

**THE LATE QUATERNARY PALAEOENVIRONMENTS  
OF A SUBALPINE WETLAND IN CATHEDRAL PEAK,  
KWAZULU-NATAL DRAKENSBERG**

By

Jared Lodder

Submitted in fulfilment of the academic requirements  
for the degree of Master in Sciences  
in the Discipline of Geography,  
School of Environmental Sciences,  
University of KwaZulu-Natal,  
Pietermaritzburg.

June 2011



## ABSTRACT

In contrast to the wealth of palaeoenvironmental research stemming from the eastern Afromontane archipelago, the southern Afromontane component, which comprises largely of the Drakensberg, remains understudied. The Drakensberg constitute an area of significant biodiversity, cultural and economic importance. Suitable sites for palaeoenvironmental research are rare in South Africa due to general arid climatic conditions over much of the country. The KwaZulu-Natal Drakensberg offers a unique opportunity for palaeoenvironmental research through its increased rainfall and higher altitudes, which enable the development of wetlands that have the potential for polliniferous accumulation to occur. Catchment Six in Cathedral Peak is one such wetland that has provided an opportunity to research palaeoenvironmental conditions of the southern Afromontane archipelago component. A 371 cm sediment core was extracted from a subalpine wetland in Catchment Six and analysed using multiple proxies including; pollen, charcoal and geochemistry (carbon and nitrogen stable isotopes). A chronological framework for the core was established based on accelerated mass spectrometry radiocarbon dating of eight bulk sediment samples. A basal date of  $15,100 \pm 445$  cal yr BP was determined at a depth of 298 cm. Poor pollen preservation of the basal portion of the core limited palaeoenvironmental inference for the late Pleistocene section of the record. The multi-proxy record provides high chronological resolution for the early to late Holocene. Multi-proxy data indicate that the Holocene period in the Drakensberg was characterised by variable climatic conditions. Charcoal data indicate periods of increased regional fires in the last *ca.* 400 cal yr BP. Palaeoenvironmental inferences from the Catchment Six record are broadly in agreement with regional climatic indications based on existing literature.

## **PREFACE**

The candidate conducted the experimental work described within this dissertation in the School of Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, between March 2009 and June 2011, under the supervision of Prof T.R. Hill and Dr J.M. Finch.

This research represents original work by the author and has not been submitted in any form for any other degree or diploma to any other University. The use of other author's works has been duly acknowledged within the text.

Signed:

J. Lodder (candidate).

June 2011

Signed:

Prof T.R. Hill (supervisor).

June 2011

Signed:

Dr J.M. Finch (co-supervisor).

June 2011



## ACKNOWLEDGEMENTS

I am greatly indebted to **Prof Trevor Hill** for first introducing me to palaeoenvironmental studies in 2007 and am further indebted to **Prof Trevor Hill** and **Dr Jemma Finch** for their continued support and encouragement throughout every stage of this research. Their support has been unwavering and confidence in this research has been matched by their own passion for palaeoenvironmental research. Advice and guidance by both my supervisors, in addition to providing the necessary tools to complete this research, is greatly appreciated.

A number of individuals and institutions have provided invaluable support for this research.

**Mike Meadows, Lynne Quick and Kelly Kirsten** (UCT); **Louis Scott** (UFS); **Sven Kaehler** (IsoEnvironmental); **Ian Rushworth, Sonja Kruger and Daryn Hiltunen** (EKZNW); **Vesselina Merhar** (Leica Microsystems); **Thomas Persson** (Lund University); **Tomasz Goslar** (Poznan Radiocarbon Laboratory); **Martin Blaauw** (Queens University, Belfast); **Renny Noble** (UKZN-Botany); **Shawn Ball** (UKZN-Chemistry); **Paul Jorgenson, Anel Geer and Ruth Howison** (UKZN-Geography); **Craig Morris and Jerry Naiken** (UKZN-Grassland Science); **Louis Titshall** (UKZN-Soil Science); **Neil Roberts and Rebecca Turner** (University of Plymouth); **Alan Hogg and Fiona Petchey** (Waikato Radiocarbon Dating Laboratory).

Further thanks are extended to **Ezemvelo KZN Wildlife** (EKZNW) for providing permission to conduct this research at Cathedral Peak; **Grassland Science** (UKZN) for allowing the use of their laboratory and equipment and to **Soil Science** and **Botany** (UKZN) for the use of their equipment.

This project was made possible through funding provided by **P.A.S.T.** and the **NRF African Origins Program**. For this funding, I am forever indebted.

Thank you to my friends and family whose unwavering support throughout this journey had made this research achievable. This research would have remained a pipeline dream without all the support provided. Thank you!

# TABLE OF CONTENTS

<b>1. INTRODUCTION.....</b>	<b>1</b>
1.1. Gaining a Palaeoenvironmental Perspective on Ecosystem Processes .....	3
1.2. Research Aim and Objectives .....	5
1.3. Thesis Outline .....	5
<b>2. RESEARCH AREA .....</b>	<b>7</b>
2.1. Introduction.....	7
2.2. Site Description.....	7
2.2.1. <i>The Drakensberg Mountains</i> .....	7
2.2.2. <i>Site Location</i> .....	7
2.2.3. <i>Geology</i> .....	10
2.2.4. <i>Climate</i> .....	12
2.2.5. <i>Historical Background</i> .....	12
2.2.6. <i>Prehistory of the Drakensberg</i> .....	13
2.3. Contemporary Vegetation .....	16
2.3.1. <i>Introduction</i> .....	16
2.3.2. <i>The Vegetation of the Drakensberg</i> .....	16
2.3.3. <i>The Vegetation of Cathedral Peak</i> .....	20
2.4. Conclusion .....	23
<b>3. LITERATURE REVIEW .....</b>	<b>24</b>
3.1. Introduction.....	24
3.2. Palaeoenvironments of Eastern Africa.....	28
3.2.1. <i>Pre-Last Glacial Maximum (&gt;45,000 – 23,000 cal yr BP)</i> .....	29
3.2.2. <i>Last Glacial Maximum (23,000 – 18,000 cal yr BP)</i> .....	30
3.2.3. <i>Post-Last Glacial Maximum (18,000 – 13,000 cal yr BP)</i> .....	31
3.2.4. <i>Younger Dryas (13,000 – 11,700 cal yr BP)</i> .....	33
3.2.5. <i>Early Holocene (11,700 – 6000 cal yr BP)</i> .....	34
3.2.6. <i>Late Holocene (6000 cal yr BP – Present)</i> .....	36
3.3. Palaeoenvironments of Southern Africa .....	37
3.3.1. <i>Pre-Last Glacial Maximum (&gt;45,000-23,000 cal yr BP)</i> .....	38
3.3.2. <i>Last Glacial Maximum (23,000-18,000 cal yr BP)</i> .....	39
3.3.3. <i>Post-Last Glacial Maximum (18,000-13,000 cal yr BP)</i> .....	39
3.3.4. <i>Younger Dryas (13,000-11,700 cal yr BP)</i> .....	40
3.3.5. <i>Early Holocene (11,700 – 6000 cal yr BP)</i> .....	40
3.3.6. <i>Late Holocene (6000 cal yr BP – Present)</i> .....	42

3.4. Synthesis of Eastern and Southern African Palaeoenvironments .....	43
3.5. Conclusion .....	44
<b>4. THEORETICAL METHODOLOGY .....</b>	<b>45</b>
4.1. Introduction .....	45
4.2. Pollen Analysis .....	45
4.3. Critique of Pollen Analysis .....	46
4.4. Charcoal Analysis .....	52
4.5. Critique of Charcoal Analysis .....	56
4.5.1. <i>Microscopic Charcoal Analysis</i> .....	56
4.5.2. <i>Digestion-Combustion Charcoal Analysis</i> .....	58
4.5.3. <i>Comparison of Charcoal Analysis Techniques</i> .....	59
4.6. Geochemical Analysis.....	59
4.6.1. <i>Stable Carbon Isotope Analysis</i> .....	60
4.6.2. <i>Critique of Stable Carbon Isotope Analysis</i> .....	65
4.6.3. <i>Stable Nitrogen Isotope Analysis</i> .....	65
4.6.4. <i>Critique of Stable Nitrogen Isotope Analysis</i> .....	67
4.7. Radiocarbon Analysis .....	68
4.8. Critique of Radiocarbon Analysis .....	69
4.9. Conclusion .....	72
<b>5. METHODS .....</b>	<b>74</b>
5.1. Introduction .....	74
5.2. Field Techniques .....	74
5.2.1. <i>Wetland Depth Profile</i> .....	74
5.2.2. <i>Coring Procedure</i> .....	76
5.3. Laboratory Techniques .....	78
5.3.1. <i>Stratigraphy</i> .....	78
5.3.2. <i>Sub-sampling</i> .....	78
5.3.3. <i>Radiocarbon Dating and Chronological Control</i> .....	79
5.3.4. <i>Gravitational-Separation Technique</i> .....	79
5.3.5. <i>Pollen Analysis</i> .....	79
5.3.6. <i>Charcoal Analysis</i> .....	80
5.3.7. <i>Geochemical Analysis</i> .....	81
5.3.8. <i>Data Zonation and Diagrams</i> .....	82
5.4. Conclusion .....	84
<b>6. RESULTS .....</b>	<b>85</b>
6.1. Introduction .....	85
6.2. Stratigraphy .....	85

6.3. Chronology .....	87
6.4. Pollen Diagrams .....	91
6.5. Description of Pollen Results .....	108
6.5.1. Zone CVI-1: 300-248 cm; 15,490-7130 cal yr BP .....	109
6.5.2. Zone CVI-2: 248-205 cm; 7130-5760 cal yr BP .....	109
6.5.3. Zone CVI-3: 205-117 cm; 5760-2190 cal yr BP .....	110
6.5.4. Zone CVI-4: 117-53 cm; 2190-890 cal yr BP .....	110
6.5.5. Zone CVI-5: 53-0 cm; 890-present cal yr BP .....	111
6.6. Charcoal and Geochemical Diagrams .....	111
6.7. Description of Charcoal and Geochemical Results .....	113
6.7.1. Zone CVI-1: 300-248 cm; 15,489.7-7129 cal yr BP .....	114
6.7.2. Zone CVI-2: 248-205 cm; 7129-5757.9 cal yr BP .....	114
6.7.3. Zone CVI-3: 205-117 cm; 5757.9-2185.3 cal yr BP .....	114
6.7.4. Zone CVI-4: 117-53 cm; 2185.3-893.2 cal yr BP .....	117
6.7.5. Zone CVI-5: 53-0 cm; 893.2-present cal yr BP .....	117
6.8. Conclusion .....	117
<b>7. DISCUSSION .....</b>	<b>118</b>
7.1. Introduction .....	118
7.2. Palaeoenvironments of the Cathedral Peak Region .....	118
7.2.1. Zone CVI-1: 300-248 cm; 15,490-7130 cal yr BP .....	119
7.2.2. Zone CVI-2: 248-205 cm; 7130-5760 cal yr BP .....	120
7.2.3. Zone CVI-3: 205-117 cm; 5760-2190 cal yr BP .....	122
7.2.4. Zone CVI-4: 117-53 cm; 2190-890 cal yr BP .....	123
7.2.5. Zone CVI-5: 53-0 cm; 890-present cal yr BP .....	124
7.3. Conclusion .....	125
<b>8. CONCLUSION.....</b>	<b>127</b>
8.1. Introduction .....	127
8.2. Review of the Aim and Objectives .....	127
8.3. Future Research Directions .....	130
8.4. Conclusion .....	130
<b>REFERENCES .....</b>	<b>132</b>
<b>APPENDICES .....</b>	<b>I</b>

## LIST OF FIGURES

Figure 2.1: Location of the uKhahlamba-Drakensberg Park.....	8
Figure 2.2: Location of the research site, Catchment Six, Cathedral Peak .....	9
Figure 2.3: Geological transect of Cathedral Peak passing through Catchment Six .....	11
Figure 2.4: Summary of geological and archaeological time periods” .....	13
Figure 3.1: Map of Africa indicating the locations of the Afromontane archipelago .....	25
Figure 3.2: Palynological sites of eastern Africa in the Afromontane archipelago.....	28
Figure 3.3: Palynological sites in southern Africa within the Afromontane archipelago .....	38
Figure 3.4: Summary of wetter and drier conditions from southern and eastern Africa .....	43
Figure 4.1: Relationship between basin size and pollen source area.....	48
Figure 4.2: $\delta^{13}\text{C}$ ranges for terrestrial and aquatic vegetation .....	63
Figure 4.3: Distribution pattern of $\text{C}_3$ and $\text{C}_4$ grasses in South Africa .....	64
Figure 4.4: Nitrogen inputs .....	66
Figure 4.5: Radiocarbon decay curve.....	68
Figure 5.1: Schematic of the wetland depth profile .....	75
Figure 5.2: Parallel sampling point and overlapping coring strategy.....	78
Figure 6.1: Stratigraphic description of the 300 cm sediment core.....	86
Figure 6.2: Sedimentation rate curve of Catchment Six, Cathedral Peak. ....	90
Figure 6.3: Calibration curves for each $^{14}\text{C}$ Date. ....	91
Figure 6.4: 248 cm regional pollen (1 of 3) .....	93
Figure 6.5: 248 cm regional and local pollen (1 of 3).....	96
Figure 6.6: 248 cm regional and local pollen summary (1 of 2) .....	99
Figure 6.7: 300 cm regional and local pollen summary (1 of 2) .....	101
Figure 6.8: 248 cm arboreal and non-arboreal pollen summary (1 of 2).....	103
Figure 6.9: CONISS and zonation of regional pollen data.....	105
Figure 6.10: 248 cm palynological richness and rate of change analysis on regional pollen diagram.....	106
Figure 6.11: 300 cm rate of change analysis on regional pollen diagram.....	107
Figure 6.12: PCA of pollen samples .....	108
Figure 6.13: PCA of geochemical data .....	112
Figure 6.14: $\delta^{13}\text{C}$ vs. C/N relationship .....	113
Figure 6.15: 300 cm geochemical and charcoal (1 of 2) .....	115

## LIST OF TABLES

Table 2.1: Nomenclature of the Drakensberg grasslands .....	18
Table 3.1: Details of pollen sites from southern and eastern Africa referenced in the text.....	26
Table 4.1: Aquatic and terrestrial plant $\delta^{13}\text{C}$ range values .....	62
Table 5.1: Summarised statistics performed in Psimpoll .....	82
Table 6.1: Radiocarbon dating results from Catchment Six, Cathedral Peak .....	89
Table 6.2: Sedimentation rates .....	90
Table 6.3: Summary of zonation .....	105
Table 6.4: Pollen PCA results .....	108
Table 6.5: Geochemical PCA results .....	112

## LIST OF EQUATIONS

Equation 4.1: Determination of the PDB isotopic standard .....	62
Equation 5.1: Digestion-Combustion charcoal technique formula .....	81



## LIST OF PLATES

Fronticepiece: Scenes from Cathedral Peak.....	ii
Plate 2.1: Catchment Six research site, Cathedral Peak .....	9
Plate 2.2: The knickpoint below the Catchment Six research site .....	10
Plate 2.3: <i>Podocarpus latifolius</i> forest at Cathedral Peak .....	21
Plate 4.1: <i>Podocarpus</i> (left) and <i>Acacia mearnsii</i> (right) pollen.....	47
Plate 4.2: Poaceae (left) and Cyperaceae (right) pollen .....	51
Plate 5.1: Conducting the wetland depth profile .....	76
Plate 5.2: Four-meter extension Russian Corer in Catchment Six .....	77
Plate 5.3: Attempting to get the Russian Corer through dense, consolidated material .....	77
Plate 6.1: Extracted sediment cores.....	87

## LIST OF APPENDICES

Appendix A: Complete Species List of Cathedral Peak, Drakensberg .....	i
Appendix B: Gravitational ‘Swirling’ Separation Technique .....	xli
Appendix C: Morphological, preservation and dispersal characteristics of major palynomorphs .....	xlii
Appendix D: Combustion-Digestion Technique .....	lxi
Appendix E: Catchment Six Calibrated Ages .....	lxii
Appendix F: Interpolated Calibrated Ages .....	lxiii
Appendix G: 300 cm Regional and Local Pollen Diagram (1 of 3) .....	lxix
Appendix H: Raw Pollen Counts .....	lxxii
Appendix I: Paired T-Test Statistical Results from Charcoal Technique Comparison .....	lxxxiv
Appendix J: Raw Digestion-Combustion Charcoal Values .....	lxxxv
Appendix K: Raw Microscopic Charcoal Counts .....	lxxxvii
Appendix L: Raw Geochemical Values .....	lxxxix

## LIST OF ABBREVIATIONS

‰	Parts per million
$\delta^{13}\text{C}$	Ratio of $^{12}\text{C}$ / $^{13}\text{C}$
$^{12}\text{C}$	Carbon-12 isotope
$^{13}\text{C}$	Carbon-13 isotope
$^{14}\text{C}$	Radiocarbon
$\delta^{15}\text{N}$	Ratio of $^{14}\text{N}$ / $^{15}\text{N}$
$^{14}\text{N}$	Nitrogen-14 isotope
$^{15}\text{N}$	Nitrogen-15 isotope
AMS	Accelerated Mass Spectrometry
AP	Arboreal
APD	African Pollen Database
BP	Before Present (starting at 1950)
C	Carbon
$\text{C}_3$	Calvin-Benson metabolic carbon fixation pathway
$\text{C}_4$	Hatch-Slack metabolic carbon fixation pathway
Ca	Calcium
<i>Ca.</i>	Approximately
Cal	Calibrated
CAM	Crassulaceam Acid Metabolism
$\text{CO}_2$	Carbon dioxide
$^{12}\text{CO}_2$	Carbon-12 isotope of carbon dioxide
CONNISS	Constrained Incremental Sum of Squares
C/N	Carbon:Nitrogen ratio
CVI-	Catchment Six (wetland in Cathedral Peak)
DW	Dry Weight
EAM	Eastern Arc Mountains
EIA	Early Iron Age
ESA	Early Stone Age
F	Fluorine
H	Hydrogen
IntCal	International Calibration curve
ITCZ	Intertropical Convection Zone
IW	Ignition Weight
Ka	Thousand of years

LGM	Last Glacial Maximum (23,000-18,000 cal yr BP)
LIA	Late Iron Age
LSA	Late Stone Age
Ma	Million
MIA	Middle Iron Age
MSA	Middle Stone Age
N	Nitrogen
N <sub>2</sub>	Nitrogen (in molecular form)
N <sub>2</sub> O	Nitrous oxide
NAD-me	Nicotinamide adenine dinucleotide malate dehydrogenase enzyme
NADP-me	Nicotinamide adenine dinucleotide phosphate malate dehydrogenase enzyme
NAP	Non-arboreal
NW	Nitric acid weight
O	Oxygen
O <sub>2</sub>	Oxygen (in molecular form)
P	Phosphorous
PCA	Principle Component Analysis
PCK	Phosphoenolpyruvate carboxykinase enzyme
pCO <sub>2</sub>	Partial CO <sub>2</sub>
PDB	Pee Dee Belemnite standard
SHCal	Southern Hemisphere Calibration curve
TDIC	Total dissolved inorganic carbon
YD	Younger Dryas event (13,000-11,700 cal yr BP)

# CHAPTER ONE

## 1. INTRODUCTION

Climate change is not a phenomenon<sup>1</sup>; rather it is a norm that has occurred throughout the Earth's history at varying spatial and temporal resolutions ranging from local to global and gradual to rapid respectively (Rafferty 2011). Changes in climatic conditions are a result of variability between forcing factors with solar radiation being the primary driving force behind climate. Climate change research must incorporate research of all interacting forces that affect the climate over extensive periods beyond millions of years (Rafferty 2011). The rapid rate of climate change during the late Holocene has been primarily attributed to anthropogenic influences, particularly through the burning of fossil fuels (Rafferty 2011). The Earth's natural feedback system to emit longwave radiation back into the atmosphere is restricted by the increased presence of greenhouse gases from the burning of fossil fuels. Greenhouse gases trap longwave radiation, which increases temperatures, affects the type of vegetation and re-affects temperatures (Rafferty 2011).

This recent period of climate change represents a fraction of the climatic instability that has occurred during the late Quaternary period (Walker 2005), spanning the last 2.5 Ma yr BP (million years before present), which has resulted in considerable impacts on global floral and faunal distributions patterns (Meadows and Hill 2002; Meadows *et al.* 1987). Vegetation distribution exists in a dynamic equilibrium with climate (Meadows and Hill 2002) with vegetation having a quick response time to climate change (Ficken *et al.* 2002). Under varying climatic conditions, vegetation habitats will shift along altitudinal and latitudinal gradients to reside in areas under optimal climatic conditions to enable reproduction and growth. Vegetation responds to changes in climate and climate may be directly affected by shifting vegetation belts; thus a feedback system occurs between climate and vegetation (Jain 2009). Despite the knowledge of these feedback processes, current vegetation distribution patterns and the response of vegetation to climatic variability in Africa remain poorly understood (Rucina *et al.* 2009; Hopley *et al.* 2007). Vegetation responds to climate changes in different ways, either by becoming locally extinct from an area or by shifting its altitudinal boundaries (Hamilton and Taylor 1991); however, vegetation does not always respond to climate change in the same way (Hamilton and Taylor 1991) and this forms an important research component of the effects of climate change.

---

<sup>1</sup> The rate of climate change is the 'real' phenomenon with climate change.

Proxy data sources including; pollen, geochemistry and dendrochronology, are used to determine historic and pre-historic climate change events. These proxy sources provide indirect evidence of the climatic variability of the Earth (Walker 2005). Pollen analysis is a common method used in palaeoenvironmental research to provide insight into how vegetation has adapted under fluctuating climatic conditions in the past (Hamilton and Taylor 1991; Hopley *et al.* 2007). An understanding of past vegetation distribution patterns will enable a better understanding of present and future distribution patterns (Meadows and Hill 2002) under varying spatial and temporal scales (Marchant 2010) to minimise global loss in biodiversity (Norström *et al.* 2008). To gain such knowledge, research should be undertaken in areas that are strongly and quickly influenced by climatic fluctuations (White 1978). One such area that could be beneficial for this research is the Afromontane archipelago region (White 1978), which occurs throughout Africa.

The Afromontane archipelago is located on mountainous topography that has been divided into altitudinal zones (White 1978). Each zone is heavily influenced by climatic conditions, primarily; humidity, temperature and altitude with fire forming an important component in the continuation of these zones (White 1978). The Afromontane region extends from South Africa into eastern and northern Africa at various altitudes. These regions in South Africa are difficult to identify due to the climatic and altitudinal variations that exist within the country. Within South Africa, the Afromontane region occurs at high altitudes in the Drakensberg<sup>2</sup> and near sea-level in the Knysna region (White 1978). An understanding of the processes within these regions can contribute for furthering an understanding of vegetation response to climatic changes; however, the Drakensberg is of particular interest as the current research is located within the Drakensberg Afromontane archipelago of Africa. The research site, which this dissertation is based, lies within the Drakensberg Afromontane region; therefore, is suitably located to gain further understanding of Afromontane grasslands.

Afromontane grassland research is useful in understanding vegetation response mechanisms under varying climatic conditions as grasslands have relatively short life-cycles and rapid response time to climate change compared with arboreal taxa (Ficken *et al.* 2002; White 1978). The Drakensberg contains high-levels of biodiversity, endemism, species richness (Carbutt and Edwards 2006, 2004) and within the Drakensberg Alpine Centre (DAC) 55% of endemics require protection as they are listed in the Orange and Red Data lists of South Africa (Carbutt

---

<sup>2</sup> The suffix 'berg' means mountains in Afrikaans; therefore, the mountain range known as the Drakensberg is referred to simply as Drakensberg.

and Edwards 2006). The Drakensberg has been recognized as an important water catchment area since the early 1900s with increased research focussing on catchment management and hydrological processes occurring from the 1980s (Sandwith and Pfothenauer 2002). The climatic and topographical features of the Drakensberg are constituents for the high endemism that occurs within this region; however, the role of fire is an important factor in understanding the existing vegetation dynamics of the region.

The Afromontane region has been characterised as fire-dominated systems with the Drakensberg being largely dominated by fire-climax grasslands communities (White 1978). Fire has been attributed a primary factor in regulating the expansion and contraction of Afromontane forests and grasslands (Everard 1986). Afromontane forests are considered the climax community while Afromontane grasslands are considered secondary fire-climax communities (Everard 1986; Killick 1963). The debate for the decrease in forests and simultaneous increase in grasslands as a result of increased fire activity by humans has been suggested for the Drakensberg area (Everard 1986). Within the Afromontane regions, it is believed that human impact, predominately from forest clearance for fuel and settlement needs, has resulted in the rapid decline of Afromontane forest throughout Africa in conjunction with the rapid increase in Afromontane grassland (Rucina *et al.* 2009; White 1978). Pollen analysis from the Afromontane region indicate that forests expanded during cooler conditions and shifted down-slope, whereas in warmer conditions forests contracted and shifted up-slope (Coetzee and van Zinderen Bakker 1970). The extent of anthropogenic influence on the distribution of grasslands has been disputed and the pollen record does not indicate that forests occupied a far greater expanse during the last glacial period (Hamilton 1981). Grasslands have been widespread throughout Africa prior to human occupation and influence, which attests to the vulnerability of grasslands to climate (Meadows and Linder 1993). Furthermore, fire regimes can be both a cause of climate change and can be the result of climate change as fire is controlled by climatic conditions and the after-effects of fire can result in climatic variability by changing the albedo, moisture and soil nutrient availability in an ecosystem (Daniau *et al.* 2010). Therefore, the role of climate and fire in the Afromontane region are important considerations when trying to understand how vegetation responds under varying conditions. These considerations have a direct impact on the conservation strategies employed to protect biodiversity.

### **1.1. Gaining a Palaeoenvironmental Perspective on Ecosystem Processes**

The southern Hemisphere has had limited palaeoenvironmental research conducted compared with the northern Hemisphere, particularly in palaeo-vegetation studies, predominately due to the general arid conditions reducing the number of viable sites for the production and preservation of polliniferous deposits (Finch and Hill 2008; Scott 1984; Meadows *et al.* 1987;



van Zinderen Bakker 1995). Suitable locations for palaeoenvironmental research throughout Africa are often restricted to i) high-altitude vleis<sup>3</sup> where temperatures are cooler and there is an increase in precipitation and ii) lakes (Meadows *et al.* 1987). Less than optimal sites (Nyakale and Scott 2002) are being utilized made possible through new proxy data sources and techniques (Chase and Meadows 2007) extending to less-optimal sediment depositional sites. The need for palaeoenvironmental research in southern Africa using case studies has long been recognised (Meadows and Meadows 1988) to provide the knowledge used in predicting the effects of climate change on vegetation and natural resources to enable conservancy measures to deal adequately with climate change (Sieben *et al.* 2009). Furthermore, reliable palaeoenvironmental data needs to be generated and incorporated into models to improve simulated climate change scenarios, which would result in better conservation policies being developed to benefit and protect biodiversity and natural resources in the long-term (Meadows *et al.* 1987; Marchant 2010; Gillson and Willis 2004). Conditions derived from palaeoenvironmental research should be incorporated into conservation policies (Hamilton 1981) to enable successful long-term decisions in conservation practices that will protect biodiversity and protect resources needed for human survival (Marchant 2010). The localities of protected areas should be continually re-assessed to ensure that these areas are and will in the future protect the greatest amount of genetic diversity (Marchant 2010).

A fundamental aim of conservation is to increase the resilience and persistence of species within an ecosystem (Willis and Bhagwat 2010) so that they have the best chance of survival under climatic change. To conduct this, ecosystem processes must be recognised and understood. Conservation must consider the distribution ranges of vegetation in relation to the physical boundaries of protected areas and by modelling varying climatic conditions. Species will migrate in and out of the protected areas and those species that migrate out of protected areas have a significant chance of being exploited by humans through a lack of protection (Marchant 2010). A concern with models is that short-term data are primarily used while long-term palaeoenvironmental data has been excluded, which results in general approximations of scenarios and ultimately misguided and ill-informed conservation policies been developed that cannot realistically achieve its primary function of protecting biodiversity over the long-term. One reason for the lack of inclusion of palaeoenvironmental data into models is the belief that past climatic changes, which have occurred over a longer period have little bearing on the effects of the current rapid rate of change; therefore, the past cannot be used to infer the future (Willis and Bhagwat 2010). This belief is misguided due to the successful and high adaptability of vegetation in the past to climatic changes. Understanding that vegetation has the ability to

---

<sup>3</sup> Vlei is an alternative term for a marsh

adapt in the past will enable better decision-making to protect vegetation and biodiversity in the future (Willis and Bhagwat 2010) and this can be achieved through palaeoenvironmental research.

Despite increased awareness of consequences of climate change, the importance of grasslands and the role of palaeoenvironmental research to inform models and test hypotheses on the response of vegetation dynamics under different climatic conditions, there is still a lack of understanding of how vegetation has responded spatially and temporally to climate change in the past (Rucina *et al.* 2009). It is vital to continue research, specifically palaeoenvironmental research, to assist with developing effective conservation policies. This research was undertaken to assist with the task of contributing further information regarding palaeoenvironmental change in the Drakensberg Afromontane region. To accomplish this task a number of objectives were developed to achieve the aim of this research.

## **1.2. Research Aim and Objectives**

The aim of this research is to use multi-proxy data to investigate and describe the palaeoenvironments of the subalpine belt of Cathedral Peak in the KwaZulu-Natal Drakensberg. Specific objectives are;

- i. To conduct a wetland depth profile to identify a suitable coring location to extract a minimally disturbed semi-continuous sediment core,
- ii. To map the stratigraphy of the extracted core,
- iii. To create a suitable reference collection for the identification of fossil pollen within the extracted sediment,
- iv. To apply a multi-proxy analysis, which includes; pollen, charcoal and geochemistry (stable carbon and nitrogen isotope) analyses through a suitable sub-sampling strategy,
- v. To establish a chronological framework using radiocarbon dating,
- vi. To determine the sediment accumulation rates of the wetland in the Drakensberg, and
- vii. To conduct data analysis and interpretation to investigate potential climatic changes and its impact on vegetation distributions.

## **1.3. Thesis Outline**

The purpose of this chapter has been to provide the rationale for conducting this research and to provide the aim and objectives that have guided this research. Chapter Two provides a site description, which includes; a prehistory discussion and historical background of the Drakensberg, the natural features of the area and the vegetation commonly found within the research site and the broader Drakensberg region. A literature review, contextualising this

research within the broader framework of pollen analysis research from the Afromontane archipelago of southern and eastern Africa is provided in Chapter Three. Chapter Four discusses the theoretical basis of the multi-proxy analyses, namely; pollen, charcoal, geochemical and radiocarbon analyses and their associated limitations. The methods employed to achieve the aim and objectives are described in Chapter Five and the results from the methods are provided in Chapter Six. A discussion of the results is provided in Chapter Seven with a palaeoenvironmental reconstruction of the research area. Finally, Chapter Eight provides a review of the initial aim and objectives, which includes a critical assessment of the research.

## **CHAPTER TWO**

### **2. RESEARCH AREA**

#### **2.1. Introduction**

This chapter contextualizes the research area of the current research. This is conducted through a brief site description of the geographical location of the Drakensberg and Cathedral Peak within South Africa. The geology, climate, historical and prehistorical background of the Drakensberg are briefly discussed as an introduction to the contemporary environmental conditions that have affected and shaped the Drakensberg. In addition, the contemporary vegetation of the Drakensberg and Cathedral Peak is described to provide insight into the floral diversity and to contextualize the current research within the wider literature of the Drakensberg vegetation.

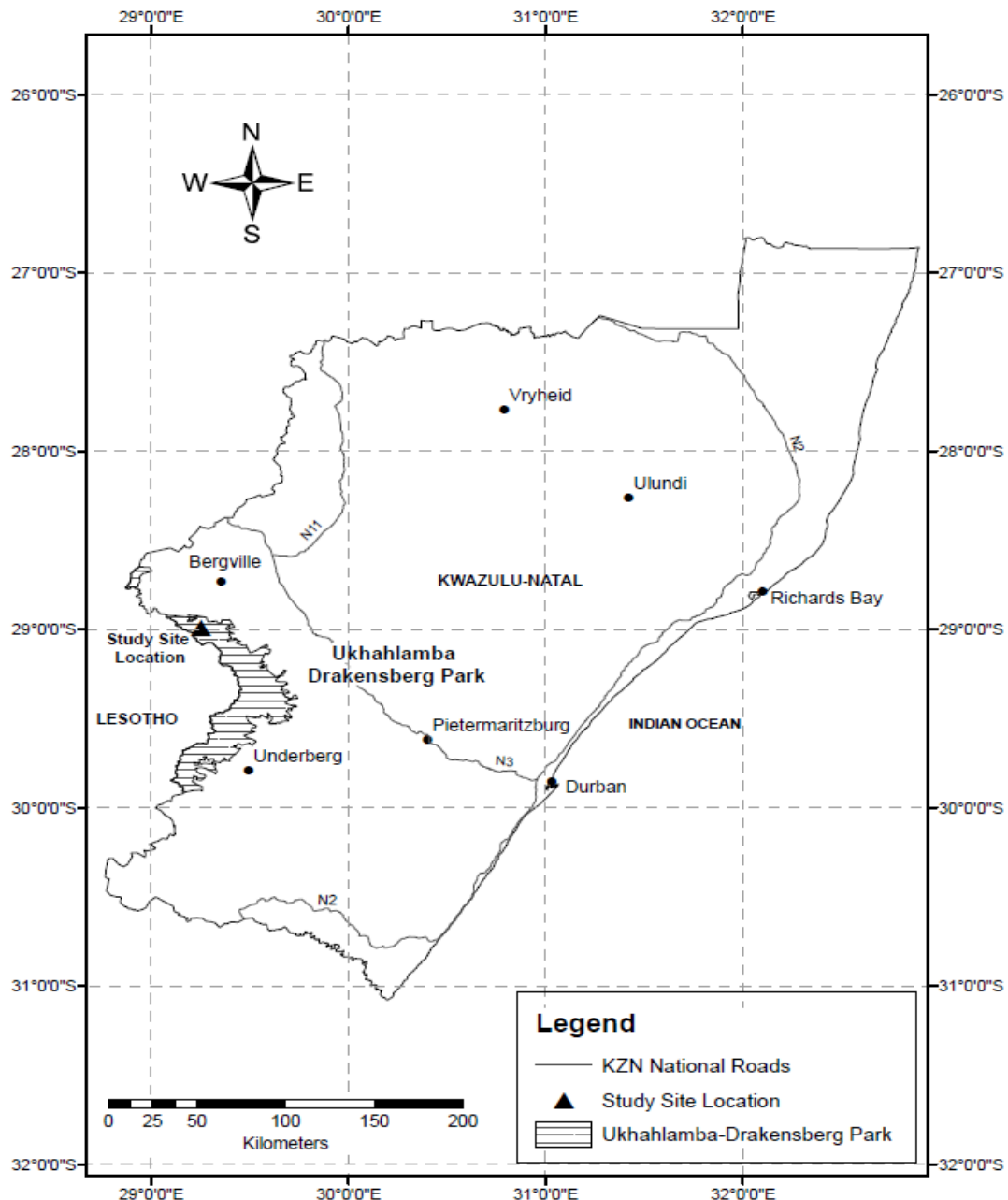
#### **2.2. Site Description**

##### **2.2.1. The Drakensberg**

The Drakensberg forms part of the Great Escarpment in eastern South Africa extending from the Eastern Cape Province to the Limpopo Province over a distance of 1000 km (Killick 1990). The uKhahlamba-Drakensberg Park forms part of the Drakensberg lying within the KwaZulu-Natal Province (Figure 2.1). The uKhahlamba-Drakensberg Park is 200 km long with the southern and northern borders lying between Bushman's Nek in the south and Royal Natal National Park to the north, with Lesotho forming the western border of the Park. The escarpment is 100-150 km west of the warm Agulhas current of the Indian Ocean (Tyson *et al.* 1976) with an altitude range from 1280-3482 m (at Thabana Ntlenyana). At present, the total area of the uKhahlamba-Drakensberg Park is 242,813 ha (Ady 2005).

