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LATE QUATERNARY GEOMORPHIC PALAEOENVIRONMENTS OF SOME CENTRAL AND MARGINAL GREAT KAROO UPLANDS, SOUTH AFRICA.

BY

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KOMPASBERG, 2502.7 m, SNEEUBERG RANGE,

CENTRAL GREAT KAROO, SOUTH AFRICA.

I look to the mountains; where will my help come from? My help will come from the Lord who made heaven and earth.

(Psalm 121, vs. 1 and 2)

ABSTRACT

LATE QUATERNARY GEOMORPHIC PALAEOENVIRONMENTS OF SOME CENTRAL AND MARGINAL GREAT KAROO UPLANDS, SOUTH AFRICA.

Central Great Karoo uplands and their easterly margins have preserved within their landscapes sedimentary sequences which attest to deposition under a variety of geomorphic conditions. Fluvial and aeolian action, and slope and pedogenic processes have influenced these environments. Most of the depositional sequences are not intact, but have been altered by erosion.

This study concentrated on a suite of high altitude valley fills and other depositional landforms situated above the Great Escarpment along an east-west transect spanning some 500 km at approximately 32° south latitude. Field logging of depositional sequences combined with morphometric and geochemical laboratory analyses were utilised in an attempt to elucidate the environmental circumstances under which the sediments were deposited. Results from this investigation were then compared to work undertaken by other researchers in an effort to compile a broad brush picture of subregional environmental change in the central Great Karoo and its eastern margins during the late Quaternary.

The findings date back approximately 20 000 years and comprise a fragmented depositional history attesting to changing geomorphic conditions during the late Pleistocene and the Holocene. The evidence from the semi-arid interior of South Africa reflects a shorter time span than do depositional environments in Lesotho and to the east of the Great Escarpment. Within central Great Karoo uplands, little evidence predating the Holocene has remained preserved. The exceptions are isolated aeolian deposits dating back to the Last Glacial Maximum.

The onset of the last cycle of sediment accumulation within Great Karoo valley headwaters appears to have been synchronous with the commencement of the Holocene. Any previous evidence was removed prior to 10 000 years BP (before present). A catastrophic model is postulated for the flushing out of these valleys. The lithology of sediments derived from the Mesozoic sedimentary rocks of the Karoo and the vegetation of the region may have exacerbated the impact of this late Pleistocene event or sequence of events.

Subsequently, inorganic sediment infilled upland valleys from about 10 000 BP to 5000 BP, at which time there was a marked change to relatively organic rich accumulation. A gradualist model is proposed for this deposition, with moister conditions prevailing subsequent to the mid Holocene. The east-west rainfall gradient has also influenced the accumulation and preservation of valley sediments. Currently, Karoo uplands are vulnerable to erosion, with a major cycle of incision responsible for the present level of land degradation at many places within the Karoo. An anthropogenic trigger, associated with the impact of European colonisation of the interior of southern Africa is suggested for this. The older, isolated aeolian deposits in the eastern margins of the study area support regional evidence for a dry Last Glacial Maximum over the southern African interior. There is also tentative evidence of greater aridity during a Younger Dryas (approximately 11 000 BP) cool phase.

The harsh appearance of the Karoo landscape belies a biophysical system which is sensitive to both climatic and anthropogenic impacts. There is a need to understand the dynamics of Karoo geomorphic systems if this potentially fragile and unique environment is not to be degraded further.

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For my father

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of Australia, has made a case for land use planning. He argues for land utilisation according to

The study attempts to combine the essential elements of both approaches identified by Thomas (1986); that is, to examine geomorphic evidence from essentially closed depositional environments *and* to search for trends with respect to geomorphic processes at the subregional scale.

Geographically, the Karoo covers a significant proportion of the interior of South Africa. The southern most mountains of the Great Escarpment bisect the Karoo from east to west (Figs. 1.1 and 1.2). The Great Karoo is a dissected landscape of plains and flat topped hills, dominated by the mountain ranges running in a general east-west direction. Separating the Great Karoo from the Little Karoo to the south is the northern most range of the Cape Fold Mountains, the Swartberg range. The Little Karoo is an intermontane region, with various mountain ranges of the Cape Fold Belt (Fig. 1.1) forming its southern margin. It is the remoteness of the Karoo in terms of its distance from the major urban centres and its lack of infrastructure which has largely determined its status as one of the most under researched areas of southern Africa.

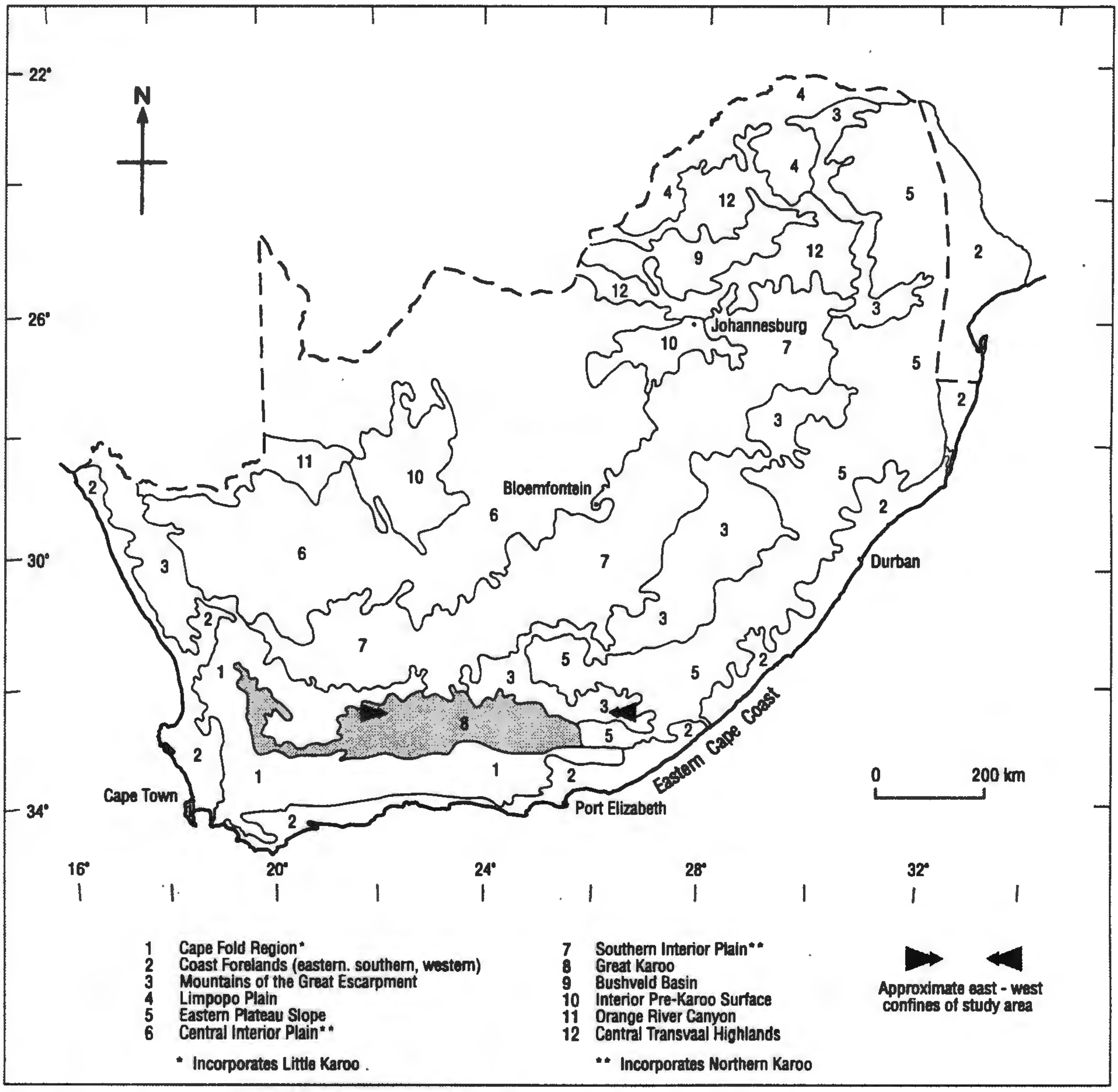


Figure 1.1 Broad terrain patterns of South Africa (after Kruger, 1983).

For the purposes of this study, the central Great Karoo and its margins may be regarded as a subregion. Within this subregion, the study area *sensu stricto* comprises the Great Escarpment and an area extending to a maximum of ~15 km north of the crest of the escarpment. Little geomorphic research has been conducted into the age, origins and palaeoenvironmental significance of Karoo late Quaternary sediments. Because of the vastness of the Karoo, much of the palaeoenvironmental research directed towards the region has been in the form of the discrete, point location type studies recognised by Thomas (1986). Such studies have typically been of a palynological nature (Meadows and Sugden, 1988, Sugden, 1989), though the study by Bousman *et al* (1988) embraced geomorphological aspects. Regional syntheses embracing environmental change in the Karoo have been undertaken in the form of review articles, for example Meadows (1988a). The palaeoclimatic significance of the Cainozoic stratigraphy of southern Africa (represented in the Karoo by various surficial deposits) has been reviewed by Partridge (1985, 1990, 1997). A comprehensive synthesis of the biophysical landscape of the Karoo is given in the reports of the Karoo biome project (Cowling *et al*, 1986; Cowling and Roux, 1987).

Sedimentological and microgeomorphological techniques are applied at a subregional level (the central Great Karoo and its eastern margins) in an attempt to understand those geomorphic processes which have influenced the landscape of the study area during the late Quaternary. The Karoo landscape is potentially very old, with evidence of old erosion surfaces (King, 1963; Dingle, Siesser and Newton, 1983; Moon and Dardis, 1988; Partridge and Maud 1987) preserved in places. The potential age of surficial deposits is therefore also old.

Any investigation into geomorphic palaeoenvironments is only really meaningful if some sort of temporal chronology can be established. Palaeoenvironmental reconstructions in semi-arid environments are hampered by the lack of ancient, preserved sediments containing material suitable for isotopic dating (Meadows, 1988b). In addition, the predominance of fine grained mud and siltstones of the Beaufort Series, and the lack of quartz can make the utilisation of luminescence dating techniques problematic. Where exposed sedimentary sequences display organic strata suitable for radiocarbon dating, these are invariably at cooler, moister sites. Such sites may be expected to occur at higher altitudes and to be more common in the wetter, eastern parts of the Karoo. High altitude valley fills have the advantage of being close to the original sediment source. They are consequently more likely to reflect the nature of the processes which were responsible for their accumulation. These include fluvial, colluvial, periglacial and pedogenic processes. The farther sediments are transported from their source, the more likely they are to undergo mixing with sediments derived from other sources. They may also be contaminated by, for example, chemical leachates from present day agricultural activities. Such contamination may complicate palaeoenvironmental interpretation.

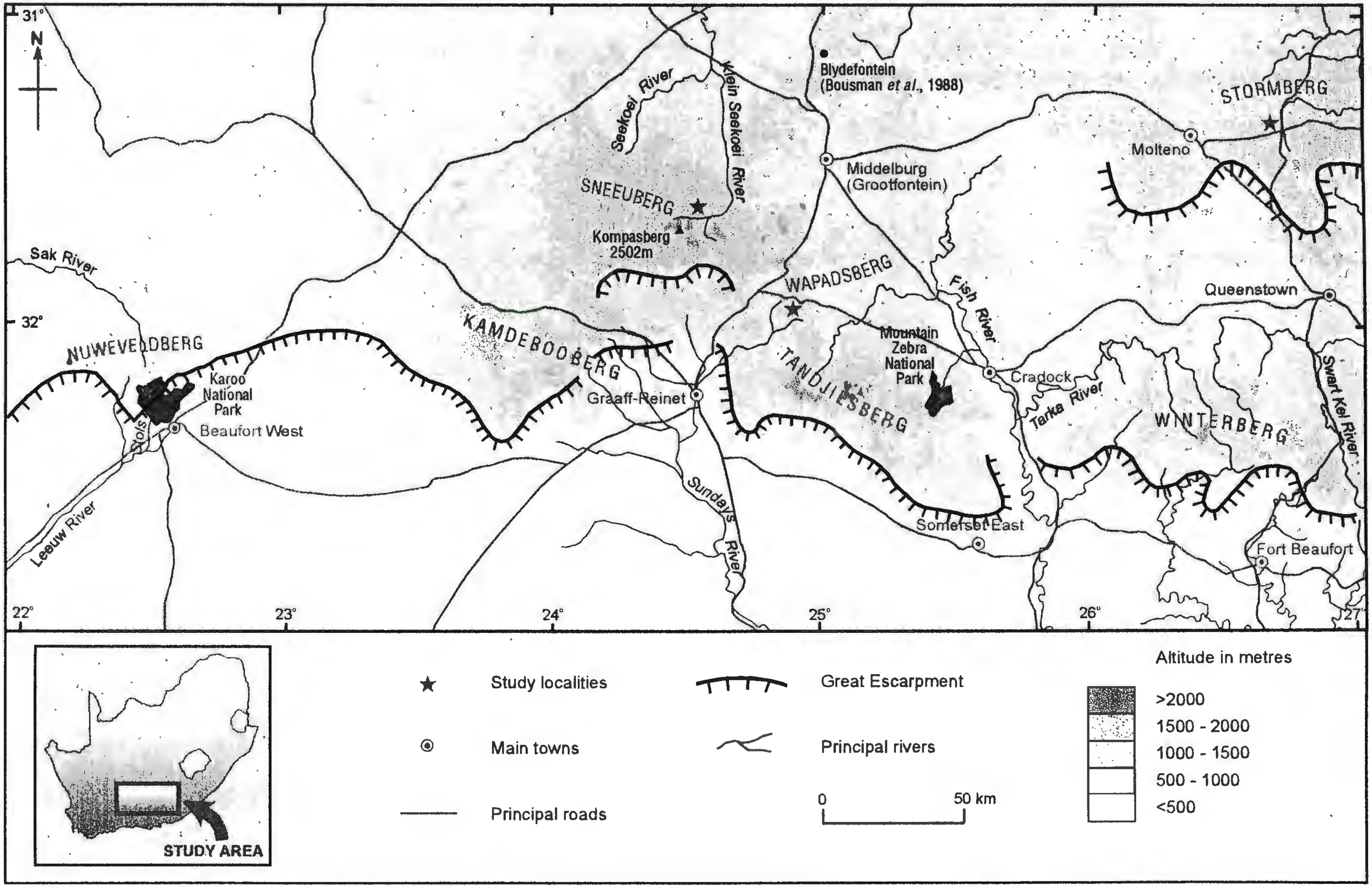


Figure 1.2 The study area.

1.3 AIM AND SPECIFIC OBJECTIVES

In order to investigate depositional sequences in a comparatively pristine state of both spatial and temporal preservation, as well as to obtain isotopic dates, this study concentrated on upland sites in the eastern and central part of the Great Karoo. Sites east of approximately 27°E (Figs. 1.1 and 1.2) effectively place the study out of the Karoo environment into a moister Lesotho type environment. Sites west of approximately 22°W would place the study in an environment which would preclude the preservation of datable organics owing to the extreme aridity of the region.

The primary aim of this study, was to examine, compare and evaluate the significance of the geomorphological evidence for palaeoenvironmental change in sediments from a number of high altitude sites along an approximate east-west transect across the Great Karoo. It is noteworthy that hiates in, or even the absence of any depositional evidence where it might reasonably be expect to occur, can also be a clue to the action of past processes.

In the light of this general introduction to the broad motivation and the aim of the study, the following are presented as specific objectives:

1. To investigate the distribution and location of central and marginal Great Karoo upland valley fills, as well as ancillary depositional environments such as pans, at selected sites.

2. To examine the morphology, and lithostratigraphy of valley fills and other deposits from a number of geographically dispersed sites. (This to be done by a single investigator so as to minimise investigative bias).

3. To review past and current geomorphic processes operating in the central Great Karoo subregion of the semi-arid interior of southern Africa and to assess the extent of anthropogenic influences on such processes at selected locations within the defined study area.

4. To establish whether a regional, spatial distribution pattern exists for late Quaternary sediments in the study area.

5. To attempt a palaeoenvironmental interpretation of the geomorphic evidence from the study area.

6. To infer, if possible, climatic trends and to recognise east-west rainfall gradients.

7. To place the findings of the study within the broader context of southern African palaeoenvironmental research.

1.4 A WORKING HYPOTHESIS AND STRUCTURAL OUTLINE

In order to contextualise this study, the author proposes the following as a working hypothesis:

Sediments sufficient in both quantity and variety are preserved at central Great Karoo upland sites such that a late Quaternary depositional chronology can be established. Depositional sequences would reflect palaeoenvironmental change to the extent that spatial and temporal climatic trends, as well as anthropogenic influences, might reliably be inferred.

The broad structure of this thesis comprises three parts:

Background and context

Chapters 1 to 5 familiarise the reader with the topic. The aim of the study is outlined, existing geomorphic evidence for palaeoenvironmental change from southern Africa is reviewed, and the methodologies utilised towards fulfilling the objectives of the study are described. The section concludes with a description of the geography of the Karoo.

Observation, analysis and classification

Chapter 6 examines the biophysical nature of each of the five study localities. A detailed analysis of the morphology and lithostratigraphy of the sites at each locality forms the basis of **Chapter 7. Chapter 8** attempts a classification of sedimentary sequences utilising a variety of statistical techniques applied to data generated during the field and laboratory stages of this research.

Interpretation and inference

Chapter 9 comprises an interpretation of the geomorphic evidence for environmental change based on the preceding section. **Chapter 10** examines the nature of Holocene valley fills and the mechanisms which impinge on them while **Chapter 11** comprises a synthesis of the discussion, culminating in a return to the working hypothesis and a number of conclusions. Future directions with regard to geomorphic environments of the Great Karoo complete the chapter.

CHAPTER 2

Environmental Change in Southern Africa

2.1 INTRODUCTION

From an exogenic perspective, landscapes are the product of a dynamic and ongoing interaction at the interface between the earth's surface and the atmosphere. Geomorphology is not simply concerned with describing earth surface features, but with gaining insights into the complex association between surface geology, endogenic forces and exogenic processes. To this may be added the role of vegetation and increasingly, during the Quaternary, the human impact dimension. It is the physical landscape, along with climate, which underpins all the biophysical life-support systems necessary for human well being. Humans impact on these systems, frequently with unforeseen consequences. The question of environmental change was raised at the start of the previous chapter. The point is reiterated that an understanding of the nature of physical environments and the mechanisms, climate driven or otherwise, which induce change, is vital for human survival. An appreciation of the geomorphic evidence for environmental change can contribute to this understanding.

Geomorphic evidence for environmental change in southern Africa may conveniently be considered on two temporal-spatial scales. Firstly, there is the long term, macroscale development of the subcontinent which is mirrored in the general form and gross relief of the current landscape. The present day form of the southern African subcontinent can be traced back to the break-up of Gondwanaland (Moon and Dardis, 1988). The subcontinent comprises a saucer shaped central depression largely enclosed to the east, south and west by the mountains of the Great Escarpment which drop abruptly to a narrow coastal margin (Ollier and Marker, 1985). The macroscale geomorphic development of the subcontinent has been controlled by phases of tectonic uplift, resulting in landscape rejuvenation and an increase in erosional activity. Moon and Dardis (1988) point out that the macroscale evolution of the southern African landscape, and specifically the concept of erosion surfaces, has attracted much controversy. This is reflected in the literature which deals with the geomorphic evolution of the subcontinent. Much of the thinking on the origin and preservation of planation (erosion) surfaces was influenced by King (1953, 1963, 1967) whose ideas dominated southern African geomorphology from the 1940s through to the 1960s. Notable criticisms levelled against the classic theory of erosional surfaces were those of de Swart and Bennet (1974), Helgren (1979) and Summerfield (1985). A significant reinterpretation of the geomorphic evolution of southern Africa since the Mesozoic was offered by Partridge and Maud (1987). This in turn has been the subject of comment, particularly with respect to the proposed origin of the Great Escarpment and its associated Cretaceous age (Burke, 1996).

While geomorphology has contributed significantly to an improved understanding of the macroscale development of southern Africa, it has, until recently, been less successful at the meso- to microscale. However over the past decade or so, geomorphic research in southern Africa has focused increasingly on regional and local evidence for processes which have shaped the landscape during the Quaternary. There are a number of problems associated with Quaternary landscape interpretation, not least the difficulties involved in coming to grips with the precise nature of climate-landform relationships (Meadows, 1988c). By way of contrast, associated earth science disciplines, notably archaeology and palynology, have contributed significantly to an improved understanding of environmental change over southern Africa during the Quaternary. Some general aspects of environmental change research in southern Africa are reviewed briefly before looking in greater detail specifically at geomorphic evidence for environmental change.

2.2 SOUTHERN AFRICA AND ENVIRONMENTAL CHANGE

The volume of research on environmental change in southern Africa has increased markedly over the past two decades. Two significant edited volumes were published in the 1980s (Klein, 1984; Vogel, 1984). Tyson (1986) discussed proxy indicators of climatic variability over southern Africa, while Deacon and Lancaster (1988) reviewed both the sources of late Quaternary palaeoclimatic evidence in southern Africa as well as summarising climatic change as reflected by this evidence. During the final stages of the preparation of this thesis, two further synopses of note appeared in the literature. Adams (1997) produced a global review of changing land environments since the last interglacial, while Partridge (1997) reviewed Cainozoic environmental change in southern Africa, focusing on the last 200 000 years. At the time of writing, the Southern African Society for Quaternary Research (SASQUA) had published twenty one volumes of the *Palaeoecology of Africa* dealing with archaeological, palynological, biogeographical and geomorphological evidence for environmental change. Alternate volumes of *Palaeoecology of Africa* were devoted to SASQUA conference proceedings.

Sugden (1989) noted that the southern African Quaternary has been the object of attention of three groups of researchers: Firstly, there are the earth scientists who are primarily concerned with geomorphic, sedimentological and pedological evidence for environmental change within the landscape. To this group may be added those marine geoscientists who seek a preserved proxy record of change in offshore sediments. Secondly, there are the natural scientists who adopt an ecological approach and seek evidence for functioning ecosystems in a temporal-spatial framework. The third group are those with an anthropogenic training who are interested in human settlement in the subcontinent. The prime concern of all three groups is a need to know how old the Quaternary record is, and to elucidate the environmental conditions reflected by this record. Baxter (1996) has compiled an up-to-date review of environmental change in southern Africa which encompasses the essential aspects of all three approaches.

Before reviewing *geomorphic* evidence for environmental change, a brief overview of the salient features of environmental, or, more precisely, climatic change pertaining to southern Africa, is presented. In line with the temporal framework of this research, it commences with the Last Glacial. Unless otherwise stated, the *resumè* is based on Adams (1997).

1. Over the last 130 000 years, the global climate has gone from warm interglacial, to cold glacial, and back to the warmer conditions which currently prevail.

2. A trend of drastic global cooling commenced some 115 000 years ago, during which time warm oscillations and pronounced cooling phases occurred.

3. About 30 000 years ago, the world's climate entered a major cold, arid phase, known as the Late Glacial Cold Stage, reaching its extreme ~21 000 to 17 000 years ago. The Last Glacial Maximum saw the maximum extent of global ice and occurred ~21 000 years (18 000 ^{14}C years BP) ago.

4. The period of maximum aridity did not necessarily correspond exactly with the Last Glacial Maximum, possibly occurring some 2000 to 3000 years later.

5. At the time of the Last Glacial Maximum, the southern African Escarpment experienced periglacial conditions (Marker, 1992), but not true glaciation. A cooling of several degrees celsius in mean annual temperature occurred over the subcontinent.

6. More arid conditions manifested themselves in two pulses of linear dune formation in the north western part of the subcontinent at ~26 000 to 20 000 years ago, and ~16 000 to 10 000 years ago (Stokes *et al*, 1997a).

7. Rapid global warming commenced 14 000 years ago (Broecker and Denton, 1989). Over southern Africa, there may have been a time lag prior to the onset of moister conditions which accompanied this warming.

8. This postglacial warming phase was interrupted by the Younger Dryas cooling, for which evidence is starting to emerge from southern Africa (Partridge, 1997). Over the western

subcontinent, a dry phase after ~12 000 BP continued into the early Holocene (Partridge *et al*, 1990; Partridge, 1997). The ~ 1300 year duration colder, drier phase terminated very abruptly about 10 000 ^{14}C years BP at the start of the Holocene when conditions became as warm as they are today.

9. The onset of the Holocene was marked by a return to warmer, moister conditions over southern Africa. Both the summer and winter rainfall regions experienced this warming, which probably peaked at between 7000 and 6500 years BP (Partridge, 1993). Discrepancies exist with respect to subregional moisture patterns within the summer rainfall region. This may be the result of interpretational difficulties with respect to the proxy data record, or due to real subregional differences (Partridge, 1997).

10. There is evidence from the Karoo (Bousman *et al*, 1988) of an increase in summer rainfall subsequent to 5000 years BP.

11. Finally, Partridge (1997) points out that changes in the southernmost parts of the subcontinent were not synchronous with the rest of the region. Baxter (1996), for example has demonstrated reduced moisture conditions along the Cape west coast during the first half of the Holocene. It must be noted that southern African climatic change research has focused on the summer rainfall area, and that the former extent of the winter rainfall region has not been fully resolved. The implication of discrepancies between rainfall regimes is that variations in solar insolation alone could not have been responsible for the evolution of Holocene climatic patterns over southern Africa.

2.3 GEOMORPHIC EVIDENCE FOR ENVIRONMENTAL CHANGE

Turning to the proxy record for environmental change in southern Africa, it is apparent that geomorphic evidence comprises but one facet of this record. A number of researchers have, at various intervals over the last two and a half decades, provided synopses of this evidence. Verhoef (1970) was the first to provide an overview of the geomorphic evidence for environmental change for the southern African Quaternary. Reynhardt (1979) followed this initial review with a summary of the relevant geomorphic literature from 1970 to 1979 dealing with the late Cainozoic, while Meadows (1988c) provided a review of research into landforms and Quaternary climatic change up to 1988. Botha (1992) has provided a comprehensive synopsis of research into hillslope sediments and colluvium, as well as discussing soils and landscape evolution during the Quaternary.

In spite of an increasing volume of earth science literature focusing on the Quaternary, Meadows (1988c) has pointed out the limitations of palaeogeomorphic features as indicators of environmental change. Various authors have elucidated the problems involved in attempting to establish a reliable chronology of events from geomorphic palaeoenvironments where available evidence is beyond the range of radiocarbon dating (Helgren, 1979; Butzer, 1984; Holmes, 1988; Meadows, 1988a; Holmes and Reynhardt, 1989). With the advent of luminescence dating techniques and their wider application to geomorphic studies, the problem of reliable chronologies is being addressed. Stokes *et al* (1997a), for example, have reported multiple episodes of aridity in southern Africa since the Last Interglacial based on no less than 48 optically stimulated luminescence dates from Kalahari palaeodunes.

The question of absolute dating of inorganic sediments is discussed at greater length in Chapters 4 and 9. More specifically, problems arising with respect to the dating of depositional sequences as a result of sediment diagenesis have been considered by Botha (1992), and Marker and Holmes (1993).

Notwithstanding problems related to the establishment of a reliable absolute chronology, a number of recent geomorphic studies of southern African palaeoenvironments have employed detailed field and laboratory investigations of largely *inorganic* stratigraphic sequences in an attempt to elucidate depositional chronologies and, by inference, palaeoenvironmental conditions from the southern African Quaternary. They include the investigation of colluvial deposits (Price Williams *et al*, 1982; Botha *et al*, 1990; Lewis and Hanvey, 1991; Botha, 1992; Botha *et al*, 1992; Wintle *et al*, 1993; Botha *et al*, 1994; Wintle *et al*, 1995a & b), sand, sand dunes and dry valleys (Shaw *et al*, 1992; Marker and Holmes, 1993; Stokes *et al*, 1997b), pans and lunettes (Buch *et al*, 1992; Marker and Holmes, 1995;) and high altitude depositional environments (Hanvey & Marker, 1994; Marker, 1995). Details are not discussed here. Rather, aspects of this literature which are relevant to this study are incorporated in the discussions in later chapters.

2.4 KAROO PALAEOENVIRONMENTS - A RESEARCH OVERVIEW

Compared to the northern hemisphere, the palaeoenvironments of southern Africa are under-researched. Even by southern African standards the Quaternary record of the Karoo is not particularly well defined, primarily because of its vast size and harsh physical environments. Baxter (1996) has listed the factors which, by and large, preclude the preservation of material suitable for radiocarbon dating in the southern African landscape. The aridity of the Karoo undoubtedly exacerbates the problem in this huge region. In spite of this, Karoo palaeoenvironments have been the object of investigation by a number of researchers. Most of these studies have been point specific, concentrating on individual sites (see 1.2). Palynological studies include those of Meadows and Sugden (1988), Scott (1989a) and Sugden (1989). Sampson (1985a, 1985b) documented the early anthropogenic impact on the palaeoecology of the Zeekoei River, which falls within the study area of this research. Bousman *et al* (1988) undertook a multidisciplinary investigation (archaeology, palynology, and geomorphology) at Blydefontein in the Great Karoo (Fig. 1.2). Harwood (1994) has provided a synopsis of southern African radiocarbon dates which includes the known dates from some ten Great Karoo sites.

Beside the study by Bousman *et al* (1988), and an investigation of valley fills (Holmes and Marker, 1995) little *geomorphic* work on palaeoenvironments has been undertaken in the Karoo *per se*. However, evidence from eastern upland sites peripheral to the Karoo has contributed considerably to a late Quaternary chronology of these eastern margins. In particular, colluvial depositional sequences and sediment accumulations in hillside hollows in the north eastern Cape and Lesotho have proved to be valuable sites (Lewis, 1988; Lewis and Hanvey, 1988; Lewis and Hanvey, 1993; Hanvey and Marker, 1994; Marker, 1994a; Marker 1994b; Marker 1995). A sand deposit and a pan/lunette complex from this eastern Karoo margin were reported by Marker and Holmes (1993, 1995).

As is the case with the broader body of geomorphic evidence from southern Africa, the principle findings from the research outlined above are not elaborated on here. Rather, the relevant points are incorporated in the discussion in Chapter 9 where the findings from this study are compared to aspects of previous research.

2.5 ARID AND SEMI-ARID PALAEODEPOSITS

2.5.1 Introduction

The object of study in this research was a variety of central Great Karoo palaeodeposits. In terms of lithology and geomorphic process, a variety of sediments can be expected to occur in arid and semi-arid depositional environments. Such material may derive from *in situ* weathering and be emplaced subsequently by one or more geomorphic agents. Alternatively, it may derive from an extraneous source and be transported into the study area by fluvial or aeolian action. In the case of both *in situ* and derived material, the sediments may have undergone subsequent diagenesis, or have been exposed and altered by pedogenic processes. Most of the sediments and environments described below occur within the study area, though not all were investigated as part of this study. Where necessary in terms of informing the reader, salient features of the study area's palaeodeposits are mentioned below. Linear dunes *per se* do not occur in the central Great Karoo. However, the presence of a sand ramp in the study area implies that a distant sand source cannot be discounted. For this reason, dunes are mentioned briefly.

2.5.2 Palaeosols

A number of authors have recognised the significance of soils as indicators of past environments and geomorphic processes (Gerrard, 1992; Botha, 1992; Lowe and Walker, 1984; Retallack, 1988; Valentine and Dalrymple, 1976). Palaeosol is the term commonly used to describe an ancient or fossil soil. The Soil Classification Working Group (1991, p. 234) define a palaeosol as a "buried soil" or as "soil that developed through processes to which it is no longer subject". Gerrard (1992, p.202) says "A palaeosol is a soil which has been formed on a past landscape". Botha (1992) quotes Ruhe (1956, p. 441) when stating that the most commonly quoted definition is "a 'fossil soil that was formed on a landscape during the geological past". Lowe and Walker (1984) distinguish between *buried, relict* and *exhumed* palaeosols. "*Buried* palaeosols occur where the land surface upon which they developed has been completely covered by younger sediments (Lowe and Walker, 1984, p. 117)." *Relict* palaeosols are soils formed under conditions other than those currently affecting a landscape, but which have not subsequently been buried. *Exhumed* palaeosols were buried but have subsequently been exposed through erosive processes.

As will be demonstrated, the palaeosols within the study area are buried. They have been exposed by incision into valley fills and are evident in gully side walls. Botha (1992) has discussed the recognition of palaeosols at some length. For the purposes of this study, colour differences between strata within the stratigraphic sequence were utilised as the primary field indicator of the presence of palaeosols, or incipient pedogenesis. The presence of soil structure was also important in identifying palaeosols. In the laboratory, textural properties and the presence of organic carbon were regarded as useful indicators.

2.5.3 Colluvial deposits

Whittow (1984, p. 105) defines colluvium as "a heterogeneous mixture of weathered materials transported downslope by gravitational forces and deposited at the foot of the slope".

A number of southern African studies have demonstrated the value of colluvial deposits as important geomorphic indicators of environmental change. They include those of Verhoef (1969) and Reynhardt (1979). Botha (1992) has provided a detailed account and palaeoenvironmental elucidation of late Quaternary colluvium in KwaZulu-Natal.

Distinctive, clast supported deposits which may be classified as colluvium are widespread on the western margins of the study area. These slope deposits are morphologically and sedimentologically distinct from the valley fills which form the main focus of this investigation.

The nature and extent of the colluvial deposits warrants a separate investigation. Colluvial deposits therefore received little attention within the context of this investigation.

2.5.4 Aeolian deposits

2.5.4.1 Linear dunes

Because inland sand dunes will only form under arid conditions, the presence of palaeodunes may serve as an indicator of drier conditions at some stage in the past. According to Partridge (1997) it was Lancaster (1979, 1981) who first noted the association between the orientation of the extensive system of parallel palaeodunes of the Kalahari and the predominant southern African anticyclone. Bullard *et al* (1995) have pursued the topic of linear dune morphological variability. Partridge (1997) discusses the inferred extent of shifts in precipitation thresholds since the Last Glacial Maximum. The ability to date such dunes (Stokes *et al*, 1997a & b) has improved significantly the resolution of arid phase chronologies represented by inland sand deposits.

2.5.4.2 Pans and lunettes

Pans with their associated dunes may preserve evidence of former climatic conditions (Butzer *et al*, 1973; Bowler and Jones, 1979; Lancaster, 1979; Goudie and Thomas, 1985; Buch *et al*, 1992). Lunette dunes or lunettes are aeolian deposits associated with seasonal pans. Their sediment (sand, silt or clay pellets), is derived by deflation from the pan floor. Typically the dune complexes are curved parallel to the downwind pan shoreline. The distribution of clay dunes is more restricted than those composed of sand since their formation requires clay fraction sediment and temporary saline pan conditions (Bowler, 1973).

Clay dunes are relatively rare in southern Africa, as compared with southern Australia (Campbell, 1968; Bowler, 1973). They occur chiefly in the Kalahari as the inner of paired lunette dunes (Lancaster, 1978). Erasmus and Harmse (1992) reported lunette dunes at Haksteen and Etosha Pans (in the southern Kalahari and northern Namibia respectively), while a pan fringing lunette dune in the southern Kalahari, comprising mainly fine sand, was reported by Thomas *et al* (1993). Lunettes are rare in the wetter eastern half of the subcontinent (Goudie and Thomas, 1984). As will be shown, where they do occur, they can contribute significantly to palaeoenvironmental reconstruction.

2.5.4.3 Sand ramps

Where topographic features are situated at more or less right angles to sediment transfer pathways, sand may become entrapped against these natural barriers to form sand ramps (Zimbelman *et al*, 1995; Thomas, 1997). D. Thomas (*pers. comm.*) has suggested the existence of similar palaeoforms south of the Orange River in the arid western parts of South Africa. Such features may well be more widespread along the eastern Karoo margins than is currently recognised. However the identification of entrapped sand deposits on vertical aerial photos or in the field at these more humid eastern localities may prove problematic because vegetation obscures their presence. Where such a feature was identified in the study area, it proved important in terms of the subregional geomorphic picture.

2.5.5 Fluvial deposits

Although ancient river courses and their associated channel bar and overbank deposits have received considerable attention in southern Africa, (Sohnge *et al*, 1937; Macfarlane, 1945; Breuil *et al*, 1948; Van Riet Lowe, 1952; Partridge and Brink, 1967; Butzer, 1971, 1980; Butzer *et al*, 1973, Helgren, 1979; Watson and Price Williams, 1985; Holmes, 1988) their reliability as palaeoenvironmental indicators remains questionable (Meadows, 1988c; Deacon and Lancaster, 1988). This is because fluvial depositional environments are a function of sediment supply, sediment properties channel morphology and fluvial dynamics. The interaction is complex and does not permit simple interpretation (Butzer, 1980; Meadows, 1988c). Rivers do not simply erode under one given set of conditions and deposit under another. Nanson and Croke (1992) have proposed a comprehensive, genetic classification of floodplains, which have been dominantly formed or modified by contemporary processes. However, they acknowledge the difficulty of recognising contemporary as opposed to palaeo-deposits. Helgren (1979) has proposed a scenario for deposition and erosion under both humid and semiarid conditions, as well as the likely preconditions for a switch from one action to another. Helgren's (1979) model and the implications in terms of this study are discussed in Chapters 10 and 11.

Within the study area a fluvial deposit comprising evidence of channel bar aggradation was examined. However, as will be demonstrated, the valley fills which are central to this investigation should not be regarded simply as the product of fluvial processes alone.

2.6 CONCLUSION

This chapter has provided the reader with an overview of the nature, type and scale of geomorphic evidence for environmental change in southern Africa in general and the Great

Karoo in particular. Landscape evolution prior to the Quaternary appears to have been strongly influenced by gross tectonic controls. This evolution had a profound influence on the climate of southern Africa (Maud and Partridge, 1987; Partridge, 1997).

During the late Quaternary, the influence of atmospheric forcing has been recognised as the primary control on environmental change over the subcontinent (Tyson, 1986; Partridge, 1997). This change is manifested by, *inter alia*, a variety of geomorphic features within the southern African landscape. An overview of this proxy evidence for environmental change has been presented above. This narrative leads into an examination of such evidence as it exists in the study area. Before doing so, the methodologies employed towards this end are outlined in the following two chapters.

CHAPTER 3

Field and Laboratory Techniques

3.1 INTRODUCTION

In this chapter, the strategy followed in identifying suitable localities for field investigation in terms of the primary aim of the study (see 1.3) is outlined. The field and laboratory techniques which were utilised during the investigation are described subsequently. For the sake of convenience, the procedural approach followed in this study may be broadly categorised as follows:

- Initial identification of study localities within a study area which had been broadly defined in terms of the theoretical context of geomorphic evidence for environmental change in southern Africa

- Field surveys, the identification of sites, logging and field sampling at the sites

- Utilisation of vertical air photos to ascertain the extent of gully erosion in a selected location (see Chapter 10)

- Routine laboratory analyses of sediments

- Additional analyses of selected sediment samples (see Chapters 4 and 8)

- Statistical treatment of data derived during field and laboratory analyses (see Chapters 4 and 8)

- Interpretation of data

3.2 IDENTIFYING STUDY LOCALITIES

The initial impetus for a detailed palaeogeomorphological investigation of central Great Karoo uplands followed a palynological study by Sugden (1989). She identified a potential stratigraphic marker in the form of a palaeosol dated 2510 ± 50 BP (Pta 5186) at its top, and 4870 ± 60 BP (Pta 5188) at its base. This palaeosol formed part of a valley headwater depositional sequence in the Sneeuberg Range above the Great Escarpment (Fig. 1.2). Sugden (1989) emphasised the difficulties involved in attempting to locate sediments suitable for ^{14}C

dating in the semi-arid Karoo other than at high altitude sites. M. Meadows (*pers. comm.*) suggested that, as the stratigraphic marker appeared to be widespread in the Sneeuberg Range, it might be of temporal and spatial significance at the regional scale.

The first step in this geomorphic investigation involved a study of 1:250 000 toposheets covering an east-west transect in an attempt to identify partly enclosed, highlying headwater valleys similar to the one in which Sugden (1989) had worked in the Sneeuberg Range. Such valleys might have, preserved within their stratigraphy, palaeosols similar to the Sneeuberg palaeosol. They would thus serve as potential suitable study localities. The transect extended from the Winterberg in the east to the Nuweveldberg in the west (Fig. 1.2). During an exploratory field trip, agricultural extension officers in the towns of Beaufort West, Graaff-Reinet, Cradock and Queenstown (Fig 1.2) were visited. An explanation was given of the type of stratigraphic marker being sought and the officers were shown photographs of the Sneeuberg palaeosol. The interview technique proved to be beneficial for the identification of prospective study localities and sites. Based on their working knowledge of the district, the officers would invariably identify specific sites which they felt would fulfil the requirements for inclusion in this study. In many cases they were also able to identify farmers who, in their opinion, could be relied upon to assist in an initial investigation. After a telephonic introduction, the individual farmers were visited by this researcher. In the case of the two National parks where potential study sites were identified, the appropriate authority was contacted for permission to enter the parks to conduct research.

An extensive field trip to numerous sites along a transect from the Winterberg and Stormberg in the east to the Nuweveldberg in the west confirmed that, in terms of the primary aim of this study, the most promising sites occurred in valley headwaters of northward draining streams, chiefly above the Great Escarpment. A few prospective headwater catchments identified on the maps and with the assistance of extension officers proved disappointing; a potentially ideal headwater catchment in the Kamdeboo Mountains (Fig. 1.2) for example yielded little evidence of sediment accumulation. The Sneeuberg locality on the other hand revealed more potential geomorphic evidence of past environments than the single palaeosol which had originally been identified. After the initial field trip, four study localities along the transect (Fig. 1.2) were provisionally chosen for more detailed investigation.

During 1991, subsequent to the commencement of the second phase of this study, a follow up *first phase* strategy was implemented. This was by way of a poster paper which was presented at the De Aar Karoo Biome Conference outlining the nature of the research and requesting information on possible additional sites. This did not prove successful; none of the conference attendees contacted the author.

3.3 FIELD SURVEYS

The second phase of this study commenced with a second, extended field trip into the study area. The objective was to identify and document sites within each study locality, to log depositional sequences and to collect samples. Two follow-up trips were made to the study localities as part of the fieldwork phase of the investigation. During the first of these, fieldwork was undertaken in the Stormberg Range (Fig. 1.2) with the intention of including it as a Karoo marginal locality. During the second follow up trip, ground truthing with respect to research undertaken on the earlier trips was done, photographs were taken and some additional samples collected for laboratory analysis. A final trip was later undertaken with the specific intention of collecting samples from two localities for luminescence dating.

High resolution field work essentially involved the identification and description of appropriate study sites, and the selection of the "best" or "most representative" depositional sequence at each site. The choice of exposed vertical profiles in depositional sequences for description and analyses implies, of necessity, a degree of subjectivity. In cases where more than one exposure existed in what was obviously the same stratigraphic sequence, the "best" profile was selected in terms of the clearest evidence of differentiation between strata, the freshness of the exposure, absence of obvious contamination through current reworking, and closeness to headwater source.

Detailed field logging (Miall, 1977; Lindholm, 1987; Graham, 1988) was undertaken at individual sites. Sedimentary profiles were described in the field in terms of their sedimentological and pedological characteristics (Gardiner and Dackombe, 1983; Graham, 1988; Soil Classification Working Group, 1991) and in terms of colour (Munsell, 1994).

Where necessary, clasts were measured with a ruler or tape measure to ascertain the range of long axes (Graham, 1988), while roundness was estimated based on the technique described by Krumbein (1941). Coring to a depth of 500 mm was undertaken using a Thompson soil auger, while coring in wetland sediments was undertaken using an Edjilkamp open chamber gouge auger. This end filling auger works effectively in homogenous, fine grained sediment (Sugden, 1989), providing undisturbed cores up to 1 m in length with a diameter of 30 mm. Extension rods permit coring to a depth of 6 m.

In exposed profiles, the face of the profile was first cleaned using a geological hammer or a spade to present a fresh face, before using a trowel to extract samples from the face. Samples thus obtained were handled and stored according to standard procedures (Gardiner and Dackombe, 1983) so as to prevent contamination. Mean gradients of stream channels and slopes were determined using an Abney level, a 2 m ranging rod and a tape measure according to the method described by Reynhardt (1979).

3.4 ROUTINE LABORATORY ANALYSES OF SEDIMENTS

Laboratory analyses of sediment samples, in order to elucidate information with respect to depositional circumstances and subsequent modification, is standard practice in any microgeomorphological investigation (Holmes, 1988; Reynhardt, 1979; van Rheede van Oudtshoorn, 1986).

All the sediment samples collected from exposed profiles and by coring during the course of this investigation were subjected to the same preparation and routine analytical procedures. This was in keeping with one of the stated objectives of this study that a single investigator should look at sediments from a variety of sites from widely dispersed localities.

Because of the uniqueness of their respective depositional environments, samples from three sites (Buffelsfontein Pan, Klipplaat Pan and the Klipkraal Sands, all within the Stormberg locality) were not necessarily subjected to the routine analytical procedures to which the profile and core samples were subjected. Conversely, samples from the above named Stormberg locality sites were subjected to a number of analyses which were not performed routinely on the samples from the other sites. These analyses are outlined in Chapter 4.

Routine laboratory work can be divided into physical (morphometric) and chemical analyses. Procedures are detailed in the following texts: Black (1965), Carver (1971), Friedman and Johnson (1982), Page *et al* (1982), Lewis (1984), Tucker (1988).

3.4.1 Physical analyses

3.4.1.1 Granular composition (Particle size analysis)

The granular composition or particle size distribution of a sediment or soil has endured in the literature as the standard method of describing the physical attributes of the sediment. Particle size distributions in sediments are a function of the parent material from which the sediment derives, the type of transport to which the material has been subjected, as well as the processes to which it has been subjected since being deposited (see for example Leeder (1982)). In this investigation, it was decided that the particle size distribution should reflect as far as possible the granular composition of the sediments as they occurred in the field. For this reason, pre-treatments were kept to a minimum and preparation methods were standardised. This was deemed to be particularly important in the case of partly weathered shale particles which frequently assume the size distribution properties of sand when they are not subjected to violent mechanical dispersion in the laboratory.

For the purposes of this procedural description, the term sediment is used in a broader context to include soil material. The methods utilised to determine particle size are based on those described in detail by Akroyd (1957), and Flemming and Thum (1978), and are presented in Appendix A.

3.4.2 Chemical analyses

3.4.2.1 pH

pH can serve as a useful indicator of post-depositional processes which may have leached ionisable bases in a sedimentary sequence. Two pH measurements were routinely undertaken on each sample, one in water and one in a 0,01M $CaCl_2$ solution. In the case of samples from the two pans (see 6.2.6), where exceptionally saline conditions were to be expected, an additional reading in a 1M KCl solution was taken. The use of either a $CaCl_2$ or KCl solution to obviate the influence of soluble salts when taking pH readings in a supernatant with a glass electrode meter has been explained by Hesse (1971) and Hawker (1986). The method described by the Non-Affiliated Soil Analysis Working Committee (1990) and by Schloemann (1994) was utilised to determine pH and is given in Appendix B.

3.4.2.2 Conductivity

To establish whether ionisable salts might be present, the conductivity of the supernatant of an identical sample to that used for determining pH in water was determined. This method is also detailed in Appendix B.

3.4.2.3 Total organic fraction

The presence of organic material may point to a reducing type environment, which will result in the preservation of such material . In order to determine the approximate percentage of organic material in each sample, the ignition loss method (Soil and Plant Analysis Council, 1992) was used. This method is detailed in Appendix B.

3.4.2.4 Organic carbon

The presence of organic carbon is an extremely useful indicator that pedogenic processes have influenced a profile or a particular stratum. To determine the amount of organic carbon in each sample, the Walkley-Black titration technique was used (Nelson and Sommers, 1982; Sugden, 1989; Non-affiliated Soil Analysis Working Committee, 1990). The method is detailed in Appendix C.

3.5 SUMMARY

The strategic approach with regard to this study has been documented in this chapter. Microgeomorphological studies rely not only on field observations, but also on a range of laboratory techniques, of which the routine techniques have been outlined above. Before proceeding to a description of the study area and a detailed examination of the study sites, a number of non-standard techniques are detailed in the next chapter. The rationale behind their application to selected suites of samples is also explained.

CHAPTER 4

Additional Techniques and Data Analysis

4.1. INTRODUCTION

In the previous chapter, the strategic approach employed during this investigation was outlined and the standard field and laboratory procedures utilised during the course of the study were described. In this chapter, a number of additional methodologies are described. They include laboratory techniques which were not routinely applied to all the samples, as well as the application of a suite of statistical techniques. These multivariate techniques were utilised to explore trends and groupings within the data set which was generated from laboratory analyses results. The rationale behind the adoption of specific techniques is discussed below and a brief description of each technique is provided.

4.2 ADDITIONAL CHEMICAL AND MINERALOGICAL ANALYSES

4.2.1 CBD extraction

Extractable Fe, Al and Mn can assist in elucidating certain environmental conditions under which sediments have existed subsequent to their deposition and burial (Mahaney *et al*, 1994). At the Buffelsfontein and Klipplaat Pans (see 6.2), CBD extraction was undertaken to determine why the pan floor sediments and the fringing lunettes display distinct colour differences. Secondary Fe, Al and Mn phases (crystalline and amorphous) were extracted by means of reduction by Na-dithionite (D) in a solution buffered by Na-citrate (C) and Na-bicarbonate (B). The method is described in detail by Jackson (1968).

4.2.2 Exchangeable cations and cation exchange capacity

To assist in determining to what extent current pedogenic processes are active, as well as to investigate differences in their chemistry, the exchangeable cations Ca, Mg, Na and K, as well as s-values (the sum of exchangeable cations) and the cation exchange capacity in cmol/kg were determined for sediment samples from the Buffelsfontein and Klipplaat Pans by means of atomic absorption spectrometry. The method is described by Knudsen *et al* (1982), and Lanyon and Heald (1982).

4.2.3 Clay mineralogy

4.2.3.1 Introduction

Soil parent material has a dominant influence on soil mineralogy, including clay mineralogy. However, the formation and alteration of clay minerals in soil environments is also a function of *inter alia* climate (see Dixon and Weed, 1989). Attempting to infer palaeoenvironments from clay mineral associations is not without problems; M. Fey (*pers. comm.*) has stressed caution because of the many extraneous factors which may contribute to the presence of certain suites of clay minerals in sediments. Bühman (1994) has discussed the limitations with respect to Karoo soils. Nevertheless, if cautiously interpreted, clay mineralogy may assist in confirming findings resulting from other analytical techniques.

4.2.3.2 Method .

To determine whether clay mineralogy might usefully reveal evidence of pedogenesis or obvious differences between horizons, exploratory, non-quantitative X-Ray diffraction (XRD) was carried out on 30 samples from a variety of depositional sequences in the study area. The samples were selected according to the relative positions of strata in the depositional sequences. Randomly orientated clay samples were analysed using XRD in the Department of Geological Sciences at the University of Cape Town, following the method described by Elsinger and Pevear (1988).

Clay mineral sequences may be utilised as indicators of the degree of weathering to which a soil has been subjected (Bühman, 1994). Palaeoenvironmental interpretations based on clay mineralogy and the behaviour of clay minerals over time have been reported for a diverse range of surficial sediments. These range from Pleistocene loess material (Kalm *et al*, 1996) to alteration of clay mineral suites over short term time scales (Righi *et al*, 1995). The relative abundance of members of a select suite of clay minerals from preserved palaeosols in a Holocene stratigraphic sequence was used by Bousman *et al* (1988) to assist in the elucidation of wetter and drier phases at Blydefontein in the Great Karoo (Fig. 1.2).

To investigate differences between the clay mineralogy of modern A horizons, palaeosols and other strata in the depositional sequences, semi-quantitative XRD of the clay fraction (<4μ) from 37 samples was undertaken by the Institute for Soil, Climate and Water. The procedure closely followed that of Bühman *et al* (1987) and Bühman (1991, 1994). XRD was undertaken on a Philips X-Ray diffractometer (PW1710). Radiation was generated at 40 mA and 45kV. Orientated samples were scanned from 2-20° or 2-35° 2θ, depending on the sample pretreatment. Semi-quantitative XRD was performed on selected samples from specific sites at all the study localities.

Plate 6.1 The Klipkraal Sand deposit. Face has been exposed by quarrying. Note partly vegetated footslope fan in foreground and Clarens sandstone boulders resting on the sand deposit.

Plate 6.2 The innermost of the lunette dunes fringing the Buffelsfontein Pan. The pan itself is to the immediate left of the photo.

Plate 6.3 Kalkoenkrans Vlei. Note the abrupt break of slope between the valley floor and the hillslope in the background.

Allemans Poort implies an almost constant thickness of sediment in the Holspruit Stream valley. The stream is located on an infilled watercourse which, prior to 1974, had incised to a depth of 2 m. Following cultivation which commenced in that year, the Holspruit incised to bedrock within two years (S. Stretton, *pers. comm.*). The implications of this accelerated erosion are discussed in Chapter 10, while the stratigraphy of the various sites at the Stormberg locality is examined in Chapter 7.

6.3 THE TANDJIESBERG STUDY LOCALITY

6.3.1 Physical setting

The Tandjiesberg is situated at the eastern extreme of an east - west aligned mountain range comprising both it and the Wapadsberg (Fig. 1.2). This range forms part of the Eastern Cape Great Escarpment (Fig. 1.1). The study locality comprises the upper catchment of the Wilgerboom River and part of the catchment of the adjacent Spekboom River (Fig. 6.7). Both streams initially flow north eastwards before joining the Great Fish River. The mean altitude of the study locality is ~1250 m.

6.3.2 Geology, geomorphology and soils

The geology of the study locality comprises mudstone, shale and sandstone of the Balfour Formation, which is the upper formation of the (lower) Beaufort Adelaide Subgroup (Table 5.1). In the study locality, the Balfour Formation sediments have been extensively intruded by dolerite, to the extent that dolerite outcrops dominate the landscape. Massive dolerite lacoliths have been exposed within the valley of the Wilgerboom River. Horizontally bedded resistant sandstone, and massive dolerite sills cap a number of mesas in the vicinity. The surrounding, elevated relief lies up to 300 m above the valley floor. Very shallow, extensively calcretised lithosols occur on the slopes. Soils of greater depth, and with a lesser degree of calcretisation occur on the alluvial fill in the Wilgerboom River valley.

6.3.3 Climate

The locality is situated west of the 500 mm isohyet which, in terms of rainfall, is typically regarded as the eastern extreme of the Karoo proper. The mean annual rainfall for the Mountain Zebra National Park (32°13'S; 25°28'E), based on 1983 to 1996 data, is 395.0 mm. The coefficient of variation is 30.7%. Most of this precipitation is the result of convectional summer thunderstorms.

Summers are hot, with daytime temperatures often exceeding 35°C. Winters are cool to cold (Figs. 5.6 and 5.7), with frost.

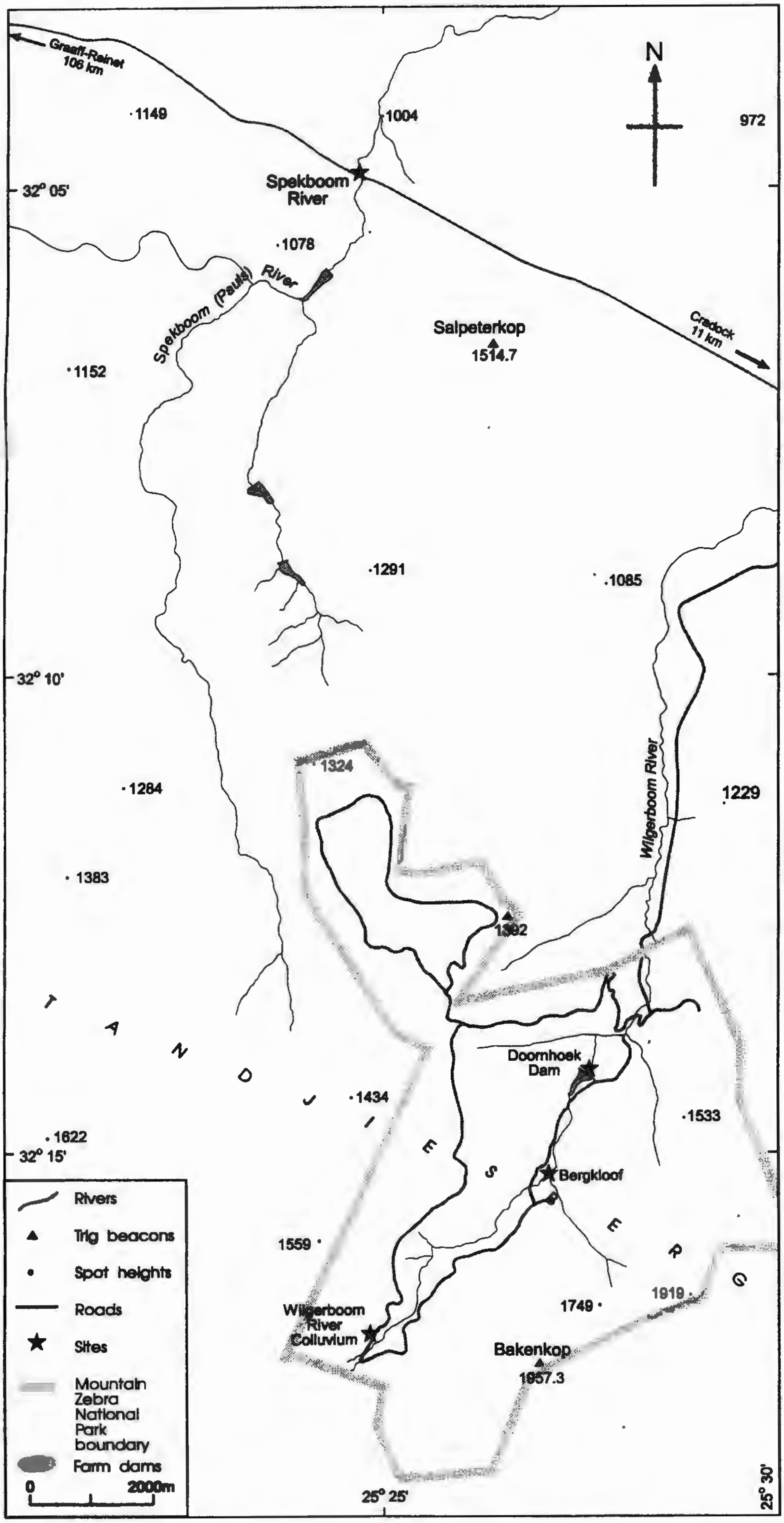


Figure 6.7 The Tandjiesberg study locality.

6.3.4 Vegetation

False Karroid Broken Veld (no. 37) occurs in the valleys and along the drainage lines of the study locality. It comprises shrubs, while *Acacia karroo* is the dominant tree species along the water courses, forming dense stands at places. Only the highest lying crests comprise patches of Karroid *Merxmuellera* Mountain Veld.

6.3.5 Land use

The major portion of the study locality lies within the Mountain Zebra National Park, which covers 6536 hectares (National Parks Board, 1988). The park was established in 1937 (Bulpin, 1986) as a protected habitat for the endangered Cape Mountain Zebra (*Equus zebra zebra*). Apart from the tourist infrastructure comprising visitor accommodation and associated facilities, and the Doornhoek Dam, the park has not been developed. It provides natural grazing for a variety of herbivores. The portion of the study locality outside the park is used for grazing small stock. The aridity of the area and the lack of perennial irrigation water precludes agriculture.

6.3.6 Individual sites

6.3.6.1 Introduction

The ephemeral Wilgerboom River forms the main drainage line in the Mountain Zebra National Park. The stream has a number of minor unnamed tributaries, none more than 2 km in length. The streams have incised deeply into the north facing slopes of the Tandjiesberg, resulting in narrow, steep sided tributary valleys. Where the Wilgerboom River emerges from such a valley, sediment has been deposited, covering the valley floor. Incision of the sediments to bedrock by the modern stream has exposed profiles, with a maximum depth of 7.5 m.

Four sections were recorded in detail. A small colluvial fan on the upper Wilgerboom River, and a profile at Bergkloof ~2.5 km from the source of the stream comprise the first and second sites respectively (Fig. 6.7). The third site is situated below the spillway of the Doornhoek Dam where the valley widens out considerably. The fourth site occurs outside the confines of the Park on the Spekboom River (Fig. 6.7).

6.3.6.2 Wilgerboom River Colluvium (32°16'50"S; 25°25'00"E) Altitude 1460 m

At 1480 m altitude, a 2.2 m vertical section of colluvium has been exposed by truncation of a small colluvial fan during road building. The fan is situated on the valley midslope ~20 m above the stream course. Because clean sections on such fans are seldom revealed, it was decided to log this exposure and to compare its microgeomorphology with that of the proximal valley fills.

6.3.6.3 Bergkloof Site (32°15'20"S; 25°27'05"E) Altitude 1260 m

At the Bergkloof site (Fig. 6.7) a profile has been exposed to bedrock at 5 m depth below the current valley floor by undercutting on a bend in the Wilgerboom River. The fluvially eroded bedrock comprises a series of step-like cascades, with a mean gradient of ~7°. The lateral extent of the full exposure is ~50 m, after which it pinches out upstream. Besides the modern topsoil, there is evidence of incipient soil formation from a depth of 80 cm to 2.98 m below the valley floor as well as a number of gravel lags upstream of the main exposure.

6.3.6.4 Doornhoek Dam (32°14'05"S; 25°27'40"E) Altitude 1240 m

3 km downstream from the Bergkloof site, a 6.3 m deep profile is exposed in the valley floor below the dolerite spillway of the Doornhoek Dam. The width of the gully is ~30 m and it extends downstream for ~200 m, with a gradient of ~2°. The profile is exposed to bedrock, though much of the stream bed is covered by very poorly sorted, angular sandstone and dolerite clasts (long axis length up to ~1.5 m) in a ~70 : 30 ratio. This site revealed the most detailed stratigraphy within the Tandjiesberg locality, with a number of palaeosols or phases of incipient soil formation being preserved within the exposure (Plate 6.4).

6.3.6.5 Spekboom (Pauls) River (32°04'50"S; 25°25'10"E) Altitude 1010 m

The Spekboom River, like the Wilgerboom River, is a non-perennial stream with its headwaters in the Mountain Zebra National Park. The stream flows more or less parallel to the Wilgerboom River (Fig. 6.7). The site on the Spekboom River chosen for detailed investigation displays a unique stratigraphy. There is evidence of cyclical fluvial deposition as well as a phase of incipient soil formation. The site is situated ~11 km from the headwater source at a point where the river has deposited both channel bar and overbank sediments. These sediments have subsequently been incised by the modern stream to a maximum depth of 6 m. Channel bar deposits comprising poorly sorted, rounded to well rounded clasts occur on the modern stream bed. The profile chosen for detailed investigation occurs on the undercut bank of a modern meander. Along with the other sites from this locality, its micromorphology is described in detail in Chapter 7.

Plate 6.4 Exposure of ~5 m depth of sediment at the Doornhoek Dam site, Tandjiesberg localit Palaeosols show grey colourin

Plate 6.5 Stone and concrete weir on the upper Klein Seekoei River, *circa* 1948. The weir, one of four in this segment of the catchment, was constructed as an anti-erosion mechanism

Plate 6.6 Gully erosion in the upper Klein Seekoei River valley. Main gully runs from left to right. Note extensive tributary gully, and human figure for scale.

6.4 THE WAPADSBERG STUDY LOCALITY

6.4.1 Physical setting

The Wapadsberg Range is situated north east of the town of Graaff-Reinet at the western extreme of the portion of the escarpment comprising it and the Tandjiesberg Range (Fig. 1.2). This study locality includes the headwater catchment of the Ruigterfontein stream (a tributary of the Sundays River) and a west facing footslope (Fig. 6.8). There is a marked altitudinal difference, with the former being situated above the escarpment and the latter at the foot of the escarpment. The mean altitude of that portion of the locality situated above the escarpment is ~1700 m, and below the escarpment it is ~1400 m.

6.4.2 Geology, geomorphology and soils

Katberg Formation sandstone and mudstone, capped by dolerite, forms the summit of the Wapadsberg Range. The footslopes below the Wapadsberg Pass comprise mudstones, shale and sandstone of the Adelaide Subgroup's Balfour Formation (Table 5.1). Above the escarpment, the undulating landscape is dominated by dolerite intrusions comprising tors, dykes and sills. Sediment has accumulated to a maximum depth of ~2 m within the valley of the Ruigterfontein Stream, while soils in the area are shallow and stony. The west facing footslope comprises a pediplain formed by the coalescence of pediments at the base of the Wapadsberg Range. Sediments have accumulated to a maximum depth of ~1.5 m on these footslopes. Soil development is poor, with extensive stripping of the modern A horizon due to sheet erosion.

6.4.3 Climate

Rainfall data for the farm Quaggasfontein (31°54'S; 24°49'E) is only available for the past four years. Mean annual rainfall is 347,7 mm. Because rainfall data is only available from 1993 to 1996, it was not possible to calculate a coefficient of variation. As is the case with the Tandjiesberg locality, summer thunderstorms provide most of the precipitation. As with the other Karoo localities, summers are hot and winters cool to cold, with frost. As no detailed temperature data is available for Quaggasfontein, Figs. 5.6 and 5.7 reflect temperature data for Graaff-Reinet.

6.4.4 Vegetation

As is the case with the Tandjiesberg study locality, False Karroid Broken Veld (no. 37) occurs in the valleys and along the water courses of the study locality, while the interfluves on the west facing footslopes of the Wapadsberg display a more open, False Upper Karoo (no. 36) type of vegetation. Above the Wapadsberg pass, Karroid *Merxmuellera* Mountain Veld occurs. The False Karroid Broken Veld is characterised by *Acacia karroo*. However, the trees are more scattered and so *Acacia karroo* does not dominate to the extent that it does in the Tandjiesberg study locality.

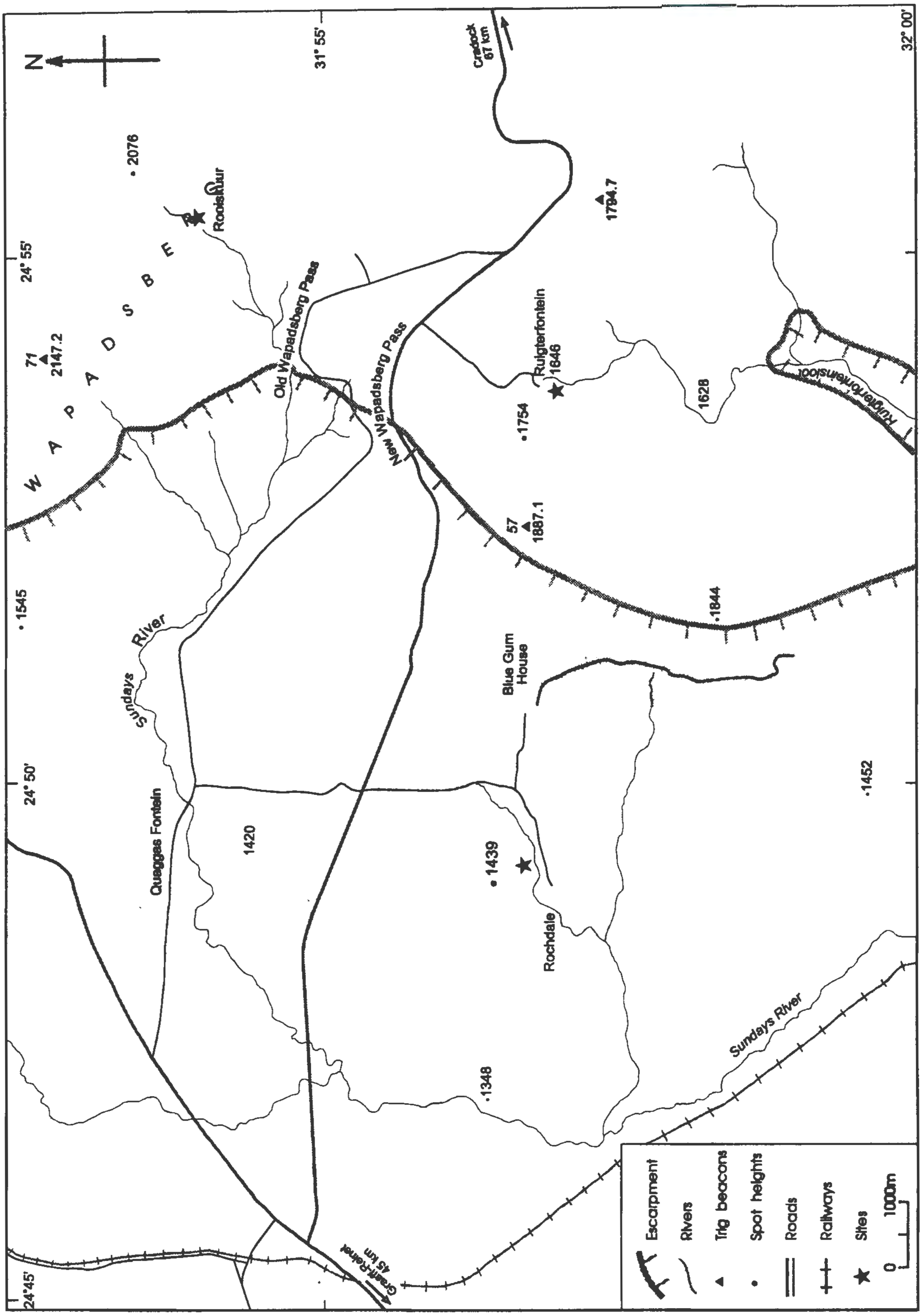


Figure 6.8 The Wapadsberg study locality.

