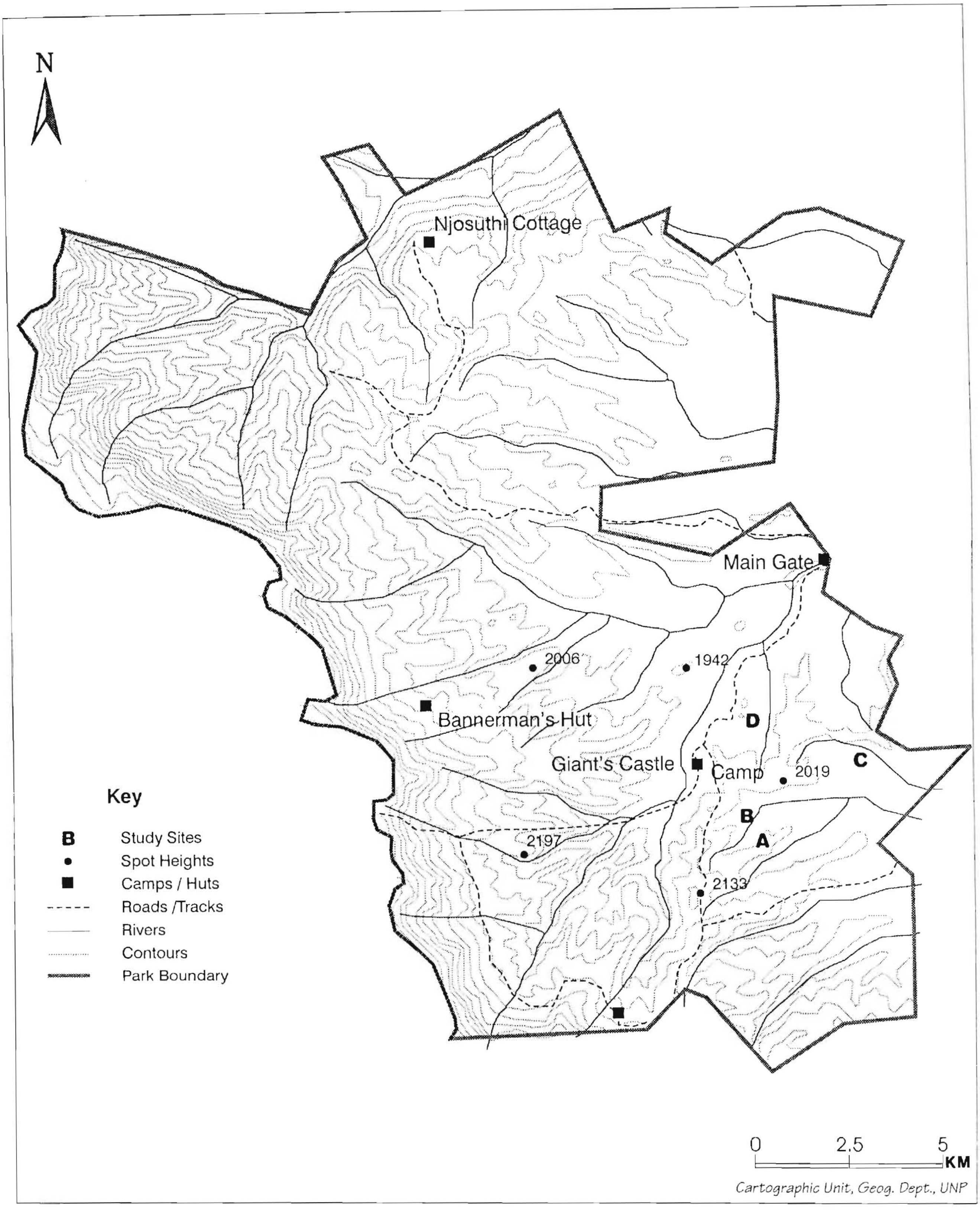

Figure 3.2 Location map of study sites in Giant's Castle Game Reserve.

3.2 Geology

3.2.1 Topography and Drainage

The KwaZulu - Natal Drakensberg forms part of the Main Escarpment which extends from the Eastern Cape Province in the south, through KwaZulu - Natal, to the Free State Province in the north. The Main Escarpment separates the coastal lowlands from the interior plateau of Southern Africa, and forms a large horseshoe-shaped step with distances ranging between 50km and 500km inland from the eastern coast (King, 1982). The topography of the Game Reserve is divided into three distinct zones, namely: the Little Berg, the Escarpment and the Lesotho Plateau. Altitudes along the Escarpment reach up to beyond 3400m and in the valleys of the Little Berg extend down to below 1500m. The valleys draining the Escarpment tend to be east - west, and this is true of the study area which is found in the upper reaches of the Bushman's River catchment, which drains to the northeast and ultimately into the Tugela River.

3.2.2 Stratigraphy

The Drakensberg is characterised by a concordant sequence of sedimentary strata which is overlain by basalts and intruded by a lattice of dolerite dykes and sills together belonging to the Karoo Supergroup (S. A. C. S., 1980), (Table 3.1). The general stratigraphy is described in texts by Du Toit (1954) and Haughton (1969), with a comprehensive listing of work on the Molteno, Elliot and Clarens Formations being found in Eriksson (1983).

The Beaufort Group

The Beaufort Group is subdivided into the Lower, Middle and Upper Subgroups and the Lower Adelaide Subgroups (S. A. C. S.,1980; Eriksson, 1983) with only the first Subgroup being found in the study area. The Upper Beaufort Subgroup consists of red and maroon coloured mudstone with blue and green shales interbedded with widely spaced yellow, fine to medium-grained felspathic sandstones (Du Toit, 1954; Haughton, 1969). The strata of this Subgroup underlie a small part of the Bushman's

River valley floor at elevations ranging from around 1500m to 1590m.

Table 3.1 Stratigraphic sequence of the Karoo Supergroup (After S. A. C. S., 1980; and Eriksson, 1983).

SUPERGROUP	GROUP	SUBGROUP/FORMATION	AGE
Karoo Supergroup	Drakensberg (volcanics)		Upper Triassic - Lower Jurassic
	No group name	Clarens Formation	Upper Triassic
		Elliot Formation	Upper Triassic
		Molteno Formation	Middle Triassic
	Beaufort group	Upper Beaufort Subgroup	Lower Triassic
		Middle Beaufort Subgroup	Lower Triassic
		Lower Beaufort Subgroup	Upper Permian

The Molteno Formation

This formation consists of light coloured, fine to very coarse grained sandstones interbedded with layers of argillaceous sediments, and conglomerate sandstones forming a subordinate component. The Molteno formation lies directly above the strata of the Upper Beaufort Subgroup. The two are easily distinguishable from one another due to the absence of deeply coloured argillite found in the former. The shales and mudstone of the formation are usually grey or blue and appear yellow in their weathered state (Du Toit, 1954; Haughton, 1969). The thickness of the Molteno Formation is estimated at between 7m and 20m (Eriksson, 1983) and occurs at an altitude of approximately 1600m in the Bushman's River valley. The sandstone horizons of the Molteno Formation form outcrops whereas the more argillaceous sediments are covered by a vegetated soil cover (Boelhouwers, 1992).

The Elliot Formation

The Elliot Formation, formerly known as "The Red Beds" is characterised by red and purple argillaceous sediments, containing occasional lenses of fine to coarse grained sandstone. The argillaceous sediments range from mudstone to very fine grained sandstone and make up approximately 92% of the stratigraphic thickness (Eriksson, 1983). The contact between the Molteno and Elliot Formations is characterised by a gradual change from predominantly arenaceous into massive argillaceous strata. The contact is at the level where red to purple argillite becomes dominant (Eriksson, 1983). The thickness of the strata in the Giant's Castle Game Reserve varies between 50m and 80m, and occurs at elevations between 1630 m and 1720 m.

The Clarens Formation

The Clarens formation, also known as the Cave Sandstone (Figure 3.1), comprises

Figure 3.3 View of the Clarens Formation in the Bushman's River Valley, with the Main Escarpment in the distance..

massive, pale coloured, very fine sandstones and siltstones, which comprise 87% of the total stratigraphic thickness. The remaining 13% consists almost entirely of fine to medium grained sandstone (Eriksson, 1983). At the basal contact with the Elliot Formation, the brilliantly coloured massive mudstone of the latter pass into pale coloured sandstones which frequently show waterlain structures (Haughton, 1969; Eriksson, 1983). The Clarens Formation attains a thickness of up to 120m at altitudes between 1720m and 1880m in the study area. The sandstones of the Clarens Formation are easily recognisable in the landscape as they often give rise to pronounced rock scarps. The Clarens Formation is also interspersed with hollows that form shallow rock shelters at the base of the scarps. A large number of these shelters were inhabited by Bushmen and are adorned with rock art, of which fine examples are present in the study area.

Several authors have noted that, in general, the sandstone layers of the formation form rock scarps, whilst the argillaceous sediments are overlain by a colluvial cover (Fair, 1947, 1948; Du Toit, 1954; Eriksson, 1983). Embleton and Thornes (1979) argue that sandstone layers are more permeable to water than shales and mudstone and thus the alternation of beds in the sedimentary strata has a bearing on the hydrology of the area, causing moisture to appear at the surface near bedding contacts (Boelhouwers, 1992). Higher soil moisture contents near the bedding contacts are resultant in increased weathering rates at the base of sandstone outcrops and thus facilitating the generation of mass wasting in the underlying colluvial cover (Young, 1972).

The Drakensberg Group

The basalts of the Drakensberg Group consist of numerous individual lava flows resting directly on the sandstone of the Clarens Formation (Boelhouwers, 1988). The basalts attain a thickness of over 1350m (King, 1982), whereas the lava flows vary considerably in vertical extent - 30-50m in northern Lesotho (Venter, 1938) and 5-30m in other parts of Lesotho (Stockley, 1947). Each lava flow usually consists of a basal zone rich in pipe amygdales, a central zone of massive basalt, and an upper zone of vesicular basalt. The amygdales consist mainly of silica, calcite, chlorite and zeolite (Bleackley and Walkman, 1964, cited in Nixon, 1973). The amygdaloidal content of the basalt varies considerably from lava flow to lava flow, with a marked absence of these enclosures in the highly massive and crystalline horizons (Du Toit, 1954). At the contact of the basalt with the underlying sandstone, contact metamorphism has taken place, causing induration of the sandstone to a quartzite which has been estimated as a few metres thick in the study area (Eriksson, 1983). The lavas are of the plateau type and resulted from fissures now present as dolerite dykes. The dykes have widths of between 3m and 6m, and lengths varying from tens of metres to numerous kilometres (Boelhouwers, 1988). Nixon (1973) demonstrates that 66% of all lineaments (dykes, kimberlites and joints) are orientated between E-W and SE-NW directions.

Moon and Selby (1983) have shown the geomorphic significance of the basalt to be it's generally high rock mass strength, and the variations therein between individual lava flows. This characteristic has been shown to be the major cause of the existence of the main escarpment and the numerous bevelled surfaces (Moon and Selby, 1983; Selby, 1982). The joint orientation of the basalt has been shown to have a major impact on the water distribution in the Drakensberg by Harper (1969) and Nixon (1973). Several reports suggest that spring levels, or horizons, provide a continuous source of moisture with distinct effects on soil and vegetation type, as well as geomorphic processes (Staples and Hudson, 1938; Killick, 1963; Granger, 1976).

The chemical composition of the basalt and its massive structure aid in dictating the mode of weathering present and it's products (Boelhouwers, 1992). This undoubtedly relates to the physical and chemical properties of the soils formed, and ultimately affects the geomorphological mechanisms in operation as well as the vegetation cover (Ollier and Marker, 1985).

3.2.3 Geological Structure

The strata of the formations in the KwaZulu - Natal Drakensberg all rest at a near horizontal position with dips seldom steeper than 6° in a south to southwesterly direction (Stockley, 1947). Consequently the strata form the northerly part of a shallow syncline that underlies the whole of Lesotho and forms the top section of the

Karoo basin that extends down into the former Cape Province (Stockley, 1947; Tankard *et al.*, 1982). Small structural domes and basins in the rock strata are considered to be the result of sill intrusions into the underlying formations (Nixon, 1973).

The first river systems on the Lesotho Plateau developed from gentle flexuring of the whole succession which resulted in a series of NE-SW trending ridges and furrows, which are still maintained today (Nixon, 1973). Undulations of the contact surface between the basalt and the Clarens Formation are as a result of the palaeotopography of the sandstone surface (Tankard *et al.*,1982). Major joints are present in the study area and a number of these are filled with dolerite dykes (Boelhouwers, 1988)

The resultant structure of Natal has been summed up with two differing theories, the 'fault' theory and the 'monoclinal' theory as discussed by Maud (1961; 1962) and Turner (1967). Observations indicated extensive faulting along the coastal plain (Beater and Maud, 1960; Hardie, 1962) and is described by Maud (1961, 1962) as a series of arcuate faults stretching to the southeast. This fault system is recognised as being associated with rifting during the breaking up of Gondwanaland (Tankard *et al.* , 1982). An alternative viewpoint was proposed by Penck in 1908 (cited in King, 1944) who, denying the existence of the Quathlamba-fault, suggested that the dominant structure in eastern KwaZulu - Natal is a coastal monocline. This viewpoint has been advocated by Du Toit (1954), King and King (1959), and King (1944, 1982). The fault pattern demonstrated by Maud (1962) cannot be denied, but the popular opinion is that it is thought to be of secondary origin (King, 1982).

3.2.4 Geomorphological evolution

Suess (1904) offers the earliest interpretation of the Main Escarpment, which is the most dominant feature of the Drakensberg, as being that of a huge fault. Work by Penck (1908) refuted the existence of a fault and suggested that the Escarpment was the result of scarp retreat. Dixey (1942) and Fair and King (1954) supported this theory and related the origin of the Escarpment to erosional processes. King (1976) identified five stages of uplift and identified five datable surfaces, with the late Pliocene stage of uplift giving rise to the rejuvenation of streams in the Little Berg. King was criticised by Young (1972) and Le Roux (1991) for lack of objectivity and empiricism

Dating and correlation of erosion surfaces proved problematic (DeSwart and Bennet, 1974; Summerfield, 1985) and consequently structural control was proposed by Birkenhauer (1985) as the main reason for the existence of the distinctly stepped topography. Simultaneously a number of problems emerged with the association and application of denudation chronology to landscape interpretation (Chorley *et al.*, 1984; Selby, 1985). An alterative suggestion was forwarded by Ollier and Marker (1985) claiming that the Escarpment was initiated by erosion on the down warped continental margins to the level of the newly emerging coastline. Due to the confusion surrounding the geomorphological interpretation of the subcontinent, Partridge and Maud (1987) re-evaluated it's geomorphological history.

Partridge and Maud (1987) interpreted the development of the mountainous regions above the Great Escarpment as being unrelated to particular phases of erosion, which contrasts with King's (1954) reference to a Gondwana surface. They did however agree that discreet phases of erosion could be identified. Partridge and Maud (1987) identified the oldest erosion surface as being the African Surface which coincided generally with the African surface described by King (1967). Two surfaces of the post-African age were identified and are referred to as the Post-African I and Post-African II surfaces. The Post-African I surface formed as a result of a stage of uplift during the Miocene and continued to develop until a second stage of uplift during the Late Pliocene. Subsequent to the first stage of uplift, increased stream incision took place resulting in the formation of the KwaZulu - Natal interior and the Little Berg. Gradients on the erosion surfaces in the KwaZulu - Natal interior are estimated to have increased from 3m/km to 30m/km during this period (Partridge and Maud, 1987). Major dissection and stream incision still continues today in the Post-African II cycle.

3.3 Climate

The pressure and wind systems of the southern hemisphere strongly influence the climate of the African subcontinent. The climate of most of Africa south of 20° is dominated by the influence of two dominant anticyclones. The South Atlantic anticyclone feeds south-westerly onshore winds onto the west coast. The South Indian anticyclone fluctuates in position off the east coast, withdrawing in summer and returning in winter. The South Indian anticyclone controls the general airflow over KwaZulu - Natal (Tyson, 1969; Tyson et al., 1976). In winter the subsidence of air causes atmospheric stability and consequently a dry season dominates. Cold fronts and the westerlies during winter are the result of the northward movement of high pressure systems. These cold fronts may extend far inland and the associated high pressure systems over the subcontinent result in subsidence and the emergence of clear skies and calm conditions

In summer the Atlantic and Indian anticyclones move southwards causing the westerlies to blow well south of the continent. There is a weakening and southward movement of the anticyclone positioned over the subcontinent. The development of weak and shallow low pressure cells over the plateau of southern Africa facilitates the influx of humid air from the Indian Ocean which influences the eastern parts of Southern Africa (Jackson and Tyson, 1971). During this season high air humidity and precipitation occur, often resulting in thunderstorms (Tyson, 1969; Jackson and Tyson, 1971). South of the high pressure cell, lies the zone of westerlies where mid-latitude frontal depressions form and travel eastwards. The essential features of circulation in summer and winter are similar, however, the seasonal variations of climate in terms of temperature and precipitation are marked (Jackson and Tyson, 1971). Since the Giants Castle Game Reserve lies within these zones it is consequently affected by the broad changes in weather patterns induced by seasonal variations.

Since only three small weather monitoring stations exist within the confines of the Drakensberg, few data are available. Two of these stations are found within the borders of Giant's Castle Game Reserve - one being operated by the Natal Parks

Board and the other by the South African Weather Bureau. The third station is situated at Cathedral Peak, some 45km northwest of Giant's Castle. Some high altitude data is available from above the Escarpment at Letseng-la-Draai in Lesotho.

3.3.1 Radiation

Incoming solar radiation is attenuated by scattering, reflection and absorption in the earth's atmosphere. The amount of total radiation transmitted to the surface of the earth is highest when skies are clear and the relative humidity is low (Tyson *et al.*,1976). This verifies claims by Schulze (1974, 1975) that incoming solar radiation at the surface of the Little Berg, as measured at Cathedral Peak, is only 53 to 58 percent of the potential in summer and only 65 to 75 percent in winter. Despite the clearer skies in winter, the mean monthly incoming solar radiation shows a minimum in June and a maximum in November (Schulze, 1974). Under clear sky conditions the diurnal variation in receipt of incoming solar radiation is almost entirely a function of slope angle and aspect. Schulze (1974) demonstrates that on a 10° north facing slope, receipt of solar radiation is 47% higher in midsummer than it is in midwinter. On a 10° south facing slope it is about 120% higher in summer than it is winter. With respect to slope angle radiation receipt on a 30° north facing slope is 11% higher in summer than it is in winter, and on south facing slopes is 410% higher in summer than in winter. On comparing north and south facing slopes it is seen that a 10° slope, a north facing slope receives only slightly more solar radiation at noon in summer than a slope of opposing aspect. In winter south facing slopes receive approximately 52% less solar radiation than north facing slopes. On a 30° south facing slope receipt is 13% less than slopes of opposing aspect and similar gradient. At noon in winter, on a 30° south facing slope, receipt of incoming solar radiation is only 19% of the radiation received by a slope of opposing aspect. These figures suggest that seasonal variations in receipt of incoming solar radiation are far greater on south facing slopes than on north facing slopes.

The variation of radiation receipt on opposing slopes impacts on the temperature, soil moisture and vegetation encountered on these slopes (Cooper, 1960). The temperature and soil moisture variations are important in assessing the microclimatic conditions which affect the operative geomorphic mechanisms. However since no continuous temperature records are available at the local level, these considerations must be viewed with caution.

3.3.2 Temperature

Mean monthly temperatures above the Escarpment at Letseng-la-Draai (3050m a.s.l.) vary between -0.5°C in July and 11.1°C in January (Grab, 1994). Temperatures in the Little Berg are higher and Schulze (1981) recorded mean monthly temperatures of between 2°C in July and 15°C in January, for Giant's Castle Game Reserve (Table 3.2)

Tyson *et al.* (1976) observed temperature inversions in the Bushman's River valley in Giant's Castle Game Reserve. These inversions soon dissipate due to the effect of direct incoming solar radiation. In winter, conditions of clear skies, temperature inversions, dry air and the absence of wind favour the development of frost. Frost may occur from May to September with a frequency of 120 days per annum (Tyson *et al.*, 1976).

Table 3.2 Mean monthly temperatures for Letseng-la-Draai (L-l-D) and Giant's Castle Game Reserve (G. C. G. R.) (After Sumner, 1995).

	J	F	M	A	M	J	J	A	S	O	N	D
L-l-D	11.1	10	9.0	4.9	2.3	-0.5	0.1	2.0	5.4	7.3	8.3	9.8
G.C.G.R.	15	12	13	7	7	2	3	4	8	10	10	12

3.3.3 Precipitation

Annual precipitation figures vary between 1000mm per annum in the foothills of the Little Berg and 1800mm per annum at the Escarpment (Tyson *et al.*, 1976) and mean monthly rainfall for the study site is featured in Figure 3.2.

