The origin and geomorphological significance of earth mounds in the Mkhuze wetlands, KwaZulu-Natal

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Submitted as a dissertation component (which counts for 50% of the degree) in partial fulfillment of the requirements for the degree of Masters in Science in the School of Environmental Sciences, University of KwaZulu Natal

December 2009

Abstract

The study sheds light on the occurrence and development of earth mounds in the Mkhuze Wetlands, KwaZulu-Natal. It compares this system with the Okavango Delta. The conceptual model developed by Ellery and co-workers for mima mound development in the Okavango Delta is said to have worldwide applicability (Ellery *at al*. 1998). This study investigates the applicability of this model in the formation and development of earth mounds in Mkhuze Floodplain. The activities of termite species are regarded as responsible for the formation of earth mounds in the Okavango Delta.

The Mkhuze Wetlands represent one of South Africa's most pristine wetland systems (Cowan 1995). They have also been declared as part of the Isimangaliso Park, a World Heritage Site (Cowan 1995). Many studies have been conducted in Mkhuze Wetlands in order to gain more knowledge and understanding of how the system functions, so that it can be managed wisely. Although termites are thought to be associated with these features (Adams 2004), very little has been done to assess or even verify if the changes in soil chemistry and mineralogy across these mounds can be linked to termite activities.

This study investigates the soil mineralogy and physico-chemical properties across mounds found in the Mkhuze Wetlands and determines through its findings any possible link to termite activities. Most mounds in Mkhuze were identified in the intermittently flooded region of the floodplain. Results from particle size analysis were indicative of a bimodal distribution in mound soils. Two major components in mounds were a combination of clay size particles, silts and very fine sand, and fine to medium sand, with traces of coarse sand. There was a significant difference in the distribution of soil particle size fractions found on mounds compared to soils adjacent to the mounds. The chemical composition of the clay size particles found on the mounds was different when compared to that found in adjacent soils. There were also higher concentrations of minerals derived from solute chemicals found in the centre of the mounds at depth. Precipitation of solutes in mid regions of the mounds is thought to attest to spatial evapotranspiration rates across mounds. Although no direct evidence of termites was found in the mounds, there are indications that termites have been responsible for the development of the mounds and that in certain mounds plants have led to mound growth due to precipitation of solutes driven by evapotranspiration.

Preface

This dissertation represents the authors own work, unless where specifically cited and has not been submitted in part or whole to any other tertiary institution. This dissertation was carried out in the School of Environmental Sciences and School of Chemistry under supervision of Prof. A. Kindness

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Zanele Hlongwane **Date**

DECLARATION 1 - PLAGIARISM

I, Zanele Hlongwane declare that

1. The research report in this thesis, except where otherwise indicated, is my original work.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from persons.

4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

   (a) Their words have been re-written but the general information attributed to them has been referenced
   (b) Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.

5. This thesis does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed…………………………………………….

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Acknowledgements

I'd like to thank my Heavenly Father for providing me with an opportunity to study and learn and for blessing me with the courage to remain steadfast in my goals. I also like to give special thanks to the following:

1) Prof Kindness my supervisor, for all the help and guidance
2) Prof Ellery, Kirsten Barnes, Dr Twala, Caroline Reid and all who offered their professional help
3) My Mother Gcinaphi and my family for their love and support
4) My friends at church, for their many words of courage and for being good to me
5) My colleagues, for many favours they allowed for me at work, to complete this study
6) Last but not least, to my husband Mpika, whom I'm traditionally married to. Looking forward to our white wedding and our future.

CHAPTER ONE: INTRODUCTION

1.1 Introduction

The Greater Mkhuze Wetland System is a diverse and dynamic ecosystem found on the coastal plain of northern KwaZulu-Natal, South Africa. The occurrence of evenly spaced earth mounds forms an interesting characteristic feature of this wetland. An earth mound is a heap formed by layers of soil and usually has the shape of a broad cone. Earth mounds do not appear randomly placed in this region but seem to occur in distinct areas. They do not occur in wet soils nearby flowing streams, pans or open water bodies, and neither do they occur in well aerated soils with high primary productivity. This study intends to investigate and shed light on the occurrence of earth mounds in the Mkhuze floodplain.

The origin of earth mounds is still a debatable issue worldwide since differing theories have been developed in different parts of the world. Existing theories include processes of zoogenic activity by vertebrates and invertebrates (Cox 1984; Cox and Gakahu 1985), periglacial phenomena (Embelton and King 1975) and geomorphological processes (Aten and Bollich 1988). Pocket gophers have been considered primarily responsible for mound formations in western North America (Cox 1984), whilst other fossorial rodents such as mole rats have been linked to mound formations in Western Cape, South Africa (Cox and Gakahu 1985). Termites have been considered responsible for earth mound formations in most parts of Africa such as Zambia, Malawi (Harris 1971), Kenya (Darlington 1985; Martin 1988) and South Africa (Moore and Picker 1991). Differential erosion/ sedimentation and termite activities are considered responsible for earth mounds formations in the Pantanal do Manto Grosso tropical wetland system in Brasil (Ponce and Cuhna 1993). This dissertation considers termites to be primarily responsible for mound formation in the Mkhuze Wetlands, but also acknowledges that other existing theories may contribute to mound formation in this area.

About 40 to 60% of the total soil macrofauna biomass in most tropical ecosystems is accounted for by termite species (Dangerfield *et al.* 1998). Of the three thousand known species of termites, 75% are classified as soil-feeding (Kaschuk *et al.* 2006).

The activities of termite species and their pronounced effects in soil have captured the attention of many researchers around the globe. Through bioturbation and construction of networks of foraging galleries underground, termites can bring about major changes in the soil physico-chemical properties (Dangerfield *et al.* 1998). Because of their effects in soil, termites are also referred to as *ecosystem engineers*. By definition, ecosystem engineering is a process whereby an organism directly or indirectly controls the availability of resources for other organisms within its surroundings (Dangerfield *et al.* 1998). Organisms responsible for bringing about change in the distribution of natural resources are known as *ecosystem engineers.* Ecosystem engineering has been viewed and considered as one of the important processes that naturally drives the storage, redistribution and transformation of resources within ecosystems (Dangerfield *et al.* 1998, Deocampo 2002). This process has helped provide a better understanding on how nutrient redistribution impacts on changes within ecosystems (Dangerfield *et al.* 1998, Ellery *et al*. 1998, Deocampo 2002).

The majority of studies carried out on earth mounds which were associated with termites (Miedem and Van Vuure 1977; Kaschuk *et al.* 2006; Jouquet *et al.* 2005) reveal somewhat common characteristics. The most noted of these characteristics include:

(i) Increased clay and organic matter contents on mounds when compared to adjacent soils, and
(ii) An abundance of fine sandy material on mound subsoils.

Earth mounds are commonly differentiated and referred to differently on the basis of their size and how they are suspected to have come about. Earth mounds which are associated with termites are generally referred to as termite mounds. *Murundus* is a commonly used name for earth mounds of small to medium sizes in Brasil, whilst the very large earth mounds of more than hundred metres are commonly referred to as *Capões* (Ponce and Cunha, 1993). Mima mound is another commonly used term which refers to very large earth mounds. A study carried out in the Okavango Delta, Botswana, by Ellery and co-workers (1998) acknowledged that the creation and growth of mounds is as a result of a combination of processes. However, termite activities seemed to have played an important role in the initial creation of a topographic relief free of flooding above the water table. Spatial evapotranspiration by woody plants was seen as an important vegetation process that led to mound growth (Ellery *et al*. 1998). Spatial evapotranspiration by woody plants leads to precipitation of solutes in the subsoils of mound sites. Furthermore, the accumulation of precipitated solutes in the soil profile led to soil volume increase and eventually to expansion of mound features (Ellery *et al*. 1998). Mound structures in the Okavango study are referred to as islands because of their vastness and occurrence in the midst of the delta.

1.2 Relevance of the study

The Mkhuze Wetlands System is one of South Africa's largest and most pristine wetland systems occupying an area of about 45 000 hectares (Stormans 1987). It consists of a diverse range of wetlands, from seasonally flooded to permanently flooded and riparian floodplains (Stormans 1987). The hydrological importance of this wetland and the socio-economic benefits it provides to the local community have attracted researchers from different fields of study in order to understand its functioning so as to manage it wisely. The Mkhuze Wetland supplies a significant input of freshwater (~ 56% annually) to Lake St. Lucia which is a World Heritage Site (van Heerden 1986; Cowan 1995). The Mkhuze Wetland has also been declared as part of the Isimangaliso Wetland Park and thus it is subject to very stringent controls.

Many studies have been performed in this area but not much has been done to investigate the significance of earth mounds and their possible impacts in the wetland ecosystem. Although termites are thought to be associated with these features (Adams 2004), very little has been done to assess or even verify if the changes in soil chemistry and mineralogy across these mounds can be linked to termite activities.

Like all African wetlands the Mkhuze wetland is different from the wetlands of other countries, especially from those found in the northern hemisphere (Garden 2007). The origin and evolution of wetlands in Africa is thought to be different mainly because;

(i) The African continent is high in relative elevation when compared to the other countries.
(ii) The last glaciation period is thought to have not had a significant effect on the origin of wetlands in the continent.
(iii) African wetlands do not heavily rely on precipitation for water balance.
(iv) The country experiences hot climatic conditions.

According to the western developed theories for the origin of wetlands, South Africa should have no wetlands at all, because the country is semi-arid and has a negative water balance when comparing the amount of precipitate it receives to the rate of evatranspiration. The ratio of evapotranspiration to precipitation in the country is 3:1. Wetlands in the country mainly occur in the drainage networks of large rivers (Garden 2007). The environmental settings of the Okavango Delta are considered comparable to those found in the Mkhuze wetland. It is because of these reasons that the study draws heavily from the study carried out in the Okavango Delta, Botswana

1.3.1 Research problem and aim

This study intends to investigate the soil mineralogy and physicochemical properties across mounds in the Mkhuze Wetlands and determine through its findings any possible link to termite activities.

1.3.2 Objectives

- Determine the variation in soil chemistry, organic matter and particle size distribution across mounds in the Mkhuze Wetland,

- Explain the observed variation in soil chemistry, organic matter and particle size distribution across mounds, and

- Confirm whether the conceptual model for the formation and development of islands in the Okavango is applicable to mound formations and development in the Mkhuze Wetland, KwaZulu-Natal.

Furthermore, the study intends to compare its findings to existing knowledge and hypotheses on how termite activities impact on soil mineralogy and physicochemical properties at a small scale and briefly view at a large spatial scale how termite activities impact on changes in landscapes and vegetation development in ecosystems.

CHAPTER TWO: STUDY AREA

2.1 Introduction

The Mkhuze Wetland System occupies an area of about 45 000 hectares on the coastal plain of Maputaland east of the Lebombo Mountains in KwaZulu-Natal (Figure 2.1). It consists of a diverse range of wetland types from seasonally flooded to permanently flooded wetlands and riparian floodplains to groundwater-fed pans. The Mkhuze River channel and floodplain are the most active components of this wetland system, occupying a drowned paleo valley (McCarthy and Hancox 2000). Climate, hydrology, sea level fluctuations, geology, vegetation and human interventions strongly affect the functioning of the Mkhuze Wetlands and its floodplain.

2.2 Origin and geology of Mkhuze Wetlands

The formation of the Mkhuze Wetlands System began thousands of years ago (Van Heerden 1986; Stormanns 1987; McCarthy and Hancox 2000). Its origin was as a consequence of a number of interrelated processes, of which major Gondwanaland rifting coupled with Pleistocene sea-level changes were main controlling factors (Watkeys *et al*. 1993).

About 450 million years ago major rifting commenced along the southern Cape and extended north-eastwards towards KwaZulu-Natal (Watkeys *et al.* 1993). This consequently led to a break-up of Gondwanaland from southern Africa (Watkeys *et al* 1993; Ellery *et al*. 2006). Major volcanic eruptions and rock deposition occurred throughout this phase. Afterwards, oceanic crust formed beneath central Mozambique. "*Interior sediment erosion of this crust began to accumulate in a newly formed oceanic basin and as a consequence spread and formed the coastal plain of KwaZulu-Natal"* (Ellery *et al.* 2006, p 10). The most predominant sediments underlying the coastal plain are Cretaceous to Paleocene-aged sediments (Watkeys *et al* 1993).

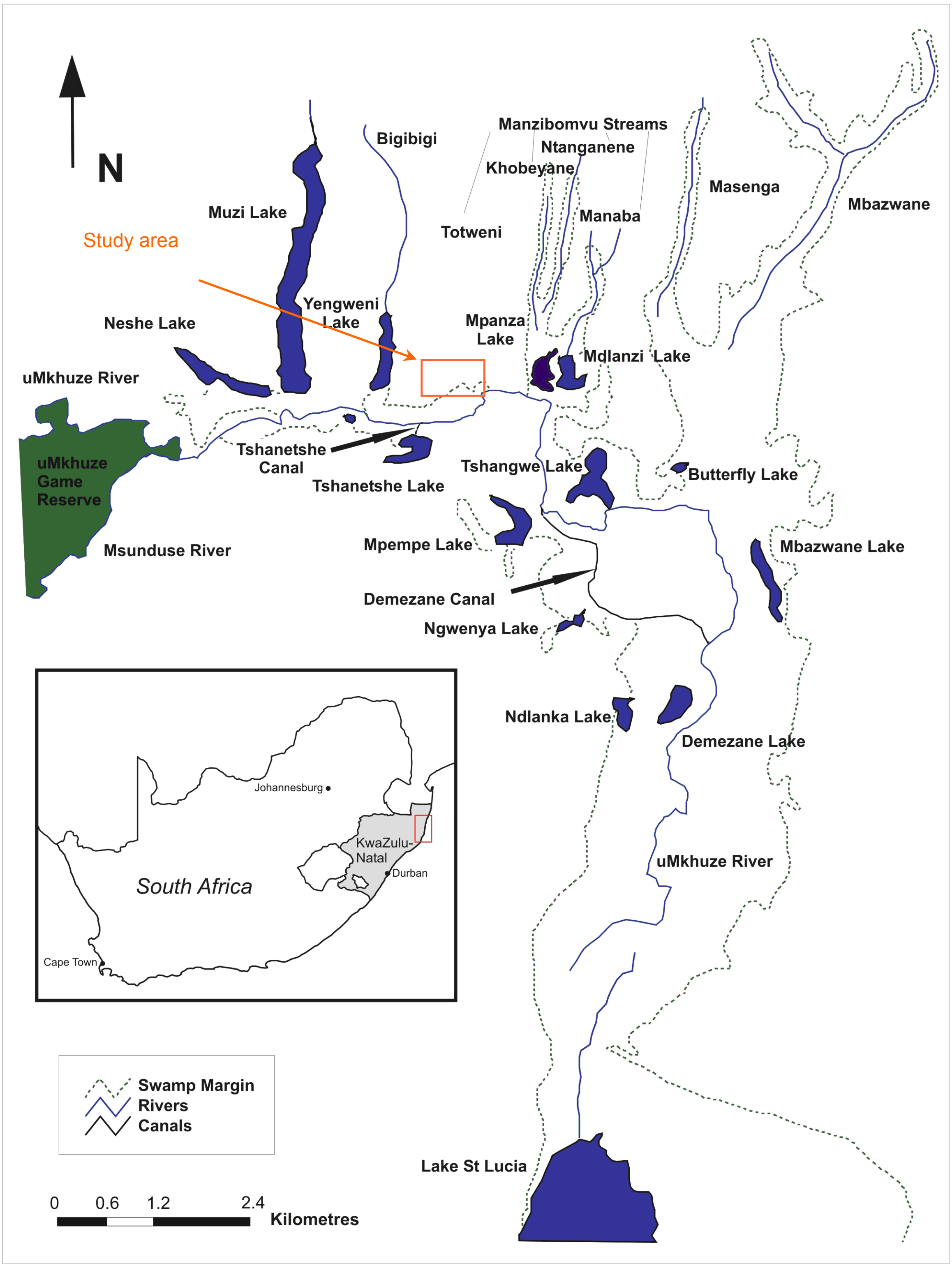


Figure 2.1 Location of the study area (inset) and the main physiographic feature of the Mkhuze floodplain (main figure)

During the Paleocene and Cretaceous periods the sea covered all of Maputuland coastal region and reached the Lebombo Mountain Range (Stormanns. 1987). This means that the Mkhuze coastal plain was once a sea bottom. It is speculated that, following this era, sea level fluctuated markedly and that *"sea-level stood 120m below present about 18 000 years before present (B.P) and 3m above present 5 000 years ago"* (Van Heerden 1986, p 5). Following the period of great fluctuations in the sea level was the Pleistocene period of lowered sea levels. It was during the Pleistocene that paleo-valley incisions took place in the Mkhuze Wetlands forming deep geomorphic basins (McCarthy and Hancox 2000). When the sea level rose after the last inter-glacial period, it drowned and inundated the paleo-river valleys.

2.3 Hydrogeology

The Mkhuze River is 290km in length and occupies a drainage basin of 4820 km^2 (Stormanns 1987). The river flows from east of Vryheid through the Lebombo Mountains and cuts across the coastal plain into Isimangaliso Wetland Park. The mean annual flow of Mkhuze River is between 211 and 326 x 10^6 m^3 (Barnes *et al.* 2002). From its headwaters to Simangaliso Wetland Park the river transports and deposits sedimentary strata of the Ecca, Dwyka Groups of the Karoo Supergroup and Pongola granites and rhyolites in the Lebombo Mountains (McCarthy and Hancox 2000).

Waters of the Mkhuze River have electrical conductivities which range between 0.3 and 3.2 dS/m (Stormanns 1987). Of the sediments carried by the Mkhuze River, suspended sediments form a big portion (McCarthy and Hancox 2000). Suspended sediments mainly consist of fine clays, predominantly kaolinitic clays derived from Pongola granites and Karoo sedimentary rocks (McCarthy and Hancox 2000). On average the discharge the Mkhuze River is said to contribute in excess of 50 kg per second of sediments into lower Mkhuze floodplain (McCarthy and Hancox 2000). Deposition and aggradation of sediment on the floodplain is continuous and contributes to continuous formation of new levees and channel switching. Pans may subsequently form on the floodplain as a result of high levee formations. Sediment deposition on the Mkhuze floodplain is viewed as an important source for fine material and clays which are critical for mound construction.

Figure 2.1 shows the map of the Greater Mkhuze Wetland System. There are four defined reaches of Mkhuze River between the Lebombo Mountains and the sea. These are:

(a) The upper reach (gorge to Yengweni pan)
(b) The delta (between Yengweni and Tshangwe pans)
(c) The Mkhuze swamps
(d) Lake St. Lucia

East and south of the Neshe pan the Mkhuze meanders across a 2 km wide floodplain and cuts across an interdune break, orientated in north-south position. The channel is a few meters wide and 2 m deep (McCarthy and Hancox 2000). In the upper reach, from Neshe pan to Mpanza pan, the channel is straight and wide with high levees. From this reach to Tshangwe the channel becomes highly sinuous and narrower. On the third reach of the Mkhuze swamps, the channel becomes straight again, but is shallow and indistinct.