6.4.5 Land use

The locality is utilised for grazing small stock. The undulating relief, ubiquitous doleritic intrusions, shallow soil cover and a lack of irrigation water preclude large scale agriculture. Because the flow regime of the upper reaches of the Sundays River is intermittent, the isolated patches of alluvium are only planted to fodder crops in wet years. At the time of undertaking field work in the early to mid 1990s, this locality was experiencing a severe drought (W. Loock, *pers. comm.*).

6.4.6 Individual sites

6.4.6.1 Introduction

From the summit of the Wapadsberg Pass, the Ruigterfontein Stream flows southwards before joining the Sundays River at the foot of the escarpment. The river valley is infilled by locally derived sediment. Two profiles on the upper reaches of the Ruigterfontein Stream were investigated, as well as one site on the pediment at the foot of the escarpment (Fig. 6.8).

6.4.6.2 Rooiskuur Site (Wapadsberg Summit) (31°55'00"S; 24°55'45"E) Altitude 1800 m

Gullying in a small headwater wetland on the farm Rooiskuur (Fig. 6.8) has exposed a depositional sequence to a depth of 3.1 m at which depth standing water occurs. The lateral extent of this exposure is limited to ~20 m and the gradient is ~2°. The Rooiskuur Wetland is fed by a weak perennial spring. The watershed to the west of the wetland comprises a dolerite capped hogback which reaches an altitude of 1887 m above sea level. There is evidence of vigorous physical weathering of the caprock in the form of abundant scree deposits scattered on the slopes of the hogback.

6.4.6.3 Ruigterfontein Site (Wapadsberg Summit) (31°57'10"S; 24°54'50"E) Altitude 1646 m

At this site, the Ruigterfontein stream has exposed a profile to a depth of 5 m below the valley floor along the undercut bank of a small meander. As is the case with the Rooiskuur profile, the exposure is of limited lateral extent and the gradient is limited to ~3°.

6.4.6.4 Rochdale Farm (31°57'00"S; 24°48'45"E) Altitude 1360 m

Sediments deposited on escarpment footslopes on the farm Rochdale to the west of the Wapadsberg summit (Fig. 6.8) have incised to bedrock, thereby creating a number of gullies. The gullies can be followed for ~2 km over a gradient which increases from ~2° to ~6° and typically reveal up to ~3 m accumulated depth of sediment. The exposure chosen for analysis displayed a variety of sedimentary structures, as well as a evidence of incipient soil formation between 91 cm and 1.62 m below the valley floor.

6.5 THE SNEEUBERG STUDY LOCALITY

6.5.1 Physical setting

The east-west orientated Sneeuberg Mountain Range (Fig. 1.2) comprises one of the most prominent ranges of the Great Escarpment. Kompasberg (2502 m) is, with the exception of the summit of the Cape Drakensberg, the highest peak in the Eastern Cape Escarpment. The locality chosen for a detailed investigation (Fig. 6.9) is situated to the north of the Kompasberg. It comprises the upper catchment and headwaters of the Klein Seekoei River, a tributary of the Seekoei River, which in turn feeds the Orange River. First and second order headwater valleys have been largely infilled with colluvially and fluvially derived sediments to maximum depths of ~8 m. Incision of these sediments has resulted in the formation of a number of gullies.

6.5.2 Geology, geomorphology and soils

The high lying relief in the study locality comprises Katberg Formation sandstone and mudstone, capped by dolerite. Numerous dolerite intrusions occur, with corresponding localised metamorphosis of the adjacent sediments. The prominent Kompasberg Peak is a dolerite pluton, while dolerite tors are common in the headwater valley of the Klein Seekoei River. They comprise deeply weathered corestones in a matrix of red ferruginous sand. Hillslopes display horizontally bedded sandstone and shale. The resistant sandstone bands stand out prominently, resulting in structurally controlled slopes dominating the landscape within this study locality. The valley floors comprises less resistant Balfour Formation mudstones, shales and sandstones covered by a veneer of unconsolidated Quaternary sediment. A notable feature of the soils within the upper catchment of the Klein Seekoei River valley is the large scale absence of a modern A horizon. This will be discussed at a later stage.

6.5.3 Climate

The Sneeuberg Mountains fall within the eastern region of the Warm Temperate Zone (Sugden, 1989). According to Schulze (1980), the area receives on average 346 mm of rain annually. Rainfall peaks in autumn rather than summer, with a February to March maximum (Sugden, 1989). Convectional thunderstorms are common in summer, while snowfalls, associated with the

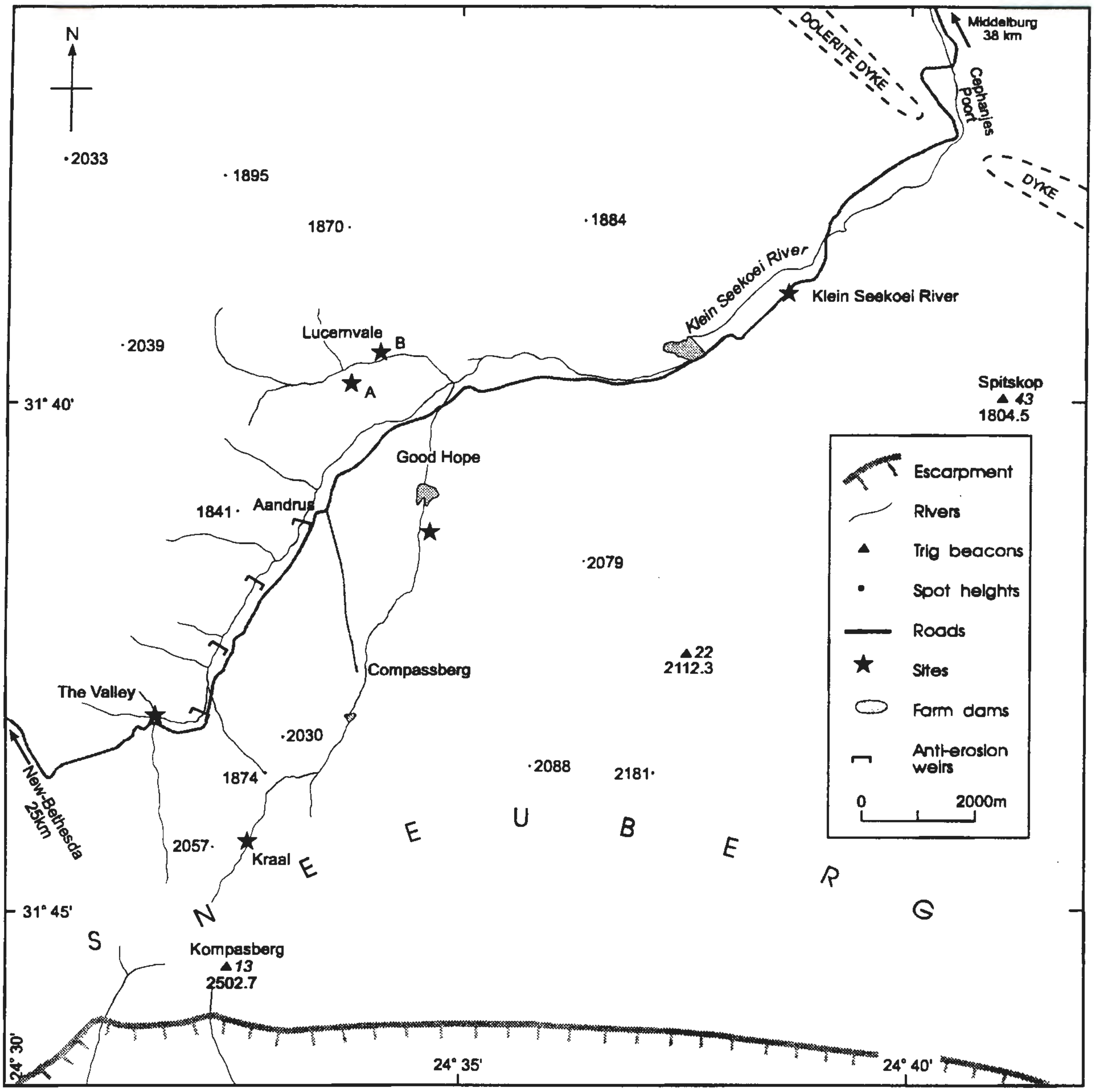


Figure 6.9 The Sneeuberg study locality.

west to east passage of cold fronts, occur in the upper mountainous areas and valley headwaters during winter. Rainfall records are available for Compassberg farm (31°42'40"S; 24°33'50"E, altitude 1720 m) for 1989 to 1992. They show a higher mean annual rainfall (474 mm) for this high altitude station. Rainfall records from 1959 to 1993 for Verdun (31°40'05"S; 24°33'00"E, altitude 1660 m) and previously referred to as Aandrus, show a mean of 433 mm and a coefficient of variation of 39,4%. Both the diurnal and seasonal temperatures show large fluctuations, with summer maxima of ~30°C and winter minima of below -10°C being recorded (Schulze, 1980).

6.5.4 Vegetation

The vegetation of the Sneeuberg Range comprises Karroid scrub on the plains and sourveld grass in the mountain reaches (Sugden, 1989). The Acocks (1988) classification is Karroid *Merxmuellera* Mountain Veld in the higher lying areas, and False Upper Karoo in the valleys.

The extensive sheetwash on the footslopes in the study locality has stripped much of the topsoil, resulting in the absence of a modern A horizon at places. At such places, the vegetation has taken root in the B horizon. Where extensive sheet wash occurs, *Lycium cinereum*, and *Eriocephalus spinescens* dominate.

6.5.5 Land use

The primary land use is large and small stock grazing. The sourveld grass of the upper slopes are utilised for grazing cattle and sheep, while the Karroid vegetation of the footslopes are more suited to small stock. At places the valley floors are cultivated to produce fodder crops, as well as cash crops such as potatoes on a small scale. The current veld management strategy on the farm Compassberg is intensive non-rotational grazing (K. Mc Cabe, *pers. comm.*). The strategy aims for ecological rehabilitation in terms of a climax vegetation which includes grass species which have been severely impacted as a result of past veld management practises.

Four large stone- and concrete weirs span the upper Klein Seekoei River at intervals of ~800 m (Fig. 6.9). These structures were built after the Second World War to arrest soil erosion by trapping sediment (N. Sheard, *pers. comm.*) and stabilising the incipient gullying along the water course. Sediment has accumulated behind all four weirs to the maximum height of each weir. This sediment is largely vegetated with reeds and grass (Plate 6.5). The implications of this are discussed in Chapter 10.

6.5.6 Individual sites

6.5.6.1 Introduction

Five sites, chosen on the basis of their positions within the catchment as well as their stratigraphy, were described and sampled (Fig. 6.9). All five sites chosen for detailed investigation display cut-and fill sequences, with profiles which have been exposed by gully erosion. Three of the sites occur on tributaries of the Klein Seekoei River, one is situated at the headwater of the Klein Seekoei River, while the fifth site is situated on the Klein Seekoei River below the confluence of the tributaries (Fig. 6.9).

6.5.6.2 Compassberg Gully (31°45'00"S; 24°32'10"E) Altitude 2000 m

This gully is situated on the northfacing footslope of the Kompasberg Peak ~1 km from the Great Escarpment watershed, on the farm Compassberg, at the site of an abandoned stock enclosure or *kraal* (Fig. 6.9). The low sinuosity gully is up to 5 m wide and extends for ~900 m, with a mean gradient of 3°. Sediment is exposed to a depth of 3.9 m along the watercourse of this unnamed tributary of the Klein Seekoei River which drains a dissected and desiccated former wetland. Remnants of the original wetland floor can still be observed as individual sediment pedestals, stripped of their original A horizon. The stream has not incised to bedrock, and the floor of the gully is vegetated.

At the head of the gully, there is evidence of pedogenesis in sediment which has accumulated to a depth of 50 cm against the foundations of a stone wall. The wall was constructed by migrant stock farmers or *Trekboers*, probably during the second half of the eighteenth century (K. Mc Cabe, *pers. comm.*).

6.5.6.3 The Valley (31°43'15"S; 24°31'30"E) Altitude 1780 m

This site is situated adjacent to a saddle which forms part of the Great Escarpment watershed. The site is situated on the primary headwater stream of the Klein Seekoei River, ~3 km from the watershed. A 10 m wide gully, exposed to bedrock at 3.8 m, extends for ~800 m along this section of the stream. There is evidence for a phase of incipient soil formation within this profile. A number of prominent dolerite tors flank the gully. Well rounded to subangular, massive (long axis up to 2 m), very poorly sorted dolerite boulders cover the stream bed, which has a gradient of ~5°.

The first of the concrete weirs described under 6.5.5 occurs ~600 m downstream from this site. The weir was constructed in 1950, and has a height of 3.8 m. Sediment has backed up behind this structure to the maximum depth of 3.8 m. The second weir, ~700 m further downstream, has likewise "filled" with sediment to its height of 4.5 m. As mentioned, the significance of this accumulation is discussed in Chapter 10.

6.5.6.4 Good Hope Site (30°41'30"S; 24°34'45"E) Altitude 1685 m

At the Good Hope site a 5.5 m deep profile has been exposed. The site is situated ~8 km downstream on the same tributary as the Compassberg site. The dip of the silt- and sandstone bedrock channel on which the valley fill has accumulated is less than 2°. Consequently, the profile does not pinch out rapidly in an upstream direction but is exposed over a distance of ~1.5 km.

6.5.6.5 Lucernvale Sites A and B (31°39'55"S; 24°33'30"E) Altitude 1680 m

On the farm Lucernvale, a number of gullies have developed in footslope deposits at the base of a sandstone ridge. These gullies intersect the Lucernvale Stream at almost right angles. The stream itself has incised to bedrock, exposing profiles which display up to 4.5 m depth of sediment.

6.5.6.6 Klein Seekoei River (31°39'00"S; 24°37"50"E) Altitude 1570 m

This site is situated immediately upstream of a constriction in the valley formed by a dolerite ridge at Cephanies Poort (Fig. 6.9). Deeply weathered dolerite boulders form a number of tors which dominate the eastern flank of the valley, while the footslope on the opposite valley flank is deeply gullyed (Plate 6.6). There is evidence of ponding behind the constriction at this site, with up to 7.5 m depth of accumulated sediment. The valley fill has been stripped of its modern A horizon, but appears to be capped by sheet wash deposited material. A discussion of the detailed morphology of this site, as well as the other sites at this locality, follows in Chapter 7.

6.6 THE NUWEVELDBERG STUDY LOCALITY

6.6.1 Physical setting

This is the most westerly of the five study localities (Fig. 1.2.). It is situated within the Nuweveld range, which forms the escarpment at this location. The non-perennial Stols River forms the main drainage line (Fig. 6.10). There are no perennial drainage lines within this locality.

6.6.2 Geology, geomorphology and soils

The geology of the locality comprises Teekloof Formation mudstone and sandstone of the Adelaide Subgroup. This member is second but one from the base of the Adelaide Subgroup and is often described simply as lower Beaufort. The sediments have been extensively intruded by dolerite sills, which form the resistant capping rock of the Nuweveld Mountain Range. Topographically, the locality comprises three distinct divisions: the upper plateau (mean altitude 1750 m), the middle plateau (1300 m), and the plains (840 m) (National Parks Board, 1991). The highest altitude in this part of the Nuweveld range is 1912 m.

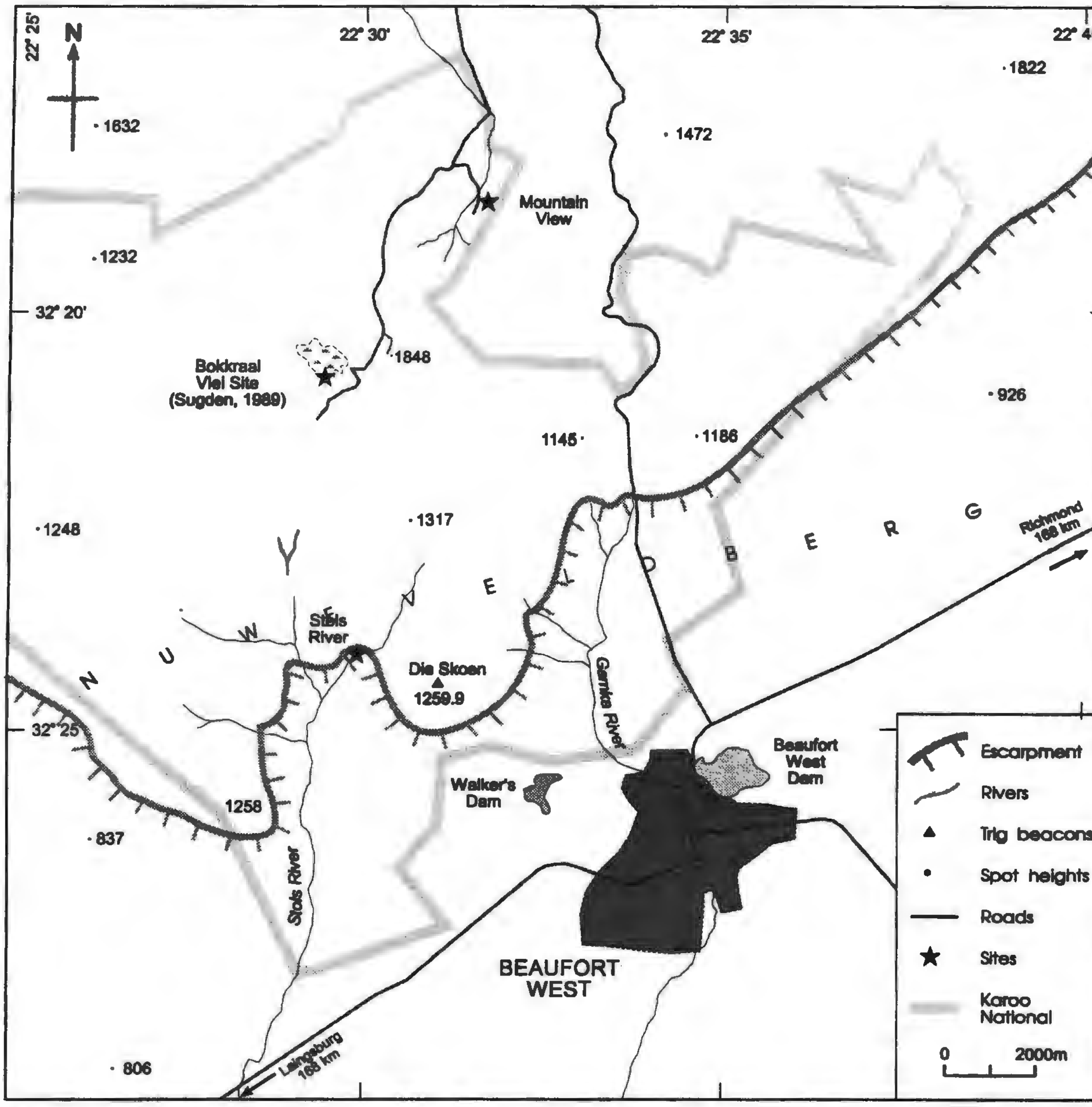


Figure 6.10 The Nuweveldberg study locality.

6.6.3 Climate

The mean annual rainfall for the Karoo National Park (32°12'S; 22°31'E), is 352.9 mm. This figure is based on the only available data set for the Park itself, namely from 1985 to 1996. The coefficient of variation is 22.6%. Convective thunderstorms occur, with most of this precipitation falling in mid summer. Summers are hot, with daytime temperatures commonly exceeding 35°C. Winters are cool to cold, with frost.

6.6.4 Vegetation

Two vegetation types occur in this study locality. The footslopes and valleys are characterised by Karroid Brokenveld (no. 26), while the higher reaches of the Nuweveldberg comprise Karroid *Merxmuellera* Mountain Veld (no. 42).

As in the case of the Tandjiesberg and Wapadsberg study localities, *Acacia karroo* occurs along water courses.

6.6.5 Land use

The Karoo National Park was proclaimed in September 1979 (Bulpin, 1986), primarily to protect flora and fauna indigenous to this the largest biome in South Africa (National Parks Board, 1991). The park covers 20 000 ha. As is the case with the Mountain Zebra National Park, development is limited to tourist accommodation and infrastructure. The park provides natural grazing for a variety of herbivores, including species such as the Black Rhino (*Diceros bicornis*) which have been reintroduced to the area.

6.6.6 Individual sites

6.6.6.1 Introduction

In terms of the types of depositional environment chosen for inclusion in this study, there is a paucity of sites at this locality. Palaeosols do not appear to have developed in the valley fill stratigraphy, and there is little evidence of incipient soil formation. However, two sites were chosen for investigation. In addition, two topsoil samples (referred to as Range 1 and Pien 1) were taken upstream of the Stols River site. They were included primarily for comparative purposes as intact A horizons are relatively uncommon at this locality.

6.6.6.2 Mountain View (32°13'20"S; 22°31'55"E) Altitude 1680 m

Dolerite crests on the plateau above the Nuweveldberg Escarpment partly enclose a small amphitheatre which is drained by the headwater tributaries of the northward flowing Sak River (Fig. 6.10). A number of minor depressions within the amphitheatre contain vlei like features within which are preserved shallow accumulations of sediment, including organic material. Headwater incision on Mountain View farm (which is incorporated in the Karoo National Park) has exposed the stratigraphy of the surficial sediment.

6.6.6.3 Stols River (32°19'10"S; 22°30'00"E) Altitude 960 m

At the base of the Nuweveldberg Escarpment, the deeply incised valley of the non-perennial Stols River is infilled with poorly sorted, angular to partly rounded, calcretised boulders resting on purple mudstone of the Adelaide Subgroup. The boulder deposit is capped by a modern lithosol. The fill has in turn been incised to reveal the sequence described above.

6.7 SYNTHESIS

This chapter has provided an overview of the physical setting of the study localities and their respective sites. The most easterly, marginal Karoo locality included three sites where aeolian activity is presumed to have played an important role in producing the distinct geomorphic features which occur here. This locality also produced a core from a valley bottom marshland or *vlei*. This locality and the central Great Karoo localities yielded profiles exposed as a result of fluvial incision of valley fills. These profiles comprise the bulk of the study sites. Chapter 7 will look in closer detail at relevant aspects of the morphology, stratigraphy and sedimentology of the various sites. This is a prerequisite in terms of the subsequent fuller palaeoenvironmental elucidation of these depositional environments.

CHAPTER 7

The Morphology and Sedimentology of Selected Palaeodeposits

7.1 INTRODUCTION

In Chapter 6, a geographic description of each of the five study localities was presented and the gross geomorphic setting of each site within the context of the study locality was described. In this chapter, the micromorphology of the profile representing each site is examined. The morphology of the Klipkraal Sands, the fringing lunettes at the Buffelsfontein and Klipplaat Pan sites, and the core from Kalkoenkrans Vlei are also discussed in greater detail. Sites are grouped according to their localities, which in turn, are presented in sequence from east to west. Information pertaining to each site is presented diagrammatically, while the text elaborates on any geomorphic features which are unique to the site. Where particularly horizons or strata are referred to by number, such numbers correspond to the sample number indicated on the relevant profile (refer to Figs. 7.2 to 7.21). A standard range of laboratory analyses (see Chapter 3) was performed on sediment samples taken from each site. In addition (see Chapter 4), certain samples were subjected to an additional range of analyses. The reader's attention is drawn to particular sedimentological or pedogenic properties only where this is deemed necessary in terms of processes which either were, or still are, active within the particular environment. The process of palaeoenvironmental reconstruction is an incremental one, proceeding from field observations through analytical routines to an ultimate interpretation. This interpretation forms the basis of Chapter 9.

At this juncture, it may be appropriate to sound a note of caution. While particle size analyses can be of assistance in reconstructing depositional environments (Folk and Ward, 1957), such data should not be used simplistically to infer modes of sediment transport. Similarly, the various chemical analyses undertaken should be interpreted within the context of the geomorphic setting of each site and are mentioned here accordingly. In the context of a single profile, relatively low pH values may be indicative of base deficiency due to some degree of leaching, while relatively high conductivity (low electrical resistance) values are taken to imply the presence of free and/or soluble salts. The presence of organic carbon, when associated with evidence of structure in a horizon, is tentatively interpreted as being indicative of incipient pedogenesis. Where sediment colours are described, these are according to the Munsell colour notation (1994). Typically, darker values may indicate zones of accumulation or pedogenesis, while mottling may be indicative of waterlogged or gley conditions.

7.2 STORMBERG LOCALITY

7.2.1 Introduction

In the context of the study area, this most easterly locality is unique in that the sites under investigation were not limited to valley fills, but included what appeared, on initial inspection, to be aeolian sediments. The actual depositional environment at each site is discussed below.

7.2.2 Klipkraal Sands (31°23'30"S; 26°41'40"E) Altitude 1820 m

In vertical section, the main sand deposit is seen as a soft well-bedded "sandstone" with incipient joints and a maximum visible depth of 7 m on the upper edge of the terrace. Compaction is sufficient to retain vertical faces, but with additional pressure or disturbance, the sediment loses coherence. The sand is almost horizontally bedded but occasional cross-bedded layers intervene (Plate 7.1). Narrow bands of greater resistance to subaerial weathering and fluvial incision protrude from the sections. In addition, horizontal laminae which vary in thickness from ~1 mm to ~1 cm occur in exposures against the back wall of the deposit. They stand proud of the back wall by up to 2 mm, implying greater resistance to erosion. All beds dip at 4° downslope parallel to the surface. On the footslope fan only shallow dissection has occurred, so few exposures are available. These show a uniform, loose, unbedded deposit.

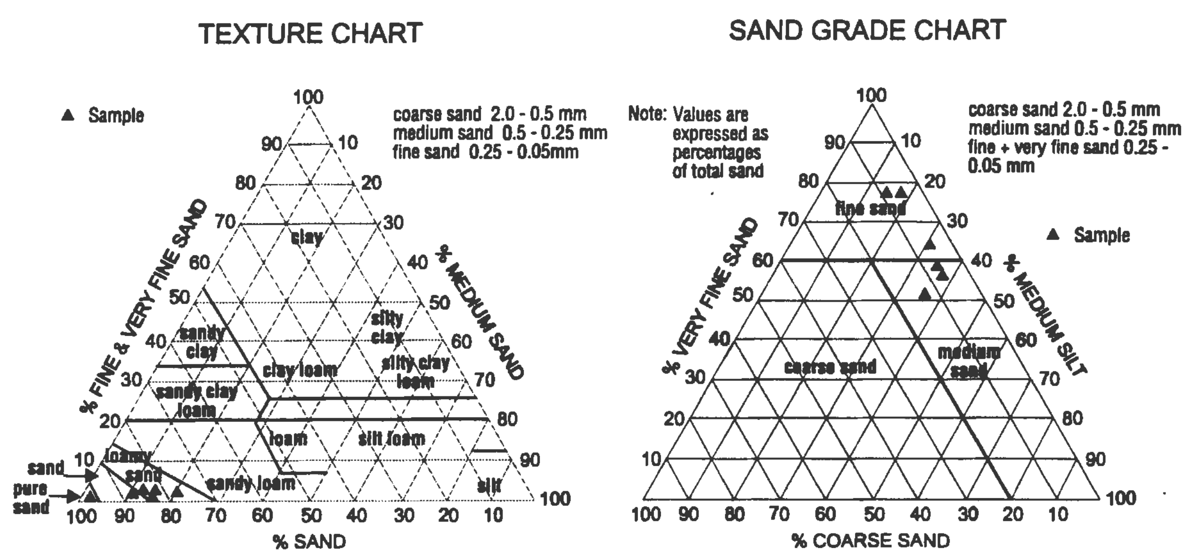
Sample	Location	General Description
1	Horizontal strata - quarry face	Friable
2	Resistant strata - quarry face	Partly lithified
3	Cross bedded strata - quarry face	Friable
4	Horizontal basal strata - quarry face	Friable
5	Lens in gully perpendicular to quarry face	Friable
6	Footslope fan	Unconsolidated

Table 7.1 Klipkraal Sands; situation of samples and general description.

The positions of the sediment samples and a general description of the stratigraphic unit from which each was derived is given in Table 7.1. Texturally, the sediments display a high degree of homogeneity. They are all in the loamy sand to pure sand range (Fig. 7.1, Table 7.2). The sand samples are fine to medium grained (Table 7.3), but even the samples classified as medium grained are only marginally so. They are all either moderately well sorted or well sorted and, with the exception of a single sample, fine-skewed (Table 7.4).

Sample	Texture			Textural Class	Munsell Colour
	% Sand	% Silt	% Clay		
1	81	16	3	Loamy sand	5YR 4/8 Yellowish Red
2	84	15	1	Loamy sand	5YR 5/8 Yellowish Red
3	83 ·	16	1	Loamy sand	5YR 5/8 Yellowish Red
4	87	12	1	Sand	5YR 4/6 Yellowish Red
5	77	20	3	Loamy sand	10YR 5/3 Brown
6	96	4	0	Pure sand	5YR 6/6 Reddish Yellow

Table 7.2 Klipkraal Sands; textural and colour properties.



Texture chart indicating the position of sediment samples.

Sand grade chart indicating the position of the sand fraction of sediment samples.

Figure 7.1 Textural properties of the Klipkraal Sands.

Optical microscopic examination of the terrace sands revealed subrounded quartz grains with a clear red translucent patina, and few foreign grains. The sand from the fan is distinct, being paler in colour than the sands of the bench which, with one exception (Table 7.2), show yellowish red colours in the 5YR colour range. The laminae in the backwall are red in colour (2.5YR 5/6). A comparison between the terrace sands and local Clarens Formation sandstone in thin section, showed the Clarens Formation sandstone to be comprised of finer grained, generally subangular quartz grains with no red patina. Non-quantitative XRF on two samples of local Clarens Formation sandstone and a sand sample from the main deposit did not reveal any obvious distinguishing geochemical differences between the samples; in both cases, the quartz peak dominated.

Sample	% Sand			Sand Grade
	Coarse	Medium	Fine	
	−1ø to 1ø	1ø to 2ø	2ø to 4ø	
1	11	37	52	Medium
2	6	35	59	Medium
3	8	15	77	Fine
4	6	17	77	Fine
5	6	38	56	Medium
6	7	30	63	Fine

Table 7.3 Klipkraal Sands; textural properties of the sand fraction.

Sample	Mean	Median	Sorting	Description	Skewness	Description
1	2.07ø	2.02ø	0.56ø	Moderately well sorted	0.18	Fine skewed
2	2.25ø	2.11ø	0.62ø	Moderately well sorted	0.32	Strongly fine skewed
3	2.59ø	2.57ø	0.57ø	Moderately well sorted	0.04	Near symmetrical
4	2.21ø	2.14ø	0.57ø	Moderately well sorted	0.21	Fine skewed
5	2.09ø	2.06ø	0.48ø	Well sorted	0.14	Fine skewed
6	2.19ø	2.14ø	0.49ø	Well sorted	0.2	Fine skewed

Table 7.4 Klipkraal Sands; graphic statistics (Folk and Ward ,1953) for the sand fraction.

The sediments indicate a narrow range of pH values clustering around neutral, and have extremely low conductivity (Table 7.5), implying a virtual absence of ionisable salts. An initial thermoluminescence (hereafter referred to as TL) age of 20 500 ± 1000 years (W1487) was determined for a sample taken from the base of the main vertical section. Subsequently, a number of optically stimulated luminescence (hereafter referred to as OSL) and TL dates were obtained in an attempt to determine rates of sand accumulation. These dates are presented in Table 7.6. Laboratory numbers are not quoted because of uncertainty with regard to the determination of the annual dose rates associated with the samples. The dates are preliminary and their interpretation with respect to the evolution of this deposit (see Chapter 9) is undertaken with extreme circumspection.

pH	Conductivity µs
7.1	42
6.8	25
7.1	28
6.7	48
6.7	150
6.8	25

Table 7.5 Klipkraal Sands; pH in water and electrical conductivity.

Plate 7.1 Klipkraal Sands profile. Note evidence of cross bedding in upper and middle portion of the deposit.

Refer to page 92 for **Plate 7.2**

Plate 7.3 Partly vegetated mound comprising grey lunette 1 abutting and overlying red lunette 2. Note hammer for scale.

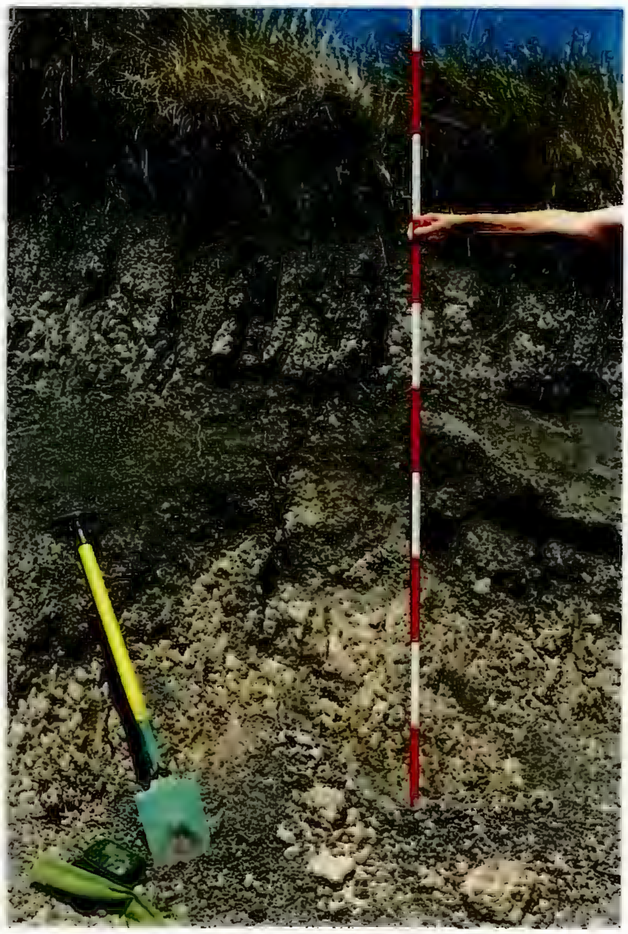


Plate 7.4 Buffelsfontein Stream profile, Stormberg locality, displaying massive columnar peds in the solum, and mottling towards the base of this exposure.

Sample Site/ Number	Sample Position	OSL	OSL (Single)	OSL (Multiple)	TL
Klipkraal Sands					
-	A (90cm depth)		13.3 ± .67	15.4 ± 1.96	
-	A (3.3m depth)		13.75 ± .5	33.0 ±1.55	11.72 ± 0.6
-	B (~ 70cm depth)		34.18 ± 1.91	52.59 ± 5.45	20.5 ± 1.0
W1407	B (basal)				20.5 ± 1.0
Buffelsfontein Pan					
Shfd 97034	P1 (50 cm depth)	12.29 ± 0.7			
Shfd 97033	P1 (85 cm depth)	15.03 ± 1.1			
Shfd 97035	P2 (130 cm depth)	18.22 ± 1.5			
W2205	Lunette 2 (1.6 m)				12.6 ± 1.5
Klipplaat Pan					
Shfd 97036	KP1 (45cm depth)	.56 ± .04			
Shfd 97037	KP2 (50cm depth)	.68 ± .08			
Shfd 97038	KP3 (45cm depth)	1.34 ± .10			

Table 7.6 Luminescence dates (ka) with one standard deviation. (Refer to Figures 7.2, and 7.3 for sample positions related to the two pans).

7.2.3 Buffelsfontein Pan (31°22'30"S; 26°44'30"E) Altitude 1830 m

The depositional environment at Buffelsfontein Pan (Plate 7.2) is one of two in this study which does not display the stratified sedimentary sequence and strata typical of valley fills. The gross morphology of the pan and its fringing lunettes was outlined in Chapter 6. The pan floor sediments comprise dark greyish brown (10YR 4/2), silty clay (Table 7.7) with a crumbly structure. At the time of the site visits, the pan was dry. The surface displayed evidence of mud cracks, though much of the surface was disturbed by animal tracks. The innermost fringing lunette (which partly overlies the older fringing lunette) comprises grey clay (5YR 5/1). The outermost of the two fringing lunettes comprises dark reddish brown (5YR 4/2) silty clay (Plate 7.3), while lunette 3 comprises chiefly fine sand and sandy loam in the 7.5YR to 5YR Munsell range (Table 7.7). There is no evidence of sedimentary structure or well defined soil horizons within the clay lunettes.

Two inspection pits were dug in lunette 3 (Fig. 7.2). The first revealed a poorly developed, blocky structure in the A horizon with some mottling towards the base at 55 cm depth. There is a smooth, conformable transition to hard sand which in turn displays some evidence of bedding. The pit on the crest displayed variation with depth, with a shallow (~10 cm) A horizon similar in texture and colour to the shallow, apedal soils of the pedologically young local landscape (Ellis and Lambrechts, 1986). There is a clear, smooth transition from this horizon to a strongly prismatic B horizon, which in turn overlies sand at a depth of 1 m from the surface. This transition is also gradual, implying a measure of *in situ* soil development on lunette 3.

Sample	% Sand			% Silt	% Clay	
Depth in cm	Coarse –1ø to 1ø	Medium 1ø to 2ø	Fine 2ø to 3ø	4ø to 8ø	8ø to 9ø	<9ø
Pan Floor 20cm	0.00	0.00	0.00	42.00	5.00	53.00
Lunette 1 20cm	0.00	0.00	0.00	35.00	11.00	54.00
Lunette 2 20cm	0.00	0.00	0.00	50.00	45.00	5.00
Lunette 3 crest	0.40	4.40	61.80	18.40	2.00	13.00
Lunette 3 20cm	1.30	7.30	60.30	6.10	2.00	23.00
Lunette 3 40cm	0.20	3.70	73.40	4.70	2.00	16.00

(a)

Sample	Textural Class	Munsell Colour
Pan Floor 20cm	Silty Clay	10YR 4/2 Dark Greyish Brown
Lunette 1 20cm	Clay	5YR 5/1 Grey
Lunette 2 20cm	Silty Clay	5YR 4/2 Dark Reddish Grey
Lunette 3 crest	Sandy Loam	7.5 YR 4/3 Brown
Lunette 3 20cm	Sandy Clay Loam	5YR 4/6 Yellowish Red
Lunette 3 40cm	Sandy Loam	7.5YR 5/6 Strong Brown

(b)

Table 7.7 (a and b) Buffelsfontein Pan; particle size, textural and colour properties.

pH readings indicate that the pan floor and adjacent lunettes are alkaline, while all three samples from lunette 3 display pH values below neutral. Electrical resistance readings indicate a clear distinction between the pan and the proximal lunettes on the one hand, and lunette 3 on the other (Table 7.8). The lower resistance readings of the pan and lunettes 1 and 2 implies a greater concentration of free salts here than in the more distant lunette 3. XRF analyses of the silt/clay material from the pan floor and lunettes 1 and 2 did not reveal any major difference between the relative abundance of elements present. Si, and Al dominate all three samples, while Fe, Mg, Na, Ca, K and Cl and S are also present. The pan floor sample contains proportionally more Na than either of the lunette samples, while the lunette 2 sample has more sulphur than either the pan floor or lunette 1.

Sample	pH			Resistance
	H_2O	$CaCl_2$	KCl	
Pan Floor	8.34	8.19	7.77	92.00
Lunette 1	8.02	7.94	7.24	273.20
Lunette 2	8.42	8.32	7.92	75.10
Lunette 3 crest	6.17	6.10	5.26	1293.70
Lunette 3 20cm	6.98	6.87	5.64	5917.20
Lunette 3 40cm	6.93	6.86	5.58	6369.40

Table 7.8 Buffelsfontein Pan; pH and electrical resistance.

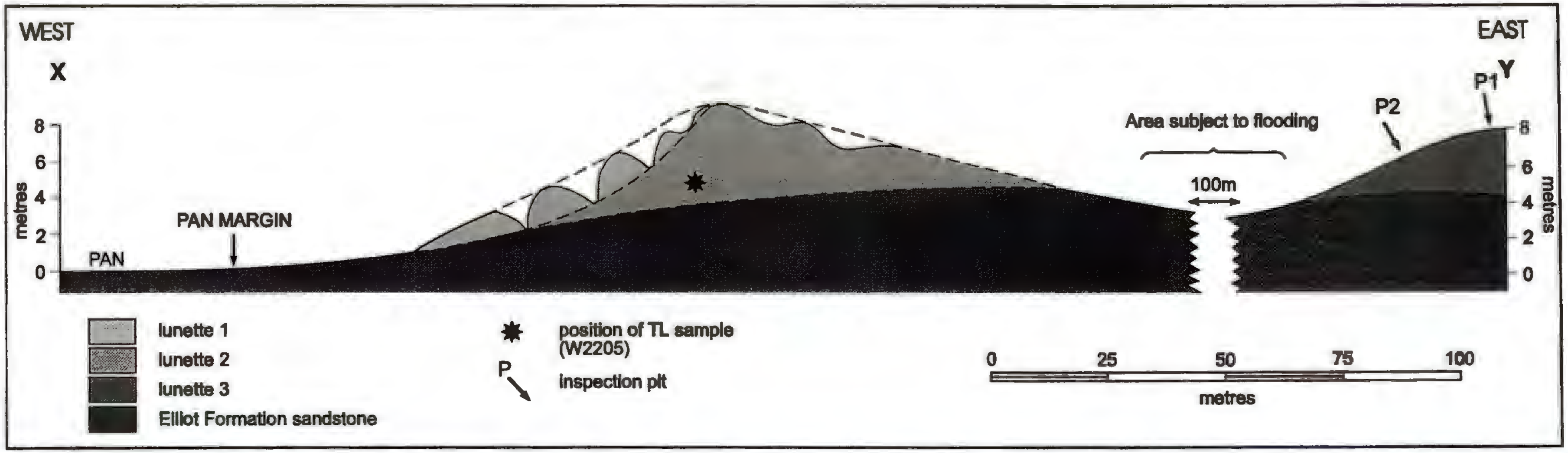


Figure 7.2 Cross section of the Buffelsfontein Pan and fringing lunette dunes.

Plate 7.2 Panoramic view of the Buffelsfontein Pan. The fringing lunette dunes are in the background. Figure 7.2 is orientated at

XRD analyses of pan floor sediment and the two proximal lunettes revealed significant proportions of quartz, plagioclase, orthoclase and, most probably, montmorillonite in all three samples. Clay minerals other than montmorillonite are not present in detectable quantities. The size of the montmorillonite peaks (4.5 Å; 23° 2θ) suggests that the proportions of this mineral in the three samples is roughly equivalent. Saturation of montmorillonite with Na is the best explanation for the broad peaks at 2θ angles smaller than 5° (d-spacing > 20 Å) and the lack of montmorillonite peaks at higher angles.

Table 7.9 indicates a decline in the s-values (the sum of the soluble and exchangeable cations) from the pan floor outwards. The predominant cation is Na. As with the s-values, there is a decrease in Na away from the pan floor with the exception of the deepest sample from lunette 3. There is a clear difference in the cation exchange capacity of the samples which comprise sediment in the silt/clay size range on the one hand, and the samples from lunette 3 on the other. Table 7.10 indicates a significantly higher proportion of secondary Fe in the sample from lunette 2, and the two samples from lunette 3, than in either the pan floor or lunette 1 samples. In all the samples, percentages of secondary Al and Mn are negligible. A TL age of 12 600 ± 1500 years (W2205) was obtained from lunette 2. OSL dates (Table 7.6) were determined for samples taken from the inspection pits on lunette 3.

Sample	Soluble and exchangeable cations (ppm)					CEC cmol/kg
	Ca	Mg	Na	K	S-value	
Pan Floor 20cm	940	1052	18600	7248	27840	45.0
Lunette 1 20cm	1500	990	12000	7480	21970	25.3
Lunette 2 20cm	1240	1960	16400	6293	25893	38.0
Lunette 3 crest	784	200	9400	6959	17343	7.8
Lunette 3 20cm	814	354	9000	6863	17031	10.7
Lunette 3 40cm	552	264	12200	6824	19840	9.0

Table 7.9 Buffelsfontein Pan; soluble and exchangeable cations.

Sample	Secondary phases		
Sample depth in cm	% Fe	% Al	% Mn
Pan Floor	0.160	0.058	0.023
Lunette 1 20cm	0.210	0.069	0.035
Lunette 2 20cm	0.720	0.069	0.031
Lunette 3 50cm	0.470	0.063	0.017
Lunette 3 85cm	0.360	0.039	0.016

Table 7.10 Buffelsfontein Pan; secondary phase of iron, aluminium and magnesium.

7.2.4 Klipplaat Pan (31°20'55"S; 26°38'10"E) Altitude 1740 m

The sediment on the floor of the Klipplaat Pan comprises dark brown (7.5YR 3/4) clay loam (Table 7.11). The crumbly structure and mud cracking apparent on the Buffelsfontein Pan floor is also evident here. On the southeastern margin of the present pan, incision of the fringing lunettes has exposed a number of shallow profiles to ~85 cm depth. They typically comprise yellowish brown to brown (10YR 5/6 to 7.5YR 5/3) apedal loamy sand to sandy loam (Table 7.11) overlying blocky, dark red (2.5YR 4/6) clay similar in texture, colour and consistency to that of lunette 2 at Buffelsfontein. The washed sand fraction of the loamy sand displays a colour two indices lighter on the Munsell value scale (10YR 7/4). On an exposure situated ~30 m from the edge of the pan floor, there is evidence of a well-developed 5 to 10 cm thick, blocky palaeosol. The limited depth suggests that the original profile may have been truncated. It is buried by up to 50 cm of yellowish brown (10YR 5/6), apedal fine loamy sand of the type mentioned above. The transition between the palaeosol and the overlying sand is abrupt and unconformable.

Sample	% Sand			% Silt	% Clay	
Depth in cm	Coarse	Medium	Fine			
	– 1ø to 2 ø	1ø to 2ø	2ø to 4ø	4ø to 8ø	8ø to 9ø	<9ø
KP1 45cm	2.36	23.26	57.86	7.92	4.8	3.8
KP2 50 cm	0.51	5	75.75	6.14	4.1	8.5
KP3 45cm	0.24	5.93	62.13	15.1	5.3	11.3
KP4 80cm	0.7	2.14	6.4	18.16	4.7	67.9
KP5 Pan Floor	0.46	2.4	29.35	31.19	5.3	31.3

(a)

Sample	Textural Class	Munsell Colour
KP1 45cm	Loamy Sand	10YR 5/6 Yellowish Brown
KP2 50 cm	Loamy Sand	10YR 5/6 Yellowish Brown
KP3 45cm	Sandy Loam	7.5YR 5/3 Brown
KP4 80cm	Clay	2.5YR 4/6 Dark Red
KP5 Pan Floor	Clay Loam	7.5YR 3/4 Dark Brown

(b)

Table 7.11 (a and b) Klipplaat Pan; particle size, textural and colour properties.

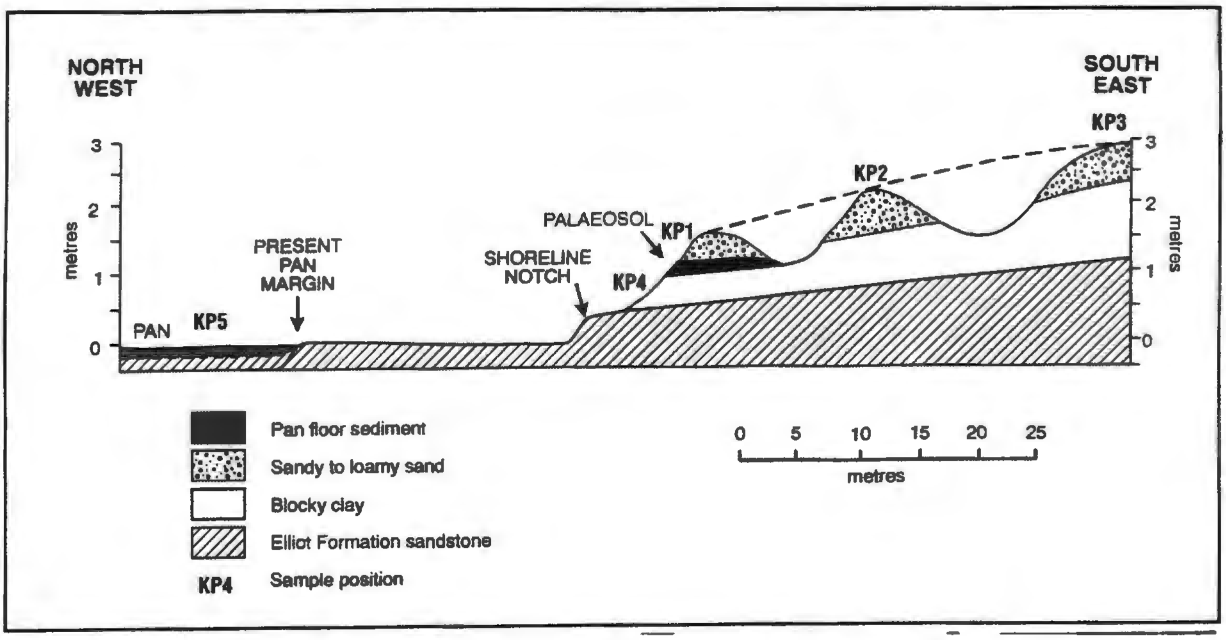


Figure 7.3 Cross section of the Klipplaat Pan and fringing lunette dunes.

Two other exposures displayed very similar profiles, but lacked evidence of pedogenesis. The dissected topography downwind and immediately adjacent to Klipplaat Pan comprises therefore a clay lunette, on which soil development has occurred in at least one position in the landscape (Fig. 7.3). This lunette was subsequently buried by sandy sediment to form a fringing lunette complex. pH readings (Table 7.12) show the sediments of the pan floor and the lunettes to be strongly alkaline, with the pan floor being exceptionally so. Electrical resistance readings reveal a clear distinction between the pan floor sediment and the clay lunette on the one hand, and the overlying sand on the other.

Sample	pH			Resistance Ω
	H_2O	$CaCl_2$	KCl	
KP1	9.08	7.79	8.29	8576.30
KP2	9.74	8.26	8.37	2531.60
KP3	9.30	7.95	7.90	9216.60
KP4	8.51	8.36	8.18	316.50
KP5	10.28	9.80	9.77	254.50

Table 7.12 Klipplaat Pan; pH and electrical resistance.

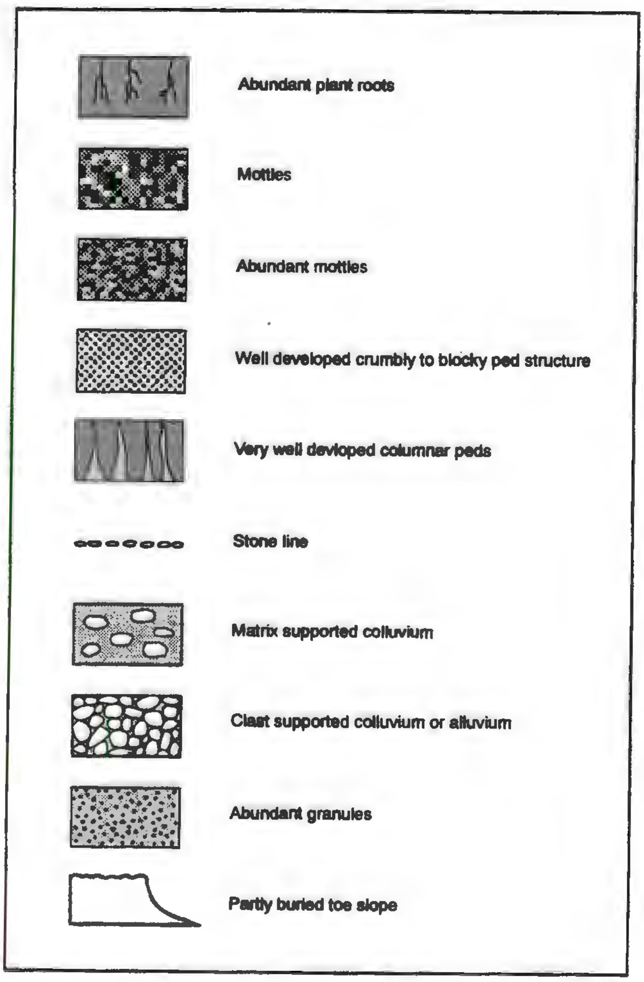
Table 7.13 indicates higher s-values for the clay lunette and the pan floor sediments than for the overlying sand. The cation exchange capacity of the finer grained clay lunette and the clay loam of the pan floor is also higher than is the case for the overlying sand. Na is the dominant individual cation, with the clay lunette and in particular the pan floor showing significant amounts. Table 7.14 shows a relatively higher proportion of secondary Fe in the blocky, dark red clay than in the samples from the overlying sand and the floor of the pan. As is the case with the Buffelsfontein lunettes, proportions of secondary Al and Mn in all samples are negligible. The palaeosol discussed above yielded a ^{14}C date of 430 ± 45 BP (Pta 7024). OSL dates from the sample positions labelled KP1, KP2 and KP3 respectively (Fig.7.3) are presented in Table 7.6. A chronological list of all the confirmed dates utilised in this study is presented in Appendix F.

Sample	Soluble and exchangeable cations (ppm)					CEC
	Ca	Mg	Na	K	S-value	cmol/kg
KP1	678	76	18	85	857	4.0
KP2	626	200	265	126	1217	6.5
KP3	208	160	120	110	598	8.5
KP4	783	727	4029	496	6035	23.4
KP5	112	8	7520	160	7800	32.4

Table 7.13 Klipplaat Pan; soluble and exchangeable cations.

Sample	Secondary Phases		
Sample depth in cm	% Fe	% Al	% Mn
KP1 45cm	0.100	0.015	0.005
KP2 50cm	0.110	0.015	0.007
KP3 45cm	0.190	0.026	0.016
KP4 80cm	0.580	0.067	0.051
KP5 Pan Floor	0.280	0.052	0.009

Table 7.14 Klipplaat Pan; secondary phases of iron, aluminium and magnesium.



Key for use with profiles which follow

7.2.5 Buffelsfontein Stream (31°20'45"S; 26°42'45"E) Altitude 1720 m

At this site, a crumbly, friable, A horizon overlies a B horizon which displays massive, well defined columnar peds (Fig. 7.2). The modern soil sequence overlies a palaeosol which displays a blocky structure and some brown (7.5YR 5/4) mottles. The underlying horizon (horizon 4) displays smaller blocky peds and reddish brown (5YR 4/4) mottles (Plate 7.4). There is evidence of structure and very many brown (7.5YR 5/4) mottles in horizon 5. Silt is the dominant size fraction in the modern topsoil, with clay dominating the palaeosol. pH values are all slightly alkaline, and conductivity readings are moderate to low. The modern solum displays significantly higher percentages of organic carbon than any of the underlying horizons.

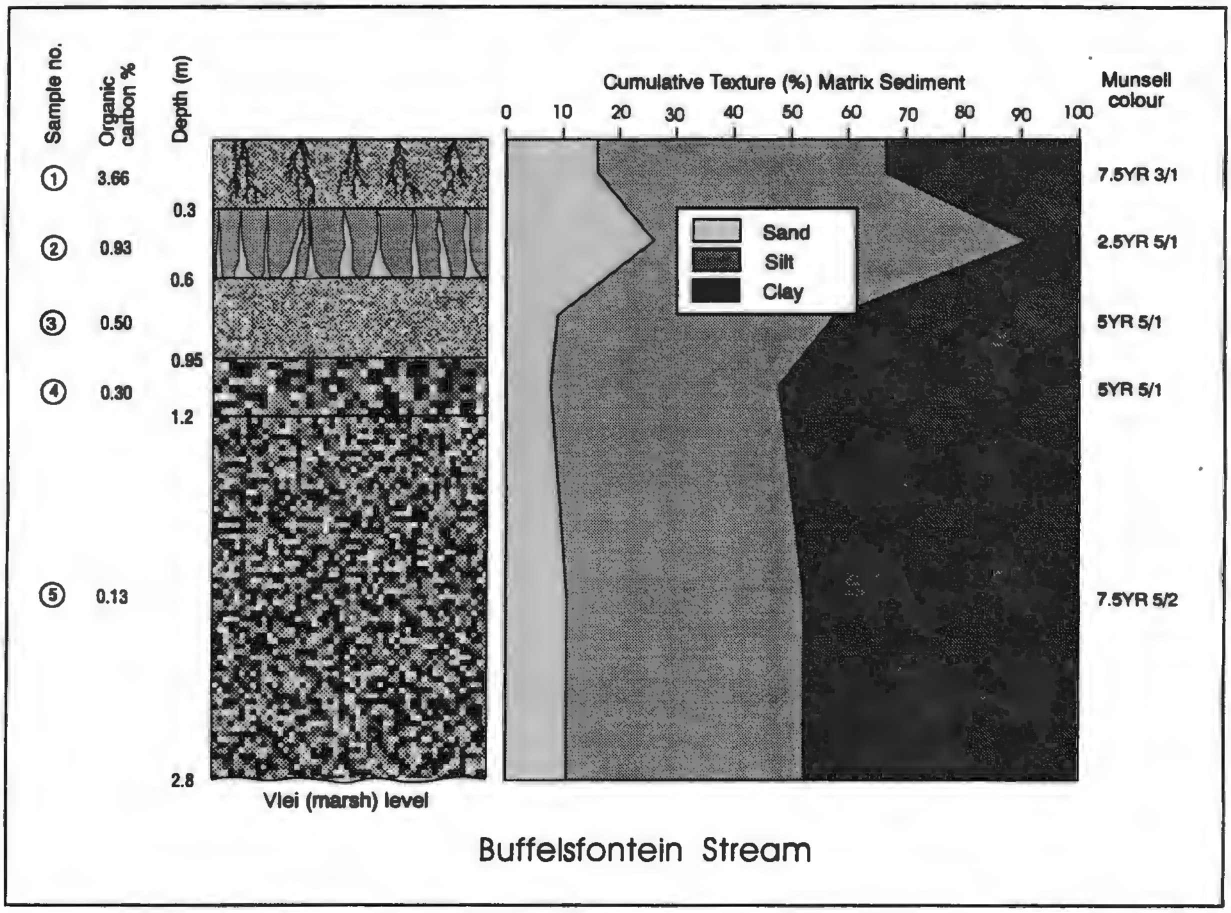


Figure 7.4 Buffelsfontein Stream profile exposed through incision by this headwater tributary of the Holspruit Stream.

7.2.6 Kalkoenkrans Vlei (31°17'40"S; 26°41'45"E) Altitude 1670 m

Because no exposed profile exists at this site, sediment was sampled using a gouge auger. The Kalkoenkrans Vlei core (Fig. 7.5) revealed dark (7.5YR 4/2 to 5YR 3/2), organic rich sediment to a depth of 1.1 m overlying reddish (5YR 4/4 to 2.5YR 4/8) sediment to a depth of 5.5 m. Because of

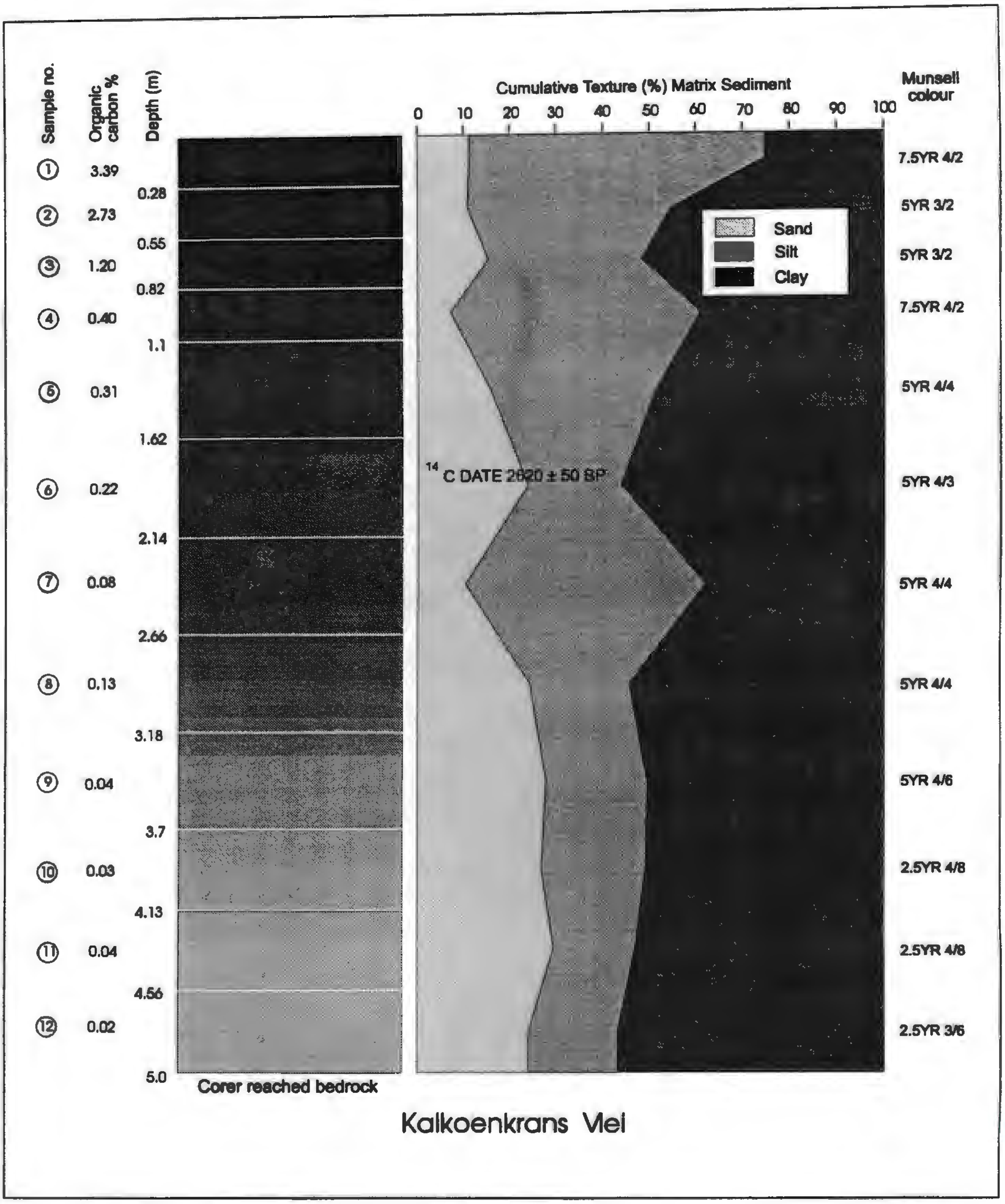


Figure 7.5 Profile from Kalkoenkrans Vlei core. The core was taken using a gouge auger.

the auger recovery method, it was not possible to discern any structure within the core. Silt loam and silty clay loam are the dominant textural classes, while there is no evidence of material coarser than sand in the core. Organic carbon values decline abruptly below horizon 6. A ^{14}C date of 2620 ± 50 BP (Pta 6994) was obtained from the base of the organic sediment accumulation. The organic sediments are slightly more acidic than the underlying reddish sediments. Conductivity readings are low, with the organic sediments displaying slightly higher readings than the underlying material.

7.2.7 Holspruit Gully (31°16'20"S; 31°44'30"E) Altitude 1660 m

This profile (Fig. 7.6) displays crumbly, well defined peds in the surface horizon underlain by a gravel lag of poorly sorted, subangular, ~1 cm to ~10 cm long axis, dolerite clasts. The lag is in turn underlain by weakly structured gritty loam, and a buried palaeosol (horizon 3) displaying very well developed columnar peds. Another gravel lag, with similar clasts to the upper lag is situated below this horizon. This sequence rests unconformably on a sequence of horizons or

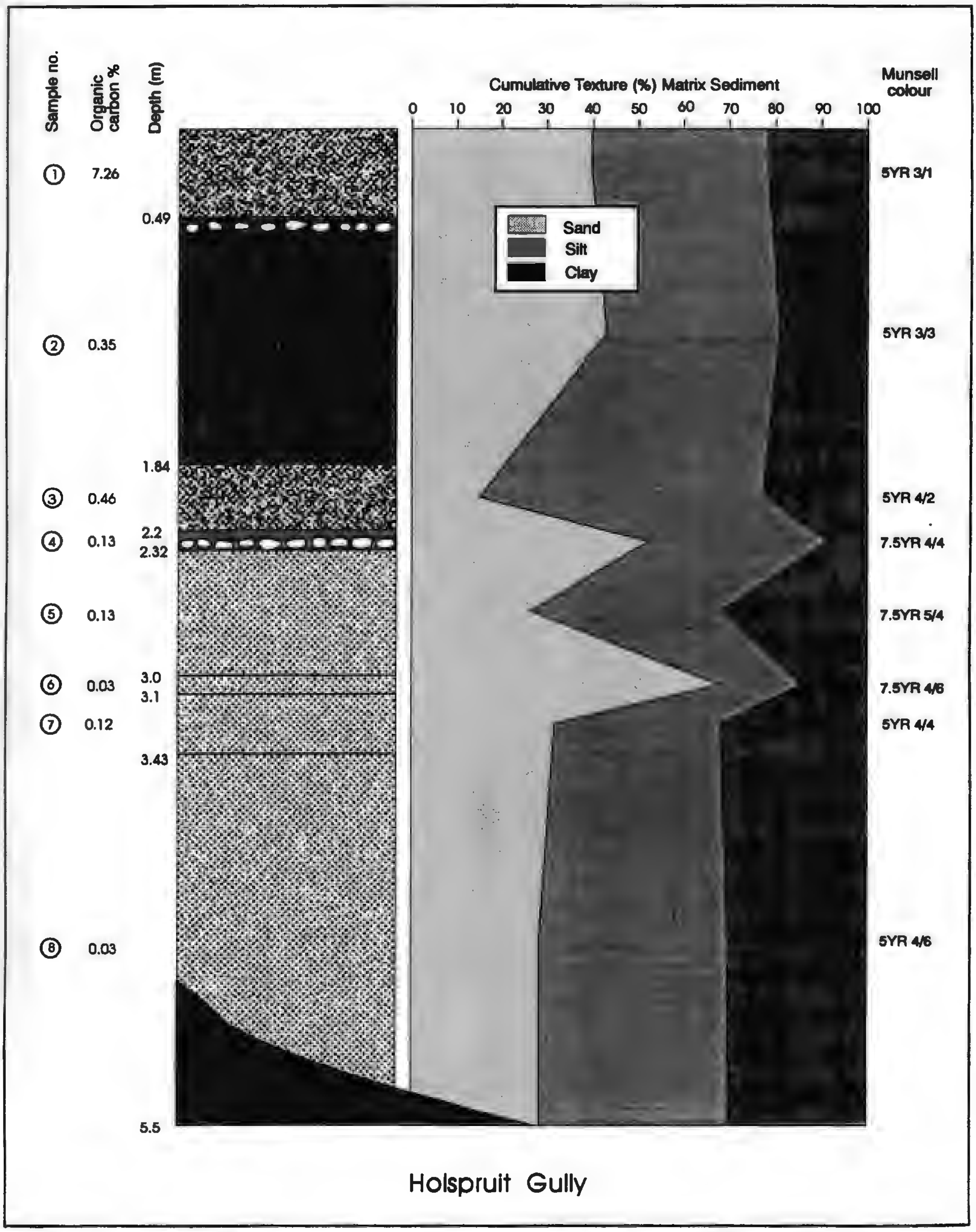


Figure 7.6 Holspruit Gully profile exposed through incision by the Holspruit Stream.

strata displaying weak structure and lower proportions of organic carbon (Fig. 7.6). Texturally, the majority of the horizons are classified as loam, with either silt or sand making up the dominant size fraction. 5YR colours, with generally low value and chroma, dominate. All the horizons display pH values in $CaCl_2$ which are close to neutral, as well as low conductivity readings.

7.2.8 Synopsis

This synopsis, and the synopses which follow in this chapter, will attempt to encapsulate the main points to emerge from the detailed investigations at each locality. These synopses are precursors to the culminating discussion in Chapter 9. At this stage then, where appropriate, preliminary inferences are made which will facilitate the palaeoenvironmental reconstruction.

Evidence of what would appear to be aeolian, fluvial and colluvial deposition is preserved within the landscape of the Stormberg locality. The aeolian deposits comprise a unique sand emplacement and pan fringing dunes. Fluvial and colluvial sediments are preserved within valley fills. There is evidence for mass wasting in the form of sandstone boulders at both the Klipkraal Sands site and along the flanks of the Holspruit Valley. While the aeolian environments record evidence of deposition dating back as far as the Last Glacial Maximum (Table 7.6), the valley fills do not appear to predate the Holocene. The Holspruit Stream channel, which here forms the main north flowing drainage line off the Great Escarpment, appears to have been infilled during two phases. The initial phase involved the accumulation of fine grained, inorganic sediment derived from the surrounding hill slopes. There is no evidence of pedogenesis during this phase, implying continuous accretion with no surface exposed for a sufficient length of time for soil to form. Alternatively, soil horizons might have been stripped away by cycles of erosion within the valley, though the apparent conformable nature of deposition during this phase would seem to preclude this.

The second phase of sediment accumulation within the Holspruit Valley saw periods of soil formation on the valley floor as well as along tributary valleys. At the Holspruit Gully site, gravel grade colluvial material interdigitates with strata displaying evidence of pedogenesis below the modern solum. This would seem to imply cyclical deposition.

7.3 TANDJIESBERG LOCALITY

7.3.1 Introduction

The Tandjiesberg locality is the most easterly of the true Karoo headwater environments (Fig. 1.2). Infilling has occurred along the entire length of the Wilgerboom River. With the exception of the first of the profiles described below, fluvial incision has exposed the sedimentary sequences at the various sites.