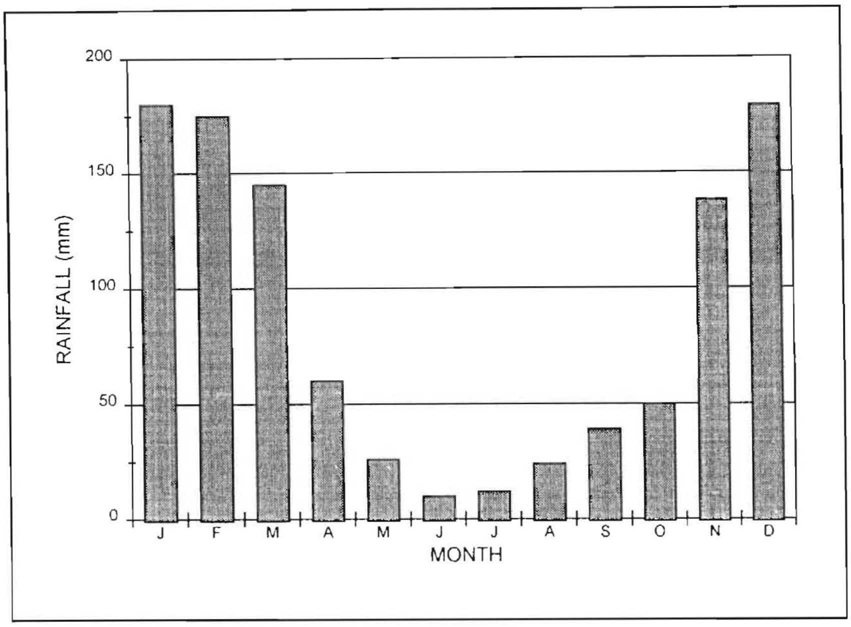

Figure 3.4 Graph showing mean monthly rainfall for Giant's Castle Game Reserve (modified after Tyson *et al.*, 1976).

Seasonal variation is distinct with the summer months (November to March) accounting for 70% of the total annual rainfall. Only 10% of rainfall is accounted for in the months from May through to August (Tyson *et al.*, 1976). Within the Drakensberg valleys notable local rainfall variations occur from place to place and from storm to storm, due to local relief and rainshadow effects. Most rainfall in the summer months occurs close to the Escarpment in the form of thunderstorms.

Snowfall totals and frequencies have not been systematically recorded. Schulze (1965) estimates a total of 8.27 days of snowfall per annum in the Drakensberg (Table 3.3). Snow falling in winter may remain from several weeks to a few months in shadow sites on the Lesotho mountains. Snowfall in the Little Berg is however rarer, and may remain for a few weeks in shadow sites (Granger, 1976).

Table 3.3 Frequency of snowfall days per month in the KwaZulu-Natal Drakensberg. (After Schulze, 1965).

J	F	M	A	M	J	J	A	S	O	N	D	YR
0.21	0.09	0.16	0.55	1.07	1.45	1.45	1.24	0.88	0.55	0.36	0.26	8.27

3.3.4 Wind

Under predominantly clear weather conditions, the presence of the Main Escarpment facilitates the occurrence of topographically induced local winds. These local winds dominate airflow patterns near the ground except when macro scale pressure gradients are strong (Tyson *et al.*,1976). Such strong pressure gradients are usually associated with the passage of frontal disturbances and can cause "Berg Wind" conditions (Hurry and van Heerden, 1981). Winds ahead of cold fronts are typically northwesterly, warm and stable. Winds behind cold fronts are generally strong, cold south westerlies (Tyson *et al.*, 1976).

Local topographically induced winds occur on a number of scales as a result of solar heating of the ground during the day and infrared radiational cooling at night (Tyson *et al.*, 1976). By day, warm air tends to move upslope as an anabatic wind, whereas by night cool air drains downslope as a katabatic wind. At approximately 2000m altitude compensating anti-winds may be observed (Tyson, 1968). On a regional scale local mountain winds in the valleys are overridden by a cool mountain plain wind blowing at night, with a reverse mountain plain wind overlying the valley winds during the daytime (Tyson *et al.*, 1976). Figure 3.2 below shows mean monthly wind directions for the Bushman's River valley in the study site for the period May 1995 to October 1997.

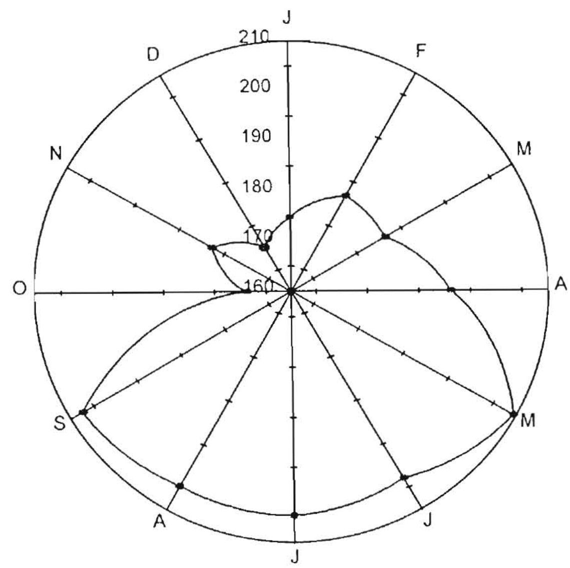

Figure 3.5 Graph showing mean monthly wind direction for the Bushman's River Valley in the study site.

3.4 Soils

As yet, no extensive soil survey has taken place in the KwaZulu - Natal Drakensberg. Van der Eye *et al.* (1969) presents a mapping of the Tugela Basin at a scale of 1:100 000 but little attention was paid to more inaccessible regions including the Little Berg and Escarpment Zones. Schulze (1974) and Granger (1976) have undertaken small scale surveys in the Cathedral Peak region. The soils in the Little Berg have been described as ferralitic, structureless and acidic due to a high degree of leaching (Schulze, 1974; Granger, 1976; Boelhouwers, 1988). At Cathedral Peak the A-horizon is described as orthic and is high in organic matter content. This horizon is best developed on moist, cool, south-facing slopes, and increases in thickness downslope to a depth of 25cm (Schulze, 1974; Granger, 1976). Soil close to the Main Camp at Giant's Castle are low in clay content and the texture class has been described by Sumner (1995) as a loamy sand according to the U. S. D. A. texture classes.

The following five soils have been identified by Boelhouwers (1988) as occurring in the Giant's Castle Game Reserve:

- Mispah,
- Clovelly,
- Hutton,
- Griffin, and
- Katspruit.

The dominant soil forms and their general locations are listed in Table 3.4.

Table 3.4 Soil forms found in Giant's Castle Game Reserve and their general location (After Sumner, 1995).

FORM	DIAGNOSTIC HORIZONS	LOCATIONS
Hutton	orthic A / red apedal B	low gradient slopes
Griffin	orthic A / yellow-brown B / red apedal B	low gradient moist conditions on cooler slopes
Clovelly	orthic A / yellow-brown apedal B	steep and/or south-facing slopes
Katspruit	orthic A / firm gley	poorly drained valley floors and in narrow strips along streams
Mispah	orthic A over rock	dolerite outcrops and along scarp edges

3.5 Vegetation

Altitude and a history of frequent and regular veld burning have influenced vegetation in the Drakensberg (Garland, 1987). Three altitudinal belts have been distinguished by Killick (1963), each having it's own distinctive vegetation (Table 3.5).

Vegetation has however frequently been burned off by natural and man induced fires, which together with other factors, may have prevented succession to a true climax community (Garland, 1987).

Edwards' (1967) study of the plant ecology of the Tugela Basin also recognises three distinct altitudinal zones which resemble Killick's (1963). These are termed the Upland, Subalpine and Alpine Belts.

Table 3.5 Vegetation belts and climax communities of the KwaZulu-Natal Drakensberg (after Killick, 1963).

VEGETAL BELT	ALTITUDE (m)	LOCATION	CLIMAX COMMUNITY
Montane	1280-1829	Valley floors to lowest basalt cliffs	*Podocarpus latilolius* Forest
Subalpine	1830-2865	Edge of Little Berg to just below summit	*Passerina-Phillipa-Widringtonia* Fynbos
Alpine	2866-3353	Plateau and peak areas	*Erica Helichrysium* Heath

Upland belt

Most of this belt supports the *Themeda* - *Trachypogon* sub-climax community, consisting of relatively short, bunched grasses, of which the dominant species are *Themeda triandra and Trachypogon spicatus*, interspersed with small communities of *Protea* savanna in favourable sites. Evergreen shrubs and woodland with *Leucosidea sericea* and *Buddleja salvifolia* occur on stream banks, in kloofs and on rocky soils. Patches of *Podocarpus* forests are sparsely distributed on steep, normally south-facing slopes (Garland, 1987).

Subalpine belt

The most extensive plant association in this belt is *Themeda* - *Festuca* grassland, where on warm north-facing slopes *Themeda triandra* is common, and *Festuca costata* can be found on cooler slopes of southerly aspect. Small scrub communities dominated by *Leucosidea sericea* may be found near gullies and streams. Subalpine Fynbos, consisting of a variety of small leaved shrubs, exists on where there is some measure of protection from fire, along streams, gullies, and on steep slopes and rock outcrops (Garland, 1987)

Alpine belt

On sites normally protected by fire *Danthonia* Tussock grassland and stands of Alpine Fynbos can be found. More common, however, is the *Danthonia - Festuca - Pentaschistis* association which forms dense swards up to a height of 1.7m (Garland, 1987).

2.6 Anthropogenic Influence

Due to the vast variation in definitions of terracettes it is important to discuss the effects of man on their possible formation. In order to do this it is necessary to look at the various landuses, past and present, within the park.

The history of the area prior to the turn of the century is poorly documented. The Amahlubi tribe, however, resided on the fringes of the area which is now the Reserve boundary. The 1849 'rebellion' by Chief Langalibalele resulted in Major Durnford of the Natal Carbineers to establish a base camp for the 75th Regiment near what is today the Main Camp (Pearse, 1987). Some of the passes in the area were dynamited in order to prevent Langalibalele from fleeing into Lesotho with his cattle.

In 1903 the original homestead was developed and is now incorporated into the Warden's house. Closely upstream from the homestead the Main Camp was developed. During the first half of the 1900's cattle were farmed in the Reserve by Natal Parks Board staff, but were phased out in the late 1960's and early 1970's. Horses were used extensively by the Reserve Management and numbered between 80-100 during the late 1960's. Due to the increase in motorised transport horses were eventually phased out. The use of vehicles necessitated the construction of jeep tracks and these provided access to the remote areas of the Reserve and a link to Loteni, south of Giant's Castle was created. A biannual veld burning was implemented when the Reserve was established, but little is known of the effects of veld burning on the development of terracettes although it can be assumed that veld burning may affect the sustaining processes active on the landforms.

Chapter 4
Methodology

4.1 Aims

The aim of this thesis is to provide a greater understanding of terracettes in the KwaZulu - Natal Drakensberg, specifically within the Giant's Castle Game Reserve. Little research has been undertaken on terracettes in the study area with Garland (1987), Watson (1988), Verster *et al.* (1986) and Day (1993) offering some insight on the landforms in other regions of the Drakensberg. Most of the work has been confined to simple morphometric and statistical analyses in order to determine relationships between morphology and slope angle (Watson, 1988; Day, 1993) and Garland (1987) and Verster *et al.* (1986) examining relationships between soil properties, slope angle and morphology.

By determining the significance of various topographic, vegetal, microclimatic and soil physical characteristics on terracette morphology, a wider range of variables is considered, and relationships between terracettes and slope stability can be determined.

By determining the relationship between terracettes and the stability of the slope on which they are found a management plan could be formulated in order to reduce possible failure and degradation.

4.2 Fieldwork

The purpose of fieldwork was to determine various morphometric, microclimatic and vegetal properties related to terracettes within the study area. Furthermore, soil samples were collected in order to facilitate the determination of soil physical properties within a laboratory.

Manual data collection included the following variables (See Figure 4.1):

- macroslope angle,
- riser height, length and angle,
- tread width, length and angle,
- aspect,
- shear strength,
- soil strength, and
- soil sampling.

Automated data collection involved the use of automated logging equipment to

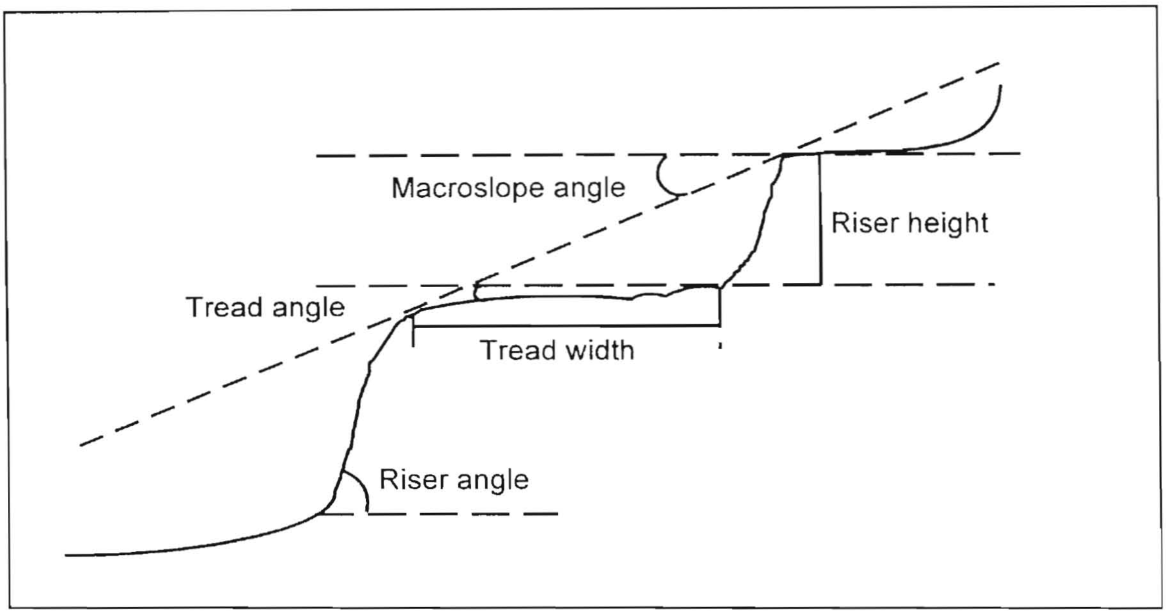

Figure 4.1 Diagrammatic representation of terracette morphology.

determine slope microclimatic conditions, together with soil moisture, rainfall volume and soil temperature conditions.

4.2.1 Manual data collection

Riser height, length and angle

Riser height was measured with a tape measure, as was the riser length. Riser angle was determined using an inclinometer found on a Brunton compass (Figure 4.2). The methodology used was based on previous work by *inter alia* Garland (1987), Watson (1988), Day (1993) and Verster *et al* (1986).

Figure 4.2 Brunton compass used for measuring tread and riser angles and aspect.

Tread width, length and angle

Tread width and length were measured with a tape measure. The tread angle was measured in a similar manner as was used to determine the riser angle, using the same equipment.

Aspect

Aspect is an important variable to be considered when undertaking a study on terracettes. Not only does vegetation differ on opposing slopes in the study area, but so to does soil moisture, solar radiation and slope angle. Aspect was measured by reading the bearing off of a Brunton compass.

Shear strength

The shear strength of a soil is defined as the maximum resistance of the soil to shearing stress under any given conditions (Smith, 1980). Several basic shear tests are described by Smith (1980) but for the purposes of this exercise a hand shear vane was used for practical reasons (Figure 4.3).

Figure 4.3 Hand-held shear vane used for measuring soil shear strength.

A shear vane measures *in situ* shear strength of a soil, which, for the purpose of this research leaves the sample relatively undisturbed. The hand shear vane offers quick, reproducible and consistent results for undrained soil shear strength (Serota and Jangle, 1972). The instrument consists of a vane attached to a torsion head and in operation the vane is pushed into the soil and rotated at a constant speed of one revolution per minute. The reading obtained once maximum shear is overcome is indicated by a pointer on the dial of the torsion head. Five readings were taken at each location with the lowest and highest being discarded and a mean *in situ* shear strength obtained from the remaining three.

Soil strength

For the purposes of this research soil strength was determined with a hand-held penetrometer (Figure 4.4).

Figure 4.4 Hand-held penetrometer used for measuring tread and riser soil strength.

The penetrometer has been widely used to determine the strength of a soil (Carter, 1990; Campbell and Hunter, 1986; Sanglerat, 1972). Beckedahl and Bird (1995) considered penetrometer resistance to be an index of effective soil strength since it is an integrated measure of soil texture, clay mineralogy, density and moisture content. Mulqueen *et al.* (!977) have shown the limitations of the technique but despite these the method is nevertheless cheap and is an efficient way of determining soil strength.

4.2.2 Automated data collection

An MCS 120-02 EX data logger was used for the purpose of monitoring slope microclimatic and soil moisture conditions. The logger was set up on a north facing slope in the study area in May 1995 (Figure 4.5). The logging systems recorded hourly averages on a 16000 data point EPROM chip that was changed every six weeks.

Figure 4.5 Micrometeorological station attached to a MCS data logger used for recording meteorological and soil moisture data.

The logger recorded air temperature, relative humidity, solar radiation, wind speed, wind direction, rainfall and soil moisture. Values for soil moisture are purely relative and do not reflect specific quantities. However due to mechanical failure and financial constraints some periods of data are unavailable. The data missing however is minimal and would not adversely affect the results obtained due to the number of logging periods recorded in order to obtain monthly averages.

4.2.3 Laboratory analysis

Particle size

Soil texture is inherently the product of five soil forming factors namely:

- climate,
- topography,

- biotic factors,
- parent material, and
- time.

Particle size was undertaken in order to establish and infer erosional processes - or secondary mechanisms - active on treads and risers of the terracettes investigated. In order for this to be achieved soil samples were taken in the field at depths up to approximately 25cm. Samples were taken from terracette treads, risers, and in close proximity to the terracettes for control purposes. Samples were placed in zip-sealed plastic bags, to maintain field moisture, for transportation to the laboratory and subsequent weighing. Particle size analysis was undertaken using the dry sieving method as described by Goudie (1981). After weighing, the samples were dried in an oven at 110°C for 24 hours after which the dry weight was recorded. The sample was then broken down with a mortar and pestle before being introduced to a sieve stack, with sieve apertures ranging from 8mm to 0.063mm. The stack was mechanically shaken for 10 minutes. The weight of each sample trapped at each sieve was weighed and converted to a percentage of the total dry weight. Field soil moisture content was calculated by subtracting the total dry weight from the initial weight of the sample before drying.

The method offers a simple and inexpensive way of determining the particle size distribution of many soils but does have shortcomings which are briefly discussed by Moodley (1997).

Atterberg Limits

Atterberg limit tests provide good indications of the states of many soils, namely solid, plastic and liquid (Figure 4.6). The variables are delimited by the shrinkage limit (SL), plastic limit (PL) and the liquid limit (LL), (Whalley, 1976) where the SL and PL are expressed as moisture content percentages of dry weight.

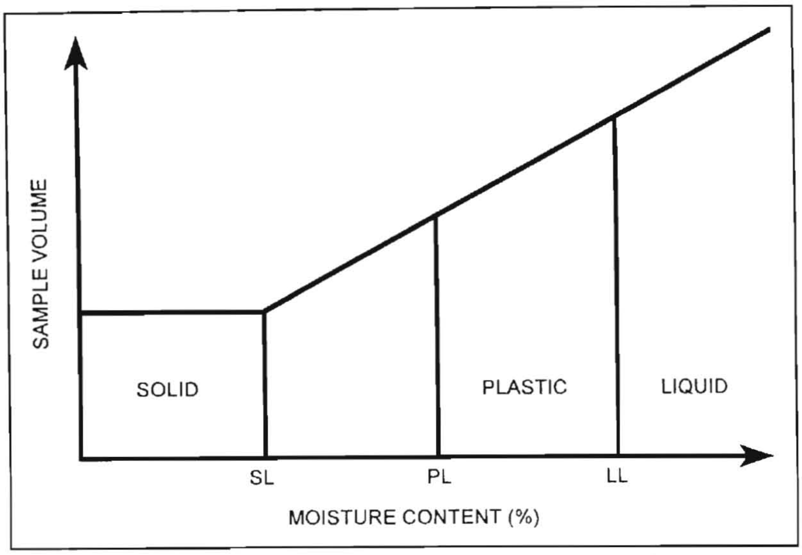

Figure 4.6 Diagrammatic representation of relationships between SL, PL and LL (After Whalley, 1976)

Shrinkage Limit

The shrinkage limit is defined by Goudie (1981) as being the moisture of a soil at which the soil stays at constant volume upon drying. A paste of soil (particle size < 0.5mm) was made and placed in shrinkage trays. The moisture content of the paste was approximately that of the liquid limit, as prescribed by Goudie (1981). The paste was smoothed, flushed and dried initially at 60°C and then at 105°C. The sample length was measured after cooling and the SL calculated from the following equation:

SL = (1- (length after drying / initial length)) x 100 .... Equation 4.1

The SL was expressed as a percentage.