There are two recent canal excavations along the Mkhuze River which have negatively impacted on the hydrologic regime of the Mkhuze Wetland System. They are the Mpempe-Demazane and Tshanetshe canals. The Tshanetshe canal was excavated in the late 1960s by The Natal Provincial Administration Reclamation Unit to enhance water flow into Lake St Lucia (Barnes *et al.* 2000). The Mpempe canal was excavated by a private landowner so as to supply permanent surface water for livestock (Barnes *et al.* 2000). The reduction in river flow brought by the two excavations along the Mkhuze River is estimated to be about 80% when compared to the former Mkhuze channel (Goodman 1987). Mpempe-Demazane was excavated over a distance of 13.5 km, and Tshanetshe over about 100 m (Ellery *et al.* 2002). These excavations have resulted in erosion and diversion of channel flow (Ellery *et al.* 2002). Although small, the excavation of the Tshanetshe canal caused more damage than Mpempe-Demazane, and has caused major erosion over a distance of about 4 km (Ellery *et al.* 2002).

2.4 Climatic conditions and vegetation

The Maputaland region has moist sub-tropical climatic conditions along the coast and dry sub-tropical inland (Watkeys *et al*. 1993). The Mkhuze Wetlands have hot wet summers and cool dry winters with mean annual temperature lows of 21 ^{o}C and highs of 23 ^{o}C (Watkeys *et al*. 1993). There is a rainfall gradient between the coast-line and the inland which has contributed to the development of impermeable horizons in the soil profile and the formation of networks of seepage-lines and wetlands (Watkeys *et al*. 1993). The annual rainfall at the coast averages between 1000 and 1100 mm and 600 mm inland (McCarthy and Hancox 2000). Reported humidities peak at 97.9% in the wet months and at 91.8% in the dry winter months (Watkeys *et al*. 1993).

The Mkhuze Wetland System is located in a vegetation type known as Coastal Bushveld-Grassland (Barnes *et al*. 2000). It consists of forest patches within a matrix of grassland and open savannas. Plant communities found in the Mkhuze Wetlands include hygrophilous grassland, sedge marsh, reed and sedge swamp, floodplain forest, riparian forest and palmveld (Stormanns 1987).

2.5 Earth mounds in the Mkhuze floodplain

An aerial photograph of the study site in the Mkhuze floodplain is shown in Figure 2.2. The study site was demarcated based on differences in hydrology regime and characteristic vegetation from floodplain to underlying coastal plain. Table 3.1 gives definitions of different and characteristic hydrological regimes or hydroperiods. Of the twenty-six mounds identified, twenty-three were identified within the intermittently flooded area, whilst the other three were found along the boundaries of terrestrial forest and intermittently flooded marsh.

A field survey on the ground revealed that mounds were of different sizes. Mound heights ranged between 1.0 and 1.6 m for most mounds. The colonization of mounds by vegetation varied from one mound to the other. Some mounds were completely barren whilst others had vegetation, normally grass.

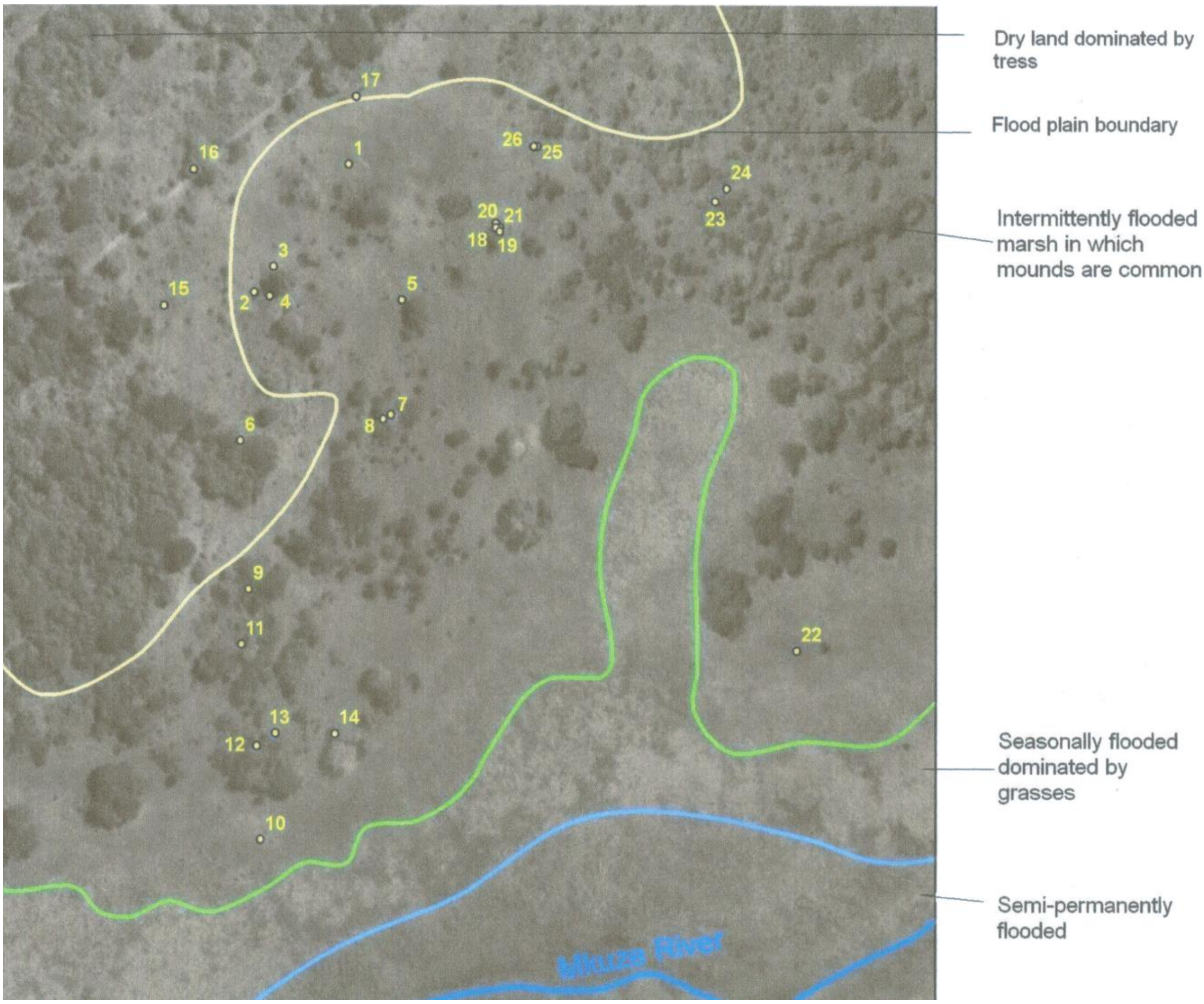


Figure 2.2 Aerial photograph showing local features of the study site and location of earth mounds

Figure 2.3 shows a photograph of one of the earth mounds in the Mkhuze floodplain. The mound looks small in the midst of grassy location and does not have vegetation on its surface.

Figure 2.3 Photograph of one of the earth mounds in the Mkhuze flood plain

CHAPTER THREE: LITERATURE REVIEW

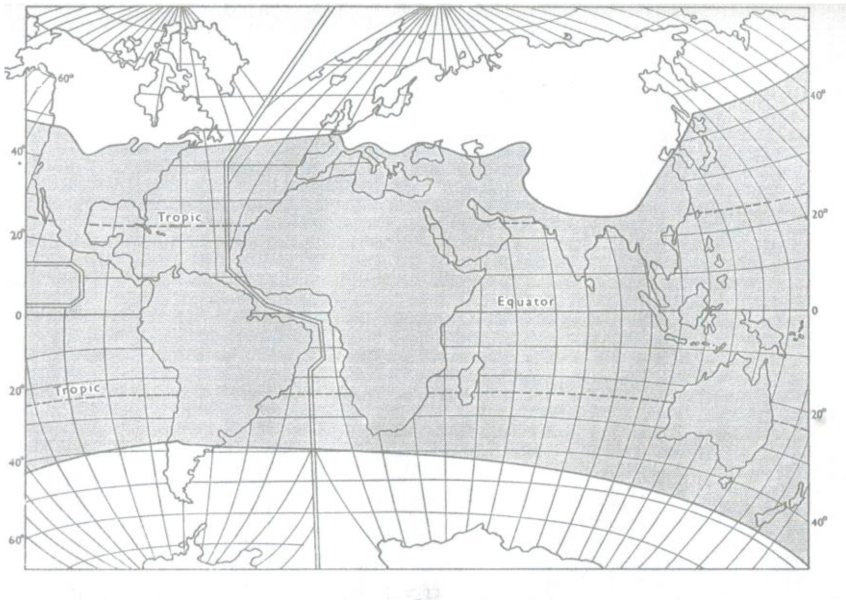
3.1 Introduction

This section will highlight the link between termites and earth mounds. It will confirm that termite activities in the soil can sometimes lead to the creation of an elevated topography or mound in the shape of a broad cone. Furthermore, it will explain that mound creation and growth is a consequence of a number of processes amongst which; termite activities are regarded as primary initiators.

3.2 Geographic distribution of termites

Termite activities generally lead to formation of earth mounds. Earth mounds occur in different regions of the world (Harris 1971). Available reports include cathedral and umbrella shaped mounds formed by the *Cubitermes species* and *Macrotermes species* respectively in Nigeria (Asawalan and Johnson, 2007), earth mounds formed by ants and termites in the wetlands of Santo Antonio Da Patrulha, Brasil, (Diehl *et al*. 2005). Other reports on the occurrence of earth mounds include cylindrical mounds reaching heights of three meters on the savannas of South America; wedge shaped mounds reaching heights of four meters in Darwin areas of Northern Territory in Australia; and very large earth mounds in a wide belt across tropical south of the Congo rainforest in Africa (Harris 1971).

Figure 3.1 shows the areas across the tropics and subtropics where f termite species occur and where termite mounds can be expected. The diversity of termite species is greatest in tropical rainforests (Harris 1971). However, their activities are generally noted in deciduous woodlands and in areas where man has grown crops, because they usually feed on wood (Harris 1971). Termites are primarily categorized according to their feeding behaviour. The commonly used groupings are subterranean soil-feeding, dry wood, damp wood and grass-eating.



World distribution of termites

Figure 3.1 Worldwide geographic areas in the tropics where termites occur (Harris 1971)

The number and types of termites species drops faster outside tropics where land elevation leads to low minimum temperatures (Harris 1971). Some forms of termites can live in cold situations (Harris 1971).

3.3 Benefits of soils found on termite mounds

Asawalam and Johnson (2007) proved experimentally that modification of soil by termites leads to "*alteration of the soil mineral constituents in favour of finer particles".* Fine soil fractions provide improved water and nutrient retention properties for soil. They also noted that termite activities increased soil pH, organic matter content and exchangeable cations. In terms of crop production requirements, termite-modified soils would have a favourable pH for crop growth.

Clays derived from termite mounds exhibit extraordinary properties when compared to ordinary clays (Mijinyawa *et al.* 2007). Termite-mound clays possess special properties. They have increased plasticity and can retain permanent shapes after moulding. Termite-mound clays are less prone to crack; they have low thermal properties and are thus good in regulating temperature fluctuations (Mijinyawa *et al.* 2007). Since termite-derived clays have such good properties they have found favour in a number of applications. Mound soils are traditionally used in pottery making. Termite-mound clays have also been found to perform better than ordinary clays in dam construction (Yohanna *et al.* 2003). Termite clays were generally used as a flooring agent together with cow dung in order to regulate heat in traditional African houses. Termite clays outweigh other materials such as wood, rubber and metals in grain silo construction (Mijinyawa *et al.* 2007). Silos made from clays taken from termite mounds show good thermoregulatory properties; they are resistant to penetration by liquids and are good in maintaining grain quality under storage (Mijinyawa *et al.* 2007).

3.4 Termite mounds in wetlands

Most available studies which investigated the impact of termite activities were conducted in savannas, natural grassland and forest regions. However, there was little available information on development of earth mounds in wetlands (Ellery *et al*. 1998; Ponce *et al*. 1993; Diehl *et al.* 2005). These studies were used as the background to this project. Generally, the occurrence of earth mounds is most common in areas with a high water table, hard basement layer and impeded drainage systems (Ellery *et al.* 1998). Wetlands, which are areas of prolonged water saturation and impeded drainage, are thought to be susceptible to earth mound formation. However, not all wetlands have earth mounds. There are vital factors which have been noted to interact and contribute to mound formations. The most significant factors that Harris (1971) considers important for mound formations are climatic conditions, presence of ecosystem engineers and favourable soil conditions. The following factors predict the occurrence of earth mounds in wetlands found in the tropics and subtropics.

(i) Fifty-six percent of the world's wetlands are found in the tropical and subtropical regions (Alho 2005).

(ii) The highest density and diversity of termite species are found in the tropics and subtropics (Harris 1971).

The Mkhuze Wetland is in a subtropical region and is likely to be a habitat to termite species. Earth mounds in the Mkhuze Wetland are only dominant in the Mkhuze floodplain. This indicates that flooding regime and therefore soil moisture content and soil properties are possibly critical to mound formation in this area. Figure 2.2 in chapter 2 shows through a demarcated aerial photograph the spatial variations in soil flooding from Mkhuze River through the floodplain to the underlying coastal plain. The photograph shows that earth mounds are dominant in areas of intermittent flooding. Table 3.1 gives definitions of different flooding regimes that can be found in wetlands.

Table 3.1 Definitions of different hydroperiods (Mitsch and Gosselink 2000).

Permanently flooded	*get inundated all year-round in all years*
Intermittently flooded	*surface usually exposed and surface water present for variable periods without detectable seasonal pattern*
Semi-permanently flooded	*flooded which are wetlands that get flooded in the growing season in most years*
Seasonally flooded	*get inundated for extended periods in the growing season with usually no water by end of growing season*
Saturated wetlands	*where substrate is saturated for extended periods, but standing water is seldom present*
Temporally flooded	*get flooded for brief periods in the growing season, but otherwise the water is well below the surface*

3.4.1 General description of wetlands

Wetlands are generally defined as interfaces between the upland terrestrial and deep water aquatic ecosystems. They form boundaries between the two ecosystems and hence share a mixed composition and characteristics of both. Wetlands are also referred to as *transitional* ecosystems because of their spatial location between the two different ecosystems. They are also transitional in terms of the amount of water they store and process, since they are neither ‘dry’ as terrestrial land nor ‘wet’ as the aquatic ecosystems (Mitsch and Gosselink 1993).

Wetlands are usually characterized by a high water table at or near the land surface, or by shallow and prolonged water saturation periods. Prolonged water saturation periods in wetlands create anaerobic soil conditions. Wetland soils are thus unique and are referred to as *hydric soils* (Mitsch and Gosselink 1993). *Hydric soils* are divided into mineral hydric soils and organic hydric soils (Mitsch and Gosselink 1993). The physico-chemical properties of hydric soils determine what vegetation species or microbes will occur. Plants which successfully adapt under anaerobic soil conditions in wetlands are referred to as *hydrophytes* (Mitsch and Gosselink 1993).

Wetlands differ in the amount of water they store and process. The amount of water a wetland stores and processes determines to a large extent the function, character and productivity of a wetland (Mitsch and Gosselink 1993). The seasonal pattern of water level in a wetland is called *wetland hydroperiod* and it gives a summation of integrated water inflows and outflows of a wetland (Mitsch and Gosselink 1993). Figure 3.2 shows by arrows the components which add to or reduce a wetland’s hydroperiod. These components define change in water storage per time unit.

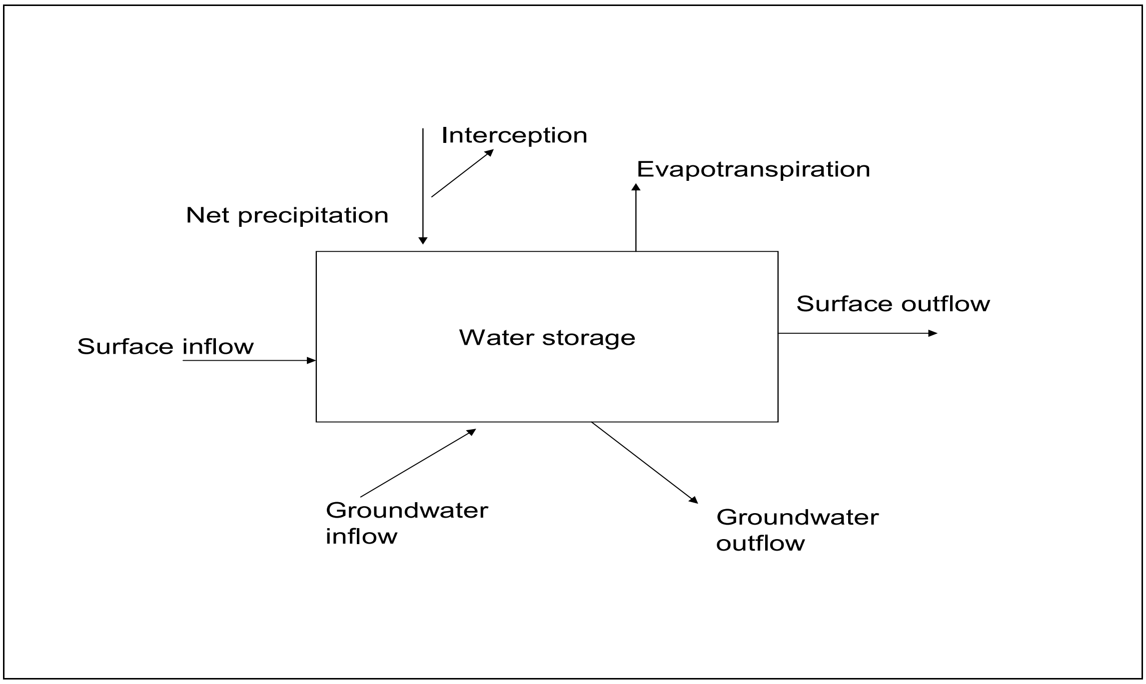


Figure 3.2 Generalized water budget of a wetland (Mitsch and Gosselink 2000)

3.4.2 Interrelated feedback mechanisms within wetlands

The three most important components that determine wetland establishment and maintenance are hydrology, climate and basin geomorphology. When considered as a single unit the three are collectively referred to as hydrogeomorphology (Mitsch and Gosselink 2000). "*Hydrology is viewed as the single most important determinant of the establishment of wetlands and maintenance of specific types of wetlands and wetland processes"* (Mitsch and Gosselink 2000, p108). Mound formation is regarded as a feedback mechanism that is a consequence of interrelated factors which are mainly influenced by hydrology.

Figure 3.3 below shows a simplified diagram illustrating the far-reaching effects of hydrogeomorphology in wetlands. Basically, it shows that the duration of water in wetlands is dependant on basin geomorphology and climate, and that hydrology has the capability to alter soil physical and chemical properties and thereby determine or influence what vegetation, micro-organisms and animal species would flourish the wetland environment. In the context of this study, hydrogeomorphology could possibly explain better how termites are distributed in the Mkhuze Wetland and how termites influence soil properties, hydrology and basin physiography.