7.3.2 **Wilgerboom River Colluvium** (32°15' 50"S; 25°25'00"E) Altitude 1460 m

The profile of this colluvial spur, truncated by a road cutting, displays a shallow lithosol overlying a number of strata, comprising poorly sorted, subangular dolerite and sandstone clasts in a matrix of loam or sandy loam, with an abrupt transition to shale bedrock (Fig. 7.7). Only the modern topsoil and subsoil display organic carbon readings above 0.25%. pH values are close to neutral down the profile, while conductivity is significantly higher in the topsoil horizon than in the underlying colluvium.

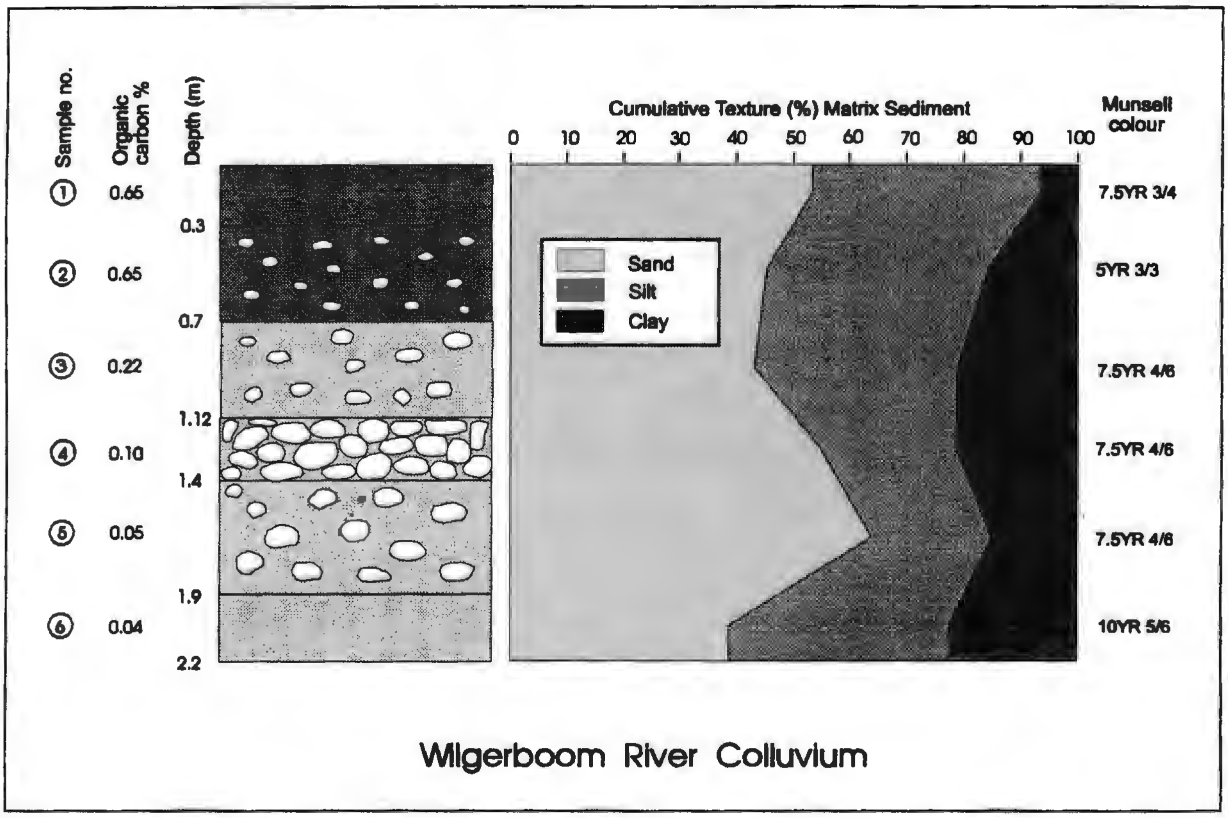


Figure 7.7 Wilgerboom River colluvium profile, exposed by a road cut in the Mountain Zebra National Park.

7.3.3 **Bergkloof** (32°15'20"S; 25°27'05"E) Altitude 1260 m

This valley fill profile comprises a modern topsoil with weakly developed blocky peds overlying a gritty subsoil (Fig. 7.8). There is an abrupt unconformity below these horizons. Below this is a partly calcretised palaeosol with well developed columnar peds. Moving down the profile, horizons 4, 5 and 6 display evidence of columnar ped development. They in turn overlie a series of strata with a lower organic carbon content where gritty sand and matrix supported gravel lags occur.

Stratum 10 is characterised by diffuse yellow mottles. The sequence rests on bedrock, and the basal horizon is currently undercut whenever the stream flows. The strata display a variety of textural properties and conductivity values, while pH readings are all slightly alkaline.

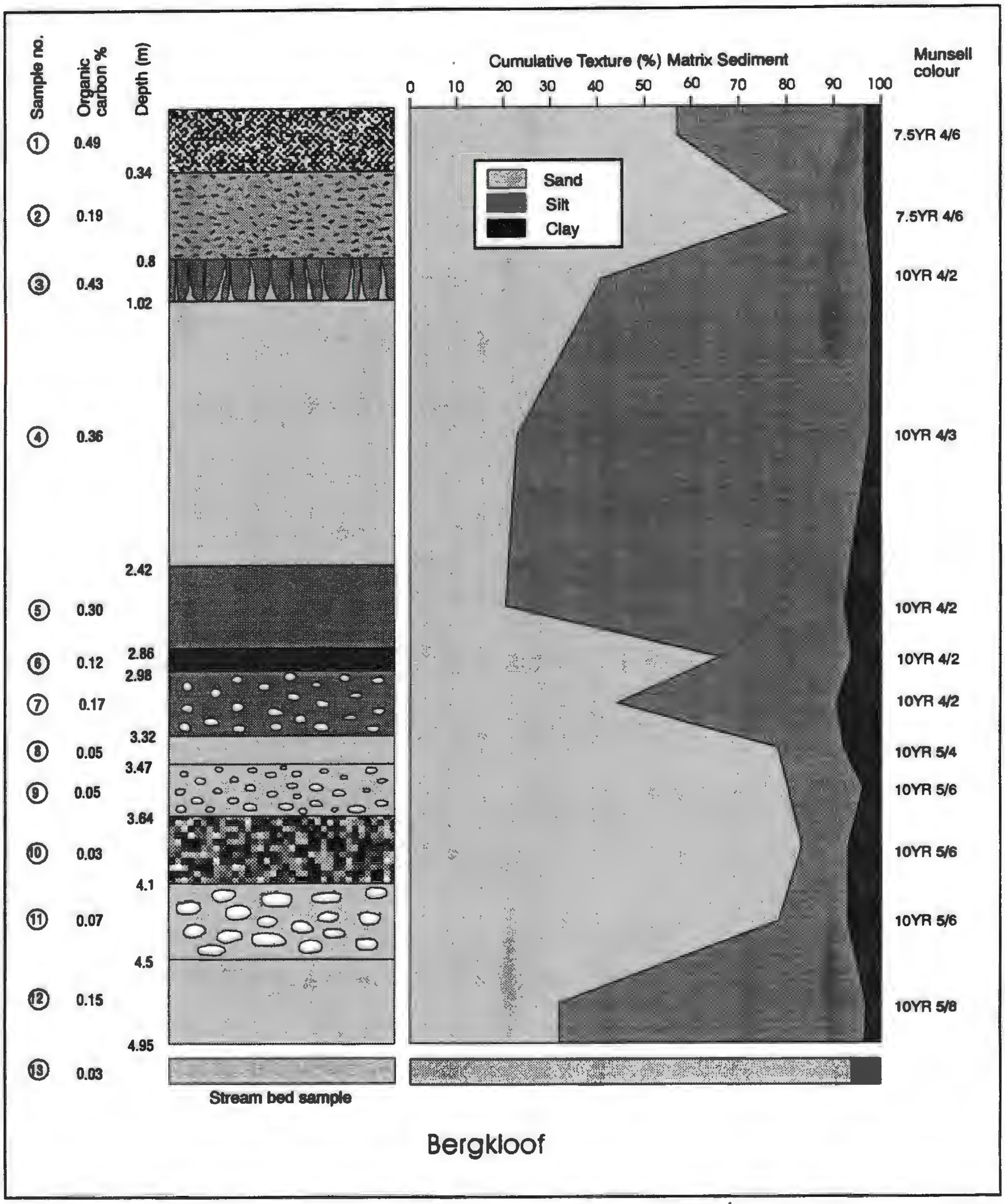


Figure 7.8 Bergkloof site profile, exposed through incision to bedrock by the Wilgerboom River.

7.3.4 Doornhoek Dam (32°14'05"S; 25°27'40"E) Altitude 1240 m

This site occurs at a point where the accumulation of valley floor sediments on the Wilgerboom River are at, or close to their maximum depth. A duplex soil caps this profile, with a stoneline at the base of the A horizon at 74 cm depth. Another stoneline occurs at 2.1 m. At least three palaeosols or phases of incipient soil formation are preserved within the exposure. There is evidence of structure (weakly developed blocky to columnar peds) all the way down the profile, while strata 5, 15, 16 and 17 display many yellowish red (5YR 5/8) mottles. The palaeosol (horizon 9) situated at a depth of 3.64 m below the floor formed by the valley fill (Fig. 7.7) yielded a ^{14}C date of 5720 ± 70 BP (Pta 6423). This dated palaeosol is underlain by sand, loam and a basal gravel lag to a depth of 6.3 m. An OSL date of 8580 ± 800 years (Shfd 97042) was obtained from the interface of the basal lag and the stratum above it. The dolerite stream bed is covered by very poorly sorted, angular sandstone and dolerite clasts in a 70:30 ratio. All pH values in the profile are alkaline. Both the pH values as well as the electrical conductivity readings cover a considerable range on their respective scales (Appendix E).

7.3.5 Spekboom (Pauls) River (32°04'50"S; 25°25'10"E) Altitude 1010 m

The profile chosen for detailed study (Fig. 7.8) occurs on the undercut bank of a stream meander (Plate 7.5). The profile is capped by a shallow soil which displays very weakly developed blocky peds. It is not possible to differentiate horizons within this topsoil. Below this horizon, poorly sorted, well rounded to angular clast-supported gravels (up to 75 cm long axis) alternate with hard, apedal, yellowish brown to strong brown (10YR 5/6 and 7.5YR 5/8) sand. The contact between sand and gravel is in each case abrupt and unconformable. None of the strata display mottling. The sedimentary sequence is not typical of the valley headwater profiles which comprise the majority of sites in this investigation. Rather, the sequence is interpreted as the product of braiding (channel bar clasts and point bar fines) in a migrating fluvial channel. A number of lenses containing either coarse sand or organic material occur within this sequence. A ^{14}C date of 2930 ± 45 BP (Pta 7088) was obtained from such a lens on the opposite bank of the stream at a depth of between 3.95 and 4.2 m from the surface. pH values are all slightly neutral, with a range of low to moderately high conductivity readings.

7.3.6 Synopsis

The Tandjiesberg locality has provided evidence of Holocene depositional environments from a truncated colluvial spur, two valley fills and a fluvial sedimentary sequence. The colluvial spur is distinguished by its hillslope position in the landscape. The primary distinction between the valley fills and the river bank profile is the presence of palaeosols of significant lateral extent which form distinct stratigraphic markers in the former, while the latter is characterised by rounded pebble to cobble grade gravels indicative of a high energy fluvial environment.

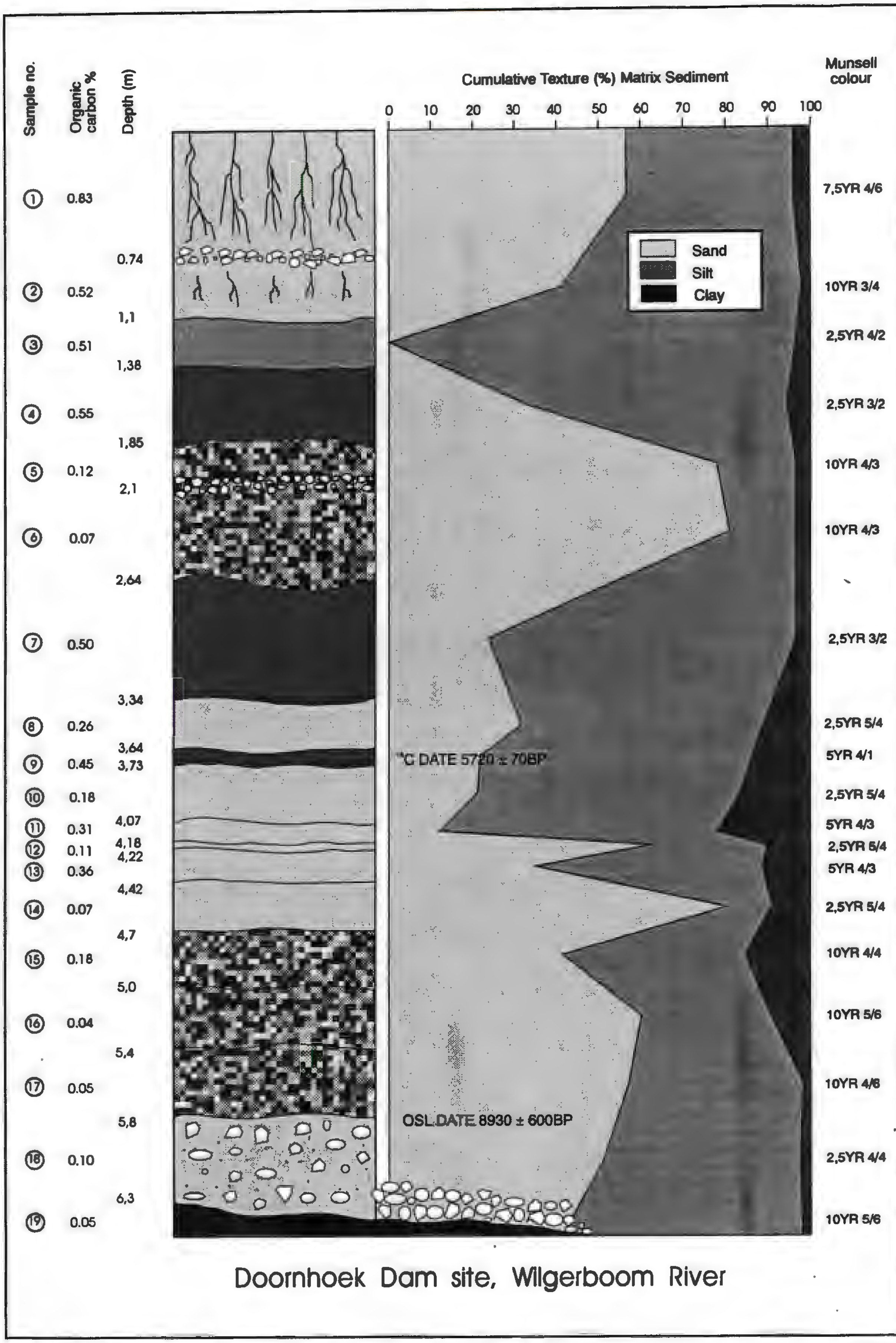


Figure 7.9 Doornhoek Dam site profile, exposed through incision by the Wilgerboom River below the spillway of the Doornhoek Dam in the Mountain Zebra National Park.

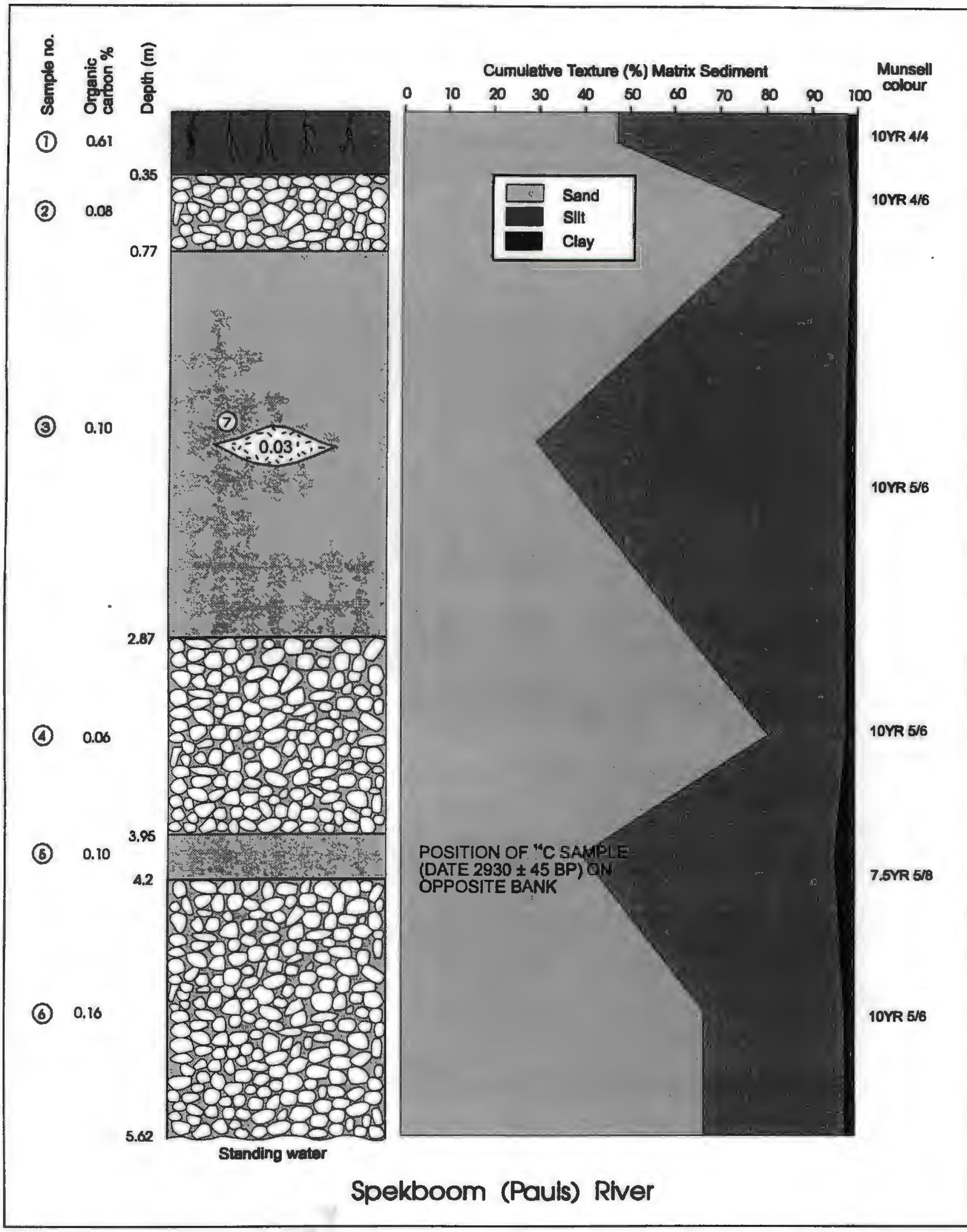


Figure 7.10 Spekboom River profile, exposed on an incised meander of the Spekboom River.

In terms of the genetic classification of floodplains (Nanson and Croke, 1992) the former could arguably be classified A4 cut and fill floodplain, while the latter would more likely be associated with a B2 - wandering gravel bed river floodplain type. As is the case with the Stormberg locality, the valley fills record an initial period of infilling by inorganic, comparatively homogenous, sandy sediment, followed by pronounced cyclical accumulations which reflect phases of soil formation. The palaeoenvironmental implications from this locality are further discussed in Chapter 9.

Plate 7.5 Exposure of clast supported, rounded gravel and apedal sand along an undercut meander bend on the Spekboom River, Tandjiesberg locality.

Plate 7.6 Good Hope profile, Sneeuberg locality. Note the basal palaeosol displaying blocky to columnar ped structure.

Plate 7.7 Klein Seekoei River profile, Sneeuberg locality. Note the distinctive palaeosol, which is also evident in Plate 6.6. The possibility that this palaeosol might have served as a regional stratigraphic marker provided the impetus for this research.

7.4 WAPADSBERG LOCALITY

7.4.1 Introduction

The Wapadsberg locality is situated on the edge of the Great Escarpment ~90 km west of the previous locality. A unique feature of this locality is the altitudinal gradient of ~300 m over a distance of ~5 km. This provided the opportunity to compare depositional environments on the summit of the escarpment with a footslope deposit at the base of the escarpment.

7.4.2 Wapadsberg summit (Rooiskuur) (31°55'00"S; 24°55'45"E) Altitude 1800m

The top three horizons in this 3.1 m deep exposure (Fig. 7.11) display weakly developed blocky to columnar peds. They overlie a stratum which contains a gravel lag of poorly sorted, angular clasts. There is further evidence of structure in the horizons below this. The basal horizon comprises friable, sandy sediment with a very weakly developed blocky ped structure. There is abundant dark red (2.5YR 4/8) mottling in this horizon and evidence of root lines. Organic carbon contents ranging between 0.4% and 0.5% characterise this profile, with only the basal stratum yielding an organic carbon content of less than 0.2%. For this reason, the horizon directly above it was sampled for ^{14}C dating. It yielded a date of 1680 ± 60 BP (Pta 6858).

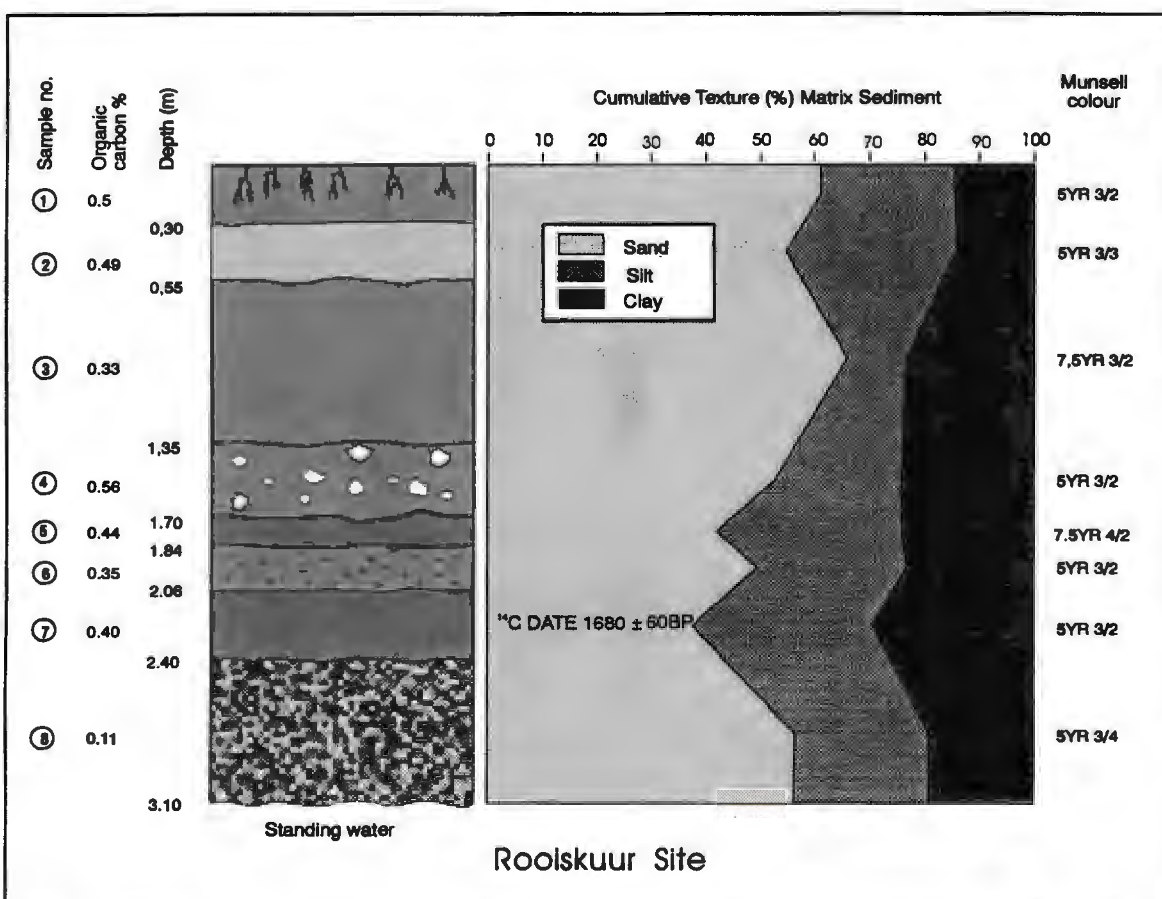


Figure 7.11 Rooiskuur site profile, exposed by gully incision in a headwater wetland.

7.4.3 Wapadsberg summit (Ruigterfontein) (31°57'10"S; 24°54'50"E) Altitude 1646 m

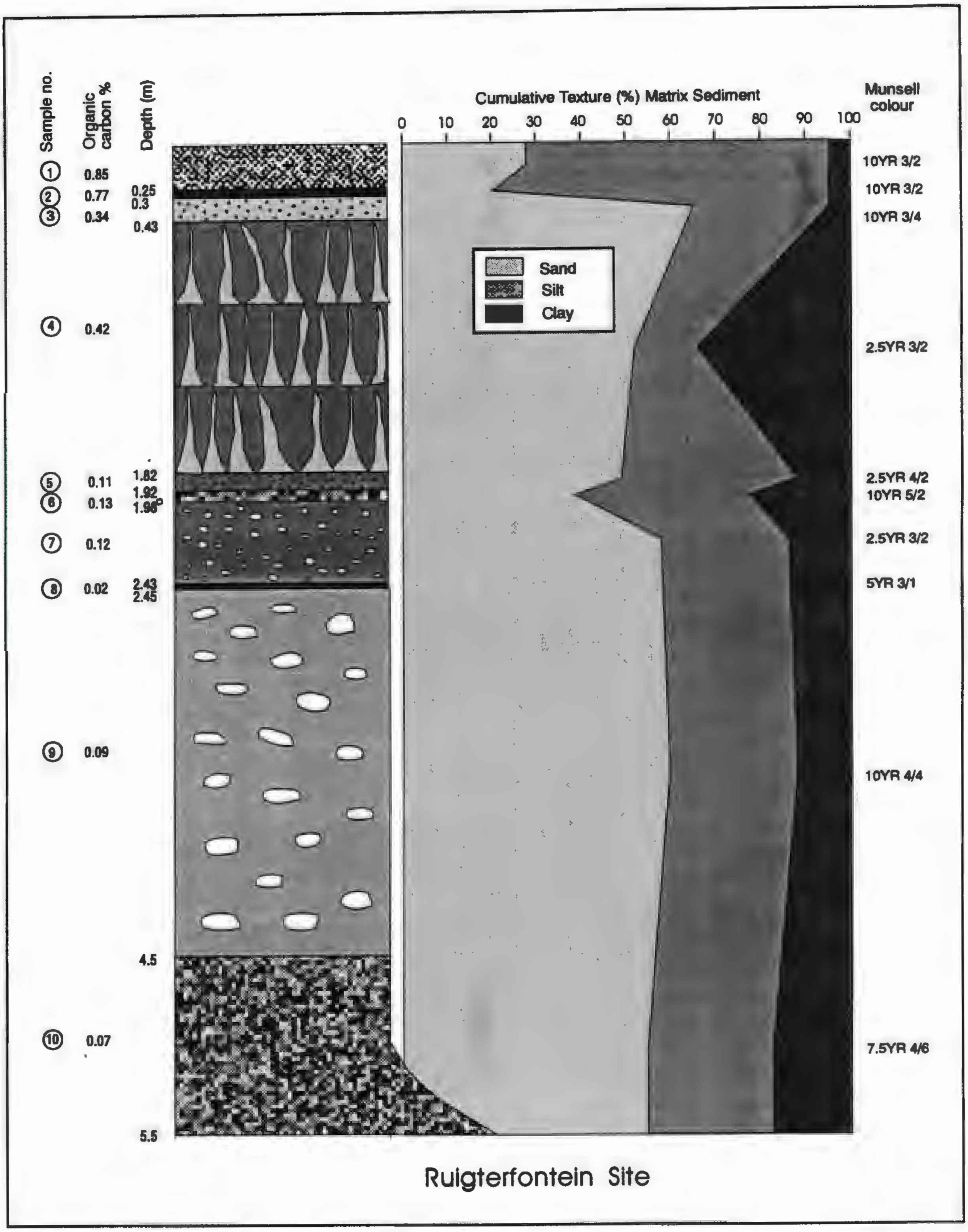


Figure 7. 12 Ruigterfontein site profile, exposed by stream undercutting on a meander.

This profile displays large, strongly developed blocky peds in the topsoil horizon, with evidence of phases of pedogenesis in horizon 4, which displays strongly developed columnar peds. Matrix supported angular to subangular clasts occur in a number of the horizons (Fig. 7.12). Horizon 10 displays a weakly developed blocky ped structure. Incipient mottling is present in horizon 6, while horizon 10 displays abundant, clear dark red (2.5YR 4/8) mottles (0.5 to 1 cm diameter) which increase in size and abundance towards the base of the horizon.

7.4.4 Rochdale Farm (31°57'00"S; 24°48'45"E) Altitude 1360 m

This exposure, on a non-perennial stream at the foot of the Wapadsberg, displays a variety of sedimentary structures, as well as a evidence of incipient soil formation in horizon 4 (Fig. 7.13). The profile appears to have been stripped of its modern A horizon, exposing an apedal B horizon which contains abundant plant roots. This is underlain by a stratum displaying distinct laminae, including cross bedding. The transition to horizon 4 is abrupt and clearly nonconformable. This horizon displays a strongly developed crumbly to blocky ped structure. Stratum 5 comprises a lag of poorly sorted clasts, of which the size and shape may be controlled by the gravel grade sediment supplied from upstream. The basal horizon displays incipient, blocky ped formation and few, diffuse dark grey to brown (7.5YR 4/1 to 4/2) mottles (up to 2 mm diameter). A few modern plant roots extend into this horizon. The amount of organic carbon falls off markedly below horizon 4.

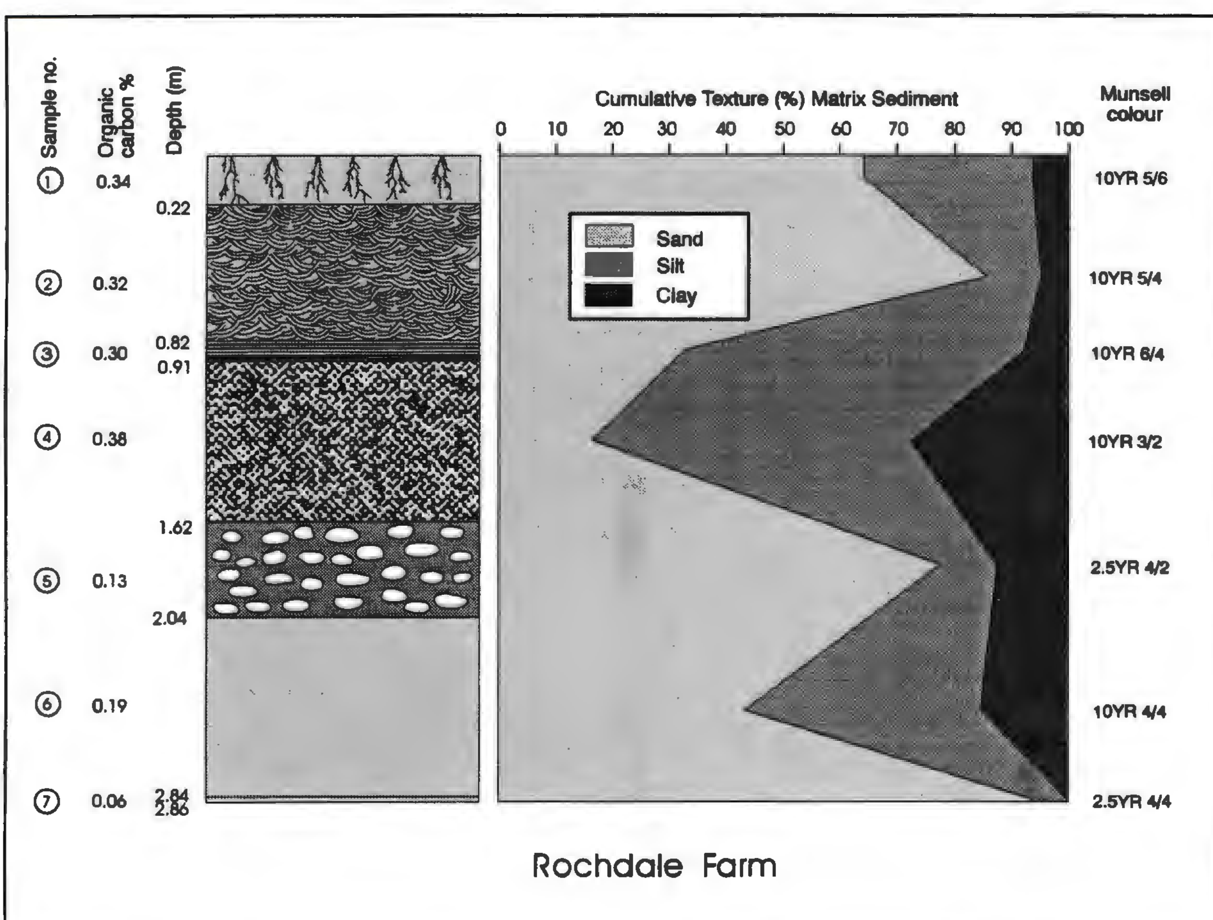


Figure 7.13 Rochdale Farm profile, exposed by gully incision of sediments which have been emplaced on escarpment footslopes.

7.4.5 Synopsis

The Rooiskuur site represents a localised headwater pond or vlei which has been desiccated following channel incision. The other two sites exhibit sedimentary accumulations of greater extent. The Wapadsberg summit sites are confined to stream channels, but the morphology of the Rochdale site and its position at the base of the escarpment suggests a footslope accumulation of considerable lateral extent. Existing footslope drainage lines have been infilled by this sediment. This implies a measure of sheet wash and colluvial emplacement, with subsequent gullying. Both the Ruigterfontein and Rochdale sites are characterised by sediments with relatively high organic carbon content overlying sandier sediment with a low organic content, a feature typical of the valley fills at the two localities discussed previously. The Rooiskuur site does not record the initial phase of inorganic accumulation.

7.5 SNEEUBERG LOCALITY

7.5.1 Introduction

Of the geomorphic environments investigated during this study, the Sneeuberg locality is proposed as the *type site* for central Great Karoo upland valley fills because of the comprehensive range of exposed depositional sequences at this locality. The initial palynological work of Meadows and Sugden (1988) and Sugden (1989) provided the impetus (see 1.2) for a wider geomorphic investigation into Karoo upland depositional environments. The sites at this locality are situated on the Klein Seekoei River or on tributary stream channels.

7.5.2 Compassberg Gully (31°45'00"S; 24°32'10"E) Altitude 2000 m

This is the highest site investigated during the course of this study. The exposure on this headwater tributary (Fig. 7.14) is not capped by a modern lithosol typical of the region, but by an exposed, friable, organic rich horizon of granular structure which, due to its incongruous situation, is interpreted as a re-exposed palaeosol. This is underlain by a sequence of strata which, with the exception of horizon 2, and the basal horizon, display low amounts of organic carbon. None of the strata display either mottling or evidence of ped structure. Most of the strata contain significant proportions (>50%) of subangular, moderately well sorted gravel clasts with a long axis of 1 cm to 5 cm; horizon 8 is clast supported. The gully at the foot of the profile is strewn with moderately well rounded, very poorly sorted sandstone and dolerite clasts with a mean long axis of ~10 cm. The basal horizon displays a significantly higher proportion of organic carbon.

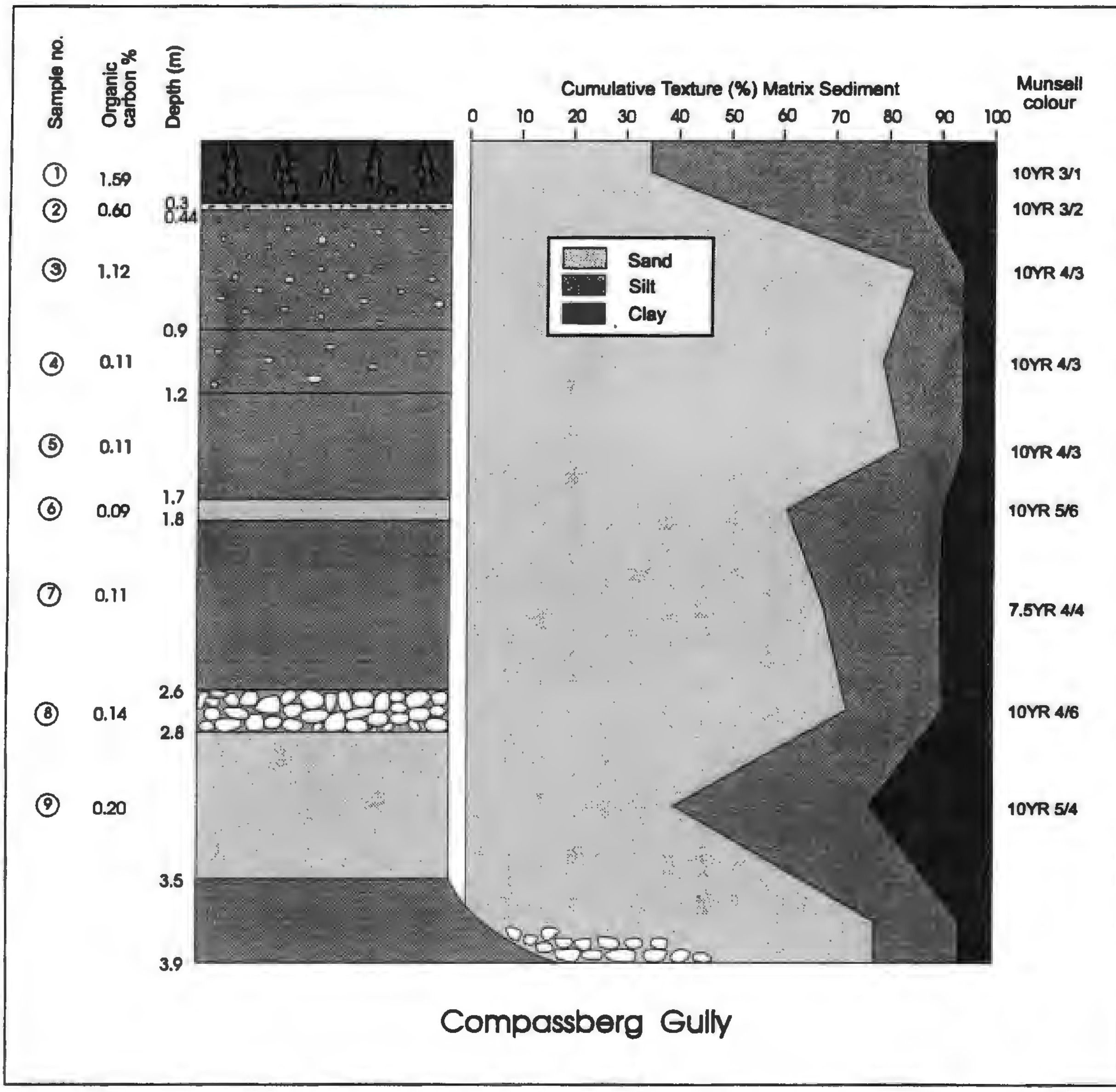


Figure 7.14 Compassberg Gully profile, exposed by gully incision on a headwater tributary of the Klein seekoei River.

7.5.3 The Valley (31°43'15"S; 24°31'30"E) Altitude 1780 m

This site is situated on the upper headwater stream of the Klein Seekoei River. The top of this profile (Fig. 7.15) exhibits a mature, structureless solum underlain by a stoneline. A number of the other strata in the profile contain poorly sorted, angular to subangular clasts, and there is evidence of a phase of incipient soil formation from 90 cm depth to 1.82 m. These horizons display poorly developed columnar peds. There is an abrupt decline in organic carbon, and a significant increase in sand below horizon 6. Well rounded to subangular, massive (up to 2 m long axis), poorly sorted dolerite boulders cover the stream bed on the floor of the Gully.

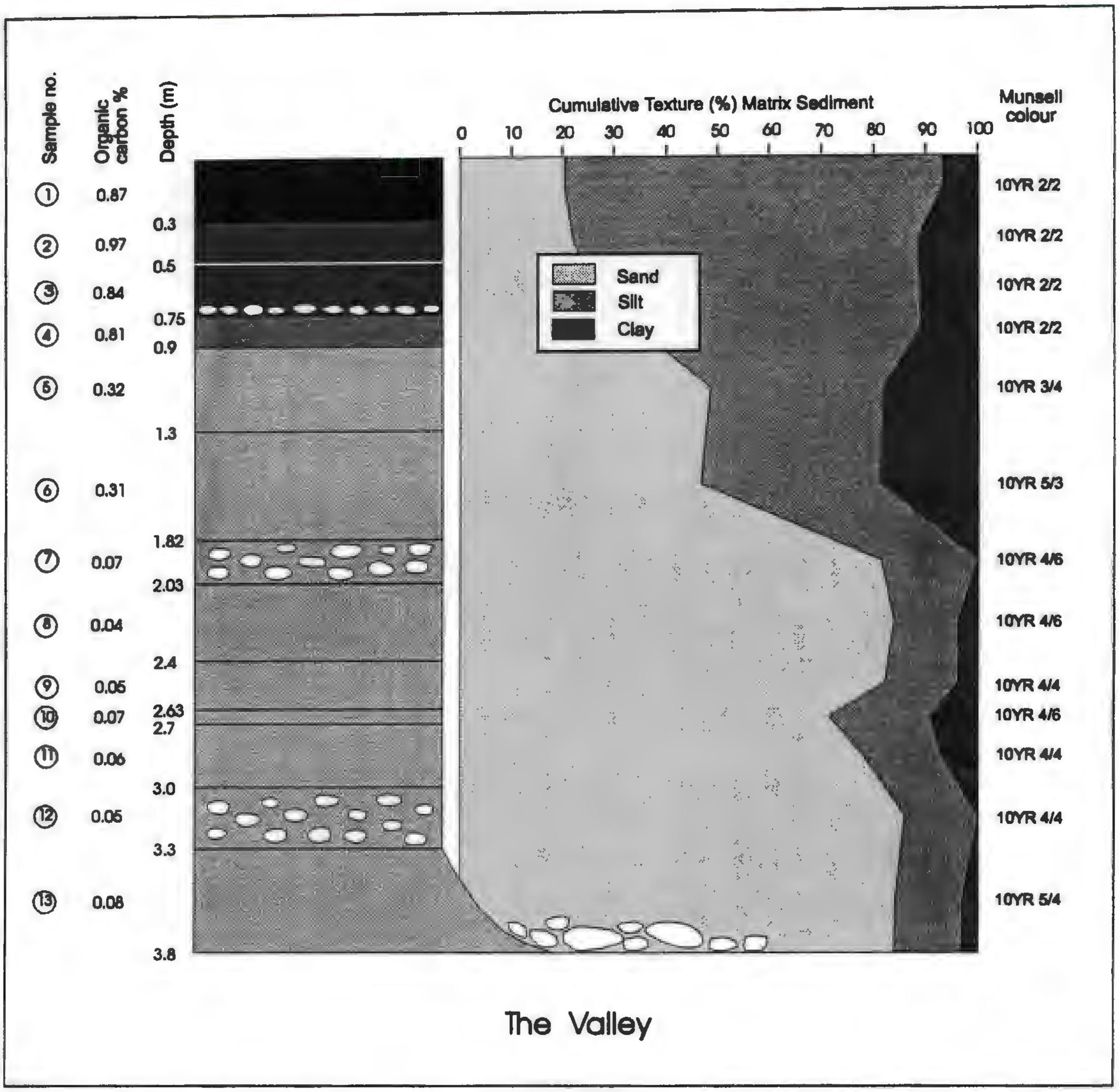


Figure 7.15 The Valley profile, exposed through headwater incision by the Klein Seekoei River.

7.5.4 Good Hope (30°41'30"S; 24°34'45"E) Altitude 1685 m

The exposed sediments (Fig. 7.16) comprise a modern, shallow loamy soil overlying alternating bands of loose gravelly sand or sandy loam, and silt/clay grade sediment. Evidence for at least three phases of incipient soil formation or organic carbon enrichment are distinguishable within the profile. While the upper four horizons display ped structures, much of this profile comprises hard clay which displays diffuse, streaky mottling. There is an abrupt, unconformable transition to a basal palaeosol. This palaeosol displays very strong columnar structure (Plate 7.6). It yielded a ^{14}C date of 5790 ± 80 BP (Pta 5493). Two horizons (10 and 15) display significantly high proportions of organic carbon, and high conductivity readings. Very poorly sorted, well rounded to angular clasts cover much of the non-perennial stream channel at the base of the profile. The clasts comprise sandstone, dolerite and shale in the ratio of 60:30:20 with a mean long axis of ~30 cm.

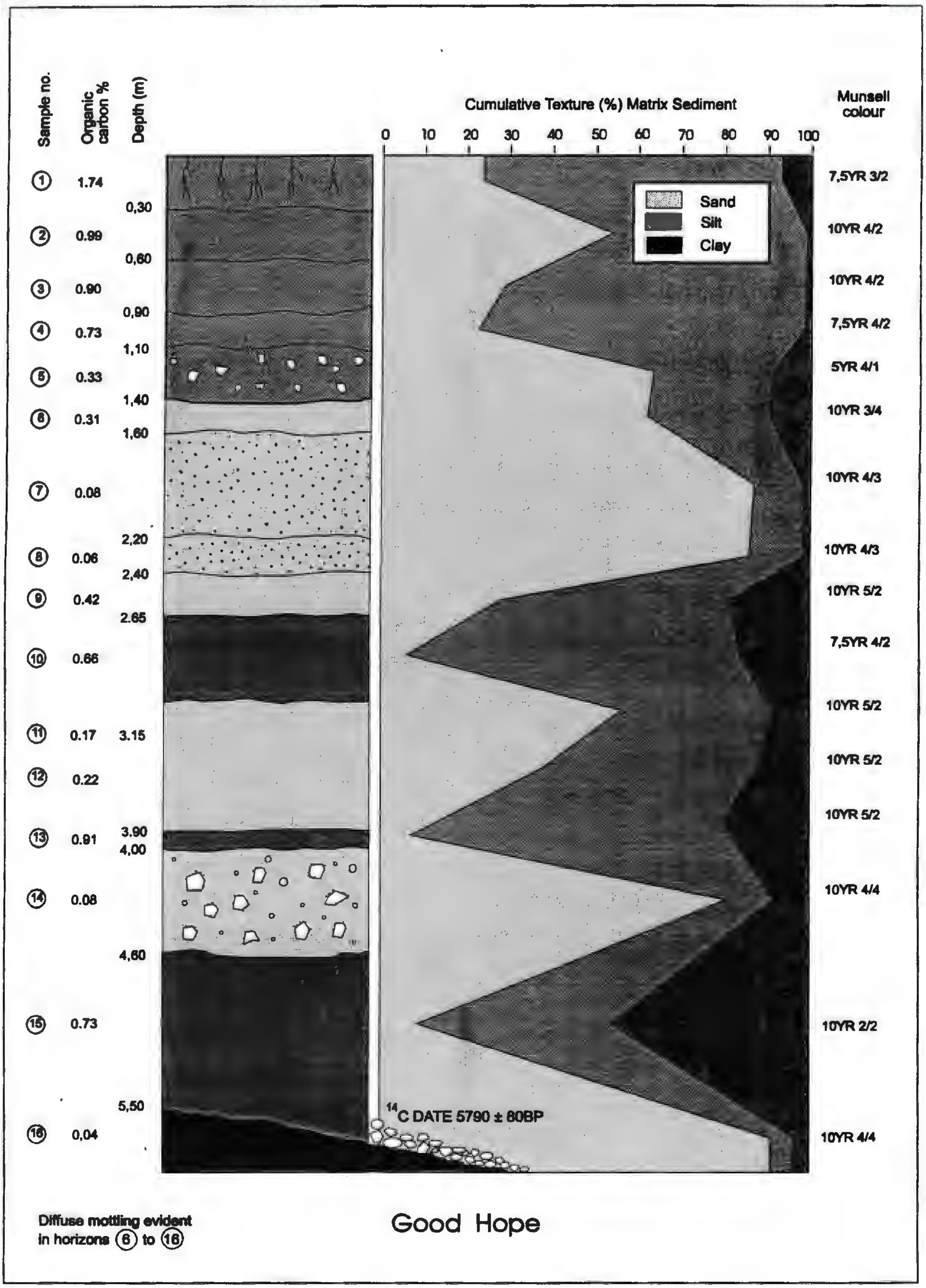


Figure 7.16 Good Hope profile, exposed by erosion and incision to bedrock in a gully system which has developed along a tributary of the Klein Seekoei River.

7.5.5 Lucernvale (A and B) (31°39'55"S; 24°33'30"E) Altitude 1680 m

Two exposures, termed Lucernvale A and B respectively (Figs. 7.17 and 7.18), were logged at this site. At the junction of a prominent side gully and the stream (Lucernvale A), a colluvial basal lag is unconformably overlain by finer sediment (Fig. 7.15). The lag deposit, which is presently being undercut by the stream, comprises very poorly sorted subangular clasts up to 60 cm long axis. The stratum above this comprises hard, apedal sediment with a weakly developed blocky ped structure at its base. There are many, diffuse orange mottles in the bottom 1 m of this stratum, which also displays a stone line.

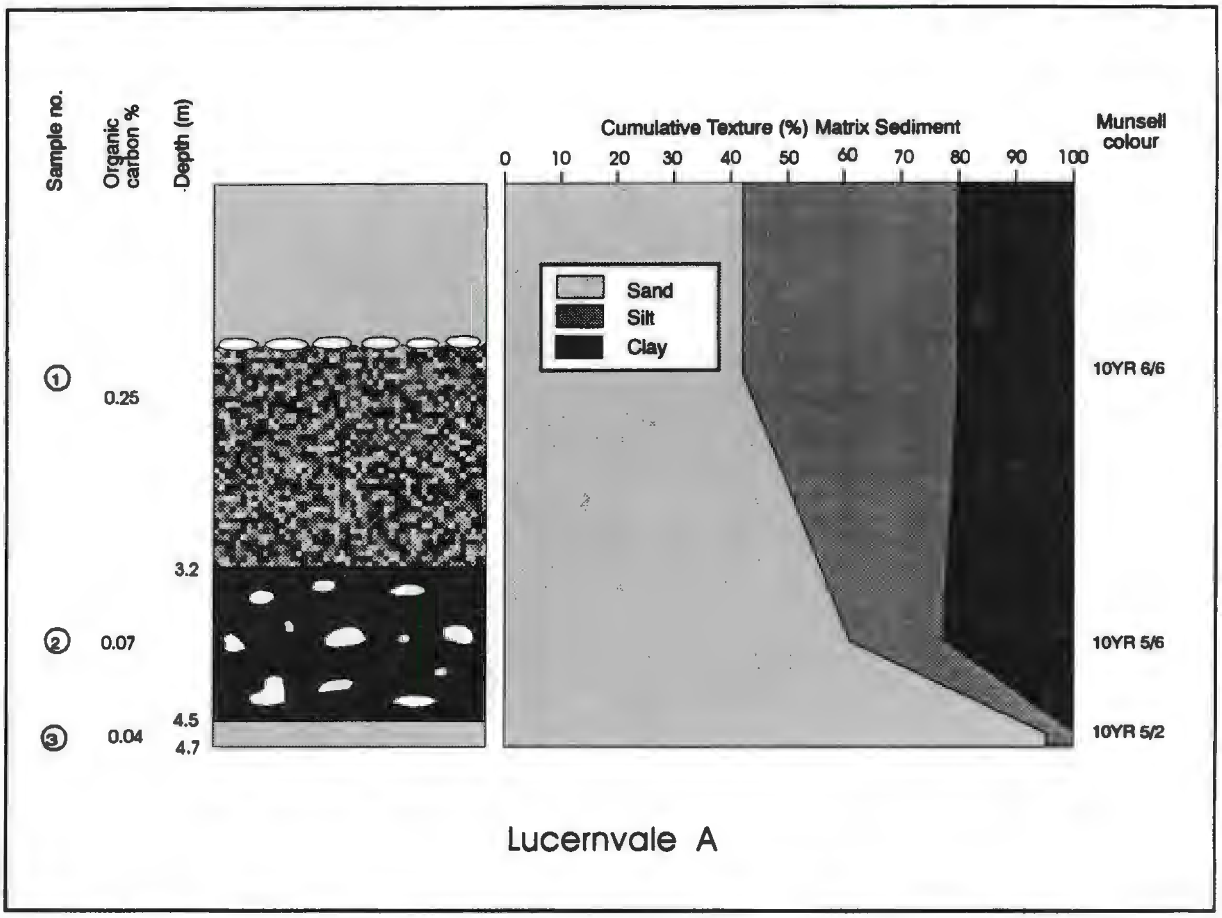


Figure 7.17 Lucernvale A profile, exposed by gully erosion.

The sequence represented at Lucernvale A is transgressed 800 m downstream, by a younger fill (Lucernvale B) comprising a modern topsoil overlying alternating organic rich horizons and strata comprising matrix supported sandstone clasts.

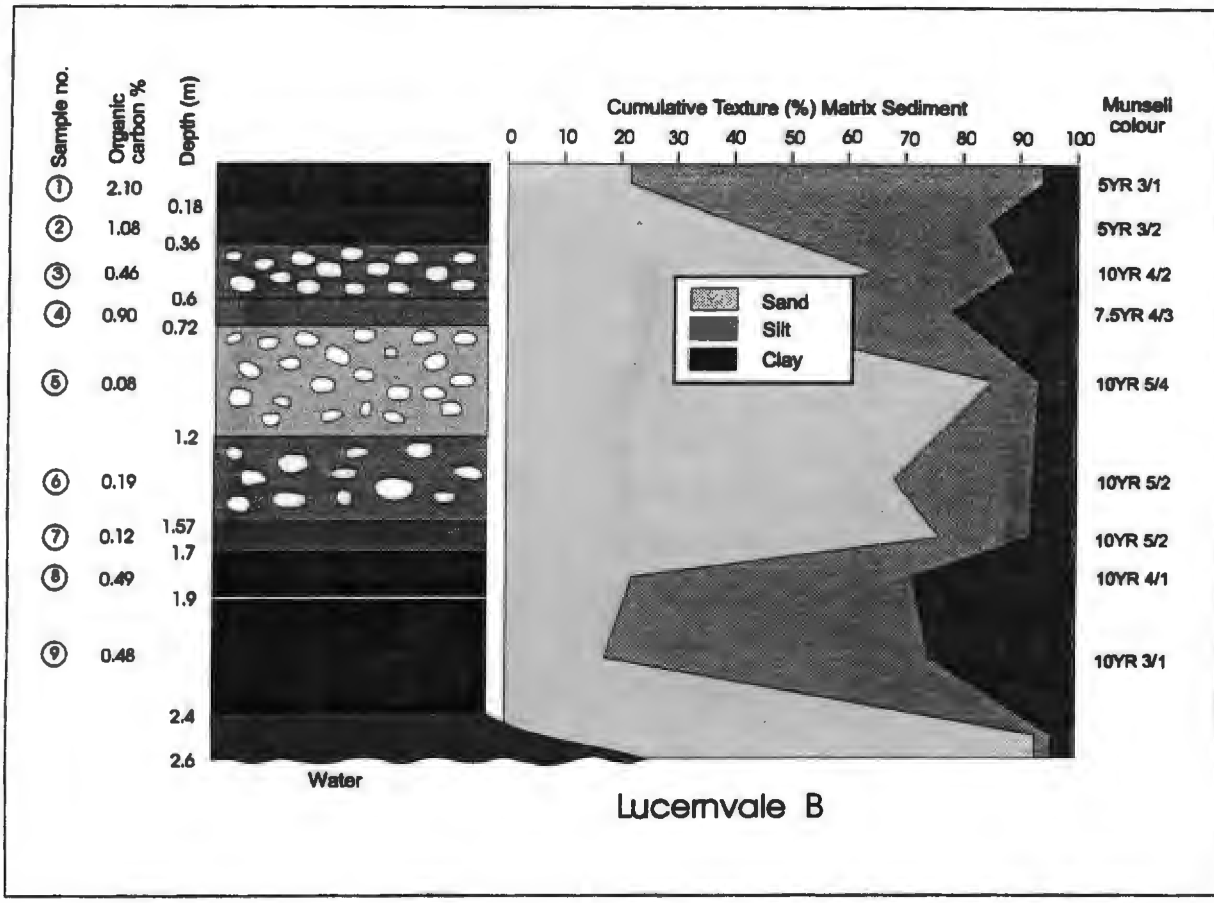


Figure 7.18 Lucernvale B profile, exposed by extensive gully erosion.

7.5.6 Klein Seekoei River (31°39'00"S; 24°37"50"E) Altitude 1570 m

Extensive gully erosion at this site has exposed profiles along the valley sidewalls as well as on freestanding sediment pedestals which have survived the present phase of incision. The profile chosen for investigation (Fig. 7.19) appears to have been stripped of its A horizon and capped by a modern sheet wash deposit. A very dark (10YR 3/1) layer (horizons 3, 4 and 5) displaying relatively high proportions of organic carbon extends to a depth of 1.98 m (Plate 7.7). This layer displays a crumbly ped structure at the top, through blocky peds in horizon 4 to a columnar structure in horizon 5. The layer overlies a sequence of clay rich strata, some of which contain lags of granule to pebble grade material. ^{14}C dates of 2510 ± 50 BP (Pta 5186) from the top of the dark layer, and 4870 ± 60 BP (Pta 5188) from the base were reported by Sugden (1989).

7.5.7 Synopsis

The Sneeuberg locality exhibits a complexity of valley headwater fill sequences which is not matched at any other locality within the study area. The tributaries of the Klein Seekoei River (represented by the Compassberg Gully, Good Hope and Lucernvale sites (Fig. 6.11)) are

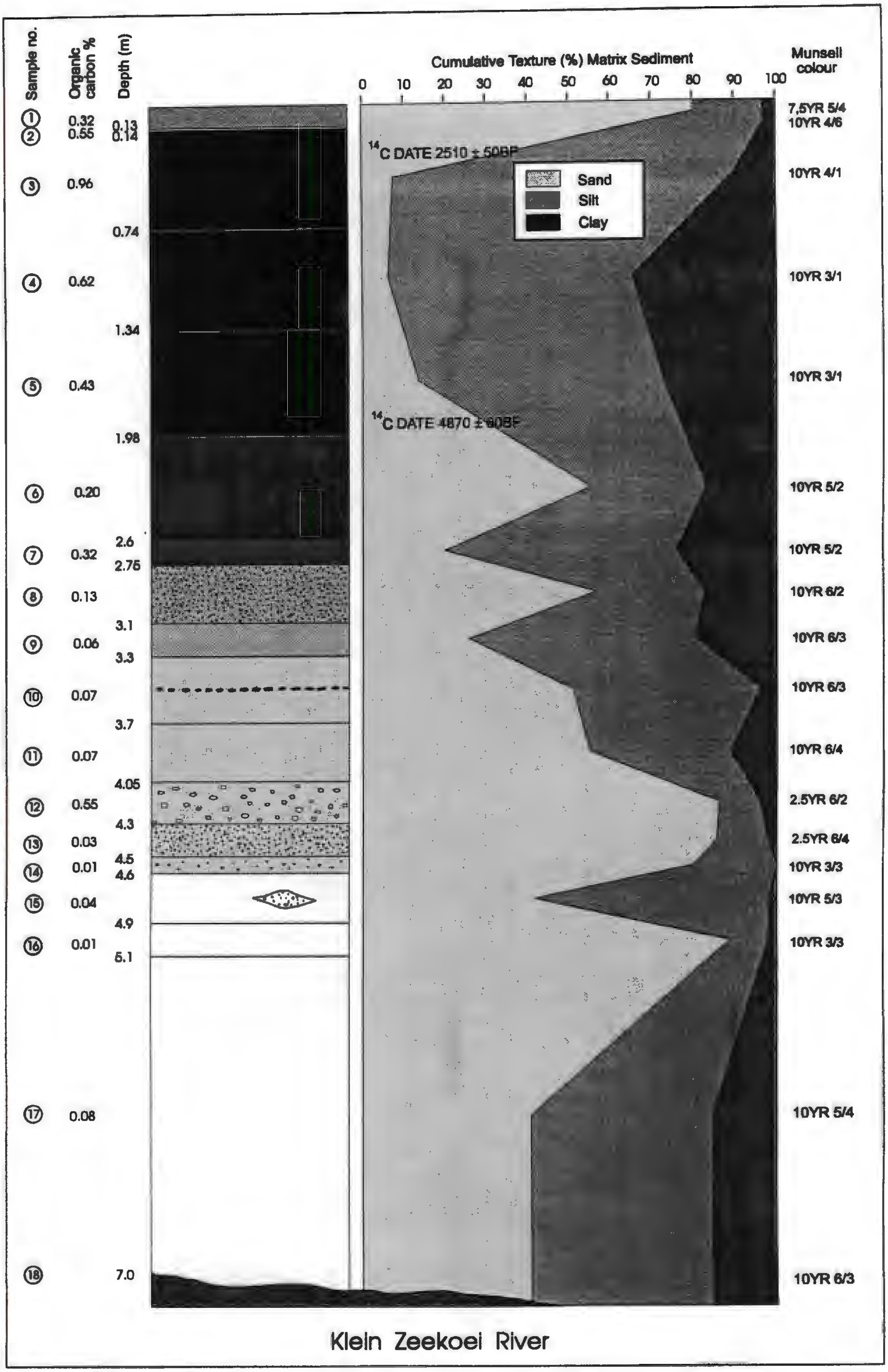


Figure 7.19 Klein Seekoei River profile, exposed by severe erosion in a complex system of gullies on the Klein Seekoei River.

unique in one respect when compared to the majority of profiles logged during this investigation; they do not display the abrupt change from relatively homogenous, sandier sediment in the lower part to relatively organic rich horizons in the upper part of their profiles (see also Bousman *et al*, 1988). Rather, organic rich sediments have been preserved in or proximal to the basal horizons in the Compassberg Gully, Good Hope and Lucernvale B profiles. However, the two sites situated on the main drainage line (The Valley and Klein Seekoei River) appear to reflect the "classic" sequence observed at other localities of organic rich fills overlying inorganic sediments. The implications are elaborated on in Chapter 9.

7.6 NUWEVELDBERG LOCALITY

7.6.1 Introduction

This, the most westerly of the five study localities did not provide evidence of valley fills of either the nature or the extent of the localities situated further east. The valleys of the Nuweveld range have been largely infilled with massive accumulations of gravel to boulder grade clast supported colluvium. Two sites were logged, principally to allow comparisons with the more easterly localities rather than to search for intrinsic evidence of environmental change. As such, the Nuweveld locality may be regarded as peripheral in terms of the objectives of this study.

7.6.2 Mountain View (32°13'20"S; 22°31'55"E) Altitude 1680 m

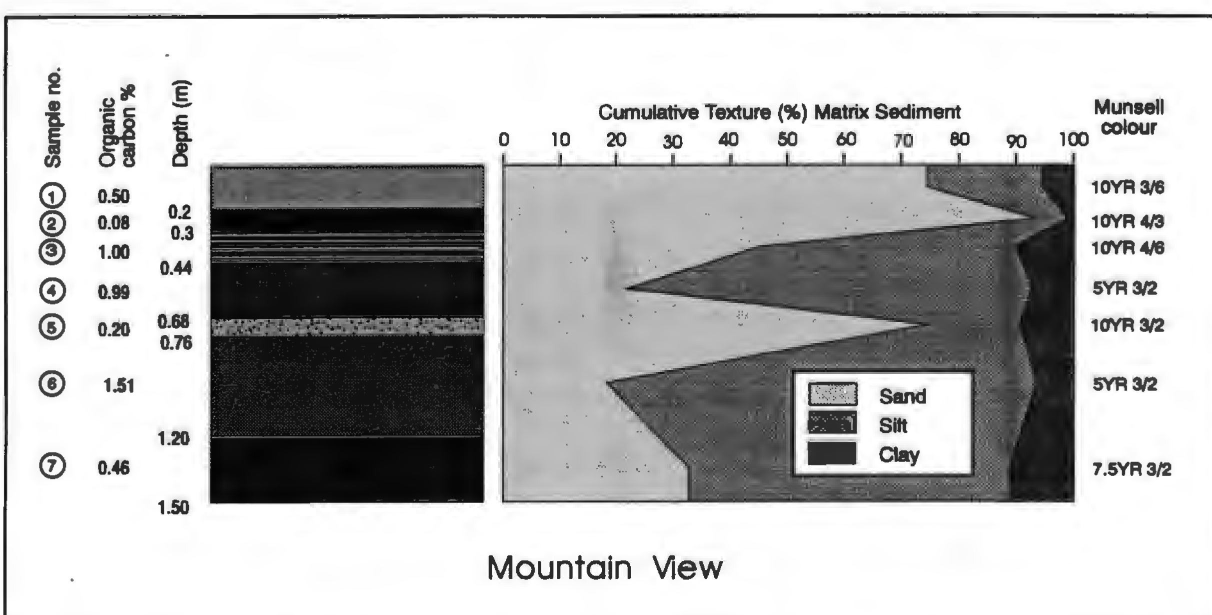


Figure 7.20 Mountain View profile, exposed by stream incision of sediments which have filled a shallow, vlei-like headwater hollow.

This profile was logged to a depth of 1.5 m (Fig. 7.20). A structureless, sandy loam overlies a series of thin strata, some of which appear to display evidence of incipient pedogenesis. Although the base of the exposure is partly concealed by dolerite gravels, the morphology of the drainage basin suggests that bedrock would be reached no deeper than ~1.8 m below the surface. Sugden (1989) extracted a core from Bokkraal Vlei, situated in an adjacent vlei-like depression ~4 km from this site. Weathered parent material was reached at a depth of 120 cm. A basal ^{14}C date of 760 ± 50 years BP (Pta 4351) was obtained by Sugden (1989) from the Bokkraal Vlei core.

The Mountain View exposure is characterised by a modern topsoil overlying a series of horizontally bedded unconsolidated sediments, some of which display fine laminations. Two horizons (3 and 6) display relatively high proportions of organic carbon.

7.6.3 Stols River (32°19'10"S; 22°30'00"E) Altitude 960 m

This stream channel has been infilled with poorly sorted, angular to partly rounded, calcretised dolerite, sandstone and mudstone, matrix supported gravels (long axis up to ~80 cm) resting on purple mudstone and capped by massive sand. The profile does not display evidence of pedogenesis and lacks a well developed, modern topsoil horizon (Fig 7.21).

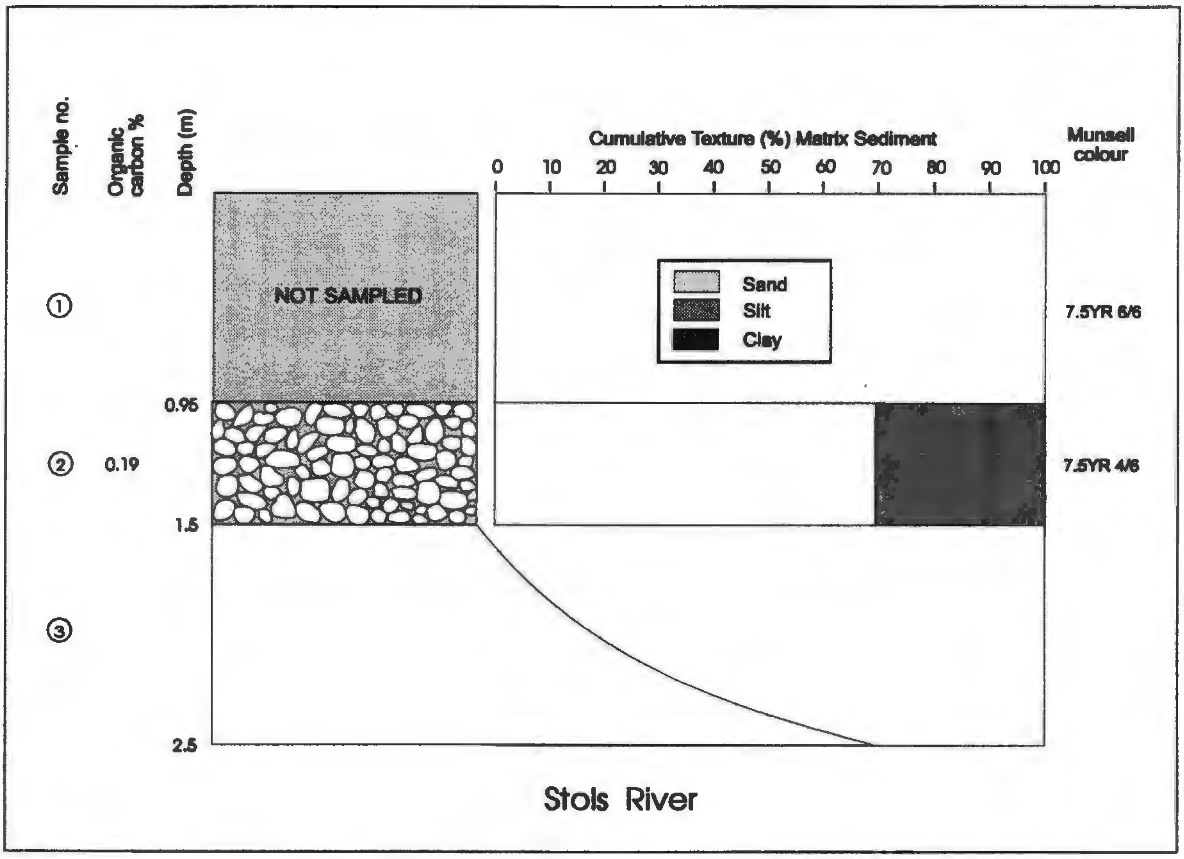


Figure 7.21 Stols River profile, exposed by stream incision of a colluvially filled channel at the base of the Nuweveldberg escarpment.