Plastic limit

The plastic limit is the delimitation between a brittle and a plastic soil (Goudie, 1981). It was determined by taking approximately 10g of moist soil and rolling it gently on a glass plate with the palm of the hand, until it was approximately 3mm thick and about to break up. The moisture content at this point was determined by weighing the wet sample, drying it, and calculating the difference in weight, thus giving the plastic limit. This process was repeated three times for each sample so as to obtain the mean

(Goudie, 1981).

Liquid limit

The liquid limit is the moisture content at which the soil changes from a plastic to a liquid state. The method used for determining the liquid limit of samples is described in Goudie (1981) by using a cone penetrometer. A standard cone was placed point down just touching the surface of the soil, which was levelled into a metal container. The cone was released and allowed to penetrate for 5 seconds, with the distance of penetration being measured from a dial gauge. Two falls with no more than 0.5mm difference in penetration and the moisture content determined from 10g of soil. The test was repeated at four different moisture contents so as to give a linear graph of penetration against moisture content. The liquid limit was determined from the graph at a penetration depth of 20mm into the soil (Goudie, 1981).

Bulk Density

Bulk density is the oven dry weight of soil per unit volume and gives an indication of soil strength and air porosity (Hazelton and Murphy, 1992). The samples were collected in the field with a core sampler of known volume and transported to the laboratory in zip-sealed plastic bags, where they were oven dried at 105°C for 24 hours. The dry samples were weighed and the bulk density values calculated from the following equation:

weight of dry soil (g) / volume of soil (cm^3) .....Equation 4.2

Aggregate Stability

The aggregate stability of a soil is a major controlling factor in topsoil erodibility and permeability. When discussing modes of formation of terracettes it can be seen that aggregate stability could play an important role in the mechanisms discussed in Chapter 2.

Aggregate stability can be measured using various techniques. The techniques most commonly employed are wet sieving (*inter alia* Whalley, 1981; Ternan *et al.* 1996), and the drop impact method (*inter alia* Imeson and Jungerius, 1976; Ternan *et al.* 1996, Imeson and Verstraten, 1989). The wet sieving method is used to determine the size distribution and the stability of aggregates that remained intact after the sample has been subjected to mechanical forces (Ahmed, 1997). This method however has shortcomings in that the assumption has to made that aggregates remaining stable after wet sieving remain intact in the field under forces of stress. Furthermore the method only involves gentle slaking of wet aggregates and these may not withstand the impact of high velocity rainfall in natural conditions. Farres and Cousens (1985) show that the drop impact method is also questionable because of it's reproducibility, the lack of consensus regarding pre-treatment of the sample, the chemistry of the drop forming liquid and the drop fall height.

For the purpose of this research the wet sieving method was employed because it provides easy reproducibility and is applicable to a wide range of soils with differing textures and structures (Moodley, 1997).

The method follows the guidelines described by Whalley (1981). A 100g sample of air dried soil was placed on a nested sieve stack with sieves of apertures of -1Ø, 0Ø and 1Ø and gently slaked in distilled water for 30 minutes. The sieving apparatus used was based on the design of Grieve (1979). Soil remaining on the sieves was transferred to beakers and dried at 105°C before being weighed. The soil was reintroduced to the sieve stack and passed through their respective screens. The soil remaining in each sieve was weighed. The weight of water stable aggregates (WSA) > -1Ø (WSA > 2.0mm), > 0Ø (WSA > 1mm) and > 1Ø (WSA > 0.5mm) were calculated from the formula introduced by Sumner (1958):

$$\textbf{Percentage Aggregation} = \frac{\textbf{mass before disp. - mass after disp.}}{\textbf{mass of soil}} \times 100$$

..... equation 4.2

4.3 Statistical Analysis

To determine the relationship between the morphology of terracettes and their composing soil, correlation analysis was employed. This method follows methods used by Vincent and Clarke (1980) and Verster *et al.* (1985) and is adequately described by Lindeman *et al.* (1980). Analysis of Variance (ANOVA) was used in order to determine the validity of the Null hypothesis formulated for various parameters, and is described by Lindeman *et al.* (1980).

Chapter Five

Terracette and Soil Survey Results

5.1 Soil Survey Results

Data presented in this section are results obtained from fieldwork and laboratory procedures outlined in Chapter 4. Results from soil analysis are presented prior to terracette physical data to provide a background to the slope environments on which the terracettes are situated within Giant's Castle Game Reserve. Where data is too expansive to include in the dissertation, condensed versions are included in tabular and graphic form. Data will be discussed in detail in Chapter 6.

5.1.1 Particle Size

Particle size gives an indication of the distribution of relative amounts of gravel, sand, silt and clay within a sample (Hazelton *et al.*, 1992), and allows for the classification of a soil. From data presented in Figure 5.1a to Figure 5.4f, the soil found within the study sites is a sandy loam. Variations in particle size distribution do occur between treads, risers and the control sites.

5.1.2 Dry Bulk Density

Measurements of dry bulk density (DBD) taken from the treads and risers of terracettes, and control sites, are illustrated in Figure 5.5 (where BT=Bottom Slope Tread; BR=Bottom Slope Riser; BC=Bottom Slope Control; MT=Mid-slope Tread; MR=Mid-slope Riser; MC=Mid-slope Control; TT=Topslope Tread; TR=Topslope Riser and TC=Topslope Control.) The slopes examined where divided into three slope segments based on Dalrymple *et al.* (1968) Nine-unit Hillslope Model. The topslope corresponds with Unit 5, the mid-slope corresponding with the zone of change between Units 6 and 5, and the bottom slope being equal to Unit 5.