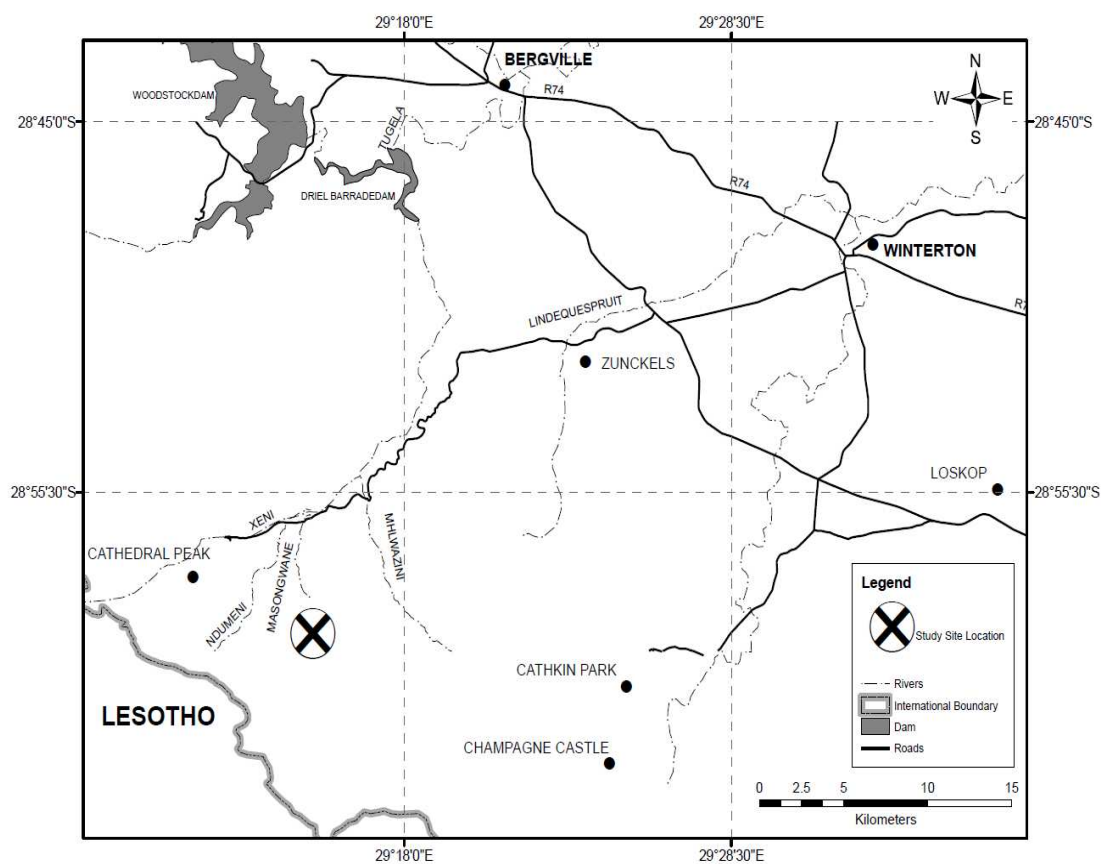
##### **2.2.2. Site Location**

The research site is located in Catchment Six of Cathedral Peak in the Central Drakensberg, KwaZulu-Natal, South Africa (Figure 2.2). A 32,246 ha State Forest (Ady 2005) exists within Cathedral Peak, which was divided into catchments as part of extensive research and Catchment Six lies within this State Forest. Catchment Six is comprised of two hill slope seepage wetlands, the adjacent wetland to the research site being north-west facing and the studied wetland being north facing (Plate 2.1). Five perennial streams feed into the two wetlands.

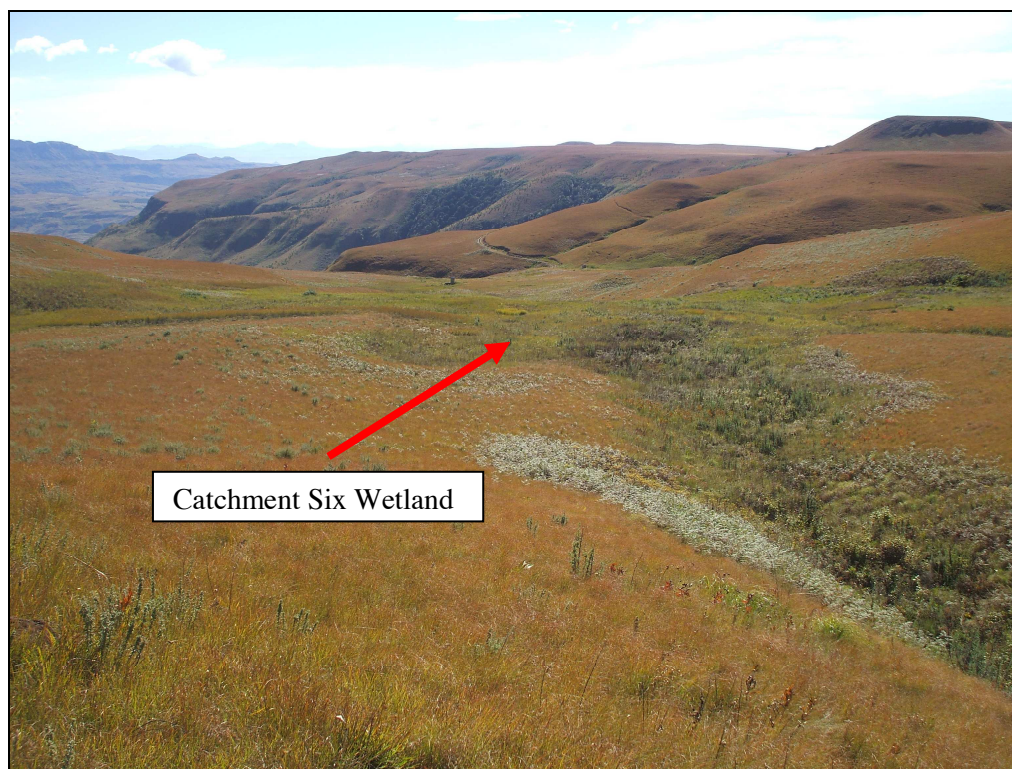


**Figure 2.1: Location of the uKhahlamba-Drakensberg Park**

The topography of the studied wetland consists of numerous undulations and a knick-point located at approximately 28°59'27"S and 29°15'05.8"E. The knick-point runs in a west to east direction at an altitude of 1887 m (Plate 2.2). The wetland is surrounded by higher raised ground with basalt outcrops. The vegetation consists predominately of sedge species, *Gunnera*, ferns and the occasional *Leucosidea serica* shrub. The area surrounding the wetland is dominated by grass species, in particular *Themeda triandra*. A full species list of the Cathedral Peak region has been compiled (Appendix A) based on the extensive studies of Killick (1963) and Hill (1992) and with the Family/Genus/Species authority provided where available (Arnold and de Wet 1993).

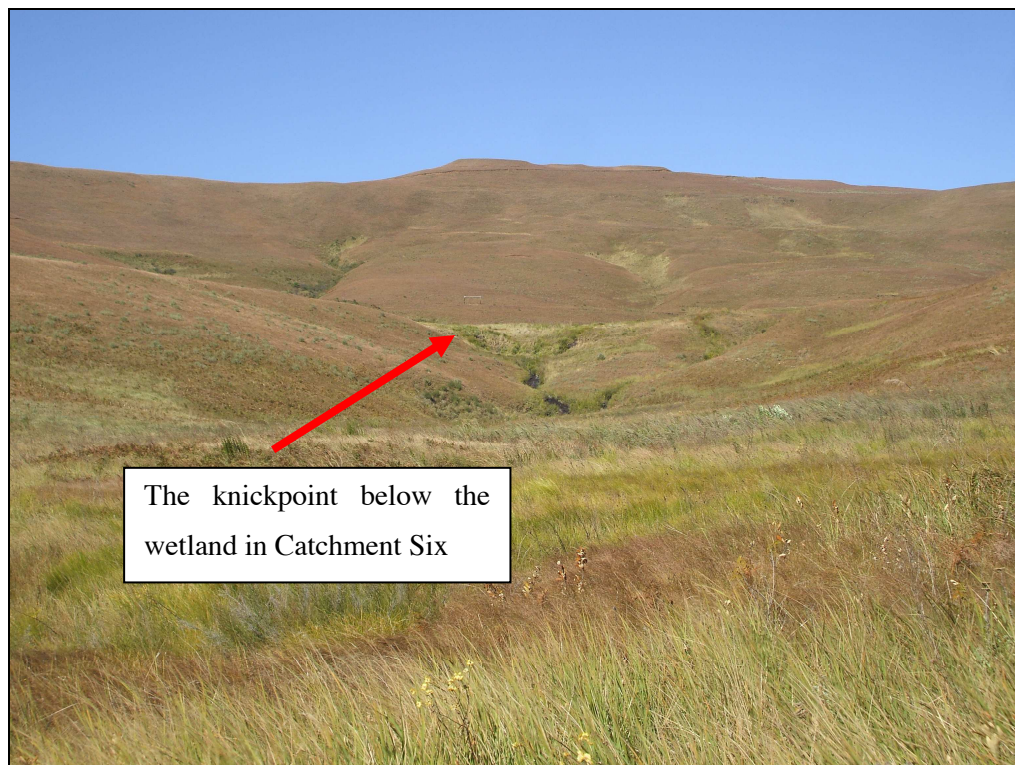


**Figure 2.2: Location of the research site, Catchment Six, Cathedral Peak**



**Plate 2.1: Catchment Six research site, Cathedral Peak**





**Plate 2.2: The knickpoint below the Catchment Six research site**

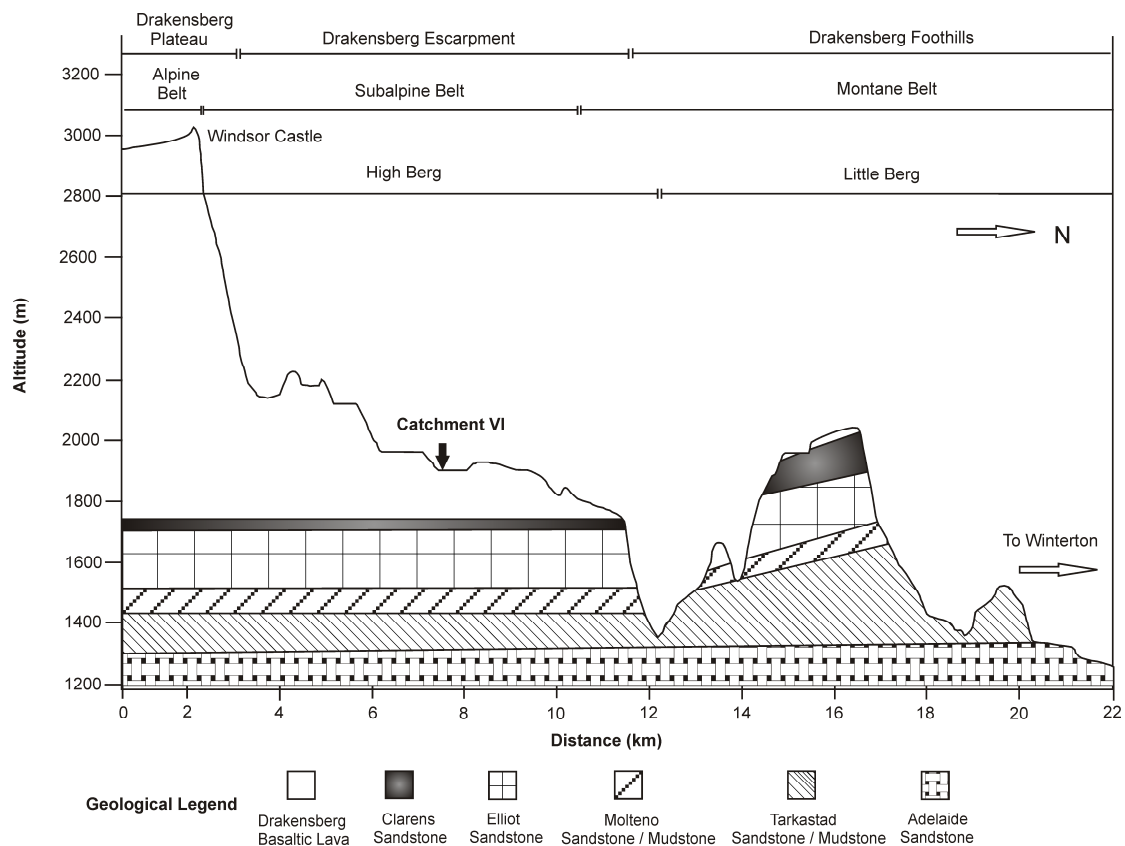
### **2.2.3. Geology**

The Drakensberg escarpment was formed between 250-180 Ma yr ago (million years ago), between the Permian-Triassic Extinction (Norman and Whitfield 2006) and the break-up of Gondwana (Uken 1999). The Karoo Supergroup formation dominates the Drakensberg escarpment, consisting of the Drakensberg Group Basalts, Clarens Formation Sandstones, Elliot Formation mudstones and sandstones, Molteno Formation sandstone and shale, Upper Beaufort Group sandstones and the dykes and sills of the Karoo dolerite (Figure 2.3).

The Drakensberg escarpment is divided into the High Berg and the Little Berg. The High Berg is characterised by the double rampart of Drakensberg Group basaltic cliffs of approximately 1800 m thick while the Little berg is shallowly capped by the Drakensberg Group, formed through a series of lava flows 180 Ma yr ago prior to the break-up of Gondwana (Killick 1963; Norman and Whitfield 2006). Underneath the basalts lies the 100-150 m thick Clarens Sandstone Formation aeolian deposited during arid conditions prior to the basaltic lava flows (Killick 1963; Norman and Whitfield 2006; Uken 1999; Johnson *et al.* 1996). The 200 m thick Elliot Formation was deposited during arid to semi-arid conditions on the flood plain with the Molteno Formation beneath, which was deposited during moist conditions as indicated by a large abundance of plant and insect fossils. The Upper Beaufort Group was deposited after the 250 Ma yr ago major extinction. The Karoo Dolerite dykes and sills are believed to be the pipes



from which the Drakensberg Group lava flows were released as they are identical in chemical composition (Norman and Whitfield 2006; Uken 1999; Johnson *et al.* 1996).



**Figure 2.3: Geological transect of Cathedral Peak passing through Catchment Six<sup>4</sup>**

The High Berg comprises of summits, plateaus, cliffs, buttresses, deep valleys and high spurs; while the Little Berg consist of high altitude grassy slopes with steep-sided river valleys and rocky gorges (Killick 1963). The Drakensberg forms a prime example of an erodible mountain range (Norman and Whitfield 2006) due to the highly erodible nature of the basalts and the sandstones which have been eroded by long-term incised, fast-flowing rivers and streams that have their beds close or on bedrock, which are characteristic of the Drakensberg escarpment (Ady 2005; Grenfell *et al.* 2008).

<sup>4</sup> This transect provides a 22 km site specific geological depiction of the research site from the escarpment towards the town of Winterton. This transect, with associated geological formations, was generated using the 1:50000 series geological maps. This would inevitable lead to variations of the depth and extent of geological zones due to the natural variation in these zones. The zones, altitudes and distances in this transect are, to scale with the 1:50000 maps.

#### **2.2.4. Climate**

The climate of the Drakensberg is topographically-driven resulting in high variability in temperature, precipitation, wind, frost, humidity and evaporation between each valley (Tyson *et al.* 1976). The climate of Cathedral Peak is dominated by low pressure subtropical anticyclones during the summer months (Tyson *et al.* 1976). The inversion layer over the Drakensberg escarpment is lifted enabling humid air from the Indian Ocean to be drawn over the escarpment resulting in thunderstorm activity. The high summer rainfall occurs mainly between November and March, accounting for 70% of the annual rainfall. Precipitation exceeds evaporation making the Drakensberg one of the least drought-prone areas in South Africa (Tyson *et al.* 1976). Mean summer temperatures in the Drakensberg are approximately 30°C and mean winter temperatures approximately -4.5°C (Tyson *et al.* 1976).

In winter the inversion layer drops below the escarpment bringing atmospheric stability, which often results in cold temperatures and the occurrence of frost (Tyson *et al.* 1976; Killick 1963). Frost can occur between 180 days in Lesotho to 60 days in the Little Berg area (Tyson *et al.* 1976). Seasonal and diurnal variations in rainfall and temperature exist due to the intermediate location of the escarpment between the mid-latitudes and the tropics (Tyson *et al.* 1976).

#### **2.2.5. Historical Background**

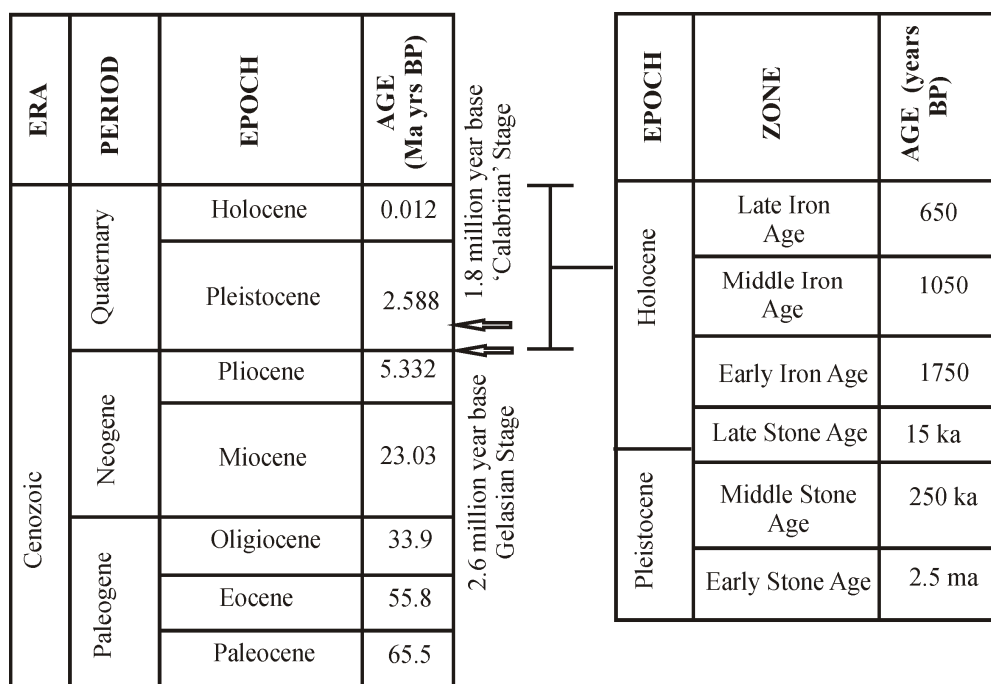
The initial conservation initiative, which led to the formation of the uKhahlamba-Drakensberg Park 90 years later, was established as a Game Reserve near Giants Castle in AD 1903 (UNEP 2005). Between AD 1903 and AD 1973 the uKhahlamba-Drakensberg Park was extended to include the Royal Natal National Park, Loteni, Kamberg, Vergelegen, Rugged Glen National Reserves and the Mkhomazi, Cathedral Peak, Garden Castle, Cobham, Highmoor, and Monk's Cowl State Forests (UNEP 2005). In AD 1922 the importance of the Drakensberg as a water resource was recognized, resulting in the formation of forest reserves designed to protect the areas water resources. The first forest reserve was proclaimed at Cathkin Peak and subsequent State Forests were declared for the conservation of water catchment areas. In AD 1973 Mdedelelo and Mkhomazi areas were proclaimed Wilderness Areas (Krüger and Crowson 2004) and in AD 1979 and AD 1989, the Mzimkulu and Mlamboja areas respectively, located within the Cathedral Peak State Forest, were declared Wilderness areas (Krüger and Crowson 2004). In AD 1993 all the protected areas of the Drakensberg were assigned to the administration of the Natal Parks Board and in the same year the protected areas were consolidated under the name of uKhahlamba-Drakensberg Park (UNEP 2005).

The uKhahlamba-Drakensberg Park was designated a Ramsar Wetland Site in AD 1997 and in AD 2000, the Park was designated a UNESCO Mixed Natural and Cultural World Heritage

Serial Site for its exceptional scenic beauty, biodiversity and for the cultural value of the Khoisan rock art. The uKhahlamba-Drakensberg Park is one of South Africa's major water catchments that have continued to gain in value as a water provider to the country. The Drakensberg has had a long history of research conducted within its boundaries due to the importance of the Drakensberg as the major water source of the country and from the diverse habitats, high levels of endemism and the largest and most diverse collection of rock art found in sub-Saharan Africa. The diversity of habitats and high endemism results from the Drakensberg being an interface between the Cape and subtropical biota (Krüger and Crowson 2004). The Drakensberg is further recognized as an International Conservation Hotspot, WWF Global 200 Eco-region and a World Endemic Bird Area.

### 2.2.6. Prehistory of the Drakensberg

The Drakensberg comprises one of most archaeologically significant areas in South Africa with artefacts found ranging from the Early Stone Age to the Late Iron Age (Figure 2.4) (Ady 2005).



**Figure 2.4: Summary of geological and archaeological time periods<sup>5,6,7</sup>**

Artefacts found in Lesotho and the interior grasslands, but not in the Drakensberg suggests that the Drakensberg was probably first inhabited by hunter-gatherers during the Acheulean period

<sup>5</sup> The ages provided are for the start of each epoch and zone

<sup>6</sup> Zone refers to the archaeological time period

<sup>7</sup> The data used to compile Figure 4-4 is derived from: (Dollar and Goudie 2000; Gibbard *et al.* 2010).

of the Early Stone Age (ESA) from approximately 1.5 Ma yr ago (Wright and Mazel 2007; Esterhuysen 2007). The ESA period is between 2,5 Ma yr ago and 250 ka yr ago (thousand years ago) and is recognised as the period which humans first started limited tool use. Stone tool use had become more specialised by the start of the Acheulean period 1.7 Ma yr ago with the dominance of *Homo ergaster* (Esterhuysen 2007).

During the Middle Stone Age (MSA), stone tools became more specialised with purpose-crafted tools being made from a wide range of rock types, prepared from cores and pre-shaped for specific uses, such as spearheads and knives. Besides stones, bones were used for tool making (Wadley 2007). There is a noticeable lack in artefacts found in the Drakensberg during the MSA and it is thought the glacial conditions between 25-15 ka yr ago contributed to the scarcity of artefacts (Wright and Mazel 2007). The MSA also saw the emergence of *Homo sapiens* from approximately 200 ka yr ago (Hilton-Barber and Berger 2004).

The Late Stone Age (LSA) saw a dramatic increase in tool artefacts, which have been found from approximately 15-10 ka yr ago suggesting greater human occupation in the Drakensberg and elsewhere in South Africa (Wadley 2007; Hone 2001). Artefacts found in the high altitude, montane region of eastern Lesotho indicate that human settlement and occupation occurred throughout the last glacial period, while sites in other regions of southern Africa reflected a decrease in human occupation (Mitchell 1992). Improved environmental conditions after the Last Glacial Maximum (LGM), *ca.* 23-18 ka yrs ago (Wooller *et al.* 2003), contributed to increased food supplies through greater floral and faunal diversity (Wadley 2007). The Khoisan people occupied the Drakensberg from approximately 8000 yr ago. Between 8000-3000 yr ago occupation has been more permanent and extensive, but without significant population numbers (Wright and Mazel 2007). From 3000 yr ago to 1600 yr ago there was a significant increase in population and occupation of the Drakensberg indicated by the increase in rock shelters, paintings and artefacts found (Wright and Mazel 2007). The abundance of water, wood and food in the Drakensberg enabled increased occupation by the Khoisan (Liebenberg 1972). After 1600 yr ago, the hunter-gatherers living in the rock shelters migrated from the Drakensberg region and settled as pastoralists in the Tsekela but returned to the northern Drakensberg 600 yr ago (Wright and Mazel 2007).

The Iron Age in South Africa began around 1800 yr ago with Bantu-speaking farmers moving into the South African landscape from northern areas growing crops of sorghum, millet, ground beans and cowpeas and having cattle, sheep and goats as livestock (Huffman 2007a). The Iron Age can be classified into three periods, the Early Iron Age (EIA) from AD 200 to AD 900, Middle Iron Age (MIA) from AD 900 to AD 1300 and the Late Iron Age (LIA) from AD 1300

to AD 1820 (Huffman 2007a). Occupation of the Drakensberg by Iron Age farmers of Kalundu Tradition, who originated from the Bantu farmers from present-day Angola, Botswana and Zimbabwe (Western Stream), probably started during the EIA around AD 800 (Huffman 2007a, 2007b). Between 600 and 700 yr ago and onwards the Drakensberg was probably occupied by hunter-gatherers and farmers, albeit in different locations, including the southern Drakensberg, up to approximately 1000 m (Mitchell 1992; Wright and Mazel 2007). It is unknown if the hunter-gatherers occupied the Drakensberg on a seasonal or all-year basis; however, indications derived from the shift of implements from end-scrapers to adzes found in southern KwaZulu-Natal suggest that seasonal occupation of the Drakensberg occurred between the Drakensberg escarpment during summer and the lower-lying Thornveld vegetation of KwaZulu-Natal during winter (Mitchell 1996). Domestic crops appear in the hunter-gatherer diets a few hundred years ago, which includes maize and sorghum seeds. Maize was probably introduced by Portuguese explorers during the 1500s along the coastline and cultivated in the Eastern Cape during the 1700s (Wright and Mazel 2007). During the late 17<sup>th</sup> century, African cattle-herders occupied the areas living adjacent to the Iron Age farmers in the northern and central Drakensberg. The Khoisan and Iron Age settlements contributed to diversity of habitats and complex relations existed between Zulus and Khoisans. Wars between the Zulus and Khoisans, under the Zulu rule of Shaka, drove the Zulus further east. During these wars, the Drakensberg was named by the Zulus as uKhahlamba, the “Barrier of Spears”. By AD 1837, European settlers had arrived in the area using the land for pastures and shooting the game, which threatened Khoisan livelihoods and subsequent raids by the Khoisan on farmers resulted in much conflict. Eventually the Khoisans were completely driven out of the land by AD 1871 and confined to the Kingdom of Lesotho (Ady 2005; Wright and Mazel 2007; Liebenberg 1972).

The Drakensberg contains one of the world’s greatest concentrations of superior quality and preservation of Khoisan rock paintings (Ady 2005; Liebenberg 1972). The significance of the rock paintings is in their interpreted symbolism and religious viewpoints, transcribed onto the cave walls. Many of the paintings depict group scenes of hunting, dancing, fighting and gathering, with the eland and male figures being the most dominant subjects (Liebenberg 1972). Rock art in Lesotho indicates that the paintings may have been conducted seasonally during times of social aggregation. Furthermore, increased number of rock art during the LIA could depict the increased social tensions of the Khoisan due to conflict with the establishing farmers (Mitchell 1992). The paints were made from a mixture of earth colours and animal blood with the dominant colours being red, white, black and yellow (Liebenberg 1972). The paintings are dated to approximately 3000 yr ago. There are approximately 600 painting sites between Royal National Park and Bushman’s Nek, containing between 35,000-40,000 paintings (Wright and Mazel 2007) some of which have been declared National monuments (Ady 2005). Ndemema

Gorge in Cathedral Peak hosts the greatest concentration of rock art in the world with 3909 individual paintings from 17 caves and rock shelters (Liebenberg 1972).

## **2.3. Contemporary Vegetation**

### **2.3.1. Introduction**

The vegetation of South Africa has been classified several times (Acocks 1953; Acocks 1988; Mucina and Rutherford 2006; Low and Rebelo 1996) with detailed floristic inventories being developed for Cathedral Peak by Schlepe (1940) and Killick (1963, 1990). This research does not aim to re-classify the vegetation of Cathedral Peak; however, the contemporary vegetation is contextualised within the framework of Cathedral Peak, based on Killick (1963) and the vegetation of the Drakensberg based on the works of Hilliard and Burtt (1987) and Mucina and Geldenhuys (2006). Much of these works are based on the early works of Thode (1893-1901<sup>8</sup>), Bews (1917<sup>9</sup>), Edwards (1967<sup>10</sup>) and Acocks (1953, 1988).

### **2.3.2. The Vegetation of the Drakensberg**

White (1983) categorised the Drakensberg within the Afromontane archipelago that extends throughout the East African mountain range. The altitudinal effect on vegetation has enabled marked similarities in vegetation throughout these high mountains of Africa. The high level of endemism (up to 75%) is a characteristic of the Afromontane region of the Drakensberg (White 1983), making this region so remarkable.

The Drakensberg falls within the Grassland Biome which extends from approximately 25°S to 33°S and 24°E to 33°E, covering approximately 349,174 km<sup>2</sup> of southern Africa (Mucina and Geldenhuys 2006). The grassland biome is characterised by high variability in rainfall, altitude, temperature and soil; with rainfall ranging between 400 mm to over 1200 mm per year; temperatures that fluctuate between frost-free and snow-bound and high diurnal variability; altitudes ranging from sea level to over 3300 m over the eastern escarpment; and soils that range between humic clays and poorly structured sands. The high environmental variability contributes to the equally highly variable vegetation communities that exist within this biome (O'Connor and Bredenkamp 2003). The vegetation of the grassland biome can be classified broadly as temperate and tropical and by their carbon isotopic ratios, either as C<sub>3</sub><sup>11</sup>,

---

<sup>8</sup> (Thode 1893, 1901)

<sup>9</sup> (Bews 1917)

<sup>10</sup> (Edwards 1967)

<sup>11</sup> Calvin-Benson metabolic carbon fixation pathway during photosynthesis

characteristic of the Drakensberg region, and C<sub>4</sub><sup>12</sup>, characteristic of the Highveld region of South Africa; based on the differences in macroclimate, structure and in the life forms and species (Mucina and Geldenhuys 2006).

The grassland areas for this research are defined by location namely; the Drakensberg foothills (Little Berg), the Drakensberg escarpment (encompassing the steeper slopes of the High Berg) and the Drakensberg plateau (also part of the High Berg). Various studies (Mucina and Geldenhuys 2006; O'Connor and Bredenkamp 2003; Acocks 1988) have applied different nomenclature to defining the vegetation of the Drakensberg; consequently, an overlap of physical boundaries exists within the studies. For this research, the author has grouped the vegetation of the Drakensberg as the Drakensberg foothills, Drakensberg escarpment and Drakensberg plateau (Table 2.1) based on the above-mentioned works. For purposes of simplification, a synthesis of the above-mentioned studies of the grassland biome will be presented. Furthermore, Hilliard and Burt (1987) and Killick (1990) conducted detailed vegetation studies in the southern and northern Drakensberg respectively, classifying vegetation according to the dominant zones and seres that exist. While these studies provide insight into the vegetation of localised areas, it is too detailed to summarise the different zones for a broad synthesis of the Drakensberg vegetation.

### **2.3.2.1. The Drakensberg Foothills**

The Drakensberg foothills include the area between 1200-2150 m, dominated by *Themeda triandra* grasslands with *Protea multibracteata*<sup>13</sup> and *Protea roupelliae* scrub occurring on the slopes. Tall grasslands including; *Acacia sieberiana*, *Hyparrhenia hirta*, *Kohautia cynanchica*, *Phyllanthus glaucophyllus*, *Rhus rehmanniana*, *Spermacoce natalensis*, *Sporobolus pyramidalis*, and *Walafrida densiflora* dominate the valley grasslands and the more undulating slopes of the Drakensberg foothills (O'Connor and Bredenkamp 2003). The tall grasslands often occur up to an altitude of 1400 m. Forested areas are dominated by *Podocarpus latifolius* with *Canthium ciliatum* and *Leucosidea sericea* occurring on the margins of the forest under -storey and fynbos areas (Acocks 1988). In areas of trampling and selective grazing pressures from livestock the grasslands are reduced to *Eragrostis plana* with *Acalypha schinzii* becoming the dominant herb species (Acocks 1988).