7.6.4 Synopsis

The sites at this locality are typical of two different depositional environments. The Mountain View site is interpreted as reflecting low energy fluvial deposition in a valley headwater depression or pond. Cyclical accumulation of sediment appears to have occurred. The accumulated sediments were subsequently incised by the headwater stream and desiccated.

The sediments at the Stols River site are interpreted as being of colluvial, rather than alluvial origin. Following infilling of the valley, low frequency high magnitude stream flows have incised the colluvial fill. This flash flood type response occurs typically in the drier western parts of the central Great Karoo where vegetation covers is sparse.

7.7 SUMMARY AND CONCLUSIONS

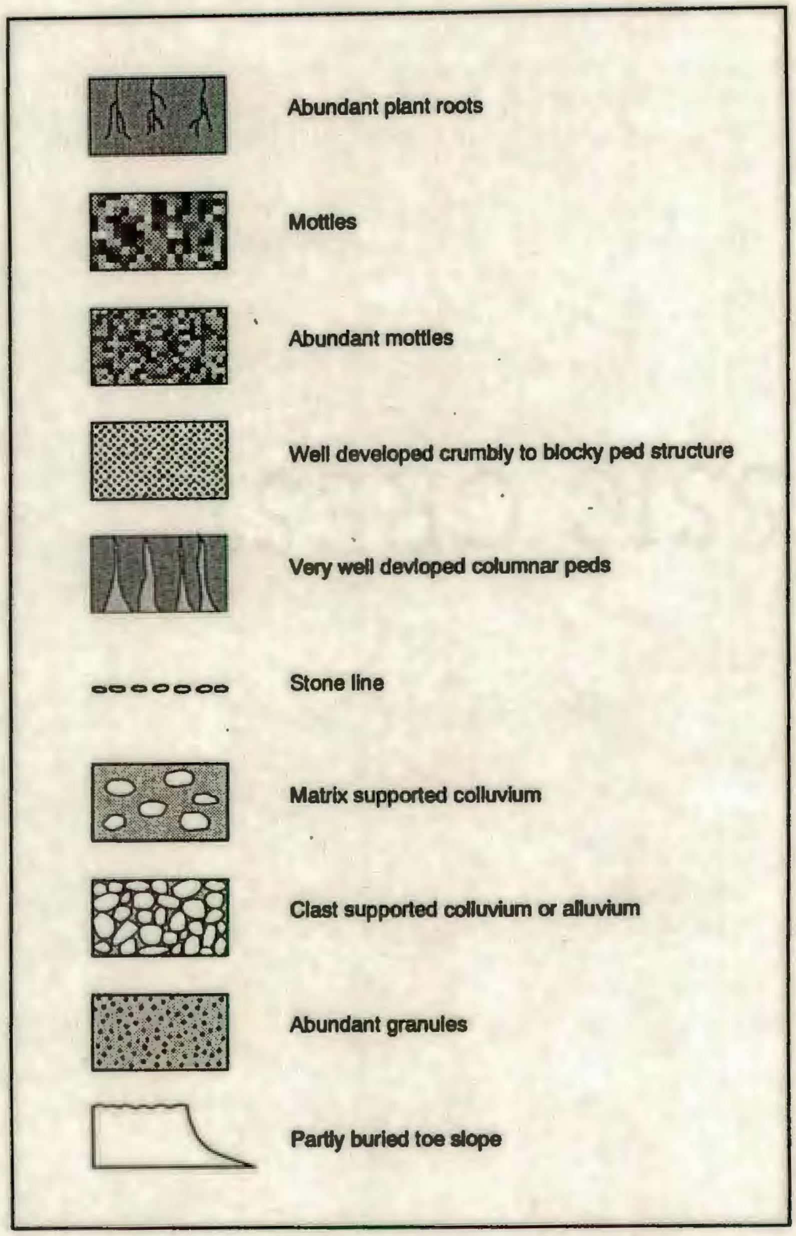
Geomorphic evidence from a variety of upland environments within the central Great Karoo and its margins attests to cyclical deposition in response to fluvial, aeolian and colluvial processes which are not necessarily active to the same extent in the present day landscape. On the basis of a number of absolute dates, it would appear that such deposition commenced at the time of the Last Glacial Maximum. It is apparent also that pedogenesis and erosion have been active at times within this environment. Currently, erosion appears to be the dominant mechanism active within Karoo upland headwaters.

It is necessary to interpret in more detail the geomorphic evidence for environmental change, to place it within the context of the broader southern African framework, and to account for the apparent cyclical nature of valley fill accretion. This forms the substance of Chapters 9 and 10. Before doing so, the data which emerged from the laboratory analyses associated with each site investigation are addressed. Two groups of data exist. Firstly, those generated from the routine laboratory analyses, and secondly, those stemming from the additional analyses discussed in Chapter 4. The utilisation of routine data as a classificatory tool is discussed in the following chapter. Aspects of the non-standard analyses are also expanded upon in Chapter 8. Both the routinely derived data and the additional data are utilised to facilitate the interpretation which forms the substance of Chapter 9.

LIST OF LOCALITIES AND SITES, AND THEIR ABBREVIATIONS, FOR USE WITH CHAPTER 7 AND FOR REFERENCE TO THE STATISTICAL ANALYSES IN CHAPTER 8.

The following abbreviations were used as codes for the various sites which formed the basis of this investigation. The codes were originally used in the field, and subsequently to label sediment samples for laboratory procedures. They were also used at the data processing stage and during statistical analyses.

LOCALITY AND SITE	ABBREVIATION
STORMBERG LOCALITY	
Klipkraal Sands	KLIP
Buffelsfontein Pan	BUFF
Klipplaat Pan	KP
Buffelsfontein Stream	BD
Kalkoenkrans Vlei	KAL
Holspruit Gully	HOL
TANDJIESBERG LOCALITY	
Wilgerboom River Colluvium	ZC
Bergkloof Site	ZB
Doornhoek Dam	ZD
Spekboom (Pauls) River	SPEK
WAPADSBERG LOCALITY	
Wapadsberg Summit: Rooiskuur	ROOI
Wapadsberg Summit: Ruigterfontein	WAR
Rochdale Farm	ROCH
SNEEUBERG LOCALITY	
Compassberg	KOM
The Valley	VAL
Good Hope	GH
Lucernvale A	LUC A
Lucernvale B	LUC B
Klein Seekoei River	ZEEK
NUWEVELDBERG LOCALITY	
Mountain View	MOUNV
Stols River	STOLS GM
Pienaars Poort	PIEN
OTHER	
The Ranges	RANGE



KEY FOR USE WITH PROFILES IN CHAPTER 7

CHAPTER 8

The Classification and Further Elucidation of Valley Fills

8.1 INTRODUCTION

In situ interpretation of the morphology of exposed valley fills, coupled with laboratory analyses of selected sediment samples, provided data which facilitate both their description as well as inferences with regard to their provenance and transportational history. The analyses also provide insights with regard to post depositional alteration of the sediments. Such data also assist greatly in identifying unique strata within a depositional sequence, as well as facilitating a comparison of strata within sequences or between sequences. In short, data can contribute to a stratigraphic classification and an interpolation of depositional environments. The former activity comprises the first part of this chapter and the latter the second.

The search for order or trends in data sets derived from the physical, geochemical and mineralogical analyses of sediments is not without problems. Inferences are frequently made on the basis of samples comprising a few grams of sediment taken from a stratum which may have been subjectively identified as the most suitable in terms of some previously defined research strategy. Helgren (1979) has pointed out that the statistical subset in terms of the number of samples chosen for analysis is extremely limited. "The data so generated provides no more than a selection of numerical parameters that are not fully representative of the lateral and vertical variation within a sedimentary unit" (Helgren, 1979, p. 345). Nevertheless, the application of a carefully selected suite of statistical techniques may assist in establishing a degree of order from a mass of data. To this end, a range of statistical analyses were undertaken as part of this study. Theoretical aspects of these techniques and the rationale behind their deployment were detailed in Chapter 4. It must be emphasised that such analyses were utilised primarily as exploratory tools and as an aid to semi-quantitative description and classification. The statistical methodologies were not employed as inferential tools, nor in any rigid, deterministic way.

8.2. APPLICATION OF STATISTICAL TECHNIQUES

8.2.1 Introduction

Because they were identified as unique landscape features in the context of this study (they are not valley fills displaying sedimentary profiles), the data from the Buffelsfontein and Klipplaat

Pan and lunette complexes and the Klipkraal Sands were not included in the exploratory multivariate analyses described below. Data from samples from all the valley fill sites were included in the analyses. The following deals with the application of the multivariate analyses, as well as commenting briefly on salient features of each analysis in turn.

8.2.2. Principal components analysis

Principal components analysis was performed in an initial attempt to search for order in the data set, ie. prior to any attempt to group or classify strata identified in the valley fills.

8.2.2.1 Primary data set

This analysis was undertaken on the standardised data from 16 variables on 173 cases. Within the matrix, variables were configured as columns, and cases as rows. Each case represents a valley fill stratum. The raw data are displayed in Appendix E. The selection of components for further utilisation in, for example, cluster analysis implies a measure of subjective judgement on the part of the researcher. After inspecting the results of this analysis, the first four components were selected for further utilisation in the cluster analyses and the Kohonen Self-Organising Map (SOM). This decision was based on the variance accounted for by these components (see below), as well as the absence of marked loadings on components other than the first four.

Variable	PC1	PC2	PC3	PC4
% sand	**.885**	.244	.025	.138
% coarse	**.890**	.066	.007	-.272
% medium	.481	-.064	.540	.323
% fine	**-.964**	.100	-.074	.076
mean	**-.953**	.161	-.044	.101
median	**-.961**	.112	-.001	.115
sorting	.044	-.414	.673	.111
skewness	**.822**	.055	-.140	-.194
kurtosis	-.209	.646	-.423	-.400
% silt	**-.811**	-.092	.199	.013
% clay	-.571	-.012	-.047	-.222
pH in water	-.096	**.762**	.538	-.094
pH in $CaCl_2$	-.002	**.724**	.596	-.049
conductivity	-.290	.133	-.074	.440
organics	-.387	-.329	.409	-.520
organic carbon	-.375	-.338	.221	-.535
Explained variance	6.671	2.065	1.862	1.243
Proportion of total	.4169	.1291	.1163	.0777

Table 8.1 Component loadings and explained variance from Principal Component Analysis (unrotated), all valley fill samples. Loadings > .7 marked in bold.

In total, the first four principal components accounted for 73.93% of the variance in the data set. In the light of the loading scores (Table 8.1), principal component 1 (which accounted for

41.69% of the variance) was interpreted as reflecting particle size or "granularity" in the data set. Principal component 2 (which accounted for 12.91% of the variance) was interpreted as reflecting "sediment acidity or alkalinity" (pH in water and in $CaCl_2$). Principal component 3 (which accounted for 11.63% of the variance) was interpreted as reflecting "homogeneity of particle size" in the data set. Principal component 4 (which accounted for 7.77% of the variance) was interpreted as reflecting "sediment organic material and organic carbon".

The four factors (principal components 1 to 4) were subjected to a number of non-orthogonal rotations (including varimax and quartimax rotation) in an attempt to establish the clearest possible (most diverse) pattern of component loadings. This exercise did not make any great difference to the loading scores on the four factors. Explained variance in terms of the first four factors after varimax rotation (Table 8.2) is similar to the unrotated analysis. This implies a robust data set, which only reflects the influence of the associations within the data set which are interpreted as being revealed by the first four principal components. Interestingly, the rotated analysis accentuated loadings marked > .7 on components 2, 3 and 4. This would appear to lend weight to the interpretation of the components as set out in the previous paragraph.

Variable	PC1	PC2	PC3	PC4
% sand	**-.845**	.191	-.027	-.304
% coarse	**-.930**	.066	.044	.012
% medium	-.379	.262	-.629	-.156
% fine	**.951**	.036	.193	.080
mean	**.948**	.100	.190	.045
median	**.960**	.088	.129	.068
sorting	-.010	.096	**-.738**	.290
skewness	**-.846**	-.040	.111	-.086
kurtosis	.100	.263	**.849**	-.013
% silt	**.790**	.063	-.084	.269
% clay	.499	-.016	.212	.296
pH in water	.075	**.936**	.080	.006
pH in $CaCl_2$	-.003	**.939**	-.013	-.016
conductivity	.392	.027	-.057	-.379
organics	.243	.047	-.140	**.791**
organic carbon	.228	-.078	-.014	**.729**
Explained variance	6.323	1.980	1.851	1.657
Proportion of total	.3952	.1237	.1157	.1036

Table 8.2 Component loadings and explained variance from Principal Component Analysis (varimax rotated), all valley fill samples. Loadings > .7 marked in bold.

Subsequently, cluster analysis and SOM were performed on all the cases using factor scores on the four principal components mentioned above as proxy variables. This is discussed below.

8.2.2.2. Secondary data sets

To search for relationships between variables similar to those revealed within the primary data set, principal components analysis was performed on secondary data sets. These comprised data derived from all the strata from each profile at four of the five study localities. The Nuweveldberg locality (Fig. 1.2) was not considered because of the limited number of cases.

As with the primary data set, in each secondary data set the first four components were interpreted as reflecting "granularity", "homogeneity", "acidity" and "organics" respectively at each locality. For the sake of brevity, the loadings are not displayed here in tabular form. Similarly, scores on the four principal components were used as proxy variables for a cluster analysis of the strata from each of the four study localities respectively.

8.2.3 Cluster analysis

Cluster analyses was also performed on a primary data set and secondary data sets. The Nuweveldberg locality was excluded from the latter for the same reason that it was excluded from the secondary principal components analysis. Within the narrative which follows, cases are referred to by the abbreviation utilised for each site and its suite of samples (see Figs. 7.4 to 7.21). A summary of localities, sites and their abbreviations is provided in Appendix G. Reference to this appendix will greatly facilitate the reader's cognisance of the following.

8.2.3.1 Primary data set

The advantage of single linkage cluster analysis is its propensity for identifying outliers, while Ward's method is particularly suited to identifying groupings. Because both unique cases and groupings are of interest in this study, both clustering methods were used. Single linkage cluster analysis (Fig. 8.1) identified case WAR 8 (Wapadsberg locality) as a completely isolated outlier, while cases BD 1, BD 2 and HOL 1 (all from the Stormberg locality) form an outlying cluster. Beyond this, single linkage cluster analysis did not prove to be particularly illuminating.

Ward's method identified the same outliers, as well as recognising seven clusters at a Euclidean distance of 10, and 5 clusters at a distance of 15 (Fig. 8.2). Of note is the fact that all the KAL cases (Stormberg locality) group within a single cluster (distance of 15), while 13 of the 19 ZD cases (Tandjiesberg locality) do likewise. The ZEEK site (Sneeuberg locality) appears to be the least homogenous, with its cases represented in all the clusters at a distance of 15. Other sites from the Sneeuberg locality (GH, VAL, KOM and LUC) reflect this lack of homogeneity to a lesser extent. The sample represented by the statistical outlier WAR 8 comprises a unique gritty lens within the stratigraphic profile at the Ruigterfontein site. Cases BD 1 and 2, and to a lesser extent HOL 1, represent fines-rich, structured A/B horizons which are particularly susceptible to gullying. The KAL cases represent a suite of sediments from the only valley floor wetland to be cored as part of this study. The significance of the relatively diverse samples represented by the ZEEK cases and the other Sneeuberg Locality sites is taken up in Chapter 9.

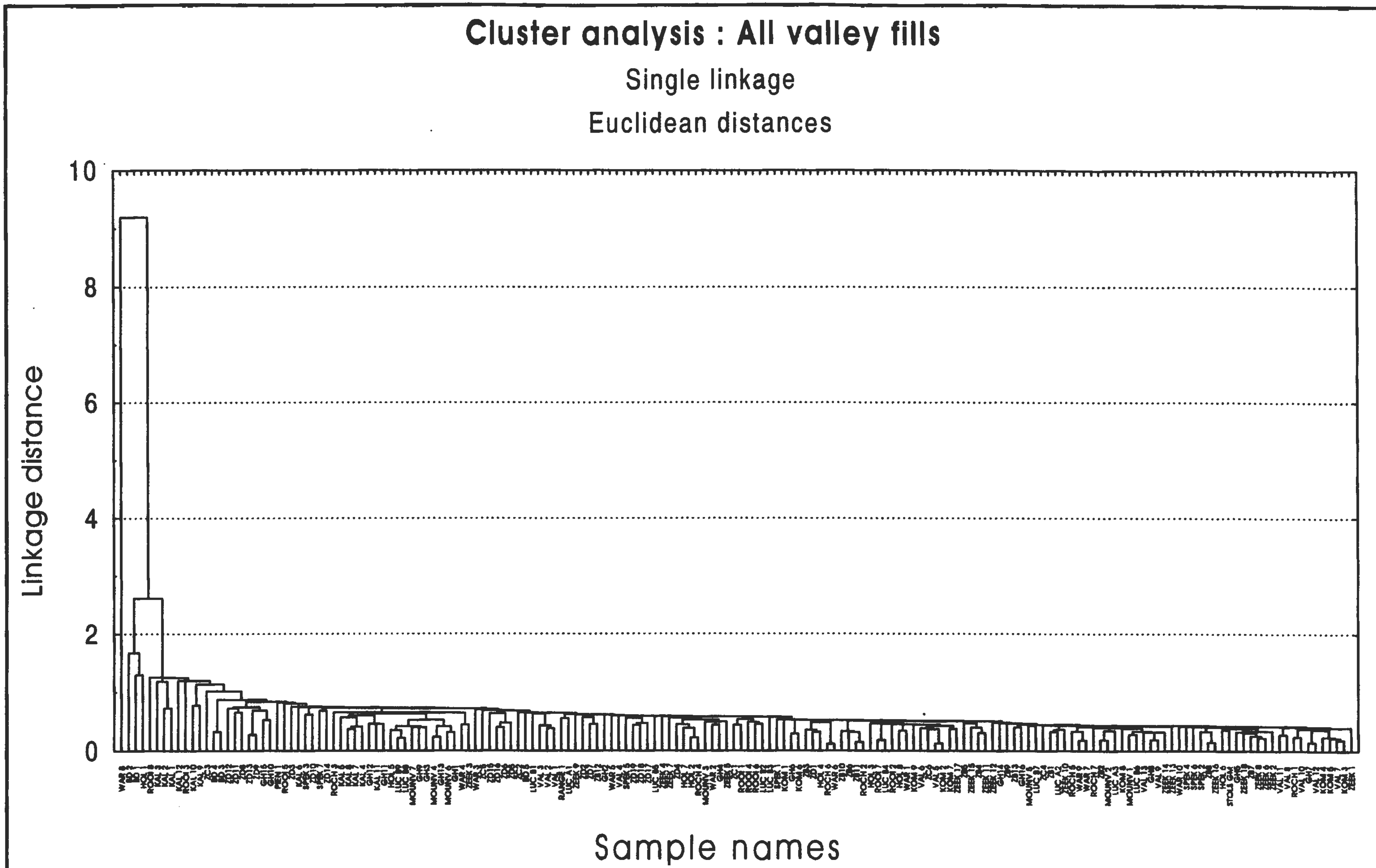


Figure 8.1 Single linkage cluster analysis, all valley fill samples.

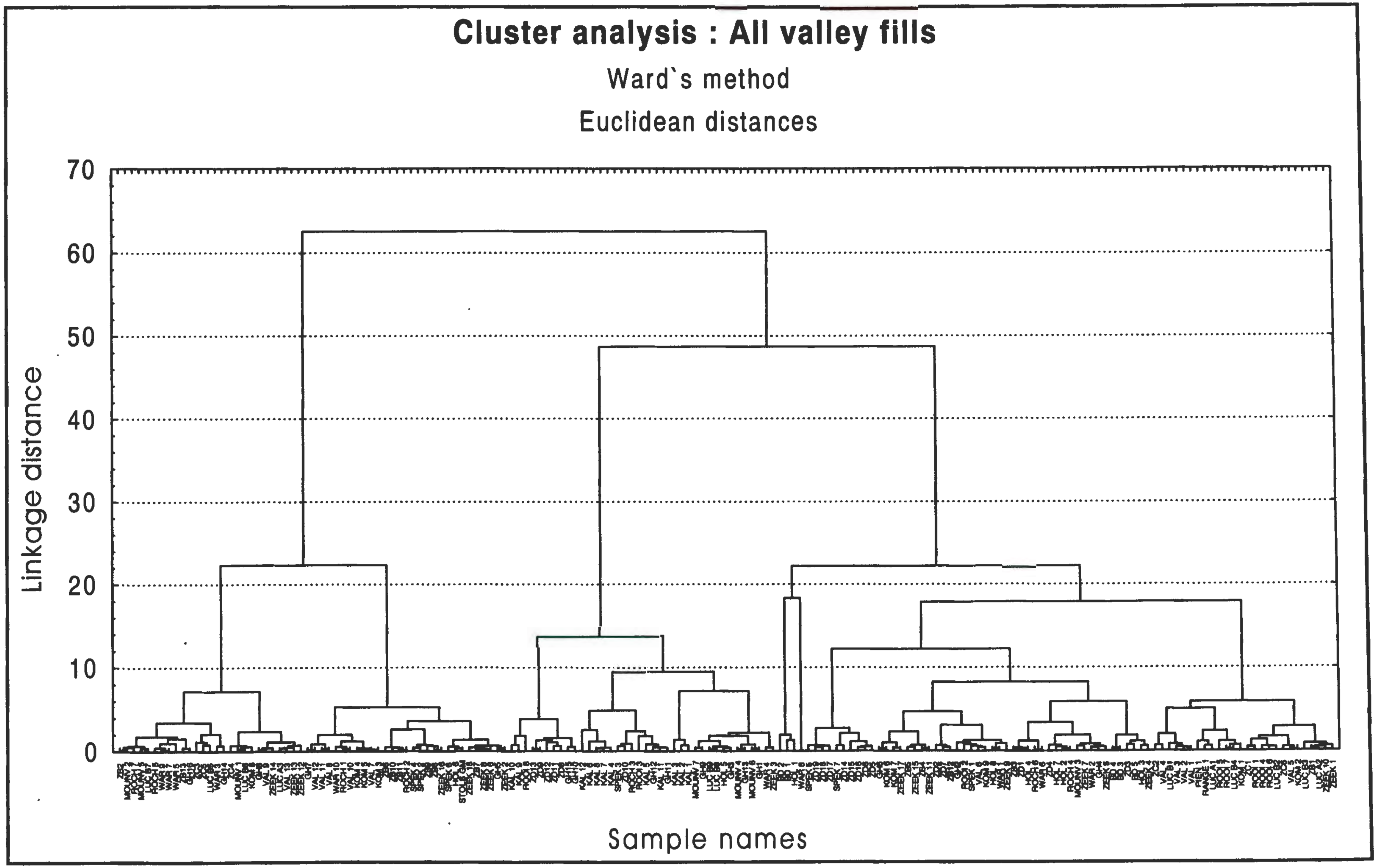


Figure 8.2 Cluster analysis, Ward's method, all valley fill samples.

8.2.3.2 Secondary data sets

Stormberg locality

The single linkage analysis (Fig. 8.3) clearly identifies HOL 1 as an outlier even within the context of its own locality. No striking relationship is apparent on inspection of the two primary clusters (Ward's method, distance 9) in Fig. 8.4. However, at a Euclidean distance of 2, the BD cases form two distinct clusters. The nature of the strata represented by these outliers was noted under 8.3.2.1.

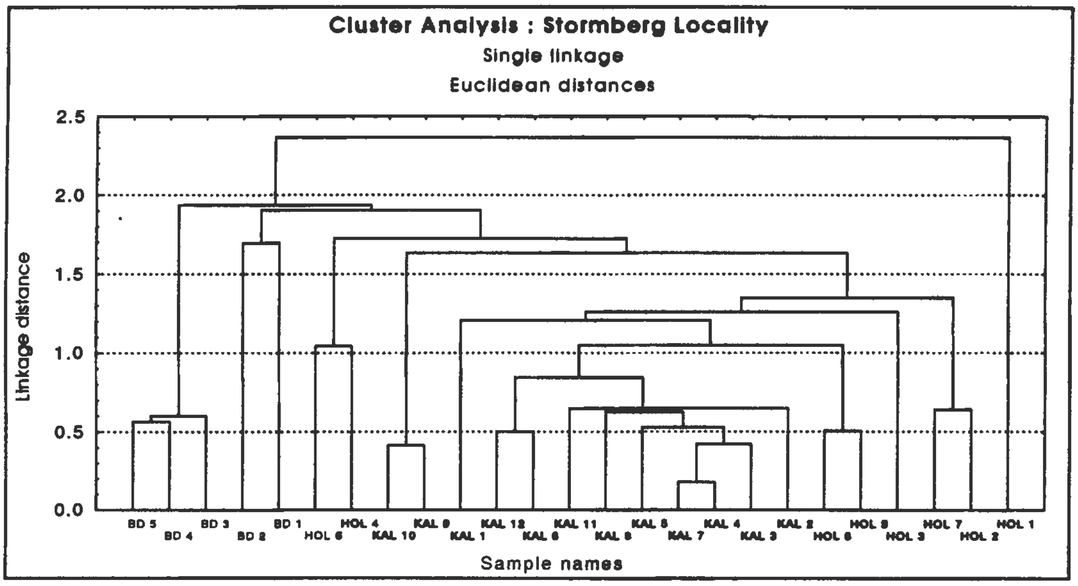


Figure 8.3 Stormberg locality, single linkage cluster analysis.

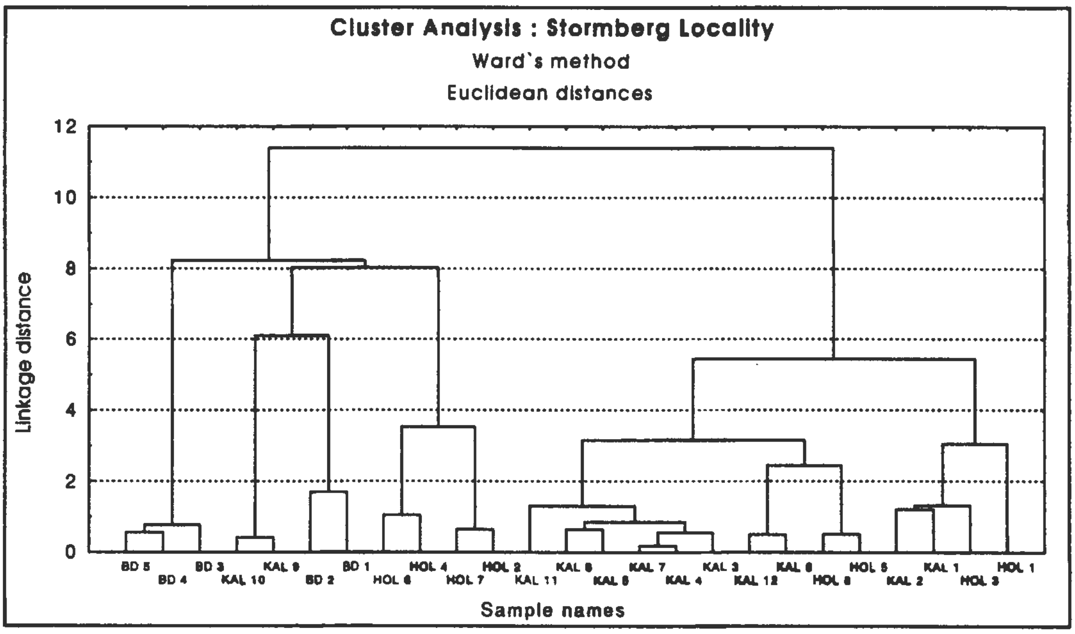


Figure 8.4 Stormberg locality, cluster analysis, Ward's method.

Tandjiesberg locality

Cases 8, 9, 10, 11, 12, 13 and 14 (Fig 8.5), which represent a group of strata situated approximately two thirds down the ZD profile (Fig. 7.9) can be regarded as an outlier group. The implications of this grouping are discussed in Chapter 9. The surface, or topsoil strata represented by ZB 1, ZC 1 and ZD 1 form part of an outlier group at the opposite end of the single linkage cluster. Similarly, in the Ward's method cluster (Fig 8.6), they belong to the same cluster at distance 6. In the Ward's method cluster (Fig. 8.6) the clear groupings of ZD cases are also apparent. The two clast supported strata in the SPEK profile form a cluster (cases SPEK 2 and 4) below distance 1.

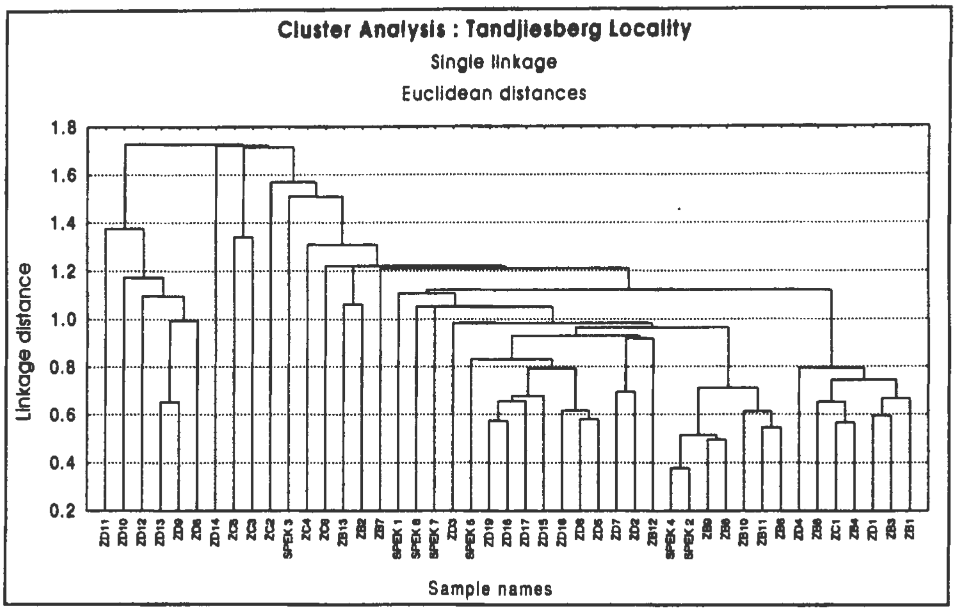


Figure 8.5 Tandjiesberg locality, single linkage cluster analysis

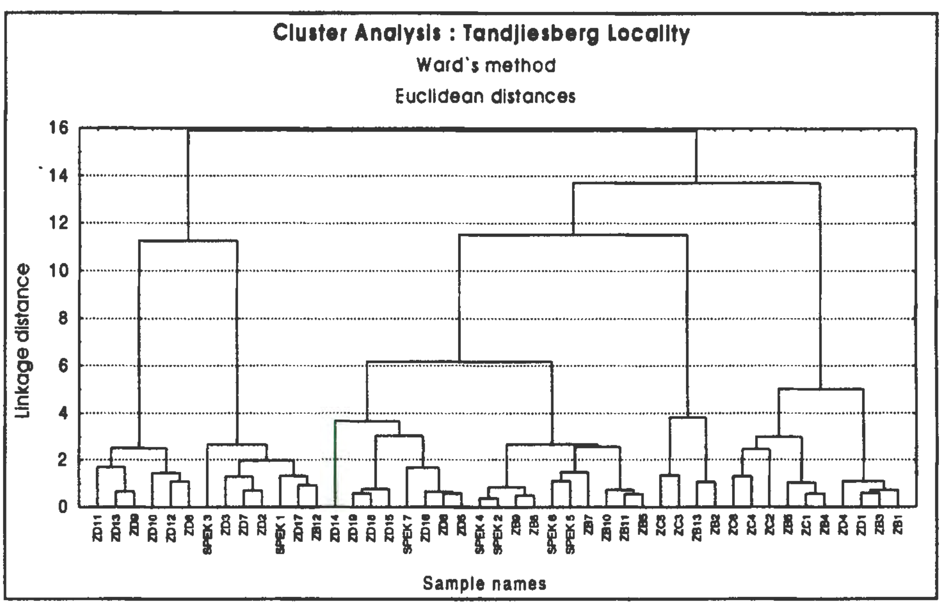


Figure 8.6 Tandjiesberg locality, cluster analysis, Ward's method.

Wapadsberg locality

The existence of WAR 8 (mentioned under 8.2.3.1) as a distant outlier is strikingly apparent from Fig. 8.7. ROOI 3 and 8, (which are generally sandier, and contain less organic carbon than the average for their site) may also be regarded as outliers. The Ward's method cluster (Fig. 8.8) reveals little of note beside a distribution of cases from all three sites across all the clusters regardless of whatever Euclidean distance is nominated as the cluster determination level.

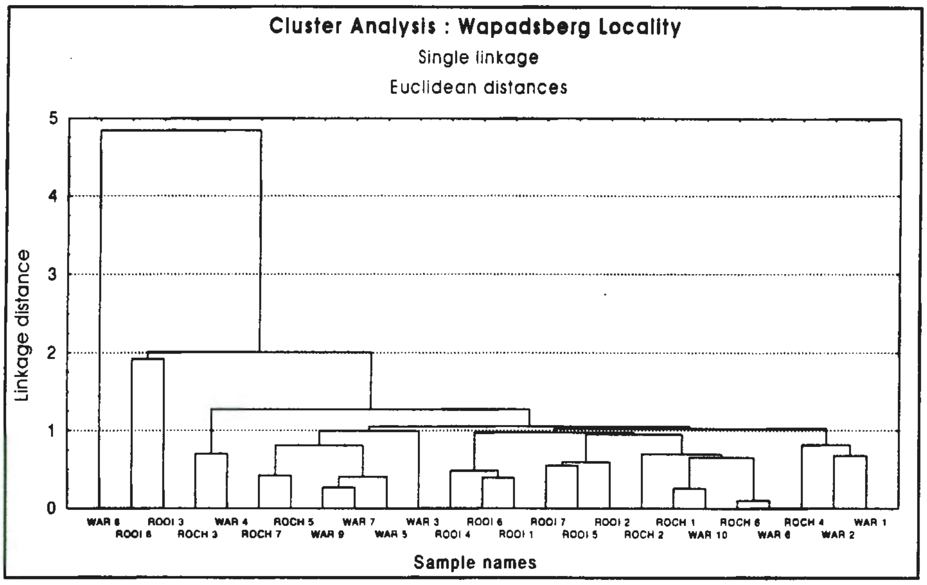


Figure 8.7 Wapadsberg locality, single linkage cluster analysis.

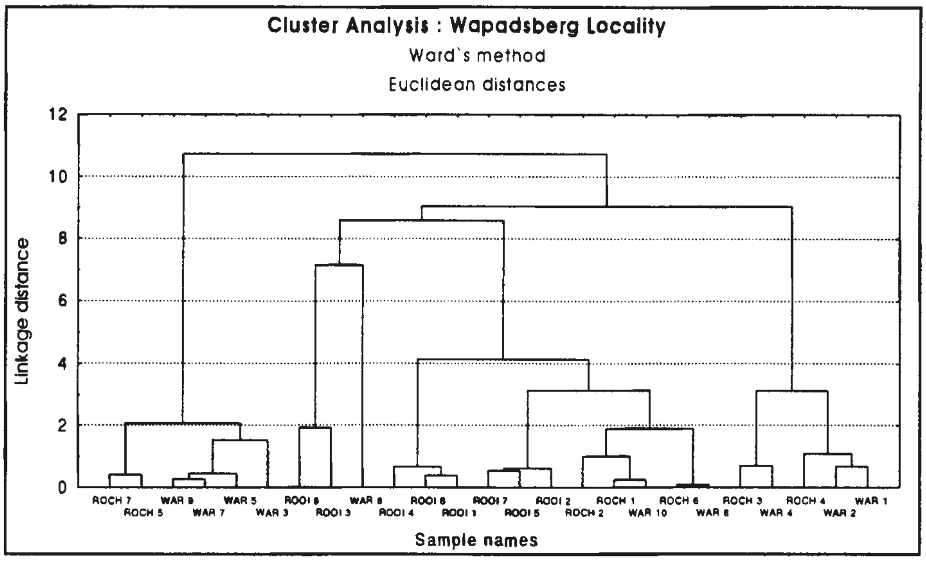


Figure 8.8 Wapadsberg locality, cluster analysis, Ward's method.

Sneeuberg locality

The reader is reminded that the Sneeuberg locality served as the hypothetical *type site* for an investigation into Karoo upland valley fills, and that a total of five sites represented by no fewer than sixty eight cases comprise the data set from this locality. GH 16, which may be regarded as a modern analogue in that the sample was taken from the river bed, forms a distinct outlier. A group comprising cases ZEEK 3, LUC A1, and GH 1, 10 and 15 might also be regarded as outliers in that they join the main cluster at the relatively great Euclidean distance of 1.1 (Fig. 8.9). The implications are considered in Chapter 9.

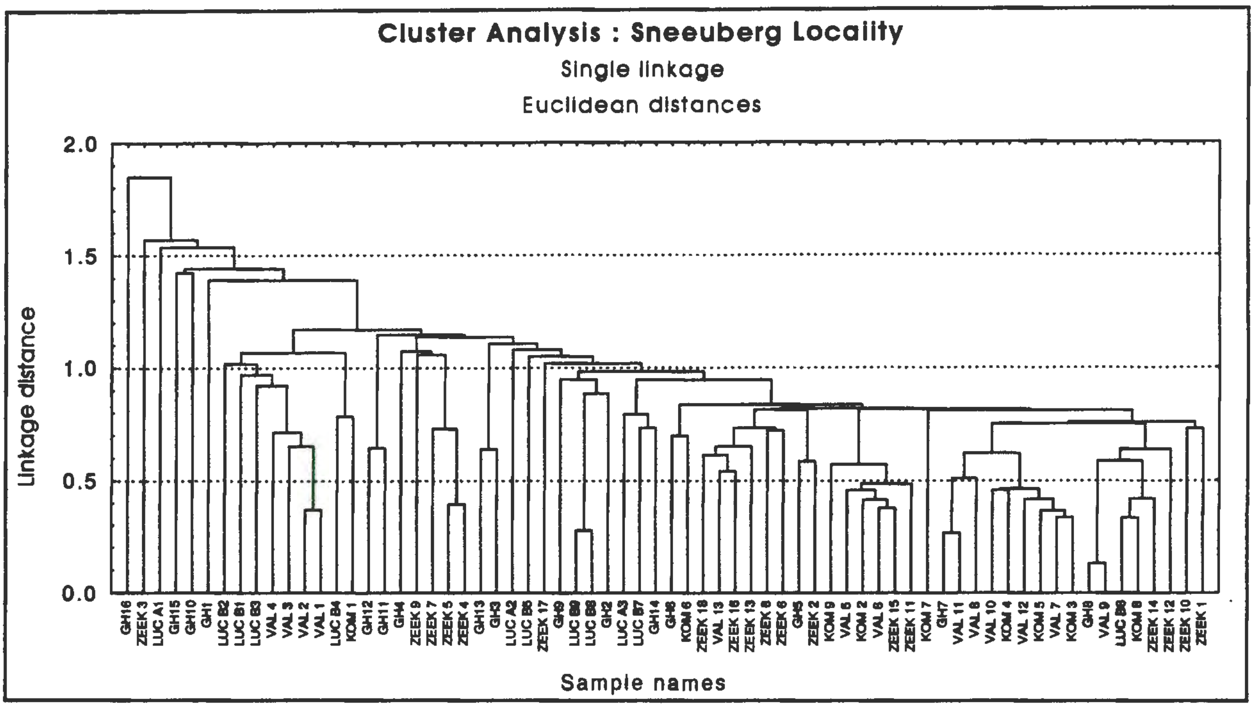


Figure 8.9 Sneeuberg locality, single linkage cluster analysis.

With regard to the Ward's method cluster analysis (Fig. 8.10), suites of cases from a number of profiles form clusters at Euclidean distances below 5. However, no single site is restricted to a single cluster, even at the extreme Euclidean distance of 21 where two clusters exist. The implications arising from the observations with respect to the groupings and outliers highlighted above are touched on under 8.3. and are utilised to facilitate the palaeoenvironmental reconstruction in Chapter 9.

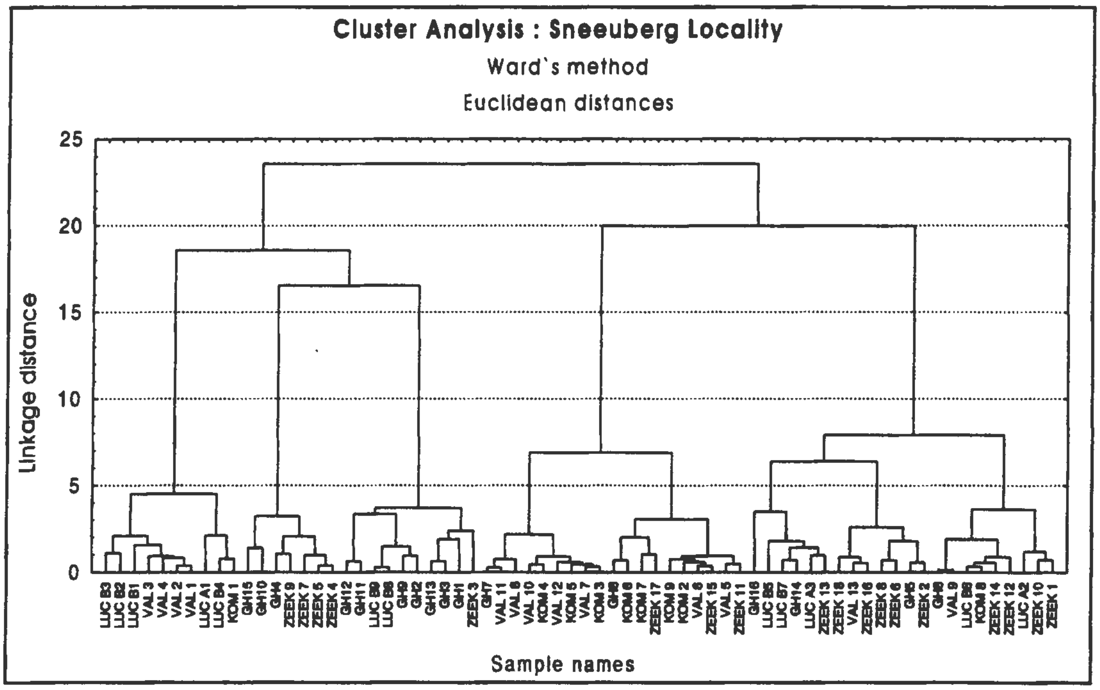


Figure 8.10 Sneeuberg locality, cluster analysis, Ward's method.

8.2.4 Self-Organising Maps (SOMs)

The Kohonen Self-Organising Map (Kohonen *at al,* 1996) was used to generate a map based on 173 samples from the valley fills. The map utilised the four factors generated by the principal component analysis as outlined under 8.2.2. The rationale behind the utilisation of these proxy variables is also discussed above. Results of the SOM technique are presented in Appendix H. Figs. 8.11 to 8.14 present a visual summary of the *archetypes* represented by each of the 15 nodes in the SOM on each of the 4 principal components respectively (refer to Fig. 4.1 for the conceptual representation of neighbouring nodes). These archetypes are similar to the centroids of clusters, that is, they epitomise the particular node. Figs. 8.11 to 8.14 reflect the degree to which the samples mapped to a particular node manifest the characteristic encapsulated by the principal component. Pure white would indicate perfect encapsulation, pitch black would indicate absolutely no reflection. The principal components characterise "granularity", "pH", "sorting" and "organics" (see 8.2.2.1). By referring to Appendix H it is possible to ascertain which samples were mapped to which nodes. For example, all the KAL samples (with the exception of the three uppermost strata) plot to node 1. This node in turn (Figs. 8.11 to 8.14) reflects poorly in terms of "granularity" and "homogeneity of particle size", somewhat better on "organics" and better still on "acidity".

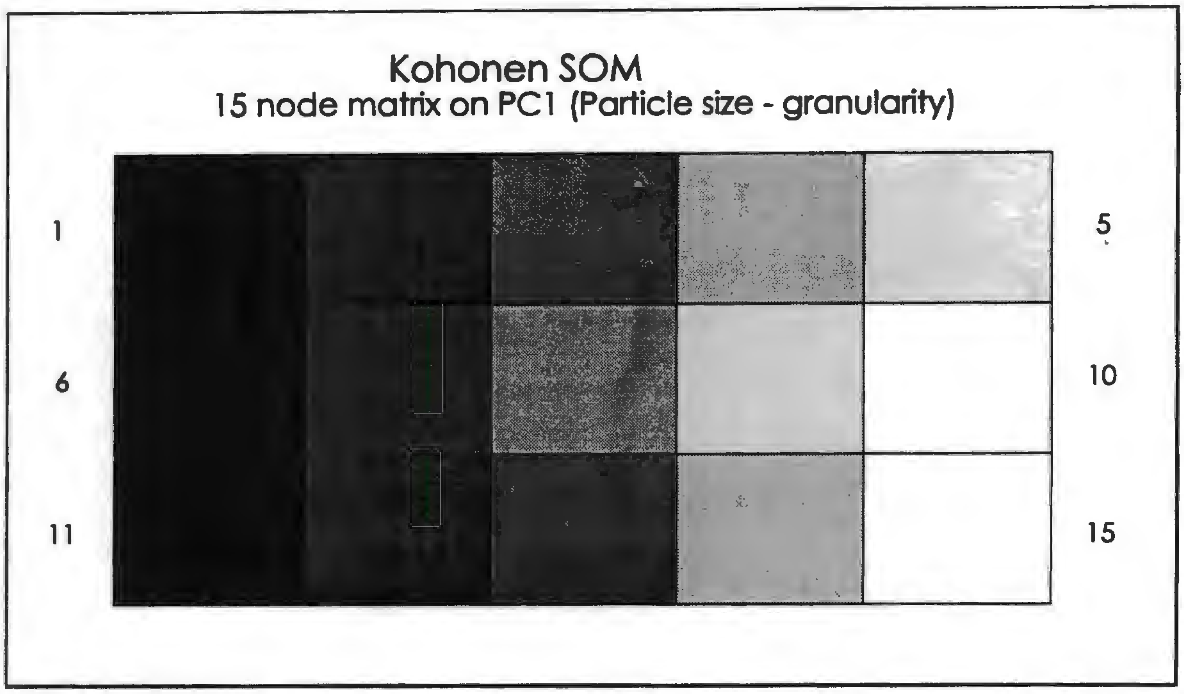


Figure 8.11 Kohonen SOM. 15 node matrix, based on 173 samples, on PC1. PC 1 is interpreted as characterising "particle size - granularity".

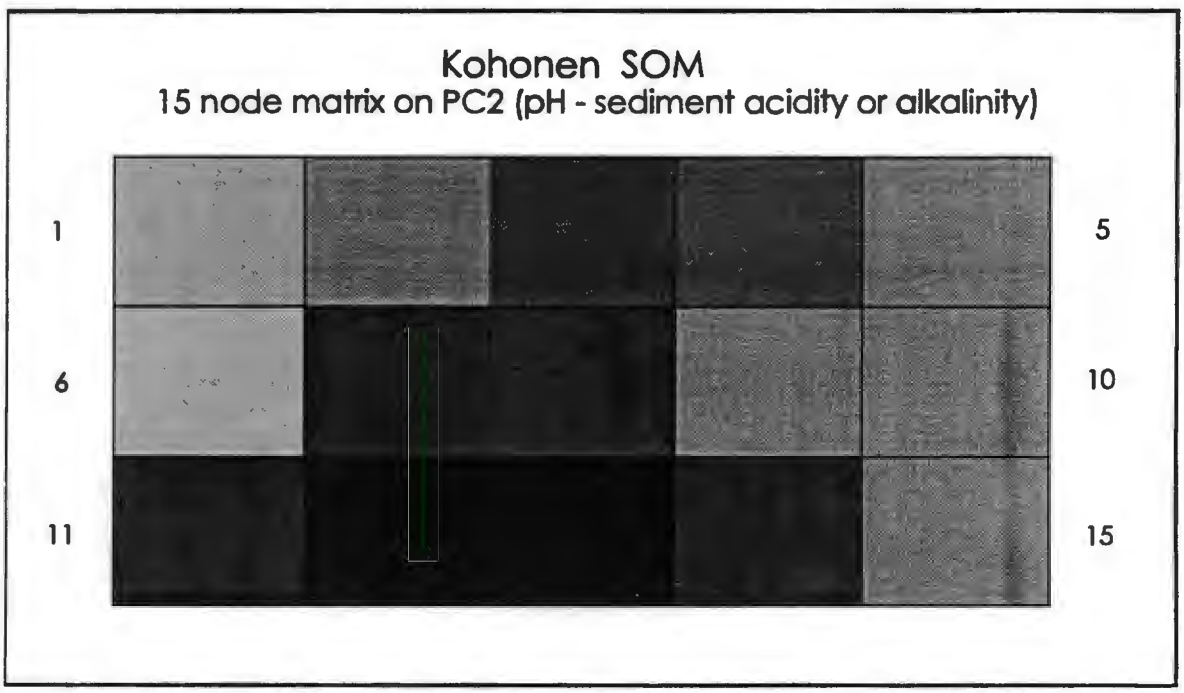


Figure 8.12 Kohonen SOM. 15 node matrix, based on 173 samples, on PC2. PC2 is interpreted as characterising "pH - sediment acidity or alkalinity".

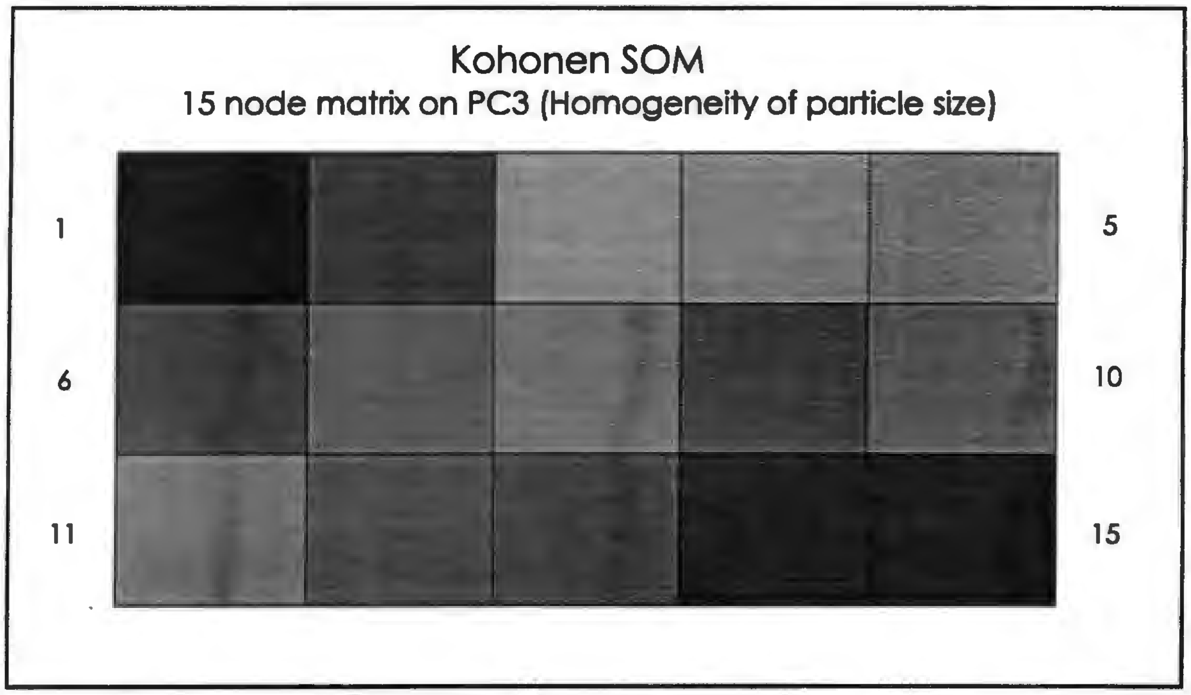


Figure 8.13 Kohonen SOM. 15 node matrix, based on 173 samples, on PC3. PC3 is interpreted as characterising "homogeneity of particle size".

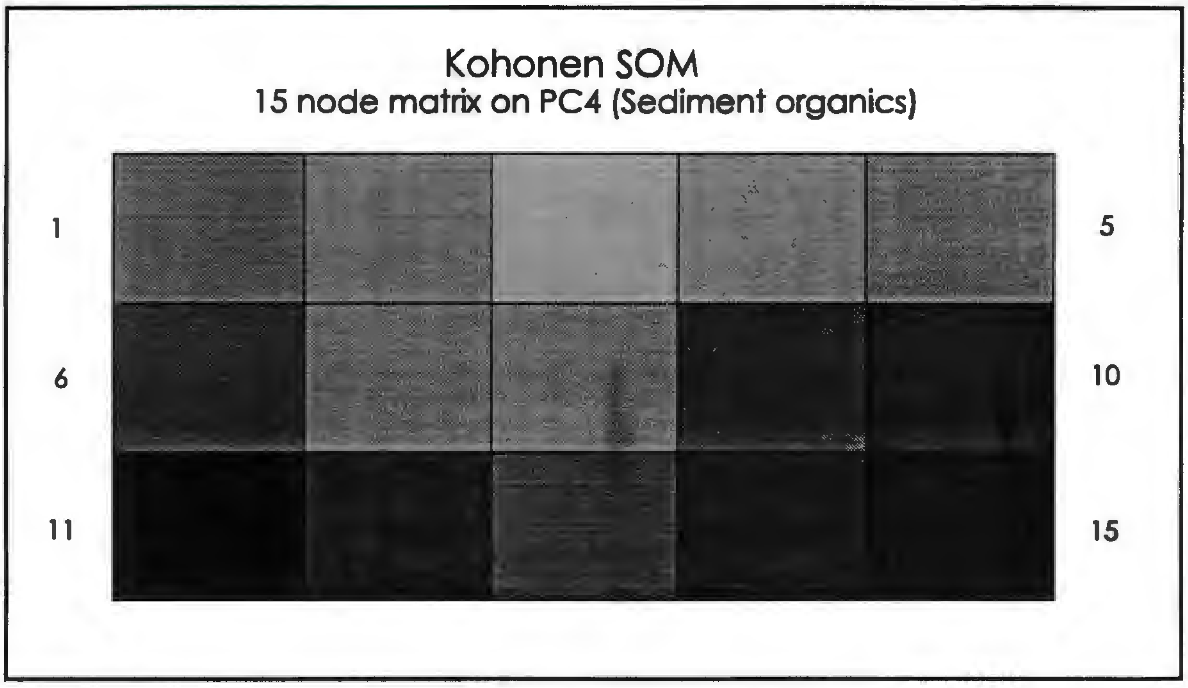


Figure 8.14 Kohonen SOM. 15 node matrix, based on 173 samples, on PC4. PC4 is interpreted as characterising "sediment organics".

8.3 STATISTICAL TECHNIQUES - A SYNTHESIS

Before continuing, it is necessary to reiterate that statistical analyses were utilised in an exploratory capacity. The number of samples precludes discussion of each case on an individual basis, and neither was this the author's intention. The aim was, rather, to facilitate the identification of patterns, trends, groupings and outliers with respect to samples from the study sites. Examining the results from the statistical analyses of data with which the researcher is familiar can facilitate the development of a conceptual framework for the interpretation of the data as a whole. In the case of this investigation, such an exercise greatly facilitated the palaeoenvironmental reconstruction which follows in Chapter 9.

The principal component analysis proved valuable in identifying traits within the original data set and in providing proxy variables for both the cluster analyses and the SOM. The advantage of utilising the first four principal components (which account for almost three quarters of the explained variance within the data set), is the minimisation of any potential "background noise" which might influence the subsequent analyses. It may therefore be argued that their utilisation as proxy variables, as opposed to the utilisation of the original sixteen variables, is statistically sound. It is noteworthy that two of these proxy variables ("granularity" and "sorting") reflect sedimentological traits, while two ("acidity" and "organics") represent what might broadly be termed chemico-mineralogical traits. The implication is that samples are best differentiated between in terms of two parameters which might reflect provenance and transportational history, and two parameters which might reflect post-depositional influences within the sediments.

The single linkage cluster analysis of the primary data set provided useful confirmation of cases which, it had been suspected in the field, might be regarded as displaying physical and sedimentological properties which differed considerably from the "norm". Ward's method proved useful in identifying those sites which might be regarded as displaying a marked degree of homogeneity within their stratigraphy, as well as revealing the opposite with respect to at least one important site; that of the Klein Seekoei River (ZEEK).

Within each individual study locality, cluster analysis assisted in identifying which topsoils and subsoils might be regarded as in some way distinct from their underlying strata, as well as providing confirmation as to which sequences have been stripped of their modern topsoils. While cluster analysis proved useful in identifying groupings and outliers within the strata, the SOMS map independently confirmed the existence of these groupings. It also permitted the characterisation of groupings on the 15 nodes within the SOM in terms of the properties circumscribed by the four principal components utilised in this study.

8.4 FURTHER ELUCIDATION OF VALLEY FILLS

8.4.1 Introduction

Of the methodologies outlined in Chapter 4, CBD extraction and X-Ray fluorescence spectrometry (XRF) were utilised only in the elucidation of the aeolian sediments from the Buffelsfontein locality. The results of the dating methods which were described in the same chapter received attention in Chapter 7. The following sections deal therefore with two additional techniques outlined in Chapter 4 which were applied to some, but not all, the valley fill sediments. They are X-Ray diffraction analysis (XRD) and stable carbon isotope analysis. The section concludes with a statistical technique (Nearest neighbour analysis) which, it was argued in Chapter 4, is most usefully considered separately from the statistical techniques discussed above.

8.4.2 XRD application and results

The relative abundance of a suite of clay minerals from thirty seven samples from representative sites across the study area are shown in Fig. 8.15. Within individual profiles, samples were intuitively selected after being identified on the basis of field and laboratory work as modern soil horizons, palaeosols or strata bounding modern soils or palaeosols. The object was to compare clay mineral suites from such samples, as well as to determine whether differences occur in relation to depth down individual profiles.

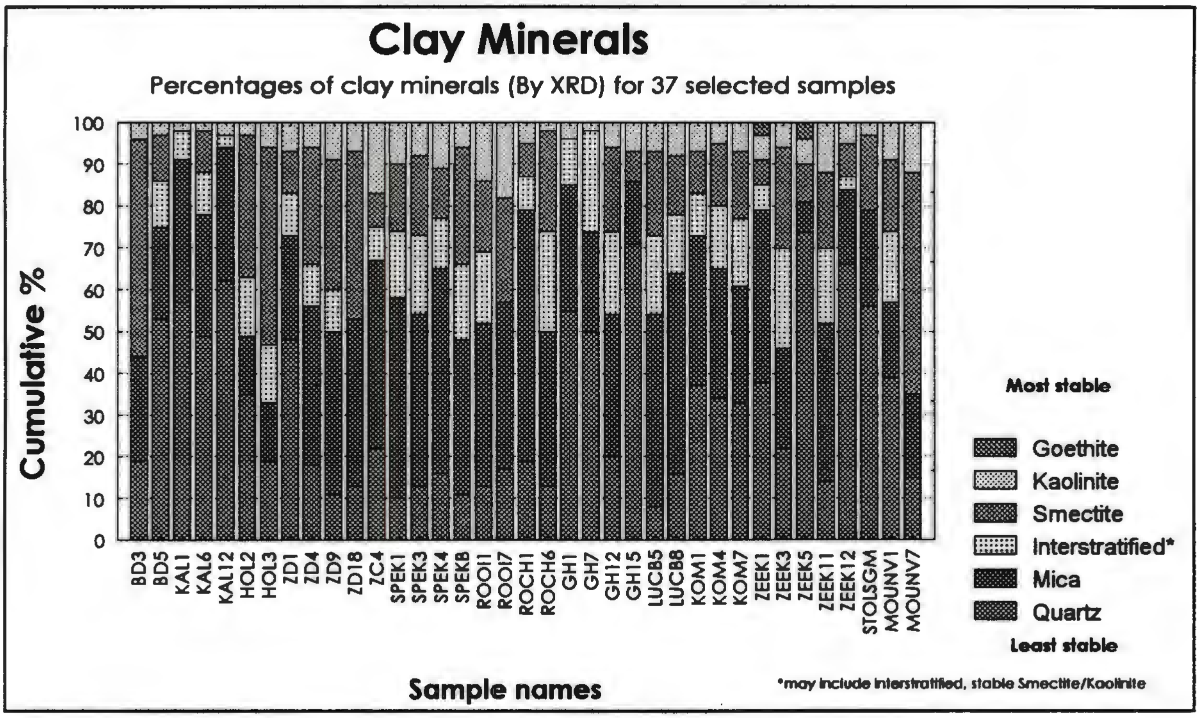
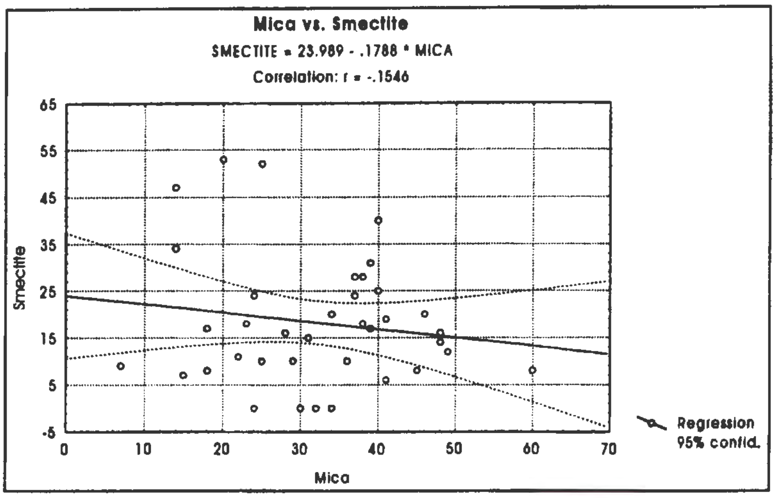


Figure 8.15 Cumulative % of clay minerals for clay samples from 37 selected sites.

The reader is referred to 4.2.3 for some important considerations with respect to clay minerals as indicators of post depositional weathering. A Pearson's product-moment correlation test was applied to micas versus smectite, and smectite versus interstratified clay minerals plus kaolinite (Fig. 8.16). The test failed to reveal any significant negative correlations which might be expected in terms of the principals outlined in 4.2.3.3. Rather, the problem of distinguishing between primary and secondary cycles of weathering in Karoo sediments was again demonstrated.



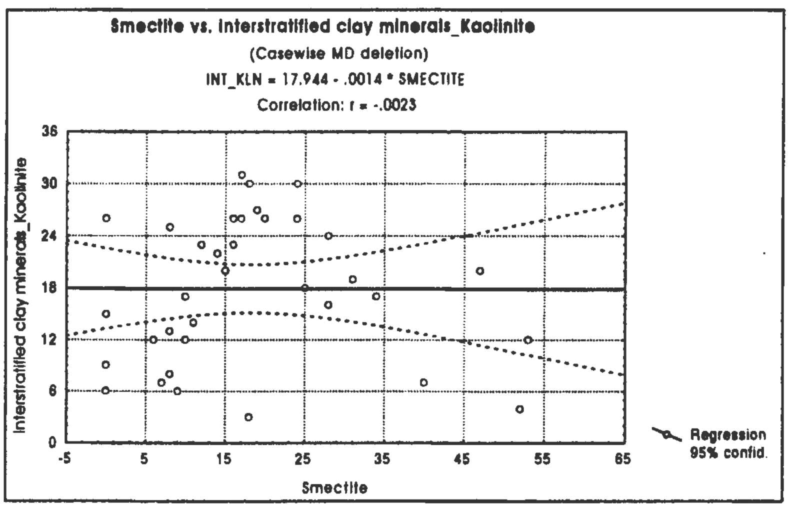


Figure 8.16 Pearson's product-moment correlation for selected suites of clay minerals.

The case of samples ZD 1, 4, 9 and 18 from the Doornhoek Dam site, Tandjiesberg locality (Fig. 7.9) serves as an example. The modern topsoil (ZD 1) is different from the other samples in that the smectite content is significantly lower and mineralogically disordered. Typically, smectite in the Karoo shale parent rock will weather more readily than mica, because mica interlayers are blocked by fixed potassium, whereas smectite inter-regions are accessible to exchangeable ions and water (C. Bühman, *pers. comm.*). The implication here is that the modern topsoil is markedly more weathered than either palaeosol sample ZD 9 or ZD 9, or the basal sample ZD

18. This in turn may indicate that the phases of soil formation at this site occupied relatively brief periods of time. Although this trend is evident at a number of other sites (Fig. 8.15), there are also sites (most noticeably Buffelsfontein Stream in the Stormberg locality) where the opposite trend is apparent. This well developed profile exhibits a smectite-rich topsoil (BD 1) with a much lower proportion of this mineral at depth (BD 5). A number of points arising out of these results will be addressed in the general discussion below.

8.4.3 Stable carbon isotopes

The results of stable carbon isotope analysis from 21 samples from a spectrum of selected sites are presented in Table 8.3. Previously, Bond *et al* (1994) utilised soil carbon isotopes in an attempt to establish whether or not the Karoo has been subject to desertification. In their study, Bond *et al* (1994) avoided Karoo upland sites because of the C_3 signature imparted by Karroid *Merxmuellera* Mountain Veld. Because of the nature of this study, such localities could not be avoided. However, within the study area, only the Wapadsberg summit is strongly characterised by *Merxmuellera*, although Sugden (1989) identified patches of this grass on the Nuweveldberg summit. Although Acocks (1988) classified the highest reaches of the Sneeuberg as *Merxmuellera* Mountain Veld, the current veld rehabilitation practise of the current owner of Compassberg Farm (Fig. 6.9) has seen the introduction of a variety of grass species. Because of the above, as well as the limited number of samples, the results from this study should be interpreted with caution. They are intended to serve as confirmatory indicators of spatial and/or temporal landscape change. Two trends emerge from the data in Table 8.3. Firstly, and not surprisingly, the Stormberg study locality, situated in a marginal Karoo area, is characterised by $\delta^{13}C$ values indicating a grassland signature. The surface sample from the Kalkoenkrans Vlei core (KAL 1) and the ^{14}C dated sample (KAL 6) display similar values, as does the sample from the Klipplaat Pan palaeosol. At the opposite extreme of the east-west transect, the Nuweveldberg study locality displays a shrubland signature, with no real evidence of temporal change in the ^{14}C dated sample. Secondly, it is the three central study localities, and in particular the Wapadsberg and Sneeuberg localities, which display temporal differences in their carbon isotope signatures. On the Wapadsberg, both the Rooiskuur and Rochdale topsoils display C_3 signatures, though in the case of the former site, the influence of Merxmuellera probably accounts for this. More significantly, both the palaeohorizons display C_4 signatures.

At the Sneeuberg locality, all the (dated) palaeohorizons display C_4 signatures, while the Good Hope and Klein Seekoei River topsoils display shrubland (C_4) signatures. It is significant to note that the topsoil at the Compassberg site (KOM 1) displays a grassland signature. Although this site falls within Acock's (1988) *Merxmuellera* classification, it is precisely this area which has regained an almost pristine varietal climax grass cover as a result of the rehabilitation practises mentioned above. It would appear, even on the basis of limited sampling, that the carbon

Sample number	δ ¹³C value	Radiocarbon Date
Stormberg		
KP 3	-16.8	430 ± 45
Kal 1	-16.9	
Kal 6	-16.5	2620 ± 50
Tandjiesberg		
ZD 1	-21.9	
ZD 9	-20.7	5720 ± 70
Spek 1	-22.7	
Spek 3	-17.9	2930 ± 45
Wapadsberg		
Rooi 1	-22.0	
Rooi 7	-17.2	1680 ± 60
Roch 1	-21.8	
Roch 6	-19.0	
Sneeuberg		
Kom 1	-18.8	
Kom 4	-18.4	3590 ± 70
GH1	-25.0	
GH16	-19.9	5790 ± 80
Zeek 1	-21.2	
Zeek 4*	-17.8	2510 ± 50
Zeek 6*	-18.4	4870 ± 60
Nuweveldberg		
Mounv 1	-26.0	
Mounv 6*	-21.0	760 ± 50
Stols GM	-24.8	

* After Sugden (1989): equates to sample listed above.

Typical carbon isotope signatures (After Bond *et al*, 1994):

C_4 grasses -14 C_3 shrubland -27

Table 8.3 δ ¹³C values from selected sites.

isotope signatures from the modern topsoils at Rochdale (Wapadsberg) Good Hope and the Upper Klein Seekoei River (Compassberg) reflect a change to a more Karroid shrub type vegetation. Bond *et al* (1994) suggested that a switch from a C_4 signature in the subsoil to a C_3 signature in the topsoil might reflect an anthropogenic impact, rather than climate change. In Chapter 10, it will be argued that the changes manifested at the Sneeuberg locality in particular are more likely a function of vegetation stress under conditions of land degradation rather than an unambiguous signal for climate change.

8.4.4 Nearest Neighbour Indices (NNIs)

The rationale behind the separation of Nearest Neighbour Indices (NNIs) from the *classificatory* statistical procedures was outlined under 4.5.3.5. Topsoils from thirteen sites across all the study localities were chosen as modern analogues for the calculation of NNIs. A number of sites where it was apparent that the modern topsoil had been stripped were not considered for inclusion in the modern analogue group. The analysis utilised standardised data on the 16 variables indicated in Appendix E. Topsoils were chosen from the following sites:

- **Stormberg** : Holspruit (HOL 1), Buffelsfontein Stream (BD 1) and Kalkoenkrans Vlei (KAL 1)
- **Tandjiesberg** : Wilgerboom River Colluvium (ZC 1), Bergkloof (ZB 1), Doornhoek Dam (ZD1) and Spekboom River (SPEK 1)
- **Wapadsberg** : Rooiskuur (ROOI 1) and Ruigterfontein (WAR 1)
- **Sneeuberg** : The Valley (VAL 1), Lucernvale B (LUC B 1), Good Hope (GH 1)
- **Nuweveldberg** : Mountain View (MOUNV 1)

The results of the NNI for each of the sixteen profiles are presented in Appendices I and J. A summary of the occurrences of nearest modern analogues is given in Table 8.4.