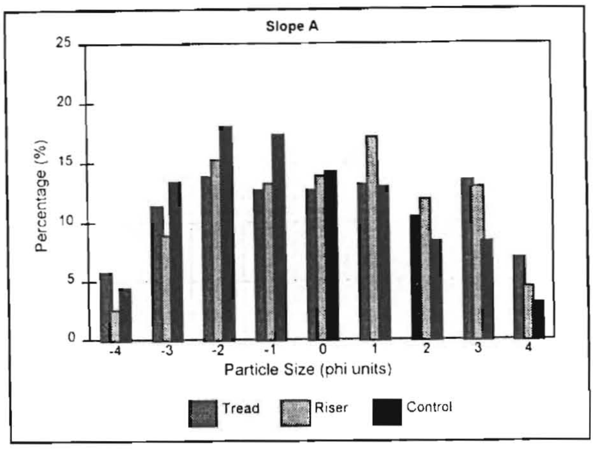

Figure 5.1a Bottom slope

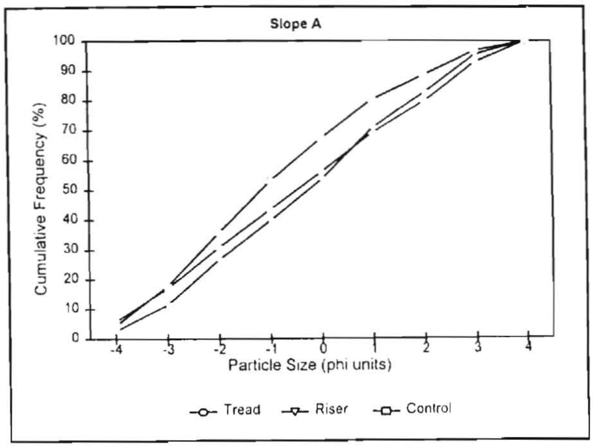

Figure 5.1b Bottom slope

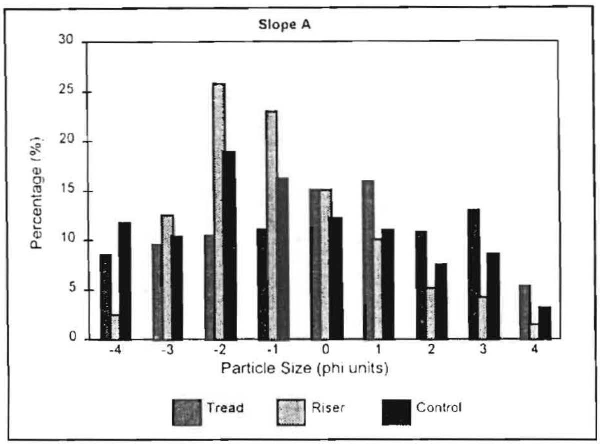

Figure 5.1c Mid-slope

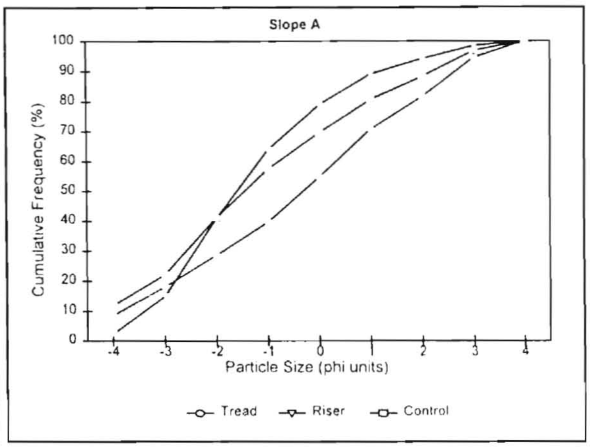

Figure 5.1d Mid-slope

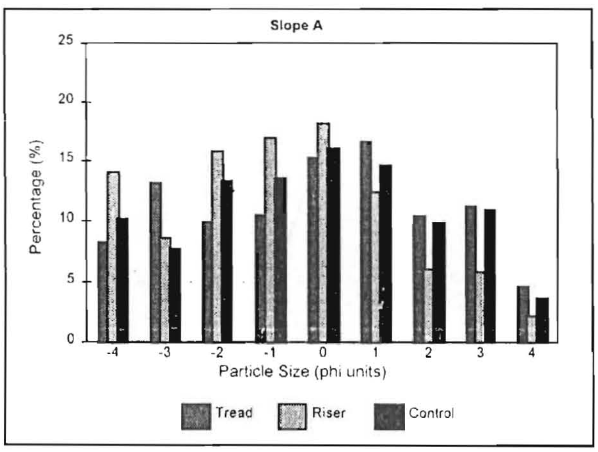

Figure 5.1e Top slope

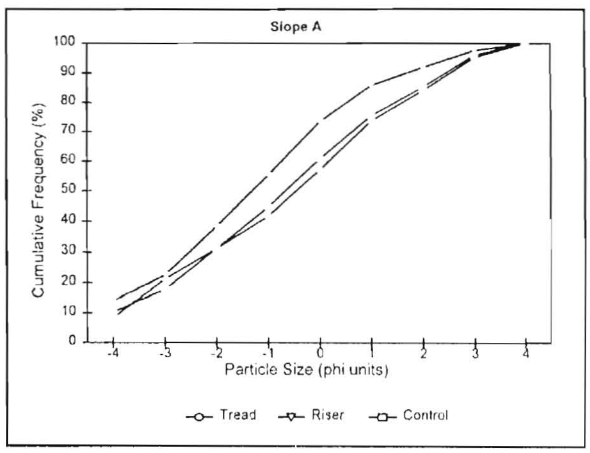

Figure 5.1f Top slope

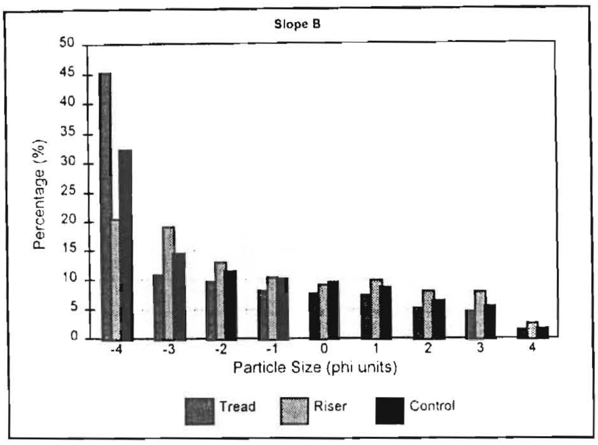

Figure 5.2a Bottom slope

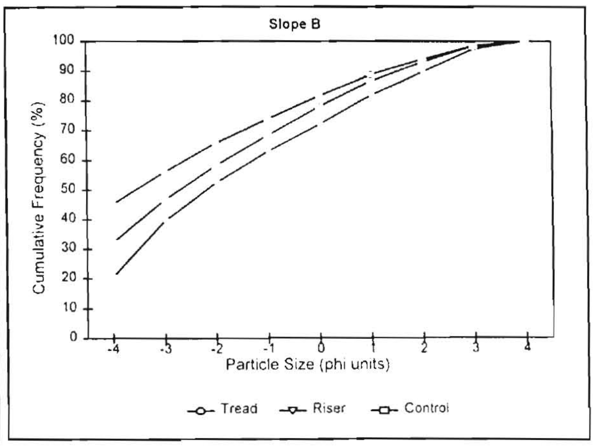

Figure 5.2b Bottom slope

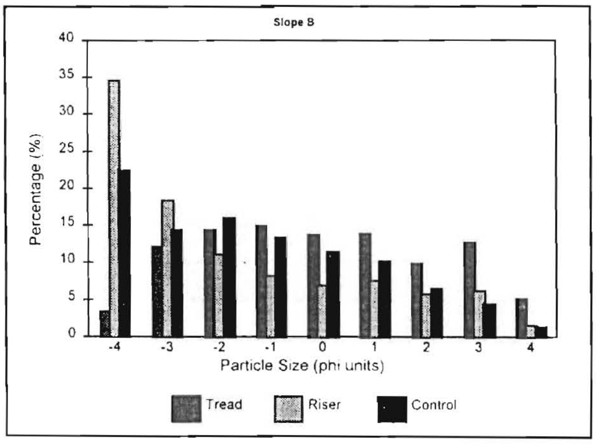

Figure 5.2c Mid-slope

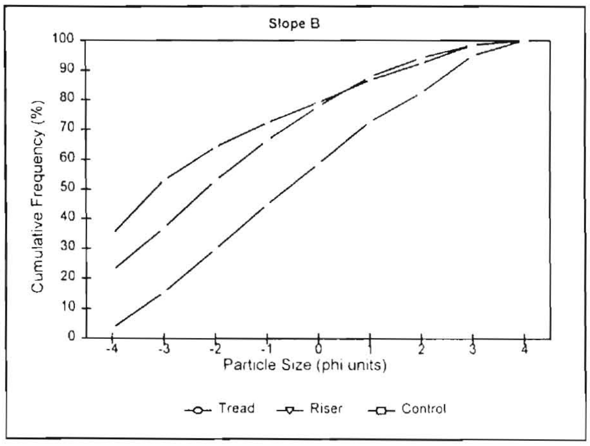

Figure 5.2d Mid-slope

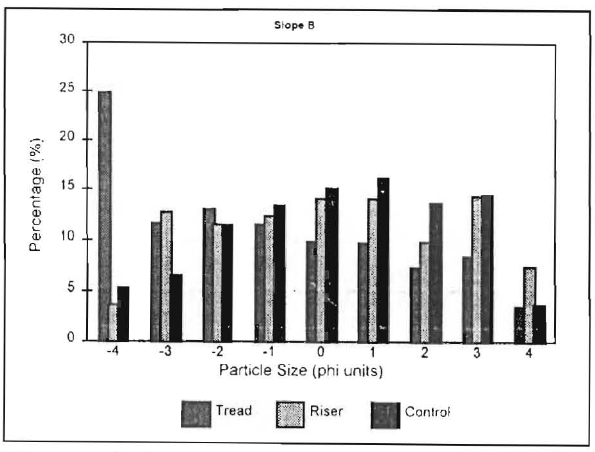

Figure 5.2e Top slope

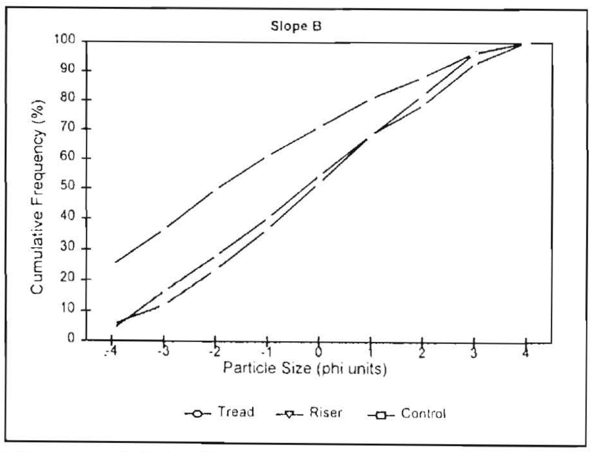

Figure 5.2f Top slope

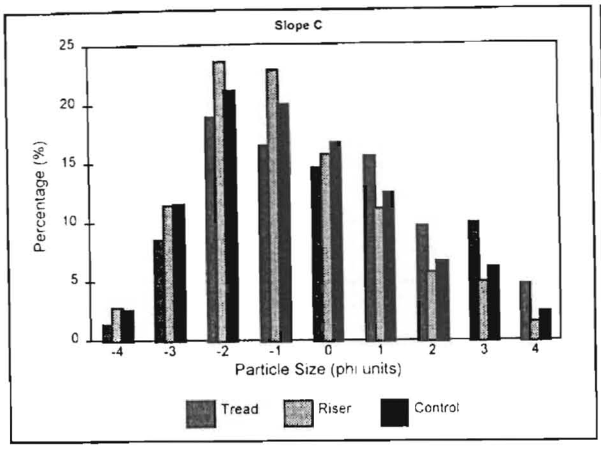

Figure 5.3a Bottom slope

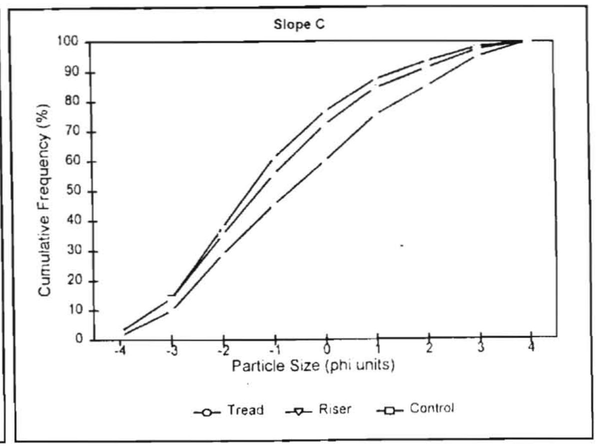

Figure 5.3b Bottom slope

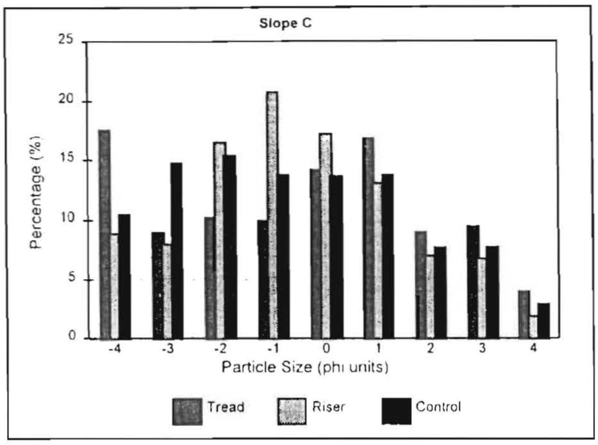

Figure 5.3c Mid-slope

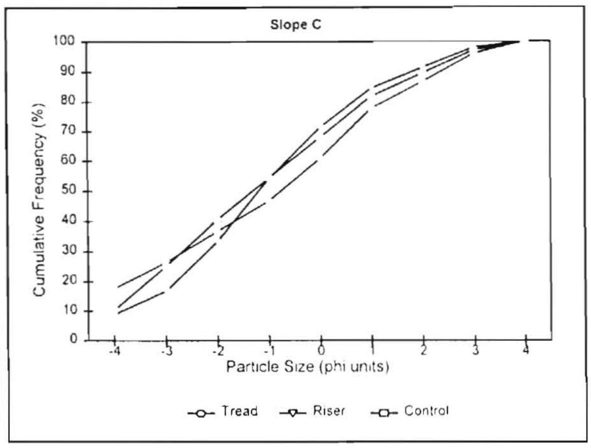

Figure 5.3d Mid-slope

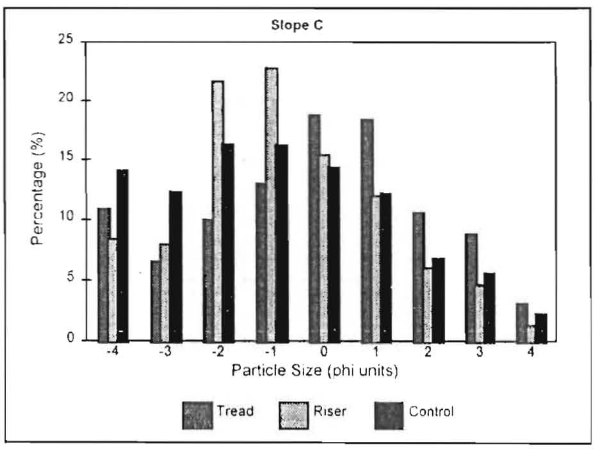

Figure 5.3e Top slope

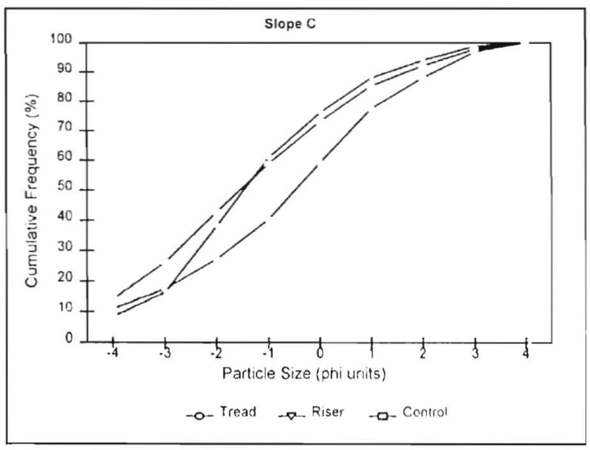

Figure 5.3f Top slope

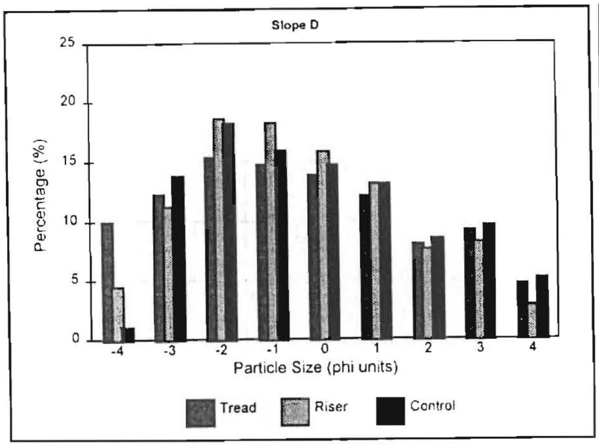

Figure 5.4a Bottom slope

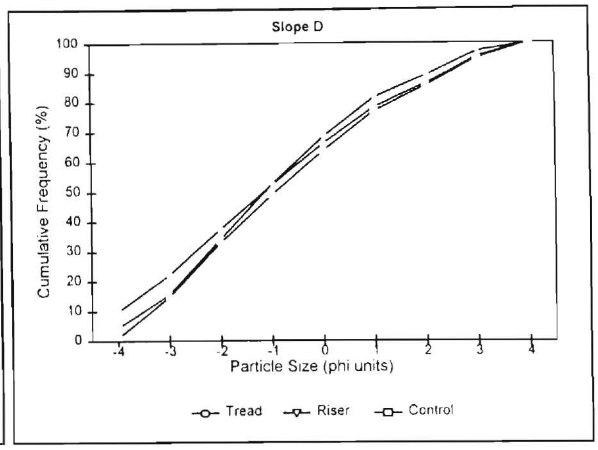

Figure 5.4b Bottom slope

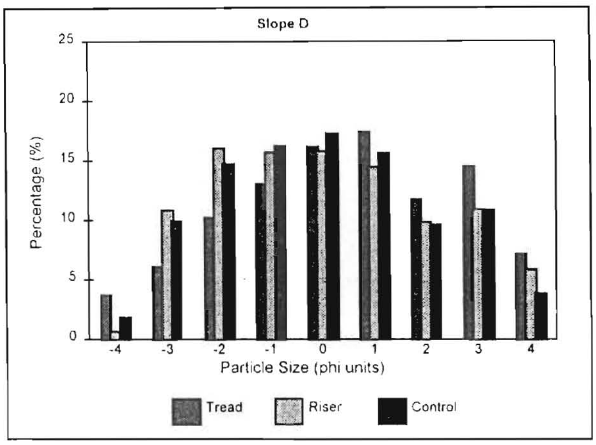

Figure 5.4c Mid-slope

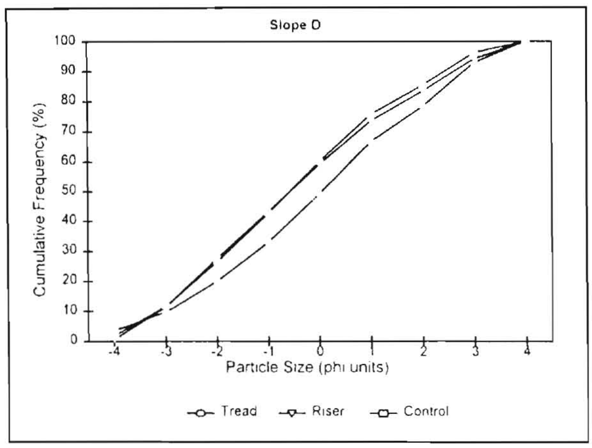

Figure 5.4d Mid-slope

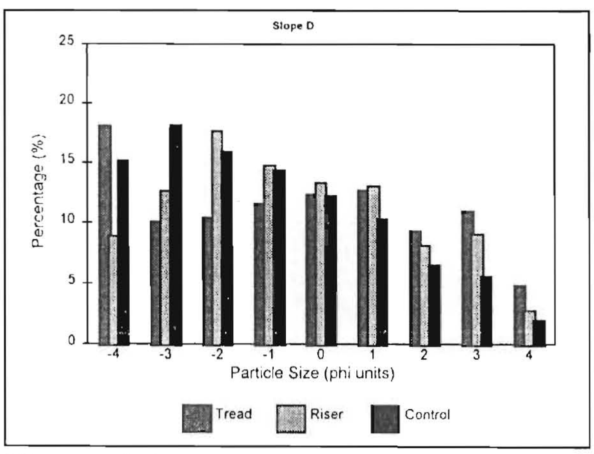

Figure 5.4e Top slope

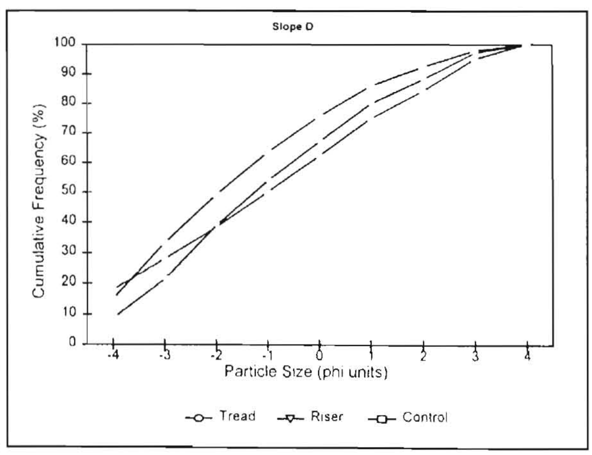

Figure 5.4f Top slope

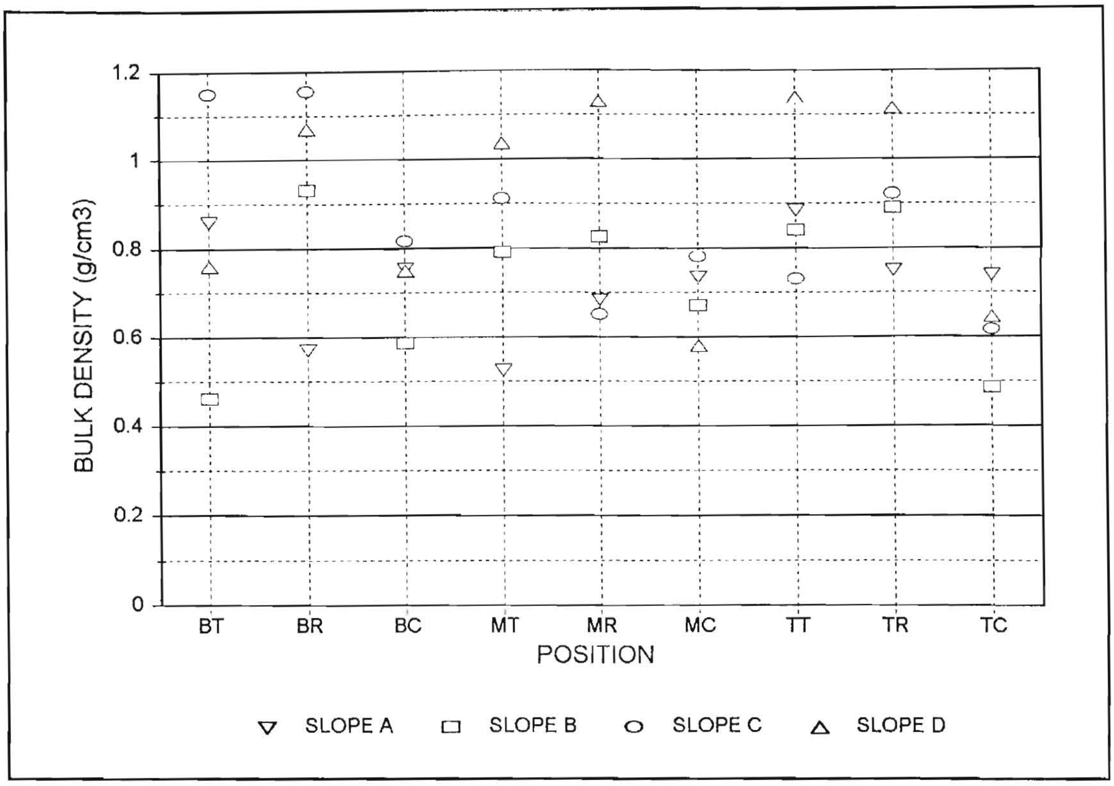

Figure 5.5 Dry bulk density relationships between tread, riser and control sites with their position on the slope.

Slope A

DBD for the respective positions are featured in Table 5.1.

Table 5.1 Dry bulk density values for Slope A. (Values are in g/cm^3).

		POSITION ON TERRACETTE		
		TREAD	**RISER**	**CONTROL**
POSITION ON SLOPE	**BOTTOM**	0.860	0.570	0.760
	MIDDLE	0.525	0.690	0.755
	TOP	0.890	0.750	0.740

The region with the highest DBD value on Slope A is the topslope tread region. Treads display the highest mean DBD for the slope, with risers displaying the least mean DBD.

Slope B

DBD for the respective positions are featured in Table 5.2.

Table 5.2 Dry bulk density values for Slope B. (Values are in g/cm^3).

		POSITION ON TERRACETTE		
		TREAD	RISER	CONTROL
POSITION ON SLOPE	BOTTOM	0.460	0.930	0.585
	MIDDLE	0.790	0.825	0.670
	TOP	0.840	0.890	0.645

As can be seen, the bottom slope riser shows the highest DBD, and the bottom slope tread the lowest. The slope position with highest mean is the topslope region with the lowest mean coming from the bottom slope. Risers display the highest mean for the slope and control sites the lowest.

Slope C

DBD for the respective positions are featured in Table 5.3.

Table 5.3 Dry bulk density values for Slope C. (Values are in g/cm^3).

		POSITION ON TERRACETTE		
		TREAD	RISER	CONTROL
POSITION ON SLOPE	BOTTOM	1.150	1.155	0.815
	MIDDLE	0.910	0.650	0.780
	TOP	0.730	0.920	0.615

As the table shows, the bottom slope riser shows the highest DBD, and the bottom slope control the lowest. The slope position withe highest mean is the bottom slope region with the lowest mean coming from the topslope. Treads display the highest mean for the slope and control sites the lowest.

Slope D

DBD for the respective sites are displayed in Table 5.4.

Table 5.4 Dry bulk density values for Slope D. (Values are in g/cm^3).

		POSITION ON TERRACETTE		
		TREAD	RISER	CONTROL
POSITION ON SLOPE	BOTTOM	0.760	1.070	0.750
	MIDDLE	1.035	1.130	0.580
	TOP	1.140	1.115	0.645

As the table shows, the topslope tread shows the highest DBD, and the middle slope control the lowest. The slope position withe highest mean is the top slope region with the lowest mean coming from the bottom slope. Treads display the highest mean for the slope and control sites the lowest.

DBD results were subjected to a correlation test in order to determine the relationships between tread, riser and control sites for their relative position on the respective slopes. Data from the bottom of each slope indicated a strong positive correlation between the tread and control sites (r=0.95), and weak positive relationships between control and riser (r=0.16) and between the tread and riser (r=0.23). For data taken from the mid-slope of each site there was a strong negative correlation between the riser and control site (r=-0.98), a fairly strong correlation between the tread and riser (r=0.63) and a fairly strong negative correlation between the tread and the control site (r=-0.52). Data from DBD samples taken from the top of each slope indicated a fairly strong relationship between tread and riser sites (r=0.64), a weak negative relationship between riser and control (-0.24), and a fairly weak relationship between tread and control sites. Relationships between DBD and other factors are shown in Table 5.5 below, where 'triscon' relates to a calculated index for the tread, riser and control sites.

Table 5.5 R-values for correlations between DBD and other factors for all sites.

PROPERTIES	DRY BULK DENSITY
FIELD MOISTURE	-0.910
SHRINKAGE LIMIT	-0.226
PLASTIC LIMIT	-0.238
LIQUID LIMIT	-0.416
SITE	0.413
POSITION	-0.019
TRISCON	-0.341
AGGREGATE STABILITY	-0.205

As can be seen from the above table, few relationships exist between DBD and other factors. A slight negative correlation exists between the DBD and liquid limit, with a slight positive relationship between DBD and site. An Analysis of Variance for DBD with site, position on slope and triscon revealed significant differences at the 95% confidence limit for DBD and site, and DBD and triscon. Figure 5.6 below gives a visual indication of the relationships between mean DBD for each site, position and triscon index. Figure 5.6 shows that DBD's at Site A and Site B are similar and lower than DBD's at Sites C and D. Site D shows the largest mean DBD. With reference to position on slope it is evident that mean DBD at the bottom of slopes is greater than in the middle and the top of the respective slopes. The middle slope regions displayed the lowest DBD mean values. DBD's measured at the control sites are lower than DBD's from the treads and risers, withe risers displaying the greatest mean DBD.

5.1.3 Shear Strength

Shear strength is an indication of the strength of a soil. For the purposes of this study, soil shear strength data was collected from the treads of each terracette investigated on each slope. Table 5.6 shows descriptive statistical data for each slope studied.

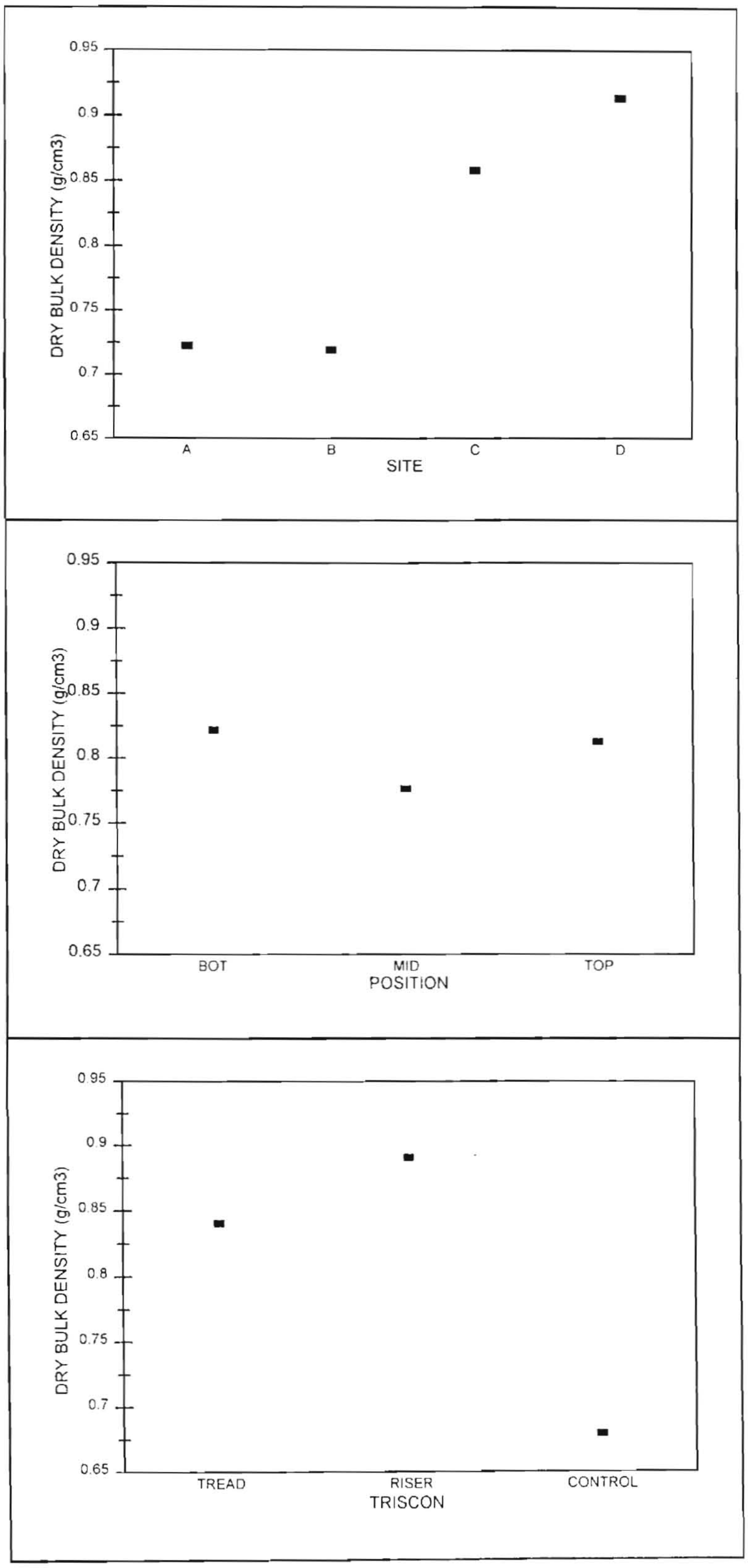

Figure 5.6 Main effects plot for mean DBD for all sites.

Table 5.6 Descriptive statistical data for soil shear strength measured at each site.

	MEAN	MEDIAN	MODE	SD	SKEWN.	RANGE
SLOPE A	31.230	27.820	18.400	12.540	0.520	46.210
SLOPE B	28.070	22.430	NA	17.890	0.720	66.760
SLOPE C	32.120	29.160	36.790	12.530	1.210	52.050
SLOPE D	16.640	13.910	6.280	11.330	0.800	35.890

Preliminary investigations using correlation revealed weak positive correlations between shear strength recordings from slope D and slope A (r=0.24), slope B (r=0.11) and a weak negative correlation with slope C (r=-0.3). Slope C showed a weak negative correlation with slope B (r=-0.1) and a fairly strong negative correlation with slope A (r=-0.5). Slope B indicated a fairly weak relationship with slope A (r=0.24). Figure 5.7 displays mean shear strengths for each site.

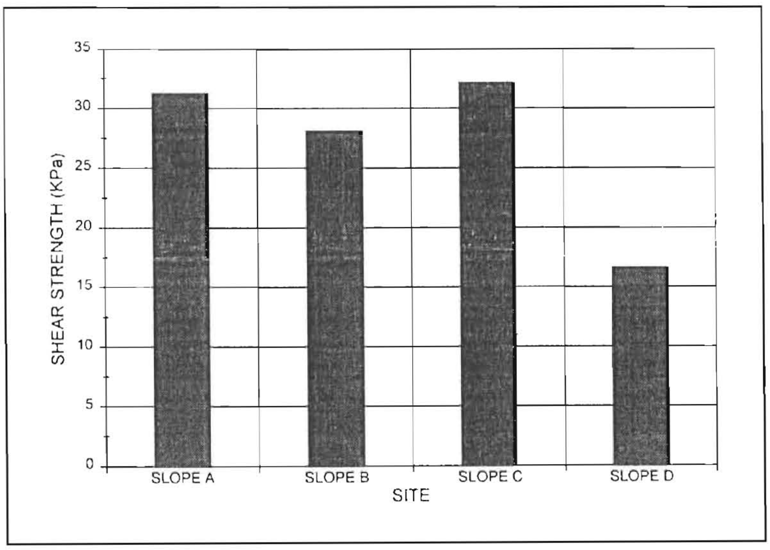

Table 5.7 Mean soil shear strengths.