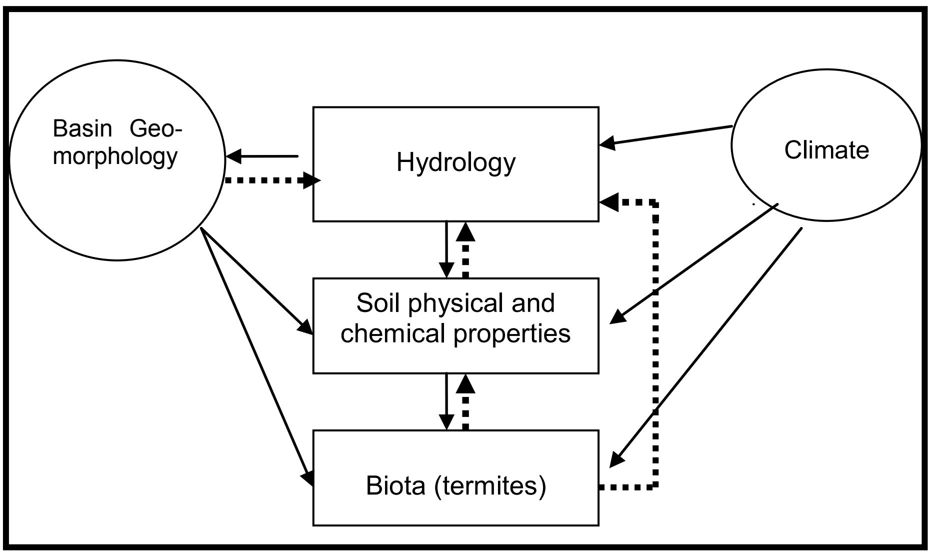


Figure 3.3 Feedback mechanisms in wetlands (Mitsch and Gosselink 1993)

The reason why termite mounds occur predominantly in certain areas and are absent in other areas in the Mkhuze Wetland is believed to be associated not only with, spatial variations in hydrology regime across the floodplain but more with the influence that hydrology has on soil chemical and physical properties.

Hydrology has far-reaching effects on the concentrations and availability of organic matter, nutrients and other chemicals in soil. Soil pH, alkalinity and oxygen-related chemical processes become modified as oxygen availability decreases in soils, or as water saturate the soil (Mitsch and Gosselink 2000). The availability of electron donors which facilitate organic matter decomposition such as oxygen (in aerobic soils), or nitrates and sulfates (in anaerobic soils) is influenced by hydrological conditions of a wetland (Mitsch and Gosselink 2000). The segregation of vegetation into communities in wetlands marks discontinuity in soil physico-chemical properties and spatial changes in hydrological regime. Wetlands are dynamic ecosystems and small changes in hydroperiod may bring about massive changes in a wetland's overall productivity (Mitsch and Gosselink 2000).

3.5 Termites as ecosystems engineers

Termite species are known to collect and carry with their mandibles desired soil particles, particularly clays or soil particles with cohesive properties, to a central foraging location where they drop the particle, and then using their saliva or faeces form paste and cement the particle on sand grains (Harris 1971; Jouquet *et al.* 2005; Ellery *et al*. 1998). The prime reason for this activity particularly by the *genus Macrotermes* is thought to be for the creation of a habitat free of flooding (Ellery *et al*. 1998; Dangerfield *et al.* 1998). Fungus-growing termites are known to construct networks of foraging tunnels underground using soil. These foraging tunnels sometimes rise above the surface of the ground as layers of soil, forming a turret or mound sphere looks like a broad cone. Erosion of a turret by wind and rain forms a pediment which gives the round shape to mound (Ellery *et al.* 1998). Figure 3.4 below shows a schematic cross-section of a termitarium consisting of a fungus garden, a basement complex and foraging passages.

The selection and relocation of desired soil particles by termites eventually impact on soil composition and on the distribution of nutrients and minerals in soil. This leads to the creation of an environment in which nutrients are distributed differently than they would if termites were absent in the environment. Termite activities therefore alter the composition of soil particle size distributions and soil texture (Harris 1971; Jouquet *et al.* 2005; Ellery *et al*. 1998). In turn, soil texture influences oxygen and water diffusion in soil and ultimately oxygen-related chemical processes within the soil (Dangerfield *et al.* 1998). An increase in the localization of soil particles by termites subsequently results in an increase in nutrients concentration on mound sites. This consequently influences the location and distribution of species within the ecosystem, particularly vegetation development (Dangerfield *et al.* 1998).

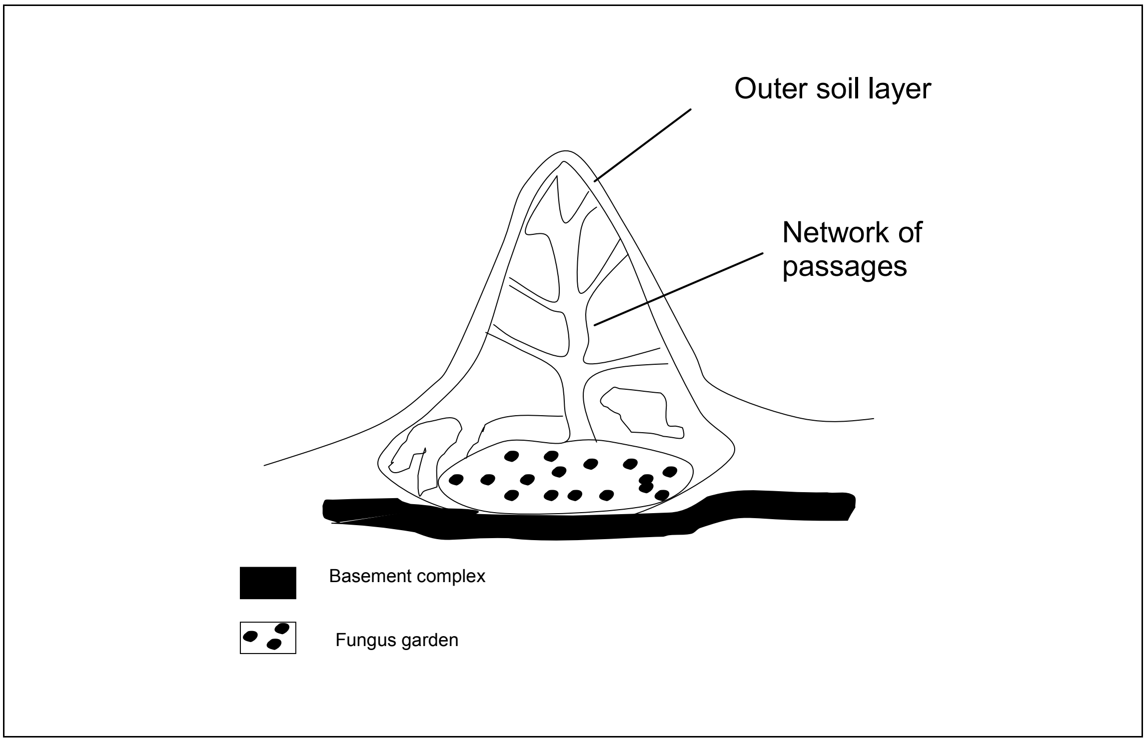


Figure 3.4 Non-scaled schematic cross-sections through termitarium (Ellery *et al*. 1998).

3.6 Geomorphologic effects of termite activities and termite mounds

The concentration of clays and organic matter on mounds improves soil fertility. Clays contain special cementing properties mainly from oxides of aluminium and iron which help bind sand material together to form stable aggregates (Giovannini and Squi 1976). In general, soil aggregation opens up pore spaces within the soil which allow for the easy passage of water and air, and hence minerals and nutrients. This helps to improve soil properties and soil fertility. Soil organic matter also helps in the formation of soil aggregates on mounds by giving more stability to the mound structure and resistance to soil erosion (Jouquet *et al*. 2005). The ratio of clay to sand on the mound seems to differ from that of adjacent soils. Most studies show that the fine sandy material of 250 µm and below is more abundant on mounds than in adjacent soils (Miedem and Van Vuure 1977; Kaschuk *et al.* 2006; Jouquet *et al.* 2005). Hesse (1955) argues that the ratio of sand to clay in adjacent subsoil is similar to that on mounds and that the reason why there seems to be high clay content on the mounds is because subsoils are used for mound construction. In general subsoils contain higher clay contents.

Clays and organic matter also represent sites for cation exchange in soil. Cation Exchange Capacity (CEC) is the capacity of the soil to exchange cations with the soil solution and is generally used to measure soil fertility and nutrient retention capacity of the soil. Any process that leads to the concentration of nutrients in any system might contribute or impact on plant distribution and composition. Because of their increased soil fertility, termite mounds can become favourable sites for plant growth (Dangerfield *et al.* 1998). But, since soil properties can serve as a limit or a stimulus for specific vegetation growth the variation in nutrient levels and mineral composition in soils across mounds subsequently results in varying vegetation species across mounds. Mound pediments also become favoured sites for vegetation development because during rainfalls nutrients and minerals on mounds are washed down to the mound pediment.

In a broader picture, the activities of termites lead to prominent changes within ecosystems. They don't only affect soils' properties but they contribute to changes in landscape physiography and vegetation distribution within systems. The differences in nutrient concentrations in the soil caused by termite activities through the redistribution and relocation of soil particles, and hence nutrients, determine and influence to a certain extent the location and type of emergent plant species in ecosystems. In fact, it is the overall composition of nutrients and minerals in soil that determine what type of vegetation the soil medium will sustain (Mitsch and Gosselink 2000). It is generally common for earth mounds to occur in groups and in evenly-spaced locations. The dispersal of earth mounds in a certain location has been linked to the manner in which termite colonies forage for resources underground. Dangerfield and co-workers (1998) have found that the lack of aggressive foraging can lead to even distribution of earth mounds of almost equal sizes. When termite mounds form, they usually occur in groups and in evenly-spaced locations. This has been found to be a result of competitive feeding and foraging for resources by separate termite colonies (Dangerfield *et al*. 1998). Adams (2004) investigated the distribution of mounds in the current study area on the Mkhuze floodplain and concluded that mounds in this area were evenly spaced.

3.7 The influence of vegetation on mound growth

The Okavango study (Ellery *et al*. 1998) which investigated the impact of termites on mound or island development, found that the establishment of vegetation on the mound pediment, particularly woody plants, plays an important role in mound growth (Ellery *et al.* 1998). Evapotranspiration, which is a process of water loss by plants, usually creates a need for water replenishment in the root zone. As more water re-collects for replenishment purposes in the root zone, more solutes are brought into the root zone. Since plants are naturally selective to what solutes they assimilate from water, solutes not assimilated during plant water uptake are rejected. Rejected solutes accumulate in the root zone and eventually precipitate out of the soil solution. This contributes to soil volume increase on mound soils, and ultimately to mound expansion (Ellery *et al.* 1998).

3.8 Sediments: An integral source of building material

The composition of hydrological inputs into wetlands determines to a large extent the wetland’s character. Nutrients and energy are major driving forces of wetland’s character and are received in wetlands mainly via water inflows. This means that the chemical composition of hydrological inflows into wetlands is critical and contributes to wetland's function and productivity. Nutrients and energy enter wetlands mainly in sediment forms. Sediments can be classified into clastic sediments, dissolved sediments and organic-form sediments (Ellery *et al.* 2005):

Clastic sediments can be subdivided into suspended sediments and bedload sediments. Suspended sediments can be represented by silt to clay-sized particles which form a suspension in the water column. Bedload sediments are larger particles ranging from, sand to boulders or anything that could be pulled from the river bed by the power of flowing water.

Dissolved sediments consist of all material dissolved in the water column. Dissolved sediments usually represent chemical solutes. Chemical solutes are subdivided into nutrients and non-nutrients. Nutrients are those dissolved solutes which usually occur in trace amounts in water and which may limit the growth of plants in rivers or streams (Ellery *et al.* 2005). An increase in the concentration of nutrient solutes in water would give an increase in primary productivity. Examples of these are nitrogen and phosphorus. The other type of dissolved sediments, called non-nutrients, may either have no effect on plant growth or they may limit primary productivity. An increase of non-nutrient solutes in water may sometimes have detrimental effects to plant growth. (Ellery *et al.* 2005). Examples of these include sodium, silica and chloride. Organic sediments are rare in rivers and are known to accumulate in low energy environments such as wetlands (Ellery *et al.* 2005). Organic sediments generally come about as a consequence of decomposition of plant litter and may enter wetlands either as fresh vegetation or in decomposed states.

Of the mentioned sediment types, clastic sediments which are constituted of clay minerals, are considered critical for mound formations (Dangerfield *et al.* 1998). Of the total dissolved solids (45000 tonnes) which enter the Okavango Delta system approximately 6% leave as surface flow and a further 10% leave as subsurface flow. The bulk remainder of about 80% accumulates within the ecosystem (Ellery *et al.* 1998). This is seen as an important depositional site for chemical sediments and an important source of material for mound construction. The Mkhuze Wetland has also been proven to be an important deposition site for clay minerals and other chemicals (Van Heerden 1986, McCarthy 2000). The Mkhuze Wetland is an important sink for silicon, sodium and clay minerals such as calcium, magnesium and potassium (Barnes *et al.* 2002). Reported data state that calcium retention is approximately 50%, potassium retention is approximately 70%, and silicon retention is approximately 80% in the Mkhuze wetlands (Barnes *et al.* 2002).

3.9 Conceptual model for mound development

A study carried out in the Okavango Delta by Ellery and co-workers acknowledged that mound creation and mound aggradation in areas with impeded drainage lines is a result of a combination of processes (Ellery *et al*. 1998). Figure 3.5 shows hypothesized relationships between factors that contribute to mound aggradation and mound size (Ellery *et al*. 1998). The role of termites in building a habitat free of flooding is seen as a primary reason to mound formation in the Okavango Delta. This initiation process can also be brought about in other ways, such as by scroll bars deposition features (which are generally caused by grazing cattle), inverted topography caused by channel switching or by tectonic activity (Ellery *et al.*1998).

Species of *Macrotermes Michaelseni* collect and relocate to a foraging central point the desired soil particles for mound construction purposes. This activity consequently leads to the formation of a mound structure or a heap of several layers of soil. Mound structure formed from termite activity is usually relatively hard, stable and resistant to destruction by winds and rain. "*Termites are highly selective for particles, in particular for size classes that afford cohesive strength to the mound"* (Ellery *et al*. 1998, p 309). In addition termite activity influences the redistribution and availability of resources for other organisms within the system.

When created, the microhabitat free of flooding allows for woody plant development. When woody plants have been established on a microhabitat or mound feature their, importance to mound development increases whilst the contribution made by termite species becomes less important. Three factors which allow this to woody plants in the Okavango are:

(i) High atmospheric demand for water in the area
(ii) The rate or capacity of transpiration by woody plants
(iii) High solute content in groundwater

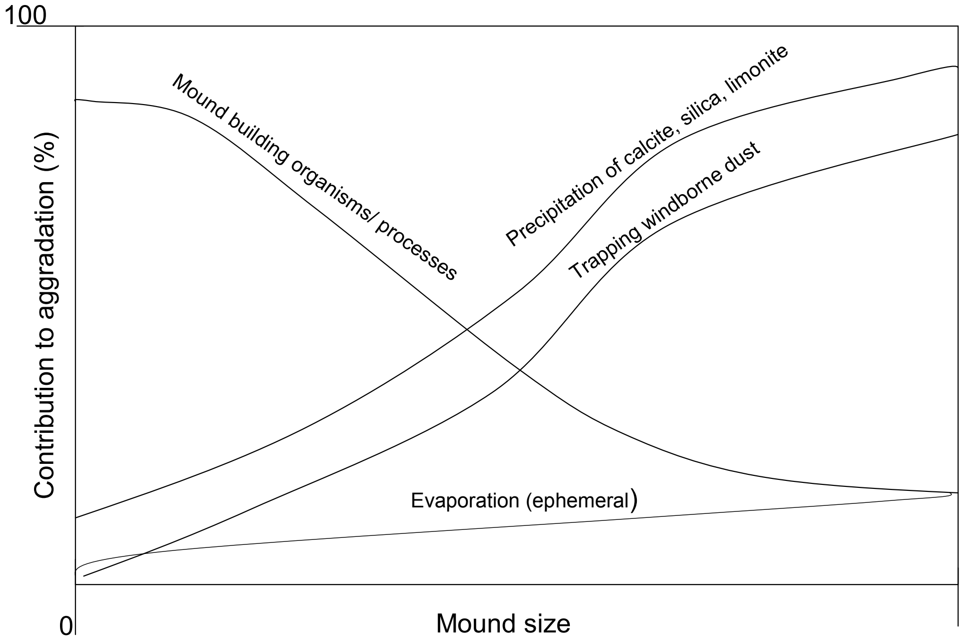


Figure 3.5 Factors that contribute to mound aggradation and mound size (Ellery *et al.* 1998)

Since plants are selective to what solutes they assimilate from the water column, solutes not assimilated are rejected and left behind in the root zone. When these rejected solutes have accumulated in the root zone, they reach a point of saturation and precipitate out of solution. Ellery *et al.* (1998) emphasizes that these precipitated solutes add to soil volume and cause mound expansion. The capability of plants to trap windborne dust also adds to mound growth. In addition, the chemistry of groundwater determines to a large extent the soil chemistry of mounds. In the Okavango Delta, calcite is the most important chemical constituent involved in mound growth. Where groundwater is different, other precipitates become important. Silica or iron oxides will produce mounds dominated by silcrete or iron laterite soils. Figure 3.6 shows the hypothesised relationships between the contribution of transpiration, mound building organisms, windborne sediments and the contribution of dissolved solutes to a wetland (Ellery *et al.* 1998).