[illegible]	[illegible]
BD 1	2
GH1	16
HOL 1	1
KAL 1	2
LUC B1	2
MOUNV 1	45
ROOI 1	14
SPEK 1	22
VAL 1	7
WAR 1	25
ZB 1	18
ZC 1	6
ZD 1	13

Table 8.4 NNIs; summary of occurrences equating to each of 13 modern analogues.

The nearest modern analogue that is most typified (Fig. 8.17) is the topsoil at the Mountain View Site (MOUNV 1), Nuweveldberg study locality. This soil is a sandy loam with neutral pH and 0.5% organic carbon. At the other end of the spectrum, the NNI algorithm does not associate a single palaeostratum with the Holspruit Gully topsoil (HOL 1), and only a single stratum is associated with each of the Kalkoenkrans Vlei (KAL 1) and Buffelsfontein Stream (BD 1) topsoils (Fig. 8.17). These soils are loams or silty clay loams, neutral to slightly acidic, with organic carbon contents ranging from ~3% to 7%. These three sites all occur in the easternmost Stormberg Locality. This locality is deemed to be marginal Karoo by virtue of its higher rainfall. Although the Sneeuberg locality may be regarded as the "Karoo Upland Type Site" for this investigation, only the Good Hope Site topsoil (GH 1) is represented to any significant extent in the NNI model. This silt loam has a neutral pH and 1.74% organic carbon.

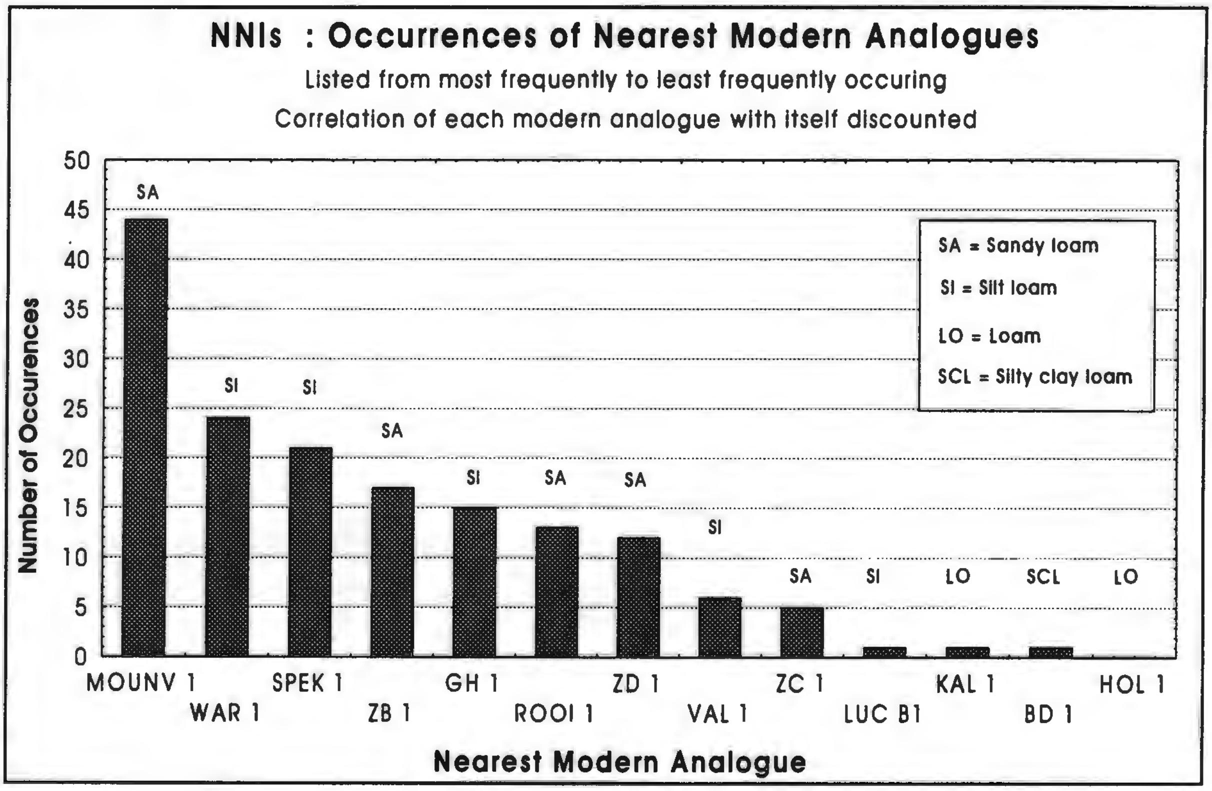


Figure 8.17 Summary of occurrences of nearest modern analogues.

The nearest modern analogue to each of the palaeosols dated as part of this study, or by Sugden (1989) follow. It is apparent from the above that the palaeosols do not demonstrate a statistical affinity for either of the two marginal environments. Neither the organic rich topsoils from the marshy environments in the eastern most (Stormberg) locality nor the topsoil from the dry, western most (Nuweveldberg) locality are represented. Rather, the palaeosols associate most closely with modern topsoils from the central localities. The associations are made on the basis of physical and chemical parameters. Soil structure was not factored into the NNI model.

Dated Palaeosol	Nearest Modern Analogue
Doornhoek Dam (ZD 17)	Spekboom River (SPEK 1)
Compassberg Gully (KOM 4)	Bergkloof Site (ZB 1)
Klein Seekoei River (Zeek 3)	Good Hope (GH1)
Klein Seekoei River (Zeek 5)	The Valley (VAL 1)
Good Hope (GH 16)	Spekboom River (Spek 1)
Rooiskuur (Rooi 7)	Ruigterfontein (WAR 1)
Kalkoenkrans (Kal 5 and 6)	Good Hope (GH 1)
Spekboom River	Not compared

Table 8.5 Nearest modern analogues to dated palaesols.

8.5 ADDITIONAL ANALYSES - SOME CONCLUSIONS

The rationale behind the utilisation of XRD and stable carbon isotope analyses to facilitate the elucidation of palaeoenvironments from valley fill stratigraphy was explained in Chapter 4. It is apparent from the results of these analyses that the techniques are deficient in a number of respects. This is particularly the case with XRD, and to a lesser extent, the stable carbon isotope analysis.

Clearly, within the context of sediments derived from Karoo sedimentary rocks, clay mineralogy cannot be simply and unequivocally interpreted as a consistent and reliable indicator of environmental change. Theoretically, weathering indices can provide a good indication of the degree to which sediments have undergone alteration over time. In practice, the lithology of the Beaufort Group shales confounds the issue. Initially, for example, it had been hoped to utilise weathering indices based on heavy minerals. This technique was applied with some success by Holmes and Reynhardt (1989) in establishing a relative age sequence for fluvial deposits comprising high proportions of heavy minerals. However, microscopic examination of the separated heavy mineral fraction during a pilot investigation demonstrated the futility of attempting heavy mineral identification in sediments derived from Karoo shale. Similarly, blurred signals emanate from XRD results as a consequence of the practical inability to filter out the influence of primary weathering phases.

While the stable carbon isotope analysis proved to be of greater benefit in identifying and, more important, explaining change within stratigraphic sequences, these results also require a cautious interpretation. Changes in soil $\delta^{13}C$ values may reflect changing vegetation patterns, but do not account for such changes. The fact that some grasses have C_3 pathways is a potentially complicating factor, as is the possibility of movement of soil carbon up or down the profile.

In conclusion, this author is of the opinion that the significance of field observations of features such as mottling, structure, stone lines and unconformities should not be underestimated. Such features provide vital clues when "reading into" the palaeodevelopment of valley fills. While a selected suite of physical, chemical and statistical parameters may assist interpretations, they should not be embraced as an ultimate means to this end. An holistic interpretation of late Quaternary sediments from central Great Karoo depositional environments will be presented in the following chapter.

CHAPTER 9

Karoo Geomorphic Environments : an Interpretation

9.1 INTRODUCTION

From the evidence presented in Chapter 7, it is apparent that Karoo upland depositional environments bear testimony to various phases of sediment accumulation. In particular, valley fills reflect within their stratigraphic sequences evidence of fluctuating environmental conditions during the Holocene. Geomorphic evidence serves, in essence, as a proxy indicator for processes which have influenced or impacted upon the landscape. Subsequent to deposition of these fills, the Karoo uplands have been further influenced by processes which have modified the morphology of landscape elements such as slopes and stream channels, as well as the sediments themselves. This chapter deals in more detail with the interpretation of the geomorphic evidence for environmental change which is preserved within the landscape at the various localities within the study area. Specifically, the question of climatic influences during the Late Pleistocene and the Holocene are addressed. Evidence of cyclical change is compared with the findings of other workers, and an attempt is made to account for anomalous findings. The initial discussion deals with each study locality in turn. This is followed by a regional synthesis which concludes the chapter.

9.2 DISCUSSION

9.2.1 Stormberg locality

9.2.1.1 Aeolian sand

On the basis of luminescence dates (Table 7.6), the Klipkraal Sands provide the oldest depositional record from both this locality and the entire study area. The physical setting and characteristics of the sands precludes fluvial deposition as a means of emplacement. Sand samples from this site are all unimodal, generally fine-grained, moderately well- to well sorted and fine-skewed, properties not uncommon in wind-derived material. The sand is not as fine as the Clarens Formation sandstone which comprises the upper, bedrock slopes at this site. In addition, had the sand derived directly from local Clarens Formation sandstone, coarser colluvial debris would almost certainly be present in the form of lag deposits. The sand was most likely emplaced as a result of aeolian activity. The remnant red patina on subrounded grains suggests that the source was a previously weathered and oxidised deposit (Marker and Holmes, 1993).

Unlike other exposures in the Buffelsfontein Basin, the sand deposit does not exhibit any evidence of clay or organic rich palaeosols preserved within its stratigraphy. This is supported by the texture, pH and conductivity of the samples. The sand lenses evidence minor differences with regard to silt content, but this is probably the result of local ponding rather than pedogenesis in the sand deposit as a whole.

The isolation and limited extent of this deposit suggests that it is a remnant of a former more extensive aeolian deposit. Similar remnants, if they occur at this locality, remain concealed under vegetation cover. The location of the deposit against a north facing slope (Fig. 6.2) suggests that deflation took place from the north. The footslope fan is interpreted as the product of postdepositional reworking off an exposed slope.

Inland aeolian deposits are rare in south eastern locations in southern Africa. Kalahari Group deposits are defined as comprising red siliceous sandstones, as well as derived sand sheets and dunes (Lancaster, 1987). They occur in Namibia, Botswana and the Northern Cape, in the arid western half of the subcontinent. In most respects the red Hutton sands of the Kimberley area are similar and probably pertain to Kalahari sand deposits (Helgren, 1979). Other sand sheets have been reported from the western Orange Free State, the Transvaal and the northern Cape Province, as well as from the inner margin of the Cape Fold Belt (Maud and Partridge, 1987). All these sand deposits are interpreted as the product of stronger anticyclonic circulation during former arid phases and periods of low sea level (Maud and Partridge, 1987).

Aeolian activity is currently of minor importance at this location. The existence of this deposit therefore implies an arid phase with strong aeolian activity. Subsequently, the onset of more humid conditions may have been responsible for sheetwash redistribution and the creation of the footslope fan. The sandstone slabs which rest on the main deposit are characterised by weathering rinds of ~3 mm thickness. The location of the slabs is best explained by rafting down slope under cryogenic conditions during one of the Pleistocene cold phases. Had they been emplaced as debris flow material, other debris should be present and it is likely that the terrace sands would themselves have been eroded.

The sand deposit records conditions of aridity with strong wind action that preceded a period of cryogenic slope processes to emplace the rock slabs. Sufficient time has elapsed to permit the development of up to 3 mm thick weathering rinds on the slabs. It is postulated that Quaternary cold periods were more arid than present conditions (Tyson, 1986). The luminescence dates combined with the relative geomorphic dating suggests that the sand deposit was emplaced early in the Late Pleistocene Hypothermal when arid conditions prevailed. The deposit was already in place when cryogenic conditions to activate solifluction, possibly as a consequence of increased snowfall from winter cyclonic activity, occurred. Sheetwash redistribution may have followed at the onset of a Holocene humid phase before the sand was completely stabilised under a re-established climax vegetation cover. The significance of the Klipkraal deposit lies in its isolation and inland position. As with pockets located on the inner margin of the Cape Fold Belt (Maud and Partridge, 1987), it may be evidence of a former much greater extent of such deflation deposits.

9.2.1.2 Pan deposits

At the Buffelsfontein Pan, the landform assemblage comprising the outlying elongated pans, the large palaeopan associated with lunette 3, and the present pan with lunettes 1 and 2, provides sufficient evidence to postulate a geomorphic sequence which points to progressive desiccation in this area.

The sedimentary and geochemical characteristics support the assumption that the lunettes are younger towards the present pan, with a longer timespan between the formation of lunettes 3 and 2 on the one hand, and lunettes 2 and 1 on the other. There is strong textural similarity between the present pan floor sediments and the material of lunettes 1 and 2. pH readings indicate declining alkalinity with distance from the present pan, while both electrical resistance and cation exchange capacity emphasise the distinction between the pan and its proximal clay lunettes on the one hand, and lunette 3 on the other. Lunette 3, believed to be the oldest on geomorphological grounds, has the lowest cation exchange capacity and the lowest soluble and exchangeable cation count. While partly a function of the type of sediment (sand) this may also indicate that pedogenic leaching has been effective over a longer period of time. The high concentration of exchangeable sodium at 40 cm depth in lunette 3 supports this view.

The similarities in sediment from the pan floor and from lunettes 1 and 2 suggest that these clay lunettes have developed by seasonal deflation from the pan floor under saline conditions. Seasonally fluctuating water tables, with intervals of pan inundation, appear conducive to the production of sediment vulnerable to wind erosion (Thomas *et al*, 1997). As the pan dries, salt concentration increases, encouraging clay dispersion and crusting (Shainberg, 1985). The mud flocculates to silt or sand size particles which are then vulnerable to wind transport from the dry pan floor (Armstrong Price, 1963; Bowler, 1973). The higher proportion of sulphur in lunette 2 revealed by XRF may indicate the precipitation of gypsum, or possibly potassium sulphate which could have formed under conditions of higher evaporation (greater aridity) than those experienced by either the younger lunette 1 or the pan floor sediments. The presence of more secondary iron in lunette 2 tends to support the assumption of climatic extremes; the red colour of lunette 2 being associated with the presence of hematite (Fe_2O_3). Munsell colours of 5YR or redder are often indicative of this mineral (Schwertmann and Taylor, 1989). Hematite imparts a bright red hue in amounts exceeding ~1.2% CBD-extractable iron (C. Bühman *pers. comm.*). The occurrence of hematite is favoured by high pH (Schwertmann and Murad, 1983), high temperatures and contrasting seasons with aridity and low organic matter (Schwertmann, 1985), and time. The relative enrichment of stable iron phases in lunette 2, and to a lesser degree in lunette 3, is best explained by the removal of salts and carbonates during cycles of weathering not experienced by lunette 1. This also points to lunette 2 being older than lunette 1.

The sedimentological and geochemical evidence from Klipplaat Pan shows a distinct difference between the pan floor sediment and the rubefied clay lunette on the one hand, and the apedal sand which covers it on the other. While the sediments reveal properties not dissimilar to the sediments from the Buffelsfontein site, the lunette morphology is very different. The ^{14}C date of 430 ± 45 BP (Pta 7024) from the palaeosol (Fig. 7.3) equates well with the OSL ages (Table 7.6) from samples KP1 and KP2 of 560 ± 40 years and 680 ± 80 years. From a study of air photos and the field investigation, it would appear that sand from an extensive, older, outer, sandy palaeolunette has been fluvially reworked by the endorheic drainage system and re-deposited on the planed clay lunette. The oldest OSL date from this site indicates that reworking on the outer margin of this system may have been underway some 1340 years ago. The clay lunette was not dated, so it is not possible to ascertain whether or not its age equates to that of the dated red clay lunette (12600 ± 1500) from the Buffelsfontein site. Although the morphological and sedimentological evidence suggests parallels between the Buffelsfontein and Klipplaat depositional environments, it is not possible to say with certainty whether or not their original formation was contemporaneous. What is apparent is that conditions conducive to soil formation occurred ~400 to 600 years BP at this site. If subsequent burial occurred through sheetwash of sand moving towards the pan from the south east, this may imply a change of state or disturbance within this landscape. Anthropogenic influences, which are discussed more fully in the following chapter, should not be discounted.

9.2.1.3 Valley fills of the Buffelsfontein Basin

Evidence from the Holspruit Valley in the form of the fills at the sites discussed under 6.2. and 7.2 suggests cyclical accumulation of sediment during the Holocene, under predominantly low energy conditions. At least one significant phase of soil formation in the late Holocene, predating the modern phase of pedogenesis, is suggested by the geomorphic evidence from all three sites. The depositional sequence at the Holspruit Gully site is significant in that the palaeosol with its underlying gravel lag (horizon 3) is virtually replicated by the modern topsoil, underlain by a similar lag. The poor sorting and angularity of the lag material suggests that it has not been emplaced by fluvial action. The moderately steep (~10°) (Young, 1972) valley side slopes may have facilitated localised mass movement of gravel off the slopes to form the prominent stone lags (Fig. 7.6). The stoneline at ~2 m depth is associated with sandy, inorganic matrix material, possibly implying sheetwash off exposed slopes during the initial transition from a dry to a wetter phase. Gravel lags may also form as a result of surface deflation of fines during depositional hiates and a subsequent settling of stones. However, apart from the stonelines, gravel is not present in the horizons at this site. The former explanation for the occurrence of these lags is thus preferred.

Upstream at Kalkoenkrans Vlei, stonelines are not present, presumably because gravel would not have been transported the considerable distance to the centre of the vlei where the core was extracted. The stratigraphy and sedimentology at this site also differs markedly from the Holspruit site. The profile lacks the complexity of the Holspruit site, displaying simply a change from an accumulation of red, silty sediment to organic rich silt. The absence of an extended, deeply incised gully system within the Holspruit catchment prevents attempts to trace a possible cut and fill sequence. Such sequences were recognised by Bousman *et al* (1988) where younger, organic rich fills overlie older valley floor sediments. However, the evidence from Kalkoenkrans Vlei suggests ponding on pre-existing inorganic silt deposits. The silt deposits suggest the comparatively rapid removal and redeposition of material from surrounding slopes which were vulnerable to sheet erosion. An absence of vegetation cover may have contributed to this. The notion is explored further in Chapter 11. The ^{14}C date of 2620 ± 50 BP (Pta 6994), associated with the change in stratigraphy outlined above, may mark the onset of moister conditions and an increase in vegetation cover within this catchment.

At the Buffelsfontein Stream site, ponding in a marshy or vlei environment is borne out by the accumulation of organic material and the high proportion of organic carbon, the exceptionally well developed ped structure, and abundant mottling. The abundant presence of snail shells of the species *Succinea exarata* and the high proportion of the clay mineral smectite tend to confirm the previous existence of marshy conditions. Neither the abrupt changes evidenced at the Holspruit Site, nor the distinct colour and organic carbon changes of the Kalkoenkrans Vlei Site are apparent here. Buffelsfontein Stream appears to reflect within its stratigraphy recently active pedogenic processes rather than a long palaeoenvironmental record. Statistical analyses(Cluster analysis, SOM and NNIs) support the observation that the Buffelsfontein Stream environment is unique within the context of this investigation. The site is particularly useful in that the current climate of Buffelsfontein Farm, situated as it is in this Karoo marginal location, is well documented (see 6.2). It may therefore serve as a modern analogue for the palaeosols preserved in the currently drier Karoo localities to the west of the Stormberg (Fig. 1.2).

9.2.2 Tandjiesberg locality

The depositional environments at this locality reflect the accumulation of sediment under a variety of conditions and positions in the landscape since the mid Holocene.

The truncated colluvial spur on the Wilgerboom River (ZC) was included as a study site to facilitate a comparison between colluvial sediment and valley fill sediment at this locality. It also provides a modern analogue in terms of the shallow lithosol which forms the A horizon. There is evidence from the single linkage cluster analysis (Fig. 8.5) to substantiate the recognition of this colluvial deposit as unique or separate from the valley floor deposits at this locality. From a palaeoenvironmental perspective however, the site yielded nothing of note.

By way of contrast, the complex stratigraphy of the profiles at the Bergkloof (ZB) and Doornhoek Dam (ZD) sites (see 7.3) do contribute to a palaeoenvironmental reconstruction. The gross stratigraphy and sedimentology of the Bergkloof profile attest to a major shift in geomorphic state during the past. Generally sandy, inorganic strata are overlain by organic-enriched strata displaying evidence of pedogenesis. This may represent a pattern evidenced at other sites, although the sequence was not dated. The Doornhoek Dam site, situated on the same water course, displays the same gross morphology. Within the upper half of the profile, three distinct phases of incipient soil formation have been initiated since approximately the mid Holocene. This is substantiated by the ^{14}C date of 5720 ± 70 BP (Pta 6423) from the bottom most stratum. Two of the phases (represented by strata 4 and 7) straddle a pronounced phase of sandy, inorganic accumulation, complete with a stone line, possibly implying a cyclical moister-drier-moister sequence before the formation of the current solum. In terms of comparison to modern analogues (see 8.4), stratum 4 associates most closely with the topsoil at this site, while stratum 7 displays an affinity for the topsoil (WAR 1) at the Ruigterfontein site, Wapadsberg locality.

The three phases of gravel grade, channel bar deposition at the Spekboom River site imply not only a high energy regime, but also the ready availability of significant quantities of gravel grade material in the upper catchment of this stream, which has its source adjacent to the Wilgerboom River (Fig. 6.7). On the basis of the ^{14}C date (2930 ± 45 BP) (see Figure 7.10), and assuming stratigraphic superposition, there is proxy evidence preserved in the form of the gravel grade material at this site of at least two high magnitude transport/depositional events dating from the last 3000 years.

9.2.3. Wapadsberg locality

Two of the sites at this locality, Rooiskuur (ROOI) and Ruigterfontein (WAR) (Fig 6.8) comprise sedimentary sequences in close proximity to the watershed, reflecting first order depositional environments. The third site occurs at the foot of the escarpment and may reflect a more complex picture in terms of sediment input and reworking. This locality does not appear to reflect a palaeoenvironmental record dating back beyond the mid Holocene. The significance of this abbreviated record is discussed below. There is evidence at all three sites for a phase of soil formation post-dating the dated palaeosol (1680 ± 60 BP) at the Rooiskuur site. However, the horizon representing this subsequent phase was not dated because of probable contamination by modern plant roots (see also 9.5.1.2).

At Ruigterfontein and Rochdale, this horizon is separated from the modern solum by a gravel lag and a laminated sand horizon respectively. The inference is colluvial/sheetwash input under less stable (possibly drier) conditions. These two sites display prominent gravel lags in the lower sections of their profiles, attesting to a least one phase of (undated) deposition dominated by slope processes.

9.2.4 Sneeuberg locality

Compared to other localities, the geomorphic evidence from the Sneeuberg suggests a greater complexity of sediment accumulation during depositional phases dating from the onset of the Holocene. The sequence of early Holocene inorganic sediment overlain by an organic sequence which is manifested at the Doornhoek Dam site (Tandjiesberg locality) and which was recognised by Bousman *et al* (1988) is evident in the main stream channel (Fig. 6.9). However, tributary streams within the upper Klein Seekoei River catchment do not necessarily record this complete sequence. Sugden's (1989) ^{14}C date of 3590 ± 70 BP (Pta 5186) from the Compassberg Gully (Fig. 7.14) was determined at 95 cm depth. However, this gully records a 3.9 m sequence, with an undated basal strata containing 0.73% organic carbon (Fig. 7.14), implying conditions conducive to incipient soil formation. The Good Hope site, situated on the same headwater (Fig. 6.9) yielded a ^{14}C basal date of 5790 ± 80 BP (Pta 5493). What is remarkable at this site is the nature of the well developed palaeosol in contact with the bedrock stratigraphy (Plate 7.6). Similarly, the Lucernvale B profile displays an organic rich basal profile. The implication is that either no deposition occurred prior to the mid Holocene, or that pre-existing sediment was remobilised and transported downstream from these sites. Given the nature and state of preservation of early Holocene sediments at other locations within this catchment, the latter explanation is more plausible. It appears therefore that first order tributary channels flushed out whatever sediment existed in the uppermost headwater valleys prior to a phase of organic accumulation. Bull and Kirkby (1997), quoting Blong (1970) point out that it is not always possible to recognise how many cut-and-fill cycles are represented at a given site. The reason is that gully widening will remove evidence of previous cycles, a situation which may have prevailed here.

The two profiles on the main stream (The Valley and Klein Seekoei River) (Figs. 6.9, 7.15 and 7.19) manifest organic enrichment within the upper sections of their respective profiles and generally sandy, organic deficient lower profiles. Sugden's (1989) date from the organic sequence on the Klein Seekoei River (Plate 7.7) was 4870 ± 60 BP (Pta 5188). On a coarse scale, these profiles are interpreted as representing a two-phase catchment response to prevailing environmental conditions. During the first part of the Holocene, sheetwash from vulnerable slopes resulted in cyclical accumulation of sediment on the valley floor. This rapid response scenario was superseded during the second half of the Holocene by generally more stable conditions. The climatic inference is a shift from generally drier conditions to more stable, moister conditions in the second half of the Holocene.

9.2.5 Nuweveldberg locality

The two sites at this locality (Fig. 6.10) are interpreted as representing two very different palaeoenvironments. At the Mountain View Site (MOUNV) the shallow accumulation of sediment in a marshy, vlei type environment occurred under low energy conditions. This is attested to by the stratigraphy and the particle size of the sediments. Subsequent stream incision resulted in severe desiccation, probably terminating the phase of sediment accumulation. The similarity in basin morphology to Bokkraal Vlei where Sugden (1989) obtained her ^{14}C date of 760 ± 50 BP (Pta 4351) has been noted (7.6.2). The current study engages a coarse resolution which does not permit the detailed interpretation of this site. However, it is noteworthy that the palaeoenvironmental record appears to be restricted to the last thousand years.

Situated at the foot of the escarpment, the Stols River site is interpreted as a typical colluvially infilled palaeochannel now occupied by an ephemeral, misfit stream. Extreme, flash flood type events, typical of the present climatic regime, may have been the transport mechanism for the sandy upper stratum. No further palaeoenvironmental interpretation is attempted, save to comment that this site is also bereft of any interpretable long term palaeoenvironmental record.

9.3 REGIONAL SYNTHESIS

At this juncture, the reader's attention is drawn to a number of general observations with respect to the discussion thus far. This is followed by a more detailed regional synthesis of environmental change. A number of the points raised immediately below will be returned to in Chapter 11:

1. Geomorphic depositional environments spanning a time period from the late Pleistocene on through the Holocene are preserved within the study area.
2. Headwater valley fills do not appear to preserve a depositional stratigraphy predating the Holocene.

3. The stratigraphic record is fragmented and marked by depositional hiatuses.

4. The subregional occurrence of valley headwater fills is patchy, their geographic distribution appearing on casual inspection almost to be random.

5. Although there is limited evidence of cyclical cut-and-fill, it does not occur on the scale recognised by Botha (1992) in the older colluvial fills to the east of the escarpment. There is however convincing evidence of cyclical accumulation, with localised cut-and-fill. A single, dominant phase of late Holocene incision (see Chapter 10) is apparent in virtually all the valley fills within the study area.

6. It is the two localities with the highest rainfall (the Stormberg and the Sneeuberg; see Fig. 5.4) which reflect within their stratigraphies the most detailed depositional record.

Finally, the multitude of variables which control cyclical accumulation of valley fill sediments at the local scale precludes the extrapolation of high resolution palaeoenvironmental interpretations from site specific locations to the study area as a whole. Put differently, it would be over ambitious to attempt a detailed regional palaeoenvironmental reconstruction based on geomorphic evidence from one or two profiles. In spite of this caveat, certain general inferences with respect to palaeoenvironmental change within the study area can be made. Accordingly, these are incorporated in the discussion below.

Thomas *et al* (1997) have provided an overview of other chronologies in the southern part of the southern African summer rainfall zone (SZR) against which they evaluate their findings with regard to late Pleistocene dune building in the southwestern Kalahari. Similarly, Table 9.1 comprises a summary of selected chronologies of inferred environmental change in the SZR which may be useful in terms of a tentative association between the findings of this study and the broader southern African SRZ picture.

If, as suspected, the Klipkraal Sands represent the oldest late Pleistocene deposit in the study area, then the age of the deposit is significant, but at the same time problematic (see 7.2). The basal TL date of 20 500 ± 1000 years suggests that the deposit dates from the Last Glacial Maximum. On the basis of radiocarbon dating combined with oxygen isotope temperature determinations from a speleothem from Cango Cave, Cape Province (32°30'S) a minimum temperature depression of 7.7°C is established for 16 000 BP (Talma, 1989). Partridge (1997) has reviewed isotopic evidence from speleothems and artesian water which suggest mean annual temperatures as low as 10°C to 12°C at this time. The *preliminary* OSL dates from this site (Table 7.6) indicate that sand accumulation may have commenced earlier in the Late Pleistocene Hypothermal, terminating soon after 16 000 BP. Certainly, there is evidence from the dating of

Reference	Site	Type of evidence	Date or time period (years BP)	Inference
Stokes *et al* (1997)	Kalahari desert	linear dunes	46 000 - 40 000	more arid
Partridge *et al* (1993)	Pretoria saltpan	sedimentary core	29 500 - 7500	more arid than today
Thomas *et al* (1997)	southwestern Kalahari desert	linear dunes	27 000 - 23 000	more arid
Thomas *et al* (1997)	southwestern Kalahari desert	linear dunes	17 000 - 10 000	more arid
Stokes *et al* (1997a)	Kalahari desert	linear dunes	26 000 - 20 000	more arid
Stokes et al (1997b)	Kalahari desert	linear dunes	17 00 - 10 000	more arid, windier
Stokes *et al* (1997a)	Kalahari desert	linear dunes	16 000 - 9 000	more arid
Talma (1989)	Cango caves (marginal to SRZ)	speleothem	~ 16 000	minimum temperatures cooler by ~ 7°C
Brook *et al* (1997)*	Ghaap escarpment	tufa deposits	11 000 - 9000	wetter
Partridge et al (1990)	Various	biological	8000 - 5000	maximum Holocene warming
Partridge et al (1993)	Pretoria saltpan	sedimentary core (palynological)	~ 7000	wetter than present
Scott & Thackeray (1987), Scott (1989)	Wonderkrater	palynological	~ 7000	wetter than today
Avery (1993)	Various	micromammalian remains	7000 - 6000	relatively low annual rainfall
Bousman *et al* (1988)	Blydefontein, Great Karoo	sedimentary sequence	~ 5000	more abundant summer rainfall
Sugden (1989)	Central Great Karoo	palynological	4 600	moister
Brook *et al* (1997)*	Ghaap escarpment	tufa	3600 - 2900	wetter
Thomas *et al* (1997)	southwestern Kalahari desert	hummocky dunes, lunette dunes	2000 - 1000	more arid (?)
Brook *et al* (1997)*	Ghaap escarpment	tufa	1700 - 500	wetter
Scott and Bousman (1990)	Blydefontein, Great Karoo	hyrax dung middens	1130 - 300	moist between 1200 and 300, sharp increase in Karroid vegetation since 300

* After Thomas *et al* (1997)

Table 9.1 A summary of selected chronologies of environmental change in the summer rainfall zone (SRZ) of southern Africa since approximately 45 000 years BP.

southern Kalahari arid phases (Stokes et al, 1997a & b; Thomas et al 1997) that conditions conducive to sand mobilisation predated the Last Glacial Maximum by tens of thousands of years (see Table 9.1). What seems certain is that the Klipkraal Sands represent a phase of accumulation spanning thousands, rather than hundreds or tens of years. This adds further weight to the notion of enduring drier conditions prior to the climatic amelioration at the termination of the Last Glacial. However, until the problems encountered with OSL age determination at this site are satisfactorily resolved, a more precise timespan for this arid phase of accumulation cannot be postulated.

Turning from the Klipkraal Sands to the pan sequences catalogued in this study, a suite of OSL dates (Table 7.6) confirms that lunette 3 at the Buffelsfontein Pan predates the inner, clay lunettes. The oldest date (18 220 years) is not necessarily a basal date (see Fig. 7.2). Formation of the sandy lunette 3 probably commenced prior to the Last Glacial Maximum and may well be contemporaneous with the Klipkraal Sands. The youngest date (12 290 ± 700 years) implies that dune formation may have continued past the Last Glacial. However, reworking of the near surface sediment, with a consequent exposure to sunlight, might also account for this date. The TL date from lunette 2 (12 600 ± 1500 years) would seem to indicate a phase of aeolian activity around 12 000 BP. The final stage of activity on lunette 3 and the formation of lunette 2 may therefore correspond to a Younger Dryas phase. It is now recognised (Anderson, 1997) that the Younger Dryas cooling was not limited to the northern Hemisphere. Partridge (1997) has mentioned that evidence for Younger Dryas cooling is beginning to emerge for the interior of the southern African subcontinent. Evidence for drier conditions in the western part of the subcontinent (the Kalahari and Namib)at this time was presented by Partridge *et al* (1990). New chronological evidence from Kalahari linear dunes (Stokes *et al*, 1997b) points to a last major phase of aridity terminating at the onset of the Holocene. With one exception, the luminescence dates from the Buffelsfontein Pan would appear to coincide with last major period of enhanced Kalahari aridity identified by Stokes *et al* (1997a &b). However, it would be premature to suggest regional aridity covering the whole of the SZR on the basis of this tentative association.

The implications of the temporal sequence postulated above warrants a brief return to the local scale because, as will be argued, they may be of subregional significance. The geomorphic evidence from the Buffelsfontein pan/lunette dune complex suggests progressive desiccation of a seasonally dry pan and deflation of floor sediment to form individual lunette dunes. The palaeopan, with its associated sand lunette 3, may not necessarily have been saline as conditions must have been considerably wetter than the present situation to fill the enlarged pan. Early in the present century the present pan was sufficiently saline for brine extraction. Operations ceased about 1930 as climatic conditions became wetter. Since that time the pan has been less saline. Buffelsfontein is a particularly valuable site because of the existence of reliable rainfall records dating from 1885. Five-year running means show that at the turn of the century, when brine extraction commenced, conditions were drier than at any period since (Fig. 9.1). During the period of brine extraction rainfall averaged only 485 mm p.a. as compared with the overall mean of 551 mm p.a. Figure 9.1 indicates peak and low rainfall years, where the mean annual rainfall was above or below one standard deviation from the mean. Ten of the eighteen low years occurred prior to 1937 (the median year for the rainfall data), while ten of the fifteen peak years occurred after 1937. As saline conditions were essential for the formation of the clay dune lunettes 1 and 2, this points to a diminution in precipitation of ~100 mm p.a. during periods of clay dune formation. The TL date from lunette 2 (Table 7.6) suggests that this may have been around 12 600 years BP. This would imply a second, more recent drier phase for the formation of lunette 1.

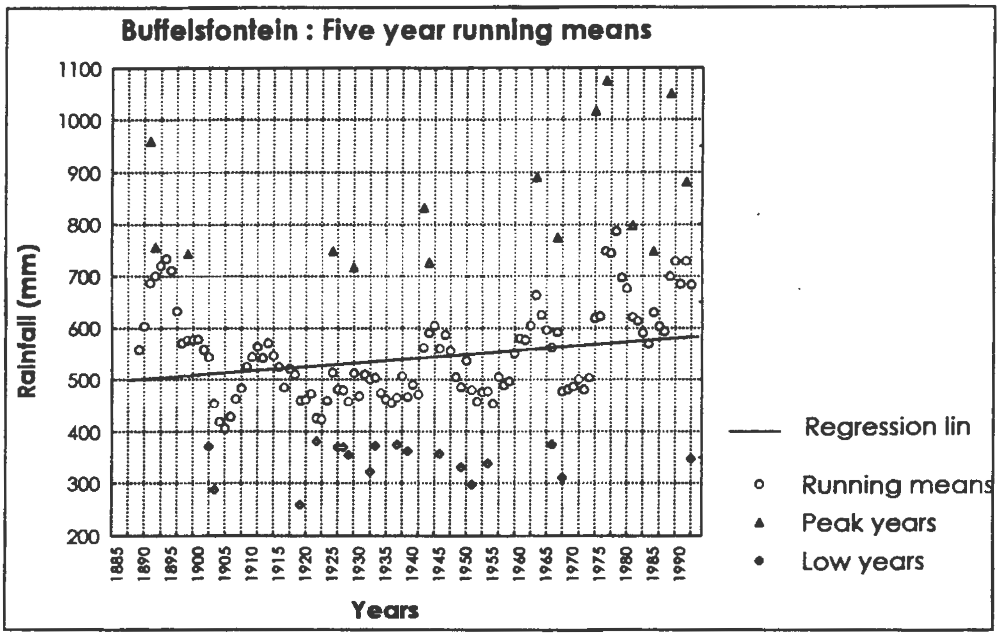


Figure 9.1 Buffelsfontein Farm, rainfall five year running means.

Staying within the subregional context while deviating from the chronological sequence, the record from the Klipplaat Pan suggests two moister phases. The first, around 1340 years ago, may have been responsible for sheetwash which reworked the sand which formed the lunette furthest from the pan. The second, around 500 years ago may be evidenced by the formation of the palaeosol in proximity to the pan.

With regard to the dated evidence from valley fills, the OSL date of 8580 ± 800 years (Shfd 97042) from the Tandjiesberg locality may reflect the onset of headwater accumulation within the central Great Karoo. Although this is the only basal date from inorganic sediment within a valley fill, the recurring pattern of clastic basal sediments capped by organic enriched material lends weight to this observation. Bousman *et al* (1988) reported fills up to 8 m deep at Blydefontein. These fills comprised accumulations of early Holocene clastic sediment capped by organic rich sediment similar to the material described above. Central Great Karoo headwater valleys do not appear to preserve depositional sequences of either the depth or the age of those reported from the higher, more easterly sites of Lesotho and the north eastern Cape (Hanvey and Marker, 1994; Marker, 1994: Marker 1994: Marker 1995: Marker, 1997). During extensive fieldwork along an east-west transect between Queenstown and Beaufort West (Fig. 1.2), the deepest profile recorded by this author was one of 7.5 m at The Valley, from which a ^{14}C date soon after the mid Holocene was reported above (see 9.2.4). The oldest reported radiocarbon date from a Karoo site appears to be 7790 ± 90 BP (Pta 4461) from organic silt at the bottom of a channel fill at Blydefontein (Bousman *et al*, 1988).

In order to compare the palaeoenvironmental trends which emerge from central Great Karoo sites with other research at similar latitudes within the subcontinent, it is necessary to look eastward to high altitude Lesotho. Marker (1995) differentiated between clastic and organic sediments from high altitude hollows at Sani Top and Tlaeeng in Lesotho. She interpreted the preserved sediments as the latest in a series of fills. At Tlaeeng, a mid Holocene date was established for the transition from clastic to organic sedimentation, which in turn ceased at between 1000 and 850 BP. A basal date of ~14 000 BP for organic accumulation was reported for Sani Top (Marker, 1995). The mid Holocene organic phase was recognised at this site too, while the absence of the older organic phase at Tlaeeng is explained in terms of the geomorphic setting within which the sediment accumulated.

In terms of headwater topography, it is possible, but unlikely that the valley fills in the study area record an older phase of organic accumulation than the one optimally represented in the Tandjiesberg and Sneeuberg localities. There is no evidence of terracing (a potential indicator of fill-within-fill) within the valleys. On the contrary, the valley fill surfaces are remarkably flat, with abrupt breaks of slope at their lateral margins (see for example Plates 6.3, 6.5 and 6.6). In addition, where tributary streams in closer proximity to flanking valley sides than the main drainage line were sampled (for example the Good Hope site, Sneeuberg locality), no evidence of older organic fills emerged. On the contrary, the evidence from the Good Hope site points to the removal of any pre-existing older organic material.

Field evidence from this study supports Marker's (1995) assumption of drier conditions during phases of clastic or inorganic sediment accumulation. However, it is suggested here that slopes are most vulnerable during change of state rather than steady state periods. Knox (1972) asserted that vegetation influences runoff and sediment yield. He pointed out that sediment yields increase when climate and vegetation are out of phase. This is represented schematically in Fig. 9.2.

Within the central Great Karoo, an *a priori* assumption with regard to the argument in favour of climatically induced landscape response is the absence of any large scale anthropogenic impact, particularly as has occurred over the last two centuries. During prolonged arid phases, vegetation cover is reduced. Slopes which are denuded of vegetation are vulnerable to erosion. With a change of state to moister conditions, sheetwash may deliver sediment to the valleys. This model precludes catastrophic events of the type which would trigger incision. Currently, there is abundant evidence of the mobilisation of inorganic sediment by sheetwash within the Klein Seekoei catchment (see 6.5.4). The evidence from this investigation points thus to broad, shallow bedrock valleys which received cyclical inputs of inorganic sediment from the surrounding slopes. Energy dissipation would have been rapid as the sediment was dispersed over the valley floor, rather than being confined to well defined stream channels. The presence of coarse clastic deposits and gravel lags has been interpreted as evidence of minor cold phases (Holmes and Marker, 1995; Marker, 1997). However, the level of resolution of this investigation precludes the fixing of individual events within the first half of the Holocene.

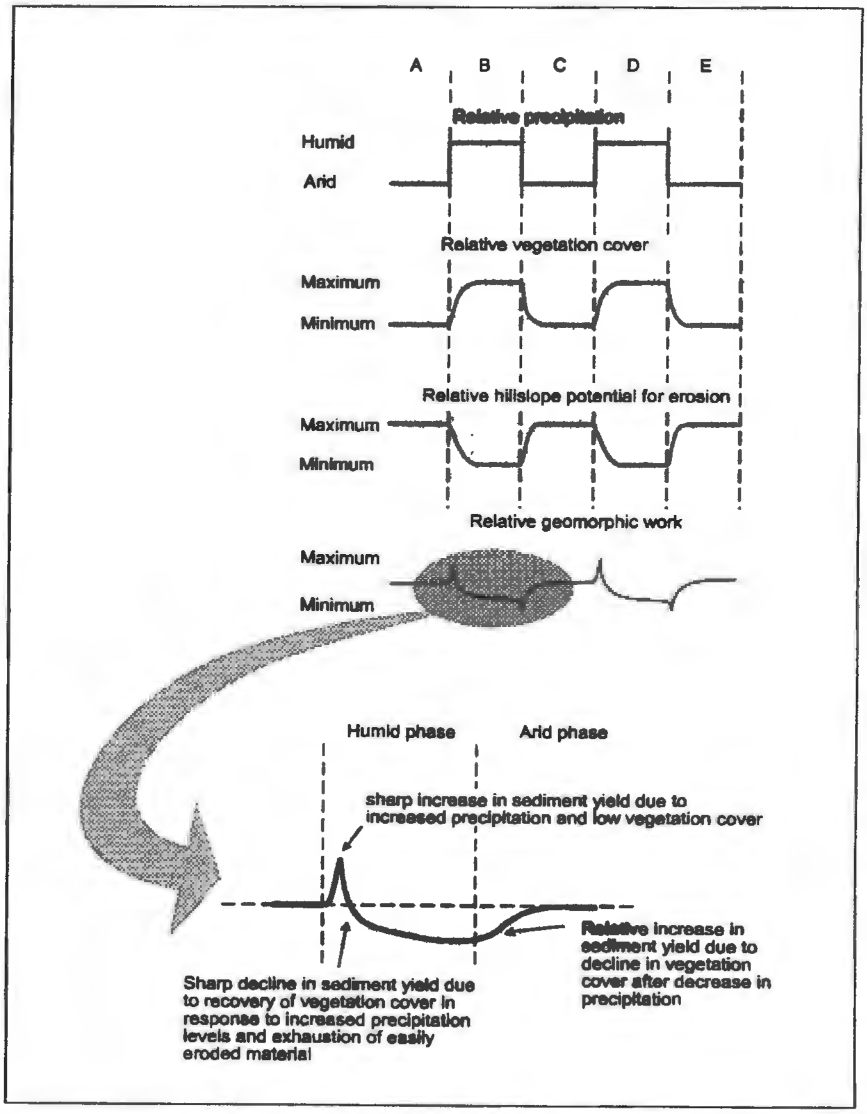


Figure 9.2 Sediment yield in terms of climate driven landscape response. After Knox (1972) and Botha (1992).

There is clear evidence from the Tandjiesberg and Sneeuberg sites of a change to cyclical, relatively organic-rich accumulation around 5000 BP (Holmes and Marker, 1995). This may well be associated with the climatic amelioration (Tyson and Lindesay, 1992) commencing in the mid Holocene. Bousman *et al* (1988) recognised slightly wetter conditions for their Karoo site commencing at this stage (See Table 9.1) and inferred an increased summer rainfall. Sugden (1989) interpreted palynological evidence from the Karoo as reflecting moister conditions commencing around 4600 BP Marker (1995, 1997) recognised warmer, wetter conditions for high altitude Lesotho commencing at this stage.

Within the study area, the morphology and stratigraphy of post- mid Holocene deposits attests to initial high energy events, and a pronounced cyclicity. At the Wapadsberg, Nuweveldberg and, to a lesser extent the Sneeuberg sites (Fig. 1.2) there is evidence of a cut cycle which preceded the cyclical deposition phase. Nowhere in the study area is this better evidenced than at the Good Hope site (Fig. 6.9). Within this tributary, any trace of the early Holocene depositional phase has been removed. The implication is increased run off from vulnerable slopes in response to warmer, wetter conditions. As vegetation cover increased and slopes stabilised, conditions conducive to valley headwater accumulation returned. Conditions of optimal stability may be represented by phases of incipient soil formation and the occurrence of preserved palaeosols. All the valley fills display evidence of fluctuations in state between optimal stability and vulnerability. If a climatic explanation is invoked, then the phases of inorganic accumulation may signify cooler, drier periods. There is evidence for an optimal state of organic accumulation at around 2600 BP. Subsequently, conditions may have again become drier. This is not to say that cyclical fluctuations did not continue after ~2600 BP. The occurrence of such fluctuations in the Karoo has been noted (Tyson and Lindesay, 1992). This study documented a dated palaeosol at 1680 ± 60 BP in the Wapadsberg locality, while organic strata at Klipplaat Pan and in the Nuweveldberg locality produced ^{14}C dates of 430 BP and 760 BP respectively. However, the reader is reminded that the resolution of this study is not such that broad extrapolations can be made from isolated dates.

9.4 CONCLUSION

This discussion has proposed a scenario of central Great Karoo upland valleys largely devoid of sediment at the onset of the Holocene. A gradualist model has been proposed for the accumulation of sediment during the Holocene. The significant change of state which occurred during the mid Holocene may have been a departure from this model; there is evidence of active incision, but not to the extent that valleys were completely flushed out. Generally, the state of sediment preservation along the main drainage lines was good. It remains to postulate as to what happened at, or prior to, the onset of the Holocene to flush out the upland valleys so effectively. This will be done in the final chapter, subsequent to the more detailed insights into Holocene valley fills and erosion which form the substance of Chapter 10.

The above has drawn heavily on the geomorphic evidence from the easternmost, marginal Karoo Stormberg locality, as well as the Sneeuberg *type site*. It has been demonstrated that the depositional record at the former locality predates the Last Glacial Maximum. There is potential, using ^{14}C and luminescence dating, to develop a high resolution Holocene chronology from both these localities. By way of contrast, the westernmost Nuweveldberg locality is revealed as somewhat of an outlier in terms the elucidation of Late Quaternary palaeoenvironments. There is a paucity of palaeoenvironmental evidence from valley fills, and what there is would appear to represent only the last quarter of the Holocene at best. The implications of this, as well as the more complete record from the other localities are considered in the final chapter.

CHAPTER 10

Holocene Valley Fills and Gully Erosion

10.1 INTRODUCTION

The previous chapter provided an elucidation of Late Pleistocene and Holocene environmental change on the basis of geomorphic evidence from a number of depositional sequences within the study area. The term landscape evolution (see Chapter 5) is, arguably, appropriate when describing the surficial terrain modification. The term implies geomorphic adjustment in response to essentially climate-driven processes. However, the question of forcing and controlling mechanisms associated with aggradation and degradation within headwater valley fills has yet to be addressed in any detail. Ideally, this question should be considered in conjunction with the discussion on environmental change. Logistically, this would prove difficult as both historical and contemporary aspects of change need to be considered. Landscape modification (as opposed to evolution) forms the subject of this chapter. The previous chapter dealt with different geomorphic states as manifested within the palaeoenvironmental record. This chapter examines *changes* of state. It attempts to account for short term landscape response, in particular changes from aggradation/equilibrium to degradation. Specifically, the question of gully erosion is addressed.

Imeson (1987) identified a number of conditions which usually characterise gullying. The identification and appreciation of contemporary conditions which may prove conducive to gully erosion is important from two perspectives: Firstly, the human life span dictates first hand observation of current processes only. Of necessity, observations of the contemporary environment must be utilised, the better to hypothesise an historical scenario for landscape change. Secondly, and perhaps more important, there is the need to manage efficiently a landscape which (it will be shown) is particularly vulnerable to erosion.

A three-pronged approach to the question of geomorphic change of state is proposed, namely: Is it possible to identify with any degree of certainty the forcing mechanisms responsible for changes from cut to fill, or vice-versa within valley sediments? Secondly, can cyclical patterns with regard to changes of state within these geomorphic environments be recognised? Finally, do the study localities fit any "model" in terms of their morphology and the processes which impinge on them?

Before addressing these questions, some relevant work in terms of upland depositional environments will be reviewed. Particular attention will be given to Australian examples for the following reasons:

- During the time this research was underway, the author visited Australia and had the opportunity to discuss aspects of research into valley fills, a topic which has received considerable attention in that country.

- On the macroscale, there are strong parallels between the biophysical environments of Australia and South Africa, particularly with respect to climate, vegetation and soil types.

- There are similarities in terms of the history of colonial settlement, and therefore in terms of changing land use. Both countries have experienced the impact of extensive stock farming under European settlement, particularly from the nineteenth century up to the present.

- Comparisons between Quaternary valley headwater fills and the mechanisms responsible for initiating and controlling gullying are facilitated by the thorough documentation of their biophysical environments and the associated geomorphic processes. In Australia, this documentation is particularly well detailed (Goede, 1971; Eyles, 1977; Dodson, 1986; Dodson, 1987; Prosser, 1991; Prosser *et al*, 1994; Prosser and Slade 1994).

10.2 SOME ALTERNATIVE DEFINITIONS OF VALLEY HEADWATER FILLS

A number of terms have been used to describe headwater valley fills. Depending on the global geographic location, colloquial terminology has been applied to what are (or were, where gullying has subsequently impacted on them) arguably similar if not identical geomorphic features.

Young (1986) quotes Penck (1924) and Schmitthener (1925) as referring to small headwater valleys as *dellen*, while she uses the term *dells* for headwater valleys which are "characteristically sediment-choked and swampy. They are largely treeless, their vegetation being dominated by sedges, restiads and proteaceous and myrtaceous shrubs" (Young, 1986, p. 318). Boast (1990) has reviewed the work undertaken on *dambos*, with particular emphasis on research published subsequent to the edited volume by Thomas and Goudie (1985). Boast (1990), referring to Rattray *et al* (1953) equates the term dambo as used in tropical Africa with the term *vlei* used in southern Africa. He defines the term *dambo* as "any flat, grass-covered depression at the head of streams within the tropics, which lacks a definite channel, except perhaps in its lower parts and which is seasonally saturated" (Boast, 1990, p. 154). In reality, the term *vlei* has a broader connotation. Within southern Africa, it is also applied to reed covered lowland swamps and the low gradient valleys with central drainage channels which are found on the high veld. In his study of the recent development of discontinuous gullying on the Tea Tree River in Tasmania, Goede (1971) referred simply to *floodplains* to describe low-lying aggradational surfaces impacted by gullying in historical times. Eyles (1977) states that nineteenth century reports made reference to *chains of ponds* when alluding to pools of water not linked by any obvious perennial drainage lines on the Southern Tablelands of New South Wales. Prosser (1991), in a study of gully erosion at Wangarah Creek on the Southern Tablelands of New South Wales, refers to remnant *swampy meadows*. In a study within the same catchment Prosser *et al* (1994) emphasise that the headwater basin is upstream of the limit of permanent channels. However, invasion by deep gully networks has subsequently occurred. They also refer to *swampy meadows* and note the similarity to the *cienegas* of the south western United States (Melton, 1965) and Africa's *dambos* (Boast, 1990). In this study the term *headwater fills* has been used to describe upland Holocene depositional environments which, with one exception, have been impacted by gullying, or *donga* erosion, to use the South African colloquial term.

10.3 FORCING AND CONTROLLING MECHANISMS ON HEADWATER GULLYING

Although climate has long been recognised as a controlling mechanism in fluvial sediment yield (Langbein and Schumm, 1958; Walling and Webb, 1983) its role as a forcing factor for geomorphic change of state has been the subject of debate (Summerfield, 1991; Prosser and Slade, 1994). Similarly, the exact nature of hydrological and geomorphic responses to changing climates cannot be unequivocally defined (Eybergen and Imeson, 1989; Thomas, 1994).

Butler (1959, 1967) put forward the concept of K- cycles, which significantly influenced research into alluvial and colluvial depositional environments in Australia (Prosser *et al*, 1994). The K- cycles concept attempted to explain the stratigraphy of Quaternary alluvial and colluvial sequences in terms of brief phases of instability, during which slopes and headwaters experienced accelerated erosion and valleys experienced synchronous aggradation. During long intervening periods of stability, soil formation occurred. A succession of buried soils would indicate alternating, cyclical stability and instability on the landscape (Gerrard, 1992). Price Williams *et al* (1982) favoured a climatic explanation (arid phases, reduced vegetation cover and subsequent landscape instability) for the accumulation of Pleistocene colluvia in Swaziland. However with more detailed Quaternary studies it became clear that valley fill stratigraphy does not simply reflect a response to changing climate (Young *et al*, 1986; Prosser *et al*, 1994). Researchers working on southern African depositional environments (Helgren, 1979; Meadows, 1988c; Botha, 1992) have also acknowledged that deposition does not simply occur under one set of climatic conditions, and erosion under another. Helgren (1979) has suggested a model for alluvial fill environments based on a permutation involving four basic geomorphic states under a variety of conditions (Table 10.1).

FROM	TO HUMID INCISION	ARID AGGRADATION	ARID INCISION	HUMID AGGRADATION
Humid Incision	Frequent, high-magnitude events lead to active channel incision. Channels have low sinuosity and high hydraulic radii. Humid, zonal soils develop on the interfluves.	Valley aggrades with sediment eroded from nearby slopes. Channel sinuosity increase and hydraulic radii decrease. Floodplain deflation may be widespread. Basal unconformities often may be steeply dipping and irregular.	Unlikely to occur when humid and arid climates alternate rapidly and deposition will typically intervene. Perhaps no definitive features preserved. Soil development on interfluves reverses from humid to arid trends.	Valleys aggrade and humid-geomorphic floodplains develop. Channels lengthen, becoming more sinuous. Basal unconformities may be steeply dipping and irregular.
Arid Aggradation	Valleys incise, perhaps destroying earlier alluvial fills. Channels become less sinuous and hydraulic radii increase. Response may be complex until humid, zonal soils develop on the interfluves.	Infrequent, high-magnitude events carry slope debris to fill river valleys. Sediments have "arid" characteristics and variable facies development. Channels have moderate sinuosity and, probably, low hydraulic radii. Shallow, arid zonal soils develop on interfluves.	Valley fill incision, perhaps of limited magnitude in response to decreasing sediment supply. Channel sinuosity decreases while hydraulic radii may increase. Limited soil development on interfluves continues.	Channels and sediments acquire humid-geomorphic attributes. Channels probably become more sinuous and hydraulic radii probably increase (as sediments become finer?). Soil development on the interfluves shifts from arid to humid trends. Intervening unconformities are smooth and perhaps gradual.
Arid Incision	Incision continues without creation of definitive new features. Humid, zonal soils develop on the interfluves	Unlikely to occur without an intervening humid phase when soils develop, or a change in the sediment-delivery system causes by availability of a new, less resistant rock-type. Channel sinuosity probably increase, hydraulic radii may decrease Soil development trends and unchanged.	Infrequent, high-magnitude events incise relict alluvia. Adjacent hillslopes are nearly sediment free. Channels have low sinuosity and variable hydraulic radii. Arid, zonal soils may develop on low-anglel interfluves and relict fills	Valleys aggrade and humid-geomorphic floodplains develop. Channels lengthen, becoming more sinuous. Soil development on the interfluves shifts from arid to humid trends. Basal unconformities may be steeply dipping and irregular.
Humid Aggradation	Valleys incise, perhaps destroying earlier alluvial fills. Channel sinuosity decreases. Soil development trends change little.	Remodeling of floodplains by attributes related to arid aggradation. Channel sinuosity and hydraulic radii may decrease perhaps after initial incision. Soil development on interfluves shifts from humid to arid types. Intervening unconformities may be gradual and subtle.	Humid-geomorphic floodplains are incised. Channel sinuosity decreases, and hydraulic radii may increase. Soil erosion is active on the interfluves. Arid soils may develop on slopes with low rates of erosion.	Frequent, moderate-magnitude events aggrade floodplains; channel morphologies are related to sediment type. Vertisols develop on floodplains, while zonal soils develop on interfluves.

Table 10.1 Alluvial fill environments and transitions (after Helgren, 1979).

Prosser *et al* (1994) argue that it is simplistic to imply that climate is the sole or even the most important factor forcing changes from sediment accumulation to degradation (or vice-versa) in headwater valleys. Neither is the alternation between periods of soil development on the landscape and phases of accumulation of inorganic sediment necessarily a function of climate. Young *et al* (1986) have demonstrated that clusterings of radiometric dates from aggradational sequences do not necessarily imply extremes of climatic change. They may simply be a function of the destruction of organic material in oxidising environments through weathering or the local reworking of alluvial sediments. This leads to disproportionally large numbers of "younger" dates.

Given the recognition that Quaternary depositional environments do not offer a simplistic response to climatic variations alone, what other forcing factors may be considered? From a comparatively early stage, climatic change, land use and intrinsic factors within the system had all been proposed as triggering mechanisms (see for example Schumm and Hadley, 1957). However the *relative* effects of climate, human impact and the biophysical parameters of valley fills on the geomorphic processes at work in these environments is an issue which has still not been resolved (Prosser *et al* 1994). Although the factors influencing erosion have long been recognised (see for example Morgan, 1995), there is no consensus about the precise causes of gully erosion (Prosser and Slade, 1994), and such causes remain poorly understood (Prosser and Winchester, 1996; Bull and Kirkby, 1997). Prosser and Slade (1994) observe that many studies have focused on the history of gully development, and circumstantial evidence for cause and effect rather than the physics of shear stress and strength forces associated with the hydraulics of overland flow.

To this end, Prosser and Slade (1994) undertook flume experiments on an unchannelled valley floor to measure flow resistance and critical shear stress for scour under characteristic discharges (Q). This was done under a typical range of natural and degraded swampy meadow vegetation cover, including tussock grass, aquatic plants and sedge. The experimental results were then applied to thirteen sites on the Southern Tablelands of New South Wales where gully formation had occurred. Discharges associated with 1 in 100 year (Q_{100}), $2Q_{100}$ and $0.5Q_{100}$ flood recurrence intervals were utilised. They found swampy meadows covered by tussock and sedge to be very resistant to gully erosion. Increases in discharge, either alone or coupled with light grazing did not result in incision. Only under heavy degradation, or with a bare surface, did gullying occur. They conclude that rapid gully formation in the last century required both significant degradation of the valley floor vegetation as well as an increase in discharge which is itself partly a function of forest clearing. Not only livestock, but also ploughing and road construction, were responsible for the degradation of swampy meadows. A poignant and graphic description of nineteenth century landscape degradation and gully formation in the colony of Victoria is provided by Bride (1858). Landscape degradation following the impact of fire, livestock and even severe frost on the climax vegetation, soil and surface hydrology of the

Wannon area of Victoria are recorded. The loss of grass diversity appears to have been a critical contributing factor to landscape degradation in the Wannon area. Marker (1959) has pointed out that the impact of hoofed animals was particularly severe. Australian marsupials have soft feet, and the indigenous flora was not adapted to sheep and cattle.

In addition to examining forcing and controlling mechanisms in valley headwater fills, a number of Australian studies have traced the historical geomorphic response of chains of ponds under gullying (Eyles, 1977; Melville and Erskine, 1986; Prosser, 1991). Eyles (1977) utilised historical records, plans and aerial photos to trace the transition of Birchams Creek, a tributary of the Yass River in New South Wales, from a chain of ponds to a gully between 1880 and 1975. At the termination of fieldwork in 1975, gully incision was continuing to consume and destroy ponds through headwater retreat. Ponds are either destroyed by sediment infill, or through excavation (Eyles, 1977). The history of land use along Birchams Creek is one of intense grazing pressure, particularly between 1925 and 1972. This study details changes to channel morphology but stops short of proposing causal mechanisms. However, Eyles (1977) speculated that a delicate equilibrium probably exists within such a system, and that any disturbance would trigger the development of active ponds or gullies.

Mellville and Erskine (1986) examined sediment remobilisation and causes of discontinuous gullying along the Fernances Creek in the Wollombi Brook catchment of south east Australia. This valley floor was unchannelled at the time of the first European settlement but gullying was well advanced by 1867. They attribute this to a combination of a local steep segment of valley floor, human disturbance and a number of successive flood events.

Prosser (1991) compared past and present episodes of gully erosion along the Wangrah Creek of the Southern Tablelands of New South Wales in an attempt to establish cause. He identified at least two previous episodes of gully erosion in addition to the modern phase. The methodology involved the identification of palaeogullies within the exposed Quaternary stratigraphy along the Wangrah creek, radiometric dating to establish a chronology, and identifying sites of gully initiation.

Prosser (1987, 1991) concluded that aggradation has occurred throughout the Holocene, with no evidence of regionally synchronous gully erosion. There is evidence of synchronous valley aggradation in the proximity of Wangrah creek during the first phase of gullying commencing at 8000 BP. The implication is that climate change had a minimal influence on erosion. Locally, no known environmental change occurred at 3000 BP (Prosser, 1991), the time of commencement of the second phase of erosion. Prosser (1991) suggests that valley fill aggradation may actually result in intrinsically unstable conditions associated with increased discharge from the expanding valley area under swampy meadows. The argument is that swampy meadows increase runoff due to their permanent saturation, implying a conversion of much of the rainfall onto them into runoff, resulting in gullying. Subsequent desiccation of the valley fills would result in decreased channel flow as both rainfall and slope runoff infiltrate the valley fill sediments.

Present day gully erosion is ascribed to a similar situation in terms of extensive valley fill aggradation and swampy meadow development, but with site specific disturbances rather than runoff changes on a catchment wide scale. Prosser (1991) does not pinpoint specific causes, but suggests that drain construction towards the end of the last century might have acted as the triggering mechanism for the modern phase of gully erosion.

10.4 GULLY EROSION IN SOUTHERN AFRICA

Within southern Africa the topic of soil erosion has probably generated more literature than any other geomorphic phenomenon. It is not the intention to review this literature here, nor to discuss the issue of soil erosion and land degradation at the broader scale. The reader is referred to Beckedahl *et al* (1988) and Beckedahl (1996) for an overview of the geomorphic effects of soil erosion in southern Africa.

Gully erosion is of concern for a variety of reasons. It degrades farmland, as well as generating large quantities of sediment which impact in a variety of negative ways on downstream environments (Patton and Schumm, 1975; Prosser, 1991). Furthermore, gully erosion impinges on water table levels, which in turn impact on both surface and sub-surface hydrology. Botha (1992) has suggested that lowered water tables impinge on pedogenesis, inducing what he terms a "regressive pedogenic pathway" (p. 218). The hydrological implications of gullying are of particular significance in semi-arid environments such as the Karoo study area.

The southern African subcontinent is vulnerable to soil erosion (Beckedahl *et al*, 1988), with gully erosion being particularly prevalent in the eastern parts. Much of this erosion has occurred in colluvial sediments on unstable hillslopes (Price Williams *et al*, 1982; Botha, 1992). Botha (1992) has considered late Quaternary cyclicity on hillslopes in northern Kwa-Zulu/Natal in some detail. Watson *et al* (1984, 1987) and Yaalon (1987) have considered aspects of susceptibility to erosion within colluvial sediments. However, the question of cyclical gully initiation in southern African headwater valley fills and the controlling mechanisms has received little attention. Van Rheede van Oudtshoorn (1986) recognised the association between sediment particle size and the presence in particular of exchangeable sodium on the erodibility of Karoo Supergroup sediments in the upper Orange River catchment. However, this vulnerability does not explain the trigger mechanism *per se* for such erosion.

When examining the initial cause of gullying, it is useful to consider the concept of geomorphic thresholds. Schumm (1979) distinguished between extrinsic thresholds where a geomorphic system will respond to external influences, and intrinsic thresholds, where there is a response which is not dependent on any external variable. Schumm (1979) cites, as an example of the latter, sediment storage in a semi-arid environment. Valley floor steepening may occur, resulting in oversteepening, failure and gullying. Botha (1992) regards the net loss of soil material as the "transgression of the threshold to net landscape instability during which erosion predominates initially" (p. 218). Once erosion is initiated, the sediments which comprise Karoo Holocene valley fills are (as will be argued later) undoubtedly vulnerable to further degradation. However, what might initiate such erosion?

Some insight into gully initiation and the role of vegetation is provided by a study of the impact of an extreme discharge event on a valley flood plain in the winter rainfall region of the Western Cape (Wesemann, 1991; Holmes and Wesemann, 1994). The section of the Middle River under investigation was characterised by identical gradient, lithological control and soil type along its entire length. The upstream section was characterised by mature, pristine *fynbos* (Mediterranean sclerophyll bush) vegetation. The lower section had been cleared and replaced by exotic kikuyu grass, resulting in a reduction in flow resistance. An extreme rain event resulted in a discharge exceeding Q_{100} moving through the catchment. No scour effect was evident on the stream section under *fynbos* vegetation. Where the vegetation had been replaced by exotic grass, the extreme discharge event resulted in instantaneous scour over a distance of ~800 m. Gullying to bedrock at 1.5 m depth occurred within the space of 12 hours. Two small earth dams were breached during this event, creating two knickpoints. Plunge pools formed immediately below these knickpoints. Cavitation and bank collapse occurred before the channel was artificially stabilised through the dumping of boulders into the channel. Although an isolated investigation, the findings appear to support those of Prosser and Slade (1994) with regard to the role of vegetation in controlling or preventing gully formation. In the next section, the question of gully erosion with specific reference to the semi-arid, summer rainfall Karoo region is considered.

10.5 GULLY EROSION IN CENTRAL GREAT KAROO VALLEY FILLS

Europeans began to move into the semi-arid central portion of South Africa during the late eighteenth century (Neville, 1996). The upper reaches of the Seekoei River (Fig. 6.9) formed a strategically important part of the colonial frontier by the end of the eighteenth century (Sampson, 1995). Following the total subjugation of the local Bushmen inhabitants, European settlement and the number of farms in the Seekoei River valley increased rapidly during the first two decades of the nineteenth century (Neville *et al*, 1994).

Prior to the turn of the century and up to 1892, some twenty five documented accounts of travellers through the valley exist (Neville et al, 1994; Neville, 1996). Although there are numerous references to the Seekoei River, as well as to "vleis", pools and what is presumably riverine vegetation, no specific mention is made of gullies or any channel form which might be interpreted as alluding to valley floor erosion. Neville (1996) observes that the river and its tributaries are seasonal. During dry periods, the main channel is restricted to a "long chain of pools, commonly referred to as *zeekoegaten* (or hippopotamus wallows)" (Neville, 1996, p. 31). Neville *et al* (1994) have reconstructed the nineteenth century wagon track system along the Seekoei River. This route to the interior became heavily utilised after the opening up of the Kimberley diamond fields in the 1870s. They point out that the growth of this traffic network was dictated by the occurrence of water and grazing. It can be speculated that the main wagon thoroughfares, which closely followed the north-south drainage lines, served as a trigger to gully erosion. Large numbers of stock were outspanned alongside pools to drink. The comparative lushness of vegetation in the proximity of such drainage lines might also have resulted in overgrazing, trampling and soil compaction with a corresponding decrease in infiltration. The increased runoff on vulnerable surfaces would have exacerbated such erosion. Neville *et al* (1994) conclude that the impact of a developing road network was instrumental in causing large scale degradation of the natural vegetation which in turn facilitated the development of gullies. However, no dates are available for the onset of this erosion.

During this investigation a series of historical vertical air photos of the Upper Seekoei River were examined. Unfortunately, aerial photography does not predate the Second World War. The earliest photos, taken in 1945, display evidence of severe gully erosion in the headwater catchment. Subsequently, a series of weirs (see 6.5.5) were constructed on the Upper Seekoei River, specifically as an anti erosion measure. During fieldwork in the early 1990s, it was noted that the dams behind all four weirs had filled with sediment, local saturation levels had risen appreciably, and the areas were extensively vegetated (Plate 6.5).