An Analysis of Variance (ANOVA) was conducted (Null hypothesis = there is no significant difference between mean shear strength data from all four sites) and revealed a significant difference between the groups of data (ρ=0.0004) at the 95% confidence level. However, the test revealed a close relationship between Slopes A and C, with Slope D being more significantly different than slopes A, B and C. Slope B was only slightly different to Slopes A and C.

5.1.4 Soil Strength

Soil strength measurements were recorded for each tread and riser at all the respective sites. Soil strength gives an indication of a soils resistance to failure and shearing, and thus, in conjunction with bulk density and shear strength, gives meaningful data as to the strength of the soil. Data from treads and risers was analysed separately.

Tread Soil Strength

Descriptive indices for tread soil strength values are displayed in Table 5.7.

Table 5.7 Descriptive indices for tread soil strength at each site.

	MEAN	MEDIAN	MODE	SD	SKEW.	RANGE
SLOPE A	2.170	1.570	1.300	1.910	2.220	8.200
SLOPE B	1.640	1.640	0.400	0.890	0.330	3.300
SLOPE C	2.920	2.630	1.870	1.060	1.160	4.500
SLOPE D	1.330	1.000	0.400	1.160	1.240	4.500

Data for each site was subjected to correlation and results can be viewed in Table 5.8 below.

Table 5.8 R-Values for tread soil strength relationships between sites.

SITE	SLOPE A	SLOPE B	SLOPE C	SLOPE D
SLOPE A	1			
SLOPE B	0.260	1		
SLOPE C	-0.240	0.080	1	
SLOPE D	0.130	0.190	-0.390	1

An Anova, with the null-hypothesis being that there is no significant difference between tread soil strengths at each site, showed a significant difference at the 95% confidence level (ρ=0.0001). Factors for this variation will be discussed in Chapter 6. Based on pooled standard deviations significant differences also existed between sites with Slope C being more significantly different than the other slopes, and Slopes B and D displaying the least significant difference.

Riser Soil Strength

Descriptive indices for riser soil strength are depicted in Table 5.9 below.

Table 5.9 Descriptive indices for riser soil strength.

	MEAN	MEDIAN	MODE	SD	SKEW.	RANGE
SLOPE A	2.080	1.930	1.700	1.880	0.910	4.000
SLOPE B	3.940	4.000	4.300	1.060	-0.400	3.900
SLOPE C	3.110	3.170	1.600	0.950	0.120	3.600
SLOPE D	5.240	5.120	8.000	1.660	0.070	5.700

Data was then correlated and r-values are displayed in Table 5.10 below.

Table 5.10 R-values for riser soil strength relationships between sites.

SITE	SLOPE A	SLOPE B	SLOPE C	SLOPE D
SLOPE A	1			
SLOPE B	-0.470	1		
SLOPE C	-0.110	-0.050	1	
SLOPE D	-0.150	-0.270	0.350	1

An Anova, with the null-hypothesis being no significant difference in riser soil strength between sites, revealed a difference at the 95% confidence level. Slopes A and D showed the greatest variance with Slopes B and C being less significantly different and thus displaying similar properties. These results were verified with a f-test.

Mean soil strength values for treads and risers at each site are depicted in Figure 5.8 below.

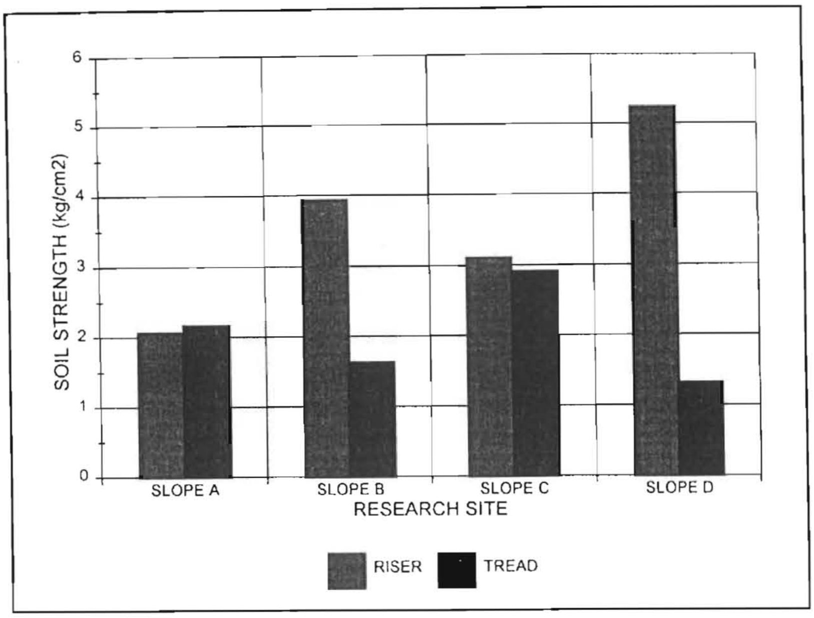

Figure 5.8 Mean soil strength values for treads and risers at each site.

As can be seen treads found at slopes A and C respectively have similar soil strength values to the risers at the respective sites. Sites B and D show a noticeable difference between the strengths of the treads and risers.

Data from all slopes revealed weak relationships between tread (SST) and riser (SSR) soil strengths, and between SST and shear strength (Table 5.11) when correlated.

Table 5.11 R-values for correlations between shear strength, riser soil strength and tread soil strength.

PROPERTY	SHEAR STRENGTH	RISER SOIL STRENGTH
RISER SOIL STRENGTH	-0.171	
TREAD SOIL STRENGTH	0.365	0.046

Data from Slope A showed the relationships depicted in Table 5.12.

Table 5.12 R-values for correlations between shear strength, riser soil strength and tread soil strength (Slope A).

PROPERTY	SHEAR STRENGTH	RISER SOIL STRENGTH
RISER SOIL STRENGTH	0.153	
TREAD SOIL STRENGTH	0.142	0.461

Data from Slope B showed correlations tabled in Table 5.13

Table 5.13 R-values for correlations between shear strength, riser soil strength and tread soil strength (Slope B).

PROPERTY	SHEAR STRENGTH	RISER SOIL STRENGTH
RISER SOIL STRENGTH	0.201	
TREAD SOIL STRENGTH	0.815	0.251

Data from Slope C showed correlations tabled in Table 5.14.

Table 5.14 R-values for correlations between shear strength, riser soil strength and tread soil strength (Slope C).

PROPERTY	SHEAR STRENGTH	RISER SOIL STRENGTH
RISER SOIL STRENGTH	0.155	
TREAD SOIL STRENGTH	0.430	0.149

Data from Slope D showed correlations tabled in Table 5.15.

Table 5.15 R-values for correlations between shear strength, riser soil strength and tread soil strength (Slope D).

PROPERTY	SHEAR STRENGTH	RISER SOIL STRENGTH
RISER SOIL STRENGTH	-0.112	
TREAD SOIL STRENGTH	0.356	0.099

From the preceding data correlations it can be seen that few relationships exist between tread soil strengths and shear strength. Slope A showed weak correlation between tread and riser soil strengths. Slope B showed a strong correlation between shear strength and tread soil strength. Slope C showed a fairly strong correlation between tread soil strength and shear strength. Slope D produced a weak correlation between tread soil strength and shear strength. Riser soil strength only correlated with tread soil strength for data from Slope A. No slopes produced correlations between riser soil strength and showed no relationships between shear strength and riser soil strength

5.1.5 Soil Moisture

Soil moisture contents were determined for the tread, riser, and control samples taken from terracettes at the bottom, middle and top of each slope. Moisture contents are greater, on average , in soils taken from slopes B and D. Control sites from the respective slopes have greater soil moisture percentages than the tread and riser samples, with the moisture contents of soils taken from the treads are lower than those taken from the riser and control regions. Samples taken from the bottom of each site display higher moisture concentrations than those taken from the mid-slope and top of each slope It is clear that aspect plays a role in determining soil moisture percentages since slope A and C are of similar aspect and slopes B and D are of similar aspect. Field soil moisture data is presented in Figure 5.9, and correlation data in Table 5.16.

Table 5.16 R-values for correlation between field soil moisture and other soil physical properties.

PROPERTIES	FIELD SOIL MOISTURE
SHRINKAGE LIMIT	-0.091
BULK DENSITY	-0.659
PLASTIC LIMIT	-0.132
LIQUID LIMIT	0.055
SITE	0.530
POSITION ON SLOPE	-0.198
TRISCON	0.376
AGGREGATE STABILITY	-0.591

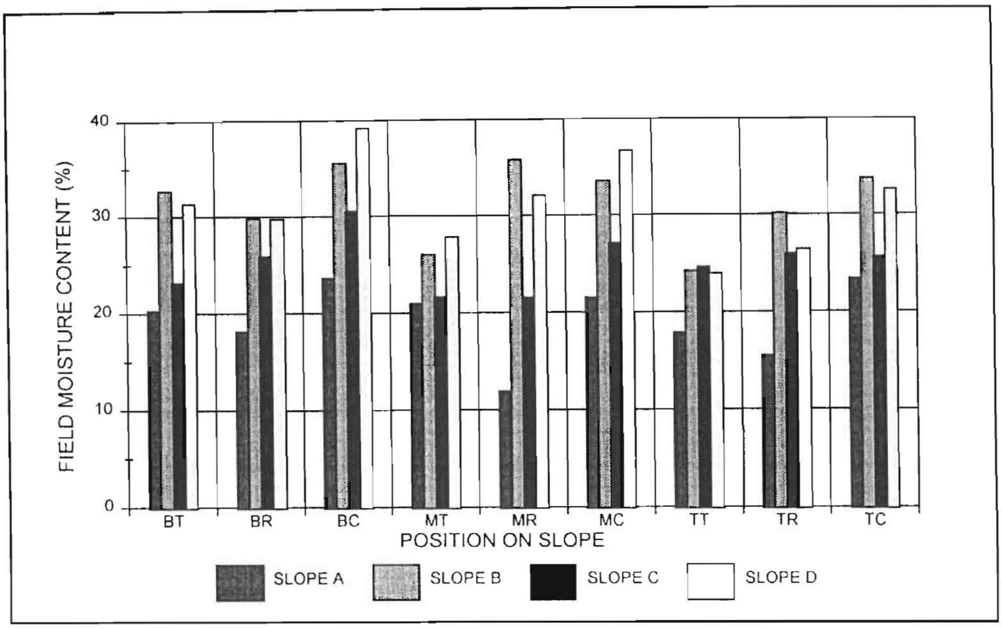

Figure 5.9 Field soil moisture percentages calculated for the tread, riser and control sites from the bottom, middle and top of each slope.

Correlation with data from all sites revealed a strong negative relationship between field soil moisture content and shrinkage limit (r=-0.659), a strong positive relationship with site (r=0.530), and a strong negative relationship with aggregate stability (r=-0.591). An Analysis of Variance, with the null-hypothesis being that there is no significant difference between field soil moisture and site, triscon index, and position on slope, revealed that significant differences are evident between moisture content and site, moisture content and triscon index, and moisture content and position on slope at the 95% confidence limit. These results were verified with an f-test.

Figure 5.10 below shows relationships between field soil moisture and site, position on slope and triscon index, based on means. As can be seen from the plots, moisture content was lowest for Slopes A and C, with Slope B displaying the highest field soil moisture content, and Slope A the lowest. With reference to position on slope, the top slope revealed the lowest moisture values and the bottom slope region the highest. Treads displayed the lowest soil moisture values and the control sites the greatest.

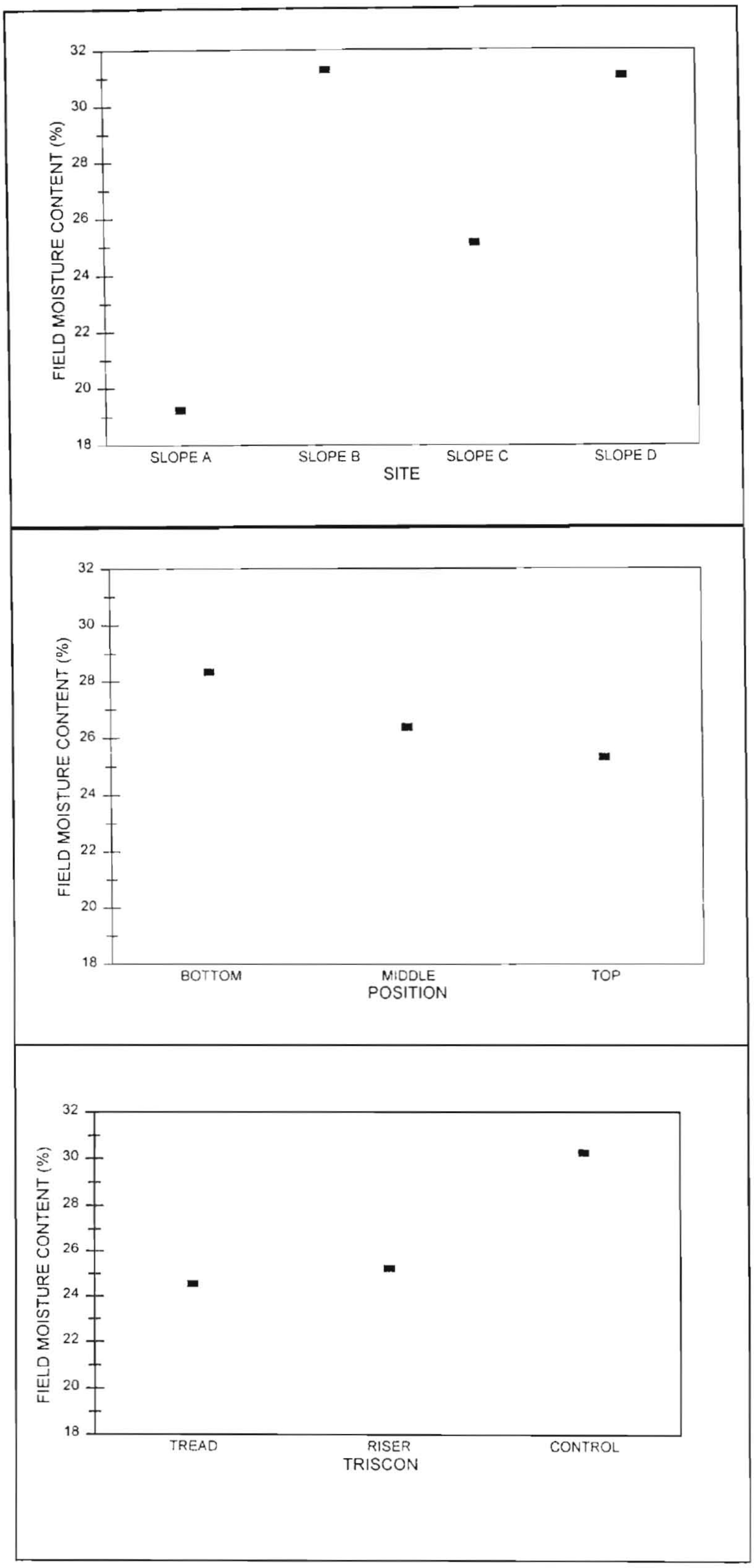

Figure 5.10 Main effects plot for mean field soil moisture content.

5.1.6 Shrinkage limit

Correlation revealed the following relationships between soil shrinkage limits and other soil physical properties (Table 5.17).

From Table 5.17 it is evident that there is a strong correlation between shrinkage limit and aggregate stability (r=0.750) and a negative correlation between shrinkage limit and site (r=-0.571). Anova analysis (null-hypothesis=there is no significant difference between shrinkage limit and site, position on slope and between shrinkage limits at tread, riser and control site) revealed a significant difference between shrinkage limit and site and between shrinkage limit and tread, riser, and control sites at the 95% confidence level. No significant differences exist for position on slope. Relationships between mean shrinkage limits for site, position on slope and triscon can be seen in Figure 5.11. These results were verified with a F-Test.

Table 5.17 R-values for correlation between shrinkage limit and other soil physical properties.

PROPERTIES	SHRINKAGE LIMIT
FIELD MOISTURE	-0.659
BULK DENSITY	-0.226
PLASTIC LIMIT	0.067
LIQUID LIMIT	-0.034
SITE	-0.571
POSITION	0.039
TRISCON	0.092
AGGREGATE STABILITY	0.750

Figure 5.11 shows that shrinkage limits were highest for Slopes A and C and lowest for Slopes B and D. Slope A displayed the highest mean shrinkage limit and Slope B the lowest. In terms of position on slope the bottom slope regions displayed the lowest shrinkage limits and the topslope regions the highest mean shrinkage limit. With respect to tread, riser and control sites, the risers displayed the lowest and the

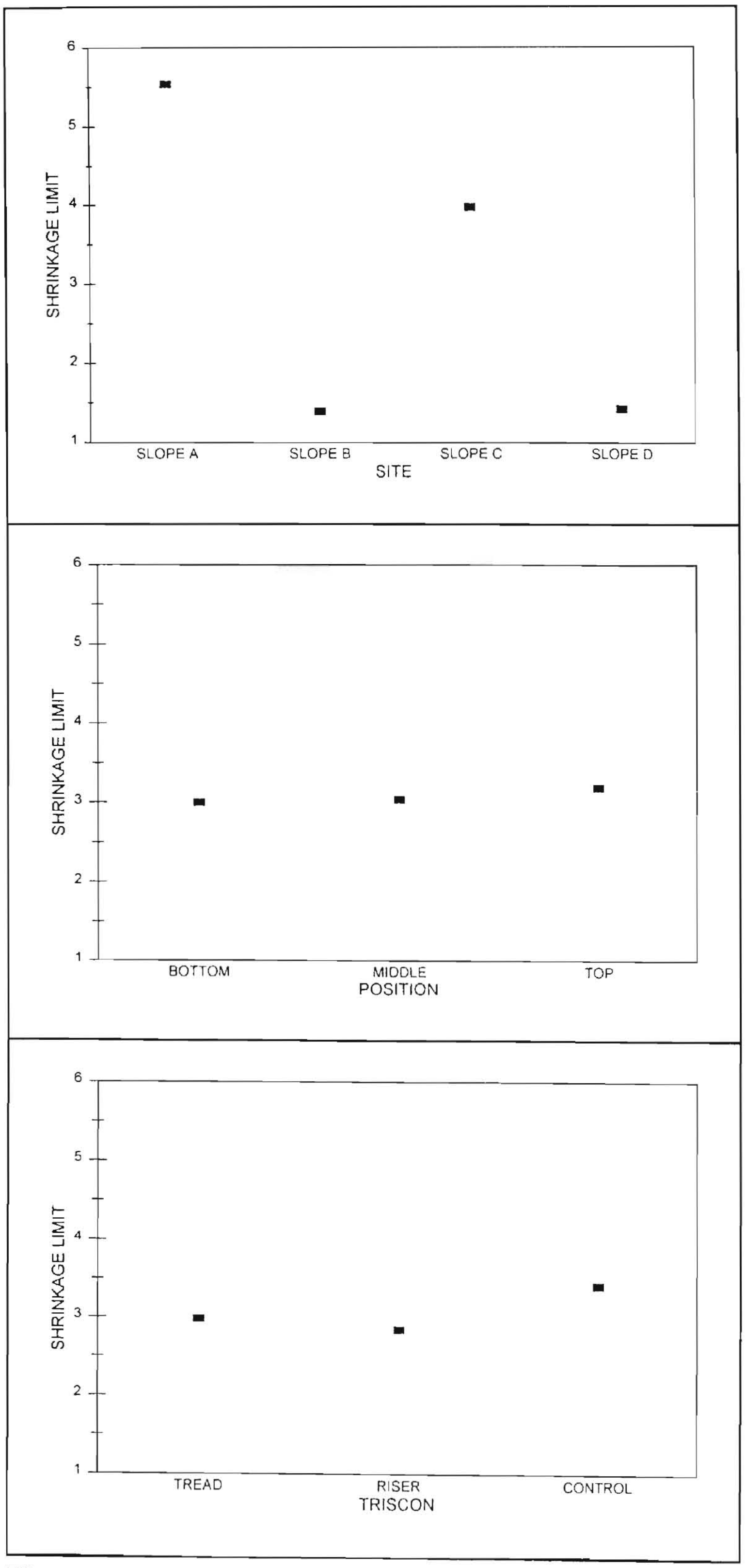

Figure 5.11 Main effects plot for mean shrinkage limits.

control sites the highest mean shrinkage limits.