---

<sup>12</sup> Hatch-Slack metabolic carbon fixation pathway during photosynthesis

<sup>13</sup> *Protea caffra* subspecies *caffra* (Phill)



**Table 2.1: Nomenclature of the Drakensberg grasslands**

	<b>This Research</b>	<b>Acocks (1988)</b>	<b>O'Connor and Bredenkamp (2003)</b>		<b>Mucina and Geldenhuys (2006)</b>
<b>Vegetation Nomenclature</b>	Drakensberg foothills	Highland Sourveld No. 44(a)	Eastern Lowlands	F14: <i>Hyparrhenia hirta</i> tall grassland	Gs 4: Northern KwaZulu-Natal Moist Grassland Gs 10: Drakensberg Foothill Moist Grassland Gd 5: Northern Drakensberg Highland Grassland
	Drakensberg escarpment	Mixed Grassveld ( <i>Themeda-Festuca</i> Alpine Veld No. 58)	Eastern mountains and escarpment	E10: <i>Rhus dentata-Leucosidea sericea</i> shrubland; and E11: <i>Monocymbium ceresiiforme-Tristachya leucothrix</i> grassland	Gd 7: uKhahlamba Basalt Grassland Gd 8: Lesotho Highland Basalt Grassland
	Drakensberg plateaux	Sweet grassveld / Scrubby mixed grassland	Eastern mountains and escarpment	E13: <i>Merxmüllera drakensbergensis-Festuca caprina</i> Afro-alpine grassland	Gd 10: Drakensberg Afroalpine Heathland

### 2.3.2.2. The Drakensberg Escarpment

The Drakensberg escarpment ranges in altitude from approximately 1750-2300 m (Mucina and Geldenhuys 2006). This altitudinal range extends from the lower altitudes to just below the high plateau (Mucina and Geldenhuys 2006). The Drakensberg escarpment contains a high-level of endemism in a species-rich environment. Mucina and Geldenhuys (2006) characterised this region as the uKhahlamba Basalt Grassland (Gd 7) and the Lesotho Highland Basalt Grassland (Gd 8) with the latter having great altitudinal variation on the Lesotho plateau and ridges. This region is dominated by *Rhus dentata-Leucosidea sericea* shrubland and the *Themeda-Festuca* alpine veld (Acocks 1988), various herbs, shrubs and tall-herb vegetation (Mucina *et al.* 2006).

The steeper, cooler and moister slopes of the Drakensberg escarpment are dominated by *Monocymbium ceresiiforme-Tristachya leucothrix* grassland (Mucina and Geldenhuys 2006) and *Themeda triandra-Festuca costata* alpine veld (Acocks 1988) at altitudes between 1700 m and 2150 m.

Fire events maintain these grasses as the dominant plagioclimax<sup>14</sup> community. Through a lack of fire events, woody vegetation becomes the dominant vegetation type (Mucina and Geldenhuys 2006). Furthermore, some species, such as *Festuca costata* and *Festuca caprina*, are less abundant in this region occurring predominately at the higher altitudes and have a southern Drakensberg affinity (Mucina *et al.* 2006; Acocks 1988).

Cyperaceae form an important component of grasslands with *Cyperus*, *Bulbostylis*, *Ficini*, *Schoenoxiphium* and *Tetraria* species being the most common sedges. On the drier north-facing slopes *Aloe*, *Aster pleiocephalus*, *Hypoxis multiceps* and *Raphionacme hirsute* are found (Hilliard and Burt 1987).

### **2.3.2.3. The Drakensberg Plateau**

The Drakensberg plateau, between the altitudes of 2500-3480 m, has a varied terrain of grasslands, marshlands and rocky areas. This area forms a thin, strip-like area of the escarpment in KwaZulu-Natal but is found mostly in Lesotho. The high variability in topography is depicted in the high variability of vegetation that exists in this area, ranging from short shrublands to grasslands with little occurrence of shrubs. The dominant vegetation groups are the *Merxmuellera drakensbergensis*-*Festuca caprina* Afroalpine grasslands (O'Connor and Bredenkamp 2003; Acocks 1988; Mucina and Geldenhuys 2006) and *Erica-Helichrysum* heathland (Hilliard and Burt 1987), consisting of tussock grasses, ericoid dwarf shrubs and creeping, mat-forming plants.

The plateau marshlands are often characterised by sedges including; *Carex monotropa*, *Isolepis angelica* and *Schoenoxiphium filiforme* and herbs, namely; *Alepidea pusilla*, *Cotula paludosa*, *Eriocaulon dregei* var. *sonderianum*, *Haplocarpha nervosa*, *Limosella longiflora*, *Lobelia galpinii*, *Ranunculus meyeri*, *Rhodohypoxis deflexa*, *Saniella verna*, *Thesium nationae* and *Trifolium burchellianum*. The rocky vegetation of the plateau consists of *Rhodohypoxis rubella*, *Rhodohypoxis deflexa*, *Morea alpina* and *Hesperantha crocopsis* (Hilliard and Burt 1987).

The Drakensberg escarpment contains a significant number of endemic species and is well protected due to its location on the highest portions of the Drakensberg and through the conservation areas of the uKhahlamba-Drakensberg Park and the Bokong Nature Reserve and as such, this area is considered 'least threatened' (Mucina *et al.* 2006).

---

<sup>14</sup> Plagioclimax is defined as "a stage in the development of a plant ecosystem where the system is kept stable by human intervention, as in managed woodlands" (Collin 2004).

### 2.3.3. The Vegetation of Cathedral Peak

Killick (1963) undertook a concise assessment of the plant ecology of Cathedral Peak area in the 1950s and divided the vegetation into three zones / belts, viz.; the Montane belt, Subalpine belt and Alpine belt (Figure 2.3<sup>15</sup>), which indicates the position of the vegetation belts). A summary of the dominant species are provided in the main vegetation communities within each zone.

#### 2.3.3.1. The Montane Belt

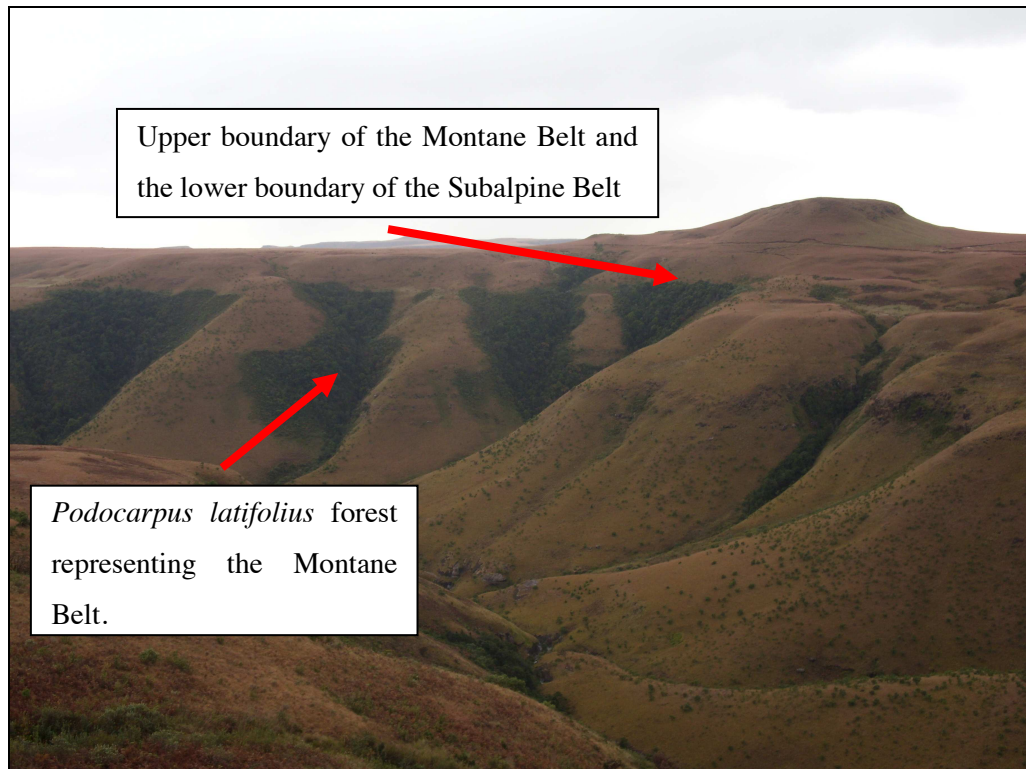
The Montane belt is located between 1280-1829 m (Killick 1990) with the vegetation found mainly on the valley slopes, cliffs and in the boulder beds. There are no tarns or lakes found in this belt and the streams and rivers that do exist are characteristically fast flowing, with steep gradients, seasonal fluctuations and much course-change, which reduces the ability of aquatic flora to inhabit this zone. Killick (1963) classified four main vegetation groups within the Montane Belt, in order of succession, *Themeda triandra* grassland, *Protea* savannah, Scrubs and *Podocarpus latifolius* forest, which is the climax community of the Montane belt (Killick 1963).

The *Protea* savanna is largely dependent on the occurrence and intensity of fires. Intense fires can kill *Protea* species even though they are fire resistant with thick bark. The two main species of *Protea* are *Protea multibracteata* and *Protea roupelliae*, which often inhabit the *Themeda triandra* grasslands. Shrublands occurring in the montane belt are often located within and invade the grasslands and are characterised by their heterogeneity.

The *Podocarpus latifolius* forest climax community is located along streambanks, river valleys and gorges where there is protection from wind and fire. At Cathedral Peak, the forests occur up to an altitude of approximately 1860 m. While *Podocarpus latifolius* is considered the climax community, it is not often the dominant tree within the forest. Killick (1963) provides two reasons for this lack of dominance, namely; selective exploitation of the hard-woods in the 1860s by loggers reduced the population of yellowwoods and if selective exploitation was not the dominant factor in reducing the yellowwood numbers, then competition for resources by other abundant species within the forests reduced the ability of yellowwoods to dominate the forests. The forests are highly stratified and Killick (1963) grouped the forests into nine categories, viz.; dominant tree layer, small tree layer, shrub layer, field layer, ground layer, boulder communities, epiphytes, climbers and stragglers.

---

<sup>15</sup> Refer to Footnote 3 for a description on why the geological transect and Killick's 1963 diagram of the different vegetation belts do not correspond exactly.



**Plate 2.3: *Podocarpus latifolius* forest at Cathedral Peak**

(Upper boundary of the *Podocarpus latifolius* forest indicating the transitional zone between the Montane and Subalpine Belts of Cathedral Peak)

### 2.3.3.2. The Subalpine Belt

The subalpine belt is located between the top of the Montane belt at 1829 m and the start of the Alpine belt at 2865 m. There are six main vegetation communities that exist in this belt with *Themeda triandra* Grassland being the dominant vegetation and *Passerina-Philippia-Widdringtonia* Fynbos the climax community (Killick 1963). The *Themeda triandra* Grassland is the most dominant of these vegetation communities. The climax community is *Passerina-Philippia-Widdringtonia* Fynbos. *Themeda triandra* is located primarily on warm, north-facing slopes while the *Festuca costata* community is found on the cooler, south-facing slopes. The subalpine belt can be divided into two seres; hydrosere and lithosere. Each sere can be divided further into streams, vleis, and tarns for the hydrosere; and horizontal outcrops and vertical outcrops for the lithosere.

*Themeda triandra* dominates the subalpine belt covering most of the Little Berg up to an altitude of 2835 m. Cyperaceae form a small component of the *Themeda triandra* grasslands, with the main sedges including: *Bulbostylis schoenoides*, *Cyperus compactus*<sup>16</sup>, *Ficinia cinnamomea*, *Scleria woodii* and *S. bulbifera*. The bracken fern, *Pteridium aquilinum*, often

invades *Themeda triandra* grasslands after disturbance events and can successfully compete with all grasses resulting in open soils under the fern fronds. The bracken veld at this stage is optimal for tall herbs and other grasses to invade the area.

The *Themeda triandra* temperate grassland occurs between 2591 m and 2743 m on steep, xerocline slopes of the escarpment. The dominant grasses in this zone include: *Anthoxanthum ecklonii*, *Aristida monticola*, *Eragrostis racemosa*, *Koeleria cristata*, *Trachypogon spicatus*, *Tristachya hispida*, *Pentaschistis pilosogluma*<sup>17</sup> and *Ehrharta longigluma*. The *Themeda triandra* temperate grasslands transitions into *Danthonia disticha*<sup>18</sup>, *Festuca caprina*, and *Pentaschistis oreodoxa* dominated grasslands. Other grasses that become more dominant in this region include *Koeleria cristata*, *Harpachloa falx* and *Eragrostis caesia*. *Festuca* and *Danthonia* are exclusively found in this ecotone.

The tall grassland are dominated by three genera, namely; *Miscanthidium capensis*<sup>19</sup>, *Hyparrhenia aucuta* and *Cymbopogon validus* with *Miscanthidium capense* occupying a larger area compared to *Hyparrhenia aucuta* and *Cymbopogon validus*.

The fynbos climax community occurs in small isolated areas in the subalpine belt, due to recurring veld-fires and consists of small shrubs that are prone to periods of drought. The main constituents of the fynbos community are *Passerina filiformis*, *Philippia evansii* and *Widdringtonia dracomontana*.

### 2.3.3.3. The Alpine Belt

The alpine belt of the Drakensberg in Cathedral Peak extends from 2866-3482 m and occupies a narrow area along the Drakensberg escarpment. The climate is harsh with major diurnal and seasonal fluctuations in temperatures, snowfall, frost, strong winds and fluctuating humidity, being reflected in the mainly xeromorphic vegetation that exists in this area. Furthermore, the topography and climate make the alpine belt conducive for hydrophytic vegetation. The dominant and climax vegetation is the low, woody *Erica-Helichrysum* heathland with *Festuca*, *Danthonia* and *Pentaschistis* grasslands being interspersed with the heathland. These grasses are xeromorphic and become dormant during the winter months. Further grasses forming part of the *Festuca-Danthonia-Pentaschistis* grassland include; *Anthoxanthum ecklonii*, *Eragrostis caesia*,

---

<sup>16</sup> *Cyperus obtusiflorus* var. *obtusiflorus* (Lam)

<sup>17</sup> *Pentaschistis aurea* (McClean)

<sup>18</sup> *Merxmeullera disticha* (Nees)

<sup>19</sup> *Miscanthus capensis* (Nees)

*Harpochloa falx*, *Koeleria cristata* and *Poa binata*. The *Erica-Helichrysum* heathland is dominated by the genera *Erica* and *Helichrysum*.

## **2.4. Conclusion**

This chapter provides the background to the research site location of Catchment Six in Cathedral Peak, KwaZulu-Natal Drakensberg by providing climatic, geological and historical descriptions of the Drakensberg region and more specifically, Cathedral Peak. Cathedral Peak and the Drakensberg have been divided into several zonations based on characteristic vegetation types. There are a number of different nomenclatures of these zonations; however, they all correlate with each other with some variations occurring in the altitudinal limits and level of classification detail. These vegetation summaries for the Drakensberg region and Cathedral Peak are provided to contextualize the contemporary vegetation within which the research site is located.

## CHAPTER THREE

### 3. LITERATURE REVIEW

#### 3.1. Introduction

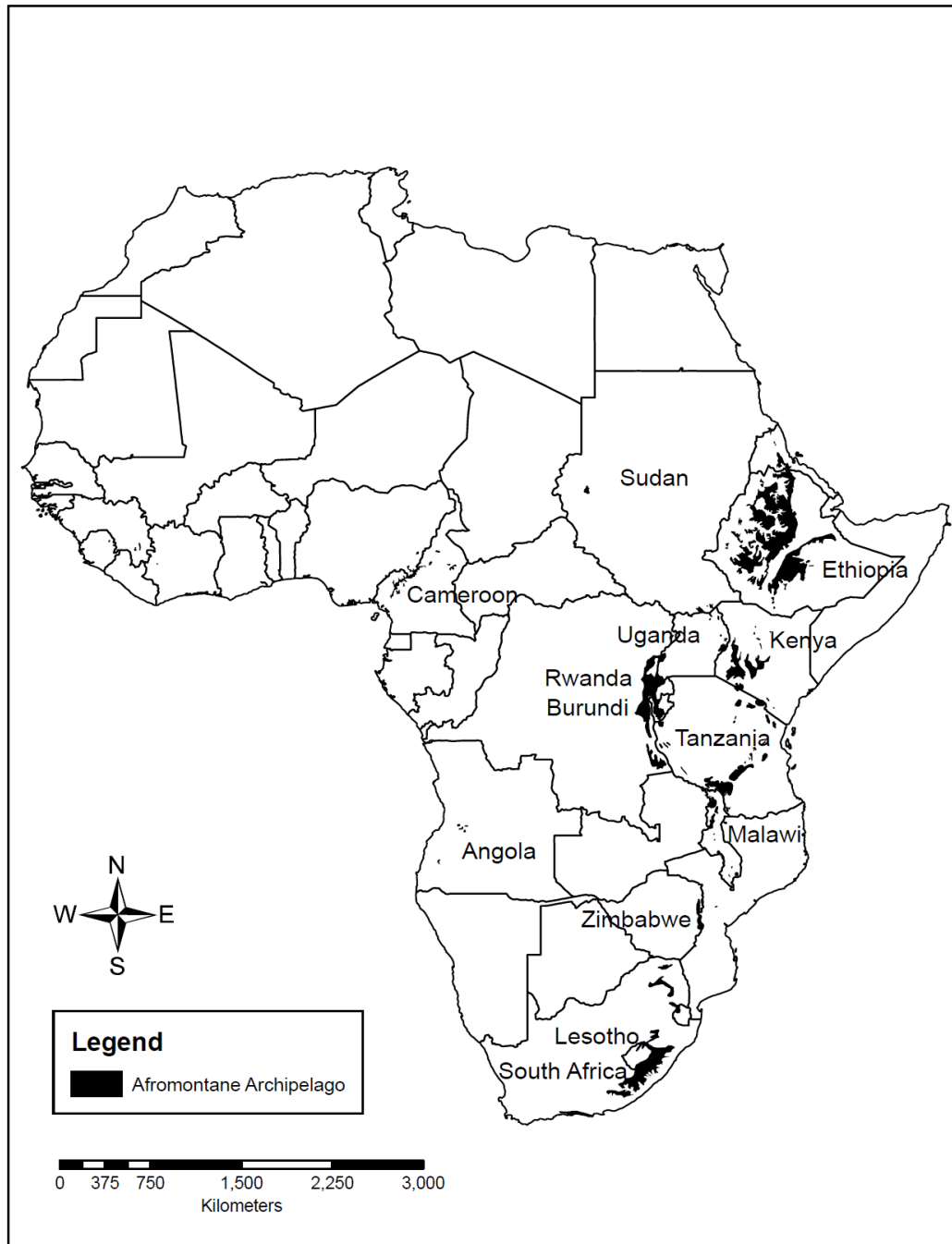
To contextualize the current research within a framework of Afromontane palaeoenvironmental research a synthesis of pollen analytical studies is described hereafter. A number of syntheses have been conducted for various regions throughout southern and eastern Africa; these have focused on the fynbos biome and south-western Cape (Meadows and Baxter 1999; Thomas and Shaw 2002; Deacon 1983; Deacon *et al.* 1983; Hendey 1983; Chase and Meadows 2007), southern Africa (Tyson 1999; Thomas and Shaw 2002) and Africa (Osmaston and Harrison 2005; Gasse *et al.* 2008). In addition, Meadows and Linder (1993) reviewed the origin of Afromontane grasslands in southern Africa. This chapter aims to synthesize palaeoenvironmental research for the phytogeographically important Afromontane archipelago to contextualize the current research location within the Drakensberg Afromontane region (White 1983). To accomplish the task, a selection of important pollen studies from the Afromontane archipelago (Figure 3.1) will be included (Table 3.1).

To effectively synthesize historical data, all the research that contained uncalibrated  $^{14}\text{C}$  (radiocarbon) dates have been calibrated by this author using the same procedure as was applied for this research<sup>20</sup>. The synthesis of historical research is conducted for eastern Africa (Figure 3.2) and southern Africa (Figure 3.3). The eastern African records include sites from Burundi, Ethiopia, Kenya, Malawi, Tanzania and Uganda. The southern African records include sites from South Africa. The synthesis has been further sub-divided into time-zones, namely; Pre-Last Glacial Maximum (>45,000-23,000 cal yr BP), Last Glacial Maximum (23,000-18,000 cal yr BP), Post-Last Glacial Maximum (18,000-13,000 cal yr BP), Younger Dryas (13,000-11,700 cal yr BP), Early Holocene (11,700-6000 cal yr BP) and Late Holocene (6000 cal yr BP–Present). The times that characterise each zone have been derived from the original research, Wooller *et al.* (2003) for the LGM and Garcin *et al.* (2007) for the Holocene. The Holocene has

---

<sup>20</sup> Sites located in the southern Hemisphere containing dates younger than 11,000  $^{14}\text{C}$  yr BP were calibrated using the SHCal04 calibration curve. Sites in the southern Hemisphere containing dates older than 11,000  $^{14}\text{C}$  yr BP were calibrated using the IntCal09 calibration curve with a reservoir value of  $40 \pm 40$  yr to compensate for variations between the SHCal04 and IntCal09 calibration curves (Reimer *et al.* 2009). All dates derived from sequences in the northern Hemisphere were calibrated using the IntCal09 calibration curve.

been differentiated into the early and late periods to separate the influence of humankind on the environment with the late Holocene representing the period of anthropogenic influence. Where possible, regions of similar climatic and environmental conditions as portrayed from the results of the relevant research will be discussed in a holistic manner.



**Figure 3.1: Map of Africa indicating the locations of the Afromontane archipelago (White 1983)**



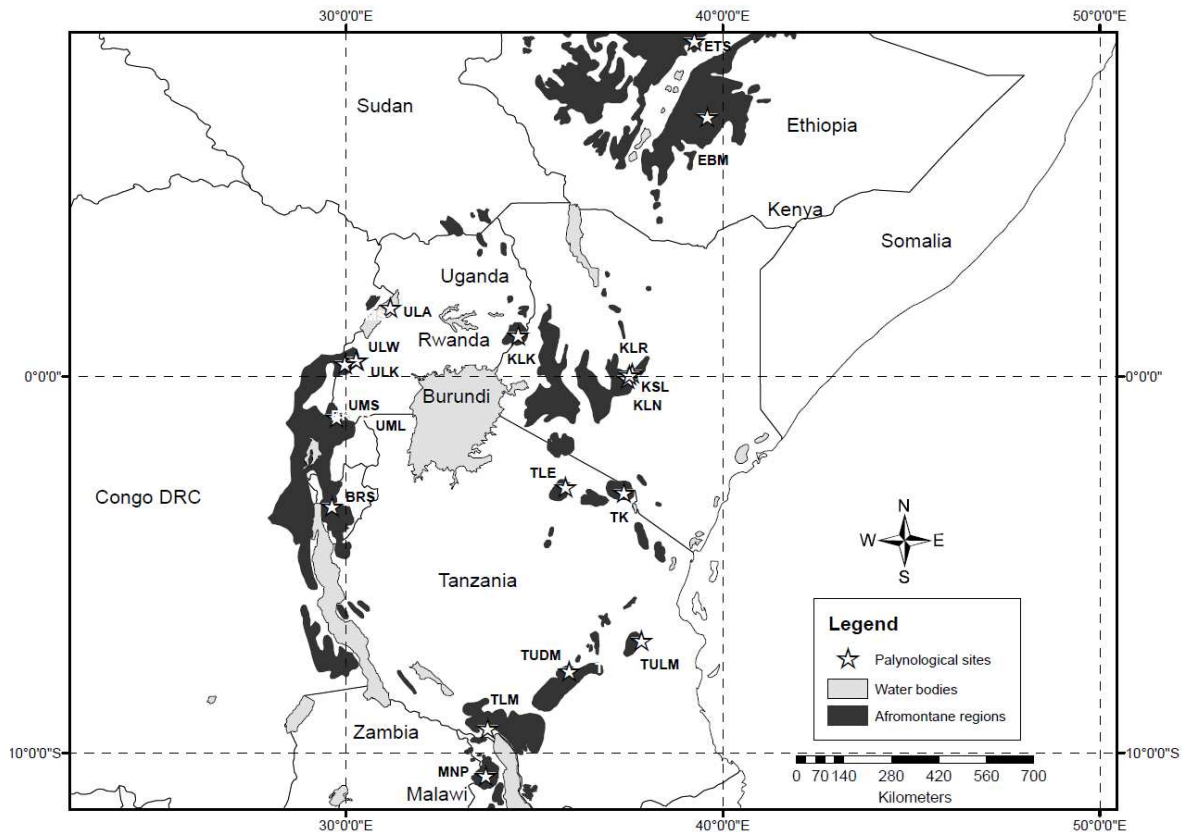
**Table 3.1: Details of pollen sites from southern and eastern Africa referenced in the text**

East African Records							
Code	Country	Name	Longitude	Latitude	Altitude (m)	Site	Site Publication
BRS	Burundi	Rusaka Swamp	29.62	-3.43	2070	Swamp	Bonnefille <i>et al.</i> 1995
EBM	Ethiopia	Bale Mountains	39.58	6.92	3950	Lake	Umer <i>et al.</i> 2007
ETS	Ethiopia	Tamsaa Swamp	39.24	8.92		Swamp	Mohammed and Bonnefille 1998
KLK	Kenya	Lake Kimili	34.56	1.10	4150	Lake	Street-Perrott <i>et al.</i> 1997
KLN	Kenya	Lake Nkunga	37.59	0.11	1820	Lake	Ficken <i>et al.</i> 1998
KLR	Kenya	Lake Rutundu	37.46	-0.04	3140	Lake	Ficken <i>et al.</i> 2002; Wooller <i>et al.</i> 2003
KSL	Kenya	Sacred Lake	37.53	0.05	2350	Lake	Coetzee 1964; Street-Perrott <i>et al.</i> 1997
MNP	Malawi	Nyika Plateau	33.70	-10.60	<i>ca.</i> 2200		Meadows 1984
TK	Tanzania	Kilimanjaro	37.36	-3.07	-		Hemp 2005
TLE	Tanzania	Lake Emakat	35.83	-2.92	2300	Lake	Ryner <i>et al.</i> 2006; Ryner <i>et al.</i> 2008
TLM	Tanzania	Lake Masako	33.76	-9.33	840	Lake	Garcin <i>et al.</i> 2007; Vincens <i>et al.</i> 2003
TUDM	Tanzania	Udzungwa Mountains	35.91	-7.81	2100	Pear	Mumbi <i>et al.</i> 2008
TULM	Tanzania	Uluguru Mountains	37.83	-7.00	-	Peat	Finch <i>et al.</i> 2009
ULA	Uganda	Lake Albert	31.17	1.84	-	Lake	Beuning <i>et al.</i> 1997
ULK	Uganda	Lake Kasenda	30.28	0.45	1260	Lake	Ssemmanda <i>et al.</i> 2005
ULW	Uganda	Lake Wandakara	30.27	0.44	1170	Lake	Ssemmanda <i>et al.</i> 2005
UMS	Uganda	Mubwindi Swamp	29.75	-1.08	2100	Peat	Marchant and Taylor 1997
UML	Uganda	Mohoma Lake	29.97	0.35	2960	Lake	Livingstone (1967)

Southern African Records							
Code	Country	Name	Longitude	Latitude	Altitude (m)	Site	Site Publication
SABH	South Africa	Braamhoek	29.58	-28.23	1700	Wetland	Norström <i>et al.</i> (2009)
SAC	South Africa	Cederberg	18.93	-32.20	-	Vlei organics	Meadows and Sugden 1991; Scott <i>et al.</i> 1995
SACO	South Africa	Cornellia	28.42	-28.50	ca. 1700-2700	Organic silt	Scott 1989
SACR	South Africa	Cragrossie	28.47	-28.52	ca. 1700-2700	Organic silt	Scott 1989
SAEL	South Africa	Elim	28.41	-28.48	ca. 1700-2700	Organic silt	Scott 1989
SAG	South Africa	Groenvlei	22.83	-33.80	-	Lake	Martin 1968
SARD	South Africa	Rietvlei Dam	28.33	-25.83	-	Organic silt	Scott and Vogel 1983; Scott <i>et al.</i> 1995
SAW	South Africa	Winterberg	26.27	-32.15		Vlei	Meadows
SAWK	South Africa	Wonderkrater	28.75	-24.43	-	Spring peat	Scott 1982b; Scott <i>et al.</i> 1995

### 3.2. Palaeoenvironments of Eastern Africa

The range of eastern African pollen analytical studies extends from the Bale Mountains in Ethiopia to Nyika Plateau in Malawi. There is an overall paucity of pollen analysis research conducted in Burundi, Ethiopia and Malawi, especially within the Afromontane region within these countries. There has been more research conducted in Kenya, Tanzania and Uganda compared with Burundi, Ethiopia and Malawi. The distribution of the Afromontane region in eastern Africa is characterised as fragmented areas of high altitudes.



**Figure 3.2: Palynological sites of eastern Africa in the Afromontane archipelago (adapted from White, 1978<sup>21</sup>)**

(BRS: Rusaka Swamp; EBM: Bale Mountains; ETS: Tamsaa Swamp; KLR: Lake Rutundu; KLN: Lake Nkunga; KSL: Sacred Lake; MNP: Nyika Plateau; TK: Kilimanjaro; TLE: Lake Emakat; TLM: Lake Masako; TUDM: Udzungwa Mountains; TULM: Uluguru Mountains; ULA: Lake Albert; ULK: Lake Kasenda; ULW: Lake Wandakara; UML: Mohoma Lake; UMS: Mubwindi Swamp)

<sup>21</sup> The Afromontane regions are derived from the spatial extent of this region provided from White (1978).

### 3.2.1. Pre-Last Glacial Maximum (>45,000 – 23,000 cal yr BP)

The oldest pollen record in eastern Africa, which extends beyond 45,000 cal yr BP, is derived from the Uluguru Mountains in central-east Tanzania (Finch 2009) and Lake Nkunga, Mount Kenya in central Kenya (Ficken *et al.* 1998). During this period until *ca.* 44,000 cal yr BP, dry montane forest taxa of *Juniperus*, *Podocarpus* and *Olea* occurred (Ficken *et al.* 1998), which is suggestive of semi-closed canopy vegetation with prevailing cool and moist conditions (Finch 2009). Increasing percentages of high-altitude Afroalpine and Ericaceous taxa indicate conditions were cooling (Ficken *et al.* 1998) and Restionaceae-type taxa are dominant during this period, which indicates that these taxa had a greater environmental range than Poaceae (Finch 2009).

Climatic amelioration occurred from 44,000 cal yr BP until *ca.* 39,000 cal yr BP and is characterised by a dominance in Poaceae and dry forest taxa at Lake Nkunga (Ficken *et al.* 1998). Dry conditions with cooler temperatures continued at Lake Nkunga supporting high-altitude taxa such as *Juniperus* while Poaceae continued to dominate the under-storey vegetation. During this drier period lake levels decreased and a corresponding increase in Cyperaceae occurred (Ficken *et al.* 1998). The Udzungwa record from the Eastern Arc Mountains (EAM) in Tanzania reflect the changing climate from wetter to drier conditions from *ca.* 42,500 cal yr BP characterised by an increase in Poaceae. The increase in *Senecio* during this same period is indicative of cooler conditions, which continued to *ca.* 36,900 cal yr BP (Mumbi *et al.* 2008).

The transition from wetter to drier conditions experienced in Ethiopia, Kenya and Tanzania between 44,000-36,900 cal yr BP is not supported from the pollen record obtained from Mubwindi Swamp located on the extreme south-western border of Uganda. During this period forest taxa dominated the pollen record in conjunction with montane forest taxa including; *Faurea*, *Podocarpus* and *Olea*, which is suggestive of humid, moist conditions similar to the conditions of present-age (Marchant and Taylor 1997).

Poaceae and Afroalpine elements, which include *Artemisia*, Asteraceae and *Stoebe*, dominated the pollen record between 38,300-25,000 cal yr BP at Lake Rutundu, located on Mount Kenya. Rumuiku swamp showed similar trends with Poaceae dominating the herbaceous pollen and having low percentages of *Artemisia* and Ericaceae (Wooller *et al.* 2003; Rucina *et al.* 2009). The C<sub>4</sub>-type grasses that dominated this zone indicated that the landscape consisted mainly of fire-dominated, open vegetation (Wooller *et al.* 2003). The occurrence of *Olea* and *Podocarpus* indicate the presence of dry montane forest at Lake Rutundu (Wooller *et al.* 2003) and Sacred

Lake, located on Mount Kenya, until 24,000 cal yr BP (Coetzee 1964; Street-Perrott *et al.* 1997; Rucina *et al.* 2009).

The vegetation from Tanzania indicate moist conditions occurred from *ca* 36,000-24,000 cal yr BP that gradually became cooler with an increase in Cyperaceae, fern spores and *Senecio*. *Prunus* and *Psychotria* pollen decreased indicating that conditions were becoming less humid but were generally still moist up to 24,000 cal yr BP (Mumbi *et al.* 2008). The pollen record from Uluguru largely corresponds to the Udzungwa Mountains record with the exception that the Uluguru record indicates drier conditions persisting from 44,000 cal yr BP into the LGM (Finch 2009). The Udzungwa Mountains record indicates that just prior to the onset of the LGM local conditions were wet as reflected in the increase swamp taxa (Mumbi *et al.* 2008).