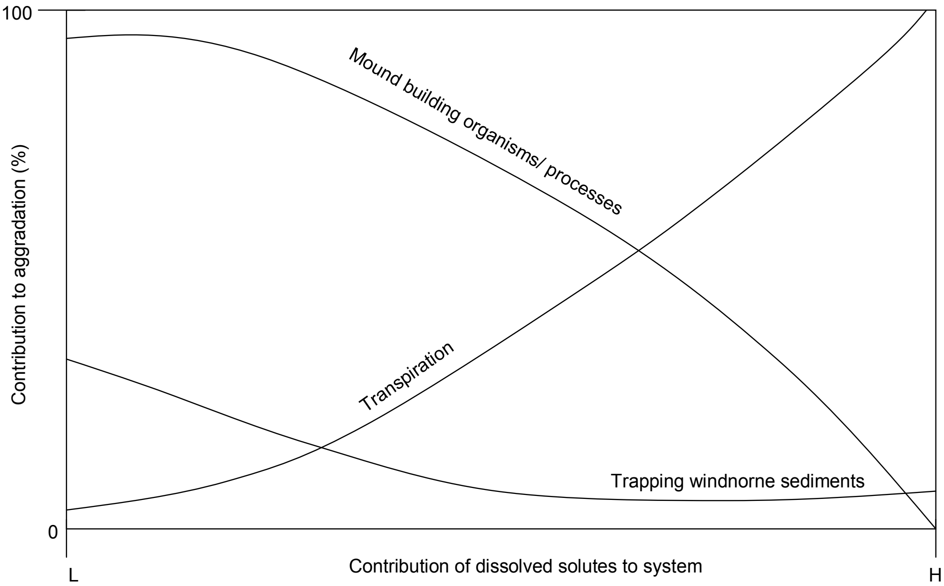


Figure 3.6 Contribution of transpiration, mound building organisms, windborne sediments and the contribution of dissolved solutes to a wetland (Ellery *et al.* 1998)

The capability of an external source or catchment to supply water that is rich in dissolved solutes has a bearing on the size of mound features that are likely to be formed. Where groundwater or surface water is rich in dissolved solutes big mounds are likely to form. In areas where rainfall is dominant, the redistribution of solutes within the system will be mainly through weathering and solution-precipitation processes. In such areas the size of mounds is predicted to be small. The developed conceptual model for mound formation and aggradation in the Okavango Delta is thought to be applicable to mound development in the Mkhuze Wetland.

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This section will outline and briefly explain the analytical test methods that were used to determine the following parameters: Soil chemistry, organic matter and particle size. Soil chemistry was obtained through the use of X-ray Fluorescence spectroscopy (XRF), Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS). Organic matter was obtained through Loss on Ignition method. Particle size was obtained through sieving, Mastersizer instrument and SEM. Findings from these tests will help to indicate and possibly confirm if the variations in soil properties across mounds are a consequence of termite activities.

4.2 Sampling of mounds and sample analysis

A clay auger was used for soil sampling. Four surface samples points were located in line across each of the four studied mounds, starting from one meter away of mound tip towards pediment base and to a measured distance off mound. Sample points were numbered starting from sample point closest to mound tip as hole 1, 2 and 3 towards the mound pediment with hole 4 located off mound. Figure 4.1 is a non-

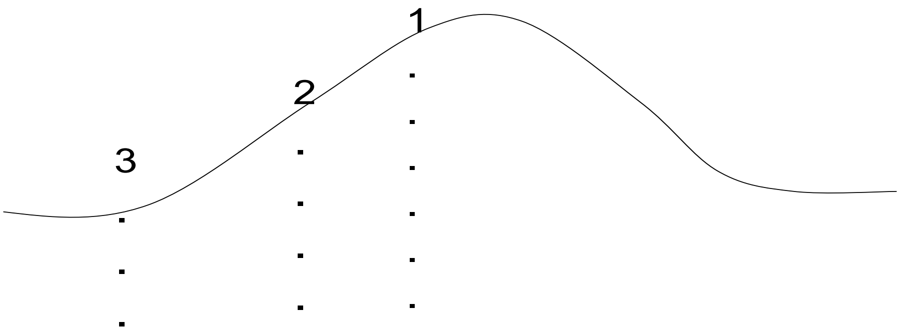


Figure 4.1 Non-scaled illustration of earth mound with intended sample location points.

Samples were taken from the surface and also at varying depths at 0.5 m intervals on each hole. Samples were then named in the following order, a sample taken on mound 2 at hole three and at interval depth of 1.5 metres would read 2 (3)1.5 m, i.e., mound number, hole number and depth.

Table 4.1 Intended sample locations on mound holes

Depth	0.5 m	1.0 m	1.5 m	2.0 m	2.5 m	3.0 m
Hole 1	x	x	x	x	x	x
Hole 2	x	x	x	x	x	
Hole 3	x	x	x	x		
Hole 4	x	x				

The intended sampling plan presented in the above table was unsuccessful in some instances because of some difficulties experienced during auguring and sample collection. Some areas on mounds contained sticky soils that were not successfully extracted with the clay auger. Soils off the mound were often too loose and sandy to abstract with an auger.

4.2.1. Soil colour analysis

A Munsell Soil Colour Chart is a book of standard colour chips used for determining colour in hydric soils. A Munsell Soil Colour chart contains a hue number on the top right-hand corner with YR units. The chart represents colour in relation to standard spectral colours such as yellow and red (Mitsch and Gosselink 2000). Value numbers on a vertical scale of the chart indicate soil lightness, while chroma values on horizontal scale indicate soil colour strength. A small fraction of soil was placed on a colour chart and moved around the colour chips until a similar match to soil matrix colour was determined. Figure 4.2 shows a Munsell Soil Colour Chart.

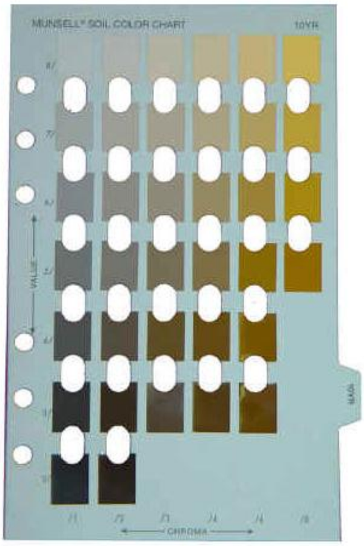


Figure 4.2 Munsell soil colour chart
http://www.prospectors.com.au/p-1925-soil-supplement-chart-10yr.aspx (5/12/2009)

4.2.2. Organic matter analysis

Organic matter content was determined in samples by use of a Loss On Ignition method. A known mass of each subsample was placed in a pre-weighed sintered glass crucible in a 105 ^{o}C preheated oven for two hours to rid the sample of impurities. From the oven, the sample was cooled in a desiccator for about 30 minutes and weighed. The sample was then placed in 550 ^{o}C muffle furnace for two hours. After two hours, each sample was cooled in a desiccator and weighed. The difference in sample mass before and after being put in a muffle furnace was calculated and recorded as percentage of organic matter loss on ignition (Schulte and Hopkins 1996).

4.2.3. Analysis of particle size distribution

Table 4.2 shows soil classification criteria by the U.S. Department of Agriculture (http://soil.gsfc.nasa.gov/pvg/mspsd1.htm 2007), which was adopted for soil characterization purposes in this study. Analysis of soil particle size distribution was carried out using sieves of different sizes. Firstly, debris and nodules were removed from samples. Each sample was gently ground using pestle and mortar. A weighed amount of sample was then put through a stack of sieves held in a shaker.

Table 4.2 Soil classification criteria by the US Department of Agriculture (http://soil.gsfc.nasa.gov/pvg/mspsd1.htm 2007)

Soil Type	Range/ mm	Range/ µm
Coarse sand	0.5 to 1.0	500 to 1000
Medium sand	0.25 to 0.5	250 to 500
Fine sand	0.1 to 0.25	100 to 250
Very fine sand	0.05 to 0.1	50 to 100
Silt	0.002 to 0.05	2 to 50
Clay	< 0.002	< 2

Samples were then allowed to pass through different micro-pore sieves for eleven minutes. The amount of soil particles collected in each sieve after sieving was weighed out, recorded and then expressed as percentage of total mass of sample taken. Sieves used were of the following micro-pore sizes; 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.053 mm. Soil particles smaller than 0.053 mm were collected in a pan.

A traditional sieve technique for soil texture analysis could not give indication of presence of clay size fractions in mound soils even when clay minerals were detected through X-ray spectroscopy. This was because the sieve sizes available did not go down to clay size and because the particles clumped together to form larger aggregates. This made difficult the confirmation of clay presence in the soil since the term ‘clay’ has both a textural and a mineralogical definition. Clay particles should be less than 2 µm in size and should be composed of minerals such as aluminium, iron, calcium, magnesium, manganese and potassium.

A more sophisticated instrument called the Malvern Mastersizer was then employed for determination of finer soil particles. The operation of the Malvern Mastersizer instrument is based on a principle of laser diffraction particle sizing. This technique involves dispersing the soil in a liquid and passing this homogenous dispersion through a coherent and intense light of a fixed wavelength coming from a laser beam. When passing through the laser beam, particles making up the sample scatter light at an angle that is directly related to their size. Large particles scatter light at narrow angles and small particles scatter light at wider angles. The intensity of scattered light is also dependant on particle size. Small particles give out low intensity light while large particles scatter light with high intensity.

A series of detectors are used to measure the light pattern produced over a wide range of angles (http://www.malvern.co.uk/LabEng/technology/laser_diffraction/particle_sizing.htm). Figure 4.3 shows a schematic diagram of the main components of a Malvern Mastersizer.

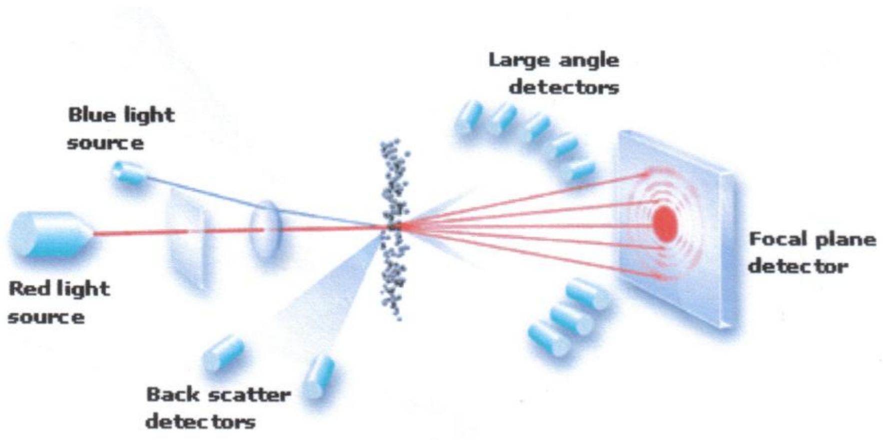


Figure 4.3 Components of a Malvern Mastersizer
(http://www.malvern.co.uk/LabEng/technology/laser_diffraction/particle_sizing.htm 2008)

4.2.4. X-ray fluorescence analysis

In order to identify the type of clay minerals present, sub-samples from mound 2 and mound 10 were taken to the X-ray laboratory in the School of Geological Sciences at University of KwaZulu-Natal where they were analysed by X-ray laboratory personnel. X-ray fluorescence theory is based on the principle that when an atom is bombarded with sufficiently high energy, an electron from one of inner orbit shells is ejected and leaves behind a vacancy in an orbit (Skoog *et al*. 1991). An electron from higher energy level then moves down to fill the vacant space. As an electron makes a transition to the vacant shell, energy is given off as fluorescent X-rays of specific wavelength (Skoog *et al.* 1991). A number of transitions can be possible at any give time. The energy spectrum obtained when energy is given off is characteristic for each element on a periodic table. A detector is used to measure lines of the spectrum and processes them out as concentration of element measured (Skoog *et al.* 1991). The intensity of energy line given out is proportional to the amount of element measured in a sample (Skoog *et al*. 1991).

A geo-statistical tool called kriging interpolation was employed to determine the variation of some chemical components across mounds. This was carried out by a technician at the Geography Information System Laboratory, University of KwaZulu-Natal.

4.3 Extraction of clay size particles from mound soils

A sampling protocol from the Environmental Restoration Project: Standard Operating Procedure for clay mineral and zeolite separation (Vaniman 2003) was employed to separate clay minerals from mound soil. The method involved frequent separation of soil particle size by ultrasound sonification. The ultrasound sonification technique enabled the dispersion of clay particles into a base material. A supernatant containing clay fractions was extracted, and then centrifuged at ~5000 RPM for about 5 minutes. The centrifuged sample was collected and placed on a hot plate to dry the collected clay fraction. Dry clay samples were then taken for electron microscope analysis at the Scanning Electron Microscope unit of University of KwaZulu-Natal. Below is the procedure that was used for clay extraction.

- 20 g of each selected sample were weighed and placed in a mill grinder for about 3 minutes to break down the sample to particle size comparable to that of its constituent phases. The grinder used was a Retsch model AS 200 Basic and was set at amplitude of 80.
- The ground sample was then palced in a beaker containing 400 ml de-ionised water.
- The beaker containing sample was placed in a 1210 Brason ultrasonic bath for about 15 minutes after which it was left to stand on a stable surface for 60 seconds to allow for the separation of quartz, feldspars and larger aggregates.

- The supernatant which contained very fine fractions was left to stand for 1 hour to settle out particles ranging from 3 - 20 μm.
- The resulting supernatant was again collected and allowed to stand overnight to settle out particles ranging from ~1 - 3 μm. Next day the sample was centrifuged at ~5000 RPM for about 5 minutes.
- The sample was then placed on a hot plate to dry the extracted clays.

4.4 Energy Dispersive X-ray Spectroscopy

An analytical technique called Energy Dispersive X-ray Spectroscopy was employed for clay mineralogy analysis. Energy dispersive X-ray spectroscopy (EDS) is a chemical microanalysis technique which is used in conjunction with a Scanning Electron Microscope (SEM). Scanning Electron Microscope can detect minute particles of less than 1 μm. Like all other spectroscopic analysis methods EDS relies on the characterization of the elemental or chemical composition of samples through interactions between electromagnetic radiation and matter. The principle of operation of EDS is similar to that of XRF except that the energy is dispersed. The EDS X-ray detector measures the number of emitted X-rays versus their energy. (Materials Evaluation and Engineering, Inc., 2009)

CHAPTER FIVE: RESULTS

5.1 Introduction

This section will present some of the results of the analyses that were carried out on soil samples. Most of the values are found in the appendices.

5.2 Soil particle size distribution

A sieve test showed that mounds in the Mkhuze Wetlands consist predominantly of silt and fine sand. It also showed that there were significant differences in the distribution of similar size fractions across mounds. Sediment fractions of 0.25 mm and 0.125 mm were more dominant in all soil samples taken from mounds. For clarity and documentation purposes, Figure 5.1 shows by way of example the colours that will be used for different size ranges of soil fractions in all samples.

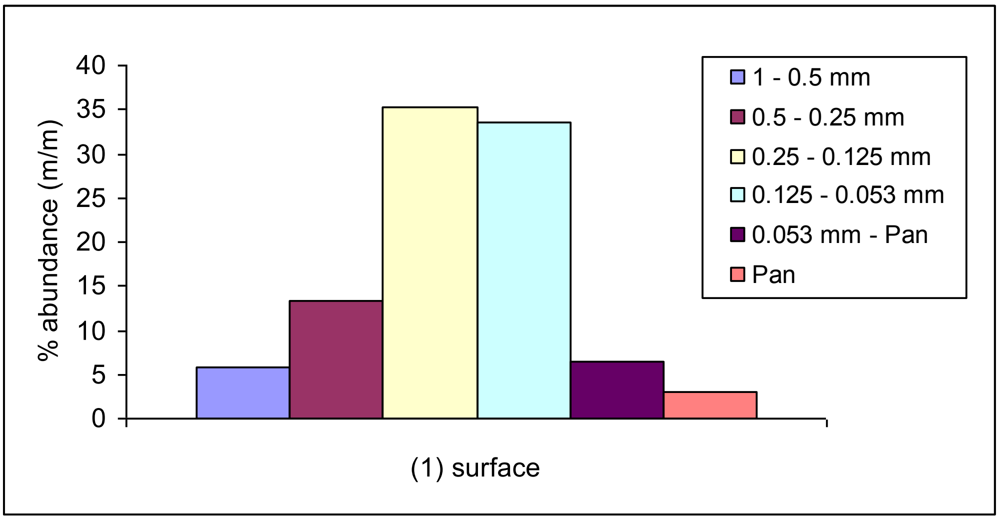
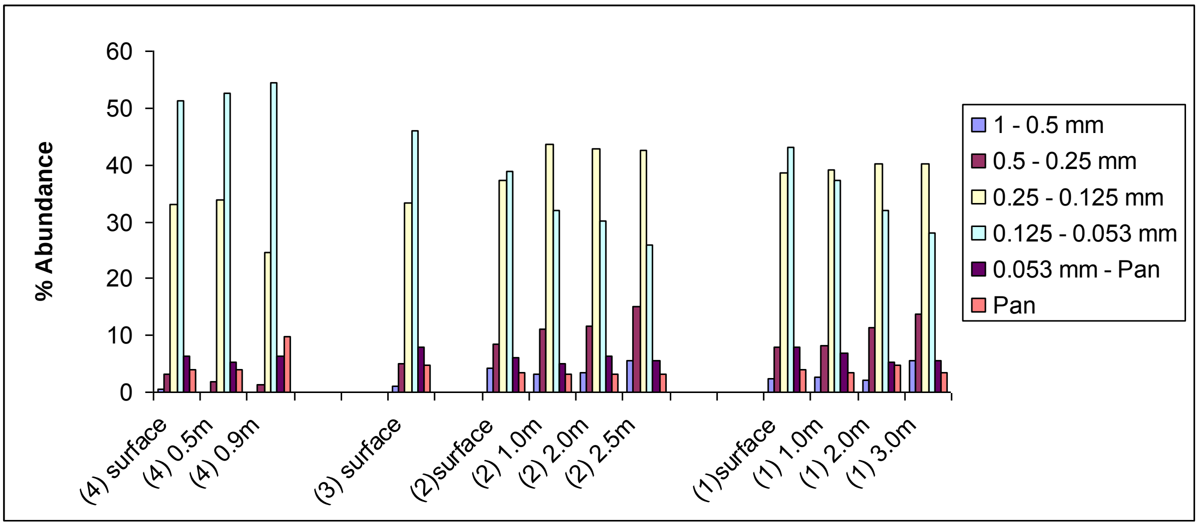


Figure 5.1 Soil size fractions contained in a surface sample of mound 2, determined by sieving.

The analysis of distributions of soil particles was carried out on four different mounds. Results obtained from all four mounds showed a fairly similar trend. However, the shortage of funds allowed for mineralogical analysis of only two mounds. Therefore most of the results and discussion will deal with these two mounds in detail.

Figure 5.2 shows the relative amounts of different size fractions of soil across the mound and topography for mound 2. Typically, mound soils were composed of about 80% of fine to very fine sand. The other 20% consisted of coarse to medium sand.