5.1.7 Plastic Limits

Correlation revealed the following r-values between the plastic limit and other soil physical properties for all sites (Table 5.18).

As is evident in Table 5.18, there is a strong positive correlation between plastic limit and liquid limit and a strong negative correlation between site. No other relationships exist for the other measured variables. Anova between plastic limits and site, position, and triscon revealed no significant differences between plastic limits with reference to position on slope and triscon, but showed differences between sites at the 95% confidence limit.

Table 5.18 R-values for correlation between plastic limit and other soil physical properties.

PROPERTIES	PLASTIC LIMIT
FIELD MOISTURE	-0.132
BULK DENSITY	-0.238
SHRINKAGE LIMIT	0.067
LIQUID LIMIT	0.505
SITE	-0.515
POSITION	-0.176
TRISCON	-0.059
AGGREGATE STABILITY	-0.023

From the main effects plot (Figure 5.12) It is evident that Slope D has the lowest plastic limit and Slope B the largest. Plastic limits for Slope C and Slope D are similar and plastic limits for Slope A and Slope B are similar.

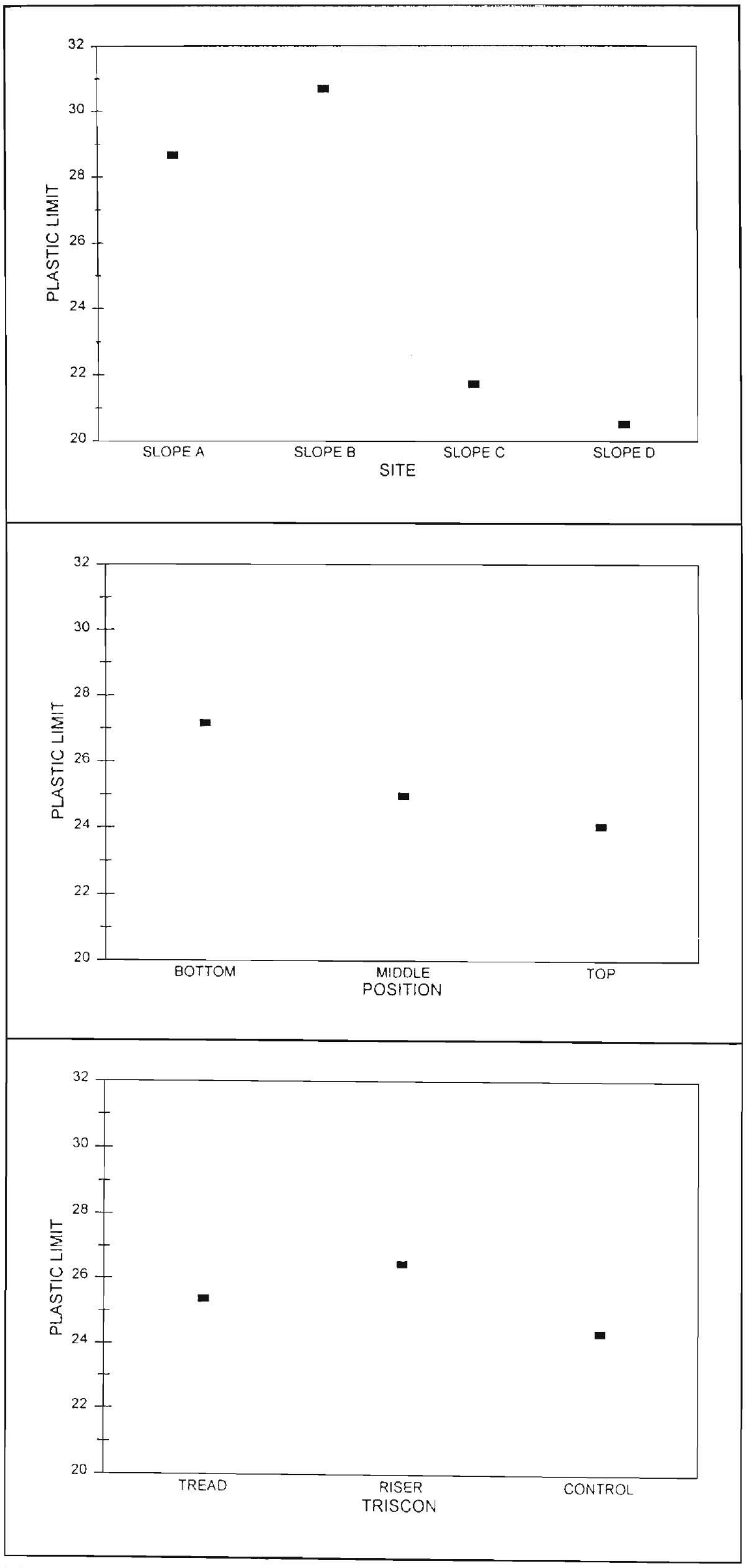

Figure 5.12 Main effects plot for mean plastic limits.

5.1.8 Liquid Limits

Analysis of liquid limits from all sites revealed a strong negative correlation with site, a strong positive correlation with the plastic limit and a positive correlation with bulk density (Table 5.19) Analysis of Variance (null-hypothesis=there is no significant difference between liquid limits and site, position on slope and triscon) revealed a significant difference at the 95% confidence level between sites. No significant difference was evident between position on slope and triscon. These results were verified with an F-Test.

Table 5.19 R-values for correlation between liquid limit and other soil physical properties.

PROPERTIES	LIQUID LIMIT
FIELD MOISTURE	0.055
BULK DENSITY	-0.416
SHRINKAGE LIMIT	-0.034
PLASTIC LIMIT	0.505
SITE	-0.635
POSITION	-0.045
TRISCON	0.137
AGGREGATE STABILITY	-0.203

From the main effects plot (Figure 5.13) it is clear Slope D has the lowest liquid limit and Slope B the highest. Slopes C and D have similar liquid limits. In terms of position on the slope, the mid-slope region has the lowest liquid limit and the bottom slope region the highest. With respect to triscon, it is evident that treads have the lowest liquid limit and control sites the highest.

5.1.9 Aggregate Stability

Mean aggregate stability data for Water Stable Aggregates (WSA)>2mm, WSA>1mm and WSA>0.5mm at all sites is displayed in Table 5.20.

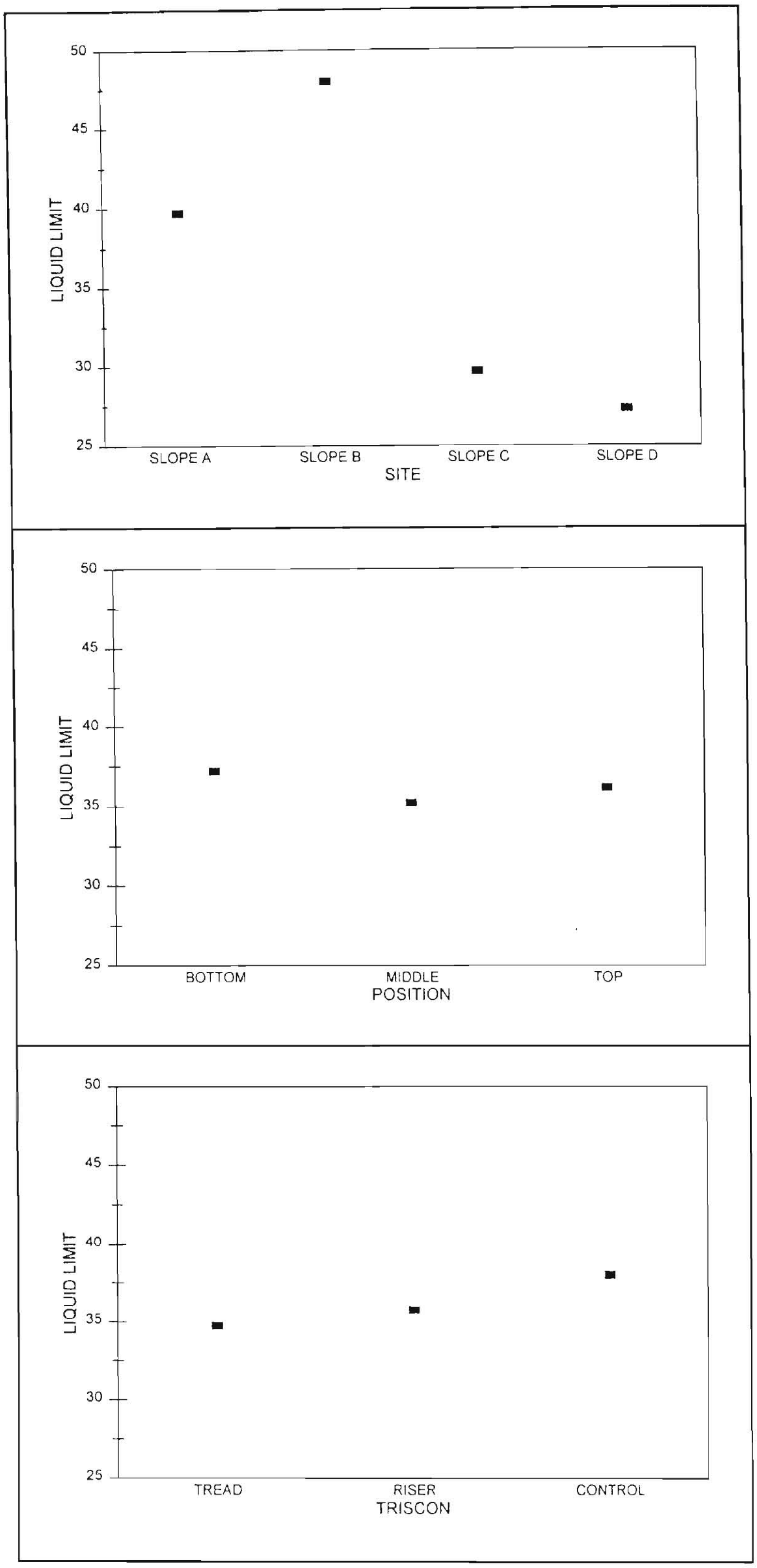

Figure 5.13 Main effects plot for liquid limits.

Table 5.20 Table showing mean aggregate stability values for tread, riser and control samples at all four sites.

SITE	POSITION	WSA>2	WSA>1	WSA>0.5	SOIL TYPE
SLOPE A	TREAD	10.500	8.370	4.270	Sandy loam
	RISER	6.330	5.400	4.390	Sandy loam
	CONTROL	5.970	5.630	3.930	Sandy loam
SLOPE B	TREAD	4.760	3.100	2.100	Sandy loam
	RISER	1.960	1.770	2.000	Sandy loam
	CONTROL	4.480	3.880	2.320	Sandy loam
SLOPE C	TREAD	10.470	8.770	4.900	Sandy loam
	RISER	8.430	4.530	4.870	Sandy loam
	CONTROL	6.330	6.200	6.200	Sandy loam
SLOPE D	TREAD	3.700	3.600	2.070	Sandy loam
	RISER	3.430	3.460	2.330	Sandy loam
	CONTROL	4.170	3.570	1.870	Sandy loam

Pearson Correlation of mean aggregate stability results revealed a strong negative correlation with field moisture content and a strong positive correlation with soil shrinkage limits. These and other relationships are shown in Table 5.21.

Table 5.21 R-values for correlation between aggregate stability and other soil physical properties.

PROPERTIES	AGGREGATE STABILITY
FIELD MOISTURE	-0.591
BULK DENSITY	-0.205
SHRINKAGE LIMIT	0.750
PLASTIC LIMIT	-0.023
POSITION	0.213
LIQUID LIMIT	-0.203

Anova (between sites), with the hypothesis being that there is no significant difference between aggregate stability and particle size, site, position and triscon, revealed the following results at the 95% confidence level.

- There is a significant difference in aggregate stability between 2mm, 1mm, and 0.5mm aggregates, with 2mm aggregates being the least stable and 0.5mm aggregates being the most stable.
- There is a significant difference in aggregate stability between sites, with Slopes B and D displaying similar means based on pooled standard deviations, and Slopes A and C displaying similar means based on pooled standard deviations. Aggregates from Slopes A and C are less stable than aggregates from Slopes B and D.
- There is a significant difference in aggregate stability between the bottom, middle and top of each slope. The bottom slope regions contain the most stable aggregates and the mid-slope region the most unstable aggregates.
- There is a significant difference in aggregate stability between treads, risers and control sites. Risers contain the most stable aggregates and treads the least stable aggregates.

Aggregate stability also produced results indicating that significant differences occur between site, position and triscon at the 95% confidence limit.

When the slopes were subjected to Anova individually no significant difference was registered between treads, risers and control sites on Slope A. Slope A showed the following significant and non-significant differences, for aggregate stability at the 95% confidence limit for the following variables:

- Between the bottom, middle and top of the slope. The middle slope displayed least stable aggregates and the topslope the most stable aggregates.
- No difference occurred between 2mm, 1mm and 0.5mm aggregates although 2mm aggregates were least stable and 0.5mm aggregates most stable.

Slope B showed differences at the 95% confidence level between:

- Treads, risers and control sites. Controls displayed the least stable aggregates and the riser sites the most stable aggregates.
- 2mm, 1mm and 0.5mm aggregates. 0.5mm aggregates were most stable and 2mm aggregates the least stable.

No difference occurred between the top, middle (most stable aggregates) and bottom (least stable aggregates) of the slope.

Slope C showed difference at the 95% confidence level between:

- Tread, riser and control sites. Risers displayed most stable aggregates and treads the least stable aggregates.
- Position on slope. Bottom slope regions displayed the most stable aggregates and the top slope the least stable aggregates.

No difference was evident between 2mm (least stable aggregates), 1mm, and 0.5mm (most stable) aggregates.

Slope D showed difference at the 95% confidence level between:

- Position on slope. The bottom slope contained most stable aggregates and the mid-slope the least stable aggregates
- 2mm, 1mm and 0.5mm aggregates. 0.5mm aggregates were more stable and 2mm aggregates the least stable.

No difference occurred between tread, riser and control sites.

The main effects plot for aggregate stability is found in Figure 5.14 below.

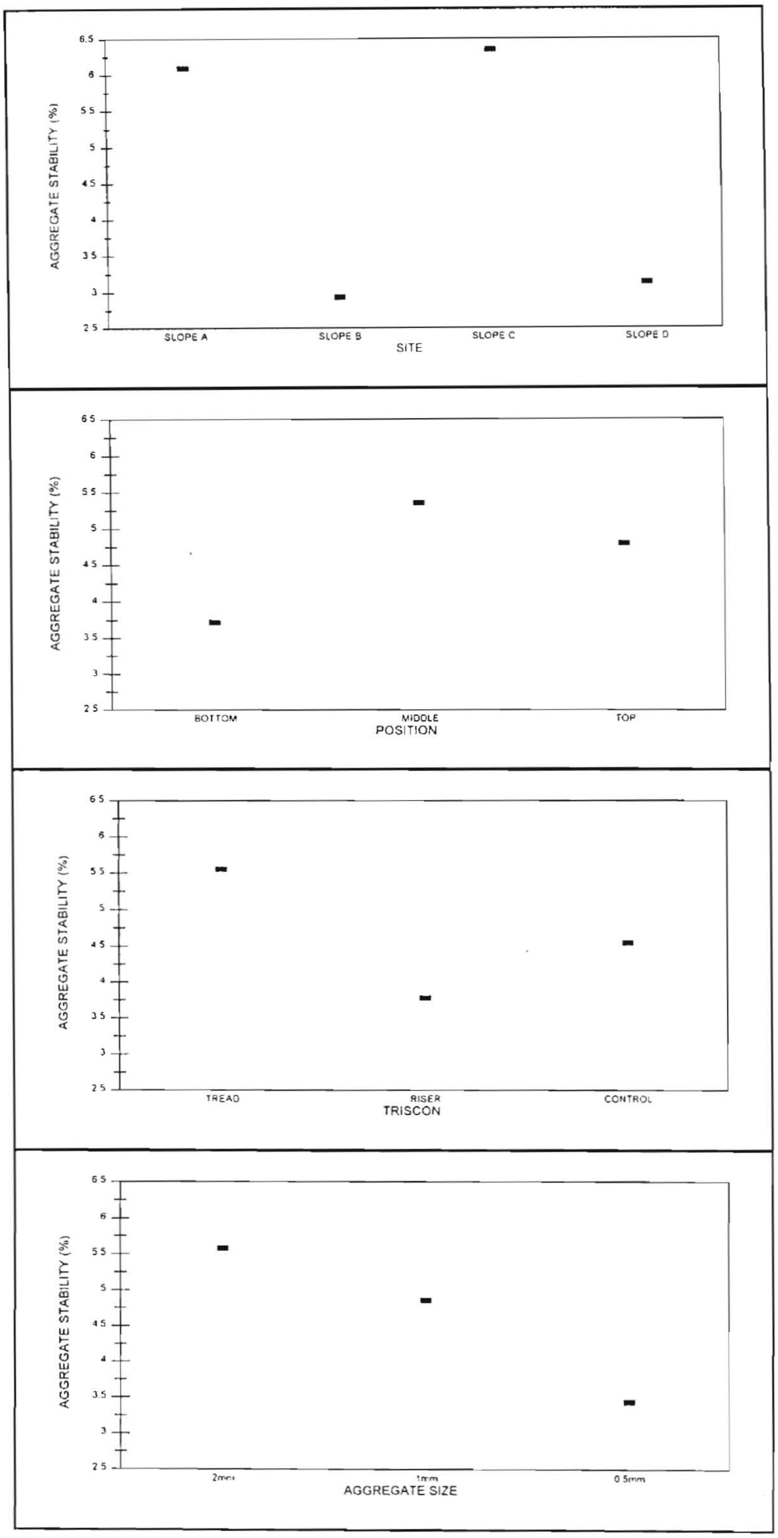

Figure 5.14 Main effects plot for aggregate stability and other factors.

5.2 Terracette Morphological Properties

5.2.1 Aspect

Mean aspect for each slope was calculated from aspects recorded for each terracette measured at respective sites. Aspects for each site are shown in Table 5.22.

Table 5.22 Mean aspect of each site.

SITE	ASPECT
SLOPE A	31.36°
SLOPE B	268.50°
SLOPE C	65.17°
SLOPE D	258.78°

Correlation values (r-values) for aspect with other morphological properties from all slopes are found in Table 5.23.

Table 5.23 R-values for correlation of aspect with other properties.

PROPERTY	ASPECT
TREAD WIDTH	0.187
TREAD LENGTH	0.471
TREAD ANGLE	-0.164
RISER HEIGHT	0.174
RISER LENGTH	0.471
RISER ANGLE	0.057
SHEAR STRENGTH	-0.381
TREAD SOIL STRENGTH	-0.281
RISER SOIL STRENGTH	0.639

As can be seen aspect shows a fairly strong positive correlation with riser soil strength and correlates slightly with riser and tread length. Anova, with the null-hypothesis being that there is no significant difference in aspect between sites, revealed that aspect was significantly different between sites at the 95% confidence limit. Indications are that Slopes A and C are of similar aspect, as are Slopes B and D.

5.2.2 Tread Width

Mean tread widths for each site are recorded in Table 5.24.

Table 5.24 Mean tread width of each site.

SITE	TREAD WIDTH
SLOPE A	0.399
SLOPE B	0.322
SLOPE C	0.353
SLOPE D	0.128

Values (r-values) for correlation of tread width with other morphological properties for all slopes are found in Table 5.25. Anova, with the null-hypothesis being that no significant difference in tread width occurs between sites, revealed that a difference does occur between sites at the 95% confidence level. Slope D showed the greatest variation, with Slopes A, B, and C showing less variation between them for means based on pooled standard deviations.

Table 5.25 R-values for correlation of tread width with other properties.

PROPERTY	TREAD WIDTH
ASPECT	0.187
TREAD LENGTH	0.458
TREAD ANGLE	-0.119
RISER HEIGHT	0.002
RISER LENGTH	0.458
RISER ANGLE	0.096
SHEAR STRENGTH	-0.184
TREAD SOIL STRENGTH	0.053
RISER SOIL STRENGTH	0.361

From table 5.25 it is evident that tread width shows only a weak correlation with tread length. All other measured properties have no significant relationship with tread width.

5.2.3 Tread Length

Mean tread lengths for each site are recorded in Table 5.26.

Table 5.26 Mean tread length at each site.