In order to assess the extent and impact of erosion in the Upper Klein Seekoei River catchment, three sets of vertical air photos were examined under a binocular stereoscope. The three sets are from Job 417 (July 1959, scale 1 : 30 000), Job 566 (May 1966, scale 1 : 40 000) and Job 832 (September 1980, scale 1 : 50 000). Although the 1945 photo series show gullying, the disparate scale and poor quality of the photos rendered them useless for inclusion in the time series analysis. Although no attempt has been made to quantify the spatial extent of erosion in the catchment, the following observations are pertinent. They are based on examination of the air photos, as well as ground truthing:

- There is evidence from all three sets of photos of extensive sheet, rill and gully erosion .

- Gully networks have cut back into valley headwaters at numerous locations within the catchment (Plate 10.1).

- There is no evidence from the air photo time series of a diminution with regard to erosion during the time period under discussion.

- By 1959, sediment had accumulated to approximately half the height of the weirs visible on the photographs, to over 75% by 1966, and to the top of the weirs by 1980.

- Viewed within the spatial context of the *entire* Upper Klein Seekoei River catchment, the impact of artificial structures in arresting the erosion and transportation of sediment appears to be minimal. However, the effect of these structures in countering desiccation and raising the saturation level in their *immediate* upstream environments is dramatic. This is manifested in the remarkable recovery of vegetation in the vleis created above these weirs (Plates 6.5 and 10.2). Individual structures appear therefore to have the potential to play a significant role in rehabilitation. With the exception of the ~200 m length of stream channel above the uppermost weir (Plate 10.2), there is little evidence of complete gully rehabilitation to what might be regarded as an original or pristine state. However, neither has gully degradation increased perceptibly during the timespan covered by the air photos.

- There is also evidence that erosion and deposition may occur simultaneously within the highest reaches of central Great Karoo headwater catchments. Upstream of the Compassberg Gully (Fig. 6.9) ~50cm of soil has accumulated on top of the remains of the stone wall of a trekboer kraal, built in *circa* 1750. Gully erosion immediately downstream of the stone wall clearly postdates this construction. That sediment may be rapidly stabilised and revegetated is confirmed by Plate 10.2. Plate 10.3 encapsulates the situation with respect to sheetwash and deposition of eroded sediment in this vulnerable and highly responsive catchment. On the one hand, there are shallow soils comprising dispersive silts derived from the local Beaufort shales and denuded of vegetation. These soils erode rapidly in response to the high magnitude rain events typical of the summer thunderstorms which deliver between 60% and 70% (Cowling *et al*, 1986) of the study area's rainfall. Where sediment accretion has filled valleys, incision to bedrock occurs rapidly under this climatic regime. On the other hand the rehabilitation of vegetation arrests erosion and leads to gully stabilisation over time scales measured in years or decades at the most.

10.6 CONCLUSIONS

The rapidity with which gullying occurred in the Stormberg study area (see 6.2.6.5 and 6.2.6.7) attests to the vulnerability of sediments derived from Upper Beaufort sedimentary rocks to

Plate 10.1 Extensive gullying in the headwater catchment of the Klein Seekoei River. Note Kompasberg Peak in the background.

Plate 10.2 Uppermost weir on the Klein Seekoei River. Note the state of vegetation rehabilitation on the valley floor.

Plate 10.3 Good Hope farm. Gully erosion in the background, sheetwash in the foreground. Note occurrence of *Lyceum*, frequently an indicator of physical disturbance in the Karoo environment.

erosion resulting from disturbance at a specific position in the landscape. Although an exact date for the onset of the modern erosional phase within the Sneeuberg study area cannot be determined, it seems likely that it postdates European migration into the Sneeuberg uplands. The extent of the degradation evident on the earliest air photos suggests that it dates at the very least from the early decades of this century.

From a control or rehabilitation perspective, the role of channel way obstructions (either vegetation or artificial constructions) in promoting aggradation appears to be significant. However, economies of scale would almost certainly preclude the large scale rehabilitation of degraded Karoo environments to any significant degree by means of engineering solutions.

The concept of "naturally unstable" environments was recognised by Marker (1959) who defined such a landscape as "one in which the balance between the processes of soil formation and the forces of erosion is precarious, and where a slight change of conditions will initiate marked accelerated erosion" (p. 125). It may be appropriate at this juncture to return to the question of change of state posed at the start of this chapter. Based on the evidence from the Stormberg and Sneeuberg study areas in particular, Karoo and Karoo marginal upland headwater environments display extreme sensitivity with respect to their intrinsic geomorphic thresholds. The response to change does not only manifest itself in a rapid transition from stability to erosion. Equally significant is the comparatively rapid return to conditions of relative stability. Unfortunately, from a human perspective, it is far easier on a regional scale to trigger the former response than to initiate the latter. Secondly, cyclical patterns with respect to change from cut to fill (and vice-versa) are not readily apparent within Karoo Holocene sediments. There is only limited evidence of minor transgressions where tributary gullies intersect the main gullies and have subsequently been partially infilled. The probable reason is that Karoo headwater valley fills (see Chapter 9) do not cover a long enough time span. Certainly, the cyclicity described by Botha (1992) for the much older colluvial deposits east of the Great Escarpment is not evident here. Finally, the argument that land degradation is the likely forcing mechanism for accelerated erosion precludes attempts to explain cyclical cut and fill in terms of any convenient "climatic" model. Whereas landscape evolution is the preferred term for the longer term changes in the central Great Karoo, the term landscape modification is suggested as being appropriate to describe short term, human impacts and their corresponding rapid landscape responses. The final chapter will attempt to synthesise the above within the broader context of environmental change which was discussed in Chapter 9.

CHAPTER 11

Synthesis and Conclusions

11.1 INTRODUCTION

Chapters 9 and 10 have highlighted a number of unresolved issues with respect to late Quaternary depositional environments in southern African high altitude catchments. Foremost amongst these is the relative importance of landscape evolution versus anthropogenic modification in shaping late Quaternary Karoo uplands. Couched as a question: have the primary forcing factors responsible for environmental change been climate driven, thereby implying a natural cyclicity, or have human impacts been chiefly responsible for this change?

Secondly, the temporal and spatial extent of geomorphic evidence for environmental change within the study area must be addressed further. Why do Karoo upland depositional environments appear not to have recorded within their late Quaternary lithostratigraphy the range of environmental fluctuations evidenced by other subregions within southern Africa, particularly those in the wetter, eastern areas? Furthermore, why does the occurrence of Karoo upland sites with preserved depositional sequences appear to be so limited in extent?

The answers to these questions may lie, at least in part, in the intrinsic biophysical properties of the central Great Karoo. While the questions may initially be considered separately, it will become apparent in the following discussion that they are essentially integrated, and should ultimately be regarded as such.

11.2 DISCUSSION

Citing his Cape West Coast work into palaeoenvironmental change, Baxter (1996) has focused succinctly on a dilemma which is not unique to his study. If climate change controls sediment supply in stream catchments, it is tempting to "invoke a simple causal relationship" (p. 250). However, human activity will also impinge on sediment supply. It was argued in the previous chapter that, in the case of the Karoo, it is particularly stock farming and associated practices such as fencing and the installation of point sources for drinking water which impact on vegetation, and therefore indirectly influence sediment supply. It is necessary therefore to proceed with caution when attempting to infer from the available geomorphic evidence whether climate or human activity has dominated environmental change. Knox (1972) has argued that changes in runoff and sediment yield resulting from anthropogenic impacts are not dissimilar to changes resulting from climatic fluctuations. In both cases (see Fig. 9.2), the modification of vegetation cover is the key issue. The experimental work of Prosser and Slade (1994) lends weight to this assertion.

With regard to the study area *sensu stricto*, the answer to the first of the above questions would seem to depend to a considerable extent on the time scale under consideration. With the marked exception of the commencement of the Holocene and, to a lesser degree the mid Holocene climatic amelioration, the effects of late Quaternary environmental change within the Karoo appear to have been subtle. Generally, Karoo headwater valleys manifest changes from aggradation to aggradation. The accumulation of valley fill sequences seems to have been more or less continuous throughout the Holocene; the fills are not characterised by extensive, refilled cuts. Within this continuum, two subphases, can be recognised. The first comprises the accumulation of inorganic sediment from the onset of the Holocene to the mid Holocene. Within the stratigraphy of the exposed fills (see Chapter 7), there is evidence of cyclicity, implying phases of deposition. The chronology of these phases is not well resolved. However, the availability of luminescence dating techniques presents an opportunity for further, site specific, high resolution research in order to establish a reliable chronology for these sequences. The second subphase is represented by cyclical aggradation of comparatively organic rich sediments since ~5000 BP. Marker (1995) recognised a particularly well defined phase of organic accumulation in highland Lesotho which occurred at ~2600 BP. On the basis of a limited number of ^{14}C dates (Appendix F) it is tentatively suggested that this may be a subregional manifestation which included the central Great Karoo.

In summary, with the exception of the Nuweveldberg locality in the extreme west (Fig. 1.2), a repetitive pattern of older, organic deficient early Holocene sediment overlain by strata which intersperse with organic rich strata and/or palaeosols occurs from locality to locality. Not all sites necessarily reflect the entire sequence, but the majority do. It is significant too that in an environment which is notoriously susceptible to gully erosion, there is limited evidence of cyclical cut phases within these Holocene sediments.

In terms of the geomorphic evidence which predates the Holocene, the position is somewhat different. While Knox's (1972) model holds good where fluvial action is responsible for the transportation of sediment, other mechanisms are also responsible for sediment transfer. Within the study area, there is unequivocal evidence for climate driven change during the Last Glacial Maximum in the form of the windblown sand deposit at Klipkraal (see 7.2). The sand does not appear to have had a local origin, implying a scale of transport and deposition which supersedes the subregional and therefore precludes human impact as a facilitator in terms of sediment supply.

Notwithstanding their likely climate driven origin, aeolian deposits in the study area have subsequently been subjected to extensive erosion. Sheetwash from the Klipkraal Sands may have been responsible for the formation of the footslope fan subsequent to sand emplacement and prior to the establishment of climax vegetation cover. The Klipkraal Sands were probably vegetated and stable till the onset of agriculture a century ago when severe gullying (see 6.2.6.2) modified the footslope portion of the sand ramp.

The origin of both the Buffelsfontein and Klipplaat Pan lunettes is ascribed to aeolian action. In terms of the dated geomorphic evidence from this study, the Buffelsfontein Pan lunettes are known to be relatively old, with an OSL date of > 18 000 years recorded for lunette 3 (Table 7.6). At both sites the fringing lunettes have undergone dissection and reworking and both bear testimony to the impact of domestic livestock in their immediate vicinities. At Buffelsfontein, the present owner recounts that his father, as a boy, could not recall the present, characteristic two-tone mounds of the inner lunettes (Plate 7.3) (S. Stretton, *pers. comm*). During the Great Drought, which lasted from 1925/6 to 1932/3 (Preston-Whyte and Tyson, 1988), *bywoners* (literally "sharecroppers") had been permitted to utilise the site, which became severely overgrazed. It appears therefore that the erosion of the lunettes occurred in comparatively recent times. If the Klipplaat Pan is as young as the OSL and ^{14}C dates (see Table 7.6) from this site indicate, then there is reason to believe that at this Pan too dissection of the fringing lunettes has occurred during post-European settlement times.

The answer to the question with regard to the temporal extent of Karoo upland depositional sequences may lie in the fact that the Karoo is marginal, and therefore more sensitive to the factors which force environmental change than are areas to the east of the Great Escarpment. This marginality is not limited to rainfall and, consequently, vegetation cover, but extends also to the dispersive soils and sediments derived from Upper Beaufort shales.

The late Quaternary stratigraphic evidence seaward of the Drakensberg in KwaZulu-Natal predates 100 000 BP (Botha, 1992), while that of high altitude Lesotho certainly predates the Holocene (Marker, 1995). Both subregions experience approximately double the mean annual rainfall of the study area, as well as more cloud cover and a lower potential evaporation rate (Schulze, 1980). Prior to the introduction of domestic stock, both were extensively grassed. In the case of KwaZulu-Natal, Botha (1992) points out that erosional and depositional phases may have co-existed on the Masotcheni Formation colluvial sediments which manifest evidence of extensive cyclical cut and fill. The implication is a landscape which, because of its intrinsic biophysical properties, was able to absorb, or at least cope, with climatically driven environmental change as its geomorphic systems responded to changes in temperature, rainfall and vegetation.

While Lesotho possesses duplex soils (soils characterised *inter alia* by a relatively impermeable B horizon, thereby promoting throughflow and exacerbating erosion in a saturated A horizon), such soils are confined to the lowlands of Lesotho (Schmitz and Rooyani, 1987). As with KwaZulu-Natal, the biophysical properties of highland Lesotho appear to be such that this area had the capacity to respond to change in such a way that critical thresholds have not been exceeded to the extent they have been in the Karoo. Interestingly, as population pressures have increased, the traditional pattern of summer *transhumance* grazing has been replaced by permanent settlement throughout much of the Lesotho highlands. The impact on the landscape has manifested itself in increased erosion (M. Marker, *pers. comm.*).

Returning to the longer term picture, and employing a dramatic metaphor, the KwaZulu-Natal and Lesotho environments were not pushed to the point of geomorphic "meltdown" at the commencement of the Holocene. Botha (1992) makes the important point that, while cyclical events are supported by physical evidence, the constraints imposed by geomorphic thresholds are of necessity inferred; the relevant biophysical features having been destroyed as the threshold was crossed.

Taking cognisance of the above, and acknowledging that, In the absence of any preserved stratigraphic record any inferences are speculative, It is the conviction of the author that a catastrophic model should be invoked to explain the curious absence of central Great Karoo headwater catchment valley fills predating the Holocene. Against the preceding discussion, it is emphasised that what proved catastrophic in terms of the Karoo might not have been so in the case of the wetter, more easterly subregions with their different geology, soils and vegetation cover. In terms of Helgren's (1979) model (Table 10.1), arid incision is currently the dominant process within Karoo upland valley headwaters. Possible reasons for this were discussed in Chapter 10. In spite of incision to bedrock in many channels, as well as active sheetwash, the current state of vegetation cover makes it seem unlikely that valley fills would ever be completely removed under the present energy regime. Yet, this study has shown that headwater valleys were effectively denuded of sediment prior to the Holocene. High energy fluvial event(s) may have been responsible for the large scale removal of material. Under little or no Karroid vegetation, the Beaufort Group sediments and their associated lithosols may have been removed by exceptional high magnitude - low frequency events. That such events occurred both prior to and during the Holocene has been conclusively demonstrated. Evidence for high magnitude palaeoflood events from the Orange River catchment has been reported by Zawada (1996). Events were dated using IRSL, TL and ^{14}C. Perhaps significantly, the oldest IRSL dates predate the Holocene by ~2000 years. In short, it is suggested that the geomorphic setting, geology and vegetation in KwaZulu-Natal and the Lesotho highlands rendered them less vulnerable to erosion of the type which must have impacted so severely on the Karoo sites.

Because, as has been pointed out, geomorphic evidence is typically removed when thresholds are exceeded, modern analogues can serve as valuable proxy indicators of how landscapes may respond to forcing factors in the environment. There is evidence of modern high magnitude - low frequency rainfall events which have impacted on the Karoo, though not on the scale postulated by Zawada (1996). The most notorious example was the 25 January 1981 flood which destroyed a large part of the Great Karoo town of Laingsburg (200 km west-south west of Beaufort West) resulting in more than 100 deaths. An estimated 7000 m^3 per second of water and silt flowed through the town at the height of the flood, of which 30% comprised silt (Weather Bureau, 1981). The estimated rainfall over the catchment of the Buffels River, which flows through the town, was 121 mm in 24 hours. Similar amounts were measured within a radius of 50 km of the town (Weather Bureau, 1981), implying that this was more than a localised occurrence. Such events are associated with the atmospheric phenomena of cut-off lows which have been described by Taljaard (1985). The potential impact of these weather systems is clearly demonstrated by means of another example. As a result of the passage of such a system in September 1968, 552 mm of rain fell on the city of Port Elizabeth (Fig. 1.1), of which 470 mm was recorded in 4 hours (Weather Bureau, 1981).

Clearly, the subregional scale of valley headwater flushing at or near the onset of the Holocene precludes any anthropogenically driven cause. Yet, on the human-induced, small scale, there is substantive evidence in the form of modern analogues from the Stormberg and Sneeuberg localities (see 6.2 and 6.5 respectively) as to how these landscapes may respond when geomorphic thresholds are exceeded. If, as has been postulated, the study area had been subjected to an extreme event (or events) of a spatial magnitude not experienced in historical times, the results may have been catastrophic in terms of sediment mobilisation within headwater catchments.

Finally, why does the distribution of "classic" depositional sequences appear to be so patchy? Either such sites are widely dispersed, or they are common but were not recognised during the fieldwork stage, possibly because they have not been incised. During initial fieldwork, it soon became apparent that not every valley headwater catchment inspected had preserved within its confines a depositional stratigraphy. Indeed, some potentially ideal sites in terms of current moisture conditions and vegetation cover yielded little or no geomorphic evidence for late Quaternary environmental change. The prime example was the high altitude, primary headwater catchment on the farm The Ranges in the Kamdeboo Range (Fig. 1.2). A number of local farmers and agricultural extension officers had confidently predicted that this catchment would yield depositional sequences of the type being sought (see 3.2), yet this locality proved to be a disappointment, with no sites manifesting exposed cuts in headwater fills. Neither was their evidence of vlei environments where coring might have yielded a useful stratigraphic sequence. In the event, just a single soil sample was taken for comparative purposes (Appendix E).

Of the five study localities, The Sneeuberg, Tandjiesberg and Stormberg have preserved the full sequence of Holocene sediments discussed in Chapter 9. In all three headwater catchments, the drainage lines exit the catchments via narrow gaps or *poorts*. In the case of the Sneeuberg and the Stormberg localities (Figs. 6.1 and 6.9), superimposition of the Holspruit and Klein Seekoei Rivers has resulted in the breaching of prominent dolerite dykes to form Allemans Poort and Cephanjes Poort respectively. At the Tandjiesberg locality the steep sided mountain slopes permit entry to and exit from the headwater catchment via a similar narrow gap. In all three catchments it appears that geomorphic constrictions have resulted in the accumulation of sediment behind what are effectively large natural weirs. A similar gross valley morphology was reported by Bousman *et al* (1988) in the Blydefontein Basin.

While sediment supply is largely a function of catchment response under a variety of environmental scenarios (see Chapters 9 and 10), it is suggested that catchment morphology may contribute significantly to the likelihood of Karoo headwater catchments retaining these sediments. It would be presumptuous to suggest that the localities visited by the author are the only ones within the confines of the study area which hold late Quaternary sediments. However, this study has shown that valley headwater fills, and indeed other depositional environments which might hold evidence of Late Quaternary environmental change, are not as widespread as was initially anticipated. Future studies might usefully commence with a more detailed analysis of air photos in order to identify potentially promising catchments prior to any fieldwork being undertaken.

At this juncture, it is appropriate to revisit the working hypothesis which was set out in Chapter 1:

Sediments sufficient in both quantity and variety are preserved at central Great Karoo upland sites such that a late Quaternary depositional chronology can be established. Depositional sequences would reflect palaeoenvironmental change to the extent that spatial and temporal climatic trends, as well as anthropogenic influences, might reliably be inferred.

The above was intended as a working hypothesis in order to provide a milieu for this research. The nature of the findings do not provide grounds for a simple, statistically based acceptance or rejection of this hypothesis. Rather, the preceding discussion permits a number of salient comments to be made.

With regard to the first part of the working hypothesis, it has been shown that the sedimentary record of the central Great Karoo uplands does permit the establishment of a late Quaternary depositional chronology, albeit one with limitations. In the first instance, the record is spatially fragmented, and lacks any sort of regional stratigraphic marker. While this study has attempted to combine aspects of both the approaches outlined under 1.2, the nature of the sedimentary record necessitates a reliance on the inductive point- or, in this case, locality- specific investigation of the type recognised by Thomas (1986). Secondly, the record from upland valley fills permits the establishment of a chronology which spans the Holocene only. If the aeolian record from the eastern margin is considered, then the chronology can be extended to the last ~10 000 years of the Upper Pleistocene. The record is thus late Quaternary in the most literal sense.

Considering the second part of the working hypothesis, spatial and temporal climatic trends were identified. The nature of the depositional environments supports the notion of an east-west rainfall gradient which has existed throughout the Holocene, as well as revealing inferred stages of aridity and greater moisture availability. These details were considered in Chapter 9. Finally, there is conclusive evidence (Chapter 10) for anthropogenic impact on the geomorphic landscape of the central Great Karoo, particularly subsequent to European colonisation which dates from the eighteenth century.

11.3 CONCLUSIONS

It remains to conclude this thesis by drawing the attention of the reader to the main points which have emerged from this investigation. This will be done in the light of the aim, and with reference to the specific objectives, which were presented in 1.3. This research has demonstrated the following:

1. Central and marginal Great Karoo valley fills, as they pertain to the study area, are more limited in both spatial and temporal extent than was anticipated at the commencement of this research. Nevertheless, certain catchments (noticeably the Sneeuberg locality) have preserved stratigraphic sequences that offer the opportunity for further, local scale, high resolution studies. With regard to ancillary depositional environments, only the eastern, marginal Stormberg locality yielded appropriate evidence in the form of pans and a sand ramp. The westerly Nuweveldberg locality would appear to hold the potential for a separate, detailed study of clast supported slope colluvium along the lines of the investigation carried out by Reynhardt (1979) in the Magaliesberg Range of the Transvaal but has little to contribute to a subregional elucidation of valley fills.

2. Typically, central Great Karoo valley fills vary in depth between ~1.5 m and ~8 m. Greater thicknesses of headwater sediment may occur, but they were not encountered during this investigation nor, as far as can be ascertained, have they been documented in the literature.

These valley fills typically comprise horizontally bedded, fine sand to silt grade material, while the occurrence of clasts is the exception rather than the rule. A transportational environment is suggested where sheetwash, as opposed to high energy mass movement, dominated. There is evidence of incipient pedogenesis, implying phase of relative stability in the landscape, within many of these fills.

3. On the basis of the geomorphic evidence, It is suggested that climatically driven factors were largely responsible for the accumulation of sediment in the central Great Karoo during the late Quaternary, and that climate in turn forced a catastrophic removal of valley fills just prior to or at the commencement of the Holocene. In post-colonial times, anthropogenic factors have contributed to landscape degradation, primarily through the removal of vegetation and the stripping of the shallow soil cover. There is evidence that enlightened farming practices, as well as the establishment of National Parks, have contributed to a partial recovery of the landscape. However, the potential for small scale catastrophic degradation under injudicious management, in particularly the ploughing of highly dispersive soils, should not be underestimated.

4. This study has shown that largely inorganic valley fill sediment predates the mid Holocene, and is superseded by sequences which are richer in organic material. It has not demonstrated conclusively the existence of a regional, spatial distribution pattern for late Quaternary sediments along the lines of that proposed by Botha (1992) for the Masotcheni Formation colluvium of central and northern Natal.

5. A coarse scale palaeoenvironmental interpretation has been undertaken on the basis of geomorphic evidence. The details are outlined in Chapter 9. In essence, evidence from the study area confirms that the arid, probably cooler conditions of the Last Glacial were superseded by warmer and ultimately moister conditions during the Holocene. The absence of valley fills predating the Holocene, and the limited aeolian sequences from the eastern margins of the study area restrict a high resolution interpretation on the subregional scale.

6. On the basis of the type of geomorphic evidence which this study focused on, or more accurately the lack of such evidence in the western, drier margins of the study area, it would appear that the east-west rainfall gradient which exists across the central Great Karoo was in existence by the mid Holocene.

7. Reference to southern African literature has placed the findings of this research in the broader southern African context, particularly with regard to the comparison with work done in the eastern, wetter regions of Lesotho, the Eastern Cape and KwaZulu-Natal. It has been demonstrated that the record from the central Great Karoo is of a comparatively limited spatial

and temporal scale. Nevertheless, the findings from this study fit the general pattern of late Quaternary environmental change in southern Africa.

11.4 FUTURE DIRECTIONS

This study has demonstrated the potential for more detailed, site specific investigations of Karoo depositional sequences. The application of luminescence dating to basal valley fill strata in, for example the Sneeuberg Range may well lead to a better understanding of environmental change at the onset of the Holocene. It is the author's opinion that little purpose would be served in attempting to extend a study of headwater valley fills in a westerly direction owing to the dearth of suitable sequences. Potential geomorphic research in the western margins of the study area should focus on the clast dominated colluvia which, on initial inspection, appear to be abundant in the Nuweveld Range.

There is a need to understand more fully the nature of landscape response in an area which covers such a significant proportion of the South African land surface. Although the current rainfall and vegetation cover of the central Great Karoo preclude the exploitation of this environment for intensive agriculture or increased grazing densities, it is precisely the marginal biophysical aspects of the Great Karoo highlighted in this study which render it vulnerable to even limited human impact. While humans can, to an extent, control potential impacts on Karoo environments by the way in which they choose to utilise and manage such environments, it is the potentially greater impacts which a changing world climate will impose on marginal areas which are a source of concern. If past warming phases over southern Africa serve as an indicator of what future global warming might bring, the Karoo is one of the southern African subregions where the greatest disruption to current rainfall patterns is likely to be felt (Partridge, 1993). Should rainfall increase in response to such warming, there exists the potential for short term catastrophe before the biophysical system readjusts. If the Karoo were to experience greater aridity, the long term biotic and economic consequences could prove disastrous. Comprehending the manner in which such environments have responded to change in the past may well lead to a better understanding of what to expect, and ultimately what to prepare for in the future.

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Appendix A

Particle size determination.

1. Between 1 kg and 3 kg of each sediment sample was dry sieved through a 2 mm sieve to separate the coarse fraction from the finer fraction.

2. The coarse and fine fractions were weighed to determine the % mass of material > and < 2 mm (-1ϕ).

3. The finer fraction was air dried for a week and split into ~100 g fractions. ~100 g of fine fraction was then oven dried at 30° C for 24 hours.

4. A split of exactly 20 g of sediment was then weighed off and treated with 200 ml of sodium hexametaphosphate solution. This solution was made up by dissolving 35,7 g $Na(PO_3)_6$ and 7,9 g Na_2CO_3 in 1 l of distilled water. Treatment comprised agitating the treated samples for 12 hours on a Protea Model SC 201 rotary (dual plane) mechanical agitator. The purpose of this was to deflocculate silt and clay size particles but not to alter the size dimensions of sand size particles. Samples were not stirred with an electric stirrer because of the damage this can cause to individual particles.

5. After this initial mild deflocculation, samples were wet sieved through a 63μ sieve to separate the silt and clay fraction from the sand size fraction.

6. The silt and clay size fraction passing through the sieve was recovered for further analysis. The sand size fraction was recovered from the sieve and oven dried at 30°C for 12 hours. The mass of the sand size fraction was then determined. By subtracting this figure from 20 g, the mass of the silt and clay size fraction was determined by default.

7. The dried sand size fraction was then fine split till a subsample of ~2 g was obtained.

8. To determine the percentages of coarse, medium and fine sand sized sediment, each ~ 2 g sample was processed in a settling column (Flemming and Thum, 1978). This apparatus operates on the principle of Stokes' settling law which determines the rate at which spherical particles of known density will settle in a liquid of known viscosity. Data from the settling column is automatically processed by a desk top computer to provide a particle size distribution as well as statistical measures for each sample (Folk and Ward, 1957).

9. The proportions of silt and clay were determined using the hydrometer method. Between 25 g and 40 g of sample were used for each analysis. The method, including hydrometer calibration, is described in detail by Akroyd (1957) and Bowles (1970).

Appendix B

Determination of pH, electrical conductivity and total organic fraction.

Determination of pH

1. 25 ml of distilled water was added to 10 g of sediment sample.

2. The sample was shaken and allowed to stand for 50 minutes.

3. It was then shaken again and allowed to stand for 10 minutes before a reading was taken. This was done by immersing the probe of an M90 multimeter (calibrated using pH 7 and 9 standards) in the supernatant and waiting for the reading to stabilise.

4. In the case of pH readings in $CaCl_2$ and KCl, 0.01M and 1M solutions in distilled water were utilised respectively.

Determination of conductivity

1. The conductivity probe of an M90 multimeter (calibrated in air and in a solution of known conductivity) was immersed in the supernatant.

2. A conductivity reading (in siemens or microsiemens) was taken after 1 hour.

3. In the case of readings from the two pans (see 4.7.2), where the presence of ionisable salts in large concentrations was suspected, conductivity readings were converted to resistance readings (ohms) simply to facilitate their interpretation.

Determination of total organic fraction

1. The bulk sample was oven dried for 12 hours at 80° C to evaporate any water.

2. ~2 g of oven dried sample was weighed, and then heated to
800° C for 12 hours.

3. The sample was subsequently weighed and loss by ignition was determined.

Appendix C

Determination of organic carbon (Walkly-Black titration).

1. A split of oven dried sediment was ground to pass through a 0.5 mm sieve.
2. A weighed sample of not more than 10 g was transferred to a 500 ml Erlenmeyer flask.
3. 10 ml $K_2Cr_2O_7$ was added and the flask was gently swirled to disperse the sediment before rapidly adding 20 ml concentrated H_2SO_4 and swirling gently for 1 minute.
4. The flask was allowed to cool for 20 minutes.
5. 200 ml distilled water and 10 ml H_3PO_4 was added.
6. Just before titration, 0.5 ml barium diphenylaminesulfonate indicator was added to the sample.
7. Titration was undertaken by adding $FeSO_4$ dropwise until a light green endpoint was reached.
8. A blank titration was run, using the same procedure, but without adding sediment in order to standardise the ferrous solution against Cr_2O_7 .

Results were calculated as follows:

$$1 \text{ ml } K_2Cr_2O_7 = \frac{12}{4000} \times \frac{100}{77}$$

or 0.0039 g carbon

$$\% \text{ organic carbon} = \frac{\text{ml } K_2Cr_2O_7 \text{ reduced} \times N \times 0.0039 \times 100}{\text{mass of sediment}}$$

$$= \frac{(B - S) \times 0.5 \times 0.0039 \times 100}{\text{mass}}$$

where : B = blank titration (ml)

S = sample titration (ml)

N = normality of Fe^{2+}

% organic matter = % carbon x 1.724

Appendix D

Determination of $\delta^{13}C$.

1. Each sample was sieved through a 2 mm soil sieve in order to remove rootlets and extraneous material.

2. 10 g of each sample was treated with 0.1 M HCl overnight, or until the reaction had ceased.

3. The residue was centrifuged and rinsed to pH 3 in distilled water.

4. The sample was freeze-dried.

5. 0.15g was measured into a quartz tube, together with copper, copper oxide and silver. The tube was placed under vacuum and combusted at 800° C in order to convert the organic carbon to CO_2.

6. CO_2 was purified by cryogenic distillation, and measured on the VG 602E mass spectrometer. Results are relative to PDB.

Appendix E

Primary data matrix for 173 valley fill strata on 16 variables, and Munsell colour notation.

Sample	% Sand	% Coarse	% Med.	% Fine	Mean	Median	Sorting	Skew.	Kurtosis	% Silt	% Clay	pH H_2O	pH $CaCl_2$	Conduct.	Organics	Organic C	Munsell C.
BD 1	16	4.73	25.42	69.85	2.42	2.5	0.82	-0.13	0.97	53	31	8.42	7.56	433	27.56	3.66	7.5YR 3/1
BD 2	25.8	6.69	26.62	66.69	2.38	2.44	0.88	-0.1	0.91	69.3	4.9	8.15	7.41	598	31.95	0.93	7.5YR 5/1
BD 3	9.1	10.08	15.14	74.78	2.69	2.97	1.06	-0.48	1.06	40.4	50.5	8.69	7.8	258	10.84	0.5	7.5YR 4/1
BD 4	7.9	9.25	14.74	76.01	2.65	2.88	0.99	-0.42	1.05	41.29	50.81	8.34	7.71	260	11	0.3	7.5YR 5/1
BD 5	10.7	20.3	10.56	69.14	2.43	2.95	1.25	-0.56	0.79	54.9	34.4	8.54	7.73	248	10	0.13	7.5YR 5/2
KAL 1	11.2	2.53	6.38	91.09	3.16	3.31	0.61	-0.48	1.79	74.64	14.16	7.95	6.77	271	9.2	3.39	7.5YR 4/2
KAL 2	10.53	1.62	6.04	92.34	3.28	3.32	0.51	-0.35	1.99	54.89	34.58	7.94	6.75	228	9.8	2.73	5YR 3/2
KAL 3	15.26	0.51	3.09	96.4	3.38	3.38	0.38	-0.2	1.47	48.5	36.24	7.98	6.74	190	9.75	1.2	5YR 3/2
KAL 4	7.01	2.43	1.57	96	3.37	3.38	0.36	-0.23	1.66	60.98	32.01	8.16	6.86	157	4.45	0.4	7.5YR 4/2
KAL 5	15.73	1.08	1.72	97.2	3.33	3.31	0.32	0.03	1	51.36	32.91	8.12	6.81	117	3.7	0.31	5YR 4/4
KAL 6	23.6	4.82	2.82	92.36	3.36	3.36	0.59	-0.34	2.46	43.9	32.5	8.45	7.11	226	3.3	0.22	5YR 4/3
KAL 7	10.06	2.57	1.43	96	3.32	3.33	0.39	-0.23	1.64	62.03	27.91	8.03	6.95	70	3.35	0.08	5YR 4/4
KAL 8	24.2	3.3	2.31	94.39	3.31	3.3	0.49	-0.24	1.91	45.8	30	8.02	7.01	84	3.4	0.13	5YR 4/4
KAL 9	27.73	3.3	2.3	94.4	3.31	3.3	0.46	-0.22	1.87	49.77	22.5	8.41	7.12	5.68 m	2.4	0.04	5YR 4/6
KAl 10	26.86	1.13	1.5	97.37	3.25	3.27	0.42	-0.2	1.18	49.39	23.75	8.59	7.14	5.68 m	2.4	0.03	2.5YR 4/8
KAL 11	29.46	1.08	1.77	97.15	3.23	3.23	0.4	-0.12	1.2	46.79	23.75	8.41	7.06	91	2.6	0.04	2.5YR 4/8
KAL 12	24.13	7.76	1.37	90.87	3.24	3.23	0.74	-0.35	3.51	43.37	32.5	8.53	6.97	136	3.45	0.02	2.5YR 3/6
HOL 1	39.8	27.8	16.9	55.3	1.89	2.23	1.26	-0.33	0.76	39.39	20.81	7.66	6.93	308	10.33	7.26	5YR 3/1
HOL 2	43.4	29.33	16.43	54.24	1.93	2.23	1.32	-0.29	0.71	38.29	18.31	8.51	7.42	450	6.96	0.35	5YR 3/3
HOL 3	15.3	10.99	13.04	75.97	2.64	2.93	1.05	-0.45	1.04	63.57	21.13	7.82	7.12	733	10	0.46	5YR 4/2
HOL 4	52.2	45.39	23.33	31.28	1.32	1.16	1.11	0.21	0.74	26.99	20.81	8.41	7.01	135	4.97	0.13	7.5YR 4/4
HOL 5	26.7	9.17	10.44	80.39	2.67	2.9	0.92	-0.45	1.42	42.49	30.81	8.04	7.04	342	6.96	0.13	7.5YR 5/4
HOL 6	67.8	61.64	25.07	13.29	0.82	0.62	0.91	0.27	0.72	18.89	13.31	8.66	7.25	79	4.68	0.03	7.5YR 4/6
HOL 7	32	29.49	19.23	51.28	1.78	2.05	1.22	-0.26	0.78	37.19	30.81	8.51	7.15	149	6.37	0.12	5YR 4/4
HOL 8	28.4	16.49	11.53	71.98	2.41	2.84	1.17	-0.52	1.01	42.97	28.63	8.1	6.8	176	5.7	0.03	5YR 4/6

Sample	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Sorting	Skewness	Kurtosis	[illegible]	% clay	pH H2O	pH CaCl2	Conductivity	Organic	Organic C	Munsell
ZC1	53.4	40.4	22.38	37.22	1.46	1.4	1.12	0.1	0.73	40.06	6.54	6.12	7.19	1122	4.97	0.65	7.5YR 3/4
ZC2	45.2	52.96	22.11	24.93	1.18	0.92	1.05	0.38	0.84	39.54	15.26	6.19	6.88	247	11.58	0.65	5YR 3/3
ZC3	43.3	77.84	12.34	9.82	0.56	0.37	0.81	0.49	1.5	35.96	20.74	6.84	6.22	65.4	7.32	0.22	7.5YR 4/6
ZC4	54.8	54.18	28.96	16.86	1.09	0.91	0.86	0.34	1.03	23.95	21.25	7.31	6.63	98.6	6.89	0.1	7.5YR 4/6
ZC5	64.2	84.54	8.81	6.65	0.38	0.28	0.7	0.4	1.65	20.15	15.65	7.32	7	90.5	6.99	0.05	7.5YR 4/6
ZC6	39.1	37.03	22.34	40.63	1.6	1.56	1.16	0.08	0.77	38.49	22.41	7.14	7.02	134.7	6.25	0.04	10YR 5/6
ZB1	57	43.64	29.35	27.01	1.28	1.18	1.01	0.14	0.82	39.63	3.37	7.23	7.1	480	5.61	0.49	7.5YR 4/6
ZB2	80.9	81.87	13.75	4.38	0.47	0.39	0.63	0.28	1.28	15.64	3.46	7.75	7.21	85.8	3.78	0.19	7.5YR 4/6
ZB3	40.7	48.13	29.68	22.19	1.16	1.06	0.96	0.19	0.83	57.24	2.06	8.41	7.33	320	5.74	0.43	10YR 4/2
ZB4	23	47.64	16.23	36.13	1.36	1.08	1.2	0.31	0.7	74.94	2.06	7.27	7.23	4.62 m	5.19	0.36	10YR 4/3
ZB5	20.6	39.93	17.82	42.25	1.59	1.5	1.32	0.1	0.69	71.64	7.76	7.15	7.04	4.17 m	3.11	0.3	10YR 4/2
ZB6	66.3	39.37	52.87	7.76	1.14	1.15	0.58	0.04	1.15	27.57	6.13	7.98	7.25	155.2	4.09	0.12	10YR 4/2
ZB7	44.4	64.4	20.2	15.4	0.87	0.63	0.96	0.4	1.07	46.37	9.23	7.93	7.18	169.1	4.31	0.17	10YR 4/2
ZB8	78.4	68.38	25.85	5.77	0.73	0.64	0.71	0.22	0.97	14	7.6	8.2	7.48	82.3	3.32	0.05	10YR 5/4
ZB9	80.4	67.44	26.52	6.04	1.45	1.47	0.77	0	1.04	15.82	3.78	8.23	7.27	185	3.06	0.05	10YR 5/6
ZB10	83.3	42.59	46.49	10.92	1.13	1.14	0.7	0	0.94	9.92	6.78	8.42	7.61	62.2	3.2	0.03	10YR 5/6
ZB11	78.4	48.05	39.46	12.49	1.04	1.04	0.83	0.02	1.05	14.81	6.79	8.14	7.65	106.7	3.45	0.07	10YR 5/6
ZB12	31.9	11.86	12.8	75.34	2.5	2.75	1.03	-0.39	1.14	64.74	3.36	8.29	7.91	239	4.21	0.15	10YR 5/8
ZB13	94.4	90.14	7.17	2.69	0.31	0.28	0.53	0.2	1.28	4.6	1	8.07	8.16	157.5	3.4	0.03	10YR 4/4
ZD1	56.6	42.35	26.1	31.55	1.31	1.19	1.12	0.18	0.82	39.25	4.15	7.93	7.21	531	5.79	0.83	7.5YR 4/6
ZD2	41.3	10.55	11.88	77.57	2.58	2.75	0.93	-0.34	1.41	56.48	2.22	8.62	7.45	580	5.62	0.52	10YR 3/4
ZD3	0	10.85	16.79	72.36	2.53	2.73	1.06	-0.37	1.11	96.45	3.55	8.66	7.66	496	6.39	0.51	2.5YR 4/2
ZD4	33.9	40.28	29.4	30.32	1.91	2.02	1.15	-0.13	0.9	60.55	5.55	8.79	7.53	509	6.67	0.55	2.5YR 3/2
ZD5	78.1	24.65	48.46	26.89	1.4	1.42	0.91	0.02	0.99	18.36	3.54	9.22	8.05	373	3.85	0.12	10YR 4/3
ZD6	80.9	25.09	39.81	35.1	1.49	1.56	0.87	-0.6	1.01	15.55	3.55	9.37	7.68	307	3.64	0.07	10YR 4.3
ZD7	23.7	7.96	11.51	80.53	2.73	2.95	0.91	-0.44	1.28	72.75	3.55	8.23	7.68	1568	6.75	0.5	2.5YR 3/2
ZD8	31.5	1.34	8.53	90.13	2.86	2.89	0.59	-0.13	1.07	57.92	10.58	7.93	7.91	3.05 m	5.17	0.26	2.5YR 5/4
ZD9	21.9	4.49	22.06	73.45	2.68	2.74	0.75	-0.18	1.12	64.67	13.43	7.84	7.39	3.88 m	3.9	0.45	5YR 4/1
ZD10	21.3	0.51	1.62	97.87	3.3	3.31	0.38	-0.18	1.19	62.56	16.14	8.18	8.09	1735	2.36	0.18	2.5YR 5/4
ZD11	12.3	7.86	4.68	87.46	2.94	3.11	0.81	-0.45	1.46	65.93	21.77	7.64	7.67	5.68 m	5.66	0.31	5YR 4/3
ZD12	62.6	1.14	13.99	84.87	2.51	2.47	0.62	0.08	1.09	27.35	10.05	8.08	7.8	2.99 m	3.62	0.11	2.5YR 5/4
ZD13	34.8	9.61	22.87	67.52	2.23	2.27	0.81	-0.11	1.29	54.03	11.17	7.9	7.23	5.99 m	6.71	0.36	5YR 4/3

Sample	% Sand	% Coarse	% Med	% Fine	Mean	Median	Sorting	Skew	Kurtosis	% Silt	% Clay	pH H2O	pH CaCl	Conduct	Organics	Organic C	Munsell C
ZD14	80.1	31.71	56.72	11.57	1.49	1.45	0.71	0.14	1.06	10.99	8.91	8.33	7.65	3.49 m	3.61	0.07	2.5YR 5/4
ZD15	41.4	26.87	25.01	48.12	1.81	1.87	1.05	-0.6	0.85	43.39	15.21	9.32	8.32	931	5.23	0.18	10YR 4/4
ZD16	60	25.94	34.49	39.57	1.89	2.02	0.98	-0.14	0.91	30.45	9.55	9.43	8.15	522	3.61	0.04	10YR 5/6
ZD17	57	23.15	9.31	67.54	1.81	1.87	1.01	-0.4	0.85	41.41	1.59	8.38	8.06	264	4.02	0.05	10YR 4/6
ZD18	51.2	22.53	37.98	39.49	1.67	1.73	0.97	-0.3	1.01	46.31	2.49	8.52	7.77	261	4.53	0.1	2.5YR 4/4
ZD19	43.4	18.56	23.11	58.33	2.13	2.28	1.04	-0.19	0.86	54.57	2.03	8.31	7.93	309	5.09	0.05	10YR 5/6
SPEK 1	47.8	11.58	21.4	67.02	2.26	2.39	0.93	-0.25	1.11	50.18	2.02	7.47	7.15	894	4.98	0.61	10YR 4/4
SPEK 2	83.8	64.61	25.33	10.06	0.81	0.73	0.79	0.24	1.21	14.43	1.67	8.54	7.36	514	2.74	0.08	10YR 4/6
SPEK 3	30	2.19	4.73	93.08	3.17	3.19	0.58	-0.21	1.38	67.97	2.03	8.96	7.77	367	2.76	0.1	10YR 5/6
SPEK 4	81.1	68.82	24.31	6.87	0.7	0.62	0.73	0.21	1.09	17.09	1.81	8.93	7.76	676	2.71	0.06	10YR 5/6
SPEK 5	39.9	34.34	36.46	29.2	1.42	1.41	0.93	0.05	0.93	56.07	4.03	8.3	7.36	1084	3.7	0.1	7.5YR 5/8
SPEK 6	67.8	61.2	26.28	12.48	0.82	0.64	0.89	0.28	0.78	30.17	2.03	8.17	7.34	261	3.13	0.16	10YR 5/6
SPEK 7	87.3	10.12	64.84	25.04	1.66	1.64	0.56	0.09	1.14	12	0.7	9.12	7.75	300	2.16	0.03	10YR 4/4
ROOI 1	61.15	37.76	27.42	34.82	1.74	1.97	1.32	-0.2	0.69	24.44	14.41	6.54	6.65	452	4.25	0.5	5YR 3/2
ROOI 2	54.6	14.42	30.43	55.15	2.08	2.26	0.98	-0.25	0.92	31.39	14.01	6.75	6.71	338	4.79	0.49	5YR 3/3
ROOI 3	66.05	67.41	21.26	11.33	2.91	2.92	0.51	-0.11	1.31	10.95	23	6.69	7.05	1414	5.52	0.33	7.5YR 3/2
ROOI 4	52.65	32.2	17.04	50.76	1.62	1.89	1.3	-0.22	0.7	23.26	24.09	6.51	6.8	530	6.04	0.56	5YR 3/2
ROOI 5	42.05	16.82	11.86	71.32	2.2	2.54	1.14	-0.43	1.17	34	23.95	6.84	6.12	120.8	4.84	0.44	7.5YR 4/2
ROOI 6	49.7	40.16	12.19	47.65	1.32	1.27	1.3	0.1	0.65	27.32	22.98	6.84	6.5	244	6.77	0.35	5YR 3/2
ROOI 7	37.7	14.42	14	71.58	2.23	2.55	1.14	-0.39	1.11	33.1	29.2	6.96	7.01	187.3	7.38	0.4	5YR 3/2
ROOI 8	56.25	4.19	8.7	87.11	2.77	2.77	0.67	-0.13	1.38	24.67	19.08	6.84	6.6	3.88 m	3.49	0.11	5YR 3/4
WAR 1	27.9	12.25	15.7	72.05	2.46	2.69	1.06	-0.36	1.17	67.69	4.41	7.59	6.93	434	7.04	0.85	10YR 3/2
WAR 2	20.4	28.96	6.01	65.03	2.03	2.55	1.33	-0.48	0.72	75.18	4.42	7.78	7.2	735	4.46	0.77	10YR 4/6
WAR 3	65.3	88.26	8.37	3.37	0.12	0.04	0.75	0.47	2.48	30.29	4.41	7.97	7.25	485	2.56	0.34	10YR 3/4
WAR 4	5.2	8.98	8.55	82.47	2.8	3.02	0.88	-0.47	1.64	60.9	33.9	8.23	7.64	324	4.82	0.42	2.5YR 3/2
WAR 5	48.8	70.98	17.72	11.3	0.77	0.52	0.86	0.47	1.16	39.59	11.61	8.15	7.74	138.7	3.27	0.11	2.5YR 4/2
WAR 6	38.4	39.18	26	34.82	1.57	1.73	1.18	-0.11	0.81	39.18	22.42	8.11	7.59	176.7	3.61	0.13	10YR 5/2
WAR 7	58.4	81.84	11.6	6.56	0.39	0.21	0.77	0.45	1.39	27.74	13.86	8.25	7.72	148.4	2.37	0.12	2.5YR 3/2
WAR 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	5YR 3/1
WAR 9	59.9	84.89	11.48	3.63	0.6	0.45	0.85	0.43	1.61	28.4	11.7	8.14	7.54	113.5	3.03	0.09	10YR 4/4
WAR 10	54.4	37.2	34.52	28.28	1.34	1.22	0.99	0.22	0.89	28.38	17.22	7.9	7.42	114.2	3.14	0.07	7.5YR 4/6

Sample	[illegible]	[illegible]	[illegible]	[illegible]	Mean	Median	Sorting	Skew	Kurtosis	% Silt	% Clay	pH H2O	pH CaCl	Conductivity	Organic	[illegible]	[illegible]
ROCH 1	64.15	35.73	30.73	33.54	1.4	1.3	0.99	0.17	0.87	29.69	6.16	7.64	7	315	3.92	0.34	10YR 5/6
ROCH 2	85.9	38.19	43.38	18.43	1.18	1.11	0.79	0.19	1	9.34	4.76	8.42	7.58	181.3	3.96	0.32	10YR 5/4
ROCH 3	33.45	4.48	4.53	90.99	3	3.09	0.73	-0.38	1.75	59.02	7.53	8.15	7.48	185.4	3.78	0.3	10YR 6/4
ROCH 4	16.9	44.44	16.83	38.73	1.7	1.76	1.35	-0.5	0.72	55.98	27.12	8.5	7.44	354	5.04	0.38	10YR 3/2
ROCH 5	77.8	80.34	14.57	5.09	0.68	0.56	0.73	0.33	1.18	9.91	12.29	8.16	7.41	166.2	4.47	0.13	2.5YR 4/2
ROCH 6	43.6	30.14	28.36	41.5	1.54	1.56	1.1	0.03	0.81	41.19	15.21	8.42	7.4	138.6	4.93	0.19	10YR 4/4
ROCH 7	93.95	93.37	3.99	2.64	0.29	0.24	0.54	0.24	1.14	5.05	1	8.45	7.35	184.6	4.28	0.06	2.5YR 4/4
KOM 1	34.5	21.13	17.26	61.61	1.99	2.32	1.12	-0.37	0.94	52.66	12.84	6.86	6.96	847	6.28	1.59	10YR 3/1
KOM 2	51.1	25.67	30.56	43.77	1.72	1.89	1.04	-0.19	0.96	36.17	12.73	7.34	6.96	278	5.18	0.6	10YR 3/2
KOM 3	84.8	35.86	46.3	17.84	0.95	0.91	0.93	0.15	0.96	9.25	5.95	7.45	6.96	112.1	3.17	0.12	10YR 4/3
KOM 4	79.2	41.72	35.31	22.97	1.05	0.96	0.99	0.15	0.76	14.83	5.97	7.56	7	89.3	3.52	0.11	10YR 4/3
KOM 5	82.3	42.97	39.15	17.88	1.15	1.21	0.93	-0.03	0.92	11.74	5.96	7.52	7.14	128.3	2.62	0.11	10YR 4/3
KOM 6	60.8	15.17	28.58	56.25	2.01	2.12	0.93	-0.17	1.13	29.69	9.51	7.57	6.89	75.3	3.18	0.09	10YR 5/6
KOM 7	67.9	29.63	21.64	48.73	1.64	1.96	1.12	-0.32	0.78	19.24	12.86	7.9	7	70.1	2.79	0.11	7.5YR 4/4
KOM 8	72.5	71.66	19.08	9.26	0.58	0.32	0.89	0.48	1.03	17.82	9.68	6.85	6.91	715	3.03	0.14	10YR 4/6
KOM 9	39.7	20.62	12.99	66.39	2.01	2.37	1.18	-0.39	1.12	36.96	23.34	7.43	7	129.6	4.8	0.2	10YR 5/4
VAL 1	20.4	35.69	17.01	47.3	1.59	1.71	1.32	-0.08	0.7	72.86	6.74	7.2	6.83	468	9.61	0.87	10YR 2/2
VAL 2	22.1	38.37	15.96	45.67	1.61	1.66	1.26	-0.02	0.71	66.51	11.39	7.11	6.72	269	9.62	0.97	10YR 2/2
VAL 3	25.8	40.12	19.83	40.05	1.48	1.46	1.24	0.06	0.73	63.12	11.08	7.43	6.97	248	9.57	0.84	10YR 2/2
VAL 4	34.6	51.16	18.89	29.95	1.13	0.94	1.21	0.26	0.76	54.46	10.94	7.1	6.78	218	7.83	0.81	10YR 2/2
VAL 5	48.8	28.63	20.73	50.64	1.8	1.97	1.21	-0.16	0.82	33.24	17.96	7.35	7.02	109.9	4.92	0.32	10YR 3/4
VAL 6	46.7	21.48	17.44	61.08	1.96	2.27	1.17	-0.33	0.93	34.69	18.61	7.1	7.04	240	4.88	0.31	10YR 5/3
VAL 7	81.7	44.84	43.7	11.46	1.17	1.19	0.88	0.02	0.89	18.3	0	7.11	7.31	143.5	3.09	0.07	10YR 4/6
VAL 8	84.3	61.13	24.5	14.37	0.85	0.74	0.89	0.23	1	12.13	3.57	7.63	7.2	92.9	2.73	0.04	10YR 4/6
VAL 9	82.3	62.27	26.84	10.89	0.44	0.3	0.73	0.37	1.29	14.06	3.64	7.59	6.97	89.3	2.77	0.05	10YR 4/4
VAL 10	71.6	37.26	31.17	31.57	1.41	1.41	0.99	0.02	0.83	19.42	8.98	7.38	7.15	82.7	3.49	0.07	10YR 4/6
VAL 11	78.3	61.67	31.7	6.63	0.77	0.69	0.78	0.18	0.89	14.81	6.89	7.5	7.22	62.9	1.67	0.06	10YR 4/4
VAL 12	86	47.02	44.46	8.52	0.77	0.69	0.73	0.21	0.95	14	0	7.86	6.95	46.1	2.75	0.05	10YR 4/4
VAL 13	84.2	73.64	15.69	10.67	0.57	0.39	0.84	0.38	1.16	12.9	2.9	8.22	7	63.4	2.62	0.08	10YR 5/4

Sample	% Sand	% Coarse	% Med	% Fine	Mean	Median	Sorting	Skew	Kurtosis	% Silt	% Clay	pH H2O	pH CaCl	Conduct	Organic	Organic C	Munsell C
GH1	23.8	0.71	8.02	91.27	3.05	3.13	0.62	-0.28	1.12	69.57	6.63	7.04	7.02	503	6.78	1.74	7.5YR 3/2
GH2	53.8	2.21	23.45	74.34	2.43	2.41	0.69	0.04	1.12	45.19	1.01	7.93	7.17	543	5.2	0.99	10YR 4/2
GH3	29	1.51	7.38	91.11	2.96	3	0.59	-0.18	1.21	69.58	1.42	7.81	7.19	672	5.58	0.9	10YR 4/2
GH4	22.7	17.43	22.6	59.97	2.12	2.33	1.14	-0.26	0.95	75.8	1.5	7.88	7.38	800	6.28	0.73	7.5YR 4/2
GH5	63.5	61.11	23.62	15.27	0.85	0.61	1.02	0.38	0.9	27.79	8.71	7.72	7.18	385	4.04	0.33	5YR 4/1
GH6	62.2	15.9	25.85	58.25	2.07	2.23	0.99	-0.23	1.04	27.94	9.86	7.72	7.1	302	1.33	0.31	10YR 3/4
GH7	86.8	52.67	35.16	12.17	0.94	0.89	0.95	0.15	0.95	11.53	1.67	7.56	7.29	118	2.15	0.08	10YR 4/3
GH8	85.8	72.49	25.46	2.05	0.74	0.64	0.71	0.26	1.11	12.78	1.42	7.59	7.02	119.2	2.9	0.06	10YR 4/3
GH9	28.2	4.76	8.56	86.68	2.8	2.93	0.85	-0.37	1.43	53.08	18.72	7.15	6.96	239	4.74	0.42	10YR 5/2
GH10	6.2	8.32	9.11	82.57	2.82	3.02	0.94	-0.44	1.3	77.69	16.11	7.65	7.21	4.62 m	5.46	0.66	7.5YR 4/2
GH11	56.3	1.25	5.99	92.76	3.05	3.06	0.54	-0.19	1.54	34.71	8.99	7.25	7.35	230	2.46	0.17	10YR 5/2
GH12	38.4	2.41	5.8	91.79	3.01	3.04	0.58	-0.22	1.4	49.36	12.24	7.51	7.2	154.2	3.56	0.22	10YR 5/2
GH13	7.1	3.14	4.28	92.58	3.03	3.05	0.59	-0.17	1.14	72.52	20.38	7.34	7.13	165.8	6.12	0.91	10YR 5/2
GH14	80.8	79.65	11.42	8.93	0.61	0.48	0.89	0.46	2.15	10.67	8.53	7.45	7.1	125.9	3.73	0.08	10YR 4/4
GH15	8.7	3.26	15.16	81.58	2.75	2.87	0.79	-0.29	1.1	45.18	46.12	7.86	7.32	4.17 m	5.23	0.73	10YR 2/2
GH16	91.1	84.73	9.4	5.87	0.34	0.21	0.83	0.44	1.74	5.11	3.79	8.41	7.89	193.7	3.35	0.04	10YR 4/4
LUC A1	42	25.44	13.61	60.95	1.98	2.28	1.27	-0.28	0.67	37.77	20.23	6.64	6.38	1083	4.8	0.25	10YR 6/6
LUC A2	60.9	43.35	38.95	17.7	1.11	0.94	1.03	0.25	0.83	16.16	22.94	6.93	6.9	406	6.47	0.07	10YR 5/6
LUC A3	95.1	87.6	11.04	1.36	0.62	0.53	0.61	0.26	1.07	4.9	0	7.78	7.59	145.4	4.38	0.04	10YR 5/2
LUC B1	21.6	23.22	19.1	57.68	2.11	2.45	1.16	-0.38	0.81	72.34	6.06	7.2	7.02	696	9.59	2.1	5YR 3/1
LUC B2	41.1	35.98	23.21	40.81	1.56	1.59	1.18	0.01	0.75	43.65	15.25	6.75	6.88	492	6.5	1.08	5YR 3/2
LUC B3	64.7	65.43	19.24	15.33	0.97	0.62	1.11	0.47	0.79	24.41	10.89	6.64	6.75	1832	4.63	0.46	10YR 4/2
LUC B4	32.9	13.3	12.86	73.84	2.27	2.56	1.11	-0.36	1.1	45.7	21.4	7.1	6.8	229	6.67	0.9	7.5YR 4/3
LUC B5	85.6	89.19	2.38	8.43	0.62	0.53	0.72	0.32	1.31	8.12	6.28	6.98	7	244	4.41	0.08	10YR 5/4
LUC B6	68.5	69.93	22.23	7.84	0.78	0.56	0.86	0.39	1.09	24.11	7.39	7.15	7	264	4.02	0.19	10YR 5/2
LUC B7	76.4	89.22	7.85	2.93	0.3	0.24	0.54	0.29	1.34	15.67	7.93	7.55	7.41	157.3	4.55	0.12	10YR 5/2
LUC B8	22.2	7.2	12.78	80.02	2.63	2.79	0.9	-0.35	1.31	49.41	28.39	7.41	7.01	340	5.54	0.49	10YR 4/1
LUC B9	17.5	5.91	15.85	78.24	2.77	2.88	0.8	-0.3	1.23	57.04	25.46	7.74	7.03	240	6.42	0.48	10YR 3/1

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ZEEK 1	80.1	46.55	29.61	23.84	1.19	1.13	0.99	0.13	0.8	16.57	3.33	7.12	6.88	580	4.45	0.32	7.5YR 5/4
ZEEK 2	66.4	57.38	20.31	22.31	1.07	0.77	1.12	0.43	0.94	30.48	3.12	7.92	7.09	362	5.51	0.55	10YR 4/6
ZEEK 3	7.5	5.24	5.6	89.16	3.08	3.16	0.76	-0.35	1.56	82.35	10.15	8.22	7.41	451	8.05	0.96	10YR 4/1
ZEEK 4	6.2	19.36	20.09	60.55	2.15	2.4	1.15	-0.28	0.86	59.49	34.31	8.08	7.23	374	8.51	0.62	10YR 3/1
ZEEK 5	13.6	25.74	15.73	58.53	2.18	2.47	1.3	-0.29	0.69	59.25	27.15	7.85	7.35	502	6.89	0.43	10YR 3/1
ZEEK 6	55.4	57.78	25.23	16.99	1.01	0.82	0.99	0.38	1.15	27.78	16.82	7.5	7.45	871	4.46	0.2	10YR 5/2
ZEEK 7	19.9	33.3	22.24	44.46	1.82	1.66	1.31	0.15	0.67	56.02	24.08	7.56	7.45	795	5.62	0.32	10YR 5/2
ZEEK 8	56.6	58.94	21.36	19.7	1.16	0.77	1.19	0.48	1.12	26.12	17.28	7.54	7.55	1213	4.55	0.13	10YR 6/2
ZEEK 9	25.8	17.06	12.11	70.83	2.45	2.84	1.21	-0.43	0.84	54.65	19.55	7.51	7.31	1270	5.61	0.06	10YR 6/3
ZEEK 10	51.1	54.31	23.99	21.7	1.1	0.88	1.08	0.37	0.94	44.96	3.94	7.34	6.85	117	3.98	0.07	10YR 6/3
ZEEK 11	55.1	27.23	22.88	49.89	1.94	1.99	1.22	-0.05	0.73	34.01	10.89	7.31	6.96	867	3.71	0.07	10YR 6/4
ZEEK 12	86.1	70.2	17.51	12.29	0.74	0.49	0.96	0.48	1.28	9.96	3.94	7.46	7.07	371	3.72	0.55	2.5YR 6/2
ZEEK 13	85.7	82.41	14.57	3.02	0.51	0.45	0.53	0.24	1.12	12.53	1.77	7.82	7.14	181.6	2.78	0.03	2.5YR 6/4
ZEEK 14	80.1	66.79	23.53	9.68	0.77	0.61	0.89	0.37	1.17	19.9	0	7.26	7.07	144.8	3.98	0.01	10YR 3/3
ZEEK 15	41.5	26.49	13.28	60.23	2.14	2.49	1.31	-0.33	0.68	56.97	1.53	7.21	7.14	708	3.23	0.04	10YR 5/3
ZEEK 16	88.9	63.41	23.83	12.76	0.88	0.71	0.88	0.38	1.2	9.07	2.03	7.99	7.36	148.2	3.63	0.01	10YR 3/3
ZEEK 17	40.8	33.54	20.07	46.39	1.8	1.81	1.23	0	0.74	44.01	15.19	8.06	7.04	184	2.81	0.08	10YR 5/4
ZEEK 18	66	59.83	23.72	16.45	0.97	0.77	1	0.37	1.16	25.5	8.5	7.73	7.4	243	3.32	0.01	10YR 6/3
MOUNV 1	74.5	70.43	19.99	9.58	0.75	0.59	0.91	0.3	1.02	20.24	5.26	7.29	7	793	5.5	0.5	10YR 3/6
MOUNV 2	93.3	89.58	6.27	4.15	0.37	0.3	0.72	0.24	1.25	5.7	1	7.92	7.15	112.3	3.73	0.08	10YR 4/3
MOUNV 3	45.2	19.29	33.1	47.61	1.87	1.94	1.1	-0.8	1	44.81	9.99	7.03	6.83	526	5.7	1	10YR 4/6
MOUNV 4	21.8	5.92	6.83	87.25	2.96	3.05	0.69	-0.34	1.52	70.95	7.25	7.25	7.07	376	6.56	0.99	5YR 3/2
MOUNV 5	74.8	87.27	4.83	7.9	0.46	0.19	1.16	0.52	1.65	16.12	9.08	7.15	7.41	164.8	2.7	0.2	10YR 3/2
MOUNV 6	18.4	2.18	10.64	87.18	2.96	3.03	0.65	-0.27	1.28	73.53	8.07	7.34	6.84	202	8.22	1.51	5YR 3/2
MOUNV 7	32.7	2.12	6.41	91.47	3.01	3.09	0.58	-0.28	1.23	56.37	10.93	7.22	6.78	228	4.74	0.46	7.5YR 3/2
PIEN 1	38.7	29.88	23.78	46.34	1.98	2.14	1.19	-0.17	0.75	43.67	17.63	8.1	4.28	1160	10.72	0.48	7.5YR 4/6
STOLS GM	69.1	69.48	22.32	8.2	0.81	0.56	1.01	0.4	0.92	30.19	0.71	8.6	7.67	376	3.67	0.19	7.5YR 4/6
RANGE 1	25.8	16.63	14.65	68.72	2.22	2.58	1.19	-0.4	0.81	68.47	5.73	6.39	6.57	264	6.21	0.63	10YR 3/1

Appendix F

Chronological list of absolute ages (ka) utilised in the study.

Age	Type of date	Lab number	Study Site	Reference
.43 ± .045	^{14}C	Pta 7024	Klipplaat Pan	This study
.56 ± .04	OSL	Shfd 97036	Klipplaat Pan	This study
.68 ± .08	OSL	Shfd 97037	Klipplaat Pan	This study
.76 ± .05	^{14}C	Pta 4351	Bokkraal Vlei	Sugden (1989)
1.34 ± .1	OSL	Shfd 97038	Klipplaat Pan	This study
1.68 ± .06	^{14}C	Pta 6858	Rooiskuur	This study
2.51 ± .05	^{14}C	Pta 5186	Klein Seekoei River	Sugden (1989)
2.62 ± .05	^{14}C	Pta6994	Kalkoenkrans Vlei	This study
2.93 ± .045	^{14}C	Pta 7088	Spekboom River	This study
3.59 ± .07	^{14}C	Pta 4342	Compassberg	Sugden (1989)
4.87 ± .06	^{14}C	Pta 5188	Klein Seekoei River	Sugden (1989)
5.72 ± .07	^{14}C	Pta 6423	Doornhoek Dam	This study
5.79 ± .8	^{14}C	Pta 5493	Good Hope	This study
8.58 ± .8	OSL	Shfd 97042	Doornhoek Dam	This study
12.29 ± .7	OSL	Shfd 97034	Buffelsfontein Pan	This study
12.6 ± 1.5	TL	W2205	Buffelsfontein Pan	This study
15.03 ± 1.1	OSL	Shfd 97033	Buffelsfontein Pan	This study
18.22 ± 1.5	OSL	Shfd 97035	Buffelsfontein Pan	This study
20.5 ± 1.0	TL	W1407	Klipkraal Sands	Marker & Holmes (1993)

Provisional luminescence dates from Klipkraal Sands (see Table 7.6) not included.

Appendix G

Localities, sites and abbreviations.

The following abbreviations were used as codes for the various sites which formed the basis of this investigation. The codes were originally used in the field, and subsequently to label sediment samples for laboratory procedures. They were also used at the data processing stage and during statistical analyses.

LOCALITY AND SITE	ABBREVIATION
STORMBERG LOCALITY	
Klipkraal Sands	KLIP
Buffelsfontein Pan	BUFF
Klipplaat Pan	KP
Buffelsfontein Stream	BD
Kalkoenkrans Vlei	KAL
Holspruit Gulley	HOL
TANDJIESBERG LOCALITY	
Wilgerboom River Colluvium	ZC
Bergkloof Site	ZB
Doornhoek Dam	ZD
Spekboom (Pauls) River	SPEK
WAPADSBERG LOCALITY	
Wapadsberg Summit: Rooiskuur	ROOI
Wapadsberg Summit: Ruigterfontein	WAR
Rochdale Farm	ROCH
SNEEUBERG LOCALITY	
Compassberg	KOM
The Valley	VAL
Good Hope	GH
Lucernvale	LUC A
	LUC B
Klein Seekoei River	ZEEK
NUWEVELDBERG LOCALITY	
Mountain View	MOUNV
Stols River	STOLS GM
Pienaars Poort	PIEN
OTHER	
The Ranges	RANGE

Appendix H

SOM data matrices.