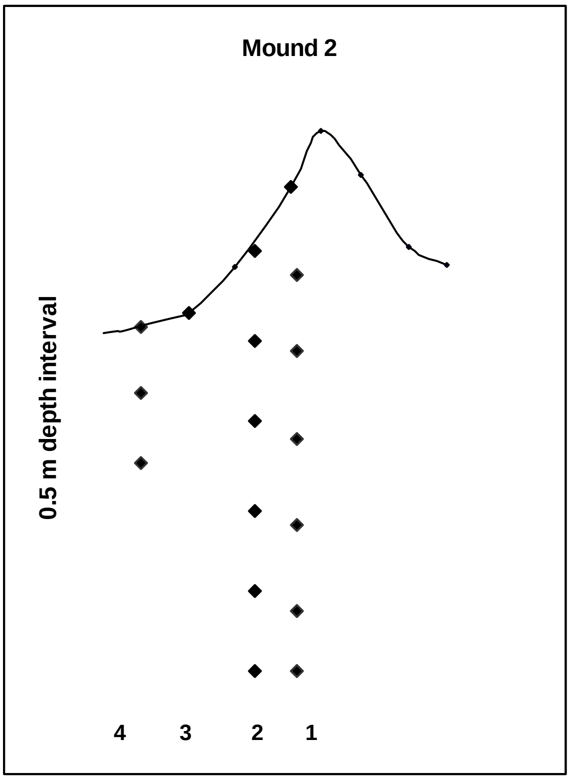
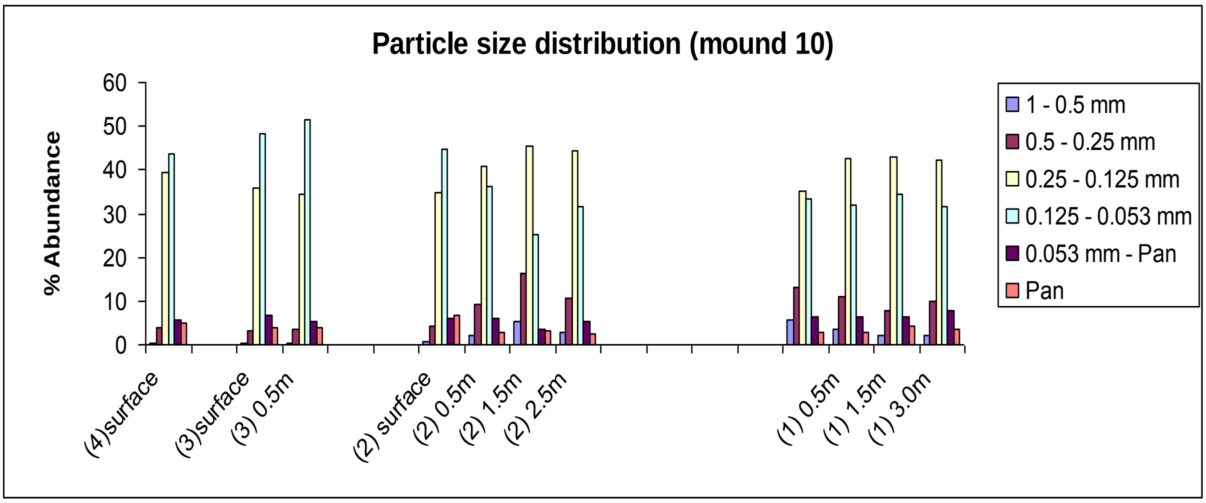


Figure 5.2 (a) Collection points across mound 2 and mound topography.

Figure 5.3 shows the relative amounts of different size particles of soil across the mound and topography for mound 10. The trends of particle size distribution in mound 2 were fairly similar to those observed in mound ten.



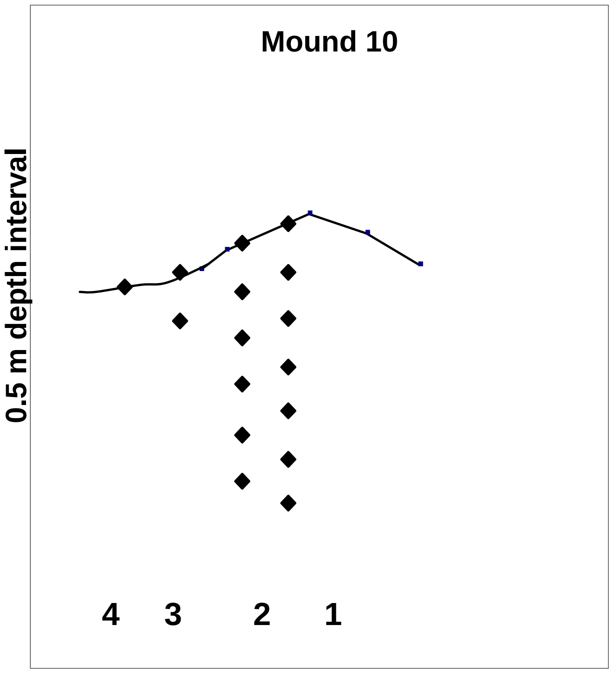


Figure 5.3 Collection points across mound 10 and mound topography.

A statistical analysis was conducted using a student's t-test (two tailed) to ascertain whether there was a significant difference in the distribution of similar size fractions across mounds. The test establishes whether there is a significance difference between two sets of data samples by comparing the values of the means and the standard deviations of separate data.

Table 5.1 and table 5.2 show the relative amounts of different size fractions of soil found at different depths in hole 1 and hole 2 of mound 2 respectively. Tables also show the mean values and standard deviations of specific range within holes.

Table 5.1 Percentage abundance of soil size fractions in hole 1 of mound 2

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
(1) 0.01 m	2.40	7.90	38.50	43.04	7.89	3.98
(1) 1.0 m	2.77	8.09	39.06	37.15	6.84	3.48
(1) 2.0 m	2.19	11.38	40.30	31.90	5.16	4.88
(1) 3.0 m	5.59	13.66	40.07	27.91	5.59	3.40
Mean ($\bar{x}$)	3.24	10.26	39.48	35.0	6.37	3.93
Std deviation	1.59	2.77	0.84	6.56	1.24	0.68

Table 5.2 Percentage abundance of soil size fractions in hole 2 of mound 2

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
(2) 0.01 m	4.36	8.33	37.19	38.91	6.00	3.31
(2) 1.0 m	3.08	11.10	43.54	32.11	5.03	3.05
(2) 2.0 m	3.31	11.71	42.89	30.23	6.23	3.29
(2) 2.5 m	5.48	15.01	42.64	25.91	5.58	3.07
Mean ($\bar{x}$)	4.05	11.54	41.56	31.79	5.71	3.18
Std deviation	1.10	2.74	2.94	5.41	0.52	0.14

Table 5.3 shows t-test results that were found when comparing particle size between hole 1 and hole 2 of mound 2. The table shows that t-calculated values were smaller than t-critical values across all particle range. This means that the distribution of soil fractions in hole 1 and hole 2 are statistically the same.

Table 5.3 T-test results of hole 1 and hole 2 of mound 2

	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
degrees of freedom	6	6	6	6	6	6
t-calculated	0.84	0.66	1.36	0.75	0.98	2.16
t-critical	2.447	2.447	2.447	2.447	2.447	2.447

Table 5.4 shows the relative amounts of different size fractions of the soil found at different depths in hole 4 of mound 2. A student's t-test analysis was carried out between hole 1 and hole 4 of mound 2

Table 5.4 Percentage abundance of soil size fractions in hole 4 of mound 2

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
2(4) 0.01 m	0.46	3.26	33.07	51.17	6.30	4.06
2(4) 0.5 m	0.11	1.98	33.91	52.61	5.19	3.93
2(4) 0.9 m	-	1.34	24.46	54.35	6.39	9.66
Mean ($\bar{x}$)	0.28	2.19	30.48	52.71	5.96	5.88
Std deviation	0.25	0.98	5.23	1.59	0.67	3.27

Table 5.5 shows t-test results that were determined when comparing particle size between hole 1 and hole 4 of mound 2. The table shows that the t-calculated values were greater than t-critical values across most of the particle range. This means that the distribution of soil fractions in hole 1 and hole 4 are statistically different.

However, size fractions of 0.053 mm and below were not statistically different as their t-calculated values were less than t-critical.

Table 5.5 T- test results of hole 1 and hole 4 of mound 2

	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
degrees of freedom	4	5	5	5	5	5
t-calculated	**3.64** (s)	**5.39** (s)	**2.95** (s)	**5.19** (s)	0.56 (ns)	1.02 (ns)
t-critical	2.78	2.57	2.57	2.57	2.57	2.57

s = significant at 5% level
ns = not significant at 5% level

A similar statistical analysis was carried out for mound 10. Table 5.6 shows data of size fractions at different depths in hole 1 of mound 10, mean values and standard deviations.

Table 5.6 Percentage abundance of soil size fractions in hole 1 of mound 10

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
10(1) 0.01 m	5.76	13.24	35.30	33.54	6.48	2.95
10(1) 0.5 m	3.65	10.90	42.46	31.98	6.25	2.83
10(1) 1.5 m	2.02	7.64	42.92	34.59	6.44	4.40
10(1) 3.0 m	1.97	10.01	42.12	31.56	7.76	3.61
Mean ($\bar{x}$)	3.35	10.45	40.70	32.92	6.73	3.45
Std deviation	1.79	2.31	3.61	1.40	0.69	0.72

Table 5.7 shows relative distributions of soil fractions found at different depths in hole 2 of mound 10; mean values and standard deviations for specific range within a hole.

Table 5.7 Percentage abundance of soil size fractions in hole 2 of mound 10

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
10(2) 0.01 m	0.67	4.42	34.71	44.76	5.99	6.88
10(2) 0.5 m	1.96	9.26	40.84	36.32	5.95	2.69
10(2) 1.5 m	5.16	16.20	45.47	25.16	3.47	3.03
10(2) 2.5 m	2.76	10.68	44.46	31.74	5.48	2.59
Mean ($\bar{x}$)	2.63	10.14	41.37	34.49	5.22	3.79
Std deviation	1.89	4.85	4.86	8.23	1.19	2.06

Table 5.8 shows results that were determined when comparing particle size between hole 1 and hole 2 of mound 10. The t- calculated values were all less that t-critical values. This means that the two sets of data are statistically the same and come from the same population.

Table 5.8 T- test results of hole 1 and hole 2 of mound 10

	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
degrees of freedom	6	6	6	6	6	6
t-calculated	0.453 (ns)	0.115 (ns)	0.221 (ns)	0.376 (ns)	2.195 (ns)	0.311 (ns)
t-critical	2.447	2.447	2.447	2.447	2.447	2.447

ns = not significant at the 5% level

Table 5.9 shows relative amounts of different size fractions of soil found at different depths in hole 3 of mound 10, mean values and standard deviations of specific range within a hole.

Table 5.9 Percentage abundance of soil size fractions in hole 3 of mound 10

Sample ID	1 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
10(3)0.5 m	0.37	3.32	35.70	48.17	3.98	3.98
10(3)1.75 m	0.23	3.46	34.31	51.63	4.01	4.01
Mean ($\bar{x}$)	0.3	3.39	35.0	49.90	3.99	3.99
Std deviation	0.09	0.09	0.98	2.45	0.02	0.02

Table 5.10 shows t-test results that were determined when comparing particle size between hole 1 and hole 3 of mound 10. The table shows that most of the t-calculated values were greater than t-critical values. This means that the distribution of soil fractions in hole 1 and hole 3 are statistically not the same. Pan fractions were not statistically different as its t- calculated value was less that t-critical value.

Table 5.10 T- test results of hole 1 and hole 3 of mound 10

	1 – 0.5 mm	0.5 – 0.25 mm	0.25 - 0.125 mm	0.125 - 0.053 mm	0.053 mm - Pan	Pan
degrees of freedom	4	4	4	4	4	4
t-calculated	**3.40** (s)	**6.09** (s)	**2.94** (s)	**9.09** (s)	**7.92** (s)	1.49 (ns)
t-critical	2.776	2.776	2.776	2.776	2.776	2.776

s = significant at 5% level

ns = not significant at 5% level

Table 5.11 below shows in a simplified way the significant differences in soils on-mound and soils off-mound

Table 5.11 Main differences in soils found on-mound and off the mound

Range	**On-mound**	**Off-mound**
< 0.125 mm> 0.053 mm	Less dominant	More dominant
<1 mm>0.5 mm	Present	Almost absent
<0.5 mm> 0.25 mm	More dominant	Less dominant

5.3 Textural identification of clay in mound soils

Four samples from mound 10 were taken for soil texture analysis by use of Malvern analyzer. These were 10(1) 1.5 m; 10(1) 3.0 m; 10(2) 2.5 m and 10(3) 1.75 m. Results from Malvern analyzer revealed that particles less than 2 μm formed part of mound soils. Figure 5.4 shows results from a Malvern analyser. It indicates a bimodal distribution of soil particles making up the mound. The two distinct major components making up mound soils are:

(i) A combination of clay, silt and very fine sand, and

(ii) A combination of fine sand to medium sand with traces of coarse sand

Universal conformity for the classification of clay particles may be arguable. Weaver (1989 p 5) cites petrologists who differed in opinion of what clay-size particles should be, these were*; "Wentworth (1922) who considered clays to be any material finer than 3.9 μm; Atterberg (1905) who considered it be material finer than 2 μm; The U.S. Bureau For Soils considered clays to be finer than 5 μm; whilst Correns (1969) put his mark at 20 μm".* However, according to the soil characterization criteria adopted for this study, figure 5.4 shows that clay component (i.e, particles < 2 μm) seemed to have formed part of the first peak in the particle size distribution. This can be seen as a shoulder at ~3 μm on the 30 μm peak.

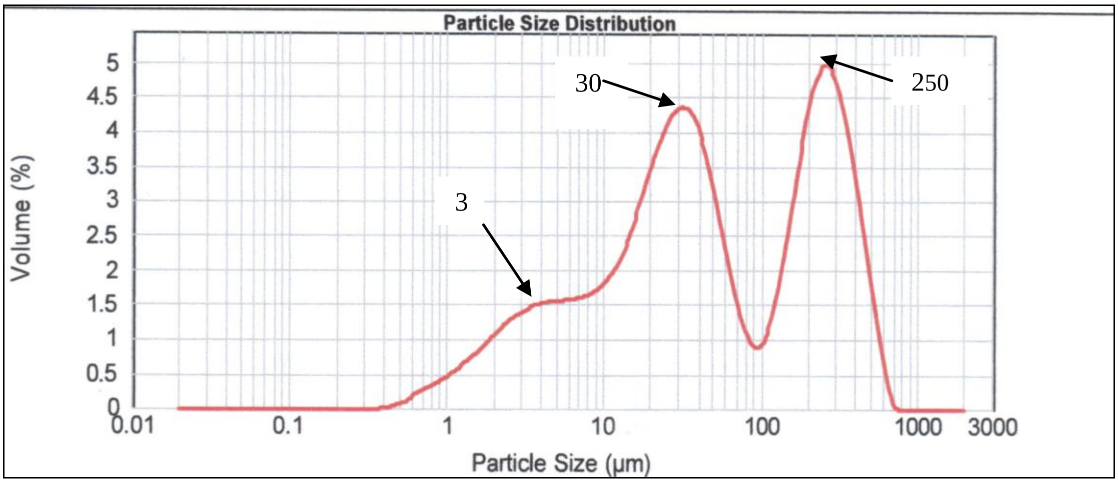


Figure 5.4 Soil particle size distribution of sample 10(1) 3.0 m on-mound.

The resolution of the first peak was poor when compared to that of the second peak. The first peak reached its maximum at about 30 μm and the second peak at about 250 μm. Both peaks were almost equal in proportion of volume of distribution. This means that the abundance of the two major components in soil was almost equal.

Figure 5.5 also shows a bimodal distribution in 10(2) 2.5 m sample. The graphs of both figure 5.4 and figure 5.5 are similar in shape; however, they differ in the ratios of the peaks. Figure 5.5 also showed a distinct peaking of soil particles at about 3 μm, 30 μm and 250 μm.

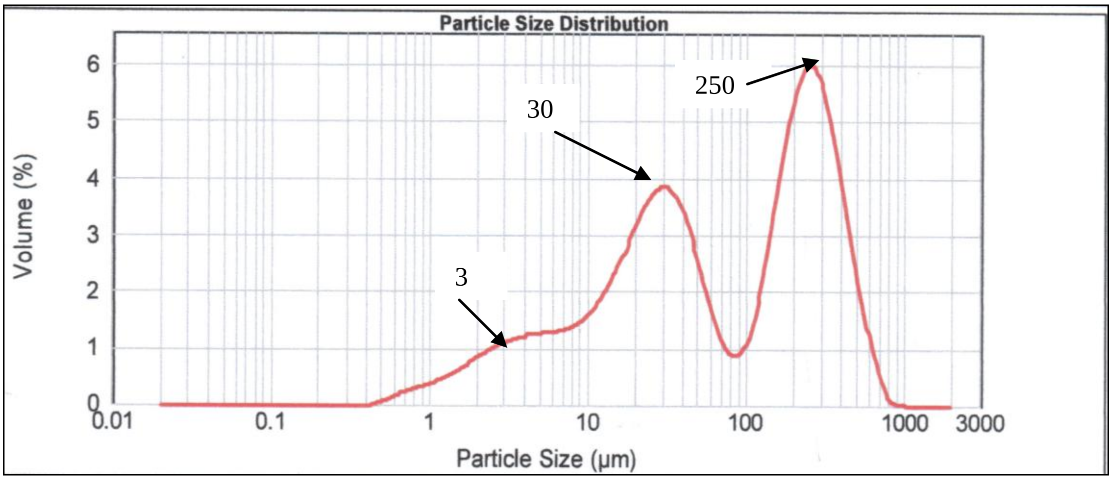


Figure 5.5 Soil particle size distribution of sample (2) 2.5 m on-mound 10

Figure 5.6 which is graph of sample 10(3) 1.75m. It was again indicative of a bimodal distribution in mound soils. It is similar in shape to the other two graphs above but differs from each in terms of peak ratios. In general, figures 5.4; 5.5 and 5.6 indicated the presence of:

(i) clay, silt and very fine sand, and
(ii) fine to medium sand with traces of coarse sand.

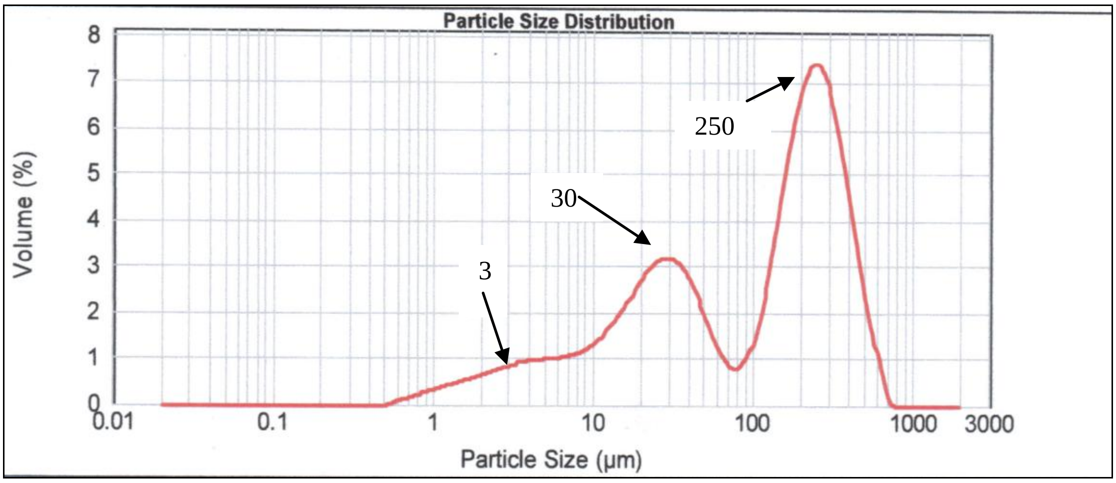


Figure 5.6 Soil particle size distribution of sample 10(3) 1.75m off-mound

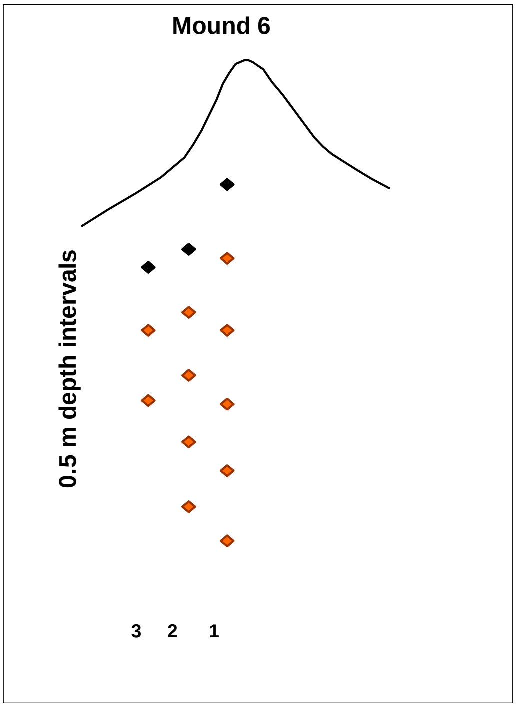
Of the three samples, sample 10(1)3.0μm is thought to have been nearest to the queen cell. This is because of both its central positioning at the base of the mound and its exceptionally high content fin fractions. According to available theories for termite mound formations, a termite colony has a queen and a king.