The pollen record at Lake Albert located in central-west Uganda between *ca* 32,000-23,000 cal yr BP indicate Ericaceae increased with a continuous presence occurring throughout this period (Beuning *et al.* 1997). Within this period, brief drying and cooling conditions occurred between 28,400-23,500 cal yr BP as indicated by the presence of *Olea* and *Podocarpus* (Beuning *et al.* 1997). The brief drying and cooling conditions experienced at Lake Albert do not correspond with the Lake Rusaka record from Burundi, which suggests that from 28,800 cal yr BP conditions become wetter as indicated by the increase in total organic carbon concentration (Bonnefille *et al.* 1995). Cyperaceae dominated the pollen record from Lake Albert and there was a continuous presence of *Typha*, which indicates shallow but stable lake levels with extensive marsh / swamp vegetation (Beuning *et al.* 1997) with Poaceae dominating the area surrounding the lake. These conditions were reflected in the pollen record from Mubwindi Swamp where swamp forest taxa dominated the pollen record suggesting moist conditions (Marchant and Taylor 1997).

### **3.2.2. Last Glacial Maximum (23,000 – 18,000 cal yr BP)**

Conditions during the LGM at Lake Albert (Uganda) and Sacred Lake (Mount Kenya) were drier than previously recorded, indicated by the lack of arboreal pollen and a corresponding lack of pollen preservation (Coetzee 1964; Street-Perrott *et al.* 1997; Beuning *et al.* 1997). Drier conditions during this period were experienced at Mohama Lake, which borders on the Ugandan-Congolese border within the Ruwenzori Mountains. The lack of arboreal pollen from Mohama Lake indicates open vegetation (Livingstone 1967). The Uluguru and Udzungwa records support the drier conditions during the LGM with the driest period occurring towards the end of the LGM *ca.* 19,500 cal yr BP (Finch 2009; Mumbi *et al.* 2008). These dry conditions are supported with the peak in Ericaceae that favour drier conditions. Furthermore, this period experienced a decrease in some moist forest taxa including *Cliffortia*, and *Olea* while some

moist forest taxa, *Ilex*, *Nuxia* / *Ficalhoa* and *Podocarpus*, remain throughout this period (Finch 2009; Mumbi *et al.* 2008).

Conditions during the LGM amelioration indicated that temperatures decreased and were indicative of drier conditions as indicated by the increase in Ericaceae until *ca* 21,000 cal yrs BP at Lake Albert (Beuning *et al.* 1997). The Ericaceae-dominated pollen record during this period is further reflected from Mubwindi Swamp where a marked increase in *Cliffortia* occurs (Marchant and Taylor 1997). A fluctuating tree-line of alpine taxa and Ericaceae occurred on the slopes of Kilimanjaro with the Ericaceae belt shifting down-slope by approximately 1000 m lower than present (Hemp 2005). The cooler conditions provided optimal habitat to support high-altitude forest at Mubwindi Swamp (Marchant and Taylor 1997) with high levels of *Ilex*, *Podocarpus* and *Olea* and montane taxa after 21,654 cal yr BP (Marchant and Taylor 1997).

The pollen record from Lake Rutundu reflects high-levels of *Artemisia*, *Hagenia* and *Stoebe*, which indicates the presence of fire-dominated open grassland vegetation (Wooller *et al.* 2003). The vegetation corresponds with the Lake Rutundu and Sacred Lake records, indicating the presence of fire-tolerant / dependant taxa (Hemp 2005).

### **3.2.3. Post-Last Glacial Maximum (18,000 – 13,000 cal yr BP)**

Post-LGM conditions reflect a return to wetter and more humid conditions than were previously experienced during the LGM. The establishment of a swamp environment occurred from 16,700 cal yr BP at Lake Rusaka with Cyperaceae and fern spores becoming dominant. The onset of humid conditions occurred during this period as indicated by the increase in montane forest shrubs and tree taxa including; *Afrocrania*<sup>22</sup>, *Alchornea*, *Apodytes*, *Hagenia*, *Ilex*, *Macaranga*, *Nuxia* / *Ficalhoa*, *Olea*, *Podocarpus*, *Rapanea*, *Syzigium* and *Ulmaceae* (Bonnefille *et al.* 1995). The pollen taxa found during this period indicate that the forest was close to the refugia of the humid montane forest during the glacial period (Bonnefille *et al.* 1995).

The climatic amelioration did not occur throughout eastern Africa. Dry conditions characterised by a lack of arboreal pollen continued from the LGM at Sacred Lake (Coetzee 1964; Street-Perrott *et al.* 1997). From 16,700-13,400 cal yr BP in the Bale Mountains of Ethiopia reflect a dry climate with herbaceous pollen and Poaceae dominating the pollen record (Mohammed and Bonnefille 1998). The presence of *Amaranthaceae* / *Chenopodiaceae*, *Artemisia* and *Cyperaceae* pollen further indicate a dry climate occupied by dwarf-shrubs in steppe-like grassland (Mohammed and Bonnefille 1998). *Apiaceae* dominated the pollen record suggesting that open

---

<sup>22</sup> *Cornus volkensii* (Harms)

areas existed at both high and low altitudes characteristic of the colonisation process on a deglaciated terrain. This core further suggests that the montane forest belt extended up to 3000 m where conditions were cooler (Mohammed and Bonnefille 1998). These drier conditions are further supported by the Ziway-Shella basin lakes where lake levels decreased, which is indicative of drier conditions (Mohammed and Bonnefille 1998).

Conditions after the LGM ameliorated indicative of the decline in Ericaceae taxa and a rapid increase in *Podocarpus* from the Uluguru Mountains pollen record (Finch 2009). Conditions at Lake Masako from 16,000 cal yr BP to the start of the Holocene consisted largely of semi-deciduous taxa, namely; *Cliffortia*, *Macaranga*, Moraceae, *Olea* and Ulmaceae (Garcin *et al.* 2007; Vincens *et al.* 2007; Finch *et al.* 2009). The presence of semi-deciduous forest suggests relatively high moisture availability of between 1000-2000 mm/yr with a short dry season. Humid conditions persisted with the relative abundance of Urticaceae indicative of closed-canopy vegetation (Garcin *et al.* 2007). While humid, moist conditions persisted during this period, the climatic conditions continued to support cooler, dry taxa such as *Artemisia*, *Olea* and *Stoebe* (Ryner *et al.* 2006). Poaceae and aquatic taxa declined throughout this period reaching a minimum *ca.* 12,400 cal yr BP (Vincens *et al.* 2007).

From 15,300-14,000 cal yr BP conditions became increasingly moist at Lake Albert (Beuning *et al.* 1997), which supported forest recovery and the expansion of semi-deciduous forest while Cyperaceae and Poaceae taxa decreased (Beuning *et al.* 1997). Increased moisture was recorded at Lake Nkungu where Poaceae and high-altitude taxa decreased (Ficken *et al.* 1998). The Ruwenzori Mountains record provides a similar indication of montane forest expansion from *ca.* 15,000 cal yr BP (Livingstone 1967). An increase in *Podocarpus* and aquatic-type pollen indicative of the onset of moist conditions favourable for forest expansion occurred at Lake Rutundu (Wooller *et al.* 2003; Rucina *et al.* 2009). While Poaceae was still dominant at Lake Rutundu during this period, the grasses are classified as C<sub>4</sub>-type grasses, which further indicate the increase in moisture availability; however, conditions were drier than present-day conditions (Ficken *et al.* 2002).

The Lake Emakat pollen record reflects that while there was an abundance of arboreal pollen including; *Hagenia*, *Juniperus*, and *Olea*. Poaceae taxa dominated the pollen record between 14,800-14,500 cal yr BP. With an onset of moist conditions, the climate continued to support *Artemisia*, Ericaceae and *Stoebe* vegetation indicating that conditions remained relatively cool and dry (Finch 2009; Ryner *et al.* 2006). These conditions are supported in the Uluguru Mountains record where lowland forest taxa including *Berlinia*, *Celtis* and *Hymenocardia* pollen was recorded indicating dry woodlands occurring at the lower altitudes (Finch 2009). From

14,500-13,200 cal yr BP, Poaceae declined while *Nuxia* and *Olea* gradually increased until the start of the Younger Dryas (Ryner *et al.* 2006).

#### **3.2.4. Younger Dryas (13,000 – 11,700 cal yr BP)**

The initial period of the Younger Dryas (YD) event recorded in Ethiopia between 13,000-12,600 cal yr BP reflect rapidly changing conditions from dry to wet, indicated by the decrease of Amaranthaceae / Chenopodiaceae and an increase in Cyperaceae (Umer *et al.* 2007). The arboreal elements of Ericaceae, *Juniperus* and *Podocarpus* increased indicating an altitudinal increase in forest (Umer *et al.* 2007). Thereafter, conditions became drier with a reduction in Cyperaceae and a subsequent increase in *Artemisia* and Poaceae elements (Umer *et al.* 2007). Similar conditions were experienced in Burundi and Lake Masako from south-central Tanzania. The Lake Rusaka record indicate that humid and cooler conditions prior to the YD continued into the YD until 11,770<sup>23</sup> cal yr BP (Bonnefille *et al.* 1995), suggested by the increase in Cyperaceae, particularly *Alchemilla*, and fern spores (Bonnefille *et al.* 1995). Arboreal taxa from Burundi declined during this period except for *Hagenia* that remained the dominant arboreal taxa until 11,800 cal yr BP (Bonnefille *et al.* 1995), while the arboreal record from Lake Masako reflects an increase in arboreal taxa between 13,400-12,000 cal yr BP (Garcin *et al.* 2007).

Drier conditions during the YD are supported by the Lake Albert record, which indicates that Poaceae increased (Beuning *et al.* 1997). During the onset of the YD at Lake Rutundu and Sacred Lake, there was a decline in montane forest taxa (Wooller *et al.* 2003). A brief increase in *Artemisia* and Poaceae taxa occurred (Wooller *et al.* 2003) probably attributed to the YD event (13,600 – 10,400 yr) which was a drier period during a largely moist-dominated period (Coetzee 1964). At the start of the YD, *Olea* decreased from Lake Masako (Vincens *et al.* 2007) and drier conditions returned with an increase in *Juniperus*, *Nuxia* and Poaceae and increased sedge development along the lake edges at Lake Emakat in Tanzania (Ryner *et al.* 2006).

The general dry conditions reflected from Lake Albert, Lake Rutundu, Sacred Lake, Lake Masako and Lake Emakat are not supported by the Mubwindi Swamp record, which suggests an increase in rainfall causing an increase in erosion, resulting in the breakage of the sediment (Marchant and Taylor 1997). The increased precipitation could be the result of the southwest monsoonal circulation system returning (Marchant and Taylor 1997).

---

<sup>23</sup> Please note: all age determination values have been rounded off to the nearest whole number to avoid unrealistically 'precise' age values.



### 3.2.5. Early Holocene (11,700 – 6000 cal yr BP)

The early Holocene is characterised by climatic variability throughout eastern Africa. At the start of the Holocene, the record from Lake Kimili indicates that from 11,700 cal yr BP there was an increase in Afroalpine taxa including; *Alchemilla* and *Helichrysum*, supporting the cooling conditions experienced at Sacred Lake and Lake Rutundu. From 11,200 cal yr BP Ericaceae increased and remained dominant in the pollen record until 4500 cal yr BP in the Bale Mountains indicating the altitudinal increase in the Ericaceous Belt in response to wetter and warmer conditions at the start of the Holocene (Umer *et al.* 2007). At Lake Tamsaa from the Bale Mountains, these wetter and warmer conditions are not evident due to a lack of peat accumulation during the mid to late Holocene epoch indicating a hiatus occurred (Mohammed and Bonnefille 1998). The Lake Albert record suggests that moister conditions returned after the YD with an increase in arboreal taxa, which continued into the late Holocene (Beuning *et al.* 1997) while the record from Mubwindi Swamp suggest that while conditions were moist they were less than previously experienced, which resulted in increased peat accumulation (Marchant and Taylor 1997).

The cooler conditions experienced at the start of the Holocene are not recorded from Rusaka Swamp where increased aridity occurred after 11,700 cal yr BP indicated by the decline in *Hagenia* while other arboreal taxa increased. Asteraceae and Poaceae increased indicating forest opening due to increased aridity (Bonnefille *et al.* 1995). The Lake Masako record supports the findings from Rusaka Swamp with a decline in forest taxa and an increase in Poaceae, deciduous and semi-deciduous forest taxa after *ca.* 11,700 cal yr BP (Garcin *et al.* 2007). The presence of deciduous and semi-deciduous forest taxa, such as *Allophylus*, *Protea*-type and *Uapaca* indicate greater variability in seasonal rainfall with a defined wet and dry season (Garcin *et al.* 2007). These conditions persisted until 4400 cal yr BP. During this period Poaceae remained abundant (Vincens *et al.* 2007). The conditions at Lake Masako correspond to the condition reflected in the Lake Emakat record during this period. The Lake Emakat record indicates that non-arboreal pollen were dominant during the early stages of the Late Holocene between 9900-9300 cal yr BP. Cyperaceae and fern spores were abundant during this period (Ryner *et al.* 2006) which is reflected in the Udzungwa Mountains record (Mumbi *et al.* 2008). However, the pollen preservation after 9300 cal yr BP was poor suggestive that decreasing lake-levels caused oxidation and subsequent corrosion of the fossil pollen (Ryner *et al.* 2006). Drier conditions continued into the Holocene in Kenya, which probably reduced the dominance of woody vegetation due to regular burning of the available biomass (Coetzee 1964). Thereafter, an increase in Ericaceae (Wooller *et al.* 2003) occurred indicating a transition from previously dominated open-grassland vegetation towards closed bushland-type vegetation that consisted of

low canopy cover and influenced by periodic occurrences of fire events. The type of grasslands shifted from C<sub>4</sub> to C<sub>3</sub>-type grasslands indicative of cooling conditions and attributed to a reduction in global carbon dioxide (CO<sub>2</sub>) conditions and lower precipitation (Wooller *et al.* 2003; Ficken *et al.* 2002).

This period of aridity at Rusaka Swamp was short-lived whereby a moist climate supported permanent humid swamp vegetation by 10,500 cal yr BP (Bonnefille *et al.* 1995). The presence of *Hydrocotyle* suggests there was an increase in ground-water input and the presence of *Potamogeton* imply the occurrence of open water (Bonnefille *et al.* 1995). Humid conditions continued to prevail with the increase in arboreal taxa including *Macaranga* from 10,000-8900 cal yr BP. Moist conditions were experienced at Sacred Lake at the start of the Holocene and continued until *ca.* 9500 cal yr BP (Coetzee 1964; Street-Perrott *et al.* 1997).

The Uluguru Mountains record supports the transition from forest-type vegetation towards more open vegetation from 6500 cal yr BP onwards, as indicated by the presence of various montane herbs and shrubs, including *Tubuliflorae*, *Crassocephalum* and *Polygalam* with a decrease in Ericaceae. From the middle of the Holocene conditions become more moist as reflected in the increase in *Euclea* and *Laurembergia* (Finch 2009).

The Holocene at Sacred lake is characterised with forest expansion from *ca.* 8000 cal yr BP up to the present (Coetzee 1964) with *Olea* and *Podocarpus* being the dominant taxa (Street-Perrott *et al.* 1997). Prior to this expansion process there was a rapid decline in Poaceae and Ericaceae indicating a rapid increase in temperatures (Coetzee 1964). Arboreal taxa decline during the late Holocene, attributed to the forest clearance by human settlements to increase the extent of agriculture lands (Rucina *et al.* 2009). The pollen record from Rumuiku swamp supports drier conditions with increased *Myriophyllum* and Poaceae with *Polyscias* and *Schefflera* declining (Rucina *et al.* 2009). Conditions during this time in Burundi were warmer and by 8900 cal yr BP dense canopy cover was present (Bonnefille *et al.* 1995). After 8900 cal yr BP conditions appeared to become more acidic with the presence of *Xyris* and drier with the occurrence of Melastomaceae around *ca.* 6000 cal yr BP (Bonnefille *et al.* 1995).

Poaceae elements were abundant in Ethiopia with low concentrations of arboreal pollen indicating that the dry Afromontane forest was not extensive during this period and probably occurred in isolated, self-contained patches (Umer *et al.* 2007). From 4500 cal yr BP, the Ericaceae elements declined sharply indicating the downward altitudinal shift of the Ericaceous belt. Pollen taxa associated with Afroalpine dwarf shrubs and herbs increased with the increase in dry Afromontane forest elements such as *Podocarpus* (Umer *et al.* 2007). The late Holocene

at Tamsaa Swamp indicates conditions were similar to the present with the expansion of *Hagenia* and *Juniperus* taxa, which could be attributed to the onset of more humid conditions (Mohammed and Bonnefille 1998). This corresponds to increased lake levels during this period (Mohammed and Bonnefille 1998).

### **3.2.6. Late Holocene (6000 cal yr BP – Present)**

The climatic variability that characterised the Holocene continued throughout the late Holocene. Rusaka Swamp reflected drier conditions from 6000 cal yr BP into the late Holocene (Bonnefille *et al.* 1995). The Lake Masako record indicates that arboreal elements including *Olea*, dominate Afromontane taxon during the period 4200-3500 cal yr BP (Vincens *et al.* 2003). The record from Udzungwa Mountains indicates that conditions after 3900 cal yr BP align with present day conditions with a decrease in swamp taxa (Mumbi *et al.* 2008). Forest taxa decreased while Cyperaceae, Poaceae and *Typha* increased suggesting increased aridity and lower lake levels at Lake Albert after 3800 cal yr BP (Beuning *et al.* 1997). The dry montane forest taxa increased during this period corresponding with the expansion of *Podocarpus* forests over the Ruwenzori highlands (Beuning *et al.* 1997; Livingstone 1967). After 3500 cal yr BP arboreal taxa declined except for *Acalypha* (Vincens *et al.* 2003). These conditions are further reflected from the two short pollen sequences extracted from Nyika Plateau, Malawi between *ca.* 4200-2500 cal yr BP (Meadows 1984). During this period, Cyperaceae and Poaceae dominated the pollen record while Poaceae declined rapidly. Arboreal pollen, namely; *Myrica*, *Olea*, and *Podocarpus* and somewhat less of *Ilex*, *Juniperus* and *Rapanea*, fluctuated throughout this period albeit as a minor component (*ca.* 5%) of the pollen sum suggesting it was unlikely that the forests had occupied greater portions of the landscape of Nyika for the last *ca.* 4150 cal yr BP (Meadows 1984). Monolet spores increased dramatically, indicative of vegetation disturbance, possibly as a result of anthropogenic forces, which created a habitat for ferns to colonise (Meadows 1984). The dramatic increase in Cyperaceae with the relatively low percentages of Poaceae indicate that human activities, particularly with the use of increased fire, has played in role in the vegetation composition of Nyika Plateau (Meadows 1984).

*Sphagnum* occurred at Rusaka Swamp from 2400 cal yr BP suggesting a highly oligotrophic environment with the wetlands becoming nutrient-deficient (Bonnefille *et al.* 1995). *Podocarpus* pollen decreased between 2000-1300 cal yr BP potentially from an increase in wood utilization by humans in the region and / or from the continuation of dry conditions. *Juniperus* pollen increased significantly during this period (Umer *et al.* 2007). After 1300 cal yr BP, an increase in *Plantago* indicates that increased anthropogenic impacts were occurring in the area (Umer *et al.* 2007).

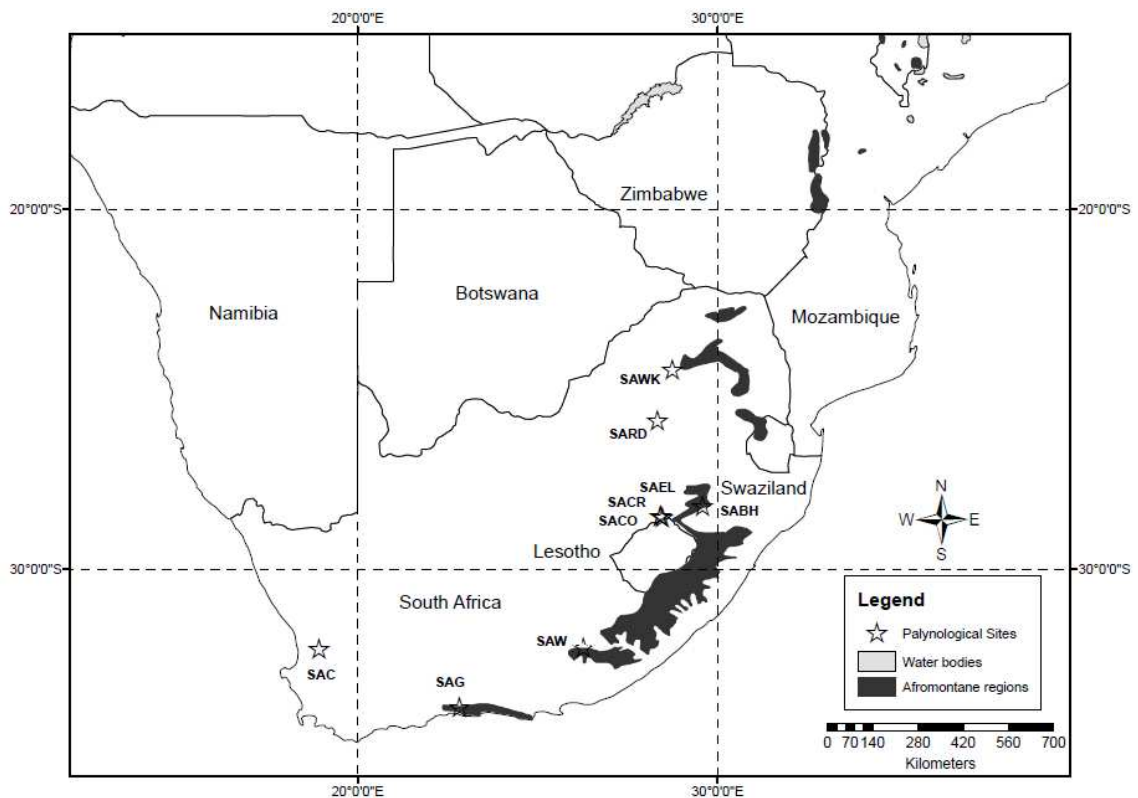
The decline in arboreal taxa lasted until 2800 cal yr BP when arboreal taxa increased. Between 1700-1500 cal yr BP *Macaranga* peaked (Vincens *et al.* 2003). Potential anthropogenic effects of forest clearance may explain the decline in *Podocarpus* after 1000 cal yr BP (Finch 2009). Asteraceae, Poaceae and *Ricinus* increased thereafter with Cyperaceae and *Ricinus* reaching a peak between 1200-500 cal yr BP (Vincens *et al.* 2003). A high-resolution climatic record is inferred from Lake Emakat from 750 cal yr BP. The Lake Emakat record reflects high Cyperaceae, *Nuxia* and Chenopodiaceae prior to 750 cal yr BP suggesting drier conditions from the lower lake levels (Ryner *et al.* 2008). Moist conditions returned until 650 cal yr BP with the onset of drier conditions. After 570 cal yr BP, Chenopodiaceae decreased and *Hagenia* increased indicating a return to moister conditions (Ryner *et al.* 2008). From 500-300 cal yr BP arboreal pollen increased with a simultaneous decrease in Poaceae (Vincens *et al.* 2003); however, the Lake Emakat record suggests drier conditions occurred between 530-280 cal yr BP as indicated by the increase in *Nuxia* on the lake margins. Moist conditions returned briefly by 270 cal yr BP with drier conditions occurring thereafter, indicated by the reduction in forest taxa (Ryner *et al.* 2008). Increased impact of eutrophication through an increase in livestock in and surrounding the swamp is suggested by the increase in algae and fungal spores (Mumbi *et al.* 2008).

The late Holocene record is well documented from the pollen records of Lake Wandakara and Lake Kasenda. From AD 600-900 herbaceous and arboreal pollen dominate the pollen record from Lake Kasenda. Whilst *Celtis*, *Olea* and Urticaceae are present, they are generally moderately well dispersed pollen and can often be over-represented in the pollen record (Ssemmanda *et al.* 2005). The presence of these taxa indicates that the regional conditions were conducive to extensive mid-altitude forest and moist lowland forest development (Ssemmanda *et al.* 2005). Lake Kasenda reflects an increase in Poaceae up to AD 1200 indicating that the semi-deciduous forests were reduced while grasslands increased. From AD 1300-1750 Poaceae pollen and tree / shrub pollen dominated the record. Swamp forest taxa were locally abundant, reflecting generally dry conditions (Ssemmanda *et al.* 2005). From AD 1750 Poaceae declines with an increase in *Acalypha*. *Celtis* and *Phoenix* increase from AD 1825-1950 and an increase in *Phoenix* was recorded in the Lake Kasenda record from AD 1200-1825; thereafter, Poaceae and aquatic pollen decline while there is an increase in arboreal taxa. The Lake Kasenda record indicates that diverse semi-deciduous forests become established between AD 1900-1965 and the appearance of *Eucalyptus* and *Pinus* in the record (Ssemmanda *et al.* 2005), which are associated with plantations (Ssemmanda *et al.* 2005).

### 3.3. Palaeoenvironments of Southern Africa

Palaeoenvironmental data based on pollen analysis is lacking from Afromontane regions of

South Africa and particularly from the Drakensberg; however, palaeoenvironmental data from other proxy sources are available for this region. Where possible, pollen analysis data have been synthesised below; however, to continue with the theme of this chapter, the palaeoenvironmental synthesis of South Africa has been derived from pollen data while excluding other proxy data sources. The study sites used in this synthesis are located throughout the country, including; the Cederberg mountains in the south-western Cape, Groenvlei in the southern Cape, Clarens in the northern Drakensberg and Rietvlei and Wonderkrater located in northern South Africa. The Clarens record has been classified in this study by their site names, namely; Cornellia, Craigrossie and Elim due to the distances between the study sites.



**Figure 3.3: Palynological sites in southern Africa within the Afromontane archipelago**  
(SABH: Braamhoek; SAC: Cederberg; SACO: Cornellia; SACR: Craigrossie; SAEL: Elim; SAG: Groenvlei; SARD: Rietvlei Dam; SAW: Winterberg; SAWK: Wonderkrater)

### 3.3.1. Pre-Last Glacial Maximum (>45,000-23,000 cal yr BP)

The period prior to the LGM in southern Africa is represented in the pollen sequences from Elim and Wonderkrater. Conditions at Elim until 26,960 cal yr BP were moist supporting an established swamp system as indicated by the high percentage of Cyperaceae. Conditions from 26,960 cal yr BP to the start of the LGM at Elim were cooler supported by fynbos elements including *Cliffortia*, *Ericaceae*, *Passerina*, *Restionaceae* and *Stoebe* (Scott 1989). The pollen record from Wonderkrater between *ca.* 28,000 cal yr BP to 23,740 cal yr BP record high

percentages of arboreal pollen associated with surrounding bushveld vegetation (Scott 1989). The bushveld contained mesic elements such as Capparaceae, Combretaceae and Oleaceae with an understory of *Aloe*-types, *Anthospermum*, *Artemisia*, Chenopodiaceae, Lactucoideae and Poaceae (Scott 1989). *Typha* was present indicating the existence of open water suggesting that temperatures were cool under a moist, sub-humid climate (Scott 1989).

### **3.3.2. Last Glacial Maximum (23,000-18,000 cal yr BP)**

The LGM period is reflected in the Wonderkrater record between 23,530-16,300 cal yr BP. Arboreal pollen, including *Podocarpus*, decrease during this period indicating drier conditions that reduced the habitat size of *Podocarpus* (Scott 1982b). Drier conditions are indicated by the increase in Capparaceae, Oleaceae, Proteaceae and Tarchonantaceae. *Artemisia*, Asteraceae, Chenopodiaceae and Poaceae occurred during this period albeit in lower proportions to the bushveld-type vegetation, further supporting drier conditions (Scott 1982b).

At Cornellia<sup>24</sup>, the LGM is reflected between 23,830-18,360 cal yr BP where fynbos elements dominate the pollen sequence. At this site, high proportion of bryophyte spores (*Anthoceros* and *Riccia*), which are local moisture indicators, are present (Scott 1989). These conditions continued at Cornelia up to the YD event. Sneeuberg Vlei in the Cederberg Mountains document the palaeoenvironments prior to the LGM until present (Meadows and Sugden 1991). Prior to 16,490 cal yr BP, restoid fynbos was established indicating high moisture conditions (Meadows and Sugden 1991). At Wonderkrater, conditions appeared to become colder and wetter than previously experienced with no arid-indicators present and *Podocarpus* possibly expanded as a result of these wetter conditions (Scott 1982b). The landscape was still dominated by open grasslands with the presence of Oleaceae and Proteaceae (Scott 1982b).

### **3.3.3. Post-Last Glacial Maximum (18,000-13,000 cal yr BP)**

After the LGM event, the vegetation from the Cederberg changed from restoid towards more xeric vegetation between 16,490-13,610 cal yr BP (Meadows and Sugden 1991). Similar cool and dry conditions were experienced during this period from Braamhoek (Norström *et al.* 2009). The period from 15,370-11,180 cal yr BP at Wonderkrater does not support these xeric conditions found in the Cederberg; however, conditions still supported the vegetation adapted to cooler conditions, such as *Artemisia*, Asteraceae, *Cliffortia*, Ericaceae and *Passerina* (Scott 1982b).

---

<sup>24</sup> The Cornellia, Cragrossie and Elim sites are commonly classified under the Clarens research. Due to slightly contrasting palaeoenvironmental conditions and the proximity of the sites to each other, they have been referred to as their individual site names.

#### **3.3.4. Younger Dryas (13,000-11,700 cal yr BP)**

The YD is not commonly reflected in southern African records; however, Meadows and Sugden (1991) perceive the YD is apparent in the Sneeuberg Vlei record between 13,610-11,760 cal yr BP with Ericaceous fynbos dominating the vegetation and with *Widdringtonia* contributing towards the over-storey. These conditions continued into the early Holocene (Meadows and Sugden 1991). While the record at Wonderkrater suggests that conditions were fairly moist during the YD, the climate was colder and the vegetation that existed during this period corresponds with the Cederberg record (Scott 1982b). The conditions on the Winterberg escarpment reflect drier conditions during the YD with high percentages of Poaceae and *Elytropappus*, which suggest arid conditions occurred from 12,830 cal yr BP until after 11,700 cal yr BP (Meadows and Meadows 1988). Conditions during the YD at Braamhoek indicate increased humidity occurred, peaking by 13,200 cal yr BP, suggested by the increase in local taxa, namely; Cyperaceae and *Gunnera perpensa*; thereafter, drier conditions returned to the area (Norström *et al.* 2009).

#### **3.3.5. Early Holocene (11,700 – 6000 cal yr BP)**

During the early Holocene, the pollen record from Rietvlei Dam from 11,490-7730 cal yr BP reflect low arboreal pollen and low local pollen concentrations, particularly of Cyperaceae. The arboreal pollen includes; Capparaceae, Combretaceae, *Euclea*, *Podocarpus*, Proteaceae, *Rhus* and Tarchonantheae. Non-arboreal pollen, which included Asteraceae, *Pellaea*-type spores, *Stoebe* and Thymelaceae were dominant (Scott and Vogel 1983). The presence of *Typha* and *Polygonum* indicate open water conditions (Scott and Vogel 1983). Based on the pollen record, grasslands dominated this period under cooler, temperate, dry, sub-humid conditions (Scott and Vogel 1983). These conditions are supported at Wonderkrater record where arboreal pollen including; *Podocarpus*, decreased indicating a reduction in *Podocarpus* habitat size and overall arboreal vegetation (Scott 1982b). Conditions on the Winterberg escarpment continued from the YD period to be dry and arid (Meadows and Meadows 1988). A period of noticeable warming occurred *ca.* 10,000 cal yr BP (Scott *et al.* 1995) which was observed at Wonderkrater *ca.* 700 cal yr later with the reduction in swamp vegetation and a further reduction in *Podocarpus* (Scott 1982b). The record from Driehoek Vlei in the Cederberg indicates that conditions were moister than previously experienced with relatively high frequencies of Proteaceae and *Widdringtonia cedarbergensis* (Meadows and Sugden 1991). Increased moisture and cooler conditions from 11,000-9700 cal yr BP are indicated from Braamhoek suggested by an increase in arboreal pollen, namely; *Acalypha*, *Buddleja*, *Celtis*, *Pittosporum* and *Podocarpus* (Norström *et al.* 2009).

The pollen record at Craigrossie from 12,520-11,130 cal yr BP is not clear. The early records indicate an increase in arboreal pollen that could suggest forest expansion or else it could reflect an over-representation of arboreal pollen when there was an overall low pollen influx in the area (Scott *et al.* 1995; Scott 1989). Furthermore, from 11,840 cal yr BP there was an increase in Chenopodiaceae, which is generally attributed to drier conditions. Again, other indications suggest that the conditions were relatively warmer and that Chenopodiaceae could have increased within disturbed areas under strong evaporative conditions (Scott *et al.* 1995; Scott 1989). Overall, this sequence from Cragrossie indicates grassland interspersed with fynbos elements under relatively wet conditions that were becoming slightly drier and with increasing temperatures towards the Pleistocene-Holocene transition (Scott *et al.* 1995; Scott 1989).

A brief period of less than 1000 cal yr BP occurred at Rietvlei whereby conditions become more arid, under further cool, temperate, dry, sub-humid conditions indicated by an increase in Acanthaceae, Asteraceae and Chenopodiaceae with Poaceae decreasing during this period (Scott and Vogel 1983). The pollen record at Groenvlei supports the drier conditions indicated by the decline in arboreal pollen of *Cussonia* and *Ilex* and dry sclerophyllous coastal vegetation. Asteraceae, Ericaceae and *Stoebe* increased during this period (Martin 1968). Conditions at Braamhoek further support drier and warmer conditions from 9700-7500 cal yr BP with a decline in forest taxa during this period (Norström *et al.* 2009). The Craigrossie record supports the increase in *Artemisia* and Poaceae during these relatively warm, humid conditions (Scott 1989). In the Winterberg record drier conditions prevailed until *ca* 8000 cal yr BP suggested by the occurrence of Asteraceae, Chenopodiaceae, *Elytropappus* and Thymelaeaceae; however, indications of increased moisture exist with the increase in Cyperaceae and other types of sedges, which are characteristic of water-logged environments (Meadows and Meadows 1988).