SITE	TREAD LENGTH
SLOPE A	4.078
SLOPE B	6.131
SLOPE C	5.107
SLOPE D	10.569

Correlation values (r-values) of tread length with other morphological properties for all slopes are found in Table 5.27. It is evident that the only relationships where significant r-values are present for tread length are those with riser soil strength, aspect and tread width. Relationships with other measured properties are not significant.

Table 5.27 R-values for correlation of tread length with other properties.

PROPERTY	TREAD LENGTH
TREAD WIDTH	0.458
ASPECT	0.471
TREAD ANGLE	-0.230
RISER HEIGHT	0.065
RISER ANGLE	-0.017
SHEAR STRENGTH	-0.261
TREAD SOIL STRENGTH	-0.040
RISER SOIL STRENGTH	0.535

Anova showed a significant difference at the 95% confidence level for tread lengths recorded at different slopes. Slope D is more significantly different than the other three sites.

5.2.4 Tread Angle

Mean tread angles for each slope are presented in Table 5.28.

Table 5.28 Mean tread angles for each site.

SITE	TREAD ANGLE
SLOPE A	9.673
SLOPE B	9.000
SLOPE C	8.572
SLOPE D	6.761

Correlation values (r-values) of tread length with other morphological properties for all slopes are found in Table 5.29.

Table 5.29 R-values for correlation of tread angle with other properties.

PROPERTY	TREAD ANGLE
TREAD WIDTH	-0.119
ASPECT	-0.164
TREAD LENGTH	-0.230
RISER HEIGHT	-0.156
RISER LENGTH	-0.230
RISER ANGLE	0.034
SHEAR STRENGTH	0.152
TREAD SOIL STRENGTH	-0.166
RISER SOIL STRENGTH	-0.235

Table 5.29 shows that tread angle bears no significant relationship with the other measured variables. Anova, with the null-hypothesis being that no significant difference occurs in tread angles between sites, allowed for the hypothesis to be

accepted as no significant differences occurred.

5.2.5 Riser Height

Mean riser height values for each slope are presented in Table 5.30.

Table 5.30 Mean riser height values for each site.

SITE	RISER HEIGHT
SLOPE A	0.294
SLOPE B	0.836
SLOPE C	0.301
SLOPE D	0.520

Correlation values (r-values) of riser height with other morphological properties for all slopes are found in Table 5.31. From Table 5.31 it is evident that there is no correlation between riser height and other properties. Anova allowed the null-hypothesis (there is no significant in riser height between sites) to be accepted.

Table 5.31 R-values for correlation of riser height with other properties.

PROPERTY	RISER HEIGHT
TREAD WIDTH	0.002
ASPECT	0.174
TREAD LENGTH	0.065
TREAD ANGLE	-0.156
RISER LENGTH	0.065
RISER ANGLE	0.065
SHEAR STRENGTH	-0.116
TREAD SOIL STRENGTH	-0.074
RISER SOIL STRENGTH	0.188

5.2.6 Riser Length

Riser length results correspond with tread length results (5.2.3) since riser and tread lengths are assumed to be the same.

5.2.7 Riser Angle

Mean riser angle values for each slope are presented in Table 5.32.

Table 5.32 Mean riser angle values for each site.

SITE	RISER ANGLE
SLOPE A	81.14°
SLOPE B	80.67°
SLOPE C	76.63°
SLOPE D	73.33°

Correlation values (r-values) of riser angle with other morphological properties for all slopes are found in Table 5.33. From Table 5.33 it is evident that riser angle shows no correlation with other properties when sites are grouped. Anova revealed no significant difference between sites with reference to riser angle at the 95% confidence limit.

Table 5.33 R-values for correlation of riser angle with other properties.

PROPERTY	RISER ANGLE
TREAD WIDTH	0.096
ASPECT	0.057
TREAD LENGTH	-0.017
TREAD ANGLE	0.034
RISER LENGTH	-0.017
RISER HEIGHT	0.065
SHEAR STRENGTH	0.041
TREAD SOIL STRENGTH	-0.040
RISER SOIL STRENGTH	0.033

5.2.8 Shear Strength

Shear strength data is presented in Chapter 5.1.3. Correlation values (r-values) of shear strength with other morphological properties for all slopes are found in Table 5.34. Table 5.34 shows no correlation between soil shear strength and other measured properties, except for tread soil strength where a strong positive relationship exists.

Table 5.34 R-values for correlation of shear strength with other properties.

PROPERTY	SHEAR STRENGTH
TREAD WIDTH	-0.184
ASPECT	-0.381
TREAD LENGTH	-0.261
TREAD ANGLE	0.152
RISER LENGTH	-0.261
RISER HEIGHT	-0.116
RISER ANGLE	0.041
TREAD SOIL STRENGTH	0.539
RISER SOIL STRENGTH	-0.260

5.2.9 Tread Soil Strength

Tread soil strength data is displayed in 5.1.4. R-values for tread soil strength and other properties are displayed in Table 5.35. Tread soil strength shows no correlation with terracette morphological parameters, but shows a positive correlation with shear strength for grouped sites.

Table 5.35 R-values for correlation of tread soil strength with other properties.

PROPERTY	TREAD SOIL STRENGTH
TREAD WIDTH	0.053
ASPECT	-0.281
TREAD LENGTH	-0.040
TREAD ANGLE	-0.066
RISER LENGTH	-0.040
RISER HEIGHT	-0.074
SHEAR STRENGTH	0.539
RISER ANGLE	-0.040
RISER SOIL STRENGTH	0.035

5.2.10 Riser Soil Strength

Riser soil strength data is displayed in chapter 5.1.4. R-values for riser soil strength and other properties are displayed in Table 5.36. Table 5.36 shows a positive correlation between riser soil strength and tread and riser lengths for grouped data from all slopes.

Table 5.36 R-values for correlation of riser soil strength with other properties.

PROPERTY	RISER SOIL STRENGTH
TREAD WIDTH	0.361
ASPECT	0.639
TREAD LENGTH	0.535
TREAD ANGLE	-0.235
RISER LENGTH	0.535
RISER HEIGHT	0.188
SHEAR STRENGTH	-0.260
TREAD SOIL STRENGTH	0.035
RISER ANGLE	0.033

5.2.11 Morphometric Properties of Each Slope

Table 5.37 (Slope A data) shows correlations between various parameters measured on Slope A. Relationships are present between tread length and riser height, tread angle and riser height, riser height and tread and riser lengths. Tread soil strength (SST) correlates positively with riser soil strength (RST). Other abbreviations included in Tables 5.37-5.40 include: shear atrength (SHEAR S), tread width (TREAD W), tread length (TREAD L), tread angle (TREAD A), riser height (RISER H), and riser angle (RISER A).

Table 5.37 R-values for Slope A data.

	ASPECT	TREAD WIDTH	TREAD LENGTH	TREAD ANGLE	RISER HEIGHT	RISER ANGLE	SHEAR S	TREAD SST	RISER SST
TREAD W	-0.130								
TREAD L	0.031	0.285							
TREAD A	0.164	0.041	0.264						
RISER H	0.002	0.360	0.488	0.524					
RISER A	-0.163	0.392	-0.047	0.131	0.089				
SHEAR S	0.155	0.087	0.049	0.357	0.156	0.056			
SST	0.034	0.041	0.048	-0.164	0.125	-0.087	0.278		
SSR	0.153	0.190	0.304	0.175	0.035	0.040	0.287	0.593	

Slope B data (Table 5.38) shows positive relationships between tread width and riser angle and between shear strength and tread soil strength. Negative correlations exist for tread width and tread soil strength and tread angle and riser height.

Table 5.39 below shows correlations for morphometric parameters pertaining to Slope C. Positive relationships exist between aspect and tread width, tread length, riser length and riser shear strength. A negative relationship exists between aspect and tread angle. Tread width correlates positively with tread length, riser height and riser length. Tread length and riser height are positively correlated. Tread angle correlates negatively with riser and tread lengths, with riser height and riser length being positively correlated.

Table 5.38 R-values for Slope B data.

	ASPECT	TREAD WIDTH	TREAD LENGTH	TREAD ANGLE	RISER HEIGHT	RISER ANGLE	SHEAR S	TREAD SST	RISER SST
TREAD W	0.059								
TREAD L	0.103	0.003							
TREAD A	0.257	0.277	-0.071						
RISER H	0.112	-0.117	-0.065	-0.493					
RISER A	0.009	0.494	-0.191	0.127	0.144				
SHEAR S	-0.257	-0.379	-0.224	0.140	-0.143	-0.219			
SST	-0.111	-0.480	-0.259	0.248	-0.132	-0.217	0.885		
SSR	-0.102	0.077	-0.129	0.150	0.340	0.398	0.268	0.360	

Table 5.39 R-values for Slope C data.

	ASPECT	TREAD WIDTH	TREAD LENGTH	TREAD ANGLE	RISER HEIGHT	RISER ANGLE	SHEAR S	TREAD SST	RISER SST
TREAD W	0.469								
TREAD L	0.591	0.691							
TREAD A	-0.572	-0.171	-0.448						
RISER H	0.356	0.551	0.587	-0.157					
RISER A	0.324	0.118	0.306	-0.393	0.217				
SHEAR S	0.037	-0.054	-0.253	-0.154	-0.293	0.065			
SST	0.321	0.067	-0.030	-0.286	-0.063	0.121	0.304		
SSR	0.433	-0.016	0.240	-0.335	0.237	0.199	0.304	0.377	

Positive relationships exist for Slope D with respect to riser height and tread width, riser height and riser soil strength, and between shear strength and tread soil strength.

R-values for Slope D are illustrated in Table 5.40 below.

Table 5.40 R-values for Slope D data.

	ASPECT	TREAD WIDTH	TREAD LENGTH	TREAD ANGLE	RISER HEIGHT	RISER ANGLE	SHEAR ST.	TREAD SST.	RISER SST
TREAD W	-0.097								
TREAD L	-0.027	0.275							
TREAD A	0.039	-0.115	-0.155						
RISER H	-0.021	0.499	0.356	-0.140					
RISER A	-0.156	0.041	-0.028	0.013	0.141				
SHEAR S	-0.058	0.176	0.181	-0.061	-0.208	0.061			
SST	-0.174	0.358	0.226	-0.055	0.042	-0.029	0.595		
SSR	0.065	0.382	0.319	-0.354	0.563	-0.099	-0.160	0.194	

5.3 Morphometric Index

A morphometric index was calculated based on the following assumptions:

- ❑ According to data, tread and riser angles - when added together - approach a right angle and can thus be treated as one.
- ❑ Terracettes are normal to the slope, and
- ❑ Tread and riser surfaces are flush.

If the above assumptions are made, terracette volume can be calculated using the following equation:

$$(L \times tw \times rh) / 2 \qquad \text{..... Equation 5.1}$$

Where L = terracette length, tw = tread width and rh = riser height. The equation creates an index based on volume for the area encompassing space from the top of the riser to the tread extremity. This could obviously be calculated accurately using trigonometry, but Equation 5.1 is simple to use, is expedient and is reproducible.

R - values were calculated, using correlation to investigate relationships between the volume index and mean tread soil strengths (MSST), mean riser soil strengths (MSSR), mean shear strength (MST), aspect and slope angle from data collected from all sites (Table 5.41). Results indicated relationships between index and mean riser soil strength, tread soil strength and shear strength, riser soil strength and aspect, and between riser soil strength and slope angle. A relationship was also evident between aspect and site.

Anova was undertaken to see if there was a significant difference in the volume index between sites and proved to be significant at the 95% confidence limit.

Table 5.41 R - values for correlation between volume index and other properties.

	INDEX	MSSR	MSST	MSS	ASPECT	ANGLE
MSSR	0.542					
MSST	0.004	0.035				
MSS	-0.231	-0.260	0.539			
ASPECT	0.375	0.639	-0.028	-0.381		
ANGLE	0.038	0.083	0.193	-0.028	-0.287	
SITE	0.354	0.611	-0.091	-0.365	0.597	0.585

Terracettes were grouped into the following classes according to aspect (Figure 5.15)

- CLASS 1 - 316° to 45°
- CLASS 2 - 46° to 135°
- CLASS 3 - 136° to 225°
- CLASS 4 - 226° to 315°

An Anova, with the hypothesis being that terracette indexes would not be significantly different according to aspect class, revealed a significant difference at the 95% level.

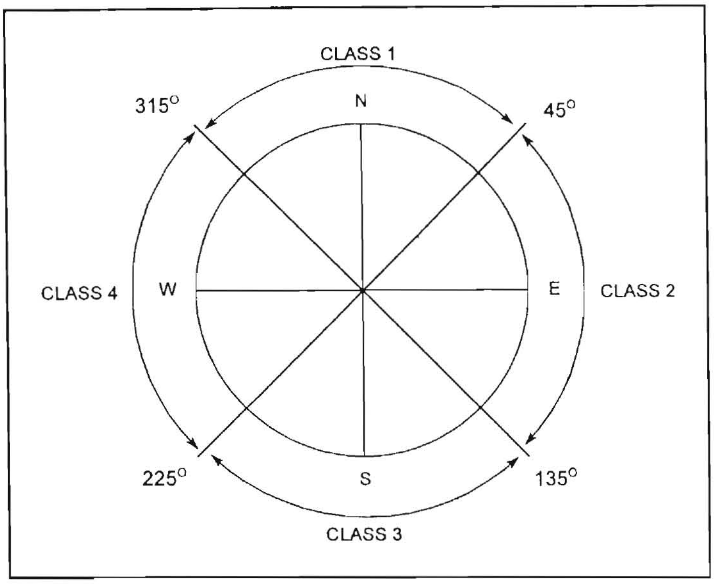

Figure 5.15 Terracette classes according to aspect and volumetric index.

Chapter 6

Discussion

The preceding Chapter has shown that relationships between soil physical properties and terracette morphology do exist. It is also evident that relationships exist between the soil properties themselves. These properties impact on the nature of the slopes on which terracettes occur, and impact on the morphology of the terracettes themselves.

6.1 Soil Property Relationships

6.1.1 Dry Bulk Density

- From Chapter 5 it is evident that significant differences occurred when DBD was related to site, and tread, riser and control sites. No significant difference in DBD was recorded when related to the position on the slope.

Between site variations can be explained in terms of differing aspect and slope angle. Slopes A and C are of similar aspect and angle and Slopes B and D are of similar aspect and angle. Aspect plays a significant role in determining slope processes and thus slope soil properties (Churchill, 1982). Rates of process differ according to aspect, with north facing slopes displaying higher process rates. Aspect also plays a role in determining soil moisture and vegetation conditions. Slopes A and C are of a northerly aspect while the other slopes are predominantly south facing. However, bulk density data shows Slopes A and B with similar mean bulk densities and Slopes C and D with similar bulk densities. It can thus be deduced that other site specific factors overplay aspect when explaining differences in DBD between sites. From data it is apparent that Slopes A and B have similar liquid limits and Slopes C and D have similar liquid limits. Liquid limits for the former slopes are higher than those for the latter slopes. This would suggest that liquid limit may play an important role in determining bulk density. The same applies to plastic limits.

Vegetation type and extent does not play a significant role in this instance since the type and cover are uniform between sites. However, when explaining variation in DBD between tread riser and control sites vegetation does play a significant role. Since treads and risers are devoid of vegetation, and the control site is vegetated, DBD for treads and risers are higher than at control sites. Low DBD values for control sites are a result of plant root growth which creates voids between soil aggregates, thus reducing the volume of soil per unit area.

DBD differences occur between the relative positions on the respective slopes. Mean DBD is greater in the bottom slope regions and increases in ascent up the slope, with the top slope region displaying the lowest DBD. This can be explained in terms of slope denudational processes. The greater percentage of fines found in the bottom slope regions would have washed out from the top and middle slope regions by throughflow, interflow and overland flow over time. Fine particles would be washed out from between aggregates upslope creating soil void spaces, reducing the DBD, and become entrapped in voids down slope increasing the DBD. Creep processes active on slopes (it is assumed that these processes are, or were, active on the slopes in the study region, since terracettes are present and are proposed to have formed from creep processes) would result in a greater DBD downslope due to compaction created by pressure exerted as a result of soil movement from upslope regions. By soil creeping downslope, the weight of the mass moving downslope would result in forces of cohesion being overcome and peds being sheared, creating more voids and decreasing DBD.

DBD shows a strong negative relationship with field soil moisture content ($r=-0.91$, Table 5.5). Thus the greater the soil moisture percentage the lower the bulk density. This does not hold true for the bottom slope regions, but does hold true for the middle and topslope regions. This would suggest that other factors are more closely related with DBD in the bottom slope region. The pressure exerted on the bottom slope from the soil mass upslope of it through creep, would result in compaction of the lower slope soil, thus resulting in a deviation from the apparent norm.

6.1.2 Field Moisture Content

Field soil moisture percentages vary between sites (Figure 5.10). Sites A and C display lower mean soil percentages than Slopes B and D. This results from the effect of aspect on soil moisture regimes since Slopes A and C are predominantly north facing, and Slopes B and D predominantly south facing. The variation between the top, middle and bottom slopes (Figure 5.10) is accounted for through standard hydrological models for hillslopes (Shaw, 1983).

Variations in soil moisture also occur between tread, riser and control sites. Treads display lower soil moisture percentages than risers and control sites. Control sites are covered in vegetation thus decreasing the loss of moisture through radiation induced evaporation. The effects of radiation, apparent in the between sites comparison, thus becomes apparent. Since treads and risers are bare radiation induced drying processes would account for lower moisture values at these sites. Variations between tread and riser moisture contents are as a result of moisture movement through the soil. Gravity would draw water through the riser surface, and away from the tread surface, thus resulting in higher near surface moisture percentages at risers.

6.1.3 Shear Strength

Shear strength was measured at treads only. Differences in mean shear strength are evident between sites (Table 5.6). Mean shear strengths were similar for Slopes A and C, and similar between Slopes B and D. Slopes B and D displayed lower shear strengths than Slopes A and C (Table 5.7). Shear strength thus also becomes a function of aspect. This suggests that shear strength is also a function of field moisture content. Since moisture content at treads for Slopes A and C and for Slopes B and D were similar, a relationship can be seen.

6.1.4 Soil Strength

Tread soil strength (SST) also showed a significant difference between sites, as did riser soil strength (SSR). Again Slopes A and C showed similarity, as did Slopes B and D for SST. Thus, again, aspect plays a role in determining relative tread soil strength. Tread soil strengths were higher, on average at Slopes A and C than they were at the other two slopes. This also becomes a function of field moisture content. Since soil strength and shear strength are both used to determine relative soil strength the results for each concur. Mean tread soil strength showed no relationships with mean riser soil strength between all terracettes measured, but did show a relationship with riser soil strength for Slope A (Table 5.12). This relationship could be explained in terms of the time elapsed since terracettes formed on the slope. The longer the time period between formation and present, the more different the soil properties between the treads and risers would become. This stands to reason since both are exposed to different processes, and different rates of process due to morphological differences. Thus a more recently formed terracette would not have been exposed to weathering and erosional processes for a sufficient period of time to allow for difference in soil strengths at the treads and risers.

6.1.5 Atterberg Limits

Atterberg Limits include:

- Shrinkage limit

As can be seen from Chapter 5.1.6, significant differences of shrinkage limits do occur between sites, but not according to position on slope and between tread, riser and control variables. As has been the case with other measured variables Sites A and C display similar shrinkage limits, as do Slopes B and D. Again aspect has played a role in determining the soil characteristics of each site. The non-significance of shrinkage limits between position on slope and tread riser and control sites, suggests that the soils are uniform at the various positions and that shrinkage limits are not affected by the measured variables. However, shrinkage limits showed positive correlations with aggregate stability (Table 5.17) and negative correlations with site, and field soil moisture. The relationship between aggregate stability and shrinkage limit suggests that soils with high aggregate stabilities reach constant volume after less moisture loss than soils with higher aggregate stabilities, and are thus more stable and display higher soil strength. The negative relationship with soil moisture suggests that initial soil moisture content plays a role in determining the erosive potential of the soil.

- Plastic limit

As with shrinkage limits, site proved to be a significant variable, and thus the same conclusions can be drawn as to variation. However, in this case Slopes A and B showed similar plastic limits as did Slopes C and D. This would suggest that soil forming properties are not a controlling factor when determining the plastic limits of a soil. Slope angle may play a role in determining the plastic limits since Slopes A and B are of similar angle, as are Slopes C and D. However, since slope angle was not considered as a variable for plastic limits, further investigation is necessary. No significant differences occurred between position on slope and between tread, riser and control sites and thus the soil appears to be uniform for these sites,

- Liquid limit

Data for liquid limits suggests the same trends as data for plastic limits and thus the same conclusions can be drawn.