Sample 10(1) 2.5m also contained a good measure of clay and silt. Clay has cohesive properties and is highly desired by termites for mound construction. Sample 10(3) 1.75 which was located on mound skirts contained a lower amount of clay, silt and very fine sand when compared to samples located on the mound.

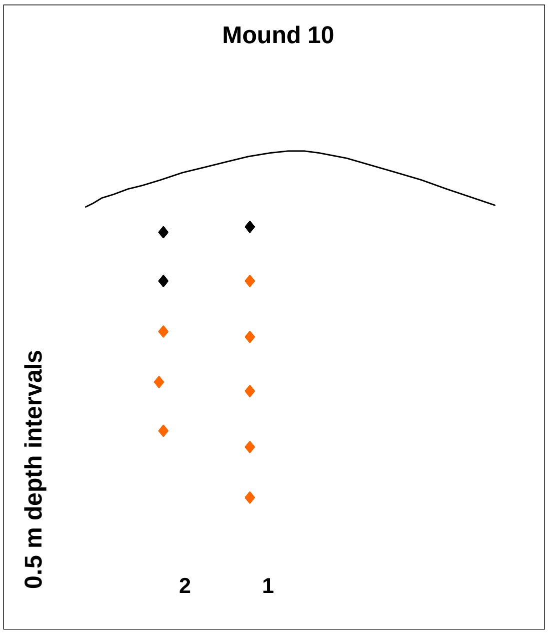
5.4 Soil colour and mottle distribution

Soil colour usually serves as an indicator of the amount of iron and organic matter contained in soil (FitzPatrick *et al.* 1983). Surface soils which covered mounds were dark brown to black in colour. Dark brown to black soils indicate the presence of organic matter (FitzPatrick *et al.* 1983). The colour of subsoils was typical of inorganic hydric soils and had low hue values and relatively low chroma. The most frequent colour chart code which matched most samples was 7.5YR, 3/2 (Mitsch and Gosselink 2000). Soil colour results for individual samples are found in appendix B.

The presence of iron in mound subsoils was not only evidenced by soil colour but also by randomly distributed iron mottles. Mottle deposits in soil attest to alternating cycles of wetting and drying of soils (Mitsch and Gosselink 2000). A mineral responsible for inorganic soil colouration is called goethite [α-FeO(OH)] and has a colour ranging from reddish brown to yellow as its hydration increases (E.A. FitzPatrick *et al*. 1983). Figure 5.7 (a) and (b) show mottle distribution in mound 6 and mound10.



(a)



(b)

Figure 5.7 Mottle deposits in subsoils of mounds 6 (a) and 10 (b) represented by orange diamond symbols

Mottle deposits were observed at great depths on mound fringes but gradually became shallow towards the mound interior. Cycles of wetting and drying of soils lead to mottle formation. Chemosynthentic bacteria can oxidize iron from ferrous form to insoluble ferric form in the presence of oxygen (Mistch and Gosselink 2000).

Another interesting characteristic feature of mound soils was the occurrence of white nodules in subsoils. Figure 5.8 shows the distribution of white nodules in the soils of mound 6 and mound 12, where diamonds represent soil samples with white nodules.

White nodules were predominant in subsoils at the centre of mounds. Generally, white nodules in soils are associated with calcium carbonate precipitation from groundwater. Of all the mounds, mound 12 showed the highest distribution of white nodules. The whole of mound 12 could not be surveyed; there was limited space to stand on the mound because of its great vegetation cover. Therefore Figure 5.8 (b) shows only a part of the topography of mound twelve.

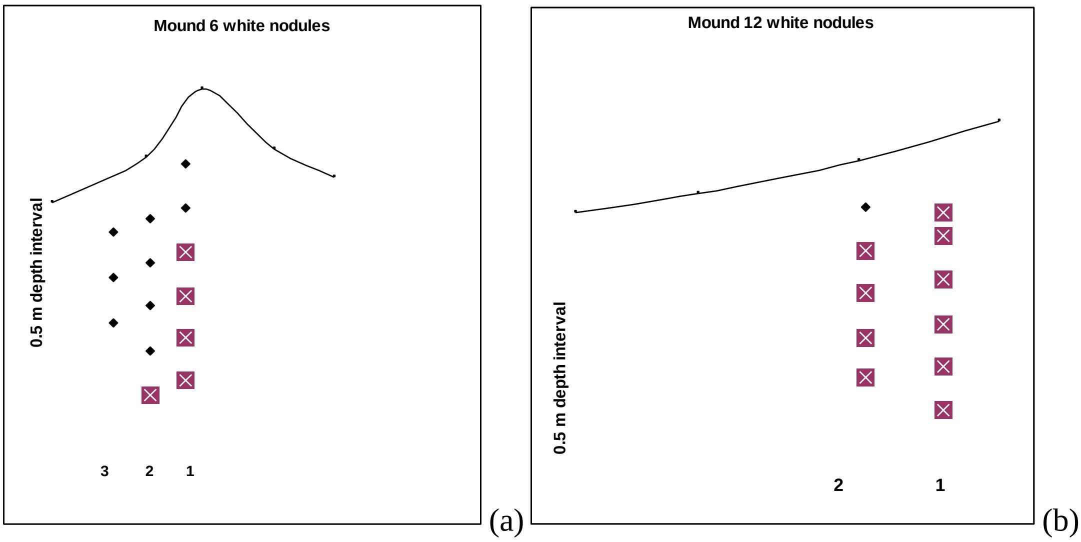


Figure 5.8 White nodules in mounds 6 (a) and 12 (b), represented by symbols X

5.5 Mineralogy and chemistry

Mineralogy and chemistry results percentages are shown in table 5.12. Results show that mound soils are rich in silica, aluminium and iron and contain traces of calcium, magnesium, manganese, potassium and sodium

	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Cr_2O_3	NiO
2(1)surface	88.74	5.54	2.62	0.0446	0.25	0.43	0.19	0.83	0.4706	0.07	0.0148	0.0029
2(1) 1.0m	89.91	5.55	2.54	0.0434	0.23	0.28	0.3	0.73	0.4189	0.02	0.0095	0.002
2(1) 2.0m	85.45	7.76	3.53	0.0399	0.36	0.37	0.25	0.77	0.5318	0.02	0.0152	0.0037
2(1) 3.0m	77.52	7.02	13.18	0.0963	0.29	0.36	0.09	0.65	0.4663	0.03	0.0184	0.0068
2(2)surface	90.73	4.84	2.25	0.0497	0.18	0.3	0.11	0.78	0.4308	0.05	0.0135	0.0028
2(2) 1.0m	87.72	6.49	3.01	0.0523	0.3	0.36	0.11	0.76	0.4858	0.02	0.0191	0.0029
2(2) 2.0m	86.96	7.45	3.23	0.0394	0.34	0.46	0.19	0.81	0.5149	0.02	0.0148	0.0015
2(2) 2.5m	85.18	8.04	3.64	0.067	0.41	0.52	0.24	0.77	0.5211	0.02	0.0149	0.0044
2(3) surface	91.72	4.24	2.05	0.0538	0.14	0.29	0.04	0.76	0.4156	0.05	0.0052	0.0025
2(4) surface	94.39	2.68	1.39	0.0438	0.09	0.19	0.21	0.69	0.4701	0.03	0.013	0.0004
2(4) 0.5m	95.76	1.96	0.99	0.0335	0	0.11	0.12	0.63	0.3736	0.01	0.0105	0.0004
2(4) 0.9m	95.15	2.16	1.14	0.0374	0.03	0.12	0.14	0.63	0.3485	0.03	0.0079	0.0006
10(1) surface	89.59	5.31	2.24	0.0491	0.26	0.36	0.25	0.85	0.5876	0.03	0.0121	0.0028
10(1) 0.5m	88.78	5.49	2.6	0.0648	0.28	0.39	0.22	0.84	0.6033	0.03	0.0147	0.0016
10(1) 1.5m	89.92	5.08	2.33	0.06	0.24	0.4	0.06	0.84	0.5747	0.02	0.012	0.0021
10(1) 3.0m	87.2	6.78	3.18	0.0699	0.32	0.44	0.17	0.85	0.596	0.01	0.0181	0.0029
10(2) surface	92.89	3.32	1.44	0.0602	0.11	0.3	0.18	0.84	0.5274	0.03	0.0109	0.0006
10(2) 0.5m	91.86	4.1	1.74	0.0489	0.17	0.24	0.24	0.81	0.4479	0.02	0.0105	0.0013
10(2) 1.5m	89.07	6.19	2.56	0.0402	0.24	0.32	0.23	0.85	0.5071	0.01	0.0098	0.0018
10(2) 2.5m	89.57	5.24	2.31	0.0532	0.2	0.31	0.32	0.8	0.5461	0.01	0.0145	0.0025
10(3)surface	94.52	2.51	1.02	0.0456	0.05	0.27	0.21	0.79	0.4269	0.03	0.0108	0.0001
10(3) 0.5m	94.81	2.22	0.96	0.041	0.02	0.14	0.06	0.77	0.5599	0.01	0.0093	0.0007
10(3) 1.75m	92.02	4.45	1.92	0.037	0.22	0.19	0.37	0.8	0.535	0.01	0.0122	0.0014
10(4)surface	93.92	2.81	1.16	0.0462	0.09	0.35	0.15	0.78	0.5081	0.04	0.0102	0.0009

Table 5.12 shows xrf results of selected samples on mound 2 and mound 10

Figure 5.9 (a), (b), (c) and (d) show graphs of distributions (m/m %) of aluminium and iron on mound 2 and mound 10 through isolines. Light colour shading represents regions in the mound where the chemical elements occur in low concentration. Moderate to intense shading represent moderate areas on the mound where the concentrations of elements occurs in medium to high concentrations.

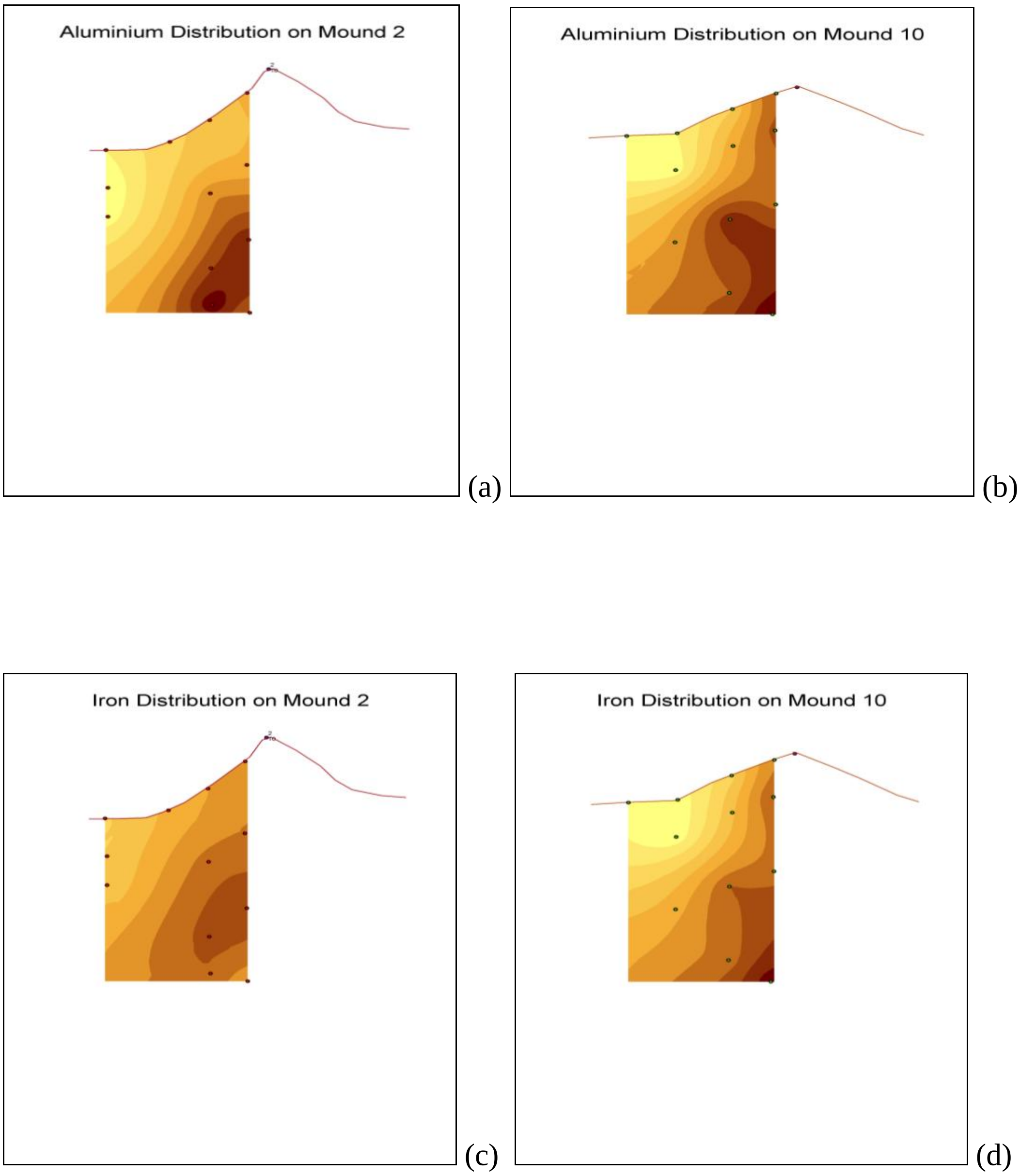


Figure 5.9 Distribution of aluminium in mounds 2 (a) and 10 (b); and distribution of iron in mounds 2 (c) and 10 (d)

There was a notable difference in distribution of aluminium in soils on-mound when compared to soils off-mound. There seemed to be a gradual increase in the amount of aluminium and iron from mound fringes towards mound interior and at greater depths in the centre of the mound.

Figure 5.10 (a), (b), (c) and (d) show graphs of distributions of calcium and magnesium in mound 2 and mound 10 through isolines. The graphs show an increase in the amount of these elements from mound fringes towards mound centre and at greater depths of mound centre.

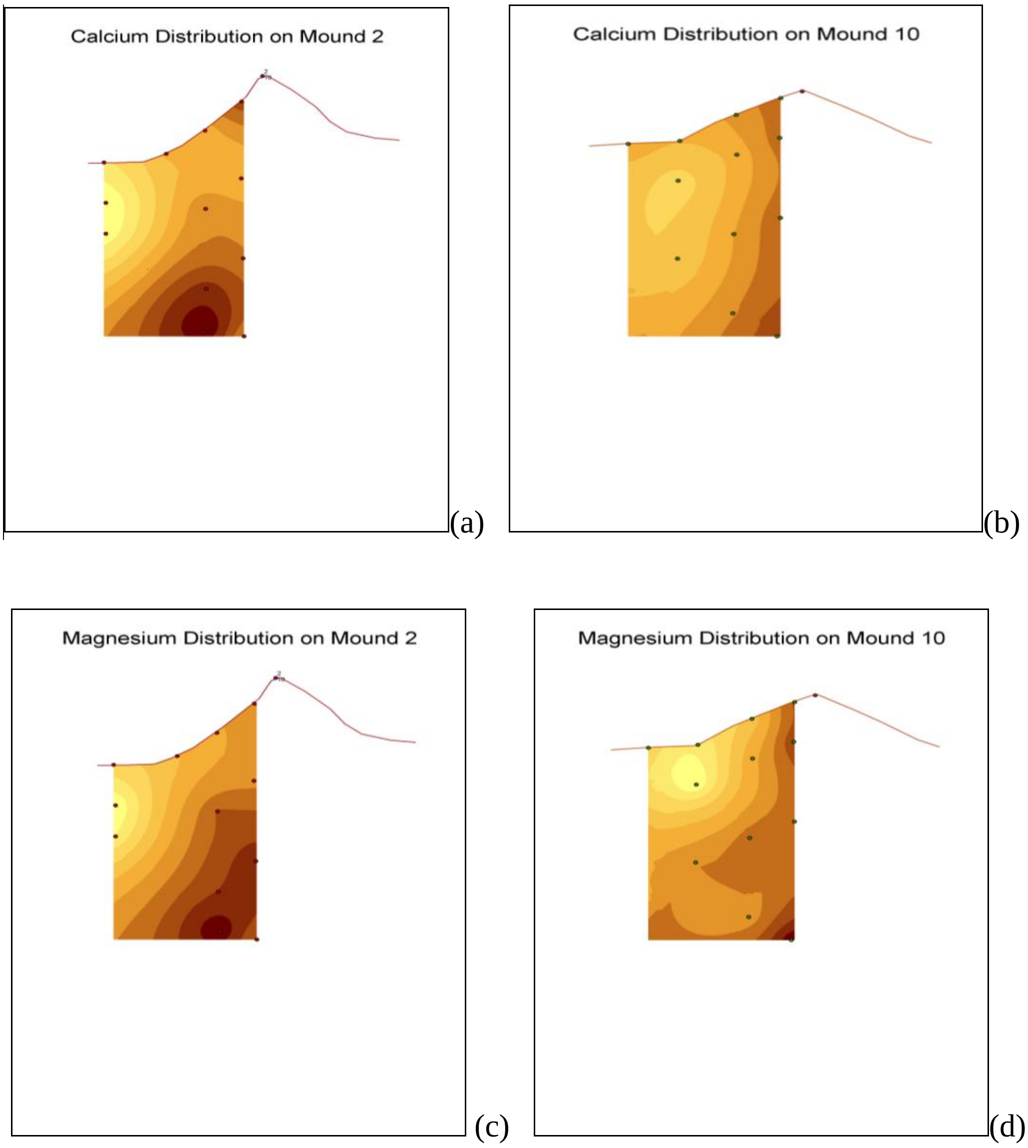


Figure 5.10 Distribution of calcium in mounds 2 (a) and 10 (b); and distribution of magnesium in mounds 2 (c) and 10 (d)

5.6 Organic matter

Organic matter is one of the two most important sources of cation exchange capacity (CEC) in soils. Cation exchange capacity is defined as the sum of exchangeable cations that a soil can hold (Mitsch and Gosselink 2000). It represents the capacity of the soil to can hold positively charged nutrients like Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}. Soils with organic matter are usually fertile and are generally considered to contain reasonable amounts of positively charged nutrients. Table 5.13 shows the amounts of organic matter from mound 6 and mound 10. Figure 5.12 (a) shows the variation in organic matter across a section of the mound.