Sample number	Sample name	X Co-ordinate	Y Co-ordinate	Error	Node number
43	GH 3	0	0	0.470337	1
51	GH 11	0	0	0.894923	1
52	GH 12	0	0	0.497432	1
86	ROOI 8	0	0	1.63543	1
89	ROCH 3	0	0	0.564335	1
100	MOUNV 7	0	0	0.818326	1
120	KAL 4	0	0	1.41262	1
121	KAL 5	0	0	0.899064	1
122	KAL 6	0	0	1.98272	1
123	KAL 7	0	0	1.1969	1
124	KAL 8	0	0	1.41212	1
125	KAL 9	0	0	1.98102	1
126	KAL 10	0	0	1.96037	1
127	KAL 11	0	0	0.721219	1
128	KAL 12	0	0	3.17791	1
149	ZD 8	0	0	0.908336	1
151	ZD 10	0	0	0.947858	1
152	ZD 11	0	0	1.24935	1
169	SPEK 3	0	0	0.949669	1
3	ZEEK 3	0	1	0.941572	2
41	GH 1	0	1	0.840508	2
49	GH 9	0	1	0.71693	2
53	GH 13	0	1	0.878294	2
67	LUC B8	0	1	0.368818	2
68	LUC B9	0	1	0.190115	2
72	WAR 4	0	1	0.947208	2
97	MOUNV 4	0	1	0.758264	2
108	HOL 5	0	1	0.350575	2
99	MOUNV 6	0	2	0.803238	3
104	HOL 1	0	2	4.17751	3
112	BD 1	0	2	4.2456	3
113	BD 2	0	2	2.9557	3
114	BD 3	0	2	1.06168	3
115	BD 4	0	2	0.775933	3
116	BD 5	0	2	1.27584	3
117	KAL 1	0	2	1.83894	3
118	KAL 2	0	2	2.40731	3
119	KAL 3	0	2	1.87389	3
42	GH 2	1	0	0.431293	4
50	GH 10	1	0	1.13473	4
55	GH15	1	0	0.780321	4
140	ZB 12	1	0	0.803407	4

Sample number	Sample name	X Co-ordinate	Y Co-ordinate	Error	Node number
143	ZD 2	1	0	0.706138	4
144	ZD 3	1	0	1.26605	4
148	ZD 7	1	0	0.695498	4
150	ZD 9	1	0	1.19807	4
153	ZD 12	1	0	1.35501	4
154	ZD 13	1	0	1.31172	4
5	ZEEK 5	1	1	0.935384	5
7	ZEEK 7	1	1	0.791003	5
9	ZEEK 9	1	1	0.822376	5
27	KOM 9	1	1	0.343322	5
32	VAL 5	1	1	0.395895	5
33	VAL 6	1	1	0.215404	5
44	GH 4	1	1	0.808411	5
70	WAR 2	1	1	0.782693	5
80	ROOI 2	1	1	0.660591	5
96	MOUNV 3	1	1	0.693549	5
110	HOL 7	1	1	0.763466	5
111	HOL 8	1	1	0.586014	5
167	SPEK 1	1	1	0.544891	5
4	ZEEK 4	1	2	0.84974	6
19	KOM 1	1	2	0.404355	6
28	VAL 1	1	2	1.15716	6
29	VAL 2	1	2	1.08922	6
30	VAL 3	1	2	1.13927	6
60	LUC B1	1	2	1.1478	6
63	LUC B4	1	2	0.25318	6
69	WAR 1	1	2	0.573998	6
85	ROOI 7	1	2	0.306071	6
106	HOL 3	1	2	0.757054	6
11	ZEEK 11	2	0	0.758858	7
15	ZEEK 15	2	0	1.02479	7
17	ZEEK 17	2	0	0.313241	7
24	KOM 6	2	0	0.69231	7
25	KOM 7	2	0	0.413529	7
46	GH 6	2	0	0.687584	7
74	WAR 6	2	0	0.482099	7
90	ROCH 4	2	0	1.08579	7
92	ROCH 6	2	0	0.580787	7
105	HOL 2	2	0	0.914522	7
132	ZB 4	2	0	0.979297	7
133	ZB 5	2	0	1.39473	7
145	ZD 4	2	0	1.09618	7
156	ZD 15	2	0	1.48055	7
158	ZD 17	2	0	0.692182	7
159	ZD 18	2	0	0.89367	7
160	ZD 19	2	0	0.69942	7
171	SPEK 5	2	0	0.551362	7
1	ZEEK 1	2	1	0.695221	8

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	ZEEK 10	2	1	0.629374	8
20	KOM 2	2	1	0.311963	8
58	LUC A2	2	1	0.713703	8
87	ROCH 1	2	1	0.358694	8
107	HOL 4	2	1	0.61464	8
129	ZB 1	2	1	0.429786	8
142	ZD 1	2	1	0.749254	8
31	VAL 4	2	2	1.03569	9
57	LIC A1	2	2	1.04247	9
61	LUC B2	2	2	0.59507	9
76	WAR 8	2	2	10.0035	9
79	ROOI 1	2	2	0.931212	9
82	ROOI 4	2	2	0.468324	9
83	ROOI 5	2	2	0.983736	9
84	ROOI 6	2	2	0.646631	9
101	PIEN 1	2	2	1.18994	9
103	RANGE 1	2	2	1.0553	9
161	ZC 1	2	2	0.63666	9
162	ZC 2	2	2	1.50717	9
166	ZC 6	2	2	0.301817	9
21	KOM 3	3	0	0.733528	10
22	KOM 4	3	0	0.643374	10
23	KOM 5	3	0	0.589334	10
34	VAL 7	3	0	0.755026	10
37	VAL 10	3	0	0.499909	10
78	WAR 10	3	0	0.0583342	10
131	ZB 3	3	0	0.68495	10
146	ZD 5	3	0	1.50837	10
147	ZD 6	3	0	1.36928	10
155	ZD 14	3	0	1.65346	10
157	ZD 16	3	0	1.54513	10
173	SPEK 7	3	0	1.77513	10
2	ZEEK 2	3	1	0.780438	11
6	ZEEK 6	3	1	0.352551	11
8	ZEEK 8	3	1	0.463748	11
14	ZEEK 14	3	1	0.505463	11
18	ZEEK 18	3	1	0.0904537	11
35	VAL 8	3	1	0.393527	11
45	GH 5	3	1	0.561623	11
135	ZB 7	3	1	0.541161	11
136	ZB 8	3	1	0.378397	11
26	KOM 8	3	2	0.626106	12
62	LUC B3	3	2	0.870998	12
65	LUC B6	3	2	0.384972	12
81	ROOI 3	3	2	1.25445	12
94	MOUNV 1	3	2	0.387526	12
163	ZC 3	3	2	1.68257	12
164	ZC 4	3	2	0.342199	12

38	VAL 11	4	0	0.602004	13
39	VAL 12	4	0	0.613197	13
47	GH 7	4	0	0.523873	13
88	ROCH 2	4	0	0.495528	13
102	STOLS GM	4	0	0.629189	13
109	HOL 6	4	0	0.518918	13
134	ZB 6	4	0	0.325156	13
137	ZB 9	4	0	0.402182	13
138	ZB 10	4	0	0.681755	13
139	ZB 11	4	0	0.378972	13
170	SPEK 4	4	0	0.921686	13
172	SPEK 6	4	0	0.252119	13
16	ZEEK 16	4	1	0.300983	14
36	VAL 9	4	1	0.508298	14
40	VAL 13	4	1	0.281425	14
48	GH 8	4	1	0.533481	14
73	WAR 5	4	1	0.47149	14
168	SPEK 2	4	1	0.608025	14
12	ZEEK 12	4	2	0.303531	15
13	ZEEK 13	4	2	0.584889	15
54	GH 14	4	2	1.33526	15
56	GH 16	4	2	1.38829	15
59	LUC A3	4	2	0.492594	15
64	LUC B5	4	2	0.993156	15
66	LUC B7	4	2	0.896185	15
71	WAR 3	4	2	1.98611	15
75	WAR 7	4	2	0.738019	15
77	WAR 9	4	2	0.836053	15
91	ROCH 5	4	2	0.442472	15
93	ROCH 7	4	2	0.88372	15
95	MOUNV 2	4	2	0.604315	15
98	MOUNV 5	4	2	0.687464	15
130	ZB 2	4	2	0.443883	15
141	ZB 13	4	2	1.13043	15
165	ZC 5	4	2	1.34827	15

Appendix I

Nearest Neighbourgh Indices (NNIs) for valley fill strata.

STRATUM: ZEEK1	SITE AND STRATUM DETAILS
1.23 .40 .89 -.68 -.60 -.61 .32 .51 -.77 -1.03 -.88 -.70 -.40 -.07 -.22 -.14	Standardised values on 16 variables
4.45 6.20 5.36 4.91 2.55 1.78 10.40 9.79 8.28 1.52 2.05 2.32 3.69	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.52 1.78 2.05 2.32 2.55 3.69 4.45 4.91 5.36 6.20 8.28 9.79 10.40	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK2	SITE AND STRATUM DETAILS
.71 .79 .11 -.73 -.73 -.97 .82 1.47 -.42 -.37 -.90 .22 -.09 -.26 .09 .18	Standardised values on 16 variables
3.99 6.27 5.23 4.88 3.51 1.57 10.13 9.42 8.06 1.78 1.46 2.82 4.05	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.46 1.57 1.78 2.82 3.51 3.99 4.05 4.88 5.23 6.27 8.06 9.42 10.13	Euclidian `distances' sorted from smallest to largest
ZD1 MOUNV1 ZB1 ZC1 ROOI1 VAL1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK3	SITE AND STRATUM DETAILS
-1.55 -1.10 -1.12 1.37 1.49 1.38 -.56 -1.03 1.14 2.08 -.24 .57 .36 -.19 .84 .74	Standardised values on 16 variables
4.64 2.44 3.91 2.56 6.27 7.13 9.79 7.73 3.66 5.90 5.70 5.94 3.58	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.44 2.56 3.58 3.66 3.91 4.64 5.70 5.90 5.94 6.27 7.13 7.73 9.79	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 KAL1 LUCB1 VAL1 ZD1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK4	SITE AND STRATUM DETAILS
-1.60 -.59 .09 .47 .46 .63 .94 -.81 -.62 1.00 2.01 .41 .11 -.25 .98 .27	Standardised values on 16 variables
3.37 4.48 3.64 3.28 4.32 5.96 9.41 7.24 5.83 4.66 4.42 4.66 3.85	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.28 3.37 3.64 3.85 4.32 4.42 4.48 4.66 4.66 5.83 5.96 7.24 9.41	Euclidian `distances' sorted from smallest to largest
WAR1 VAL1 LUCB1 SPEK1 ROOI1 ZD1 GH1 ZB1 ZC1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK5	SITE AND STRATUM DETAILS
-1.32 -.36 -.27 .41 .49 .70 1.52 -.84 -1.05 .99 1.34 .14 .28 -.14 .50 .01	Standardised values on 16 variables
2.82 4.48 3.40 2.95 3.69 5.61 9.59 7.96 6.26 4.23 3.98 4.05 3.45	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.82 2.95 3.40 3.45 3.69 3.98 4.05 4.23 4.48 5.61 6.26 7.96 9.59	Euclidian `distances' sorted from smallest to largest
VAL1 WAR1 LUCB1 SPEK1 ROOI1 ZD1 ZC1 ZB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK6	SITE AND STRATUM DETAILS
.28 .80 .53 -.89 -.80 -.92 .32 1.31 .11 -.50 .38 -.26 .42 .18 -.21 -.30	Standardised values on 16 variables
4.43 6.36 5.59 5.10 3.49 1.85 10.57 9.51 8.14 2.14 2.27 2.82 4.17	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.85 2.14 2.27 2.82 3.49 4.17 4.43 5.10 5.59 6.36 8.14 9.51 10.57	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ZEEK7	**SITE AND STRATUM DETAILS**
-.08 -.08 .27 -.03 .10 -.09 1.55 .57 -1.10 .83 1.06 -.19 .42 .11 .13 -.14	Standardised values on 16 variables
2.66 5.19 3.96 3.67 3.20 4.46 9.90 8.50 7.16 3.12 2.92 3.01 3.57	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.66 2.92 3.01 3.12 3.20 3.57 3.67 3.96 4.46 5.19 7.16 8.50 9.90	Euclidian `distances' sorted from smallest to largest
VAL1 ZD1 ZC1 ZB1 ROOI1 SPEK1 WAR1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK8	**SITE AND STRATUM DETAILS**
.33 .85 .20 -.81 -.63 -.97 1.09 1.63 .03 -.58 .42 -.21 .56 .47 -.19 -.40	Standardised values on 16 variables
4.47 6.68 5.77 5.31 3.58 2.25 10.68 9.70 8.47 2.56 2.48 2.95 4.46	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.25 2.48 2.56 2.95 3.58 4.46 4.47 5.31 5.77 6.68 8.47 9.70 10.68	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK9	**SITE AND STRATUM DETAILS**
-.85 -.67 -.58 .80 .79 1.07 1.17 -1.29 -.67 .77 .64 -.25 .22 .52 .12 -.50	Standardised values on 16 variables
3.29 3.95 3.61 2.41 3.61 5.67 10.15 8.62 6.16 4.29 4.21 3.91 2.66	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.41 2.66 3.29 3.61 3.61 3.91 3.95 4.21 4.29 5.67 6.16 8.62 10.15	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 VAL1 LUCB1 ROOI1 ZC1 GH1 ZD1 ZB1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK10	**SITE AND STRATUM DETAILS**
.12 .68 .42 -.74 -.70 -.86 .67 1.28 -.42 .31 -.82 -.44 -.44 -.48 -.36 -.48	Standardised values on 16 variables
3.60 6.03 5.11 4.54 3.21 2.12 10.70 9.87 8.10 1.46 1.82 2.41 3.77	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.46 1.82 2.12 2.41 3.21 3.60 3.77 4.54 5.11 6.03 8.10 9.87 10.70	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ZC1 ROOI1 VAL1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK11	**SITE AND STRATUM DETAILS**
.27 -.31 .33 .14 .23 .23 1.21 -.07 -.95 -.21 -.17 -.48 -.28 .17 -.44 -.48	Standardised values on 16 variables
3.23 4.95 4.19 3.30 1.68 3.59 10.20 9.35 7.30 2.18 2.29 2.11 2.38	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.68 2.11 2.18 2.29 2.38 3.23 3.30 3.59 4.19 4.95 7.30 9.35 10.20	Euclidian `distances' sorted from smallest to largest
ROOI1 ZC1 ZB1 ZD1 SPEK1 VAL1 WAR1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK12	**SITE AND STRATUM DETAILS**
1.46 1.26 -.12 -1.04 -1.10 -1.24 .21 1.63 .44 -1.34 -.82 -.31 -.12 -.26 -.43 .18	Standardised values on 16 variables
5.57 7.19 6.56 6.11 4.32 1.33 10.71 10.42 8.81 3.02 3.08 3.72 5.07	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.33 3.02 3.08 3.72 4.32 5.07 5.57 6.11 6.56 7.19 8.81 10.42 10.71	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK13	**SITE AND STRATUM DETAILS**
1.45 1.70 -.37 -1.33 -1.35 -1.28 -1.45 .86 .03 -1.22 -1.02 .11 -.02 -.42 -.71 -.54	Standardised values on 16 variables
6.33 7.45 7.22 6.58 5.21 2.22 11.65 11.04 9.20 3.73 3.99 4.61 5.48	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.22 3.73 3.99 4.61 5.21 5.48 6.33 6.58 7.22 7.45 9.20 11.04 11.65	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK14	**SITE AND STRATUM DETAILS**
1.23 1.13 .38 -1.12 -1.06 -1.13 -.06 1.28 .16 -.87 -1.19 -.54 -.12 -.45 -.36 -.56	Standardised values on 16 variables
5.24 7.00 6.38 5.77 4.03 1.25 11.24 10.54 8.90 2.43 2.83 3.35 4.68	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.25 2.43 2.83 3.35 4.03 4.68 5.24 5.77 6.38 7.00 8.90 10.54 11.24	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ZEEK15	**SITE AND STRATUM DETAILS**
-.25 -.33 -.48 .46 .45 .72 1.55 -.97 -1.08 .88 -1.05 -.59 -.02 .04 -.58 -.52	Standardised values on 16 variables
2.92 4.41 3.68 2.55 2.98 4.91 10.36 9.67 6.94 3.40 3.42 3.04 2.32	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.32 2.55 2.92 2.98 3.04 3.40 3.42 3.68 4.41 4.91 6.94 9.67 10.36	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 VAL1 ROOI1 ZC1 ZB1 ZD1 LUCB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK16	**SITE AND STRATUM DETAILS**
1.57 1.01 .41 -1.03 -.94 -1.03 -.10 1.31 .23 -1.38 -1.00 .30 .29 -.45 -.46 -.56	Standardised values on 16 variables
5.73 7.25 6.74 6.04 4.38 1.76 11.31 10.56 9.03 2.90 3.00 3.96 4.86	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.76 2.90 3.00 3.96 4.38 4.86 5.73 6.04 6.74 7.25 9.03 10.56 11.31	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK17	**SITE AND STRATUM DETAILS**
-.28 -.08 .09 .03 .07 .05 1.25 .09 -.93 .27 .23 .38 -.17 -.42 -.70 -.47	Standardised values on 16 variables
3.12 5.08 4.27 3.34 2.56 3.84 10.21 9.34 7.20 2.53 2.30 2.90 2.83	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.30 2.53 2.56 2.83 2.90 3.12 3.34 3.84 4.27 5.08 7.20 9.34 10.21	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 ROOI1 SPEK1 ZC1 VAL1 WAR1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZEEK18	**SITE AND STRATUM DETAILS**
.69 .88 .40 -.91 -.84 -.97 .36 1.28 .13 -.61 -.40 .00 .35 -.37 -.55 -.56	Standardised values on 16 variables
4.72 6.61 5.93 5.25 3.66 1.61 10.95 10.11 8.47 2.11 2.23 3.09 4.23	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.61 2.11 2.23 3.09 3.66 4.23 4.72 5.25 5.93 6.61 8.47 10.11 10.95	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM1	**SITE AND STRATUM DETAILS**
-.52 -.53 -.14 .51 .28 .56 .82 -1.09 -.42 .67 .01 -1.00 -.28 .16 .32 1.60	Standardised values on 16 variables
2.57 3.06 1.83 2.03 3.03 4.87 8.05 7.62 4.90 3.50 3.41 2.98 2.24	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.83 2.03 2.24 2.57 2.98 3.03 3.06 3.41 3.50 4.87 4.90 7.62 8.05	Euclidian `distances' sorted from smallest to largest
LUCB1 WAR1 SPEK1 VAL1 ZC1 ROOI1 GH1 ZD1 ZB1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM2	**SITE AND STRATUM DETAILS**
.12 -.36 .97 -.05 -.01 .13 .51 -.52 -.37 -.10 .00 -.44 -.28 -.34 .00 .25	Standardised values on 16 variables
3.13 4.45 3.60 2.92 1.91 3.49 9.46 8.48 6.46 1.91 2.10 2.33 2.04	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.91 1.91 2.04 2.10 2.33 2.92 3.13 3.49 3.60 4.45 6.46 8.48 9.46	Euclidian `distances' sorted from smallest to largest
ROOI1 ZB1 SPEK1 ZD1 ZC1 WAR1 VAL1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM3	**SITE AND STRATUM DETAILS**
1.41 .01 2.29 -.87 -.87 -.83 .09 .57 -.37 -1.37 -.63 -.32 -.28 -.48 -.60 -.41	Standardised values on 16 variables
5.59 7.13 6.38 5.83 3.51 2.90 11.05 10.36 9.02 2.61 3.05 3.66 4.55	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.61 2.90 3.05 3.51 3.66 4.55 5.59 5.83 6.38 7.13 9.02 10.36 11.05	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ZD1 ROOI1 ZC1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM4	**SITE AND STRATUM DETAILS**
1.20 .22 1.37 -.70 -.76 -.78 .32 .57 -.87 -1.11 -.63 -.19 -.22 -.50 -.49 -.43	Standardised values on 16 variables
4.83 6.62 5.80 5.26 2.91 2.26 10.75 10.05 8.66 1.87 2.24 2.97 4.03	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.87 2.24 2.26 2.91 2.97 4.03 4.83 5.26 5.80 6.62 8.66 10.05 10.75	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ROOI1 ZC1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: KOM5	SITE AND STRATUM DETAILS
1.32 .27 1.69 -.86 -.64 -.54 .09 .00 -.47 -1.26 -.63 -.24 -.02 -.47 -.76 -.43	Standardised values on 16 variables
5.22 6.65 5.95 5.31 3.03 2.66 10.84 10.25 8.61 2.28 2.71 3.29 4.01	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.28 2.66 2.71 3.03 3.29 4.01 5.22 5.31 5.95 6.65 8.61 10.25 10.84	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ZD1 ROOI1 ZC1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM6	**SITE AND STRATUM DETAILS**
.49 -.74 .81 .34 .31 .36 .09 -.45 .06 -.41 -.30 -.18 -.38 -.51 -.59 -.45	Standardised values on 16 variables
4.14 4.55 4.56 3.18 2.66 3.89 10.36 9.32 6.73 2.61 2.84 3.11 1.96	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.96 2.61 2.66 2.84 3.11 3.18 3.89 4.14 4.55 4.56 6.73 9.32 10.36	Euclidian `distances' sorted from smallest to largest
SPEK1 ZB1 ROOI1 ZD1 ZC1 WAR1 MOUNV1 VAL1 GH1 LUCB1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM7	**SITE AND STRATUM DETAILS**
.77 -.22 .22 .10 -.10 .20 .82 -.93 -.82 -.90 .01 .20 -.22 -.52 -.71 -.43	Standardised values on 16 variables
4.19 5.36 4.80 3.82 2.18 3.72 10.24 9.59 7.43 2.79 2.77 3.18 2.85	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.18 2.77 2.79 2.85 3.18 3.72 3.82 4.19 4.80 5.36 7.43 9.59 10.24	Euclidian `distances' sorted from smallest to largest
ROOI1 ZD1 ZB1 SPEK1 ZC1 MOUNV1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM8	**SITE AND STRATUM DETAILS**
.94 1.31 .01 -1.13 -1.27 -1.41 -.06 1.63 -.19 -.97 -.29 -1.01 -.35 .04 -.64 -.39	Standardised values on 16 variables
5.36 7.21 6.58 6.16 4.04 1.30 11.16 10.67 9.11 2.82 3.21 3.25 5.13	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.30 2.82 3.21 3.25 4.04 5.13 5.36 6.16 6.58 7.21 9.11 10.67 11.16	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KOM9	**SITE AND STRATUM DETAILS**
-.32 -.55 -.50 .66 .31 .60 1.05 -1.16 .03 -.07 .99 -.34 -.22 -.46 -.11 -.30	Standardised values on 16 variables
3.57 4.27 3.99 2.74 2.87 4.87 9.90 8.71 6.16 3.78 3.73 3.60 2.65	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.65 2.74 2.87 3.57 3.60 3.73 3.78 3.99 4.27 4.87 6.16 8.71 9.90	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ROOI1 VAL1 ZC1 ZD1 ZB1 LUCB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL1	**SITE AND STRATUM DETAILS**
-1.06 .00 -.16 .06 -.16 -.04 1.59 -.16 -1.03 1.63 -.56 -.61 -.47 -.17 1.30 .62	Standardised values on 16 variables
.00 4.44 2.35 2.72 3.58 4.71 9.13 7.73 6.30 3.21 3.07 3.08 3.28	Euclidian `distance' of stratum to each of the 13 modern topsoils
.00 2.35 2.72 3.07 3.08 3.21 3.28 3.58 4.44 4.71 6.30 7.73 9.13	Euclidian `distances' sorted from smallest to largest
VAL1 LUCB1 WAR1 ZD1 ZC1 ZB1 SPEK1 ROOI1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL2	**SITE AND STRATUM DETAILS**
-.99 .10 -.25 .01 -.14 -.09 1.36 .03 -1.00 1.33 -.13 -.71 -.62 -.34 1.31 .75	Standardised values on 16 variables
.69 4.37 2.45 2.85 3.35 4.44 8.93 7.54 6.18 3.07 2.94 2.91 3.33	Euclidian `distance' of stratum to each of the 13 modern topsoils
69 2.45 2.85 2.91 2.94 3.07 3.33 3.35 4.37 4.44 6.18 7.54 8.93	Euclidian `distances' sorted from smallest to largest
VAL1 LUCB1 WAR1 ZC1 ZD1 ZB1 SPEK1 ROOI1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL3	**SITE AND STRATUM DETAILS**
-.85 .16 .07 -.17 -.28 -.29 1.28 .29 -.95 1.17 -.15 -.34 -.27 -.36 1.29 .58	Standardised values on 16 variables
1.04 4.68 2.81 3.06 3.30 4.01 9.11 7.56 6.47 2.60 2.39 2.76 3.29	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.04 2.39 2.60 2.76 2.81 3.06 3.29 3.30 4.01 4.68 6.47 7.56 9.11	Euclidian `distances' sorted from smallest to largest
VAL1 ZD1 ZB1 ZC1 LUCB1 WAR1 SPEK1 ROOI1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: VAL4	**SITE AND STRATUM DETAILS**
-.51 .56 -.01 -.49 -.67 -.80 1.17 .93 -.87 .76 -.17 -.72 -.54 -.39 .78 .53	Standardised values on 16 variables
2.10 5.37 3.78 3.94 3.10 3.05 9.39 8.37 7.18 2.08 2.04 2.27 3.77	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.04 2.08 2.10 2.27 3.05 3.10 3.77 3.78 3.94 5.37 7.18 8.37 9.39	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 VAL1 ZC1 MOUNV1 ROOI1 SPEK1 LUCB1 WAR1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL5	**SITE AND STRATUM DETAILS**
.03 -.25 .15 .16 .07 .21 1.17 -.42 -.72 -.24 .49 -.43 -.19 -.48 -.08 -.14	Standardised values on 16 variables
3.02 4.72 3.85 3.09 1.68 3.76 9.71 8.73 6.81 2.46 2.45 2.45 2.53	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.68 2.45 2.45 2.46 2.53 3.02 3.09 3.76 3.85 4.72 6.81 8.73 9.71	Euclidian `distances' sorted from smallest to largest
ROOI1 ZC1 ZD1 ZB1 SPEK1 VAL1 WAR1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL6	**SITE AND STRATUM DETAILS**
-.05 -.51 -.13 .49 .25 .51 1.01 -.97 -.45 -.17 .55 -.72 -.17 -.37 -.09 -.15	Standardised values on 16 variables
3.23 4.23 3.71 2.70 2.08 4.36 9.73 8.70 6.38 3.10 3.17 2.82 2.27	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.08 2.27 2.70 2.82 3.10 3.17 3.23 3.71 4.23 4.36 6.38 8.70 9.73	Euclidian `distances' sorted from smallest to largest
ROOI1 SPEK1 WAR1 ZC1 ZB1 ZD1 VAL1 LUCB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL7	**SITE AND STRATUM DETAILS**
1.30 .33 2.08 -1.07 -.62 -.55 -.10 .16 -.55 -.95 -1.19 -.71 .22 -.45 -.62 -.48	Standardised values on 16 variables
5.31 6.78 6.04 5.50 3.38 2.84 11.07 10.39 8.84 2.29 2.93 3.27 4.18	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.29 2.84 2.93 3.27 3.38 4.18 5.31 5.50 6.04 6.78 8.84 10.39 11.07	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL8	**SITE AND STRATUM DETAILS**
1.39 .93 .46 -.97 -.98 -1.00 -.06 .83 -.27 -1.24 -.86 -.11 .06 -.50 -.72 -.52	Standardised values on 16 variables
5.34 6.94 6.35 5.71 3.73 1.52 11.10 10.55 8.87 2.42 2.69 3.40 4.51	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.52 2.42 2.69 3.40 3.73 4.51 5.34 5.71 6.35 6.94 8.87 10.55 11.10	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL9	**SITE AND STRATUM DETAILS**
1.32 .97 .66 -1.08 -1.43 -1.43 -.68 1.28 .46 -1.15 -.85 -.16 -.27 -.50 -.71 -.51	Standardised values on 16 variables
5.92 7.35 6.92 6.26 4.60 1.82 11.45 10.80 9.09 3.04 3.38 4.07 5.10	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.82 3.04 3.38 4.07 4.60 5.10 5.92 6.26 6.92 7.35 9.09 10.80 11.45	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL10	**SITE AND STRATUM DETAILS**
.91 .06 1.02 -.44 -.36 -.34 .32 .16 -.70 -.89 -.35 -.40 -.01 -.51 -.50 -.48	Standardised values on 16 variables
4.32 5.85 5.20 4.47 2.28 2.52 10.52 9.70 8.00 1.63 2.07 2.48 3.25	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.63 2.07 2.28 2.48 2.52 3.25 4.32 4.47 5.20 5.85 8.00 9.70 10.52	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 ROOI1 ZC1 MOUNV1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL11	**SITE AND STRATUM DETAILS**
1.16 .95 1.07 -1.22 -1.06 -1.05 -.49 .67 -.55 -1.11 -.55 -.26 .09 -.52 -1.04 -.50	Standardised values on 16 variables
5.55 7.08 6.49 5.93 3.81 1.97 11.19 10.69 9.03 2.52 2.96 3.53 4.71	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.97 2.52 2.96 3.53 3.81 4.71 5.55 5.93 6.49 7.08 9.03 10.69 11.19	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: VAL12	SITE AND STRATUM DETAILS
1.46 .41 2.14 -1.16 -1.06 -1.05 -.68 .77 -.40 -1.15 -1.19 .15 -.30 -.54 -.72 -.51	Standardised values on 16 variables
5.98 7.40 6.80 6.21 4.36 2.82 11.43 10.72 9.26 2.90 3.32 4.19 4.92	Euclidian \`distance' of stratum to each of the 13 modern topsoils
2.82 2.90 3.32 4.19 4.36 4.92 5.98 6.21 6.80 7.40 9.26 10.72 11.43	Euclidian \`distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: VAL13	**SITE AND STRATUM DETAILS**
1.39 1.38 -.28 -1.09 -1.29 -1.34 -.26 1.31 .13 -1.20 -.92 .57 -.22 -.52 -.76 -.47	Standardised values on 16 variables
5.86 7.43 6.94 6.27 4.75 1.84 11.36 10.87 9.12 3.31 3.33 4.31 5.23	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.84 3.31 3.33 4.31 4.75 5.23 5.86 6.27 6.94 7.43 9.12 10.87 11.36	Euclidian \`distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH1	**SITE AND STRATUM DETAILS**
-.93 -1.27 -.92 1.44 1.46 1.35 -1.10 -.81 .03 1.47 -.57 -.79 -.19 -.14 .47 1.81	Standardised values on 16 variables
4.44 .00 3.20 2.55 5.54 6.63 8.68 7.62 3.32 5.36 5.33 5.08 3.11	Euclidian \`distance' of stratum to each of the 13 modern topsoils
00 2.55 3.11 3.20 3.32 4.44 5.08 5.33 5.36 5.54 6.63 7.62 8.68	Euclidian \`distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 KAL1 VAL1 ZC1 ZD1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH2	**SITE AND STRATUM DETAILS**
22 -1.21 .38 .91 .77 .64 -.83 .22 .03 .32 -1.09 .24 .02 -.11 .00 .78	Standardised values on 16 variables
4.15 3.06 3.87 2.67 4.24 4.66 9.45 8.27 5.32 3.35 3.27 3.78 1.65	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.65 2.67 3.06 3.27 3.35 3.78 3.87 4.15 4.24 4.66 5.32 8.27 9.45	Euclidian \`distances' sorted from smallest to largest
SPEK1 WAR1 GH1 ZD1 ZB1 ZC1 LUCB1 VAL1 ROOI1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH3	**SITE AND STRATUM DETAILS**
-.73 -1.24 -.97 1.43 1.36 1.22 -1.22 -.49 .26 1.47 -1.06 .10 .05 .00 .12 .66	Standardised values on 16 variables
4.50 1.67 3.88 2.35 5.56 6.24 9.84 8.38 4.30 5.00 4.94 5.02 2.57	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.67 2.35 2.57 3.88 4.30 4.50 4.94 5.00 5.02 5.56 6.24 8.38 9.84	Euclidian \`distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 KAL1 VAL1 ZD1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH4	**SITE AND STRATUM DETAILS**
-.97 -.66 .30 .46 .43 .57 .90 -.74 -.40 1.77 -1.05 .18 .32 .12 .32 .42	Standardised values on 16 variables
2.31 3.50 2.46 1.50 4.02 5.24 9.49 8.20 5.58 3.48 3.28 3.62 1.96	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.50 1.96 2.31 2.46 3.28 3.48 3.50 3.62 4.02 5.24 5.58 8.20 9.49	Euclidian \`distances' sorted from smallest to largest
WAR1 SPEK1 VAL1 LUCB1 ZD1 ZB1 GH1 ZC1 ROOI1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH5	**SITE AND STRATUM DETAILS**
.60 .93 .39 -.95 -.98 -1.13 .44 1.31 -.52 -.50 -.38 -.01 .03 -.24 -.34 -.13	Standardised values on 16 variables
4.36 6.55 5.61 5.22 3.44 1.29 10.49 9.80 8.41 1.78 1.83 2.80 4.28	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.29 1.78 1.83 2.80 3.44 4.28 4.36 5.22 5.61 6.55 8.41 9.80 10.49	Euclidian \`distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH6	**SITE AND STRATUM DETAILS**
.55 -.72 .58 .40 .37 .47 .32 -.65 -.17 -.49 -.27 -.01 -.08 -.32 -1.14 -.15	Standardised values on 16 variables
4.31 4.57 4.56 3.26 2.66 4.10 10.13 9.58 6.73 2.88 2.94 3.20 2.01	Euclidian \`distance' of stratum to each of the 13 modern topsoils
2.01 2.66 2.88 2.94 3.20 3.26 4.10 4.31 4.56 4.57 6.73 9.58 10.13	Euclidian \`distances' sorted from smallest to largest
SPEK1 ROOI1 ZB1 ZD1 ZC1 WAR1 MOUNV1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: GH7	SITE AND STRATUM DETAILS
1.49 .62 1.36 -1.04 -.88 -.85 .17 .57 -.40 -1.27 -1.03 -.19 .19 -.47 -.90 -.47	Standardised values on 16 variables
5.47 7.09 6.36 5.76 3.55 2.21 11.11 10.65 9.04 2.39 2.75 3.43 4.47	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.21 2.39 2.75 3.43 3.55 4.47 5.47 5.76 6.36 7.09 9.04 10.65 11.11	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH8	**SITE AND STRATUM DETAILS**
1.45 1.34 .54 -1.36 -1.10 -1.10 -.76 .93 .01 -1.21 -1.06 -.16 -.19 -.47 -.67 -.50	Standardised values on 16 variables
5.85 7.26 6.79 6.18 4.41 1.66 11.38 10.80 9.08 2.93 3.31 3.96 5.01	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.66 2.93 3.31 3.96 4.41 5.01 5.85 6.18 6.79 7.26 9.08 10.80 11.38	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH9	**SITE AND STRATUM DETAILS**
-.76 -1.12 -.87 1.29 1.18 1.16 -.22 -1.09 .81 .69 .56 -.66 -.28 -.37 -.13 .00	Standardised values on 16 variables
4.33 2.69 4.06 2.30 4.50 6.00 10.04 8.61 4.81 4.85 4.90 4.60 2.59	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.30 2.59 2.69 4.06 4.33 4.50 4.60 4.81 4.85 4.90 6.00 8.61 10.04	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ROOI1 ZC1 KAL1 ZB1 ZD1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH10	**SITE AND STRATUM DETAILS**
-1.60 -.99 -.83 1.16 1.20 1.24 .13 -1.32 .49 1.86 .31 -.09 .08 3.42 .08 .33	Standardised values on 16 variables
5.30 4.38 4.83 4.09 6.29 7.40 10.50 9.03 5.79 6.34 6.24 5.87 4.37	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.09 4.37 4.38 4.83 5.30 5.79 5.87 6.24 6.29 6.34 7.40 9.03 10.50	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 KAL1 ZC1 ZD1 ROOI1 ZB1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH11	**SITE AND STRATUM DETAILS**
.32 -1.25 -1.09 1.48 1.46 1.28 -1.41 -.52 1.09 -.17 -.35 -.55 .28 -.38 -.80 -.34	Standardised values on 16 variables
5.79 3.49 5.54 3.74 5.28 5.97 10.93 9.71 5.74 5.19 5.32 5.11 3.09	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.09 3.49 3.74 5.11 5.19 5.28 5.32 5.54 5.74 5.79 5.97 9.71 10.93	Euclidian `distances' sorted from smallest to largest
SPEK1 GH1 WAR1 ZC1 ZB1 ROOI1 ZD1 LUCB1 KAL1 VAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH12	**SITE AND STRATUM DETAILS**
-.37 -1.21 -1.10 1.45 1.41 1.26 -1.26 -.61 .74 .52 -.05 -.25 .06 -.44 -.48 -.28	Standardised values on 16 variables
5.13 2.80 4.89 3.02 5.18 6.05 10.65 9.15 5.17 5.05 5.12 5.01 2.79	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.79 2.80 3.02 4.89 5.01 5.05 5.12 5.13 5.17 5.18 6.05 9.15 10.65	Euclidian `distances' sorted from smallest to largest
SPEK1 GH1 WAR1 LUCB1 ZC1 ZB1 ZD1 VAL1 KAL1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH13	**SITE AND STRATUM DETAILS**
-1.57 -1.18 -1.23 1.48 1.43 1.27 -1.22 -.45 .08 1.61 .71 -.44 -.04 -.43 .27 .67	Standardised values on 16 variables
4.61 1.97 4.09 2.97 5.72 6.78 9.76 7.98 4.17 5.58 5.57 5.37 3.59	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.97 2.97 3.59 4.09 4.17 4.61 5.37 5.57 5.58 5.72 6.78 7.98 9.76	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 KAL1 VAL1 ZC1 ZD1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: GH14	**SITE AND STRATUM DETAILS**
1.26 1.60 -.63 -1.15 -1.24 -1.25 -.06 1.57 2.63 -1.31 -.39 -.32 -.08 -.47 -.43 -.47	Standardised values on 16 variables
6.67 7.84 7.61 6.79 5.70 3.23 11.76 11.08 9.05 4.64 4.74 5.22 5.97	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.23 4.64 4.74 5.22 5.70 5.97 6.67 6.79 7.61 7.84 9.05 11.08 11.76	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: GH15	SITE AND STRATUM DETAILS
-1.51 -1.18 -.32 1.13 1.12 1.10 -.45 -.84 -.02 .32 3.12 .15 .23 3.03 .01 .42	Standardised values on 16 variables
6.29 5.44 5.95 5.43 6.30 7.52 10.40 8.63 6.52 6.73 6.62 6.33 5.38	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.38 5.43 5.44 5.95 6.29 6.30 6.33 6.52 6.62 6.73 7.52 8.63 10.40	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 GH1 LUCB1 VAL1 ROOI1 ZC1 KAL1 ZD1 ZB1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: GH16	SITE AND STRATUM DETAILS
1.66 1.78 -.80 -1.24 -1.54 -1.52 -.30 1.51 1.59 -1.57 -.84 .79 1.05 -.41 -.54 -.52	Standardised values on 16 variables
7.02 8.29 7.95 7.23 6.14 3.21 11.96 11.29 9.63 4.75 4.66 5.57 6.26	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.21 4.66 4.75 5.57 6.14 6.26 7.02 7.23 7.95 8.29 9.63 11.29 11.96	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCA1	SITE AND STRATUM DETAILS
-.23 -.37 -.45 .49 .27 .52 1.40 -.81 -1.10 -.03 .70 -1.25 -1.11 .36 -.11 -.24	Standardised values on 16 variables
3.20 4.67 3.94 3.29 2.08 4.71 9.90 9.09 6.90 3.58 3.72 2.86 3.08	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.08 2.86 3.08 3.20 3.29 3.58 3.72 3.94 4.67 4.71 6.90 9.09 9.90	Euclidian `distances' sorted from smallest to largest
ROOI1 ZC1 SPEK1 VAL1 WAR1 ZB1 ZD1 LUCB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCA2	SITE AND STRATUM DETAILS
.50 .28 1.68 -.87 -.69 -.80 .48 .90 -.70 -1.05 .95 -.92 -.37 -.23 .38 -.48	Standardised values on 16 variables
4.66 6.76 5.76 5.48 2.85 2.84 10.64 9.28 8.62 2.48 2.93 3.01 4.57	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.48 2.84 2.85 2.93 3.01 4.57 4.66 5.48 5.76 6.76 8.62 9.28 10.64	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ROOI1 ZD1 ZC1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCA3	SITE AND STRATUM DETAILS
1.81 1.89 -.67 -1.38 -1.23 -1.20 -1.14 .93 -.09 -1.58 -1.19 .06 .62 -.45 -.24 -.52	Standardised values on 16 variables
6.50 7.71 7.38 6.83 5.39 2.38 11.67 10.95 9.46 3.98 4.16 4.76 5.74	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.38 3.98 4.16 4.76 5.39 5.74 6.50 6.83 7.38 7.71 9.46 10.95 11.67	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCB1	SITE AND STRATUM DETAILS
-1.01 -.45 .01 .38 .42 .68 .98 -1.13 -.75 1.60 -.62 -.61 -.19 .03 1.30 2.30	Standardised values on 16 variables
2.35 3.20 .00 2.35 4.32 5.77 7.47 6.72 4.53 4.28 4.05 4.03 3.21	Euclidian `distance' of stratum to each of the 13 modern topsoils
00 2.35 2.35 3.20 3.21 4.03 4.05 4.28 4.32 4.53 5.77 6.72 7.47	Euclidian `distances' sorted from smallest to largest
LUCB1 WAR1 VAL1 GH1 SPEK1 ZC1 ZD1 ZB1 ROOI1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCB2	SITE AND STRATUM DETAILS
-.26 .01 .36 -.15 -.19 -.16 1.05 .12 -.90 .25 .23 -1.12 -.40 -.15 .39 .90	Standardised values on 16 variables
2.25 4.55 3.08 3.25 1.94 3.42 8.78 8.08 6.50 2.04 2.12 1.65 2.89	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.65 1.94 2.04 2.12 2.25 2.89 3.08 3.25 3.42 4.55 6.50 8.08 8.78	Euclidian `distances' sorted from smallest to largest
ZC1 ROOI1 ZB1 ZD1 VAL1 SPEK1 LUCB1 WAR1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCB3	SITE AND STRATUM DETAILS
.64 1.08 .02 -.94 -.84 -1.12 .78 1.60 -.80 -.66 -.17 -1.25 -.58 1.01 -.16 .05	Standardised values on 16 variables
4.49 6.77 5.76 5.64 3.36 1.84 10.46 10.00 8.73 2.54 2.81 2.41 4.75	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.84 2.41 2.54 2.81 3.36 4.49 4.75 5.64 5.76 6.77 8.73 10.00 10.46	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZC1 ZB1 ZD1 ROOI1 VAL1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: LUCB4	**SITE AND STRATUM DETAILS**
-.58 -.81 -.51 .89 .59 .79 .78 -1.06 -.02 .35 .81 -.72 -.51 -.38 .44 .66	Standardised values on 16 variables
3.12 3.18 2.96 2.05 3.22 5.24 8.95 7.77 5.03 3.99 3.93 3.64 2.45	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.05 2.45 2.96 3.12 3.18 3.22 3.64 3.93 3.99 5.03 5.24 7.77 8.95	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 LUCB1 VAL1 GH1 ROOI1 ZC1 ZD1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: LUCB5	**SITE AND STRATUM DETAILS**
1.44 1.95 -1.39 -1.16 -1.23 -1.20 -.72 1.12 .51 -1.43 -.60 -.86 -.22 -.37 -.23 -.47	Standardised values on 16 variables
6.16 7.41 7.16 6.58 5.06 2.25 11.49 10.89 9.11 4.04 4.30 4.41 5.67	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.25 4.04 4.30 4.41 5.06 5.67 6.16 6.58 7.16 7.41 9.11 10.89 11.49	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: LUCB6	**SITE AND STRATUM DETAILS**
.79 1.25 .27 -1.18 -1.05 -1.17 -.18 1.34 -.04 -.67 -.50 -.66 -.22 -.35 -.34 -.32	Standardised values on 16 variables
4.91 6.75 6.09 5.62 3.81 .96 10.90 10.18 8.61 2.25 2.67 3.06 4.63	Euclidian `distance' of stratum to each of the 13 modern topsoils
96 2.25 2.67 3.06 3.81 4.63 4.91 5.62 6.09 6.75 8.61 10.18 10.90	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: LUCB7	**SITE AND STRATUM DETAILS**
1.09 1.95 -.93 -1.33 -1.58 -1.49 -1.41 1.02 .59 -1.07 -.45 -.20 .36 -.44 -.19 -.41	Standardised values on 16 variables
6.29 7.47 7.23 6.68 5.52 2.41 11.53 10.68 9.03 4.07 4.29 4.76 5.76	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.41 4.07 4.29 4.76 5.52 5.76 6.29 6.68 7.23 7.47 9.03 10.68 11.53	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: LUCB8	**SITE AND STRATUM DETAILS**
-.99 -1.03 -.52 1.08 .99 1.02 -.03 -1.03 .51 .52 1.46 -.36 -.21 -.28 .10 .09	Standardised values on 16 variables
4.20 3.23 4.02 2.65 4.29 5.93 9.79 8.13 4.99 4.78 4.76 4.58 2.96	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.65 2.96 3.23 4.02 4.20 4.29 4.58 4.76 4.78 4.99 5.93 8.13 9.79	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ROOI1 ZC1 ZD1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: LUCB9	**SITE AND STRATUM DETAILS**
-1.17 -1.08 -.26 1.03 1.15 1.11 -.41 -.87 .31 .88 1.19 .02 -.18 -.37 .36 .08	Standardised values on 16 variables
4.10 2.93 3.86 2.45 4.60 6.04 9.84 7.83 4.77 4.76 4.72 4.75 2.87	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.45 2.87 2.93 3.86 4.10 4.60 4.72 4.75 4.76 4.77 6.04 7.83 9.84	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ROOI1 ZD1 ZC1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR1	**SITE AND STRATUM DETAILS**
-.77 -.85 -.27 .83 .80 .92 .59 -1.06 .16 1.38 -.78 -.16 -.32 -.20 .55 .59	Standardised values on 16 variables
2.72 2.55 2.35 .00 4.03 5.48 9.25 7.91 4.67 3.94 3.82 3.91 1.68	Euclidian `distance' of stratum to each of the 13 modern topsoils
00 1.68 2.35 2.55 2.72 3.82 3.91 3.94 4.03 4.67 5.48 7.91 9.25	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 LUCB1 GH1 VAL1 ZD1 ZC1 ZB1 ROOI1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR2	**SITE AND STRATUM DETAILS**
-1.06 -.24 -1.09 .61 .33 .78 1.63 -1.45 -.98 1.74 -.78 .06 .06 .06 -.21 .48	Standardised values on 16 variables
2.64 3.93 2.84 2.22 4.18 5.79 9.48 8.91 5.92 4.37 4.11 4.10 2.97	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.22 2.64 2.84 2.97 3.93 4.10 4.11 4.18 4.37 5.79 5.92 8.91 9.48	Euclidian `distances' sorted from smallest to largest
WAR1 VAL1 LUCB1 SPEK1 GH1 ZC1 ZD1 ROOI1 ZB1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: WAR3	**SITE AND STRATUM DETAILS**
.67 1.91 -.89 -1.32 -1.78 -1.69 -.60 1.60 3.46 -.38 -.78 .28 .13 -.16 -.77 -.11	Standardised values on 16 variables
7.25 8.23 8.07 7.30 6.94 4.28 12.04 11.52 9.11 5.54 5.55 6.20 6.64	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.28 5.54 5.55 6.20 6.64 6.94 7.25 7.30 8.07 8.23 9.11 11.52 12.04	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 SPEK1 ROOI1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR4	**SITE AND STRATUM DETAILS**
-1.64 -.97 -.87 1.16 1.18 1.24 -.10 -1.42 1.34 1.06 1.97 .58 .69 -.30 -.11 .00	Standardised values on 16 variables
5.33 4.09 5.01 3.68 5.85 7.11 10.35 8.49 5.04 6.09 5.92 6.05 4.21	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.68 4.09 4.21 5.01 5.04 5.33 5.85 5.92 6.05 6.09 7.11 8.49 10.35	Euclidian `distances' sorted from smallest to largest
WAR1 GH1 SPEK1 LUCB1 KAL1 VAL1 ROOI1 ZD1 ZC1 ZB1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR5	**SITE AND STRATUM DETAILS**
.03 1.28 -.10 -1.07 -1.06 -1.21 -.18 1.60 .13 .06 -.11 .49 .84 -.46 -.57 -.43	Standardised values on 16 variables
4.91 6.71 6.13 5.55 4.70 2.41 11.05 10.06 8.41 2.93 2.86 3.85 4.77	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.41 2.86 2.93 3.85 4.70 4.77 4.91 5.55 6.13 6.71 8.41 10.06 11.05	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR6	**SITE AND STRATUM DETAILS**
-.37 .13 .59 -.33 -.18 -.02 1.05 -.26 -.75 .04 .90 .44 .62 -.42 -.47 -.40	Standardised values on 16 variables
3.57 5.48 4.51 3.83 2.79 3.88 10.16 9.04 7.35 2.73 2.54 3.19 3.28	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.54 2.73 2.79 3.19 3.28 3.57 3.83 3.88 4.51 5.48 7.35 9.04 10.16	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 ROOI1 ZC1 SPEK1 VAL1 WAR1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR7	**SITE AND STRATUM DETAILS**
.40 1.68 -.62 -1.22 -1.48 -1.52 -.53 1.54 .71 -.50 .10 .60 .81 -.45 -.83 -.41	Standardised values on 16 variables
5.91 7.40 7.00 6.38 5.40 2.69 11.40 10.65 8.88 3.87 3.82 4.68 5.57	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.69 3.82 3.87 4.68 5.40 5.57 5.91 6.38 7.00 7.40 8.88 10.65 11.40	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR8	**SITE AND STRATUM DETAILS**
-1.84 -1.29 -1.59 -1.43 -1.92 -1.72 -3.49 .09 -2.79 -1.81 -1.19 -8.90 -10.24 -.58 -1.53 -.55	Standardised values on 16 variables
15.08 15.25 15.57 15.50 14.26 14.63 18.37 18.87 16.75 14.72 15.41 14.18 15.23	Euclidian `distance' of stratum to each of the 13 modern topsoils
14.18 14.26 14.63 14.72 15.08 15.23 15.25 15.41 15.50 15.57 16.75 18.37 18.87	Euclidian `distances' sorted from smallest to largest
ZC1 ROOI1 MOUNV1 ZB1 VAL1 SPEK1 GH1 ZD1 WAR1 LUCB1 KAL1 HOL1 BD1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR9	**SITE AND STRATUM DETAILS**
.46 1.79 -.63 -1.31 -1.25 -1.28 -.22 1.47 1.27 -.47 -.10 .48 .55 -.48 -.64 -.45	Standardised values on 16 variables
5.78 7.30 6.87 6.18 5.28 2.63 11.38 10.59 8.69 3.83 3.79 4.63 5.42	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.63 3.79 3.83 4.63 5.28 5.42 5.78 6.18 6.87 7.30 8.69 10.59 11.38	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR10	**SITE AND STRATUM DETAILS**
.25 .06 1.30 -.54 -.43 -.53 .32 .80 -.55 -.47 .42 .20 .38 -.48 -.60 -.48	Standardised values on 16 variables
4.35 6.05 5.36 4.68 3.03 2.89 10.58 9.50 8.01 2.01 2.12 3.00 3.66	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.01 2.12 2.89 3.00 3.03 3.66 4.35 4.68 5.36 6.05 8.01 9.50 10.58	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ROOI1	**SITE AND STRATUM DETAILS**
.51 .08 .71 -.33 .01 .21 1.59 -.55 -1.05 -.66 .16 -1.37 -.72 -.19 -.28 .11	Standardised values on 16 variables
3.58 5.54 4.32 4.03 .00 3.67 9.72 9.35 7.61 2.55 2.85 2.13 3.33	Euclidian \`distance' of stratum to each of the 13 modern topsoils
.00 2.13 2.55 2.85 3.33 3.58 3.67 4.03 4.32 5.54 7.61 9.35 9.72	Euclidian \`distances' sorted from smallest to largest
ROOI1 ZC1 ZB1 ZD1 SPEK1 VAL1 MOUNV1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI2	**SITE AND STRATUM DETAILS**
.25 -.77 .96 .30 .38 .50 .28 -.71 -.47 -.33 .12 -1.12 -.64 -.28 -.12 .09	Standardised values on 16 variables
3.67 4.23 3.89 3.05 1.94 4.16 9.70 8.74 6.47 2.70 3.08 2.60 2.13	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.94 2.13 2.60 2.70 3.05 3.08 3.67 3.89 4.16 4.23 6.47 8.74 9.70	Euclidian \`distances' sorted from smallest to largest
ROOI1 SPEK1 ZC1 ZB1 WAR1 ZD1 VAL1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI3	**SITE AND STRATUM DETAILS**
.69 1.15 .19 -1.07 1.30 1.15 -1.53 -.26 .51 -1.29 .96 -1.19 -.15 .65 .10 -.13	Standardised values on 16 variables
5.95 5.61 6.01 5.31 4.37 4.42 10.69 9.37 7.27 4.46 4.85 4.45 4.47	Euclidian \`distance' of stratum to each of the 13 modern topsoils
4.37 4.42 4.45 4.46 4.47 4.85 5.31 5.61 5.95 6.01 7.27 9.37 10.69	Euclidian \`distances' sorted from smallest to largest
ROOI1 MOUNV1 ZC1 ZB1 SPEK1 ZD1 WAR1 GH1 VAL1 LUCB1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI4	**SITE AND STRATUM DETAILS**
.18 -.12 -.16 .17 -.13 .13 1.52 -.61 -1.03 -.71 1.06 -1.40 -.51 -.12 .25 .19	Standardised values on 16 variables
3.44 5.23 4.16 3.93 1.53 4.09 9.46 8.71 7.20 3.21 3.33 2.54 3.52	Euclidian \`distance' of stratum to each of the 13 modern topsoils
1.53 2.54 3.21 3.33 3.44 3.52 3.93 4.09 4.16 5.23 7.20 8.71 9.46	Euclidian \`distances' sorted from smallest to largest
ROOI1 ZC1 ZB1 ZD1 VAL1 SPEK1 WAR1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI5	**SITE AND STRATUM DETAILS**
-.23 -.68 -.60 .81 .52 .77 .90 -1.29 .16 -.21 1.05 -1.02 -1.48 -.47 -.10 .03	Standardised values on 16 variables
3.97 4.19 4.17 3.07 3.00 5.29 9.74 8.86 5.97 4.32 4.42 3.94 3.13	Euclidian \`distance' of stratum to each of the 13 modern topsoils
3.00 3.07 3.13 3.94 3.97 4.17 4.19 4.32 4.42 5.29 5.97 8.86 9.74	Euclidian \`distances' sorted from smallest to largest
ROOI1 WAR1 SPEK1 ZC1 VAL1 LUCB1 GH1 ZB1 ZD1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI6	**SITE AND STRATUM DETAILS**
.07 .16 -.57 .07 -.46 -.48 1.52 .41 -1.15 -.52 .96 -1.02 -.94 -.37 .47 -.10	Standardised values on 16 variables
3.27 5.70 4.61 4.35 2.26 3.53 9.83 8.86 7.65 2.98 3.01 2.62 4.01	Euclidian \`distance' of stratum to each of the 13 modern topsoils
2.26 2.62 2.98 3.01 3.27 3.53 4.01 4.35 4.61 5.70 7.65 8.86 9.83	Euclidian \`distances' sorted from smallest to largest
ROOI1 ZC1 ZB1 ZD1 VAL1 MOUNV1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI7	**SITE AND STRATUM DETAILS**
-.39 -.77 -.42 .82 .55 .78 .90 -1.16 .01 -.25 1.54 -.88 -.21 -.41 .65 -.03	Standardised values on 16 variables
3.80 4.17 3.96 3.06 3.20 5.33 9.63 8.00 5.93 4.27 4.29 3.90 3.15	Euclidian \`distance' of stratum to each of the 13 modern topsoils
3.06 3.15 3.20 3.80 3.90 3.96 4.17 4.27 4.29 5.33 5.93 8.00 9.63	Euclidian \`distances' sorted from smallest to largest
WAR1 SPEK1 ROOI1 VAL1 ZC1 LUCB1 GH1 ZB1 ZD1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROOI8	**SITE AND STRATUM DETAILS**
.32 -1.14 -.86 1.31 1.15 1.00 -.91 -.32 .69 -.65 .59 -1.02 -.80 2.78 -.50 -.43	Standardised values on 16 variables
6.09 4.82 6.01 4.80 5.24 6.03 11.12 9.88 6.80 5.56 5.72 5.04 4.03	Euclidian \`distance' of stratum to each of the 13 modern topsoils
4.03 4.80 4.82 5.04 5.24 5.56 5.72 6.01 6.03 6.09 6.80 9.88 11.12	Euclidian \`distances' sorted from smallest to largest
SPEK1 WAR1 GH1 ZC1 ROOI1 ZB1 ZD1 LUCB1 MOUNV1 VAL1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ROCH1	SITE AND STRATUM DETAILS
.62 .00 .99 -.37 -.37 -.45 .32 .64 -.60 -.41 -.61 -.10 -.22 -.30 -.37 -.11	Standardised values on 16 variables
3.85 5.52 4.78 4.13 2.55 2.31 10.17 9.36 7.61 1.05 1.35 2.29 2.97	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.05 1.35 2.29 2.31 2.55 2.97 3.85 4.13 4.78 5.52 7.61 9.36 10.17	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 ZC1 MOUNV1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH2	**SITE AND STRATUM DETAILS**
1.46 .09 2.05 -.85 -.61 -.63 -.45 .70 -.27 -1.37 -.74 .80 .61 -.42 -.36 -.14	Standardised values on 16 variables
5.80 6.96 6.39 5.79 4.28 3.08 10.86 9.91 8.68 2.91 2.98 4.21 4.49	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.91 2.98 3.08 4.21 4.28 4.49 5.79 5.80 6.39 6.96 8.68 9.91 10.86	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ZC1 ROOI1 SPEK1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH3	**SITE AND STRATUM DETAILS**
-.56 -1.13 -1.21 1.43 1.40 1.31 -.68 -1.13 1.62 .97 -.49 .49 .46 -.42 -.42 -.17	Standardised values on 16 variables
5.30 3.19 4.93 2.91 5.77 6.54 10.69 9.22 4.88 5.53 5.43 5.63 3.06	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.91 3.06 3.19 4.88 4.93 5.30 5.43 5.53 5.63 5.77 6.54 9.22 10.69	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 KAL1 LUCB1 VAL1 ZD1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH4	**SITE AND STRATUM DETAILS**
-1.19 .32 -.18 -.21 -.04 .01 1.71 -1.51 -.98 .83 1.34 .89 .41 -.27 -.04 -.06	Standardised values on 16 variables
3.40 5.51 4.11 3.76 3.85 5.36 9.81 8.68 6.95 4.25 3.91 4.40 4.02	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.40 3.76 3.85 3.91 4.02 4.11 4.25 4.40 5.36 5.51 6.95 8.68 9.81	Euclidian `distances' sorted from smallest to largest
VAL1 WAR1 ROOI1 ZD1 SPEK1 LUCB1 ZB1 ZC1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH5	**SITE AND STRATUM DETAILS**
1.15 1.62 -.37 -1.27 -1.16 -1.17 -.68 1.15 .18 -1.34 -.04 .50 .36 -.43 -.21 -.40	Standardised values on 16 variables
5.86 7.29 6.84 6.27 4.81 1.92 11.17 10.26 8.87 3.46 3.49 4.37 5.30	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.92 3.46 3.49 4.37 4.81 5.30 5.86 6.27 6.84 7.29 8.87 10.26 11.17	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH6	**SITE AND STRATUM DETAILS**
-.17 -.20 .79 -.12 -.21 -.19 .75 .19 -.75 .13 .23 .80 .35 -.46 -.08 -.32	Standardised values on 16 variables
3.33 5.24 4.33 3.57 2.99 3.56 10.09 8.73 7.17 2.18 1.85 3.09 2.89	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.85 2.18 2.89 2.99 3.09 3.33 3.56 3.57 4.33 5.24 7.17 8.73 10.09	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 SPEK1 ROOI1 ZC1 VAL1 MOUNV1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ROCH7	**SITE AND STRATUM DETAILS**
1.77 2.10 -1.26 -1.34 -1.59 -1.49 -1.41 .86 .08 -1.57 -1.10 .83 .28 -.42 -.27 -.50	Standardised values on 16 variables
6.93 8.07 7.81 7.22 6.08 3.02 11.88 11.18 9.61 4.67 4.70 5.52 6.24	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.02 4.67 4.70 5.52 6.08 6.24 6.93 7.22 7.81 8.07 9.61 11.18 11.88	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: MOUNV1	**SITE AND STRATUM DETAILS**
1.02 1.26 .09 -1.12 -1.09 -1.14 .01 1.06 -.22 -.86 -.70 -.50 -.22 .11 .09 .11	Standardised values on 16 variables
4.71 6.63 5.77 5.48 3.67 .00 10.40 9.76 8.40 2.15 2.40 2.90 4.49	Euclidian `distance' of stratum to each of the 13 modern topsoils
.00 2.15 2.40 2.90 3.67 4.49 4.71 5.48 5.77 6.63 8.40 9.76 10.40	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: MOUNV2	**SITE AND STRATUM DETAILS**
1.74 1.96 -1.07 -1.30 -1.51 -1.43 -.72 .86 .36 -1.54 -1.10 .22 -.01 -.48 -.43 -.47	Standardised values on 16 variables
6.48 7.82 7.44 6.83 5.41 2.39 11.64 11.15 9.42 4.15 4.25 4.91 5.85	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.39 4.15 4.25 4.91 5.41 5.85 6.48 6.83 7.44 7.82 9.42 11.15 11.64	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: MOUNV3	**SITE AND STRATUM DETAILS**
-.11 -.59 1.19 .07 .15 .18 .75 -2.48 -.27 .30 -.26 -.80 -.47 -.12 .15 .79	Standardised values on 16 variables
3.62 4.42 3.21 2.91 2.90 5.09 9.09 8.46 6.05 3.61 3.79 3.60 2.64	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.64 2.90 2.91 3.21 3.60 3.61 3.62 3.79 4.42 5.09 6.05 8.46 9.09	Euclidian `distances' sorted from smallest to largest
SPEK1 ROOI1 WAR1 LUCB1 ZC1 ZB1 VAL1 ZD1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: MOUNV4	**SITE AND STRATUM DETAILS**
-1.01 -1.08 -1.02 1.31 1.36 1.27 -.83 -1.00 1.04 1.54 -.51 -.55 -.12 -.25 .40 .78	Standardised values on 16 variables
4.40 1.54 3.64 2.12 5.47 6.45 9.63 8.12 3.72 5.25 5.25 5.10 2.81	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.54 2.12 2.81 3.64 3.72 4.40 5.10 5.25 5.25 5.47 6.45 8.12 9.63	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 KAL1 VAL1 ZC1 ZB1 ZD1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: WAR	**SITE AND STRATUM DETAILS**
1.03 1.88 -1.19 -1.18 -1.41 -1.54 .98 1.76 1.37 -1.05 -.34 -.66 .36 -.43 -.73 -.30	Standardised values on 16 variables
6.09 7.92 7.29 6.74 5.19 2.81 11.45 11.20 9.38 4.27 4.28 4.57 5.99	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.81 4.27 4.28 4.57 5.19 5.99 6.09 6.74 7.29 7.92 9.38 11.20 11.45	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: MOUNV6	**SITE AND STRATUM DETAILS**
-1.14 -1.22 -.70 1.31 1.36 1.25 -.99 -.77 .44 1.66 -.44 -.44 -.45 -.40 .89 1.49	Standardised values on 16 variables
4.19 .95 3.12 2.24 5.56 6.57 8.90 7.30 3.18 5.27 5.22 5.18 3.08	Euclidian `distance' of stratum to each of the 13 modern topsoils
95 2.24 3.08 3.12 3.18 4.19 5.18 5.22 5.27 5.56 6.57 7.30 8.90	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 KAL1 VAL1 ZC1 ZD1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: MOUNV7	**SITE AND STRATUM DETAILS**
-.59 -1.22 -1.05 1.44 1.41 1.31 -1.26 -.81 .31 .85 -.17 -.58 -.54 -.38 -.13 .05	Standardised values on 16 variables
4.71 2.11 4.34 2.62 5.04 6.15 10.26 8.78 4.76 5.02 5.13 4.87 2.69	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.11 2.62 2.69 4.34 4.71 4.76 4.87 5.02 5.04 5.13 6.15 8.78 10.26	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 LUCB1 VAL1 KAL1 ZC1 ZB1 ROOI1 ZD1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: PEN1	**SITE AND STRATUM DETAILS**
-.36 -.21 .40 .03 .27 .38 1.09 -.45 -.90 .25 .46 .43 -4.12 .43 1.63 .08	Standardised values on 16 variables
4.44 6.12 5.11 4.84 4.60 5.89 10.14 8.54 7.34 5.11 5.07 5.37 5.06	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.44 4.60 4.84 5.06 5.07 5.11 5.11 5.37 5.89 6.12 7.34 8.54 10.14	Euclidian `distances' sorted from smallest to largest
VAL1 ROOI1 WAR1 SPEK1 ZD1 ZB1 LUCB1 ZC1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: STOLSGM	**SITE AND STRATUM DETAILS**
.81 1.23 .28 -1.17 -1.02 -1.17 .40 1.38 -.47 -.39 -1.12 1.01 .74 -.25 -.45 -.32	Standardised values on 16 variables
5.03 7.11 6.21 5.72 4.52 2.15 10.99 10.26 8.88 2.67 2.40 3.87 4.78	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.15 2.40 2.67 3.87 4.52 4.78 5.03 5.72 6.21 7.11 8.88 10.26 10.99	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: RANGE1	SITE AND STRATUM DETAILS
-.85 -.69 -.36 .73 .54 .81 1.09 -1.19 -.75 1.42 -.65 -1.54 -.84 -.35 .30 .29	Standardised values on 16 variables
2.41 3.35 2.63 1.90 3.39 5.55 9.57 8.64 5.78 3.95 4.13 3.37 2.54	Euclidian 'distance' of stratum to each of the 13 modern topsoils
1.90 2.41 2.54 2.63 3.35 3.37 3.39 3.95 4.13 5.55 5.78 8.64 9.57	Euclidian 'distances' sorted from smallest to largest
WAR1 VAL1 SPEK1 LUCB1 GH1 ZC1 ROOI1 ZB1 ZD1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL1	**SITE AND STRATUM DETAILS**
-.31 -.28 -.17 .31 .17 .47 1.36 -.97 -.87 .05 .75 -.08 -.32 -.31 1.52 9.39	Standardised values on 16 variables
9.13 8.68 7.47 9.25 9.72 10.40 .00 7.70 7.21 9.94 9.42 9.73 9.64	Euclidian 'distance' of stratum to each of the 13 modern topsoils
.00 7.21 7.47 7.70 8.68 9.13 9.25 9.42 9.64 9.72 9.73 9.94 10.40	Euclidian 'distances' sorted from smallest to largest
HOL1 KAL1 LUCB1 BD1 GH1 VAL1 WAR1 ZD1 SPEK1 ROOI1 ZC1 ZB1 MOUNV1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL2	**SITE AND STRATUM DETAILS**
-.18 -.23 -.21 .28 .22 .47 1.59 -.84 -1.00 .00 .52 .90 .38 -.19 .52 -.10	Standardised values on 16 variables
3.11 4.93 3.78 3.11 3.10 4.65 9.63 8.19 6.71 3.46 2.99 3.70 3.00	Euclidian 'distance' of stratum to each of the 13 modern topsoils
2.99 3.00 3.10 3.11 3.11 3.46 3.70 3.78 4.65 4.93 6.71 8.19 9.63	Euclidian 'distances' sorted from smallest to largest
ZD1 SPEK1 ROOI1 WAR1 VAL1 ZB1 ZC1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL3	**SITE AND STRATUM DETAILS**
-1.26 -.90 -.50 .96 1.00 1.16 .55 -1.35 -.17 1.19 .78 .11 -.05 .06 1.42 .05	Standardised values on 16 variables
3.30 3.27 3.12 2.08 4.58 6.23 9.65 7.18 5.00 4.85 4.71 4.74 3.04	Euclidian 'distance' of stratum to each of the 13 modern topsoils
2.08 3.04 3.12 3.27 3.30 4.58 4.71 4.74 4.85 5.00 6.23 7.18 9.65	Euclidian 'distances' sorted from smallest to largest
WAR1 SPEK1 LUCB1 GH1 VAL1 ROOI1 ZD1 ZC1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL4	**SITE AND STRATUM DETAILS**
.16 .35 .37 -.44 -.46 -.58 .78 .77 -.93 -.54 .75 .79 -.21 -.46 -.06 -.40	Standardised values on 16 variables
3.93 6.08 5.16 4.59 3.04 2.91 10.29 9.08 7.88 2.40 2.09 3.27 3.90	Euclidian 'distance' of stratum to each of the 13 modern topsoils
2.09 2.40 2.91 3.04 3.27 3.90 3.93 4.59 5.16 6.08 7.88 9.08 10.29	Euclidian 'distances' sorted from smallest to largest
ZD1 ZB1 MOUNV1 ROOI1 ZC1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL5	**SITE AND STRATUM DETAILS**
-.82 -.96 -.72 1.10 1.04 1.13 .05 -1.35 .79 .19 1.69 .36 -.17 -.28 .52 -.40	Standardised values on 16 variables
4.70 3.96 4.63 3.16 4.74 6.21 10.27 8.13 5.36 5.23 5.13 5.22 3.46	Euclidian 'distance' of stratum to each of the 13 modern topsoils
3.16 3.46 3.96 4.63 4.70 4.74 5.13 5.22 5.23 5.36 6.21 8.13 10.27	Euclidian 'distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ROOI1 ZD1 ZC1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL6	**SITE AND STRATUM DETAILS**
.76 .95 .51 -1.01 -1.01 -1.12 .01 .96 -.98 -.92 .05 1.08 .13 -.51 -.15 -.54	Standardised values on 16 variables
5.01 7.01 6.18 5.68 4.03 2.24 10.90 9.81 8.78 2.66 2.50 3.89 4.75	Euclidian 'distance' of stratum to each of the 13 modern topsoils
2.24 2.50 2.66 3.89 4.03 4.75 5.01 5.68 6.18 7.01 8.78 9.81 10.90	Euclidian 'distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: HOL7	**SITE AND STRATUM DETAILS**
-.61 -.22 .02 .18 .05 .29 1.21 -.74 -.82 -.06 1.69 .90 -.01 -.45 .35 -.41	Standardised values on 16 variables
3.66 5.31 4.43 3.72 3.38 4.89 9.98 8.30 6.91 3.86 3.56 4.15 3.67	Euclidian 'distance' of stratum to each of the 13 modern topsoils
3.38 3.56 3.66 3.67 3.72 3.86 4.15 4.43 4.89 5.31 6.91 8.30 9.98	Euclidian 'distances' sorted from smallest to largest
ROOI1 ZD1 VAL1 SPEK1 WAR1 ZB1 ZC1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: HOL8	SITE AND STRATUM DETAILS
-.75 -.70 -.62 .83 .75 1.07 1.01 -1.58 -.25 .22 1.48 .43 -.51 -.42 .15 -.54	Standardised values on 16 variables
4.05 4.43 4.30 3.02 3.89 5.92 10.19 8.57 6.09 4.79 4.64 4.74 3.36	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.02 3.36 3.89 4.05 4.30 4.43 4.64 4.74 4.79 5.92 6.09 8.57 10.19	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 ROOI1 VAL1 LUCB1 GH1 ZD1 ZC1 ZB1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: BD1	**SITE AND STRATUM DETAILS**
-1.23 -1.12 .54 .76 .76 .73 -.33 -.32 -.35 .69 1.70 .80 .58 -.20 6.60 4.45.	Standardised values on 16 variables
7.73 7.62 6.72 7.91 9.35 9.76 7.70 .00 6.72 9.02 8.65 9.17 8.55	Euclidian `distance' of stratum to each of the 13 modern topsoils
00 6.72 6.72 7.62 7.70 7.73 7.91 8.55 8.65 9.02 9.17 9.35 9.76	Euclidian `distances' sorted from smallest to largest
BD1 LUCB1 KAL1 GH1 HOL1 VAL1 WAR1 SPEK1 ZD1 ZB1 ZC1 ROOI1 MOUNV1	Reference numbers of the corresponding modern topsoils
STRATUM: BD2	**SITE AND STRATUM DETAILS**
-.85 -1.05 .64 .67 .71 .67 -.10 -.23 -.50 1.46 -.73 .49 .36 -.06 7.89 .70	Standardised values on 16 variables
7.21 8.00 7.11 7.57 9.23 9.41 11.22 4.76 8.43 8.53 8.40 8.84 8.16	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.76 7.11 7.21 7.57 8.00 8.16 8.40 8.43 8.53 8.84 9.23 9.41 11.22	Euclidian `distances' sorted from smallest to largest
BD1 LUCB1 VAL1 WAR1 GH1 SPEK1 ZD1 KAL1 ZB1 ZC1 ROOI1 MOUNV1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: BD3	**SITE AND STRATUM DETAILS**
-1.49 -.93 -.32 .92 1.06 1.19 .59 -1.45 -.12 .10 3.52 1.11 .92 -.35 1.67 .11	Standardised values on 16 variables
5.71 5.69 5.55 5.07 6.08 7.58 10.08 7.10 6.37 6.63 6.34 6.65 5.54	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.07 5.54 5.55 5.69 5.71 6.08 6.34 6.37 6.63 6.65 7.10 7.58 10.08	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 LUCB1 GH1 VAL1 ROOI1 ZD1 KAL1 ZB1 ZC1 BD1 MOUNV1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: BD4	**SITE AND STRATUM DETAILS**
-1.54 -.96 -.35 .96 1.01 1.11 .32 -1.26 -.14 .14 3.55 .71 .79 -.35 1.71 -.17	Standardised values on 16 variables
5.62 5.57 5.57 5.01 5.97 7.44 10.31 7.18 6.44 6.50 6.30 6.47 5.45	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.01 5.45 5.57 5.57 5.62 5.97 6.30 6.44 6.47 6.50 7.18 7.44 10.31	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ROOI1 ZD1 KAL1 ZC1 ZB1 BD1 MOUNV1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: BD5	**SITE AND STRATUM DETAILS**
-1.43 -.56 -.71 .74 .77 1.18 1.32 -1.70 -.80 .78 2.02 .94 .82 -.36 1.42 -.40	Standardised values on 16 variables
4.31 5.11 4.49 3.89 5.17 6.89 10.18 7.58 6.42 5.71 5.41 5.68 4.56	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.89 4.31 4.49 4.56 5.11 5.17 5.41 5.68 5.71 6.42 6.89 7.58 10.18	Euclidian `distances' sorted from smallest to largest
WAR1 VAL1 LUCB1 SPEK1 GH1 ROOI1 ZD1 ZC1 ZB1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL1	**SITE AND STRATUM DETAILS**
-1.41 -1.20 -1.06 1.43 1.58 1.53 -1.14 -1.45 1.72 1.71 .13 .26 -.55 -.34 1.18 4.08	Standardised values on 16 variables
6.30 3.32 4.53 4.67 7.61 8.40 7.21 6.72 .00 7.47 7.19 7.41 5.54	Euclidian `distance' of stratum to each of the 13 modern topsoils
00 3.32 4.53 4.67 5.54 6.30 6.72 7.19 7.21 7.41 7.47 7.61 8.40	Euclidian `distances' sorted from smallest to largest
KAL1 GH1 LUCB1 WAR1 SPEK1 VAL1 BD1 ZD1 HOL1 ZC1 ZB1 ROOI1 MOUNV1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL2	**SITE AND STRATUM DETAILS**
-1.44 -1.24 -1.08 1.47 1.71 1.54 -1.53 -1.03 2.22 .78 2.04 .25 -.58 -.38 1.36 3.17	Standardised values on 16 variables
6.81 4.08 5.50 5.25 7.59 8.38 8.18 6.65 2.44 7.66 7.44 7.60 5.91	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.44 4.08 5.25 5.50 5.91 6.65 6.81 7.44 7.59 7.60 7.66 8.18 8.38	Euclidian `distances' sorted from smallest to largest
KAL1 GH1 WAR1 LUCB1 SPEK1 BD1 VAL1 ZD1 ROOI1 ZC1 ZB1 HOL1 MOUNV1	Reference numbers of the corresponding modern topsoils