6.1.6 Aggregate Stability

Aggregate stability test results revealed the following results:

- A significant difference in stability between aggregates of 2mm, 1mm and 0.5mm, with the 0.5mm being most stable.

This suggests that smaller aggregates have been exposed to more weathering than larger aggregates and are nearing their equilibrium stage in development. Larger aggregates have not been exposed to significant weathering processes at the surface and thus retain their erosional potential.

- Mean aggregate stability shows significant differences between sites.

Slopes A and C showed similar aggregate stabilities, as did Slopes B and C. Again aspect plays a significant role in determining the properties of soils on slopes, with predominantly south facing slopes being less developed due to decreased process rates, and showing aggregates more stable than the ones from Slopes A and C. Aggregates from slopes B and D are thus less weathered and less likely to break down through drop impact.

❑ Aggregate stability increases significantly downslope.

Bottom regions contain material that has been deposited from areas above it after being removed and transported by wash processes. The stability of the aggregates has increased due to being exposed to wash processes and have neared their equilibrium stage.

❑ Significant differences exist between tread riser and control sites.

Tread aggregates display less stability than control aggregates, which in turn display less stability than riser aggregates. Riser aggregates are more stable since they have been exposed to greater throughflow action and have had fines removed by this process, thus rendering the aggregates more stable.

6.2 Morphological Relationships

From the morphological data displayed in Chapter 5 it is evident that some relationships do exist between morphological parameters. Morphological relationships do vary from site to site, and from terracette to terracette. However, in order to establish overall relationships, means and trends from numerous terracettes need to be observed in order for statistically significant conclusions to be drawn.

6.2.1 Aspect

Aspect can be seen as a significant controlling factor in soil properties due to variation in soil physical properties between slopes. This variation is transferred to terracette morphology in a less significant manner. Aspect for each slope is shown in Table 6.1.

Table 6.1 Aspect of all slopes

	SLOPE A	SLOPE B	SLOPE C	SLOPE D
ASPECT	31° 24"	268°30"	65° 10"	258° 47"

Aspect showed positive correlations with terracette length (r=0.5) and riser shear strength (r=0.639). This relationship suggests that aspect plays an important role in determining the length of the terracette and suggests that the shear strength of the riser also plays a determinant role. However, since the original set of conditions on the slope have changed since the formation of the terracette, the relationship could be as a result of aspect having played a role in determining the present conditions on the terracettes thus not playing a significant role in formation. Conversely, terracette length remains fairly constant through time, thus relating length of the terracette to aspect at the formative stage. Since some soil conditions are related to aspect suggestions are that original soil conditions, dictated by aspect affect the length of the terracette. Riser soil strength would have changed since formation and thus soil strength is as a result of transformation at the riser surface due to process and does not relate to formative mechanisms in this instant. However, riser soil strength would determine effects of sustaining processes and thus aspect has a bearing on sustaining mechanisms.

6.2.2 Mesoslope Angle

Mesoslope angles of the four slopes measured are displayed in Table 6.2.

Table 6.2 Mesoslope angle for each site

	SLOPE A	SLOPE B	SLOPE C	SLOPE D
ANGLE	24°40"	14°30"	28°10"	24°30"

From the above table, mesoslope angles range from 14°30" to 24°40". Since only four slopes were investigated these figures cannot be extrapolated throughout the study region since the sample for slope angle is not representative. However, relationships between these slope angles and morphometric properties will be valid for each site. Due to the limited gradient variations limiting angles are not calculated but slope angle and terracette occurrence does fall within the limiting angle range reported by other authors (Table 2.1).

Verster *et al.* (1986) found that terracettes with narrow treads were associated with steeper slopes. This relationship was not evident in the present study.

6.2.3 Tread Properties

Tread variables can be found in Table 6.3. Tread width and tread length correlate positively (r=0.5). Although the relationship is fairly weak, tread length is still a determinant of tread width. The longer the terracette, the greater the tread width. If shear planes exist within the soil as proposed by Sharpe (!938), the shear plane would have a fixed length normal to the slope. The length of the shear plane would thus determine the length of the terracette, which, in turn, would determine the width of the terracette. Longer shear planes would mean a greater volume and mass of soil sliding downslope, pulling the moving soil further away from the shear plane, creating longer tread surfaces. Tread properties showed no correlation with other morphological variables.

Table 6.3 Morphological parameters of present study.

		MORPHOMETRY				
		RISER		TREAD		
	MESOSLOPE (DEGREES)	ANGLE (°)	HEIGHT (m)	ANGLE (°)	WIDTH (m)	LENGTH (m)
n	121	121	121	121	121	121
RANGE	14 - 28	-5 - 94	0.170 - 1.080	-4 - 28.660	0.140 - 23.740	0.140 - 0.820
MEAN	23	74.900	0.470	8.180	0.400	7.140

6.2.4 Riser Properties

Riser properties are displayed in Table 6.3. Few relationships exist between riser properties and other morphological parameters. Riser length correlates positively with riser soil strength (r=0.54). This correlation shows that the longer the riser the greater the soil strength at the riser surface. This, however, does not reflect the original soil strength at the time of terracette formation. Soil strength at the time of formation could have been greater or less than the present values indicate. This is so because processes active on the riser surface could either have made the soil strength less, by needle ice action for example, or greater through such processes as surface sealing resulting from rainsplash erosion.

6.3 Volumetric Index Relationships

Since the volumetric index, calculated by Equation 5.1, uses all terracette morphological parameters, the index gives a good indication of terracette morphology with other calculated variables (Table 5.41). Overall terracette morphology correlated with riser soil strength (r=0.542). It can thus be deduced that riser soil strength shares a significant relationship with terracette morphology. If slip planes do exist, which have been found by (Vincent, 1995, *pers. comm.*), in the soil where the terracettes form, they would exist along the length of the riser, thus relating riser soil strength to terracette formation. However, since the relationship is positive, the occurrence of a shear plane at a certain point in the soil would reduce the soil strength at that point, and thus produce a negative relationship between riser soil strength and terracette morphological indices.

6.4 Sustaining Mechanisms

Sustaining mechanisms active on terracettes within the reserve are deduced from field observations. Mechanisms are not active on all terracettes since aspect plays a role in determining process, thus variation occurs from site to site. Mechanisms will thus be discussed in a broad context.

6.4.1 Needle Ice

Needle ice growth was observed on both treads and risers of terracettes. The occurrence of needle ice growth was dependant on aspect and position on slope. The growth of needle ice was observed in the lower regions of predominantly south facing slopes. This shows that there is a strong relationship between process and aspect since moisture content and soil physical properties and moisture content vary accordingly between north and south facing slopes (Boelhouwers, 1988). As discussed in Chapter 2.2.1 needle ice growth can play a significant role in sustaining

Figure 6.1 Soil disturbance due to needle ice growth on a terracette tread.

terracette development. Figure 6.1 shows soil disturbance on the tread of a terracette within the study region. From the figure it is evident that soil has become displaced, and thus becomes exposed to other forms of erosion and transport. Needle ice growth on risers results in soil being deposited on the tread where it can be removed by aeolian deflation and wash processes. The growth of needle ice reduces the soil strength at the surface, and melting of the ice crystals provides water which facilitates the removal of clay and silt particles from the respective riser and tread surfaces.

Needle ice growth, according to Killick (1963) can also cause over-steepening of the riser. Plant roots binding the soil together prevent needle ice growth disturbance, but soil loss still occurs lower down the riser. Over time the riser becomes over-steepened and plant roots cannot compete with the forces of gravity, resulting in dislodgement of significant amount of soil, and accentuating riser retreat.

6.4.2 Wind

Removal of particles by wind action is also evident. Wind action is not site specific and occurs on all terracettes within the region. Wind however, seems to act more as an agent of removal of already disturbed soil particles, and not as an erosive agent since soil strengths at tread and riser surfaces are relatively high. Particle size distributions tend to indicate that few fines exist at these surfaces and thus deflation becomes unlikely. However, the particle size distributions at the tread surface suggest that fines washed out from the riser - by interflow and throughflow - onto the tread have been removed either by wind action or wash processes.

6.4.3 Interflow and Surfacewash

Interflow plays a significant role in riser deterioration. Not only does it remove soil particles from unstable aggregates, but washes out fines found at ped surfaces, increasing the size of the inter-ped boundaries This leads to instability on the riser and causes large quantities of soil to be deposited on the tread surface where it becomes exposed to rainsplash. Riser soil displayed the aggregates with the most stability, but this does not preclude further degradation from the dislodged peds through drop impact. Figure 6.2 illustrates degradation at riser surfaces through this process. Gaps between ped surfaces can be clearly seen and evidence of dislodgement of peds can be seen. This process was not visibly active at all sites, with only Slopes C and D displaying pronounced degradation.

Figure 6.2 also illustrates how the process can result in over-steepening at the top of the riser. This occurs due to the binding effect of plant roots in the upper soil layers. Plant roots bind the soil together and prevent, or reduce, soil loss while interflow in the lower horizons removes soil from the riser surface. Over-steepening occurs and consequently the forces of gravity overcome the binding forces at the 'overhang' and soil falls to the tread, continuing riser retreat.

Figure 6.2
Riser degradation at inter-ped boundaries caused by inter-flow.

Lichen growth on risers gives an indication of riser stability. However, some risers have been destabilised by the above process. This is clearly evident in Figure 6.3 below. Grass and lichen visible at the riser surface indicate that the riser was stable. However, riser retreat has been reactivated due to removal of soil particles at the inter-ped boundaries. This process therefore becomes important when considering terracette stability.

Surfacewash plays an important role as a secondary mechanism. Water flowing down a slope would increase in velocity when descending down a riser due to increase in angle and lack of vegetation. This would aid in the removal of soil aggregates from the riser surface, as well as facilitating the removal of fines at inter-ped boundaries. On over-steepened risers the flow could create a plunge-pool effect near the riser-tread boundary, creating a channel for water to flow through on the tread, reducing tread angle. Although terracettes are considered to be normal to the slope, there is variation and treads do not always run parallel to the contour. This would concentrate flow along the tread and accentuate the denudational process, and facilitate transport of already dislodged material.

Figure 6.3 Lichen and grass growth indicating a once stable riser.

Rillwash may also occur at riser surfaces due to surfacewash, as is evident in figure 6.4. This process is aided by throughflow at inter-ped boundaries as discussed above. Gaps at ped boundaries resulting from throughflow create flow lines which are accentuated by rillwash resulting in distinct rills.

Figure 6.4 Development of rills at riser surface.

6.4.4 Wetting and Drying

The results of wetting and drying are also evident on predominantly north-facing slopes. Figure 6.5 shows extensive polygonal cracking due to this process. The process was not evident on predominantly south-facing slopes due to soil moisture retention at these sites, and reduced insolation. Polygonal cracking creates a greater surface area for other denudational and weathering process to operate and facilitates further riser degradation and retreat.

Shrinkage limits from Sites A and C showed higher values than Sites B and D. The shrinkage limit not only reflects the quantity of water lost before the soil retains volume, but conversely reflects the ability of the soil to swell. Soils with higher shrinkage limits would thus have a greater swell capacity than soils with lower shrinkage limits.

Figure 6.5 Polygonal cracking as a result of wetting and drying.

6.4.5 Animal Disturbance

Since animals are found within the Reserve, and antelope droppings have been observed on terracettes, it is assumed that animals have moved along terracette surfaces. This would impact on the terracette morphology since the weight of the animal would compact the soil at the tread surface, thus altering tread angle and soil physical properties. If animals graze on the terracette surfaces the vegetation cover is reduced and increases the potential for soil loss through splash and wash processes. Increased erosion potential would undoubtedly result in higher erosion rates, thus speeding up terracette retreat.

6.5 Formative Mechanisms

From the present study it is not possible to determine precise formative mechanisms. However, from soil property data it is possible to suggest possible formative mechanisms for the area.

Soil survey results show sandy loam soils with very low bulk densities (Hazelton *et* *al.*, 1992), relatively low soil strengths, and low liquid and plastic limits. These properties suggest that soils on the slopes are susceptible to creeping. This is further verified by higher mean dry bulk densities found in the lower slope regions, as discussed in Chapter 6.1.1. The low liquid and plastic limit values indicate that the soils on the slopes studied are susceptible to creep and sliding processes. The lower the liquid limit the lower the compressibility of the soil. This would suggest that when moisture is added to the slopes through precipitation events, forces of cohesion may be overcome by the added weight of the moisture, and creeping or sliding may occur. If sliding occurs shearing at the surface of the turf cover is likely along shear planes and inherent lines of weakness. This process can occur through rotational slippage, slumping and creep. It is not evident that needle ice growth plays a role in the formation of terracettes within the reserve since few freeze-thaw cycles are present in the study area.

From the formative mechanisms discussed in Chapter 2.1 the following can be excluded from the Reserve:

❑ Gelifluction, since the study sites do not fall within a periglacial zone,

❑ Regolith control, since terracettes are found on lower slope regions where regolith exceeds 1m in depth and cannot be considered superficial,

❑ Surfacewash and deposition, since it seems unlikely that sediment would accumulate in such a regular pattern on a slope, and since the slopes are well vegetated sediment loss would be minimised.

❑ Animal disturbance, since following Garland's (1987) argument, pressure exerted by grazing animals would be confined to an area the size of the hoof of the animal, and would probably result in soil compaction rather than a coherent mass of soil shearing and moving downslope.

Thus it seems most likely that terracettes within the Reserve occur as a result of mass movement processes, associated with shear planes and lines of weakness within the soil, and with soil physical properties as mentioned above.

6.6 Terracettes and Stability

It is thought that terracettes add to the stability of the slope as a whole as they form in reaction to the disequlibrium of forces on and within the slope (Garland, 1987). When assessing stability it is necessary to examine the stability of the terracettes themselves, as well as the stability of the slopes on which they are found.

6.6.1 Terracette Stability

Terracettes within the study region showed few signs of stability. This can be assessed through the occurrence of vegetation and lichen on risers. Nontheless, some risers displayed signs that at some stage in the past they had become stable as figure 6.3 indicates. However, evidence of riser retreat was present and it must be assumed that riser retreat had been reactivated. Scarp retreat is initiated by sheetwash (Garland, 1987) and throughflow. In order to assess the rates of retreat it would be necessary to insert markers on terracettes and observe changes in position over a long period of time. It must thus be assumed that terracettes are active phenomena, and once returning the slope to an equilibrium state, changes in terracette form again put the forces acting on and within the slope into disequilibrium, either by the initiation of new terracettes or, on a larger scale, or by larger mass movement complexes such as slip scars.

6.6.2 Slope Stability

The occurrence of terracettes on a slope indicates that at some stage in the past the slope was unstable. Data suggests that creep processes are, or were, active on the slopes where terracettes occur. Creep, in conjunction with relatively low liquid limits, suggests that the potential for the occurrence of instability features is enhanced. Terracettes, by retreating and altering form, can again change the forces and resistances in the soil mantle. It must therefore be assumed that at some time in the future the slope will become unstable, or that the slope is in a stage of instability until failure occurs to re-establish equilibrium.

Chapter Seven

Conclusions

From the results, and discussion thereof, few definite conclusions can be drawn regarding terracette origin, however general conclusions can be ascertained from the data, observations and methodology. The results reveal a diversity concerning composing soil properties and morphological aspects. Not only is variability evident in this study, but comparisons with work by Verster *et al.* (1986), Garland (1987), Watson (1988), and Day (1993) reveal considerable between site variations.

Soil properties differ between treads and risers. This indicates a difference in sustaining mechanisms between the morphological facets. This is due to a number of reasons previously discussed, with the most important factor influencing process, and rate thereof, being angle relative to the slope. Treads are almost horizontal to the slope plane, and risers almost vertical. From field observations, throughflow and interflow, accompanied by surfacewash, are the dominant processes in the study region active on and behind riser surfaces, resulting in riser retreat and thus an increase in tread width.

The following conclusions have been drawn with regards to tread, riser and surrounding slope soil properties in the study region:

- ❑ Terracette treads have low dry bulk densities, relatively high shear strengths, low field soil moisture percentages, low linear shrinkage limits, low plastic and liquid limits, and contain aggregates that are less stable than risers and control sites. All of the above are dependant on aspect, and relative slope position.

- ❑ Terracette risers have dry bulk densities higher than those of treads - but are still relatively low - have field soil moisture contents higher than treads, and have lower shrinkage limits - but higher liquid and plastic - limits than treads. Aggregates found on risers show greater stability than those found on treads.

Riser soil strength is greater than tread soil strength. These properties are also dependant on aspect.

- Control sites give a good indication of the surrounding slope properties and the slopes on which the terracettes are found. They have dry bulk density values lower than both treads and risers, higher field soil moisture contents, higher shrinkage and liquid limits but lower plastic limits, and aggregates more stable than treads but less stable than risers.

The following sustaining processes are active within the study site:

- Needle ice plays a role in terracette morphological change, however the extent has not been examined in the present study. The growth of needle ice on riser and tread surfaces is dictated by aspect, with terracettes on cool, moist south facing slopes being more susceptible to the process. However predominantly north facing slopes cannot be precluded from the process, since, if the conditions for needle ice growth are met, it will form and aid in morphological alteration of both treads and risers.

- Wind does not play a dominant role in morphological modification. However, wind can play a significant role in the removal of already disturbed material from both treads and risers, and thus is valuable as a transport mechanism. Wind also affects the moisture conditions at riser and tread surfaces through increased evaporation. Moisture conditions are significant variables to consider with regard to soil properties, both physical and chemical.

- Fluvial processes such as throughflow, interflow and surfacewash are dominant on risers, with treads being altered by surfacewash and leaching.

- Animal disturbance is evident, but the extent of the disturbance is unknown. It is assumed that it is a minor secondary mechanism on most terracettes.

Statistical analysis of the data indicated that there are relationships between soil properties and morphology. However this becomes rather insignificant if it is inferred that morphology results from these properties. It would be more cautious to suggest that the soil properties present at the time of measurement are as a result of morphology. The soil properties at the time of formation cannot be measured and thus soil properties present at the time of sampling cannot be inferred to that time. The inclusion of a control site does not reveal the soil conditions necessary for formation, since if the conditions were the same as those present when and where the terracette formed, it must be questioned as to why a terracette did not form at the control site. This type of reasoning would tend to favour the existence of shear planes within the soil as the dominant controlling variable influencing terracette formation.

The variation in relationships between soil properties and the morphological set, from slope to slope, indicates that relationships are site specific. For example, Table 5.38 shows a correlation between riser angle and tread width for Slope B. This relationship is not present on any of the other slopes investigated, suggesting site specificity.

The morphometric index discussed in Chapter 5.3 gives a good indication of relationships between terracette morphological facets and soil strength properties, and between overall morphology and site properties. It can be seen that the overall terracette shows a positive relationship with riser soil strength, suggesting that riser soil strength plays an important role when considering the terracette as a complete unit. However this cannot be related to formation and has occurred as a result of processes dictated by the morphological set.

It appears that terracettes play a role in maintaining, and destroying, the stability of the slopes on which they are found. They impart strength to the slope as a result of redistributing the forces present within the soil mantle. However continued retreat and degradation of terracettes can change the set of conditions that maintained, or reintroduced stability to the slope, possibly resulting in the formation of new terracettes or continuing into slip-scars.

7.1 Where to From Here?

Since no general theory on terracette formation can be drawn from the relationships between soil data and terracette development in this study, it must be assumed from the data presented that, in Giant's Castle Game Reserve, the dominant formative mechanism is soil creep. However in order for this to become entrenched further research will need to be undertaken. A detailed study of the soil mantle is required and long term field observations implemented in order to establish if creep is in fact present.

It seems that in order to determine the formative process/processes it is necessary to determine why terracettes occur in some places and not in others. Due to the various time spans estimated for terracette development to occur, a long-term study seems necessary. This would be aided with the help of a small scale database of terracette occurrence, and a detailed microtopographic mapping of terracette morphology and soil physical properties on particular slopes. The investigation of the occurrence of shear planes would also be necessary, and their distribution within the slope environment mapped. Soil samples taken where shear planes, and where no shear planes occur, would allow for time sequential changes in soil properties to be observed, prior to and after terracette formation. This would facilitate the observation of new terracettes within the landscape (if they form), which could then be related to soil physical data at the point of occurrence. Changes in the soil characteristics over a period of time would be noted and soil properties at the time of terracette formation extrapolated.

A detailed study of the role of terracettes in slope stability is required before any conclusions can be reliably drawn. This would involve a detailed study of the forces active within the soil, which in turn could be overlain with soil physical properties, shear plane occurrence and terracette morphometric data in the form of a Geographic Information System. Digital terrain maps of the microforms may aid in determining their distribution and could help in solving the problems associated with nomenclature.

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