Table 5.13 Organic content of soils found in mounds 6 and 10.

Mound 6 sample point	Organic matter (%)		Mound 10 sample point	Organic matter (%)
(1) Surface	5.95		(1) Surface	5.73
(1) 1.0 m	2.19		(1) 1.0 m	2.87
(1) 2.0 m	2.1		(1) 1.5 m	2.33
(1) 3.0 m	2.2		(1) 3.0 m	2.63
(2) Surface	3.26		(2) Surface	4.00
(2) 0.5 m	1.66		(2) 0.5 m	1.98
(2) 1.5 m	1.28		(2) 1.5 m	0.45
(2) 2.5 m	0.94		(2) 2.5 m	0.35
(3) Surface	3.64		(3) Surface	5.81
(3) 1.0 m	0.35		(3) 0.5 m	0.91
(3)1.5 m	0.59		(3) 1.75 m	1.70
(4) Surface	1.89		(4) Surface	2.57

Organic matter in mound topsoils ranged between 2% and 5%. However, mound 12 showed a higher organic matter concentration in the topsoil which ranged between 2% and 9%. Mound 12 was one of mounds closest to flooded plains and was more poorly drained. Waterlogged soils are known to limit the decomposition of organic matter (Mitsch and Gosselink 2000). In addition, mound 12 formed a habitat to a diverse range of vegetation. Fallen leaves and branches on mound 12 are believed to have contributed to the high organic matter content in the topsoil.

In the subsoils, organic matter increased from mound fringes towards the mound interior. Organic matter in topsoils and subsoils is believed to be of different origin. Organic matter in the topsoil is believed to be directly from decomposition of plant litter. The occurrence of organic matter in subsoils is thought to be a result of termite activities. Organic matter has a strong affinity for cations such as calcium and magnesium (Mitsch and Gosselink 2000). Graphs of organic matter versus calcium oxide and magnesium oxide were plotted to highlight the difference in relationships of organic matter with calcium and magnesium between topsoil and subsoil. Figures 5.11 (a) and (b) show the relationships of organic matter to calcium and magnesium in topsoil and subsoil.

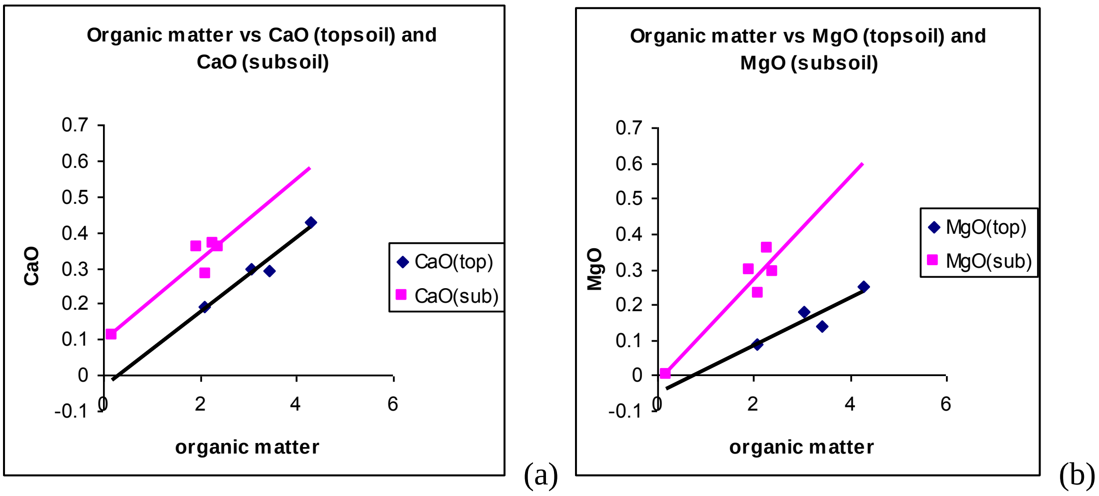


Figure 5.11 Relationship of organic matter in topsoil and subsoil with oxides of calcium (a) and magnesium (b)

Calcium and magnesium in the topsoil showed a direct relationship to organic matter. The relationship of calcium and magnesium to organic matter in the subsoil was different. Organic matter plays an important role in formation of soil aggregates which help impart firmness to mound structure (Jouquet *et al*. 2005). Organic matter also imparts erosion resistance to soils by supplying desirable cementing substances (Jouquet *et al*. 2005)

5.7 SEM and EDS analysis of clay size particles

Below is a micrograph of a clay sample 2(1) 3.0m

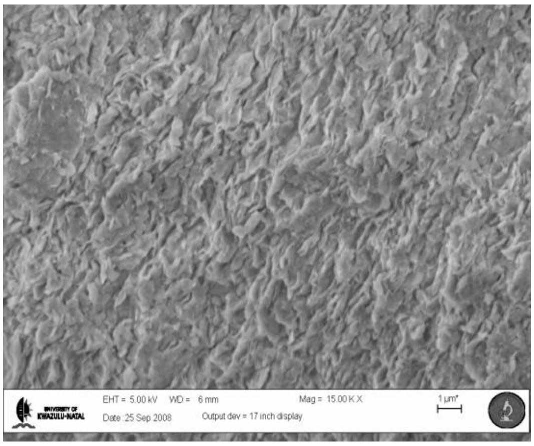


Figure 5.12 Micrograph of clay samples 2(1) 3.0m at magnification of 15 00K X with a scale bar of 1 µm.

Clay-sized particles were successfully separated from mound soils through ultrasound sonification. Scanning electron microscope analysis (SEM) also allowed for elemental analysis of some clay particles with diameters of less than 1µm.

The determination of chemical composition of clays (i.e., particles <2 µm) through EDS showed that clays were predominantly made of silica, aluminium and iron, with traces of titanium, magnesium, potassium and calcium. Four scans per sample were captured and an average for each oxide in all four scans was calculated and recorded. These are shown in Table 5.14.

The results below indicate that the distributions of (%)Si, (%)Ti and (%)K were lower in mound clays of 2(1) 3.0m and 2(2) 2.5m when compared to off-mound clays of 2(4) 0.9m sample. Aluminium and calcium were found in high amounts in-mound clays when compared to off-mound clays.

Sodium and Magnesium showed no significant difference in distribtion on-mound and off-mound. The results for iron were highly variable, particurlaly on 2(2) 2.5m sample.

This made difficult the comparison of iron distribution in samples found on the mound. However it is apparent that all clay-sized particles were rich in iron.

Table 5.14 EDS analysis of clay sized particles

2 (1) 3.0 m on-mound					
Mass %	scan 1	scan 2	scan 3	scan 4	average
Na_2O	1.8	1.97	2.09	1.05	1.73
MgO	0.86	1	0.97	1.07	0.97
Al_2O_3	23.80	25.17	24.02	25.06	24.51
SiO_2	51.98	54.18	51.87	54.27	53.07
K_2O	1.25	1.2	1.15	1.17	1.19
CaO	1.34	1.16	1.29	1.28	1.27
TiO_2	1.22	1.13	1.08	1.06	1.12
Fe_2O_3	17.01	13.6	16.65	14.32	15.39
2(2) 2.5 m on-mound					
Mass %	scan 1	scan 2	scan 3	scan 4	average
Na_2O	0.39	1.01	1.08	0.85	0.83
MgO	0.98	0.96	1.17	0.87	0.99
Al_2O_3	23.42	21.27	24.21	22.32	22.80
SiO_2	51.63	44.83	53.51	47.13	49.27
K_2O	1.3	1.19	1.13	1.2	1.20
CaO	1.68	1.69	1.5	1.33	1.55
TiO_2	1.27	1.53	1.29	1.21	1.32
Fe_2O_3	19.11	26.59	15.86	24.52	21.52
2(4) 0.9 m off-mound					
Mass %	scan 1	scan 2	scan 3	scan 4	average
Na_2O	1.19	1.14	0.73	0.74	0.95
MgO	0.68	0.87	0.9	1.08	0.88
Al_2O_3	15.4	18	17.43	19.44	17.57
SiO_2	66.41	61.22	61.22	65.23	63.52
K_2O	1.51	1.66	1.59	1.47	1.56
CaO	0.7	0.72	0.89	0.62	0.73
TiO_2	1.88	1.74	1.92	1.54	1.77
Fe_2O_3	11.68	14.03	14.87	9.67	12.56

The mineralogy of clays of 2(1) 3.0m and 2(2) 2.5m seem to correspomd well the general chemistry of smectite clays. Smectite clays are primarily composed of two silica sheets which sandwhich an aluminium sheet in between (Weaver 1989). The structures of silica molecules and aluminium in this type of clay occur in tetrahedra and octahedra dimensions, respectively. Water and other ions may be accommodated in spaces between smectite clays. The percentage of silica in clays of 2(1) 3.0m and 2(2) 2.5m was almost twice that of aluminium in the samples. A typical model of the chemical structure of smectite clay is shown below.

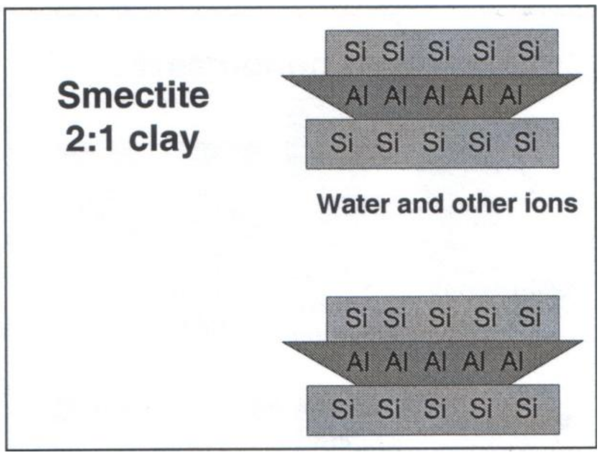


Figure 5.13 Basic chemical composition of smectite clays (Brown n.d.)

The amount of silica and aluminium in the clay of sample 2(4) 0.9m off-mound appears to be different to that which was found on the mound. This difference in proportionality of silica and aluminiun indicates mineralogical differences in clays found on mound and off the mound.

CHAPTER SIX: DISCUSSION

6.1 Introduction

Although there was no direct evidence of the presence of termite activity, the findings of this study are consistent with the findings that are generally generated by other studies carried out on termite mounds. The variations of soil properties across mounds, particularly of soil particle size distribution, organic matter and elemental composition across mounds, strongly suggest that termites may be responsible for formation of earth mounds in the Mkhuze Floodplain. This section will highlight the link between the observed findings in soil properties and termite activities.

6.2 Soil particle size and organic matter

Termites require both large particles and smaller clay sized material to form a composite material similar in structure to concrete. Therefore, the proportion of large particles to small particles needed to be investigated. Sieving of soil samples through five different sieves showed that the distribution of soil particles on mounds was different when compared to soils found off the mound. The variation in soil particle size distribution was further confirmed statistically by conducting a student's t-test. The student t-test made it possible to compare the distribution of similar size fractions in topsoil and subsoil across mounds. Generally, the Mkhuze floodplain is made of fine sediments and silts, and is underlain by reworked coastal sand. Of the sediments found on the floodplain, very fine sand and clay-sized particles seemed highly desired for mound construction as these were found in high amounts in the soils analysed from the mounds. Termites are known to collect soil particles of very small sizes and relocate them to a desired focal point. Usually, these soil particles should have adhesive properties such as those of clays. Termites then mix the soil particles with their body fluids and thereafter cement it on a sand grain, thus forming a concrete structure between sand and the collected particles. The magnitude at which this simple process takes place must be great, because about 40 to 60% of the total soil microfauna biomass in the tropics and sub-tropics is said to be made of termites (Dangerfield *et al.* 1998). Therefore termites can be viewed as ecosystem engineers and large amounts of soil particles of specific grain sizes are moved and relocated within the system.

Another distinct difference in the distribution of soil particles on-mound when compared to soil found off-mound was the occurrence of soil aggregates. Medium to coarse sand was found in on-mound soils and was mostly absent in soils found off the mound. This can be observed in Figures 5.2 and 5.3 in chapter five. Particles in the range between 0.25 mm and 1.0 mm were relatively abundant in on-mound soil when compared to off-mound soil. Other than clay, organic matter is also one of the components in soil that can help impart cohesion between soil particles.

Organic matter results determined by the Loss On Ignition method showed that there was a high concentration of organic matter in topsoils when compared to subsoils. Organic matter in the topsoil is believed to be derived from decomposition of plant litter. It is likely that the high concentrations of organic matter in subsoils around the centre of mounds are a consequence of termite activities. The cementing of clay onto sand grains by termites generally contributes to the formation of soil aggregates and opens up soil micro-pores, which join to become networks of channels for the movement of termites within underground (Jouquet *et al*. 2005; Dangerfiled *et. al* 1998). These pore spaces may make possible the easy passage or infiltration of organic matter from topsoil to subsoil. When in the subsoil, organic matter may enhance aggregate formation. Soil aggregates give stability to the soil and offer resistance to soil erosion. The high amount of soil aggregates observed on mounds is thought to offer stability and firmness to mound structures and to also help reduce mound erosion by wind and rain. There were low concentrations of organic matter in the subsoil along mound skirts. This may be due to the fact that there was less termite activity on mound skirts and that the soil particles along mound skirts were closely packed together, thus preventing easy passage or infiltration of organic matter from the topsoil to subsoils.

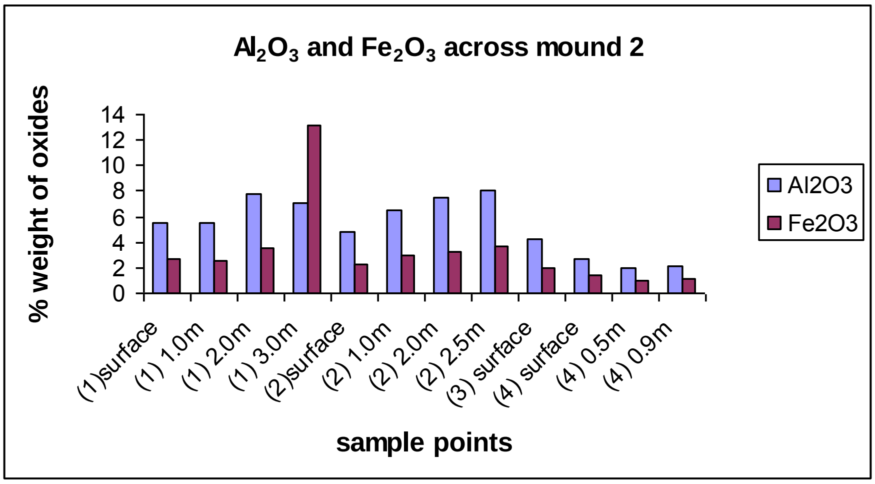
Generally, organic matter serves to hold and exchange positively charged ions such as those of magnesium and calcium. Calcium and magnesium in topsoils found on the mound showed a direct relationship to organic matter. Calcium and magnesium in subsoils showed a different relationship to organic matter. Figures 5.11 (a) and (b) show by means of scatter graphs the two distinct soil organic matter and cation relationships, *i.e.* between topsoil and subsoil. Organic matter in the topsoil is believed to be derived from the decomposition of plant litter. It is suspected that organic matter in subsoils may have been brought from deeper soil layers through termite activities.

Clay is also regarded as very important in mound construction, particularly because of its special adhesive properties. The particle size distribution values obtained through Malvern particle size analysis showed that clay-sized particles formed part of earth mound soils. Unlike the determination of particle size distribution through sieves, the use of the Malvern analyser is a more sophisticated technique that can determine particle size distributions in a sample across all size ranges rather than in discrete sieve ranges. All results from particle size analyser were indicative of a bimodal distribution in mound soils.

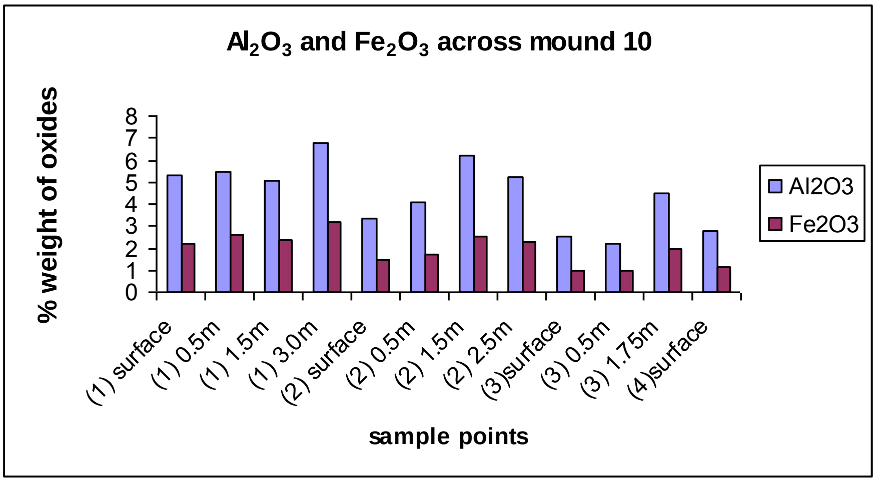
Clay-sized particles were found at relatively high concentration on the mounds when compared to adjacent soils. A comparison of the first peak, which represents mainly silt and clay, to the second peak (which is mainly sand) on Figures 5.3, 5.4 and 5.5 in terms of volume percentage of peaks, clearly indicate a gradual decrease of clay and fines from mound centre region to mound skirts.

6.3 Soil mineralogy

An interesting relationship was observed in the distribution of aluminium and iron in mounds. Figures 6.1 (a) and (b) show this relationship in samples.



(a)



(b)

Figure 6.1 Distribution of the ratio of aluminium to iron on mounds 2 (a) and 10 (b)

The ratio of aluminium to iron is ~ 2:1 in most samples except for sample 2(1) 2.0 m. This sample contained the highest iron content: a ratio Al:Fe of 1:2. Aluminium and iron are clay minerals. Their occurrence in the soil indicated not only the presence of clay component on the mounds but a special type of clay with an unchanging distribution ratio between aluminium and iron.