After *ca.* 8000 cal yr BP montane forest taxa, including; *Olea* and *Podocarpus*, appeared in the Winterberg pollen record, albeit in low concentrations, indicative of increased moisture availability (Meadows and Meadows 1988). During this period, taxa associated with drier, arid conditions declined, while cooler conditions are suggested by the increase in *Stoebe*. After 7400 cal yr BP, there was an increase in fern spores, arboreal pollen and a decrease in Acanthaceae, *Anthospermum*, Cyperaceae, Poaceae and *Stoebe*. These changes reflect warmer climatic conditions with the development of broad-orthophyll / upland bushveld (Scott and Vogel 1983). The Wonderkrater and Groenvlei records shows similar trend with *Artemisia*, *Olea*, *Podocarpus* and Restionaceae all declining (Scott 1982b; Martin 1968). The pollen record from the Cederberg indicates that during this period there was an increase in moisture availability and the vegetation returned to restoid fynbos (Meadows and Sugden 1991). The Craigrossie records



supports this with a peak in *Artemisia* occurring with the possibility of increased winter rainfall in this area (Scott 1989).

### **3.3.6. Late Holocene (6000 cal yr BP – Present)**

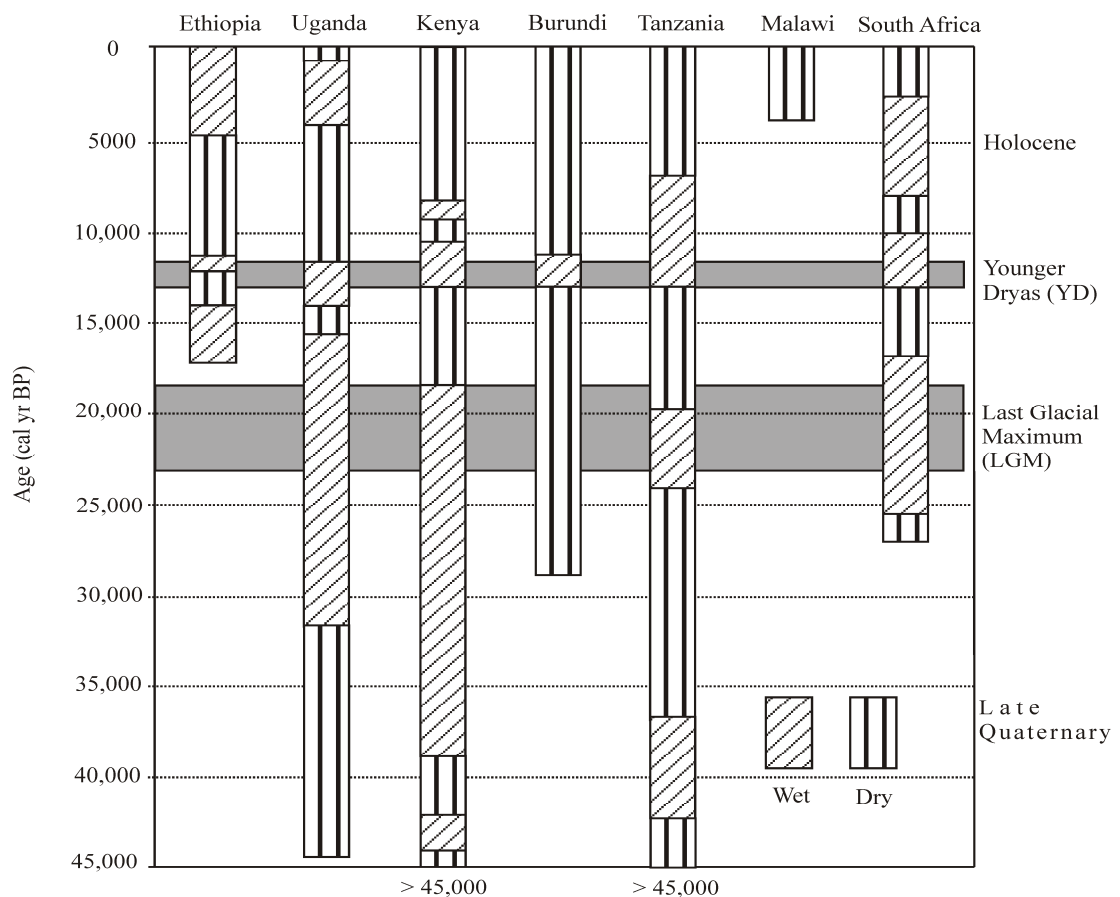
From 4460 cal yr BP more xeric conditions were experienced with the Ericaceous fynbos once again replacing the restoid fynbos in the Cederberg region (Meadows and Sugden 1991) and reflected in the Groenvlei record (Martin 1968). The Groenvlei record further indicates the occurrence of pioneer scrub formation with an increase *Anthospermum*, Ericaceae, *Myrica* and Restionaceae. Towards 2200 cal yr BP, *Podocarpus* decreased while there was an increase in Chenopodiaceae and *Ruppia*, indicating that the vlei was more heavily influenced by marine conditions during this period. Furthermore, the decline in Asteraceae indicates a period of sustained amelioration that were not conducive to forest expansion (Martin 1968). The warmer and drier conditions experienced at by the Groenvlei and Cederberg records are evident in the local and regional Braamhoek records (Norström *et al.* 2009). Cooler, more temperate conditions were experienced at Wonderkrater between 4030-2090 cal yr BP indicated by the reduction in arboreal pollen and montane forest (Scott 1982b). The Driehoek Vlei record shows this transition albeit *ca.* 2000 yr earlier. Furthermore, the Driehoek Vlei sequence shows signs of human disturbance on the landscape with the increase in Montiniaceae, Oxalidaceae and Plantaginaceae and the decline in fire-sensitive taxa. Based on the age at Driehoek Vlei, it is unlikely that the disturbance could be attributed to colonial expansion, rather it could have been the result of Khoi-San occupation in the region (Meadows and Sugden 1991).

From 2240 cal yr BP onwards, arboreal pollen declined with an increase in Amaranthaceae, Asteraceae and Chenopodiaceae at Rietvlei. Fern spores remained dominant in the non-arboreal taxa while Cyperaceae decreased. These changes indicate open grassland with cooler temperate, moist, sub-humid conditions were experienced at Rietvlei (Scott and Vogel 1983). The decline in arboreal pollen is not supported at Wonderkrater where arboreal pollen increased with a more mesic bushveld vegetation being supported, indicating warmer conditions, albeit not as warm as at present (Scott 1982b). The contrast in conditions after 2240 cal yr BO are further suggested at Braamhoek with increased humidity, wetland accumulation and forest taxa occurring during this period (Norström *et al.* 2009). At Groenvlei, conditions are suggestive of further climatic amelioration with increased scrub coverage on the dune environments up until 1800 cal yr BP (Scott 1989). Increased Cyperaceae and *Gunnera perpensa* in the Craggrossie record indicate that conditions during the last 1860 cal yr BP changed with a transition into summer-rainfall (Scott 1989). Thereafter, *Podocarpus* increased dramatically along with a peak in *Olea* which indicates a possible vegetation succession occurring. This succession appeared to begin with sclerophyll scrub elements such as *Passerina* and Proteaceae followed by forest taxa (Martin 1968). The

spread of forest further indicate increased moisture availability conducive to forest growth. Near the base of the core, arboreal taxa decline and could be inferred as the result of human colonisation in the area or possibly the onset of drier conditions (Martin 1968). The last *ca.* 890 cal yr BP on the Winterberg escarpment provides indications of anthropogenic influences with a decline in montane forest taxa, which are replaced with disturbance-type shrubs, such as *Anthospermum*, *Ericaceae*, *Mimosoides* and *Stoebe*. Furthermore, *Pinus* is recorded during this period in the record indicative of the plantations that were established in the last 150 yr (Meadows and Meadows 1988).

### 3.4. Synthesis of Eastern and Southern African Palaeoenvironments

Similar trends in climatic conditions have been experienced throughout southern and eastern Africa since 44,000 cal yr BP (Figure 3.4). A general summary of these palaeoenvironmental conditions is provided hereafter.



**Figure 3.4: Summary of wetter and drier conditions from southern and eastern Africa<sup>25</sup>**

<sup>25</sup> The summary of wet / dry periods depicted is all derived from the authors used in the literature review and referenced therein. In some cases, conflicting periods exist and the majority consensus was used to formulate the table; therefore, cognizance of discrepancies may occur.

Prior 44,000 cal yr BP, the upper-moist boundary of  $^{14}\text{C}$ , conditions in Kenya and Tanzania indicate dry conditions that were becoming colder with semi-closed canopy, dry montane forest taxa dominating the pollen record as well as increases in high-altitude Afroalpine and Ericaceous taxa. From 44,000-24,000 cal yr BP in Kenya, Tanzania and Uganda, conditions became colder and drier but remained relatively moist with Poaceae dominating the record. Dry montane forest existed and lake levels appeared to be decreasing. The LGM was arid with fire-dominated grassland and a lack of arboreal taxa.

The Ericaceous belt declined lower onto the slopes and there was a decline in moist forest taxa. After the LGM, conditions reflected greater moisture availability with an increase in arboreal taxa and aquatic pollen and a decrease in  $\text{C}_3$  taxa. These conditions persisted until the YD event where conditions once again became drier and cooler, with indications of decreasing lake levels. Conditions in South Africa indicate that whilst climate was cooler there was still moisture availability. The Holocene reflects fluctuating climates moving between slightly drier and slightly wetter conditions, with conditions reflecting present conditions. With the fluctuating conditions, there were alternating periods of forest expansion and grassland expansion. The period that characterises increased human occupation continues the trend of alternative drier and wetter conditions, but over much of Africa, the trend was towards drier conditions.

### **3.5. Conclusion**

While a number of pollen analytical studies have been conducted within the Afromontane archipelago, few attempts have been made to synthesize this work. While this research and synthesis does not portray itself as being comprehensive, it does provide some insight into the similarities between palaeoenvironmental conditions across southern and eastern Africa. This is an attempt of a very complex synthesis where much research has been excluded that would be vital in any further synthesis to include understanding the variability of African climates and past climates. The majority of sites discussed found similar trends in climate, especially those relating to the LGM, YD and the Holocene. Variability, extent of climatic changes and the timing of such changes is often different between research sites; however, similar trends do exist.

## CHAPTER FOUR

### 4. THEORETICAL METHODOLOGY

#### 4.1. Introduction

This chapter provides a theoretical basis for the methods applied in this research. To achieve this, the theoretical basis underpinning each proxy, namely; pollen, charcoal, geochemical and radiocarbon analysis is provided. Cognisance of the difficulties, possible errors and limitations of each theoretical analysis used is detailed. Understanding the results derived through the methods used in palaeoenvironmental research is determined through the recognition of these limitations and the importance of a theoretical basis and critique are strengthened.

#### 4.2. Pollen Analysis

Pollen analysis was developed in the early 20<sup>th</sup> century as the research of fossil pollen and spores (hereafter referred to as pollen for the sake of brevity) preserved in geological deposits (Faegri and Iversen 1989; Seppä and Bennett 2003; Moore *et al.* 1991). The pollen analysis technique was developed to research Quaternary lakes and bogs and has been used extensively on a wide array of deposits including; marine, lacustrine, loose and consolidated sediments (Faegri and Iversen 1989). Pollen analysis is a fundamental quantitative method for investigating palaeoenvironmental and palaeovegetation conditions over various spatial and temporal scales (Faegri and Iversen 1989); however, an important assumption of pollen analysis is that the pollen record is correlated to plant diversity on a landscape scale (Cowling *et al.* 2008). Based on this assumption, pollen analysis can be conducted on temporal scales ranging from decades to millennia at a variety of spatial scales (van Odgaard 1999) ranging from local to continental scales (Duffin and Bunting 2008; Power *et al.* 2008).

The spatial and temporal versatility of pollen analysis enable a wide variety of processes to be analysed, which include inferences of human disturbance impacts on vegetation. Climate is paramount to the usefulness of pollen analysis as climatic conditions determine vegetation composition (Meadows and Hill 2002). However, topographical features and fire regimes (Conedera *et al.* 2009) need to be considered when determining what the prevailing climatic conditions were when using pollen analysis (Scott and Brink 1992). Through understanding these factors, important inferences can be made regarding past terrestrial and aquatic environments (Feurdean *et al.* 2008; Barkley 1934; Faegri and Iversen 1989; Seppä and Bennett 2003) and the ability of vegetation within these environments to respond to abrupt climatic changes (Ortu *et al.* 2006). Furthermore, vegetation diversity, richness, distributional patterns

and vegetation type can be determined under both natural and anthropogenically influenced conditions (Ortu *et al.* 2006; Brown 1999).

Climatic conditions can be inferred through the application of pollen analysis. Analysis of stratigraphically constrained archives such as pollen from sediment cores (Duffin and Bunting 2008) enables a high spatial and temporal resolution of climatic factors including; seasonality, annual temperatures, annual precipitation, potential and actual evapo-transpiration and growing degree days above 0°C and 5°C respectively (Feurdean *et al.* 2008). Vegetation is a strong climatic indicator with vegetation changes reflected in changes in abundance, geographic extent, location of source areas and floral composition of plant populations (Flantua *et al.* 2007). Pollen analysis can contribute towards an understanding of modern biodiversity by identifying the 'base-line' levels of species richness under natural environmental conditions. Pollen data can be used to describe diversity aspects of long-term succession, gradual environmental changes such as soil development, determine long-term and landscape-scale effects of land-use changes on biodiversity and information on diversity variations (van Odgaard 1999).

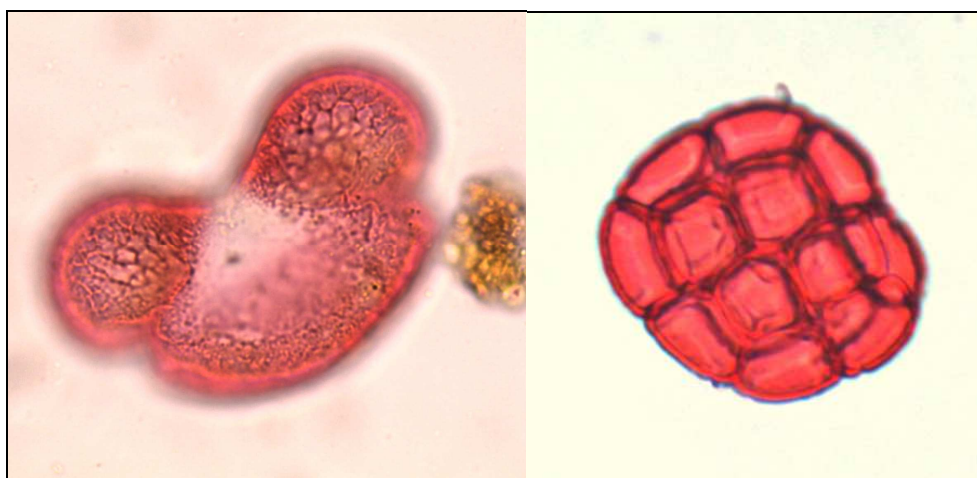
The long history, advances in techniques, interpretation of pollen assemblages and the wide variety of applications of pollen analysis is a testament to the importance of this technique in palaeoenvironmental reconstructions. Nevertheless, cognisance of the limitations in pollen analysis is crucial in understanding palaeoenvironmental conditions; therefore, a critique detailing the limitations of pollen analysis is provided hereafter.

#### **4.3. Critique of Pollen Analysis**

A number of challenges exist when attempting to understand the pollen record, namely; the variation in pollen production, dispersal mechanisms and ratios, pollen deposition between species (Feurdean *et al.* 2008) and the paucity of data in some parts of the world (Kershaw and Bulman 1996). These variations are a major limitation for pollen analysis as a measure of past vegetation development and climate (Feurdean *et al.* 2008). As such, five areas of limitations in pollen analysis are discussed, namely; pollen dispersal and deposition, source of errors in the pollen analysis procedures, counting methods and pollen identification.

Understanding pollen production and dispersal is the first step in pollen analysis (Faegri and Iversen 1989). Pollen dispersal can occur through three methods namely; via wind (anemophily), water (hyp-hydrogamous), or insects and other animals (zoophily). The dispersal method adopted is directly correlated to the quantity of pollen produced for dispersal. Anemophilic dispersal relies on large amounts of pollen to be produced to ensure successful

reproduction; zoophilic and hyp-hydrogamous dispersal requires substantially less pollen to be produced compared to anemophilic dispersal (Bunting 2008; Mullins and Emberlin 1997; Oksanen and Ranta 1992). Pollen dispersal is dependent on meteorological conditions, as plants will only open their mature anthers when conditions are favourable for successful fertilization. The assumption that all pollen is dispersed in large quantities by the same dispersal method can cause misinterpretation of the pollen record. For example, *Podocarpus*, which is a common pollen in African sediments is produced in large quantities and is widely dispersed by wind (Scott 1982a; Hamilton 1972) while, *Acacia* is found in a wide variety of habitats throughout Africa but is poorly dispersed (Scott 1982a; Coetzee 1955).



**Plate 4.1: *Podocarpus* (left) and *Acacia mearnsii* (right) pollen**

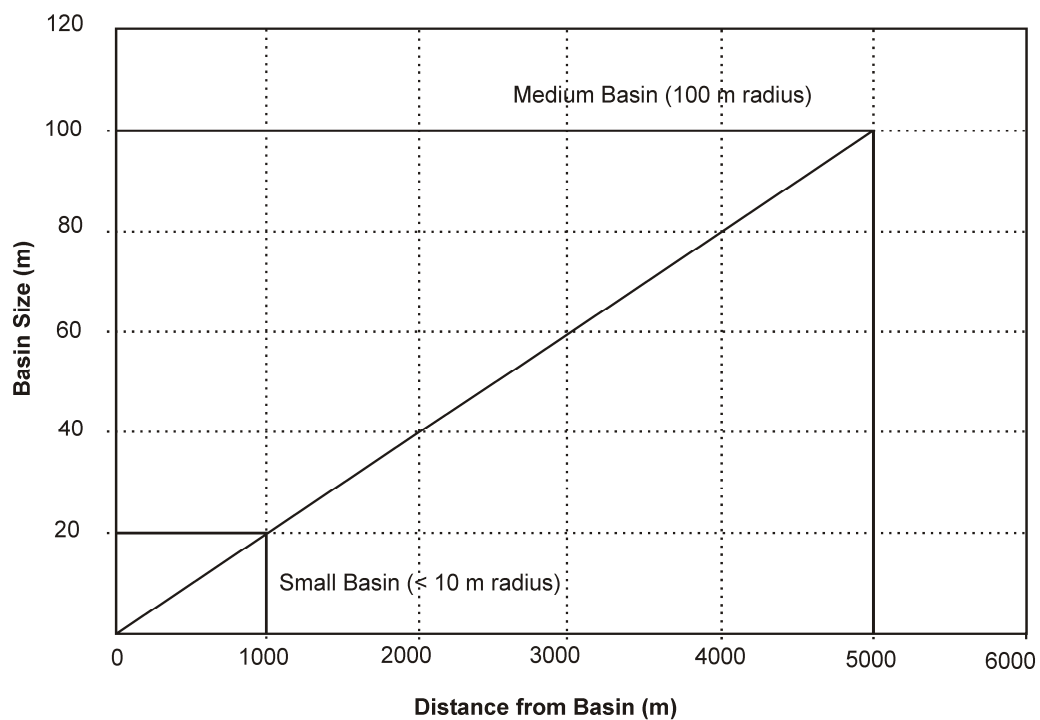
(*Acacia mearnsii* picture courtesy of Anel Geer)

However, additional adaptive qualities of pollen, which include pollen size ranging between 10  $\mu\text{m}$  and 100  $\mu\text{m}$  and the spherical shape, are fundamental aspects for the successful dispersal of pollen (Faegri and Iversen 1989). Therefore, an understanding of the various dispersal mechanisms and key drivers, such as prevailing atmospheric conditions, the relative importance of frequent and rare taxa can be discerned.

Morphological, physiological and atmospheric conditions not only allow for successful dispersal of pollen but successful deposition of pollen. Pollen deposition and successful preservation are important factors for a continual vegetation presence and for palaeoenvironmental research. Pollen deposition is governed largely by atmospheric conditions and follows Stoke's law, which states that the rate of deposition is proportional to the square of the pollen radius in still air. The relatively small size and spherical shape of pollen is thus conducive to uniform deposition (Mullins and Emberlin 1997; Oksanen and Ranta 1992; Faegri and Iversen 1989); however, the size of the pollen depositional basin is an important factor in determining the abundance and

diversity of pollen preserved in various environments (van Odgaard 1999). Depositional basins differ in size, shape, abundance of vegetation, and vegetation types and these variables influence the spatial resolution (local or regional) determination of pollen.

A hypothetical small woodland hollow (Figure 4.1) with a radius between two and ten meters, predominately reflects local vegetation populations occurring within 50 m of the depositional basin (van Odgaard 1999), whereas reality dictates that the situation is far more complex (Bunting 2008). In contrast, medium and large size basins reflects vegetation populations occurring within five kilometres of the depositional basin (van Odgaard 1999).



**Figure 4.1: Relationship between basin size and pollen source area (adapted from van Odgaard 1999)**

To summarise, small basins have small pollen source areas and lower pollen abundance while large basins have large pollen source areas and higher pollen abundance (Seppä and Bennett 2003). Furthermore, local pollen signals are often overrepresented in small basins resulting in rare taxa being 'hidden' in the pollen record with an over-representation of local pollen (Brown 1999). To complicate matters, every pollen taxa has its own source area and the source area can shift over time (van Odgaard 1999) resulting in shifting vegetation structures over time. Recent advances in modelling of pollen source area on a local and regional scale have helped to improve an understanding of how heterogenic landscapes and pollen dispersion mechanisms occur in relation to pollen source area. These advances include the development of models, such

as Regional Estimates of Vegetation Abundance from Large Sites (REVEALS) (Sugita 2007a) and Local Vegetation Estimates (LOVE) (Sugita 2007b) and algorithms, such as Landscape Reconstruction Algorithm (LRA) (Sugita 2007b). These models and algorithms are used in conjunction with each other to develop quantitative vegetation reconstruction for various pollen sinks (Sugita 2007b). The characteristics of the deposition basin, the vegetation structure and the unique attributes of each pollen taxa can determine the spatial resolution of pollen deposited and later analysed (van Odgaard 1999); however, the depositional characteristics of pollen are an important factor contributing to the pollen signal.

The pollen signal is strongly influenced by the morphological characteristics includes a robust, decay resistant sporopollenin outer wall that enables successful preservation under anaerobic conditions for many thousands of years (Duffin and Bunting 2008; Feurdean *et al.* 2008; Faegri and Iversen 1989). Wetland, peatland and lacustrine environments provide suitable locations anaerobic conditions for the relatively high pollen abundance; however, wetlands and peatlands have their own challenges in understanding the deposition of pollen. Duffin and Bunting (2008) outline four factors that complicate the analysis of the pollen signal in wetlands namely; i) the confusion of pollen taxa that are found both within and outside of the wetland basin, ii) the dilution of the regional pollen signal by the local pollen signal, iii) filtration of pollen from the wider landscape through removal prior to deposition in the wetland, and iv) a combination of the above three points when dealing with the various seral stages of succession on different parts of the wetland. Furthermore, some pollen taxa are more heavily influenced by competitive interactions, climatic changes determining the availability of water, sunlight, and anthropogenic disturbance and a combination of factors, which affect their abundances within the wetland (Chambers *et al.* 2007). All these factors should be considered and understood to interpret the pollen record in any meaningful way.

Pollen analysis, as for any analysis, has inherent variability resulting in an increase in associated errors of the analysis. Variability exists in pollen types, the deterioration and preservation of pollen, deposition rates, quantities of pollen produced, dispersal rates, distances of dispersal and the pattern of dispersion, while associated errors in pollen analysis include; the sampling strategy of pollen analysis, whereby a sediment core is extracted from a larger basin, sub-samples are then extracted from the sediment core, and finally, a percentage of the sub-sample is used to create pollen slides, which creates uncertainties in the pollen representation of the basin and surrounds. However, this is unavoidable and methods to minimise these uncertainties have been developed such as conducting high-resolution pollen analysis (Barkley 1934). Furthermore, a fine spatial and temporal resolution analysis of the pollen signal can determine, based on specific research designs, what processes can be reflected in the results (van Odgaard



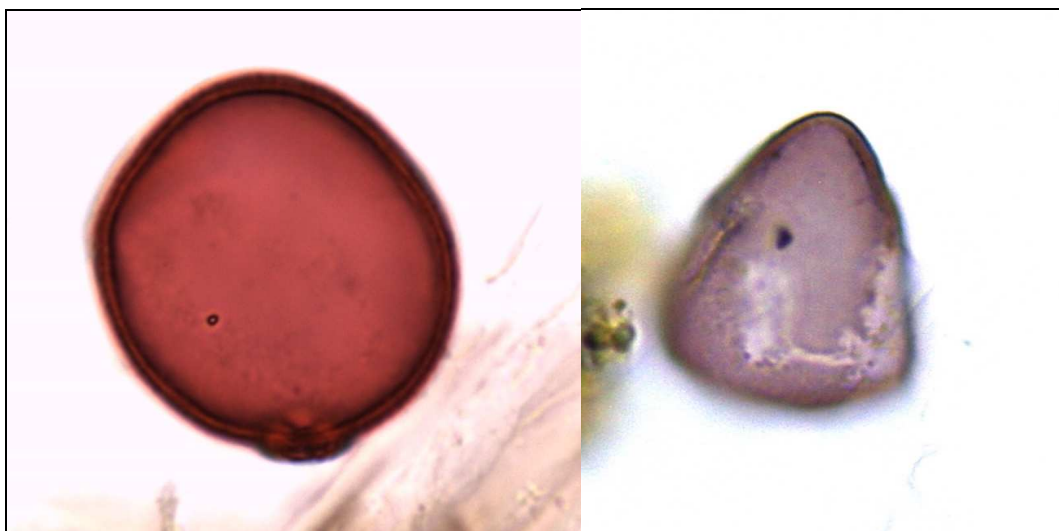
1999). Besides having a high-resolution chronology of the sediment core under analysis, the counting methods used can minimise the errors associated with sampling strategies.

Various counting methods have been developed to determine species richness, abundance, diversity and rareness and the counting strategy should be adapted to be site specific and research dependant. The minimum number of pollen counted per slide is contentious and dependant predominantly on the research site. It has been proposed that there is little value in counting above 200 pollen grains per slide at a fixed depth (Barkley 1934); however, in South Africa a minimum of 250 pollen grains and spores should be counted per depth to be statistically significant (Meadows *et al.* 1996; Grab *et al.* 2005). In the Drakensberg, it was found that there was no significant difference in pollen species when slides were counted at 250, 500 and 1000 pollen grains and spores (Hill 1992). Value can be added to the results when a slide from an adjacent sediment core is analysed and the two adjacent slide values are averaged (Barkley 1934). It is possible that the magnification used during counting could create further uncertainties; however, Barkley (1934) suggested that no significant advantage was incurred by counting under a low or high-powered microscope; however, general analysis protocols standardise the counting magnification at 400 x and 1000 x.

As previously mentioned, counting methods should be adjusted depending on the question asked by the research. Pollen richness is influenced by taxonomic precision, pollen preservation, productivity and the vegetation richness, enabling the analysis to determine ecological change, which is a fundamental aspect of pollen analysis (Brown 1999). Pollen richness is determined by counting a fixed number of pollen per slide, using the rarefaction technique (Cowling *et al.* 2008). Counting to a fixed number of pollen grains can also remove some variability from counting uncertainties (Brown 1999). However, problems of determining pollen richness include; the relationship between pollen richness and pollen concentration where pollen richness is negatively correlated with pollen concentration. Low pollen concentrations need a greater proportion of total pollen counted as compared with high pollen concentration. It is inferred that by counting a larger sample of pollen there will be more rare taxa found, inflating the relative quantities of rare taxa in low concentrated samples as compared to high concentration samples. Furthermore, unevenness in pollen concentration could cause rare taxa to be under-represented (Cowling *et al.* 2008). Key aspects in determining rare taxa is governed by high sample counts, consistent chronologies and consistent pollen identification (Berglund *et al.* 2008).

Reliable identification of pollen is crucial in pollen analysis. To assist in pollen identification there are many digital libraries and tools, which include; the African Pollen Database (APD) (APD 2004), Pollen and Spores of Barro Colorado Island (Roubik and Moreno 1991), and the

Neotropical Pollen Key (Bush and Weng 2007) pollen reference databases and a knowledge of the local and regional pollen flora (Hooghiemstra and van Geel 1998). Pollen identification is hindered by low and uneven taxonomic resolution whereby some palynomorphs can only be identified to family level (Kershaw and Bulman 1996; Seppä and Bennett 2003)., such as Poaceae and most Cyperaceae taxa (Plate 4.2).



**Plate 4.2: Poaceae (left) and Cyperaceae (right) pollen**

This is a critical limiting factor in pollen analysis as not all species, which belong to a single family, occupy the same habitats or are influenced by climatic conditions in the same way. Species belonging to one family can occupy different habitats and be influenced differently by changing climates. Thus, identification to family level can result in minor environmental fluctuations and vegetation compositional changes to be overlooked. Furthermore, pollen diversity determined through the analysis technique can be vastly less than the vegetation diversity recorded at the research site due to the inability to determine pollen taxa below family level. This would result in the simplification of the pollen sequence and the subsequent analysis (Ortu *et al.* 2006; Kershaw and Bulman 1996). Thus, cognisance of the limitations in pollen interpretation is needed to provide credible and realistic palaeoenvironmental reconstructions.

The interpretation of pollen records is often conducted through the use of pollen diagrams, which illustrate abundance and variation of pollen taxa through time (Flantua *et al.* 2007; Bunting 2008). These changes in vegetation allow environmental conditions to be inferred (Flantua *et al.* 2007); however, errors can occur as a result of incorrect interpretation of pollen diagrams when trying to distinguish climatic ‘events’. Pollen diagrams can only provide descriptions of the rate and direction of change over time; they cannot identify the key drivers of those changes (Power *et al.* 2008). The development of computerised pollen analysis has

assisted in the interpretation of pollen diagrams by increasing the reliability and objectivity in pollen diagrams, this is achieved by grouping the pollen records into zones based on the relative uniformity of pollen composition (Seppä and Bennett 2003). There are two commonly used computer programs; namely Tilia (Grimm 1992) and Psimpoll (Bennett 2005), which have been designed to create pollen diagrams and provide a level of statistical analysis operations including CONNISS (Grimm 1987), a statistical application for the zonation of pollen.

While there is little dispute over the importance of pollen analysis in Quaternary Science, researchers must acknowledge the limitations of the techniques used and develop approaches to address these limitations. To reduce the limitations on pollen analysis a number of factors need to be considered including; pollen production, dispersal, deposition, preservation and environmental and geological conditions. Cognisance must be taken of all of these factors and sub-factors to ensure that credible and reliable palaeoenvironmental reconstructions are made. This will allow for the continual development of pollen analysis within the equally vast array of disciplines within which it is practised under.

#### **4.4. Charcoal Analysis**

Charcoal is formed through the incomplete combustion of plant material (MacDonald *et al.* 1991; Patterson *et al.* 1987) and can be preserved for millennia (Carcaillet 2007). The importance of charcoal analysis was first recognized in the early 1900s by using charcoal fragments to determine the role of fire in human communities. These early studies were time consuming, analysing thin-sections removed from archaeological sites. Microscopic charcoal identification and analysis was developed within the palaeoecological discipline to enable rapid identification and counting of charcoal fragments (Figueiral and Mosbrugger 2000). The method has since been used in a wide array of studies including; vegetation and ecosystem changes, forest succession, natural and anthropogenic-induced fire regimes, biomass burning influences on global carbon cycles and climate change (Tinner and Hu 2003; Turner *et al.* 2008). Figueiral and Mosbrugger (2000) divide charcoal analysis into two groups, namely; archaeological charcoal and soil-profile charcoal. Archaeological charcoal analysis can determine changes in former ecosystems, vegetation communities and the affect of humans on vegetation change. Charcoal derived from soil profiles can be used to determine the evolution of plant communities and the importance of fire on vegetation structure and composition (Figueiral and Mosbrugger 2000).

Charcoal can be produced through a variety of mechanisms from natural to anthropogenic-induced events including; volcanic activity, meteorite fallouts, lightning strikes, rock falls, spontaneous combustion, hunting, farming and domestic use of fire. The factors that result in

charcoal production include; i) fire intensity and duration, biomass volume, type and characteristics including hardness, compactness and moisture content and ii) meteorological conditions, especially wind direction, wind velocity and rainfall, at the time of, or soon after the fire event (MacDonald *et al.* 1991; Patterson *et al.* 1987). These factors contribute to the variability of the charcoal influx values (Carcaillet 2007) and affects the amount and size of charcoal produced, and how readily the charcoal is dispersed. Typically, surface fires in shrub or herb-dominated habitats are quick and cool burning and produce large quantities of charcoal (Scott *et al.* 2000) whilst fires in woody and tree dominated areas are longer and warmer burning and produce less charcoal as the fire temperatures completely combusts the organic matter.

Two key aspects of charcoal dispersion is the time that charcoal takes to disperse and the dispersal distance. Dispersal of charcoal can occur either by primary dispersal occurring during or soon after the fire event, or secondary dispersal occurring as surface run-off and lake sediment mixing (Whitlock and Larsen 2001). Dispersal time of charcoal depends on rainfall, slope steepness, drainage ditches, run-off and wind regimes at the time of the fire event (Patterson *et al.* 1987).