STRATUM: KAL3	SITE AND STRATUM DETAILS
-1.26 -1.28 -1.33 1.60 1.82 1.60 -2.03 -.55 .91 .48 2.19 .29 -.60 -.41 1.35 1.07	Standardised values on 16 variables
6.25 3.68 5.55 4.71 6.84 7.67 9.77 7.18 4.16 6.89 6.79 6.87 5.16	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.68 4.16 4.71 5.16 5.55 6.25 6.79 6.84 6.87 6.89 7.18 7.67 9.77	Euclidian `distances' sorted from smallest to largest
GH1 KAL1 WAR1 SPEK1 LUCB1 VAL1 ZD1 ROOI1 ZC1 ZB1 BD1 MOUNV1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL4	**SITE AND STRATUM DETAILS**
-1.57 -1.21 -1.46 1.58 1.81 1.60 -2.11 -.65 1.39 1.07 1.80 .50 -.42 -.44 -.22 -.03	Standardised values on 16 variables
6.48 3.91 6.08 4.63 6.97 7.74 11.01 8.99 4.91 6.92 6.88 6.94 4.97	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.91 4.63 4.91 4.97 6.08 6.48 6.88 6.92 6.94 6.97 7.74 8.99 11.01	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 KAL1 SPEK1 LUCB1 VAL1 ZD1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL5	**SITE AND STRATUM DETAILS**
-1.24 -1.26 -1.45 1.62 1.76 1.53 -2.26 .19 -.27 .61 1.88 .45 -.50 -.48 -.44 -.15	Standardised values on 16 variables
6.26 4.02 6.09 4.82 6.50 7.28 10.97 9.08 5.75 6.45 6.43 6.44 4.87	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.02 4.82 4.87 5.75 6.09 6.26 6.43 6.44 6.45 6.50 7.28 9.08 10.97	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 KAL1 LUCB1 VAL1 ZD1 ZC1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL6	**SITE AND STRATUM DETAILS**
-.94 -1.12 -1.36 1.47 1.80 1.58 -1.22 -1.00 3.41 .26 1.84 .83 -.07 -.38 -.56 -.28	Standardised values on 16 variables
7.33 5.22 6.97 5.31 7.30 7.96 11.52 9.78 5.57 7.40 7.30 7.50 5.48	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.22 5.31 5.48 5.57 6.97 7.30 7.30 7.33 7.40 7.50 7.96 9.78 11.52	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 KAL1 LUCB1 ROOI1 ZD1 VAL1 ZB1 ZC1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL7	**SITE AND STRATUM DETAILS**
-1.46 -1.20 -1.47 1.58 1.75 1.55 -1.99 -.65 1.34 1.12 1.42 .35 -.30 -.52 -.54 -.47	Standardised values on 16 variables
6.35 3.88 6.09 4.44 6.76 7.54 11.34 9.42 5.24 6.68 6.70 6.70 4.70	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.88 4.44 4.70 5.24 6.09 6.35 6.68 6.70 6.70 6.76 7.54 9.42 11.34	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 KAL1 LUCB1 VAL1 ZB1 ZD1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL8	**SITE AND STRATUM DETAILS**
-.91 -1.17 -1.40 1.53 1.74 1.52 -1.60 -.68 2.02 .35 1.61 .34 -.21 -.50 -.53 -.40	Standardised values on 16 variables
6.53 4.23 6.26 4.56 6.52 7.29 11.23 9.42 5.34 6.60 6.58 6.62 4.66	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.23 4.56 4.66 5.34 6.26 6.52 6.53 6.58 6.60 6.62 7.29 9.42 11.23	Euclidian `distances' sorted from smallest to largest
GH1 WAR1 SPEK1 KAL1 LUCB1 ROOI1 VAL1 ZD1 ZB1 ZC1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL9	**SITE AND STRATUM DETAILS**
-.78 -1.17 -1.40 1.53 1.74 1.52 -1.72 -.61 1.92 .54 .91 .79 -.05 4.34 -.82 -.52	Standardised values on 16 variables
7.92 6.09 7.58 6.33 8.00 8.32 12.30 10.71 7.16 7.87 7.80 7.65 6.02	Euclidian `distance' of stratum to each of the 13 modern topsoils
6.02 6.09 6.33 7.16 7.58 7.65 7.80 7.87 7.92 8.00 8.32 10.71 12.30	Euclidian `distances' sorted from smallest to largest
SPEK1 GH1 WAR1 KAL1 LUCB1 ZC1 ZD1 ZB1 VAL1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL10	**SITE AND STRATUM DETAILS**
-.81 -1.25 -1.47 1.63 1.68 1.49 -1.87 -.55 .18 .52 1.03 1.00 -.02 4.34 -.82 -.54	Standardised values on 16 variables
7.61 5.92 7.32 6.23 7.71 8.18 12.12 10.52 7.39 7.62 7.53 7.37 5.87	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.87 5.92 6.23 7.32 7.37 7.39 7.53 7.61 7.62 7.71 8.18 10.52 12.12	Euclidian `distances' sorted from smallest to largest
SPEK1 GH1 WAR1 LUCB1 ZC1 KAL1 ZD1 VAL1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: KAL11	**SITE AND STRATUM DETAILS**
-.71 -1.26 -1.44 1.62 1.65 1.45 -1.95 -.29 .23 .40 1.03 .79 -.14 -.50 -.76 -.52	Standardised values on 16 variables
6.10 3.83 5.95 4.29 6.15 6.86 11.17 9.45 5.73 6.03 5.98 6.14 4.17	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.83 4.17 4.29 5.73 5.95 5.98 6.03 6.10 6.14 6.15 6.86 9.45 11.17	Euclidian `distances' sorted from smallest to largest
GH1 SPEK1 WAR1 KAL1 LUCB1 ZD1 ZB1 VAL1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: KAL12	**SITE AND STRATUM DETAILS**
-.92 -1.01 -1.48 1.42 1.67 1.45 -.64 -1.03 6.05 .24 1.84 .93 -.27 -.46 -.51 -.55	Standardised values on 16 variables
8.99 7.34 8.75 7.14 8.98 9.33 12.81 11.14 7.04 9.03 8.93 9.18 7.36	Euclidian `distance' of stratum to each of the 13 modern topsoils
7.04 7.14 7.34 7.36 8.75 8.93 8.98 8.99 9.03 9.18 9.33 11.14 12.81	Euclidian `distances' sorted from smallest to largest
KAL1 WAR1 GH1 SPEK1 LUCB1 ZD1 ROOI1 VAL1 ZB1 ZC1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB1	**SITE AND STRATUM DETAILS**
.35 .29 .87 -.58 -.50 -.56 .40 .54 -.72 .06 -.87 -.57 -.08 -.16 .12 .09	Standardised values on 16 variables
3.21 5.36 4.28 3.94 2.55 2.15 9.94 9.02 7.47 .00 1.10 1.71 2.97	Euclidian `distance' of stratum to each of the 13 modern topsoils
00 1.10 1.71 2.15 2.55 2.97 3.21 3.94 4.28 5.36 7.47 9.02 9.94	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 ZC1 MOUNV1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB2	**SITE AND STRATUM DETAILS**
1.26 1.68 -.44 -1.29 -1.40 -1.34 -1.07 .99 .44 -1.07 -.87 .03 .08 -.50 -.42 -.32	Standardised values on 16 variables
6.00 7.26 6.93 6.33 5.06 1.88 11.33 10.66 8.89 3.51 3.72 4.39 5.32	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.88 3.51 3.72 4.39 5.06 5.32 6.00 6.33 6.93 7.26 8.89 10.66 11.33	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB3	**SITE AND STRATUM DETAILS**
-.28 .45 .90 -.73 -.63 -.68 .21 .70 -.70 .89 -1.00 .79 .25 -.30 .16 .01	Standardised values on 16 variables
3.29 5.57 4.44 4.04 3.91 3.03 10.18 8.93 7.42 1.80 1.56 3.18 3.41	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.56 1.80 3.03 3.18 3.29 3.41 3.91 4.04 4.44 5.57 7.42 8.93 10.18	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 MOUNV1 ZC1 VAL1 SPEK1 ROOI1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB4	**SITE AND STRATUM DETAILS**
-.96 .44 -.23 -.29 -.41 -.66 1.13 1.09 -1.03 1.73 -1.00 -.53 .11 3.42 .00 -.08	Standardised values on 16 variables
4.26 6.37 5.28 5.25 5.35 5.09 10.93 9.98 8.34 4.44 4.39 4.05 4.87	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.05 4.26 4.39 4.44 4.87 5.09 5.25 5.28 5.35 6.37 8.34 9.98 10.93	Euclidian `distances' sorted from smallest to largest
ZC1 VAL1 ZD1 ZB1 SPEK1 MOUNV1 WAR1 LUCB1 ROOI1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB5	**SITE AND STRATUM DETAILS**
-1.05 .16 -.10 -.10 -.16 -.25 1.59 .41 -1.05 1.57 -.46 -.66 -.17 3.03 -.61 -.17	Standardised values on 16 variables
3.88 5.95 4.84 4.66 4.59 5.19 10.71 10.06 8.00 4.26 4.23 3.69 4.33	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.69 3.88 4.23 4.26 4.33 4.59 4.66 4.84 5.19 5.95 8.00 10.06 10.71	Euclidian `distances' sorted from smallest to largest
ZC1 VAL1 ZD1 ZB1 SPEK1 ROOI1 WAR1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB6	**SITE AND STRATUM DETAILS**
.70 .14 2.84 -1.18 -.66 -.59 -1.26 .22 .11 -.51 -.62 .29 .13 -.44 -.32 -.41	Standardised values on 16 variables
5.77 6.77 6.30 5.67 4.57 3.67 11.20 9.92 8.46 3.11 3.55 4.41 4.50	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.11 3.55 3.67 4.41 4.50 4.57 5.67 5.77 6.30 6.77 8.46 9.92 11.20	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ZC1 SPEK1 ROOI1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ZB7	**SITE AND STRATUM DETAILS**
-.14 1.05 .10 -.94 -.95 -1.11 .21 1.38 -.09 .38 -.33 .24 .03 -.43 -.26 -.34	Standardised values on 16 variables
3.99 6.22 5.40 4.87 4.01 2.12 10.68 9.67 8.00 2.16 2.15 3.18 4.20	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.12 2.15 2.16 3.18 3.99 4.01 4.20 4.87 5.40 6.22 8.00 9.67 10.68	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 VAL1 ROOI1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB8	**SITE AND STRATUM DETAILS**
1.17 1.19 .58 -1.24 -1.11 -1.10 -.76 .80 -.35 -1.15 -.48 .55 .46 -.51 -.55 -.51	Standardised values on 16 variables
5.69 7.14 6.62 6.03 4.43 1.96 11.21 10.36 8.92 2.88 3.03 4.05 4.89	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.96 2.88 3.03 4.05 4.43 4.89 5.69 6.03 6.62 7.14 8.92 10.36 11.21	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB9	**SITE AND STRATUM DETAILS**
1.25 1.16 .63 -1.24 -.31 -.28 -.53 .09 -.17 -1.06 -.84 .58 .16 -.42 -.63 -.51	Standardised values on 16 variables
5.34 6.51 6.06 5.29 3.86 2.35 10.98 10.22 8.33 2.68 2.85 3.82 4.12	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.35 2.68 2.85 3.82 3.86 4.12 5.29 5.34 6.06 6.51 8.33 10.22 10.98	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB10	**SITE AND STRATUM DETAILS**
1.36 .25 2.31 -1.08 -.67 -.60 -.80 .09 -.42 -1.34 -.56 .80 .65 -.52 -.59 -.54	Standardised values on 16 variables
6.09 7.19 6.66 6.01 4.44 3.49 11.29 10.26 8.95 3.26 3.47 4.53 4.71	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.26 3.47 3.49 4.44 4.53 4.71 6.01 6.09 6.66 7.19 8.95 10.26 11.29	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ROOI1 ZC1 SPEK1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB11	**SITE AND STRATUM DETAILS**
1.17 .45 1.72 -1.03 -.77 -.70 -.30 .16 -.14 -1.11 -.56 .48 .71 -.48 -.51 -.48	Standardised values on 16 variables
5.46 6.83 6.17 5.51 3.89 2.74 11.00 10.04 8.61 2.59 2.80 3.85 4.26	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.59 2.74 2.80 3.85 3.89 4.26 5.46 5.51 6.17 6.83 8.61 10.04 11.00	Euclidian `distances' sorted from smallest to largest
ZB1 MOUNV1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB12	**SITE AND STRATUM DETAILS**
-.62 -.86 -.52 .94 .85 .98 .48 -1.16 .08 1.24 -.88 .65 1.08 -.37 -.29 -.37	Standardised values on 16 variables
3.89 3.61 3.92 2.11 4.66 5.78 10.42 9.01 5.79 4.35 4.15 4.52 2.20	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.11 2.20 3.61 3.89 3.92 4.15 4.35 4.52 4.66 5.78 5.79 9.01 10.42	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 VAL1 LUCB1 ZD1 ZB1 ZC1 ROOI1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB13	**SITE AND STRATUM DETAILS**
1.78 1.98 -.99 -1.34 -1.57 -1.45 -1.45 .73 .44 -1.59 -1.10 .40 1.44 -.44 -.53 -.54	Standardised values on 16 variables
7.13 8.10 7.91 7.30 6.19 3.27 12.01 11.33 9.69 4.75 4.84 5.50 6.23	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.27 4.75 4.84 5.50 6.19 6.23 7.13 7.30 7.91 8.10 9.69 11.33 12.01	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD1	**SITE AND STRATUM DETAILS**
.33 .24 .60 -.44 -.47 -.55 .82 .67 -.72 .04 -.80 .24 .08 -.12 .18 .56	Standardised values on 16 variables
3.07 5.33 4.05 3.82 2.85 2.40 9.42 8.65 7.19 1.10 .00 2.27 3.01	Euclidian `distance' of stratum to each of the 13 modern topsoils
.00 1.10 2.27 2.40 2.85 3.01 3.07 3.82 4.05 5.33 7.19 8.65 9.42	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 ZC1 MOUNV1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ZD2	**SITE AND STRATUM DETAILS**
-.26 -.91 -.59 1.01 .94 .98 .09 -1.00 .76 .85 -.98 1.03 .42 -.07 .13 .14	Standardised values on 16 variables
4.10 3.23 3.84 1.93 4.80 5.56 9.96 8.49 5.04 4.36 4.08 4.69 1.96	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.93 1.96 3.23 3.84 4.08 4.10 4.36 4.69 4.80 5.04 5.56 8.49 9.96	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 ZD1 VAL1 ZB1 ZC1 ROOI1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD3	**SITE AND STRATUM DETAILS**
-1.84 -.90 -.18 .84 .88 .96 .59 -1.09 .01 2.74 -.86 1.08 .72 -.15 .35 .12	Standardised values on 16 variables
3.72 3.77 3.59 2.43 5.78 6.82 10.23 8.44 5.38 5.23 4.97 5.46 3.41	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.43 3.41 3.59 3.72 3.77 4.97 5.23 5.38 5.46 5.78 6.82 8.44 10.23	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 LUCB1 VAL1 GH1 ZD1 ZB1 KAL1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD4	**SITE AND STRATUM DETAILS**
-.54 .17 .88 -.47 .20 .26 .94 -.32 -.52 1.05 -.67 1.23 .53 -.14 .44 .18	Standardised values on 16 variables
2.87 4.90 3.53 3.00 3.80 4.31 9.71 8.25 6.57 2.79 2.33 3.68 2.81	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.33 2.79 2.81 2.87 3.00 3.53 3.68 3.80 4.31 4.90 6.57 8.25 9.71	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 SPEK1 VAL1 WAR1 LUCB1 ZC1 ROOI1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD5	**SITE AND STRATUM DETAILS**
1.16 -.40 2.47 -.58 -.37 -.33 .01 .16 -.30 -.94 -.86 1.72 1.28 -.25 -.39 -.41	Standardised values on 16 variables
5.90 7.01 6.37 5.64 4.77 4.31 11.11 9.88 8.67 3.58 3.41 4.86 4.44	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.41 3.58 4.31 4.44 4.77 4.86 5.64 5.90 6.37 7.01 8.67 9.88 11.11	Euclidian `distances' sorted from smallest to largest
ZD1 ZB1 MOUNV1 SPEK1 ROOI1 ZC1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD6	**SITE AND STRATUM DETAILS**
1.26 -.38 1.75 -.32 -.27 -.19 -.14 -1.83 -.25 -1.08 -.86 1.89 .75 -.31 -.46 -.48	Standardised values on 16 variables
5.94 6.63 6.10 5.20 4.67 4.86 10.99 9.93 8.17 4.14 4.01 5.21 4.13	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.01 4.13 4.14 4.67 4.86 5.20 5.21 5.94 6.10 6.63 8.17 9.93 10.99	Euclidian `distances' sorted from smallest to largest
ZD1 SPEK1 ZB1 ROOI1 MOUNV1 WAR1 ZC1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD7	**SITE AND STRATUM DETAILS**
-.93 -1.01 -.63 1.10 1.10 1.18 .01 -1.32 .44 1.62 -.86 .58 .75 .78 .46 .11	Standardised values on 16 variables
4.03 2.95 3.57 1.96 5.31 6.29 10.09 8.28 4.92 4.94 4.75 4.96 2.45	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.96 2.45 2.95 3.57 4.03 4.75 4.92 4.94 4.96 5.31 6.29 8.28 10.09	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 ZD1 KAL1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD8	**SITE AND STRATUM DETAILS**
-.63 -1.25 -.88 1.40 1.25 1.12 -1.22 -.32 -.09 .92 -.20 .24 1.08 2.06 -.01 -.22	Standardised values on 16 variables
5.23 3.57 4.96 3.71 5.79 6.32 10.77 8.88 5.88 5.31 5.25 5.12 3.27	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.27 3.57 3.71 4.96 5.12 5.23 5.25 5.31 5.79 5.88 6.32 8.88 10.77	Euclidian `distances' sorted from smallest to largest
SPEK1 GH1 WAR1 LUCB1 ZC1 VAL1 ZD1 ZB1 ROOI1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD9	**SITE AND STRATUM DETAILS**
-1.00 -1.13 .26 .88 1.05 .97 -.60 -.49 .03 1.24 .06 .13 .33 2.78 -.38 .04	Standardised values on 16 variables
4.92 4.04 4.66 3.68 5.37 6.22 10.51 9.00 6.03 5.05 5.03 4.84 3.26	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.26 3.68 4.04 4.66 4.84 4.92 5.03 5.05 5.37 6.03 6.22 9.00 10.51	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 GH1 LUCB1 ZC1 VAL1 ZD1 ZB1 ROOI1 KAL1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

STRATUM: ZD10	**SITE AND STRATUM DETAILS**
-1.02 -1.28 -1.46 1.64 1.73 1.53 -2.03 -.49 .21 1.14 .32 .52 1.34 .93 -.83 -.33	Standardised values on 16 variables
6.23 3.72 5.85 4.39 6.71 7.26 11.29 9.58 5.79 6.32 6.26 6.22 4.20	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.72 4.20 4.39 5.79 5.85 6.22 6.23 6.26 6.32 6.71 7.26 9.58 11.29	Euclidian `distances' sorted from smallest to largest
GH1 SPEK1 WAR1 KAL1 LUCB1 ZC1 VAL1 ZD1 ZB1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD11	**SITE AND STRATUM DETAILS**
-1.37 -1.01 -1.20 1.32 1.33 1.33 -.37 -1.35 .89 1.30 .84 -.10 .74 4.34 .14 -.15	Standardised values on 16 variables
6.55 5.41 6.15 5.34 7.15 7.98 11.37 9.60 6.69 7.20 7.13 6.70 5.35	Euclidian `distance' of stratum to each of the 13 modern topsoils
5.34 5.35 5.41 6.15 6.55 6.69 6.70 7.13 7.15 7.20 7.98 9.60 11.37	Euclidian `distances' sorted from smallest to largest
WAR1 SPEK1 GH1 LUCB1 VAL1 KAL1 ZC1 ZD1 ROOI1 ZB1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD12	**SITE AND STRATUM DETAILS**
.56 -1.25 -.42 1.24 .86 .70 -1.10 .35 -.04 -.52 -.25 .41 .92 2.01 -.46 -.43	Standardised values on 16 variables
5.69 4.68 5.71 4.44 5.17 5.29 10.98 9.47 6.91 4.64 4.58 4.64 3.28	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.28 4.44 4.58 4.64 4.64 4.68 5.17 5.29 5.69 5.71 6.91 9.47 10.98	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ZD1 ZC1 ZB1 GH1 ROOI1 MOUNV1 VAL1 LUCB1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD13	**SITE AND STRATUM DETAILS**
-.51 -.95 .33 .69 .55 .51 -.37 -.26 .46 .74 -.15 .20 .11 4.61 .45 -.08	Standardised values on 16 variables
5.89 5.73 5.82 5.20 6.22 6.50 11.08 9.32 7.27 5.79 5.75 5.57 4.66	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.66 5.20 5.57 5.73 5.75 5.79 5.82 5.89 6.22 6.50 7.27 9.32 11.08	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ZC1 GH1 ZD1 ZB1 LUCB1 VAL1 ROOI1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZB14	**SITE AND STRATUM DETAILS**
1.23 -.14 3.17 -1.06 -.27 -.30 -.76 .54 -.12 -1.29 -.36 .70 .71 2.44 -.47 -.48	Standardised values on 16 variables
6.88 7.75 7.24 6.73 5.42 4.74 11.71 10.48 9.42 4.48 4.64 5.21 5.37	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.48 4.64 4.74 5.21 5.37 5.42 6.73 6.88 7.24 7.75 9.42 10.48 11.71	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 MOUNV1 ZC1 SPEK1 ROOI1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD15	**SITE AND STRATUM DETAILS**
-.25 -.32 .51 .08 .08 .11 .55 -1.83 -.65 .24 .23 1.84 1.67 .23 .01 -.33	Standardised values on 16 variables
4.60 5.51 4.77 3.97 4.60 5.37 10.35 8.78 7.07 4.26 3.89 4.85 3.54	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.54 3.89 3.97 4.26 4.60 4.60 4.77 4.85 5.37 5.51 7.07 8.78 10.35	Euclidian `distances' sorted from smallest to largest
SPEK1 ZD1 WAR1 ZB1 ROOI1 VAL1 LUCB1 ZC1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD16	**SITE AND STRATUM DETAILS**
.46 -.35 1.30 -.18 .17 .26 .28 -.36 -.50 -.37 -.30 1.96 1.42 -.13 -.47 -.52	Standardised values on 16 variables
5.05 5.96 5.46 4.49 4.36 4.57 10.74 9.37 7.70 3.56 3.19 4.57 3.54	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.19 3.54 3.56 4.36 4.49 4.57 4.57 5.05 5.46 5.96 7.70 9.37 10.74	Euclidian `distances' sorted from smallest to largest
ZD1 SPEK1 ZB1 ROOI1 WAR1 ZC1 MOUNV1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD17	**SITE AND STRATUM DETAILS**
.35 -.45 -.81 .69 .08 .11 .40 -1.19 -.65 .14 -1.04 .75 1.29 -.35 -.34 -.51	Standardised values on 16 variables
4.14 4.67 4.53 3.26 4.08 4.64 10.49 9.39 6.89 3.61 3.37 3.94 2.55	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.55 3.26 3.37 3.61 3.94 4.08 4.14 4.53 4.64 4.67 6.89 9.39 10.49	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ZD1 ZB1 ZC1 ROOI1 VAL1 LUCB1 MOUNV1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

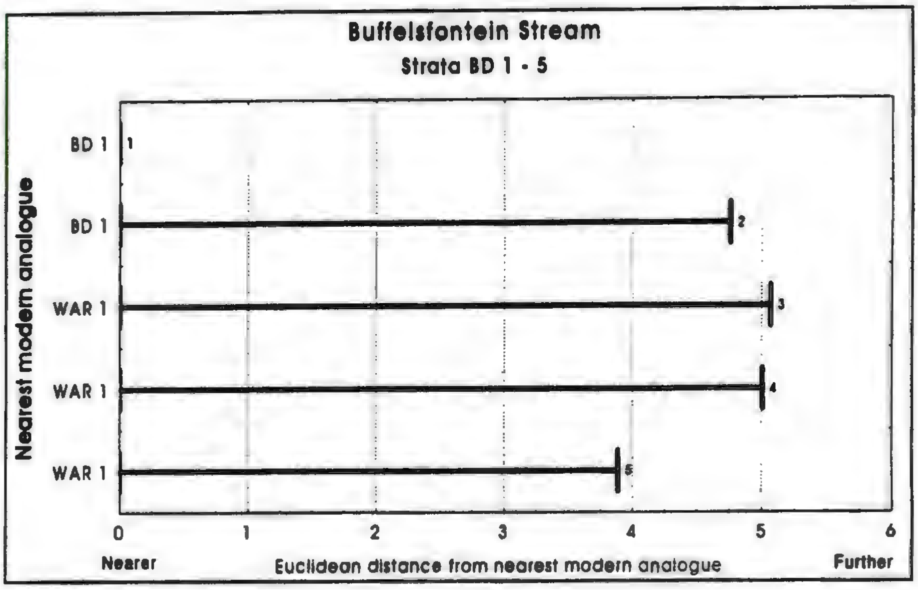
STRATUM: ZD18	**SITE AND STRATUM DETAILS**
.12 -.48 1.60 -.19 -.07 -.02 .24 -.87 -.25 .37 -.96 .91 .88 -.35 -,19 -.44	Standardised values on 16 variables
4.12 5.27 4.55 3.56 3.78 4.29 10.51 9.14 7.18 2.77 2.72 3.80 2.63	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.63 2.72 2.77 3.56 3.78 3.80 4.12 4.29 4.55 5.27 7.18 9.14 10.51	Euclidian `distances' sorted from smallest to largest
SPEK1 ZD1 ZB1 WAR1 ROOI1 ZC1 VAL1 MOUNV1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZD19	**SITE AND STRATUM DETAILS**
-.18 -.62 .35 .40 .44 .52 .51 -.52 -.62 .76 -1.00 .67 1.11 -.31 -.03 -.51	Standardised values on 16 variables
3.44 4.32 3.93 2.63 3.82 4.67 10.40 8.87 6.63 3.07 2.88 3.59 1.98	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.98 2.63 2.88 3.07 3.44 3.59 3.82 3.93 4.32 4.67 6.63 8.87 10.40	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ZD1 ZB1 VAL1 ZC1 ROOI1 LUCB1 GH1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC1	**SITE AND STRATUM DETAILS**
.21 .17 .29 -.26 -.30 -.35 .82 .41 -.95 .08 -.58 -1.85 .05 .39 -.06 .31	Standardised values on 16 variables
3.08 5.08 4.03 3.91 2.13 2.90 9.73 9.17 7.41 1.71 2.27 .00 3.05	Euclidian `distance' of stratum to each of the 13 modern topsoils
.00 1.71 2.13 2.27 2.90 3.05 3.08 3.91 4.03 5.08 7.41 9.17 9.73	Euclidian `distances' sorted from smallest to largest
ZC1 ZB1 ROOI1 ZD1 MOUNV1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC2	**SITE AND STRATUM DETAILS**
-.11 .63 .26 -.64 -.61 -.82 .55 1.31 -.67 .06 .24 -1.77 -.40 -.36 1.89 .31	Standardised values on 16 variables
3.33 5.89 4.64 4.87 3.56 3.11 9.79 7.98 7.69 2.72 3.08 2.64 4.53	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.64 2.72 3.08 3.11 3.33 3.56 4.53 4.64 4.87 5.89 7.69 7.98 9.79	Euclidian `distances' sorted from smallest to largest
ZC1 ZB1 ZD1 MOUNV1 VAL1 ROOI1 SPEK1 LUCB1 WAR1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC3	**SITE AND STRATUM DETAILS**
-.18 1.53 -.56 -1.12 -1.30 -1.36 -.37 1.67 .99 -.11 .75 -1.02 -1.34 -.52 .63 -.28	Standardised values on 16 variables
5.10 6.91 6.38 5.98 4.92 3.01 10.99 9.69 8.28 3.90 4.19 4.28 5.57	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.01 3.90 4.19 4.28 4.92 5.10 5.57 5.98 6.38 6.91 8.28 9.69 10.99	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 VAL1 SPEK1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC4	**SITE AND STRATUM DETAILS**
.26 .67 .84 -.90 -.71 -.83 -.18 1.18 -.19 -.68 .79 -.48 -.75 -.49 .50 -.44	Standardised values on 16 variables
4.45 6.34 5.63 5.18 3.38 2.28 10.59 9.08 8.08 2.39 2.76 3.19 4.41	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.28 2.39 2.76 3.19 3.38 4.41 4.45 5.18 5.63 6.34 8.08 9.08 10.59	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC5	**SITE AND STRATUM DETAILS**
.62 1.78 -.85 -1.22 -1.50 -1.45 -.80 1.38 1.37 -.86 .27 -.47 -.22 -.50 .53 -.51	Standardised values on 16 variables
5.89 7.34 6.98 6.42 5.36 2.60 11.39 10.09 8.69 4.10 4.30 4.69 5.73	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.60 4.10 4.30 4.69 5.36 5.73 5.89 6.42 6.98 7.34 8.69 10.09 11.39	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: ZC6	**SITE AND STRATUM DETAILS**
-.34 .05 .28 -.15 -.15 -.19 .98 .35 -.85 .01 .90 -.67 -.19 -.46 .31 -.52	Standardised values on 16 variables
2.94 5.23 4.28 3.73 2.22 3.47 10.15 8.68 7.33 2.32 2.48 2.37 3.28	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.22 2.32 2.37 2.48 2.94 3.28 3.47 3.73 4.28 5.23 7.33 8.68 10.15	Euclidian `distances' sorted from smallest to largest
ROOI1 ZB1 ZC1 ZD1 VAL1 SPEK1 MOUNV1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

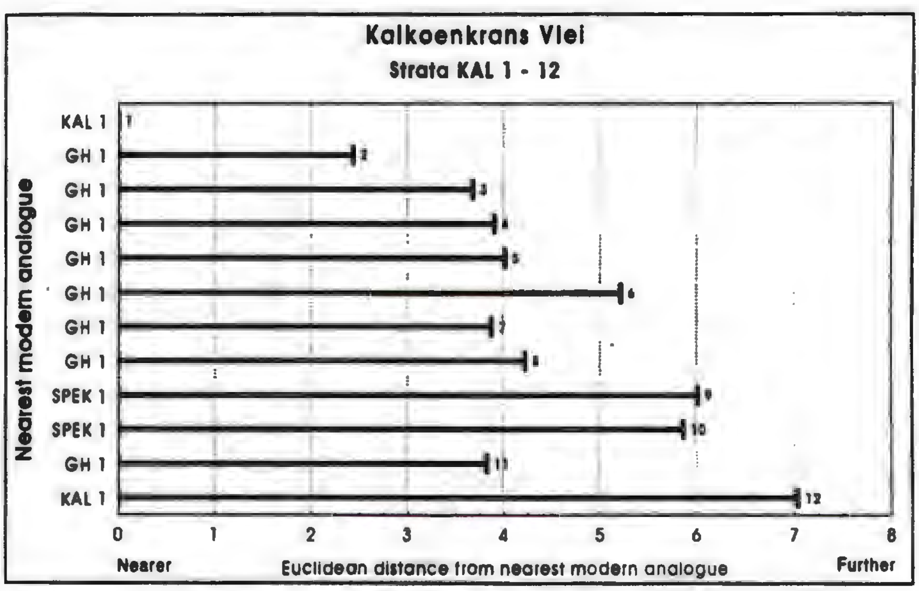
STRATUM: SPEK1	SITE AND STRATUM DETAILS
-.01 -.87 .20 .68 .58 .62 .09 -.71 .01 .56 -1.00 -.29 -.01 .20 -.06 .26	Standardised values on 16 variables
3.28 3.11 3.21 1.68 3.33 4.49 9.64 8.55 5.54 2.97 3.01 3.05 .00	Euclidian `distance' of stratum to each of the 13 modern topsoils
.00 1.68 2.97 3.01 3.05 3.11 3.21 3.28 3.33 4.49 5.54 8.55 9.64	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 ZB1 ZD1 ZC1 GH1 LUCB1 VAL1 ROOI1 MOUNV1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK2	SITE AND STRATUM DETAILS
1.38 1.05 .53 -1.11 -1.02 -1.01 -.45 .86 .26 -1.13 -1.03 .94 .29 -.13 -.72 -.47	Standardised values on 16 variables
5.79 7.15 6.67 5.93 4.61 2.11 11.26 10.57 8.83 3.03 3.03 4.24 4.74	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.11 3.03 3.03 4.24 4.61 4.74 5.79 5.93 6.67 7.15 8.83 10.57 11.26	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK3	SITE AND STRATUM DETAILS
-.69 -1.21 -1.19 1.49 1.59 1.41 -1.26 -.58 .69 1.40 -1.00 1.42 .88 -.26 -.72 -.44	Standardised values on 16 variables
5.70 3.66 5.46 3.59 6.45 6.89 11.23 9.63 5.59 5.81 5.64 6.11 3.56	Euclidian `distance' of stratum to each of the 13 modern topsoils
3.56 3.59 3.66 5.46 5.59 5.64 5.70 5.81 6.11 6.45 6.89 9.63 11.23	Euclidian `distances' sorted from smallest to largest
SPEK1 WAR1 GH1 LUCB1 KAL1 ZD1 VAL1 ZB1 ZC1 ROOI1 MOUNV1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK4	SITE AND STRATUM DETAILS
1.27 1.21 .45 -1.21 -1.14 -1.12 -.68 .77 -.04 -1.00 -1.02 1.39 .86 .01 -.73 -.50	Standardised values on 16 variables
6.03 7.37 6.87 6.20 5.09 2.59 11.41 10.63 9.03 3.41 3.31 4.63 5.04	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.59 3.31 3.41 4.63 5.04 5.09 6.03 6.20 6.87 7.37 9.03 10.63 11.41	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZD1 ZB1 ZC1 SPEK1 ROOI1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK5	SITE AND STRATUM DETAILS
-.31 -.05 1.47 -.51 -.35 -.34 .09 .25 -.45 .84 -.81 .66 .29 .36 -.44 -.44	Standardised values on 16 variables
3.71 5.41 4.59 3.82 3.73 3.58 10.61 9.36 7.42 2.09 2.14 3.21 2.91	Euclidian `distance' of stratum to each of the 13 modern topsoils
2.09 2.14 2.91 3.21 3.58 3.71 3.73 3.82 4.59 5.41 7.42 9.36 10.61	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 SPEK1 ZC1 MOUNV1 VAL1 ROOI1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK6	SITE AND STRATUM DETAILS
.76 .93 .61 -1.03 -1.01 -1.10 -.06 .99 -.82 -.39 -1.00 .51 .26 -.35 -.61 -.36	Standardised values on 16 variables
4.75 6.69 5.88 5.38 3.93 1.82 10.88 10.18 8.64 2.02 2.08 3.33 4.31	Euclidian `distance' of stratum to each of the 13 modern topsoils
1.82 2.02 2.08 3.33 3.93 4.31 4.75 5.38 5.88 6.69 8.64 10.18 10.88	Euclidian `distances' sorted from smallest to largest
MOUNV1 ZB1 ZD1 ZC1 ROOI1 SPEK1 VAL1 WAR1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils
STRATUM: SPEK7	SITE AND STRATUM DETAILS
1.51 -.93 3.85 -.64 -.08 -.11 -1.34 .38 .08 -1.25 -1.12 1.61 .85 -.32 -.89 -.54	Standardised values on 16 variables
7.46 7.82 7.68 6.85 6.08 5.60 12.04 10.82 9.39 4.96 5.07 6.18 5.55	Euclidian `distance' of stratum to each of the 13 modern topsoils
4.96 5.07 5.55 5.60 6.08 6.18 6.85 7.46 7.68 7.82 9.39 10.82 12.04	Euclidian `distances' sorted from smallest to largest
ZB1 ZD1 SPEK1 MOUNV1 ROOI1 ZC1 WAR1 VAL1 LUCB1 GH1 KAL1 BD1 HOL1	Reference numbers of the corresponding modern topsoils

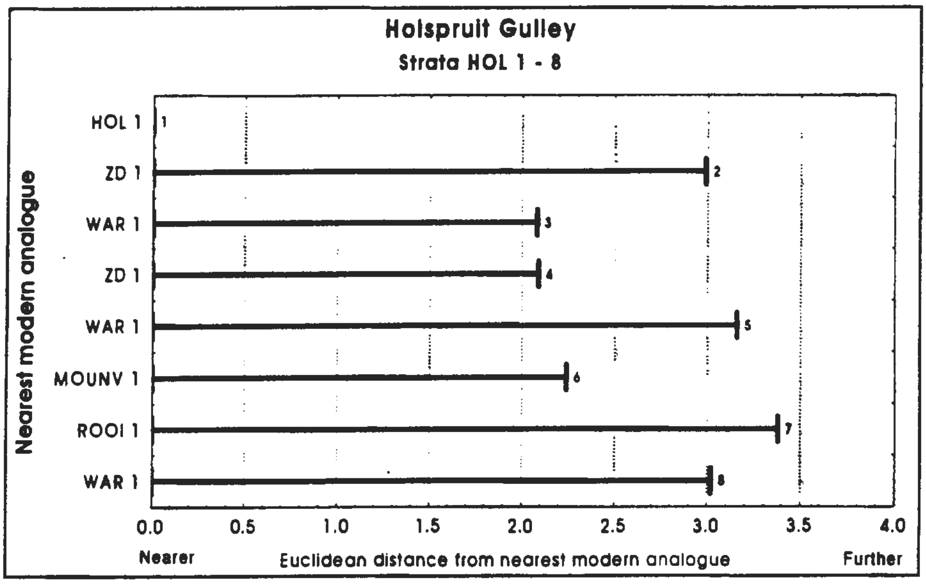
Appendix J

Graphic representation of NNIs for valley fill strata.

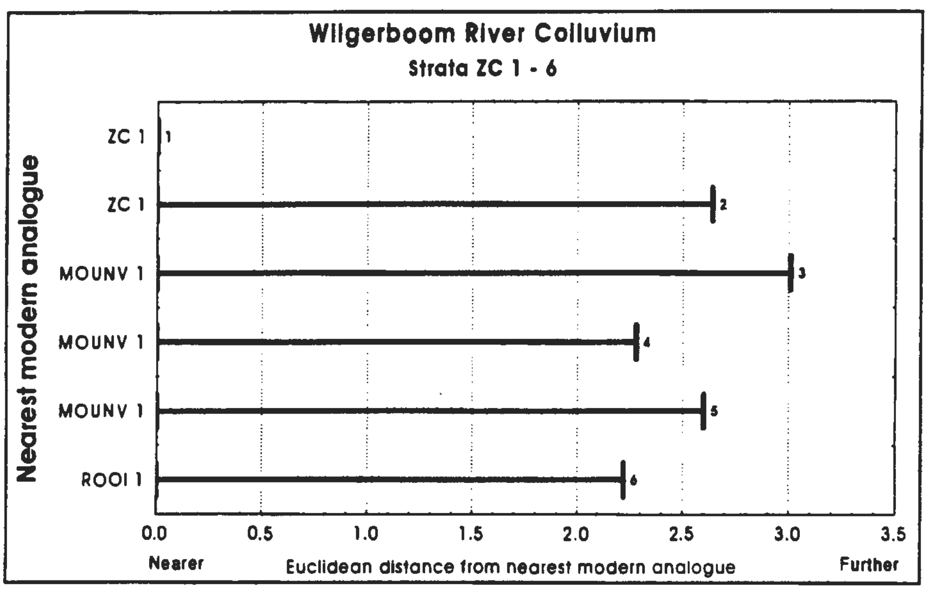
Stormberg locality

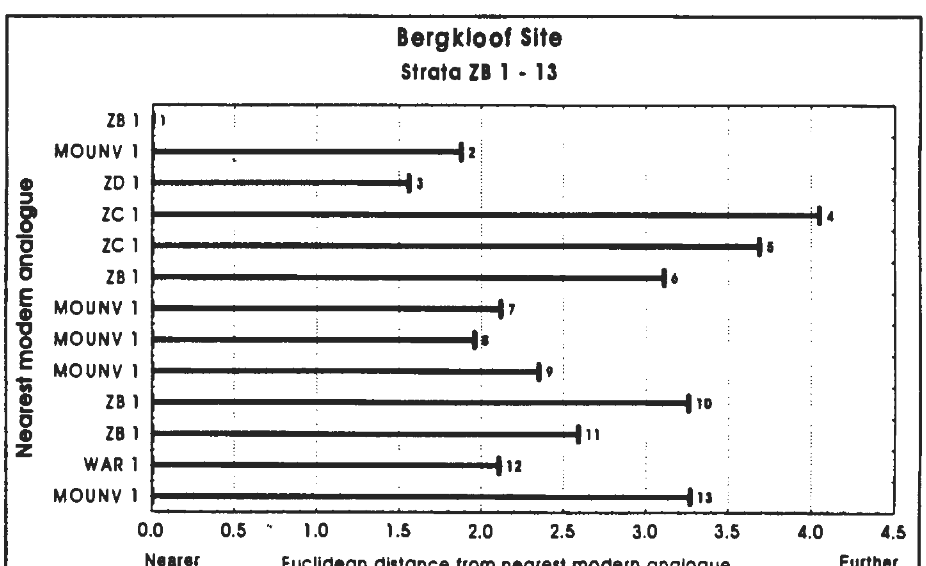


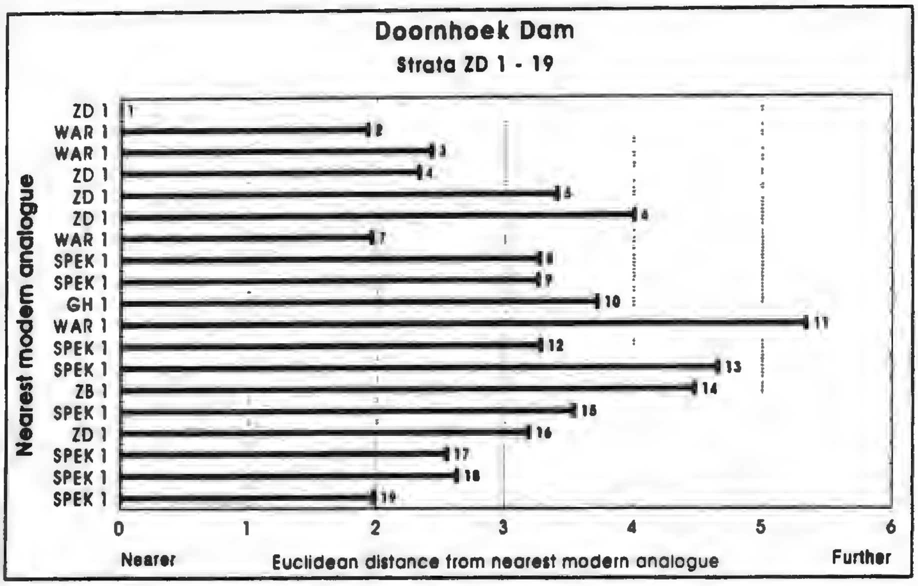


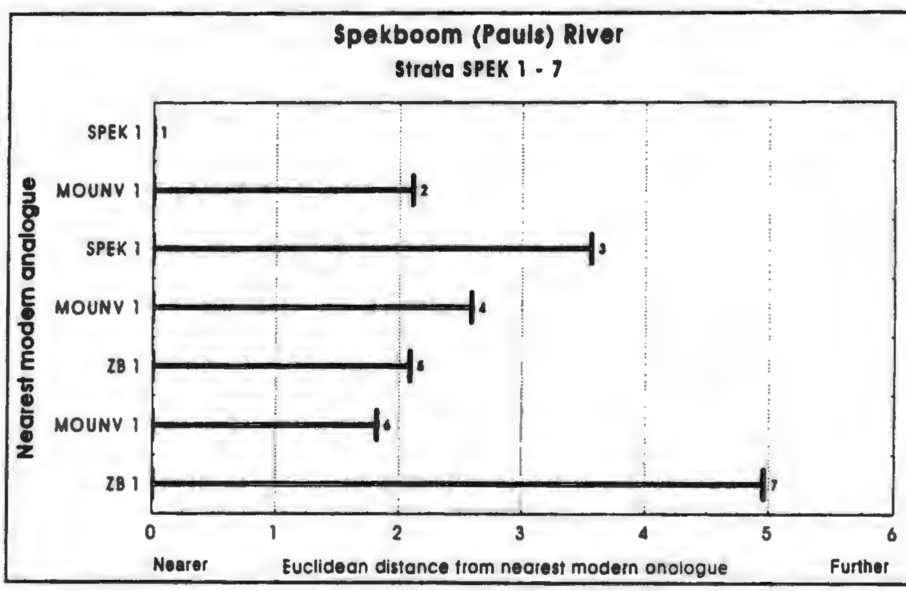


Tandjiesberg locality

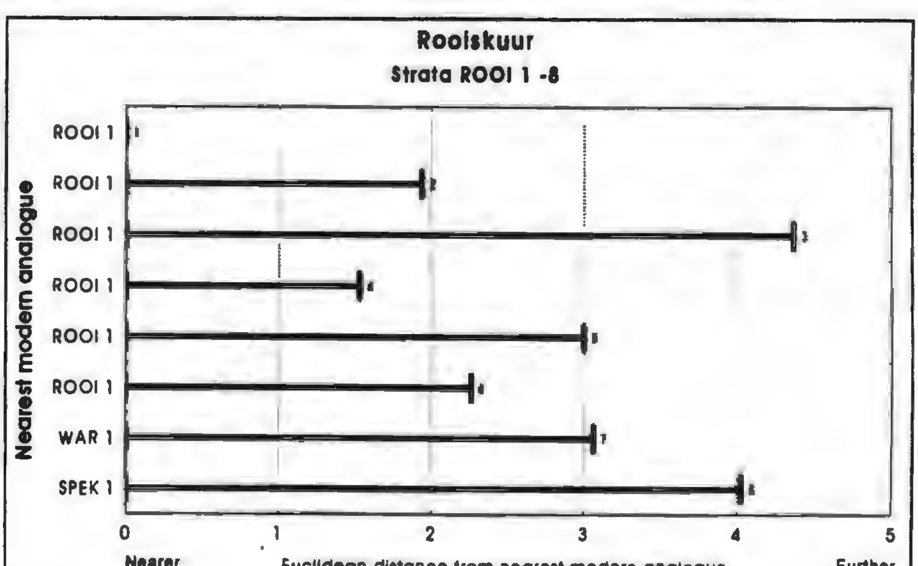


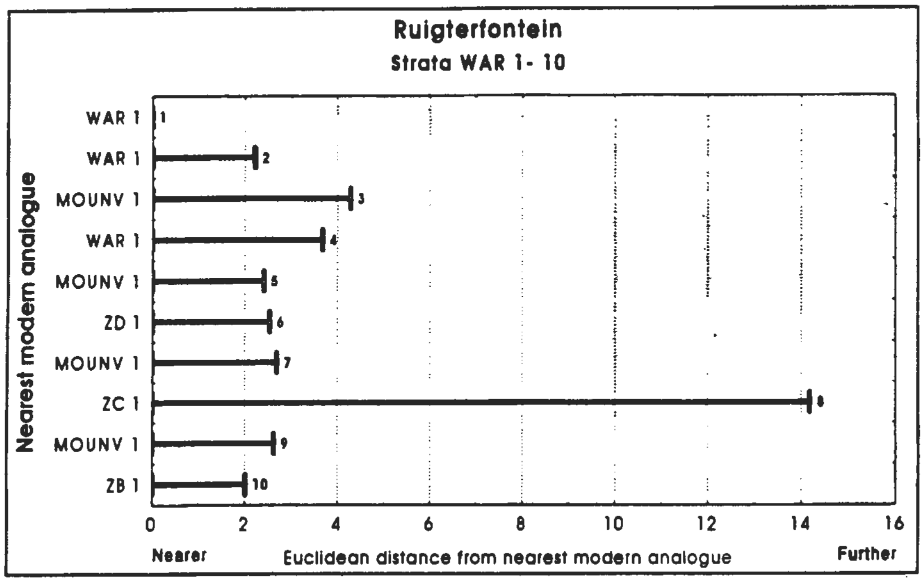


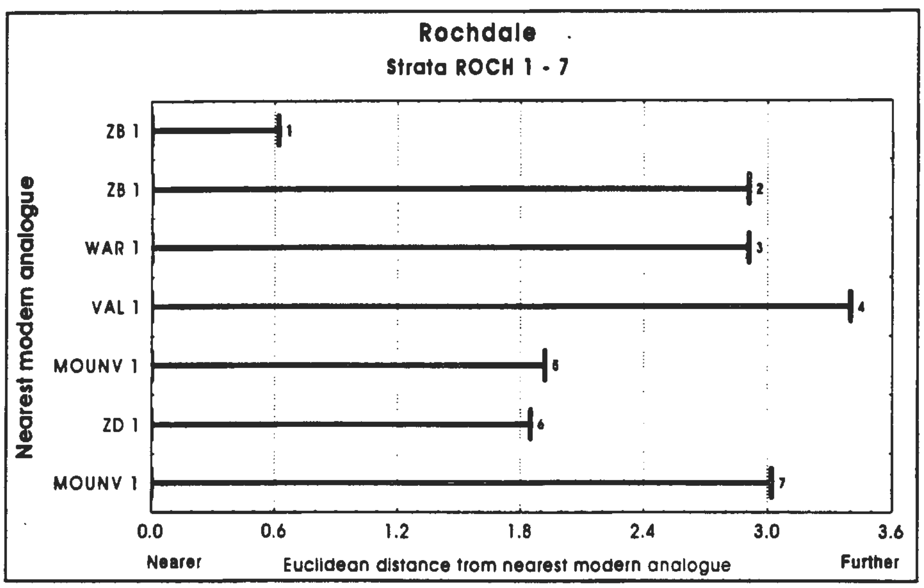




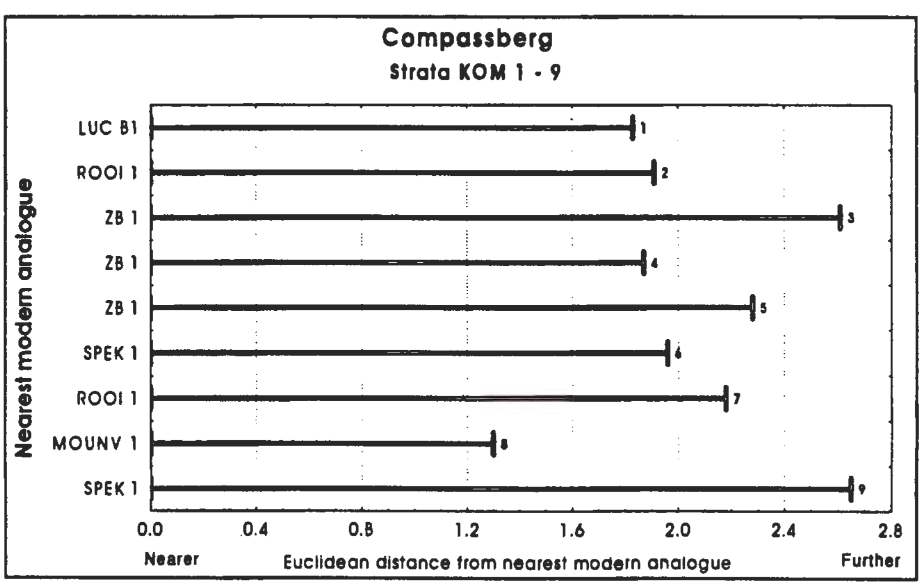
Wapadsberg locality

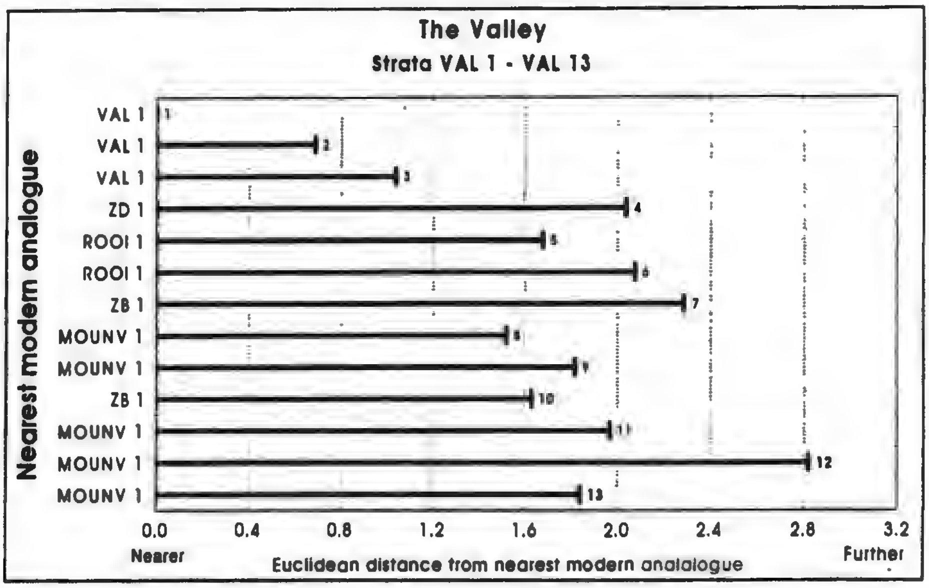


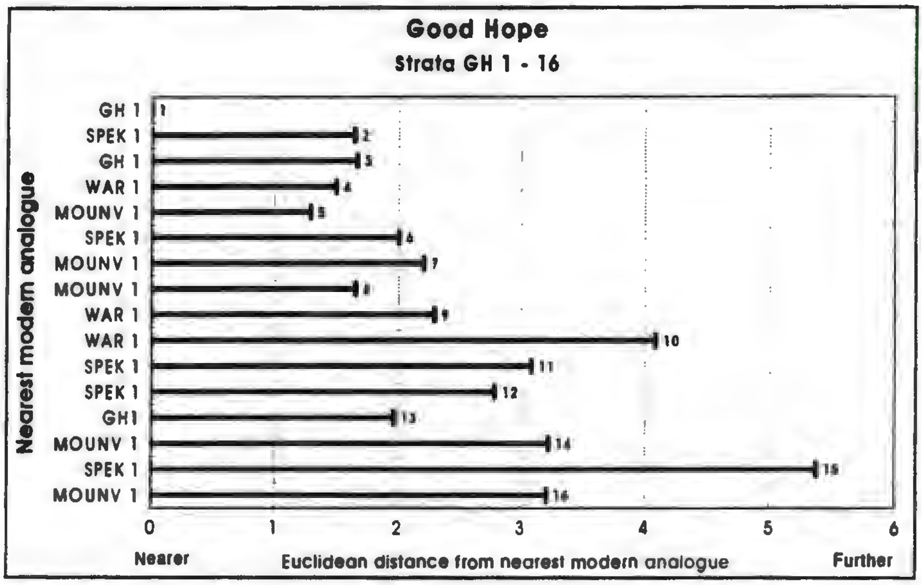


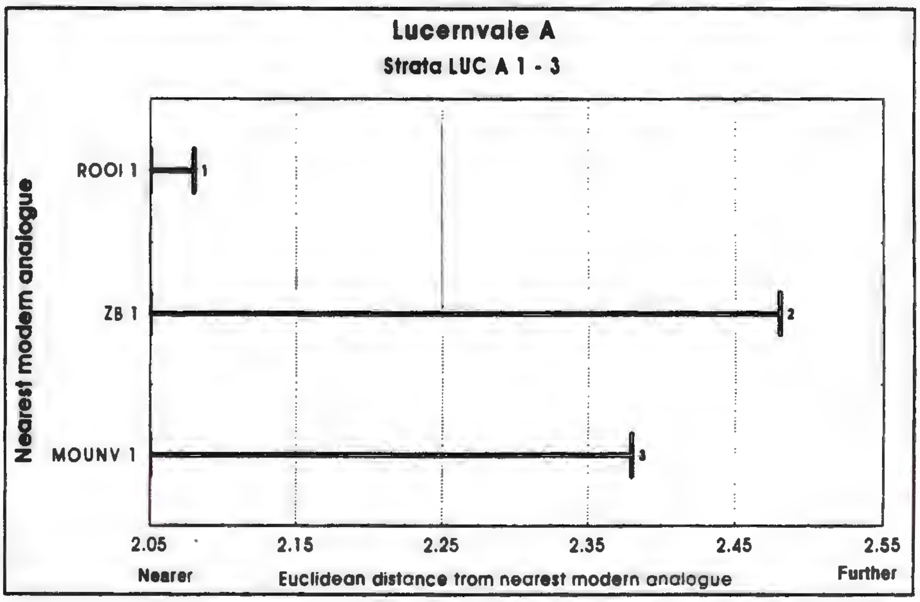


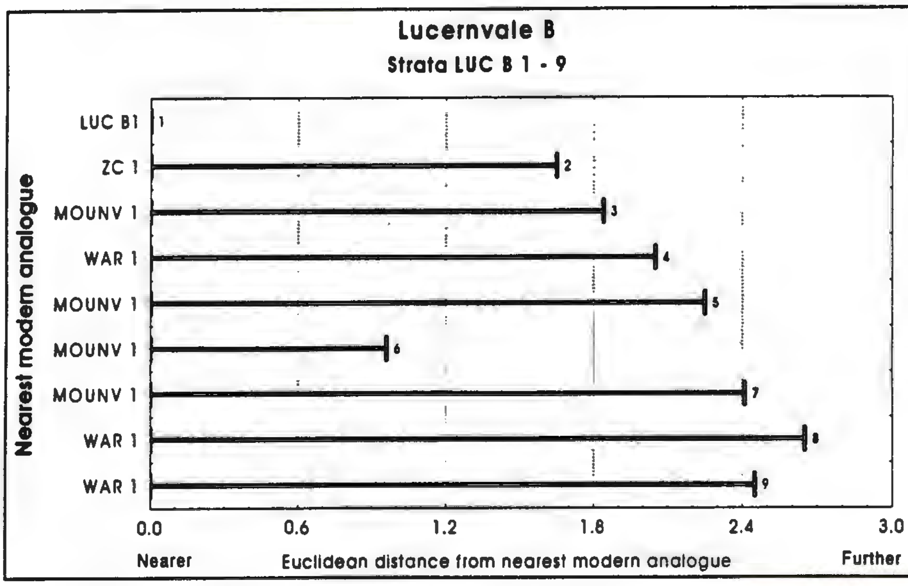
Sneeuberg locality

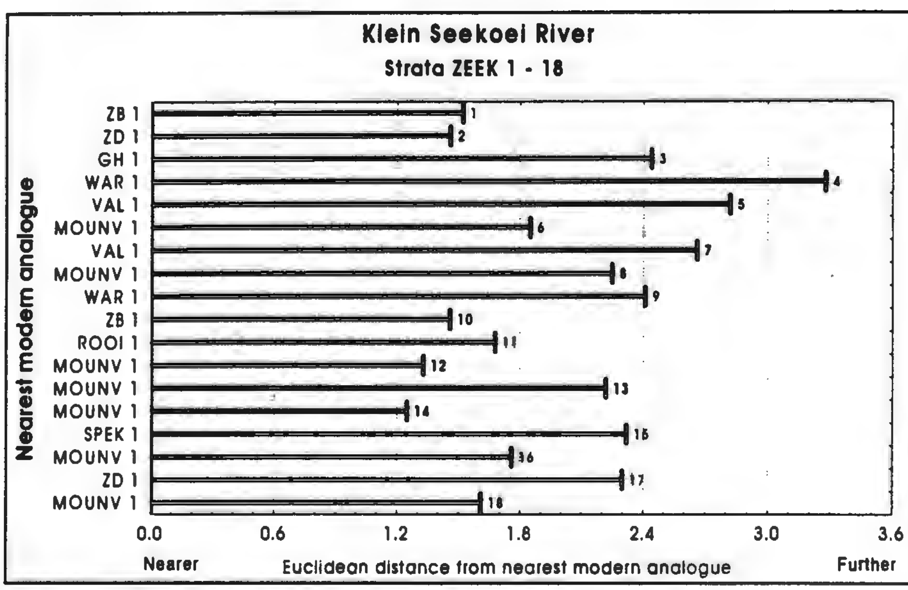



The Valley
Strata VAL 1 - VAL 13
Nearest modern analogue
VAL 1
VAL 1
VAL 1
ZD 1
ROOI 1
ROOI 1
ZB 1
MOUNV 1
MOUNV 1
ZB 1
MOUNV 1
MOUNV 1
MOUNV 1
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
Nearer
Euclidean distance from nearest modern analogue
Further

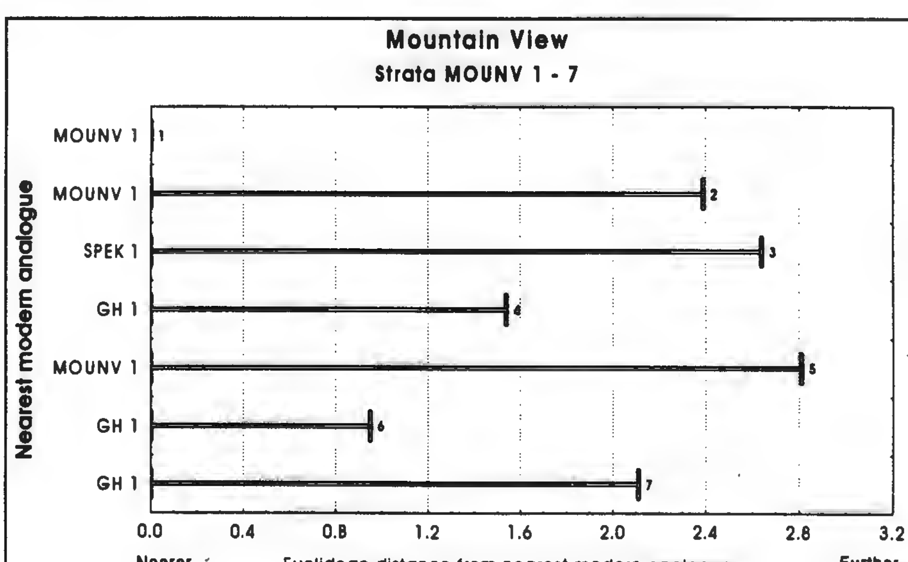

Good Hope
Strata GH 1 - 16
Nearest modern analogue
GH 1
SPEK 1
GH 1
WAR 1
MOUNV 1
SPEK 1
MOUNV 1
MOUNV 1
WAR 1
WAR 1
SPEK 1
SPEK 1
GH1
MOUNV 1
SPEK 1
MOUNV 1
0
1
2
3
4
5
6
Nearer
Euclidean distance from nearest modern analogue
Further

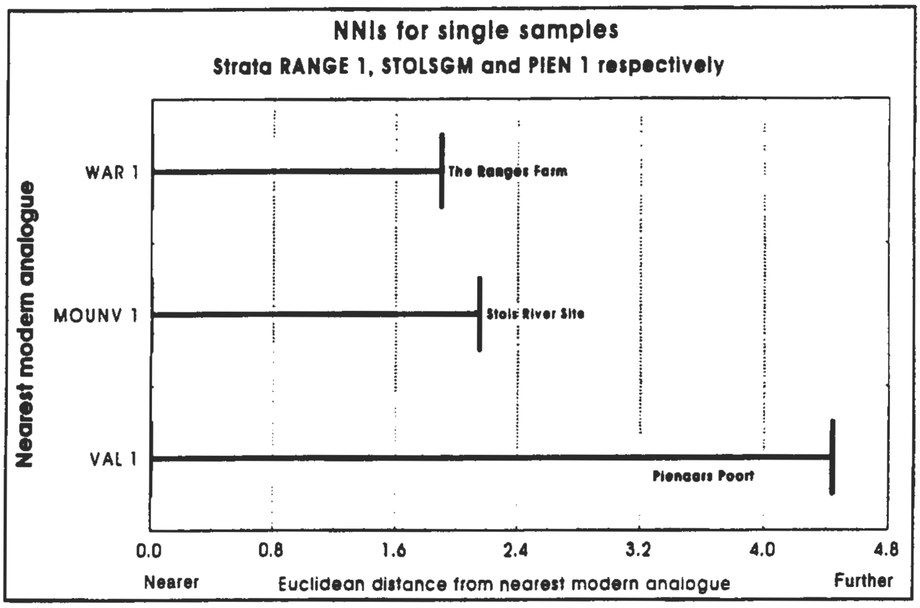

Lucernvale A
Strata LUC A 1 - 3
Nearest modern analogue
ROOI 1
ZB 1
MOUNV 1
2.05
2.15
2.25
2.35
2.45
2.55
Nearer
Euclidean distance from nearest modern analogue
Further





Nuweveldberg locality




NNIs for single samples
Strata RANGE 1, STOLSGM and PIEN 1 respectively
Nearest modern analogue
WAR 1
MOUNV 1
VAL 1
The Ranges Farm
Stols River Site
Pienaars Poort
0.0
0.8
1.6
2.4
3.2
4.0
4.8
Nearer
Euclidean distance from nearest modern analogue
Further