6.4 Elemental composition of clay sized particles

Not only was there a difference in proportional clay distribution on mounds and off mounds. The elemental composition of clay sized particles on mound was different to that of clay found off mound. The ratio of silica to aluminium found on-mound soil was ~ 2:1, whereas that found off-mound was ~3:1. This suggests that clay found on the mound is different to clay found off-mound. This variation in elemental composition of clay on mound and off mound is consistent with the findings of studies carried out on termite mounds (Dangerfield *et al*. 1998; Jouquet *et al*. 2005; Kaschuk *et al*. 2006). This observation may also serve to confirm that termites have the capability to modify clay properties. The type of clay that best fit the observed elemental composition of clay found on mounds is smectite clay. A typical model of a chemical structure of smectite clay is shown in figure 5.14. *"In laboratory experiments, Jouquet et al. found not only an enrichment in fine particles within the nest (or mound) due to termite selection, but also a modification of clay properties by* *termite action"* (Jouquet *et al.* 2005, p 369). Knowledge generated thus far may serve as evidence that mound formation in the Mkhuze floodplain could be as a consequence of termite activities.

6.5 Termites in the Mkhuze floodplain

Termite species were not seen above ground in the field or in any of the soils removed from the mounds. Termites hardly expose themselves to atmospheric conditions. They prefer to reside under moist sheets of soil with constant humidity of about 100% and high temperatures varying between 29 ^{o}C and 31 ^{o}C (Anitei 2007). Such conditions seem necessary for both the fungi and the termites who cultivate them and can help protect the soft bodies of termites from atmospheric conditions (Anitei 2007). It is not known whether mounds studied were active or inactive.

Earth mounds were distributed over an area with a particular hydrologic regime in the Mkhuze floodplain. Demarcation on an aerial photograph (Figure 2.2) based on differences in hydrological regime and characteristic vegetation between floodplain and underlying coastal plain revealed that earth mounds occurred mostly in intermittently flooded marsh. A few occurred at the border of terrestrial forest and intermittently flooded marsh. This represents the limit to where clay particles will be deposited by the Mkhuze River during flooding. Clay sediments and sand are regarded as important resources for mound construction (Harris 1971). Termites sometimes forage competitively for these resources (Dangerfield *et al.* 1998). Other than soil feeding, the use of soil by termites to construct a mound or a habitat free of flooding seems as a primary requirement for their survival. Without a habitat free of flooding termites would drown. The Mkhuze floodplain has a high water table. This was evidenced by mottles in soils found on mounds. Mottles form as a consequence of alternating cycles of drying and wetting of soil. In a bigger picture, this suggests that the study area experiences cycles of rising and falling water table. Adams (2004) found that the earth mounds which occur in Figure 2.2 were evenly distributed. This strongly suggests that these mounds may have formed under competitive foraging of different termite colonies.

6.6 Applicability of Okavango conceptual model for mound formation in Mkhuze

Although this disertation tried to find links between termite activities and soil properties across mounds, there are other aspects which were not looked at, but which could have provided more supporting data for this study. Such data have been sourced from available literature on the Mkhuze Wetland System. This helped to broaden the understanding of mound development in the Mkhuze area. Table 6.1 outlines some of these factors in comparison to those found in the Okavango Delta. The two environments seem to have some common environmental settings.

Table 6.1 Comparisons between the Okavango Delta and the Mkhuze Wetland.

Okavango Delta	**Mkhuze Wetland**
Is situated in the Kalahari Basin and underlain by clean well-sorted white sand (Ellery *et al.* 1998)	The area was once a sea bottom and is predominantly underlain by unconsolidated sands (Stormans *et al.* 1987)
A-horizon of the floodplain is 10 cm thick and contains roots, organic matter and fine material (Ellery *et al.* 1998)	Substratum is composed of aeolian sands and clay rich alluvium associated with Mkhuze River Floodplain (Stormans *et al*. 1987)
Climate is semi-arid (Ellery *et al.* 1998)	Climatic conditions are subtropical (Van Heerden 1986)
Evapotranspiration high, about 96% of water entering the system is lost to atmosphere (Ellery *et al.* 1998)	Evapotranspiration high. Annual evapotranspiration about 1800 mm (Ellery *et al*. 2005)
River transports high sediment loads to the system including kaolinite material (Ellery *et al.* 1998)l	River transports high sediment load to the system, 50 kg/sec (McCarthy and Hancox 2000)
Of the dissolved solutes entering the system 80% accumulates within the system. Calcium regarded as an important solute within the system (Ellery *et al.* 1998)	The system is a sink with 80 % retention for silicon, 50% retention for calcium, 70% for potassium with magnesium and sodium retained at lesser extent (Barnes et al. 2001)
Termites present as ecosystem engineers (Ellery *et al.* 1998)	Termites thought to exist as ecosystem engineers

Although the levels at which these elements occur differ, the fact that they are common in both areas gives more support and probability that the same concept for mound formation may be applicable to Mkhuze floodplain system.

In brief, the Okavango conceptual model states that mound development is the result of a combination of processes, of which termite activity is seen as a primary precursor. After the creation of a microhabitat free of flooding, and when vegetation has developed on mound sites, the importance of termites activity to mound growth depreciates, whilst vegetation takes a lead in contributing to mound growth. The process of evapotranspiration by woody plants on mounds leads to solute precipitation on mounds. This adds to soil volume increase on mounds, and thus to mound growth. Figure 3.5 shows the relationship of mound-building organisms (in this case termites) to mound aggradation, and that these are important at the initial growing stages of mound, whereas precipitation of solutes to mound aggradation takes a lead when mound size is of medium growth, and when vegetation has been established on mound.

Mound formation in the Mkhuze Wetlands also seems to be a result of a combination of processes. The creation of a microhabiat free of flooding by termites could be the primary reason for the initiation of the mound formation process, as the Mkhuze floodplain has a high water table that fluctuates periodically. McCarthy and Hancox (2000, p 221) explain with exactness that *“much of the KwaZulu-Natal coastal plain has a high water table and the numerous pans, wetlands and streams are considered to be reflections of the ground water rest level”.* Mottle deposits found on mounds also attest to the high water table in the area.

It is important to remember that different processes become important at different growing stages of the termite mounds. High concentrations of clay solutes in mound soils, particurlaly at great depths of the central parts of the mound, as shown through isolines in Figures 5.9 (a), (b), (c), (d) and figures 5.10 (a), (b), (c) and (d) in chapter five, are thought to be results of termite activities. The focal points, where the concetration of clay solutes is highest, are believed to be close to termites’ fungus gardens. As shown in Figure 3.4, the fungus garden forms the most important part of a mound or termite colony (Ellery *et al.* 1998). It is a place which houses the queen of a termite colony, and where new eggs are laid. The queen cell is surrounded by a distinct layer of clay (Harris 1971).

The concentration of soil particles on the floodplain may have been initially seen as a consequence of termite activity, but as soon as vegetation colonises mounds, it takes over this responsibility by drawing solutes towards mound sites through their roots. Vegetation is believed to play a role on mound development in the Mkhuze floodplain. For instance, mound 12, which was a habitat to a number of plants, showed a high concentration of white nodules. Figure 5.8 (b) shows the distribution of white nodules in mound 12. White nodules are generally associated with calcium carbonate in groundwater. There was high deposition of white nodules in the middle area of this mound when compared to adjacent soils in mound 12 and in other mounds. This was indicative of a solute precipitation activity on mounds with vegetation. The Okavango study highlighted that, depending on groundwater chemistry, certain precipitates could be of importance in mound growth. Solutes which could be regarded important for mound growth in Mkhuze include silica, calcium and iron, as these were highly concentrated on-mounds.

The high concentration of white nodules in the mound centre may also be indicative of the effect that evapotranspiration has on mound growth. Annual evapotranspiration in Mkhuze is generally higher than annual rainfall. It is mainly the high atmospheric demand for water that influences plant transpiration, and hence solute precipitation on mounds. Hot and dry conditions are generally known to lead to high evapotranspiration rates. High evapotranspiration would further mean high precipitation of solutes on mounds. However, McCarthy and Hancox (2000, p 221) argue that " *although the potential evapotranspiration slightly exceeds rainfall, chemical deposition is not prevalent in this region, mainly because of the addition of recharge water from dunes."* This could be a possible reason why mounds are not bigger than they are in this area.

The model for mound formations in the Okavango developed a relationship between the size of mounds and the amount of external solutes which enter the system. In brief terms, it states that the capability of an external source or catchment to supply water that is rich in dissolved solutes has a bearing on the size of the mound features that are likely to be formed (Ellery *et al.* 1998). Ellery and co-workers (1998) acknowledged that mound size and mound spacing is influenced by the type of water inflow into the wetland. Wetlands in which water balance is dominated by rainfall are thought to favour evenly-spaced mounds of almost equal sizes. This is considered so, because rain action is thought to affect the processes of weathering, dissolution and precipitation and eventually the local redistribution of solutes. The rain action is thought to locally spread solutes in a manner that is regarded as even. Wetlands which are dominated by an external source of surface water inflow are thought to favour large and less uniform mounds. These could result in processes of differential sedimentation and erosion and in uneven spread of solutes or rather soil particles of fine sizes.

Adams (2004) investigated the pattern of mound distribution in the current study area by taking into consideration the following environmental gradients

(i) pH of soil on mounds and pH of soils found off the mounds
(ii) Particle size distribution on of soil on mounds and off the mounds
(iii) Size of mound in relation to the distance between the location of mound and the Mkhuze River

Each mound was considered as a single organism. All mounds, small and big were treated the same in this study as there was no expertise to differentiate between young (small) and old (big) mounds. Adams (2004) found that soils on the mounds were basic and soils off the mounds were acidic. The particle size distribution showed bimodal distribution for both soils on the mounds and soils off the mounds. From this Adams concluded that the distribution of mounds in the area was even due to the fact that the underlying environment was homogenous, and it made it difficult to establish any relationships between different variables. There was no significant relationship found between the size of mounds in relation to the distance between the mound location and the Mkhuze River. However, since the Mkhuze River was the only source of fine materials in this area, Adams considered the distance to the Mkhuze River very important and that it will affect the distribution of particle size within the wetland. However, Humphries (2008) has also found that precipitation of materials due to evapotranspiration is a significant source of fine materials in this wetland.

Figure 3.6 shows the relationship between the contribution to mound aggradation by mound building organisms, transpiration and windborne sediments and the contribution of solutes to the system. On average, the Mkhuze River transports into the lower Mkhuze floodplain in excess of 50 kg of sediment load (McCarthy and Hancox 2000). Of the sediment load which enters the system, most is retained within the system (Barnes *et al.* 2000). This explains why the Mkhuze floodplain is a favourable site for mound development. However, canal excavations along the Mkhuze river may have possibly reduced solute transportation and solute deposition into the floodplain. The reduction in river flow brought about by the two excavations along the Mkhuze River is estimated to be 80% when compared to the former Mkhuze channel (Goodman 1987). In the context of this study, the reduction of solute concetration within the river system may mean limited solutes for the vegetation on mounds, and this may further mean low precipitation of solutes on the mounds. Such a situation may have a negative influence on mound development. It is possible that the altered hydrological regime brought about by the canal excavations no longer favours the existence of termites and the mounds are no longer active.

CHAPTER 7. CONCLUSIONS

This study has highlighted a possible link between termite activities and soil properties in mounds on the Mkhuze floodplain. It has also suggested the possible effect that plant transpiration has on mound growh. The sizes that mounds can grow to are thought to be related to the amount of solutes that the Mkhuze River can transport into the system. Mounds characteristically occur in the floodplain area of the Mkhuze wetland. Most mounds occurred in intermittently flooded marsh areas, which are an intermediate location between the Mkhuze River and terrestrial systems. Clay sediments and sand grains, which are important resources for mound construction, seemed prevalent and intermixed in this locations. The results obtained through this study indicated distinct variations in organic matter and soil particle size distributions in soils found on the mounds and off mounds. Variations in these variables between soils from the mounds and adjacent soil suggest the possible involvement of ecosystem engineers within the environment, most likely termite species. The precipitation of solutes on mound sites contributes to mound growth.

From the Okavango study, Ellery and his co-workes (1998) developed a conceptual model for mima-mound formations and development. They believed this model would be widely applicable and would give a better understanding to the development of mima (or earth) mounds worldwide, especially in areas with a high atmospheric demand for water and which contain a high external source of dissolved solutes. This model seems applicable to mound formation and mound development in the Mkhuze floodplain. The climatic conditions within the system are conducive for both the existence of termite species and the formation of termite mounds.

Future work

A more detailed study which will allow (i) detection of termite species within the system; (ii) measurements of vegetation transpiration rates locally on the floodplain and on mounds; (iii) assessment of growth of existing mounds over a long period of time and; (iv) observing whether there are new or young mounds developing within the system, is recommended. This would allow for an opportunity to better understand the origin of earth mounds in this region and possibly help to understand their role within the wetland system. This would also give more support to the applicability of the Okavango model in the Mkhuze wetland system.

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APPENDIX A:

Table 1. Location and size dimensions of the mounds in the Mkhuze floodplain.

Mound identity	Location	Height/ dm	Diameter/m
1	$27^0$39.190'S $32^0$26.931'E	12.5	
2	$27^0$39.220'S $32^0$26.906'E	12	6
3	$27^0$39.214'S $32^0$26.911'E	14	8
4	$27^0$39.221'S $32^0$26.910'E	10	2
5	$27^0$39.222'S $32^0$26.945'E	17	10
6	$27^0$39.255'S $32^0$26.902'E	12.5	10
7	$28^0$39.249'S $32^0$26.942'E	16	16
8	$27^0$39.250'S $32^0$26.940'E	16	16
9	$27^0$39.290'S $32^0$26.904'S	10	10
10	$27^0$39.349'S $32^0$26.907'E	10	10
11	$27^0$39.303'S $32^0$26.902'E	10	5
12	$27^0$39.327'S $32^0$26.906'E	12.5	14
13	$27^0$39.324'S $32^0$26.911'E	1	1
14	$47^0$39.464'S $32^0$26.900'E	16.5	12
15	$27^0$39.223'S $32^0$26.882'E	20	18
16	$27^0$39.191'S $32^0$26.890'E	14	3 (radius/dead side)

17	$27^0$39.174'S $32^0$26.933'E	17	10
18	$27^0$39.204'S $32^0$26.970'E	1	1
19	$27^0$39.205'S $32^0$26.971'E	1	1
20	$27^0$39.205'S $32^0$26.970'E	1	1
21	$27^0$39.206'S $32^0$26.971'E	14	3
22	$27^0$39.305'S $32^0$27.049'E	15	12
23	$27^0$39.199'S $32^0$27.028'E	9	6
24	$27^0$39.196'S $32^0$27.031'E	1	1
25	$27^0$39.186'S $32^0$26.981'E	12.5	4
26	$27^0$39.186'S $32^0$26.980'E	10	4

APPENDIX B:

Table 1. Matrix colour results, visual inspection results for mottles and white nodules in mound 2

Sample Identity	Matrix colour	Mottles	Nodules
2(1) 0.01m	4/2.5	Nil	None
2(1) 0.5m	4/2.5	High	None
2(1) 1.0m	3/2.5	Moderate	None
2(1)1.5m	3/2	High	None
2(1) 2.0m	3/2	Moderate	None
2(1) 2.5m	3/2	High	None
2(1) 3.0m	3.5/2	High	None
2(2) 0.01m	2.5/2	Nil	None
2(2) 0.5m	2.5/2	Nil	None
2(2) 1.0m	4/2.5	Slight	None
2(2) 1.5m	4/2.5	Moderate	None
2(2) 2.0m	4/3.5	High	None
2(2) 2.5m	4/3	High	Present
2(3) 0.01m	3/1.5	Nil	None
2(4) 0.01m	4/3	Nil	None
2(4) 0.5m	3.5/3	Slight	None
2(4) 0.9m	4/3.5	Slight	None

Table 2. Matrix colour results, visual inspection results for mottles and white nodules in mound 2

Sample Identity	**Matrix colour**	**Mottles**	**Nodules**
6(1) 0.01m	4/2	Nil	None
6(1) 0.5m	3/1.5	Nil	None
6(1) 1.0m	4/3	Slight	Present
6(1) 1.5m	3/2.5	Slight	Present
6(1) 2.0m	3.5/3	Moderate	Present
6(1) 2.5m	4/1.5	High	None
6(1) 3.0m	4/2.5	High	None
6(2) 0.01m	3/1.5	Nil	None
6(2) 0.5m	3/1.5	Nil	None
6(2) 1.0m	3/1.5	Slight	None
6(2) 1.5m	3/1.5	Moderate	None
6(2) 2.0m	3/1.5	Moderate	None
6(2) 2.5m	4/1.5	High	Present
6(3) 0.01m	3/3	Nil	None
6(3) 0.5m	4/2	Nil	None
6(3) 1.0m	4/2.5	Moderate	None
6(3) 1.5m	4/3	High	None
6(4) 0.01	4/2.5	Nil	None

Table 3. Matrix colour results, visual inspection results for mottles and white nodules in mound 10

Sample Identity	Matrix colour	Mottles	Nodules
10(1) 0.01m	3/1.5	Nil	None
10(1) 0.5m	3/1.5	Nil	None
10(1) 1.0m	4/2.5	Slight	None
10(1) 1.5m	3/2.5	Nil	Present
10(1) 2.0m	3/2.5	Moderate	None
10(1) 2.5m	4/1.5	High	None
10(1) 3.0m	4/2.5	High	None
10(1) 0.01m	3/1	Nil	None
10(2) 0.5m	3/1.5	Nil	None
10(2) 1.0m	4/1.5	Slight	None
10(2) 1.5m	3/1.5	High	Present
10(2) 2.0m	3/2.5	Slight	None
10(2) 2.5m	3/2.5	Slight	None
10(3) 0.01m	3/1.5	Nil	None
10(3) 0.5m	5/3	Nil	None
10(3) 1.0m	5/2.5	Nil	None
10(3) 1.5m	3/2.5	Nil	Present
10(3) 1.75m	3/2	Moderate	None
10(4) 0.01m	3/1.5	Nil	None

Table 4. Matrix colour results, visual inspection results for mottles and white nodules in mound 10

Sample Identity	**Matrix colour**	**Mottles**	**Nodules**
12(1) 0.01m	3/1.5	Nil	None
12(1) 0.5m	3/1.5	Nil	Present
12(1) 1.0m	3/1.5	Nil	Present
12(1) 1.5m	3.5/2	Slight	None
12(1) 2.0m	4/3.5	Slight	Present
12(1) 2.5m	3.5/2	High	Present
12(1) 3.0m	4/2.5	High	Present
12(2) 0.01m	3/1.5	Nil	Nil
12(2) 0.5m	3/1.5	Nil	Nil
12(2) 1.0m	3/2.5	Slight	Present
12(2) 1.5m	3/2.5	Slight	Present
12(2) 2.0m	3/2.5	Moderate	Present
12(2) 2.5m	4/2.5	High	Present
12(3) 0.01m	3/1.5	Nil	None
12(4) 0.01m	3/2.5	Nil	None
12(4) 0.3m	3/2.5	Slight	None