The distance of charcoal dispersal often depends heavily on the intensity of the fire event. Fire intensity determines the charcoal particle size and as a result the dispersal capabilities of the charcoal. Dispersal distances can be classified as regional, extra-local (outside of the watershed area) and local (within the watershed). The intensity of the fire can cause convective plumes which in turn affect the size of charcoal particles that can be entrained and the distances that those particles can cover, called the 'skip-distance' before being deposited (Whitlock and Larsen 2001). It is generally assumed that smaller particles are dispersed greater distances from the source of the fire than large particles. However, the intensity of the fire and therefore the 'skip-distance', can entrain larger fragments and carry them for longer distances before deposition than what would normally be considered possible (Whitlock and Larsen 2001). Experiments with charcoal particles sizes indicate that large particles,  $>100\ \mu\text{m}$  are deposited close to the source of the fire, covering distances in the region of tens of kilometres if caught within the convective plume, whereas, smaller particles  $<100\ \mu\text{m}$  can be transported hundreds to thousands of kilometres. While smaller particles are able to be transported over long distances prior to deposition, they are more difficult to initially entrain than larger particles (Laird and Campbell 2000; Patterson *et al.* 1987). However, larger particles are generally not kept entrained for long distances (Clark 1988) resulting in the deposition closer to the source of the fire than smaller fragments.

Charcoal analysis involves a number of assumptions due to the lack of comprehensive research in transport and size dynamics of charcoal; i) charcoal peaks are considered to be above background values of charcoal concentrations, ii) primary dispersal of charcoal contributes to the majority of microscopic charcoal found in sediments and secondary dispersal is minor in comparison, iii) large particles are considered local representation of fires as they cannot be transported for long distances compared with smaller particles that can be transported over very long distances, iv) microscopic charcoal analysis provides a reliable source to interpret palaeo-fires and palaeoecology (Blackford 2000), and v) the lack of distinctive charcoal peaks is often related to sediment mixing, secondary deposition or integrated samples that have 5-20 years of sediment (Clark 1988).

The entrainment time of charcoal prior to deposition is crucial to understanding the occurrence of fire. The timing of charcoal deposition depends on a number of factors including; the area of the depositional site, the topography of the site and the physical properties of charcoal. The size of the depositional site influences the amount of charcoal that could be deposited and are classified into three groups; i) local sites consisting of small closed lakes and peat bogs in forest clearing with an approximate diameter of 25 m, which receive local deposits from 20-30 m away from the site, ii) extra-local sites consisting of small bogs or medium-sized lakes, and iii) regional sites consisting of blanket bogs, large lakes, and watersheds that can receive deposits from over 100 km away (Laird and Campbell 2000; Patterson *et al.* 1987). Charcoal deposition is further influenced by the topography of the depositional basin. Depositional basins with steep slopes often contribute to increased secondary charcoal deposition through erosion of soil into the lakes or wetlands within the regional, extra-local, or local depositional sites (Figueiral and Mosbrugger 2000; Whitlock and Larsen 2001). Bioturbation processes could affect the type and quantity of charcoal found in a stratigraphic layer (Figueiral and Mosbrugger 2000) and the physical structure of charcoal can impact on charcoal deposition.

Charcoal is porous and can be buoyant with a true specific gravity ranging from 0.3-0.6 to 1.4-1.7 (Patterson *et al.* 1987). Buoyant charcoal fragments can be lost through water replacement in basins and these losses are very difficult to quantify (Patterson *et al.* 1987). While primary and secondary deposition affects the amount and size of charcoal found, re-deposition and mixing can also influence charcoal concentrations and sizes. Redeposition and mixing can occur through a number of reasons including; burrowing insects and small animals and trampling by larger animals, frost heaving at higher altitudes (Patterson *et al.* 1987) and from streams and rivers and from the littoral zones of lakes and wetlands (Whitlock and Larsen 2001). The rate and extent of redeposition and mixing is highly variable and heavily dependent on climate, water levels, vegetation, animal populations, and human activity (Patterson *et al.* 1987).

There are numerous techniques that can be used in charcoal analysis *viz.* thin-sections, sieving, combustion-digestion, spectrographic, and the pollen slide technique. The pollen-slide technique is a commonly used technique as the method is often combined during pollen analysis and shows a strong correlation between the source area of vegetation for both charcoal and pollen (Tinner and Hu 2003). The results derived from microscopic charcoal analysis can be expressed through number counts along transects or area determinations both expressed as a percentage of the pollen sum, as a ratio to total pollen (Patterson *et al.* 1987), as accumulation rates (Clark 1988), or through size-class classification. Charcoal analysis is based on the assumption of homogenous charcoal distribution over the entire slide enabling a comparison of charcoal concentrations at different stratigraphic layers.

Comparisons made between quantifying charcoal per unit area and the number of fragments per slide has shown a strong correlation at various stratigraphic layers (Tinner and Hu 2003). Microscopic charcoal is an indication of regional fire activity and limited local inference can be made as techniques used for charcoal preparation limit the number of macroscopic charcoal fragments. As a result, microscopic charcoal analysis can generally be used to detect fire events that occur between 20 km and 100 km from the fire source (Tinner and Hu 2003). For charcoal to be used representatively and statistically for environmental reconstructions, a minimum number of between 200 and 250 charcoal fragments should be counted at each stratigraphic layer (Figueiral and Mosbrugger 2000). A crucial factor in microscopic charcoal analysis is the identification of charcoal fragments. Microscopic charcoal is identified as being jet-black or black, opaque, angular, planar (Patterson *et al.* 1987; Whitlock and Larsen 2001), straight edged and processing a blue hue on the edges of the fragments (Turner *et al.* 2008).

The digestion-combustion technique is another possible technique that has been used to determine charcoal concentrations (Winkler 1985). The digestion-combustion technique has been used since the 1970s as an alternative technique to the microscopic charcoal technique. This method aims to minimise errors resulting from the microscopic charcoal analysis techniques and to make the process more efficient although this method does have its detractors (Carcaillet 2007; Rucina *et al.* 2009). The digestion-combustion technique calculates the percentage of charcoal after chemical digestion by nitric acid and inorganic and organic material. The ignition/combustion process was quicker than that of Robinson (1984), and Winkler (1985) described the process as being relatively fast and simple, whilst the results are comparable to microscopic charcoal analysis results (Rucina *et al.* 2009).

The long history and continual development of charcoal analysis has enabled a number of techniques to be developed for a wide array of disciplines. There are a number of critiques levelled at the charcoal analysis techniques and understanding the limitations of these techniques would improve palaeo-fire interpretations. Therefore, a critique of charcoal analysis and the methods used in this research has been provided to highlight the potential limitations involved in this research.

#### **4.5. Critique of Charcoal Analysis**

To understand and interpret the charcoal record, cognisance should be taken of the possible sources of errors, not only because of the data collection and analysis techniques used, but also from taphonomic processes, which include; production, dispersal and deposition of charcoal. Charcoal fragments are subject to these taphonomic process from the time of production to the time of sampling, and from the data collection processes (Patterson *et al.* 1987). There are a number of methods available to sample and quantify charcoal (Patterson *et al.* 1987; Whitlock and Larsen 2001), yet, no single method has been universally accepted (Clark 1982; Patterson *et al.* 1987). Two techniques will be discussed here; the microscopic charcoal analysis technique and the digestion-combustion technique as these techniques have been implemented in this research. Within each discussion, the difficulties and errors associated with each technique will be highlighted and a section comparing the two techniques is provided.

##### **4.5.1. Microscopic Charcoal Analysis**

Microscopic fossil charcoal analysis is a relatively quick and inexpensive technique, which provides accurate estimates of the amount of microscopic charcoal particles (Clark 1982; Patterson *et al.* 1987). Major sources of error in microscopic charcoal analysis are associated with the technique lacking methodological uniformity, coupled with incorrect and inconsistent charcoal identification, difficulties associated with size-classification, and the limited use of size-class distributions (Patterson *et al.* 1987). Minimising errors as a result of a lack in methodological uniformity could be achieved by conducting standardised laboratory procedures (Clark 1982).

Standard practice for charcoal analysis and especially the comparative analysis of different sites is to conduct identical laboratory procedures in charcoal preparation for each of the comparable sites (Patterson *et al.* 1987; Whitlock and Larsen 2001; Clark 1982, 1984). Analytical laboratory processes have little effect on the charcoal fragments (MacDonald *et al.* 1991), however, general consent indicates that conducting the same procedure minimises erroneous results (Clark 1982), thereby widening the applicability of charcoal analysis in ecological interpretations (Patterson *et al.* 1987). Possible affects of analytical laboratory processes on

charcoal analysis include; increased charcoal fragmentation and creating a bias towards small particles in addition to the loss of very small fragments (Campbell *et al.* 2000; Carcaillet 2007; Tinner and Hu 2003; Whitlock and Larsen 2001). While these losses are difficult to quantify (Clark 1984), methodological standardisation allows for identification of losses which occur at all comparable sites and thus the trends in charcoal peaks and fire-free periods can be identified (Tinner and Hu 2003).

Charcoal particles are counted in size-classes with the underlying assumption that large fragments will be deposited closer to the source of the fire event, thus indicating a local source, while smaller fragment will be deposited further from the source of the fire, indicating a regional fire event (Carcaillet 2007; MacDonald *et al.* 1991). These results have been found to be covariant (MacDonald *et al.* 1991) suggesting that charcoal analysis cannot distinguish between local and regional fires. Therefore, microscopic charcoal analysis tends to describe regional fire events and macroscopic charcoal analysis tends to describe local fire events (Whitlock and Larsen 2001).

A further set of problems with microscopic charcoal analysis is the classification process of charcoal into size-classes. The proportion of charcoal could increase exponentially with the decrease in size classes, thus causing over-representation of charcoal during the counting procedure. Reducing the number of size-classes could contribute to an over-representation of small charcoal particles or other mineral particle such as pyrite that could be confused with charcoal, present in the sample. Removing the small size-class to prevent incorrect counting of non-charcoal materials could distort the overall total area and counts of charcoal exponentially (Patterson *et al.* 1987); however, estimation errors associated with the counting procedure can be quantified (Clark 1984).

Incorrect identification of charcoal on a microscopic slide could account for erroneous results, as there are often other materials on the slide that could be confused with charcoal, including minerals, plant fragments and insect cuticles. Familiarisation with other materials that could be confused with charcoal is required to prevent confusion and resulting over- or under-representation of charcoal. Minerals are usually distinguished through their crystalline form or birefringence in polarized light (Whitlock and Larsen 2001), such as pyrite, which could be confused with charcoal due to its colour. However, pyrite is generally very small ( $<3\ \mu\text{m}$ ) and the exclusion of objects smaller than  $3\ \mu\text{m}$  could prevent misidentification. Another option is to use a nitric acid pre-wash to remove pyrite (and other minerals), however, nitric acid can cause breakage in the charcoal fragments (Patterson *et al.* 1987). Insect cuticles are characteristically thinner than charcoal fragments. To distinguish plant material from charcoal, a dissecting needle



should be used to apply pressure to the material. When under pressure charcoal should fracture while plant material should compress. Familiarisation of charcoal could also occur through observation of previously published pictures and/or crushing modern charcoal and observing it (Whitlock and Larsen 2001).

#### **4.5.2. Digestion-Combustion Charcoal Analysis**

The digestion-combustion method was developed as an alternative to the microscopic charcoal analysis; however, there has been much criticism levelled against this method. Errors in the digestion-combustion process could occur through the loss of small charcoal fragments through pollen sieves and large particles captured in the preparation sieve. Robinson (1984) regarded the process as having subjective limitations and saw no value of the process to determine general trends in charcoal abundance. The results indicate that the process is time-consuming, has a low sensitivity and resolution and is ultimately an unreliable process (Whitlock and Larsen 2001; Patterson *et al.* 1987; MacDonald *et al.* 1991).

Winkler (1985) used a similar technique to Robinson (1984) combining the ignition/combustion process with nitric acid digestion where the percentage of charcoal is calculated by the division of the sample weight after nitric digestion by the weight calculated after ignition/combustion. This technique proved to be quicker, simple and less complicated than the microscopic charcoal analysis technique and the results were deemed comparable with the microscopic charcoal analysis results (Rucina *et al.* 2009).

Errors associated with the digestion-combustion technique include; i) the masking of natural fire charcoal from charcoal resulting from the burning of fossil fuels in the last 100 years; ii) changes in sediment type possibly obscuring changes in charcoal concentrations; iii) organic carbon removal and unaccounted losses during the digestion and combustions processes; iv) moisture loss in clays during combustion could be inferred as weight loss (Campbell *et al.* 2000; MacDonald *et al.* 1991; Patterson *et al.* 1987; Winkler 1985), however, it is not significant during the ignition phase of ashing at 500°C (Campbell *et al.* 2000); v) clay minerals (mica, kaolinite and smectite) are lost through the combustion process; vi) possible unintentional variations in laboratory procedures may influence the results (MacDonald *et al.* 1991; Patterson *et al.* 1987; Winkler 1985); vii) the results are often difficult to reproduce, especially in small samples that have low charcoal concentrations (Laird and Campbell 2000); and viii) the inorganic content increased in the late-glacial sections of the studied core causing an underestimation of charcoal abundance compared to the results found through microscopic techniques (Patterson *et al.* 1987).

#### **4.5.3. Comparison of Charcoal Analysis Techniques**

Few studies have been conducted to compare the results between the microscopic technique and the digestion-combustion technique. MacDonald *et al.* (1991) note a poor correlation between the microscopic, macroscopic and digestion-combustion charcoal analyses to identify peaks in charcoal deposition and local fires. While none of the charcoal techniques provided a good indicator of local individual fires, macroscopic charcoal analysis appears to be more sensitive to local fire events and microscopic charcoal analysis appears to be more sensitive to regional fire events (MacDonald *et al.* 1991). The lack of distinction between local and regional fire events could be caused by the failure of either technique to classify charcoal according to size-distributions. While some studies indicate that the digestion-combustion compares weakly to microscopic charcoal analysis with charcoal abundances in post-settlement and late-glacial sediments (Winkler 1985), other studies such as Rucina (2009) indicate that there is good correlation between the two techniques. The digestion-combustion technique holds promise for better intra-method comparisons; however, the method needs to be further researched (Clark 1988; MacDonald *et al.* 1991; Patterson *et al.* 1987). To assist in the development of the digestion-combustion method a greater understanding of the dynamics of charcoal production and dispersal is needed to fulfil the objective of using charcoal for fire reconstructions (Patterson *et al.* 1987).

It is clear that each method used for fire reconstruction has its own advantages and limitations. There remain difficulties in quantitatively comparing the two techniques; however, the two techniques can be used simultaneously in studies. In this research, both techniques have been used for a variety of reasons. The digestion-combustion is a relatively quick, hassle-free, inexpensive technique to discern trends in charcoal content. The point-count technique is a more time-consuming technique compared to the digestion-combustion technique; however, the point-count technique is established within Quaternary Science as the favoured technique in palaeo-fire reconstructions. A significant benefit of the point-count technique is that it is used in conjunction with pollen analysis and thus, direct comparisons between pollen concentration and charcoal concentration can be determined. Regardless of the technique used, the researcher must be aware of the limitations of each technique and the taphonomic processes that enable charcoal to be studied, enabling a more reliable interpretation of the charcoal record.

#### **4.6. Geochemical Analysis**

All organisms are composed of a variety of radioactive and stable isotopes including; hydrogen (H), carbon (C), nitrogen (N), oxygen (O), sulphur (S), fluorine (F), calcium (Ca) and phosphorous (P). Isotopes have the same number of electrons and protons but the number of nuclei varies between the elements with even-numbered isotopes being the most abundant

isotopes in the atmosphere. The ‘heaviness’ and reaction rates for isotopes to form bonds are dependent on the number of neutrons. The reaction rate further determines the fractionation of the isotope. The knowledge of isotope fractionation enables a variety of processes to be studied, from human migratory behaviour to palaeovegetation structures (Schoeninger 1995; Peterson and Fry 1987).

This research has included stable carbon and nitrogen analysis as a proxy record to assist in the interpretation of the available record used for palaeoenvironmental reconstruction of Cathedral Peak, Drakensberg, South Africa. Therefore, only these two stable isotopes will be discussed hereafter, and a theoretical background and critique of each isotopic analysis will be provided as applied to palaeoecological investigations.

#### **4.6.1. Stable Carbon Isotope Analysis**

Stable carbon isotopes occur naturally in the atmosphere in the form of  $^{12}\text{C}$  and  $^{13}\text{C}$  with  $^{12}\text{C}$  being the more abundant, occupying 98.9% and  $^{13}\text{C}$  occupying 1.1% of atmospheric  $^{13}\text{C}$  concentrations (Farquhar *et al.* 1989). Atmospheric  $^{13}\text{C}$  changes over time and since the 1950s atmospheric  $^{13}\text{C}$  has decreased by approximately 1.5 ‰ to -8 ‰ (parts per million), through the burning of fossil fuels (Farquhar *et al.* 1989; Codron *et al.* 2005).

The study of  $\delta^{13}\text{C}$  originated to understand the different photosynthetic pathways that plants use to absorb  $\text{CO}_2$  from the atmosphere and store it in the plants’ tissue. The  $^{13}\text{C}$  stored in plant tissue is commonly less than the  $^{13}\text{C}$  found in the carbon of atmospheric  $\text{CO}_2$  ( $\Delta^{13}\text{C}$ ) because of discrimination during the intake of  $^{13}\text{C}$  into the plant biomass. Plants utilise three photosynthetic pathway groups, namely;  $\text{C}_3$ ,  $\text{C}_4$  and Crassulacean Acid Metabolism (CAM), based on the method of carbon fixation (Farquhar *et al.* 1989).

The photosynthetic pathways used by plants are environmentally controlled, with temperature being the most important environmental factor determining the amount of  $^{13}\text{C}$  found in plants. Other important environmental factors utilized in determining the photosynthetic pathway are evaporation (salinity value), moisture and moisture seasonality, which determines the temperature of the growing season (Scott and Vogel 2000).  $\text{C}_3$  plants are strongly affected by these environmental factors, which can cause the concentration of  $^{13}\text{C}$  found in plants to vary between species and populations (Fiorentino *et al.* 2008; Codron *et al.* 2005) as a result of isotopic discrimination.  $\text{C}_4$  plants are also subjected to similar environmental conditions as  $\text{C}_3$  plants but do not exhibit as much variation in  $^{13}\text{C}$ . The lack of susceptibility to  $^{13}\text{C}$  variation is due to the early  $\text{CO}_2$  fixation during the isotopic discrimination process (Codron *et al.* 2005). A number of proxy sources can be used to determine  $^{13}\text{C}$  values, which include; pollen, plant

material (leaves etc), bone, enamel and soil organic matter. The ratio of  $^{13}\text{C}$  and  $^{14}\text{C}$  ( $\delta^{13}\text{C}$ ) of soil organic matter in soil profiles can be used to infer changes in  $\text{C}_3$  and  $\text{C}_4$  plant abundances over time and the rate and magnitude of environmental processes, such as scrub encroachment (Gillson *et al.* 2004). Therefore, by determining the  $^{13}\text{C}$  of proxy sources, inferences can be made regarding the dominant plant types being classified as  $\text{C}_3$  and  $\text{C}_4$ .

To determine these proxy sources, knowledge of the three photosynthetic pathways is needed. Carbon from atmospheric  $\text{CO}_2$  undergoes fixation in the plant during photosynthesis through the assimilation of carbon. The carbon is then fractionated through the preferential utilization of  $^{12}\text{C}$  and exclusion of  $^{13}\text{C}$  (Smith 1972). The process of carbon assimilation and the resulting  $^{13}\text{C}$  value varies between the different photosynthetic pathways (Wooller and Beuning 2002). The three photosynthetic pathways ( $\text{C}_3$ ,  $\text{C}_4$  and CAM) are discussed briefly below.

The  $\text{C}_3$  photosynthetic pathway, or the Calvin-Benson pathway, is the most primitive photosynthetic pathway utilizing Rubisco, a three-carbon acid. The majority of plants, trees, shrubs, herbs, some grasses and dicotyledons fall within this group (Cerling *et al.* 2003; Yang and Ding 2006).  $\text{C}_3$  plants draw atmospheric  $\text{CO}_2$  by preferentially incorporating  $^{12}\text{C}$  from  $\text{CO}_2$  ( $^{12}\text{CO}_2$ ) into fixed carbon and excluding  $^{13}\text{C}$ , resulting in the depletion of  $\delta^{13}\text{C}$  (Wooller and Beuning 2002) and lower  $\delta^{13}\text{C}$  values.

The  $\text{C}_4$  photosynthetic pathway, or the Hatch-Slack pathway, is the more advanced photosynthetic pathway compared to  $\text{C}_3$ . The majority of  $\text{C}_4$  plants include; tropical savannah grasses, sedges and some dicotyledonous herbs and shrubs (Boom *et al.* 2002; Cerling *et al.* 2003; Zech 2006).  $\text{C}_4$  plants transport  $\text{CO}_2$  as oxaloacetic acid, a four-carbon acid, into the bundle sheath cells prior to carbon fixation via the Calvin cycle (Wooller and Beuning 2002; Yang and Ding 2006). The early carbon fixation of  $\text{C}_4$  plants limits further fractionation or discrimination of carbon resulting in lower  $\delta^{13}\text{C}$  values than of  $\text{C}_3$  plants (Codron *et al.* 2005). The  $\text{C}_4$  pathway can be divided into three sub-groups with each sub-group using a different enzyme for carbon fixation namely; Nicotinamide adenine dinucleotide phosphate malate dehydrogenase enzyme (NADP-me and NAD-me) and Phosphoenolpyruvate carboxykinase enzyme (PCK) (Boom *et al.* 2002).

While there are fundamental differences in each of the sub-groups,  $\text{C}_4$  plants are mostly found in tropical regions. Differences in each sub-group include; the different processes of  $^{13}\text{C}$  discrimination, which results in a small but significant (1 ‰) variation in  $\delta^{13}\text{C}$  between the sub-groups (Codron *et al.* 2005). Each sub-group favours different environmental conditions, with

NADP-me plants favouring more mesic and non-saline habitats and NAD-me plants favouring more arid and saline habitats and the differing leaf morphology and physiology.

CAM plants have the ability to utilize both C<sub>3</sub>- and C<sub>4</sub>-type photosynthetic pathways depending on the environmental conditions present. CAM plants are few in number, typically occurring in desert / arid environments (Mackie *et al.* 2005) and for the purposes of this research, C<sub>3</sub> and C<sub>4</sub>-type vegetation will be focused on exclusively.

Typically, plants are grouped as aquatics, terrestrial C<sub>3</sub> and terrestrial C<sub>4</sub>. Each group falls within a range of <sup>13</sup>C values (Table 4.1), which can distinguish plants from each other.

**Table 4.1: Aquatic and terrestrial plant  $\delta^{13}\text{C}$  range values (Mackie *et al.* 2005; Lamb *et al.* 2006)**

	Aquatic	Terrestrial C <sub>3</sub>	Terrestrial C <sub>4</sub>
<b>Min (‰)</b>	-50	-32	-15
<b>Max (‰)</b>	-10	-20	-12
<b>Average (‰)</b>	-27	27	-13

Discrepancies in values are evident and these values should not be seen as absolute, fixed values, but rather as a guideline value. Isotopic ratios are commonly reported relative to the Pee Dee Belemnite (PDB) isotopic standard where:

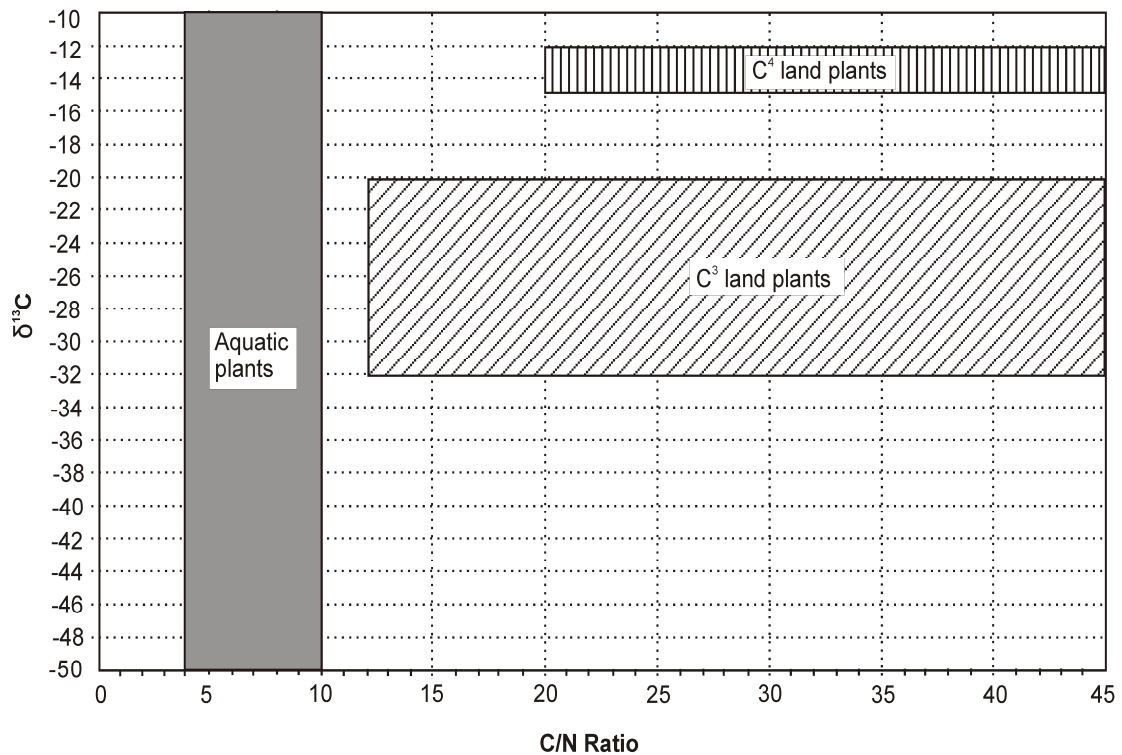
$$\delta^{13}\text{C} \text{ (in ‰)} = [({}^{13}\text{C}/{}^{12}\text{C})_{\text{sample}}/({}^{13}\text{C}/{}^{12}\text{C})_{\text{standard}} - 1] * 1000$$

**Equation 4.1: Determination of the PDB isotopic standard (Cerling *et al.* 1997)**

Plants with the highest and greatest <sup>13</sup>C values range are aquatic, desert, salt marsh plants and panicoid grasses. Most of the higher plants, all the lower vascular plants and all gymnosperms except *Welwitschia* spp. are C<sub>3</sub> plants. C<sub>4</sub> plants are generally tropical grasses and have the lowest <sup>13</sup>C values. Algae, lichens, festucoid grasses and bamboo have intermediate values between C<sub>3</sub> and C<sub>4</sub> (Smith 1972; Lamb *et al.* 2006; Mackie *et al.* 2005).

Carbon:Nitrogen (C/N) ratios provide an alternative method from photosynthetic pathways to distinguish between different types of plants. The organic material used by plants differs in terrestrial plants, which are rich in lignin and cellulose, whilst aquatic plants are rich in protein resulting in high nitrogen content. Thus, by determining the ratio of carbon to nitrogen, terrestrial and aquatic plants can be differentiated. Furthermore, the source of organic material used by the plants can be used as an indication of the relative proportions of autochthonous and allochthonous sources of organic matter. Typical C/N values of aquatic plants are between 4 and

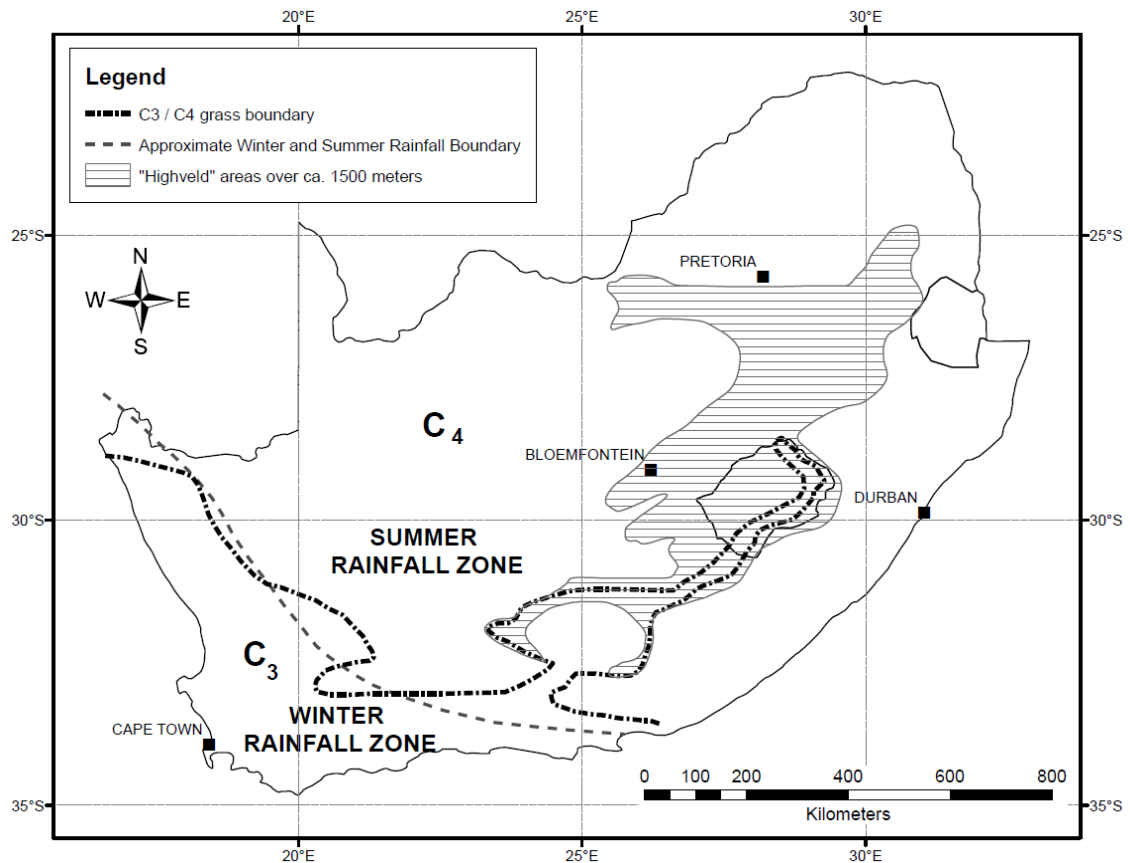
10, while terrestrial plants have values generally above 20. Organic matter values between 10 and 20 may represent a mix of aquatic and terrestrial plant material although some marginal macrophytes have intermediary ratios (Mackie *et al.* 2005). A general trend is to plot isotopic data using  $\delta^{13}\text{C}$  and C/N ratio values (Figure 4.2) to determine the trend towards  $\text{C}_3$ ,  $\text{C}_4$  and aquatic plants.



**Figure 4.2:  $\delta^{13}\text{C}$  ranges for terrestrial and aquatic vegetation (adapted from Mackie *et al.* 2005; Lamb *et al.* 2006)**

$\text{C}_4$  and  $\text{C}_3$  plants inhabit a wide range of environments (Figure 4.3).  $\text{C}_3$  plants are found predominately in the winter-rainfall areas of South Africa and the high-lying eastern escarpment of South Africa and Lesotho (Smith *et al.* 2002).  $\text{C}_3$  plants were the dominant vegetation-type prior to the LGM when conditions were more temperate than the present day (Zech 2006).  $\text{C}_3$  plants utilize the Rubisco enzyme, which appeared approximately three billion years ago when  $\text{CO}_2$  and oxygen ( $\text{O}_2$ ) concentrations were much higher and lower respectively than at present. Under these temperate conditions carbon fixation by the Rubisco enzyme was sufficient for plant adaptation (Boom *et al.* 2002). However, a decrease in  $\text{CO}_2$ <sup>26</sup> (Boom *et al.* 2002), an increase in  $\text{O}_2$  and overall increase in temperatures after the LGM, resulted in the distributional decrease of  $\text{C}_3$  plants and an increase in  $\text{C}_4$  plants.

<sup>26</sup> An increase / decrease in  $\text{CO}_2$  may be reflected differently at different sites. The author acknowledges that this is a broad statement derived from Boom *et al.* (2002).



**Figure 4.3: Distribution pattern of C<sub>3</sub> and C<sub>4</sub> grasses in South Africa (adapted from Scott 2002)**

C<sub>4</sub> plants adapted to the changing environmental conditions after the LGM by adapting their photosynthetic pathway. The Rubisco enzyme, inefficient under warmer conditions due to their photorespiration mechanism, was replaced by the oxygenase enzyme in C<sub>4</sub> plants (Boom *et al.* 2002). The rapid carbon fixation of C<sub>4</sub> plants enabled the plants to become better adapted to more arid conditions, warmer temperatures and lower atmospheric partial pressure CO<sub>2</sub> ( $p\text{CO}_2$ ) as their water use efficiency increased. However, by gaining better water use efficiency, C<sub>4</sub> plants needed warmer conditions to utilize the available energy required to have enhanced water stress (Boom *et al.* 2002; Cerling *et al.* 2003; Zech 2006).

In southern Africa, C<sub>4</sub> plants are predominantly found in the central summer rainfall areas, areas of aridity and along a latitudinal gradient, mainly found in the low latitudes, where the gradient is a function of the temperatures of the growing season, which in turn is dependent on availability of  $p\text{CO}_2$ . The main environmental condition that determines the distribution pattern of C<sub>4</sub> is temperature (Scott 2002; Boom *et al.* 2002; Hopley *et al.* 2006) with a mean maximum and mean minimum temperature of 25°C and 8°C respectively (Smith *et al.* 2002). However,

some C<sub>4</sub> grasses and sedges are able to tolerate low temperatures prevalent in montane environments (Zech 2006).

#### **4.6.2. Critique of Stable Carbon Isotope Analysis**

While the use of carbon isotopes assists in the understanding of palaeoenvironmental conditions relating to the type of vegetation that existed at any one time, there are a number of limitations that researchers are faced with.

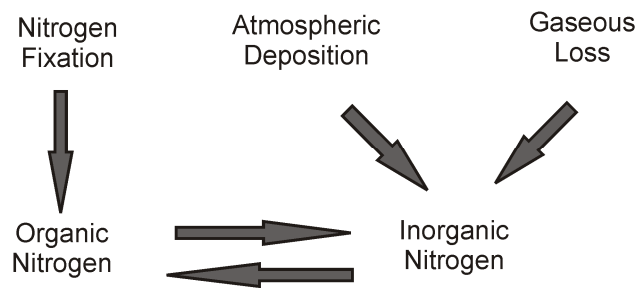
The analysis of carbon isotope in sediments is often complicated by the processes that existed to form the organic content of sediments. There are a diverse array of sources that carbon isotope signals can be derived, including; terrestrial grasses, arboreal and aquatic plants. A C<sub>3</sub> signal can be derived from either sedges or aquatic plants; or, the signal could be derived from when the inputs from sedges or aquatic plants were high in relation to the grass-derived organic matter. To alleviate this problem, analysis of  $\delta^{13}\text{C}$  could be conducted in conjunction with pollen records and mixing models; however, even through the comparison of different proxy records, there may be subtle shifts in the percentage of C<sub>3</sub>/C<sub>4</sub> grasses that the pollen record and models may not detect (Wooller and Beuning 2002). The difficulty in determining the spatial scale of the isotopic record prevents determining whether the isotopic signal relates to regional or local conditions (Scott 2002). The distribution of C<sub>3</sub> / C<sub>4</sub> grasses is further complicated as a function of microclimate, site history, herbivore activity, soil conditions, burning, topography, seed dispersal and competition (Winslow *et al.* 2003).

A further limitation is the analysis of the  $\delta^{13}\text{C}$  in soil organic material. The proportion of  $^{13}\text{C}$  in soil organic matter depends on the relative abundance of C<sub>3</sub> and C<sub>4</sub> plants; however, the relationship between soil  $\delta^{13}\text{C}$  and vegetation assemblages is not linear as the proportion of C<sub>3</sub> to C<sub>4</sub> plants in the standing crop biomass may not be the same as the proportion of carbon from C<sub>3</sub> and C<sub>4</sub> plants in the soil organic matter. The origin of soil organic matter is often unclear and is difficult to distinguish whether  $\delta^{13}\text{C}$  profiles represent local heterogeneity of vegetation or more widespread shifts in plant community type (Gillson *et al.* 2004).

#### **4.6.3. Stable Nitrogen Isotope Analysis**

Nitrogen is important for the long-term stability and health of an ecosystem as nitrogen assists plant growth and reproduction. Nitrogen inputs into the environment can either be as a result of atmospheric deposition or through *in situ* biological fixation (Figure 4.4) with atmosphere being the main nitrogen reservoir (Evans and Ehleringer 1993; Schoeninger 1995).





**Figure 4.4: Nitrogen inputs (Evans and Ehleringer 1993)**

Knowledge of nitrogen inputs provide vital information of long-term ecosystem stability and on how systems are influenced by anthropogenic influences (Evans and Ehleringer 1993).

The nitrogen isotope ratio present in plants can be indicative of a multitude of processes that occur in environmental conditions. The ratio of  $^{14}\text{N}$  /  $^{15}\text{N}$  ( $\delta^{15}\text{N}$ ) of plants reflect the source nitrogen, enzymatic fractionations within a plant and plant-microbial interactions in soil (Terwilliger *et al.* 2008). Soil  $\delta^{15}\text{N}$  reflects aridity, rainfall, succession age and the soil crust density in arid environments (Wang *et al.* 2009).  $\delta^{15}\text{N}$  can be used to research the deposition of atmospheric nitrogen, forested ecosystems (Poulson *et al.* 1995), the processes that affect the nitrogen cycle including the effect on soils, vegetation, animals and the atmosphere (Aranibar *et al.* 2008), climate, nitrogen assimilation and nitrogen availability (Codron *et al.* 2005; Aranibar *et al.* 2008).

Plants can utilize nitrogen dissolved in soils or by absorption through their leaves and volatile ammonia, originating from animal colonies can influence  $\delta^{15}\text{N}$  of plant leaves. Either following a rainfall event or made available through dry deposition, ammonia and nitrate can be taken up by plants and incorporated into biomass (Terwilliger *et al.* 2008). It is commonly found that there is greater  $^{15}\text{N}$  enrichment with an increase in aridity across the globe. Furthermore,  $^{15}\text{N}$  enrichment is associated with environments that frequently burn, which decreases the amount of nitrogen in the soil (Hogberg 1986). The pattern of enrichment reflects the degree of nitrogen loss relative to the internal intake of nitrogen cycling (Aranibar *et al.* 2008).

On Earth, 99.6337% of nitrogen atoms are  $^{14}\text{N}$  with the remaining 0.3663% being the stable  $^{15}\text{N}$  (Robinson 2001). The  $\delta^{15}\text{N}$  value of atmospheric nitrogen ( $\text{N}_2$ ) and terrestrial plants in temperate zones is 0 ‰ (Terwilliger *et al.* 2008; Robinson 2001) due to the lack of fractionation needed to assimilate the nitrogen (Schoeninger 1995). Biological materials typically range between -10 ‰ and 20 ‰ (Codron *et al.* 2005); however, actual values of  $\delta^{15}\text{N}$  can range considerably. Fractionation effects occur during biological denitrification processes in soils may be as large as 30 ‰ and greater than 60 ‰ in the case of nitrous oxide ( $\text{N}_2\text{O}$ ) production via nitrification;

however, extreme fractionation events are rare (Codron *et al.* 2005). Variations in the  $\delta^{15}\text{N}$  of plants can be as much as 10 ‰ between different species inhabiting the same environment (Terwilliger *et al.* 2008). Human activities such as grazing, fires and cultivation can affect the amount of nitrogen assimilation and abundance within ecosystems; however, studies on Australian grazing and South African fires show no apparent effect on  $\delta^{15}\text{N}$  values of plants and soils (Aranibar *et al.* 2008). Seasonal variations in  $\delta^{15}\text{N}$  can occur with wetter seasons exhibiting enriched values possibly due to the increase in microbial activity, through denitrification and mineralization processes, resulting in enriched residual substrates (Wang *et al.* 2009). Soil  $\delta^{15}\text{N}$  values can also vary substantially (Delwiche *et al.* 1979). Nitrogen content in soils decreases due to net mineralization of soil organic matter and gaseous loss by volatilization and denitrification, which corresponds with an increase in  $\delta^{15}\text{N}$  due to fractionation. Decomposition of organic matter causes an increase in  $\delta^{15}\text{N}$  with depth (Evans and Ehleringer 1993); however, soil types and the depth of soil could result in further variations in nitrogen isotope ratios. Depth variations in  $\delta^{15}\text{N}$  values are complex and can be attributed to various processes of isotope discrimination (Delwiche *et al.* 1979), nitrogen transport processes, depth-dependant plant nitrogen inputs, multiple nitrogen pools other than those from plant tissues. Depending on climatic conditions, a vertical profile can exhibit random distributions such as in gravely desert soil, little variation as in montane environments, or most commonly a consistent (exponential) increase with depth found in grasslands (Wang *et al.* 2009).

#### **4.6.4. Critique of Stable Nitrogen Isotope Analysis**

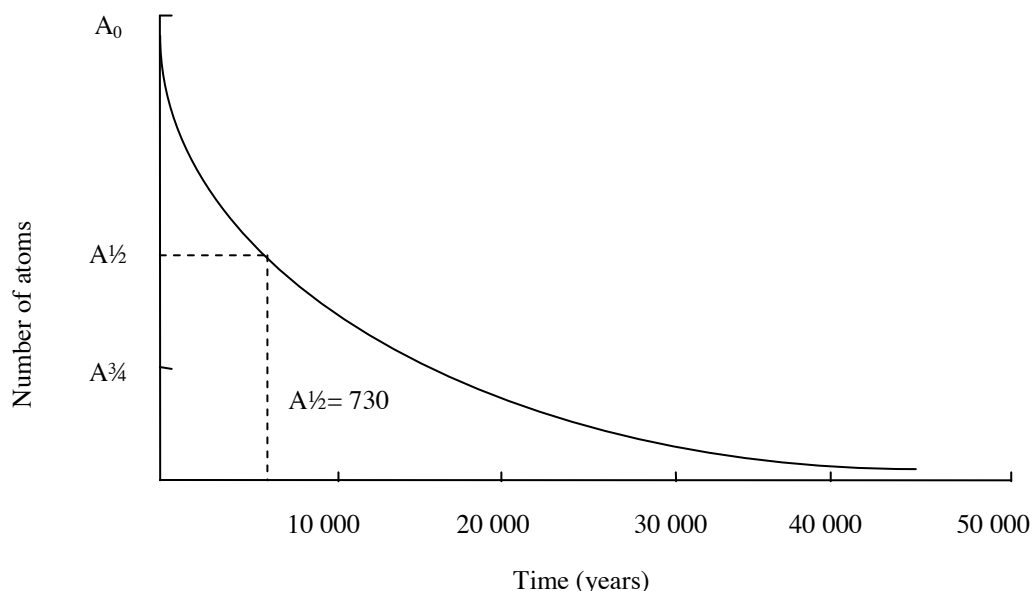
The main critique of nitrogen stable isotope analysis is the uncertainty in determining the sources of nitrogen or the values of the plant due to physiology and local conditions. There has been no accepted model to predict these values (Dawson *et al.* 2002). Key aspects in these uncertainties are the variation of nitrogen uptake in plants as some plants can uptake nitrogen without fractionation with the aid of symbiotic bacterial relationships that convert nitrogen directly into ammonia. Other plants take up nitrogen directly as nitrates. Another concern is that the value of the studied material can often have its nitrogen isotopic value changed by a variety of processes enacting on the material. This is especially true of soil sediments whereby soil  $^{15}\text{N}$  often increases with depth and with decomposition of organic material; soil nitrates vary the  $^{15}\text{N}$  values due to leaching throughout the soil profile; denitrification, influenced by bacterial activity, influences the  $^{15}\text{N}$  value and climatic conditions influencing the plants ability to metabolise nitrogen changing the soil chemistry. Uncertainty around these factors could result in discrepancies during isotopic analysis (Hedges *et al.* 2004; Dawson *et al.* 2002).

Stable light isotopic analysis, with a focus on the  $^{13}\text{C}$  and  $^{15}\text{N}$ , provides a useful proxy to assist in palaeoenvironmental reconstructions of the late Quaternary. The ability for  $^{13}\text{C}$  to reflect

dominant vegetation composition based on the plants photosynthetic pathways allows inferences to be made regarding the development environmental conditions, for instance, moving from a predominant C<sub>4</sub> vegetation composition towards a C<sub>3</sub>-dominated vegetation. <sup>15</sup>N compliments <sup>13</sup>C analysis as a proxy of moisture availability, thereby, enhancing the understanding of climatic conditions.

#### 4.7. Radiocarbon Analysis

Atmospheric <sup>14</sup>C is produced by cosmic rays in the upper atmosphere and mixed throughout the troposphere and in carbon reservoirs, namely; the oceans and the biosphere (Fairbanks *et al.* 2005). The result of atmospheric <sup>14</sup>C mixing is that all organisms living in the oceans and the biosphere become radioactive with the <sup>14</sup>C isotope. The amount of <sup>14</sup>C produced and absorbed into organisms is determined by the cosmic ray flux, which in turn is controlled by solar activity, variations of the geomagnetic field (Kuznetsova and Tsirolnik 2004) and changes in the carbon cycle (Fairbanks *et al.* 2005). When an organism dies, the <sup>14</sup>C equilibrium is broken, resulting in the decay of <sup>14</sup>C. Williard Libby determined in 1949 that <sup>14</sup>C decays exponentially (Figure 4.5) through a series of maximum eight half-lives (Walker 2005) where the half-life is  $5568 \pm 30$  years (Fairhall and Young 1973). Since 1949, the half-life has been modified to  $5730 \pm 40$  years based on calculations of atmospheric <sup>14</sup>C (Fairbanks *et al.* 2005).



**Figure 4.5: Radiocarbon decay curve (Adapted from Walker, 2005)**

Knowledge of the rate of decay of <sup>14</sup>C has allowed age determinations to be made of all organisms by calculating the current <sup>14</sup>C content with the exponential rate of decay of <sup>14</sup>C (Fairbanks *et al.* 2005), with a maximum age of 50,000 years BP (Ascough *et al.* 2009). The application of <sup>14</sup>C dating provides temporal control in palaeoenvironmental records and is used

for many interregional correlations and comparisons with palaeoclimatic time-series. The various applications for  $^{14}\text{C}$  require age determinations to be effective, accurate and reliable to provide credible chronologies (Porter 1981). A solid understanding of atmospheric radiocarbon variations and the calibration of  $^{14}\text{C}$  is needed to determine accurate and reliable dates.

Quantities of atmospheric  $^{14}\text{C}$  produced has fluctuated over time depending on the strength of the geomagnetic field, solar fluctuations and rearrangements in equilibrium between the major carbon reservoirs, *viz*; the atmosphere, oceans and biosphere. There is variation between the two hemispheres due to the larger expanse of ocean in the southern Hemisphere compared to the northern Hemisphere and atmospheric-ocean  $\text{CO}_2$  exchanges. This results in offsets between 23 and 40 years between the two hemispheres (McCormac *et al.* 2002), which can be corrected through calibration.

Calibrating the variations in atmospheric  $^{14}\text{C}$  of samples is critical and should be conducted at the first stage of  $^{14}\text{C}$  analysis. Calibration allows  $^{14}\text{C}$  dates to be compared with dates derived from alternative methods and for the determination of sediment accumulation rates within single records. Global and hemisphere specific calibration models such as the international calibration model (e.g. IntCal09) (Reimer *et al.* 2004; Reimer *et al.* 2009) and the southern Hemisphere calibration model (e.g. SHCal04) (McCormac *et al.* 2004) have been developed using proxy data. The variation in atmospheric radiocarbon between the two hemispheres have prompted the development of SHCal04 (McCormac *et al.* 2004). The southern Hemisphere has been defined by the position relative to the ITCZ rather than the geographic equator. SHCal04 should be used up to 11,000 cal yr BP and not beyond that date due to the lack of absolute records for the southern Hemisphere and from the large-scale changes in the carbon reservoirs before the Holocene (McCormac *et al.* 2004). The models have been included in a number of calibration programs including; OxCal, Calib (Stuiver and Reimer 1993), Bpeat (Blaauw *et al.* 2007) and BCal (Buck *et al.* 2003) to provide accurate and precise calibrations (Ramsey *et al.* 2001). Datasets incorporated into the calibration models are derived from dendrochronological and marine records. Dendrochronological records provide a high resolution calibration up to 12,400 cal yr BP (Reimer *et al.* 2004) using a matched floating tree ring curve. Marine and lake records have been used to extend the calibration curve beyond 12,400 cal years BP.

#### **4.8. Critique of Radiocarbon Analysis**

Errors in  $^{14}\text{C}$  dating can occur in every step of the analysis process including; sample preparation, laboratory procedures, calibration methods and during age determination analysis. It is imperative that errors are identified and accounted for to result in credible, reliable and accurate age determinations.

Samples for  $^{14}\text{C}$  dating can often be contaminated during the preparation process. External sources of contamination include; i) the inclusion of carbon from rootlet penetration, ii) percolation of humic acids through groundwater, iii) carbonate exchanges between ground water and relic shells and/or water being deposited onto an organic matrix and iv) isotopic fractionation, resulting in age determination errors (Blockley *et al.* 2007; Fairhall and Young 1973). These sources of contamination can often be minimised through chemical treatment of the samples prior to  $^{14}\text{C}$  determination and isotopic fractionation can be determined and accounted for (Fairhall and Young 1973). While contamination of samples is minimised, it still does result in 10-20% of samples being chronological outliers. Outliers are a significant problem as they are often manually and heuristically removed during  $^{14}\text{C}$  analysis as they do not 'fit' within the chronology. Furthermore, statistical methods are often not equipped to deal with offsets and outliers (Blaauw and Christen 2005) resulting in chronological inconsistencies.

The advance of  $^{14}\text{C}$  analysis over time has lead to improvements in sampling, dating and calibration techniques resulting in greater accuracy, reliability and credibility of the results. The improvement of dating techniques from radiometric dating to accelerated mass spectrometry (AMS) analysis has formed a crucial part in  $^{14}\text{C}$  analysis. AMS dating has resulted in improved accuracy with smaller errors in the dating of samples compared with radiometric dating. Errors in radiometric dating are often approximately 100 years while the errors AMS dating errors are often on the decadal scale. Furthermore, AMS dating shows a stronger correlation with deep-sea cores than that of radiometric dating. The increased precision in dating has allowed for changes on the decadal scale to be discerned (Andrews 1998).

Dendrochronology produces finite ages and are limited by the availability of suitable records after 11,500 years BP (Bard *et al.* 1990; Chiu *et al.* 2005; Porter 1981). Marine records need to be corrected for the reservoir effect (Kitagawa and van der Plicht 1998), which is the effect of surface water and / or groundwater on the  $^{14}\text{C}$  values. External sources of water can have different quantities of total dissolved inorganic carbon (TDIC) than the reservoir to which it enters. As a result, the additional water could cause lower or higher  $^{14}\text{C}$  values. Furthermore, the depth of a reservoir can affect the  $^{14}\text{C}$  values with shallow lakes being more affected by seasonal and daily changes resulting in lower  $^{14}\text{C}$  values than deep lakes (Geyh *et al.* 1998). While these errors should be taken note of, in relation to this research, peatland and wetland sediments typically consist of locally-grown plants that decay *in situ*, resulting in an equilibrium between the dated sediment and atmospheric  $^{14}\text{C}$  (Blaauw *et al.* 2004). As such, the reservoir effect has little bearing on the errors of calibration.

A further problem associated with calibration of  $^{14}\text{C}$  is the use of calibration curves, specifically the SHCal04 curve. The SHCal04 was developed to deal with the variation in spatial fluctuation of atmospheric  $^{14}\text{C}$  between the two hemispheres (McCormac *et al.* 2004). Variations between hemispheres are further subjected to assumptions due to the lack of data including a lack of pre-industrial calibration data for high or low latitudes to calculate offsets. To compensate this lack of data, there are data available of post-bomb atmospheric  $^{14}\text{C}$ , which suggests that a  $^{14}\text{C}$  gradient exists between 40-70°S. However, these data have not been corroborated with dendrochronological records. The latitudes between 20-45°S show a similar peak of post-bomb measurements. From this it is assumed that the atmosphere is well-mixed and that the datasets used to compile the calibration curves from the southern Hemisphere are valid (McCormac *et al.* 2004). Furthermore, the variation in atmospheric  $^{14}\text{C}$  between the northern Hemisphere and southern Hemisphere may relate to the location of the ITCZ and the origin of  $\text{CO}_2$  sources where  $\text{CO}_2$  fluctuates seasonally in the northern and southern hemispheres; however, these fluctuations cannot be accounted for at present in the models (McCormac *et al.* 2004).

The sources of calibration data and the calibration curve used during calibration are only two aspects that need to be taken into account during  $^{14}\text{C}$  analysis. Understanding the calibration model and the data, output can provide a further source of error. Each calibration model deals with these differently, based on statistical methods, with each method having its own advantages and limitations (Blaauw and Christen 2005b). Calibration programs deal with interpretation of age plateaus and age reversals of individual  $^{14}\text{C}$  ages differently. To account for this, 'wiggle-match' dating has been developed to provide precision dating of trees, peat deposits and other archives (Blaauw *et al.* 2007). There are multiple methods of wiggle-matching with most techniques providing good agreement in the results and age ranges (Ramsey *et al.* 2001). Age models aim to remove researcher subjectivity and make the calibration of data automated, yet their subjectivity cannot be totally removed from the process; however, researcher decisions can be made more transparent, explicit and heuristic using a Bayesian framework (Blaauw *et al.* 2007). Bayesian age models should be aimed at replacing classical age models for low-resolution dated material; yet, these models may not add extra value (Blaauw 2010). The full distributional range value of  $^{14}\text{C}$  dates provided as a single value cannot describe a multimodal distribution of calibrated data. When single values are used, they should be derived from weighted average or medians as these describe the distribution better than intercept-based methods (Telford *et al.* 2004).

The probability of  $^{14}\text{C}$  dates are determined through statistical analysis and often expressed in degrees of confidence. The statistical method used to derive the probabilities (Blockley *et al.* 2007) and misinterpretation of the probabilities can often cause errors in the analysis of the

dated samples. The confidence levels usually range between 68% and 95.4% probability (Fairhall and Young 1973) and  $^{14}\text{C}$  dates are often stated for one and two standard deviations (Walker 2005) to ensure reliability of the dated sample (Blockley *et al.* 2007). Assigning one age from the probabilities is often at the exclusion of valuable information (Walker 2005). As such, all probabilities should be given for all  $^{14}\text{C}$  dates (Blaauw and Christen 2005).

There are a number of errors associated with the accuracy of  $^{14}\text{C}$  which have been discussed above, including; statistical analysis, sampling differences, sample pre-treatment, laboratory procedures (Reimer *et al.* 2004; Blockley *et al.* 2007) and conflicting methods of calibration (Porter 1981). Further sources of error include; the response times of events, the lack of high resolution records and variations in atmospheric  $^{14}\text{C}$  over time (Ascough *et al.* 2009; Porter 1981; Blackwell *et al.* 2006).

The relationship between atmospheric  $^{14}\text{C}$  of the measured sample and the actual timing of the event within the palaeoenvironmental record (Ascough *et al.* 2009) is often influenced by lag and response times. The inherent lag and response times of atmospheric  $^{14}\text{C}$  reflected in the measured sample determine whether the event is ‘visible’ in the record. The response time in the measured sample is dependent on climatic changes and the abruptness of the event. An event that occurs abruptly may be too subtle to be visible in the sample. To compound this matter, there are insufficient high-resolution records (<100 years) that allow abrupt climatic changes to be visible in the sample material. Furthermore, weak chronologies resulting from a lack of sampled material could affect the accuracy of the dated material. To account for the lack of strong chronologies, Bayesian statistical techniques can be used to minimise inherent uncertainties of isolated  $^{14}\text{C}$  dates, leads, lags, and the relationship between different events can be properly identified (Blaauw and Christen 2005).

While  $^{14}\text{C}$  dating and analysis is a fundamental component of palaeoenvironmental and Quaternary research, there are numerous limitations relating specifically to errors that can hinder the analysis. Cognisance of the sources of error and how errors can be accounted for is crucial for building accurate chronologies. Researchers must take into account the type of environment (wetland, marine) they are investigating to be able to identify and account for potential sources of errors.

#### **4.9. Conclusion**

Palaeoenvironmental research relies on the use of multiple proxies including; pollen, charcoal, stable isotopes and radiocarbon analysis. The purpose of this chapter was to provide the theoretical basis and critique of each technique used in this research. The limitations of each

technique have been discussed in detail. Limitations must be acknowledged prior to any interpretation of the datasets to enable reliable palaeoenvironmental reconstructions. The use of multiple proxies can enable palaeoenvironmental research to contribute meaningfully to Quaternary Science and reduce the paucity of data that exists, especially within South Africa.



## **CHAPTER FIVE**

### **5. METHODS**

#### **5.1. Introduction**

The following section describes the method techniques applied in the field and laboratory. The fieldwork consisted of a wetland depth profile and the extraction of a sediment core. Laboratory techniques include; i) a stratigraphic description of the sediment core, ii) sub-sampling of the sediment core and iii) pollen, charcoal, geochemical and  $^{14}\text{C}$  analyses.

#### **5.2. Field Techniques**

The fieldwork component of this research was conducted in May 2009 and November 2009 in Catchment Six of Cathedral Peak, KwaZulu-Natal Drakensberg. Catchment Six is comprised of two wetlands, a wetland adjacent to the study site, which is north-west facing and the studied wetland being north facing. Five perennial streams feed into the two wetlands. The topography of the studied wetland consists of many gentle undulations in northerly direction towards the knick-point located at 28°59'27"S 29°15'05.8"E. The knick-point runs in a west to east direction at an altitude of 1887 m. The wetland is surrounded by higher raised ground with sandstone outcrops protruding the topography.

##### **5.2.1. Wetland Depth Profile**

A walkover survey was initially conducted to identify the best position within the wetland to conduct the sediment depth profile. The aim of the sediment depth profile was to determine the best location to extract the longest, semi-continuous, minimally disturbed sediment core.

The sediment depth profile was conducted on the southern portion of the wetland, upstream from the knick-point. To conduct the depth profile, the wetland was divided up into 3 m by 6 m grids. At each point, extendible one-meter fibreglass rods were manually pushed into the wetland and the depth recorded to provide an estimated sediment depth. A total area of 1098 m<sup>2</sup> was profiled (Figure 5.1 and Figure 5.2) before being discontinued due to the raised topography and dry, shallow sediment. Based on the deepest portion of the wetland the core extraction location was determined in the south-western corner of the wetland at a geographic location of 28°59'30.40"S 29°15'04.20"E at an altitude of 1899 m.

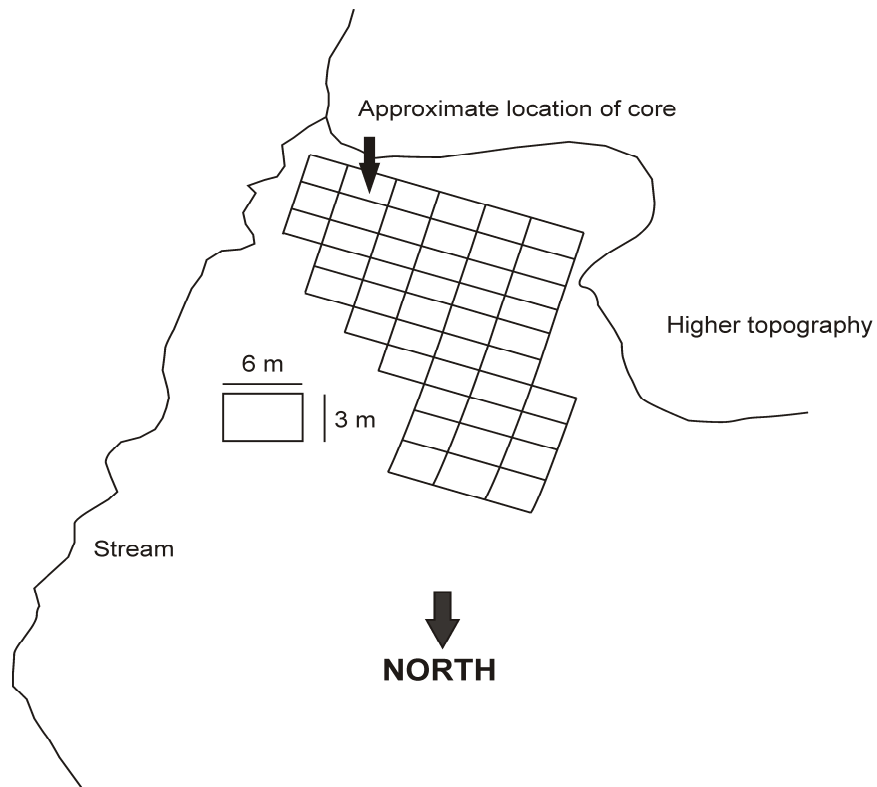


Figure 5.1: Schematic of the wetland depth profile

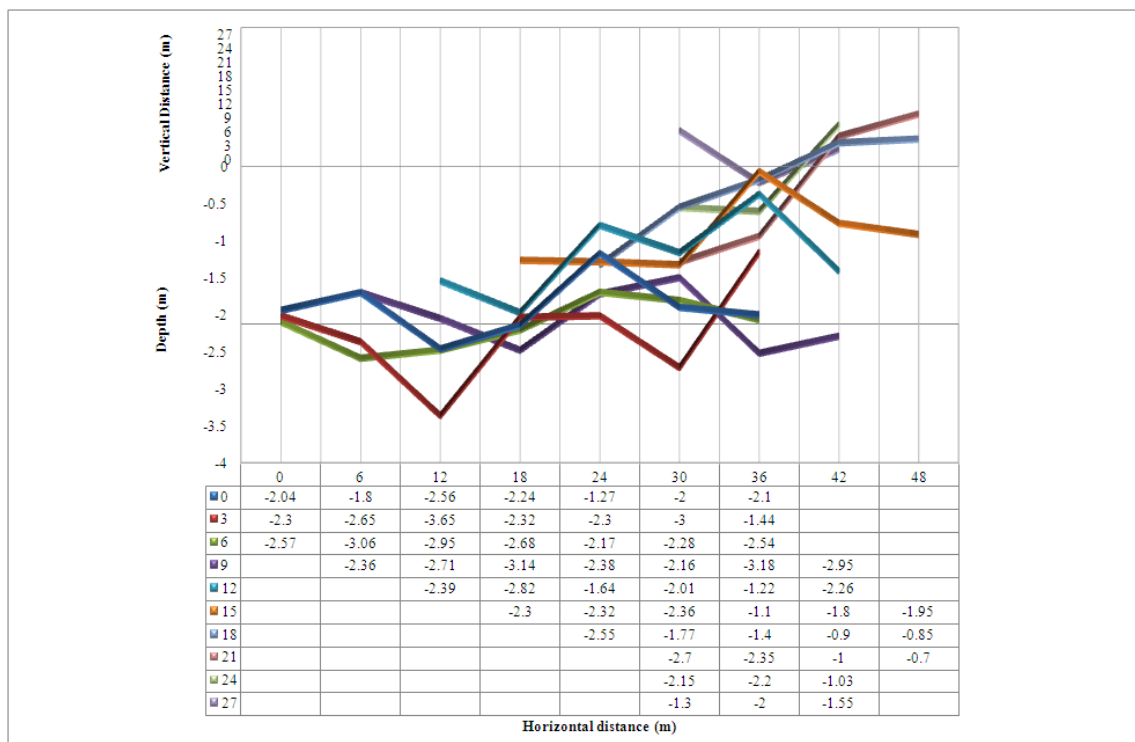


Figure 5.2: Wetland Depth Profile Transects<sup>27</sup>

<sup>27</sup> Each line depicts a horizontal transect conducted vertically down the wetland (i.e. each point is at a horizontal increment of 6 m and vertical increment of 3 m as per Figure 5.1)

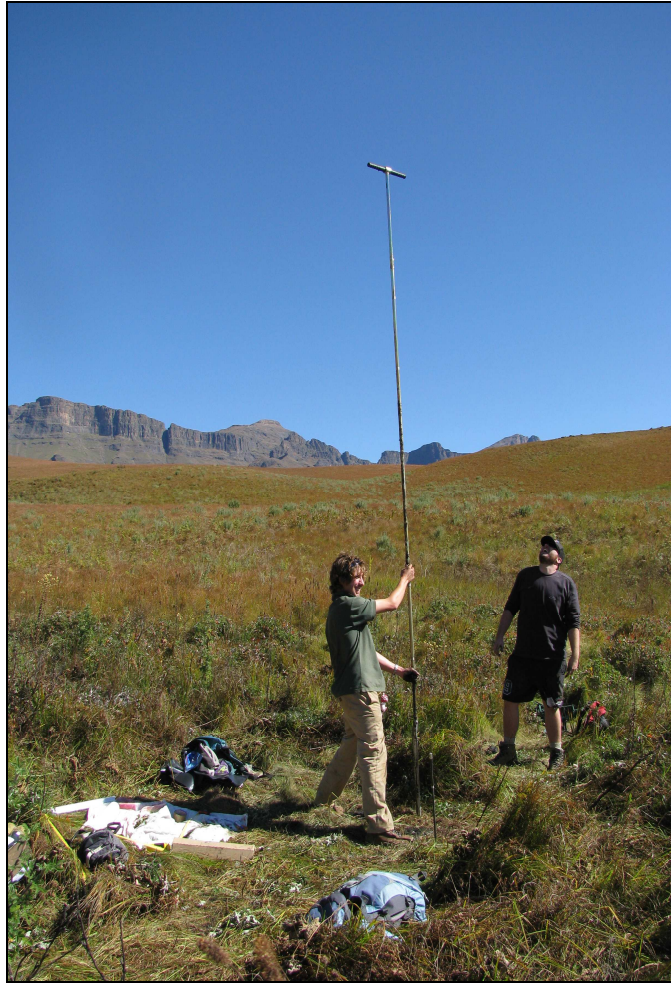


**Plate 5.1: Conducting the wetland depth profile**

### **5.2.2. Coring Procedure**

A 361 cm-long minimally disturbed, semi-continuous sediment core was extracted from Catchment Six using a 50 cm-long, 5 cm diameter Eijkelkamp Russian corer from parallel sampling points with overlapping segments (Figure 5.3) to reduce contamination of the sediment due to the coring technique. Each segment overlapped the previous segment by 1 cm on either side of the segment. These overlaps were removed prior to the segments being placed into labelled 48 cm PVC piping, wrapped with aluminium foil and heavy-duty industrial plastic ready for transport to the laboratory for cold-storage, stratigraphic description and sub-sampling.

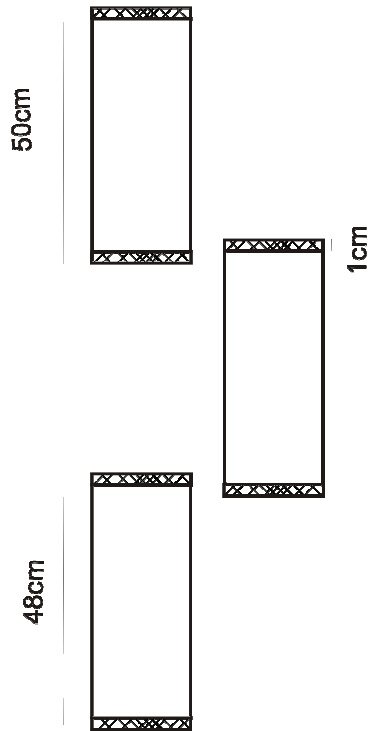




**Plate 5.2: Four-meter extension Russian Corer in Catchment Six**



**Plate 5.3: Attempting to get the Russian Corer through dense, consolidated material**



**Figure 5.3: Parallel sampling point and overlapping coring strategy**

### **5.3. Laboratory Techniques**

#### **5.3.1. Stratigraphy**

A stratigraphic description of the sediment core was conducted using the Troels-Smith sediment classification scheme (Troels-Smith 1955; Kershaw, 1997) and the Munsell Colour Description (Figure 6.1).

#### **5.3.2. Sub-sampling**

A total of 92 sub-samples at a 4 cm resolution<sup>28</sup> were extracted for microscopic charcoal and pollen analysis, Digestion-Combustion charcoal analysis and geochemistry (stable carbon and nitrogen isotope) analysis from the sediment core. Sub-samples for pollen analysis and charcoal analysis were placed into labelled polypropylene, sealable bags and refrigerated. The sub-samples for the geochemical analysis were placed into an oven at 40°C overnight, cooled in desiccators and placed into labelled polypropylene sealable bags.

---

<sup>28</sup> The resolution of 4 cm was chosen from a logistical perspective, to achieve a fairly high resolution sample analysis whilst considering the time aspect of conducting such an analysis.

### **5.3.3. Radiocarbon Dating and Chronological Control**

A total of eight sub-samples were extracted for  $^{14}\text{C}$  analysis based on stratigraphic boundaries and proxy evidence. Rootlets were removed from the sub-samples prior to being dried overnight in an oven at  $80^{\circ}\text{C}$ . Once dried, the sub-samples were placed into desiccators, cooled and then packaged into polypropylene bags. Four samples were sent to the University of Waikato Radiocarbon Dating Laboratory, New Zealand and four samples sent to Poznan Radiocarbon Dating Laboratory, Poland. The location of the samples extracted for  $^{14}\text{C}$  analysis was based upon the stratigraphy and the CONISS results from the Digestion-Combustion Method for charcoal analysis (Winkler 1985). Visible breaks / changes in the stratigraphy together with the charcoal analysis results were considered applicable areas to extract samples for  $^{14}\text{C}$  analysis.

CLAM (Classic Age Modelling) software (Blaauw 2010), integrated into the R open-source statistical environment (Team 2010), was used to calibrate the  $^{14}\text{C}$  dates and to develop a suitable age-model for the  $^{14}\text{C}$  dates. Standard procedures as documented by Blaauw (2010) were used for the  $^{14}\text{C}$  calibration. Initially, the  $^{14}\text{C}$  dates were calibrated with every calibration curve and statistical method available in CLAM to determine the best calibration curve and statistical method to calibrate the  $^{14}\text{C}$  dates. Thereafter, the  $^{14}\text{C}$  dates were calibrated using the Intcal09\_bomb\_curve, which included the following parameters;

- A reservoir offset of  $40 \pm 40$  years to correct for southern Hemisphere variations (Reimer *et al.* 2009);
- Iterations of 10,000;
- The last date was defined as an outlier; and
- The statistical method of linear interpolation was used to develop the age-models.

### **5.3.4. Gravitational-Separation Technique**

Sub-samples were chemically processed using potassium hydroxide and tetra-sodium pyrophosphate digestion techniques and the gravitational ‘swirling’ separation technique (Hunt 1985; Hunt and Rushworth 2005; Wheeler 2007). These techniques served to remove unwanted silts, clays and macroscopic fossils while retaining the microscopic charcoal, pollen and fungal spores (Appendix B).

### **5.3.5. Pollen Analysis**

#### **5.3.5.1. Pollen Counts**

Concentrated pollen slides were mounted using Aquatex Mounting Gel medium for each of the 75 sub-samples prepared by the Gravitational Separation technique. The Aquatex mounting

medium prevented the pollen from moving during pollen counting and identification. Relative pollen counts and identification was conducted for each of the 75 sub-samples. This was achieved using fixed traverses across the slide using an adjustable stage. A Leica DM750 microscope with an attached Leica EZ3 camera was used to count and identify pollen on 200x and 400x magnification. Pollen abundances varied throughout the core and as such, the magnification used to count / identify pollen was adjusted accordingly. Where possible, dependant on time and pollen abundance, pollen counts between 250 and 500 per depth was counted. Ideally, a minimum of 250 pollen grains and spores should be counted per depth to be statistically significant (Meadows *et al.* 1996; Grab *et al.* 2005). Hill (1992) showed that there was no significant difference in pollen species were found when slides were counted at 250, 500 and 1000 pollen grains and spores from the Drakensberg region. However, time constraints are recognised as a major limiting factor in pollen counting / identification process (Coetzee and van Zinderen Bakker 1952) hence, slides of poor pollen preservation / abundance were counted along all possible traverses before discontinuing. As a result, less than 250 pollen counts were reported for a total of 32 out of 75 slides. To assist with the counting procedure, PolyCounter 2.6.1 program was used (Nakagawa 2007).

### **5.3.5.2. Pollen Identification**

To aid in the identification of pollen, several references were used, including a number of digital databases, the African Pollen Database (APD 2004), Pollen and Spores of Barro Colorado Island (Roubik and Moreno 1991) the Neotropical Pollen Key (Bush and Weng 2007) and modern pollen collections from the Drakensberg (Hill 1992). Further sources used for pollen identification included modern samples collected from the Karkloof Nature Reserve, Mfabeni Swamp (Finch 2005) and the use of pollen reference material (van Zinderen Bakker 1953, 1956; van Zinderen Bakker and Coetzee 1959; van Zinderen Bakker and Welman 1970). Pollen was classified as local<sup>29</sup>, regional, arboreal and non-arboreal based on distribution patterns and ecology of the parent vegetation found in the Cathedral Peak region. To assist in this classification process Appendix C was compiled, which contained, where possible, morphological, preservation and dispersal characteristics of the major palynomorphs found in Cathedral Peak region from this research.

### **5.3.6. Charcoal Analysis**

#### **5.3.6.1. Microscopic Charcoal Counts**

Microscopic charcoal fragments were counted and classified in conjunction with pollen counts and identification. Charcoal fragments were counted along the same number of traverses per

---

<sup>29</sup> Local pollen included all wetland-favoured palynomorphs and grasses surrounding the wetland.

slide / depth as pollen. This procedure was to ensure that microscopic charcoal was counted as a ratio of pollen counts (Tinner and Hu 2003; Turner *et al.* 2008; Blackford 2000). Ideally, charcoal should be counted to a minimum of 250 fragments (Clark 1982); however, this should be taken within context of the situation. Charcoal fragments are commonly counted alongside pollen on the same slides, where pollen is often counted to a minimum of 250 grains per slide. Due to the low pollen abundances found in this research, counting charcoal to 250 counts would skew the relationship between charcoal and pollen through an over-representation of charcoal. To reduce this effect, charcoal was counted along the exact same number of traverses as pollen to ensure a pollen:charcoal ratio was achieved. Charcoal fragments were classified according to size into the following groups: 3-10  $\mu\text{m}$ , 11-20  $\mu\text{m}$ , 21-50  $\mu\text{m}$ , 50-75  $\mu\text{m}$ , 76-100  $\mu\text{m}$ , and >100  $\mu\text{m}$ . Fragments less than 3  $\mu\text{m}$  were omitted from the counts due to uncertainty of identification (Rucina *et al.* 2009; Tipping and Milburn 2000; Duffin 2008). The size classes between 3  $\mu\text{m}$  and 50  $\mu\text{m}$  are regarded as either derived from regional fire regime or from high intensity fire events (Duffin *et al.* 2008; Blackford 2000). Charcoal sizes greater than 50  $\mu\text{m}$  are regarded as derived either from local fire regimes or from low intensity fire events. To assist with the counting procedure, PolyCounter 2.6.1 program was used (Nakagawa 2007).

### **5.3.6.2. Digestion-Combustion Charcoal Analysis**

Sub-samples were processed according to the methods described by Winkler (1985) to determine the charcoal percentage of the sub-sample (Appendix D). The sub-samples were placed into ceramic crucibles, dried overnight and weighed to determine the dry weight. The dried sub-samples were then treated with concentrated nitric acid to remove the organic material and pyrites through digestion. The chemically processed sub-samples were centrifuged, decanted, dried overnight and weighed to determine the weight of the sub-sample after nitric acid digestion. The dried sub-samples were placed into a furnace at 450°C to undergo ignition to burn off any remaining organic material, pyrites and carbonates. The percentage charcoal was then calculated as the dry weight divided by the ignition weight (Equation).

$$\%Charcoal = [Dry\ Weight\ (DW)/Ignition\ Weight\ (IW)]*100$$

**Equation 5.1: Digestion-Combustion charcoal technique formula (Winkler 1985)**

### **5.3.7. Geochemical Analysis**

The 75 sub-samples extracted for geochemical analysis were prepared by being dried overnight in the oven at 40°C, removed and cooled in a desiccator. Once cooled, each sample was ground up using a mortar and pestle and the finely ground samples placed into polypropylene vials and sent to IsoEnvironmental cc at Rhodes University, South Africa for geochemical analysis of stable carbon and nitrogen isotopes. The geochemical analysis was conducted using a Europa



Scientific Elemental Analyser and 20-20 IRMS with beet sugar and ammonium sulphate used for the internal standards and Casein, calibrated against IAEA-CH-6 and IAEA-N-1, was used for the certified protein standard. Due to the low organic material and variable weights, each sample was processed twice, once to determine the elemental composition and required weight and once to determine the carbon and nitrogen isotope values.

### 5.3.8. Data Zonation and Diagrams

The results from the microscopic pollen and charcoal analysis, geochemical analysis and Digestion-Combustion charcoal analysis were plotted using Psimpoll Version 4.263 (Bennett, 2002). The results from the pollen analysis indicated poor pollen preservation and low pollen counts between 248 cm and 300 cm, which resulted in the development of diagrams for the 248 cm section of the core. Three diagrams, Regional and Local Pollen, Regional and Local Pollen Summary and the Geochemical / Charcoal data, were plotted for the 300 cm section of the core. The poor pollen preservation and low counts may be reflected in all other proxy data sources between 248-300 cm of the sediment core and not only the pollen data. While this data have been included in the dataset, reference to this data hereafter would be mostly on a descriptive basis. The uncertainties in the proxy data values mean that all inferences on conditions and trends during this period should be read with caution. The following diagrams and the description of the diagrams, which include the statistics conducted on each dataset where applicable, are presented hereafter (Table 5.1);

**Table 5.1: Summarised statistics performed in Psimpoll**

<b>Statistic Conducted</b>	<b>Dataset</b>	<b>Dataset Depth (cm)</b>	<b>Taxa used</b>	<b>Variables</b>
Palynological Richness	Regional and Local Pollen	248 and 300	All taxa included	Standardized 150 counts per depth
Rate of Change Analysis	Regional and Local Pollen	248 and 300	All taxa included	Chord Distance dissimilarity measure; smoothing parameter of 3
Zonation	Regional Pollen	248	Only regional taxa included	CONISS; nine zones; square root transformation
Depth to calibrated age axis	Regional Pollen	248	Only regional taxa included	Linear interpolation between dates
Principal Component Analysis (PCA)	Geochemical and Charcoal Data	300	$\delta^{13}\text{C}$ , $\delta^{15}\text{N}$ , TN, TOC, and C/N	Covariance matrix, square-root transformation

1. Regional pollen: only regional counts for the section 0 cm to 248 cm, excluding all local counts and the percentages were calculated from the regional total counts. Pollen zonation using CONISS was run on this dataset to ensure that zonations of the data would not be influenced by local pollen concentrations. The zonation result was included on all other diagrams.
2. Regional and local pollen: all pollen counts for all pollen taxa found during the counting / identification analysis stage. This diagram was constructed for both the 0- 248 cm and 0-300 cm sections. Palynological richness and rate of change analysis using Psimpoll was calculated for this dataset for both sections.
3. Regional and local pollen summary: this is a summary of the results of Diagram 2. Regional taxa counts constituted a minor percentage of the total pollen sum. As such, the dominant taxa were defined as those taxa having 10 counts or more for the entire 0-300 cm section of the core. This diagram was constructed for both the 0-248 cm and 0-300 cm sections.
4. Arboreal and non-arboreal pollen summary: this is a summary of the pollen taxa classified as arboreal (AP) or non-arboreal (NAP) taxa. All local taxa were included in the total sum, with non-pollen palynomorphs and unidentified pollen being excluded from the total counts.
5. Geochemical and charcoal data: this diagram included all the results from the geochemical analysis, microscopic charcoal analysis and the digestion-combustion charcoal analysis. To compare the results from the Digestion-Combustion charcoal analysis and the microscopic charcoal analysis, for both techniques, values per depth were converted into a percentage of total values of the entire 0-300 cm section. This allowed for both techniques to be compared on the same scale and unit.

A paired T-test was conducted on the microscopic charcoal and Digestion-Combustion charcoal results to determine the correlation between the results of the two techniques. This was conducted using the statistical functions found within the Data Analysis packages in Microsoft Excel 2003 software (Microsoft 2003).

For each diagram, the following data were included over-and-above what has been mentioned above;

1. Depth axis (cm);
2. Troels-Smith Lithology;

3. Uncalibrated dates ( $^{14}\text{C}$  yr BP);
4. Calibrated dates (cal yr BP); and
5. Calibrated age to depth axis (cal yr BP).

All diagrams and statistical results have been included in **Chapter Six**.

#### **5.4. Conclusion**

Palaeoenvironmental research requires a wide range of methods to be used to interpret the multi-proxy data. The methods can be divided into two groups, namely, fieldwork and laboratory methods. A description of the methods, namely; microscopic pollen and charcoal techniques, digestion-combustion technique for charcoal, geochemical determinations for stable carbon and nitrogen isotopes and  $^{14}\text{C}$  determinations and calibration techniques have been provided.

## **CHAPTER SIX**

### **6. RESULTS**

#### **6.1. Introduction**

This chapter provides the results from the multi-proxy analysis, which will be used to inform the palaeoenvironmental interpretation of Cathedral Peak. The stratigraphy and chronology results are first described, followed by pollen, charcoal and geochemical results. A description of the pollen, charcoal and geochemical results, grouped into the five zones (CVI-1-5) are provided.

#### **6.2. Stratigraphy**

The sediment core is divided into ten zones based on colour and composition as defined according to the Munsell Colour Code and Troels-Smith sediment description. The ten zone boundaries occur at the following depths; i) 25 cm, ii) 48 cm, iii) 56 cm, iv) 73 cm, v) 115 cm, vi) 192 cm, vii) 209 cm, viii) 240 cm, ix) 245 cm and x) 300 cm (Figure 6.1).

The sediment core is comprised of fibrous topsoil within a matrix of greenish black clay in the top 25 cm, underlain by fine-grained mineral particles in a matrix of clay to a depth of 300 cm. A zone comprised of medium to large-grained mineral particles occurs between 240-245 cm. The colour of the sediment varies throughout the core from light olive brown to black with various mottling / streaked conditions (Plate 6.1).

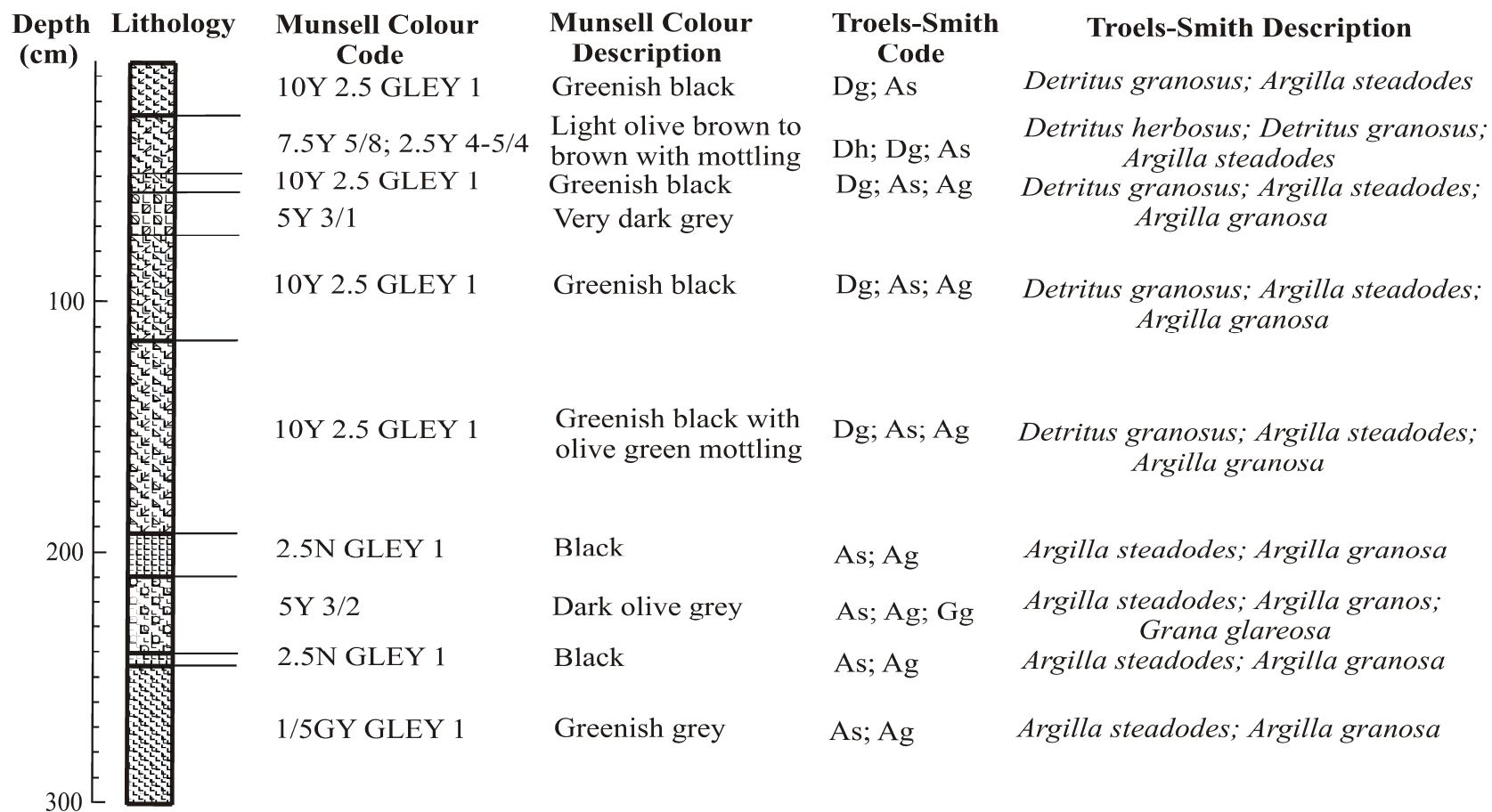
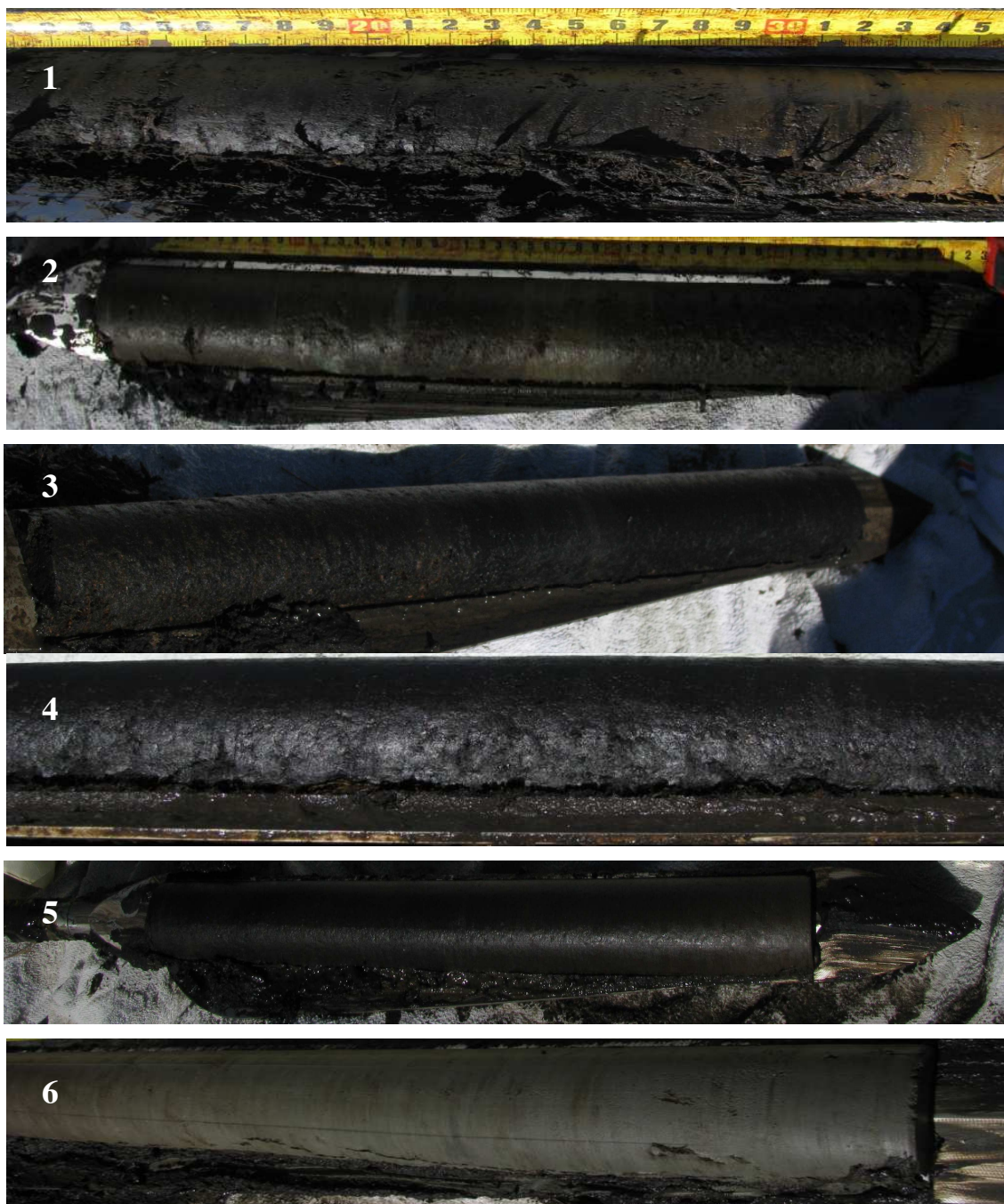


Figure 6.1: Stratigraphic description of the 300 cm sediment core



**Plate 6.1: Extracted sediment cores**

(The cores depicted above were extracted at the following depths: **1.** 0 - 48 cm; **2.** 48 - 96 cm; **3.** 96 -144; **4.** 144 – 192 cm; **5.** 192 – 240 cm; **6.** 240 – 288 cm)

### **6.3. Chronology**

The chronology was determined through  $^{14}\text{C}$  AMS dating of eight sub-samples extracted from the 371 cm sediment core. The chronology contains seven linear dates to a depth of 298 cm and one outlier date at 361 cm.

The uncalibrated  $^{14}\text{C}$  dates were calibrated using CLAM (Blaauw 2010) software integrated

within the open-source statistical environment of R (Team 2010). The IntCal09\_Bomb calibration curve (Blaauw 2010) with a reservoir offset of  $40 \pm 40$  yr BP (Reimer *et al.* 2009) was used as this calibration curve has the ability to deal with both modern dates and dates older than 11,000 yr BP, both of which are present in this chronology (Table 6.1). The calibration of the  $^{14}\text{C}$  dates resulted in the production of calibrated dates for eight samples<sup>30</sup> (Appendix E), sedimentation rates (Table 6.2), sedimentation rate curve (Figure 6.2), a calibration curve for each  $^{14}\text{C}$  date (Figure 6.3) and per centimetre resolution interpolated ages (Appendix F).

The sedimentation curve indicates moderate to slow sedimentation during the late Quaternary and the late Holocene up to  $6869.5 \pm 81$  cal yr BP with values ranging from 203 yr/cm to 103 yr/cm. The sedimentation rate increases substantially between  $6869.5 \pm 81$  cal yr BP and  $4723 \pm 38$  cal yr BP with sedimentation rates between 30.473 and 22.947 yr/cm. A slight decline in sediment occurs between  $2219 \pm 93.5$  cal yr BP and  $4723.5 \pm 38$  cal yr BP. Thereafter, sedimentation increases dramatically to present conditions. These sedimentation rate variations are based on the assumption that no sediment removal through erosion or deflation has occurred; however, these mechanical mechanisms could have contributed to sedimentation rate variations.

The chronology is linear with the oldest date of  $15096.5 \pm 445$  cal yr BP located at 298 cm which extends into the late Quaternary. The outlier, signalling an age reversal, has an age estimate of  $6089 \pm 94.5$  cal yr BP, restricted the multi-proxy analysis to the first 300 cm of sediment. The cause of the age reversal is unknown but could be attributed to; i) bioturbation effects from insects and / or natural events, or ii) root contamination of the sediment.

---

<sup>30</sup> Derived calibrated dates are presented in all graphs / diagrams etc hereafter. These dates are rounded off to the nearest whole number in the text to avoid unrealistically ‘precise’ age determinations and.

**Table 6.1: Radiocarbon dating results from Catchment Six, Cathedral Peak**

Sample No	Zonation <sup>31</sup>	Lab Code	Depth (cm)	<sup>14</sup> C yr BP	Cal yr BP range	Cal yr BP <sup>32</sup>	Highest probability (%)	Cal AD/BC
1	CVI-5	Poz-32913	5-7	978 ± 27	-44 - -42	43±1	67.4	AD 1994-1996
2	CVI-3	Poz-32912	117.5-119	2230 ± 30	2126-2313	2219±93.5	100	BC 203.5-326
3		Wk-27613	160.5-161	4244 ± 31	4686-4762	4724±38	48.4	BC 2861-2912
4	CVI-2	Poz-32911	217-218	5310 ± 40	5935-6128	6031±96.5	78.8	BC 4039-4257
5		Wk-25926	244-245.5	6068 ± 30	6789-6951	6870±81	100	BC 4895-5055
6	CVI-1	Wk-27614	269.5-270	8424 ± 39	9303-9486	9394±91.5	100	BC 7451-7577
7		Poz-32910	296.5-298	12,760 ± 70	14,652-15,542	15097±445	100	BC 12,760-13,668
8		Wk-25927	360-361	5346 ± 30	5995-6184	6089±94.5	100	BC 4145-4263

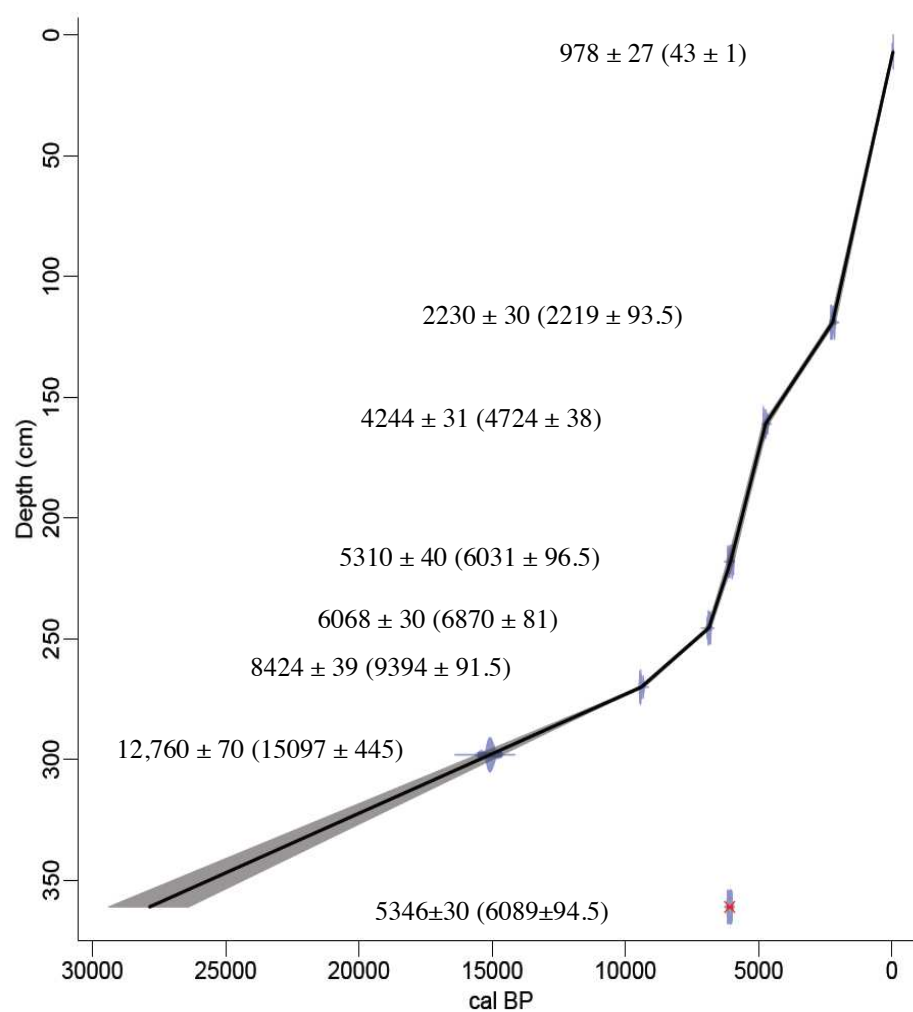
<sup>31</sup> Zonation as determined through CONISS on the Regional Pollen Data using Psimpoll.

<sup>32</sup> The single calibrated date was calculated as the mean of the calibrated age range as determined by CLAM integrated with R software.



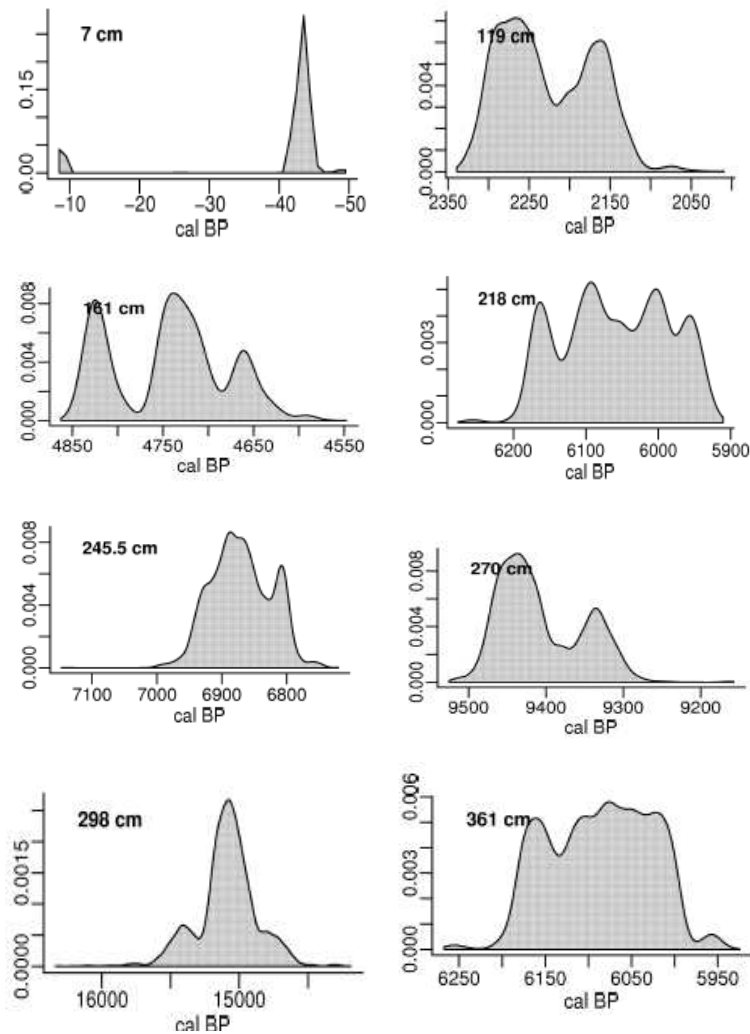
**Table 6.2: Sedimentation rates**

Sample No	Depth Range (cm)	Depth Thickness (cm)	Sedimentation Rate (yr/cm) <sup>33</sup>
1	0-7	7	6
2	7-119	112	19
3	119-161	42	60
4	161-218	57	23
5	218-245.5	27.5	30
6	245.5-270	24.5	103
7	270-298	28	204



**Figure 6.2: Sedimentation rate curve of Catchment Six, Cathedral Peak.**

<sup>33</sup> Sedimentation rate values have been rounded of to the nearest whole number



**Figure 6.3: Calibration curves for each  $^{14}\text{C}$  Date.**

#### **6.4. Pollen Diagrams**

Pollen diagrams were developed using the raw pollen data collected during the counting and identification process (Appendix G). A total of 52 pollen taxa (Appendix H) were identified during the microscopy analysis and these pollen taxa were grouped according to the parameters of local, regional, arboreal (AP) and non-arboreal (NAP). These parameters were then used to construct Regional / Local and AP / NAP pollen diagrams. Furthermore, a Regional Pollen diagram, Regional / Local pollen Summary Diagram and AP / NAP Summary pollen diagram were constructed.

During the microscopy analysis of pollen, the section of sediment core between 248 and 300 cm was found to have extremely low pollen counts; thus the pollen analysis was concentrated between 0-248 cm of the core. The poor pollen preservation makes the task of inferring any vegetation changes virtually impossible as there is a shortage of reliable data; therefore, the results from zone CVI-1 will be merely described. Pollen diagrams depicting the 300 cm pollen

sequence was created for the Regional / Local Pollen diagram and Regional / Local pollen Summary diagram. All other pollen diagrams were constructed for the 248 cm pollen sequence. The following pollen diagrams have been included in this chapter;

- i) Regional pollen at 248 cm (Figure 6.4),
- ii) Regional and local pollen at 248 cm (Figure 6.5),
- iii) Regional and local pollen summary at 248 cm (Figure 6.6),
- iv) Regional and local pollen summary at 300 cm (Figure 6.7),
- v) Arboreal and non-arboreal pollen summary at 248 cm (Figure 6.8),

In addition, the Regional and local pollen diagram at 300 cm is included as Appendix G for reference purposes.

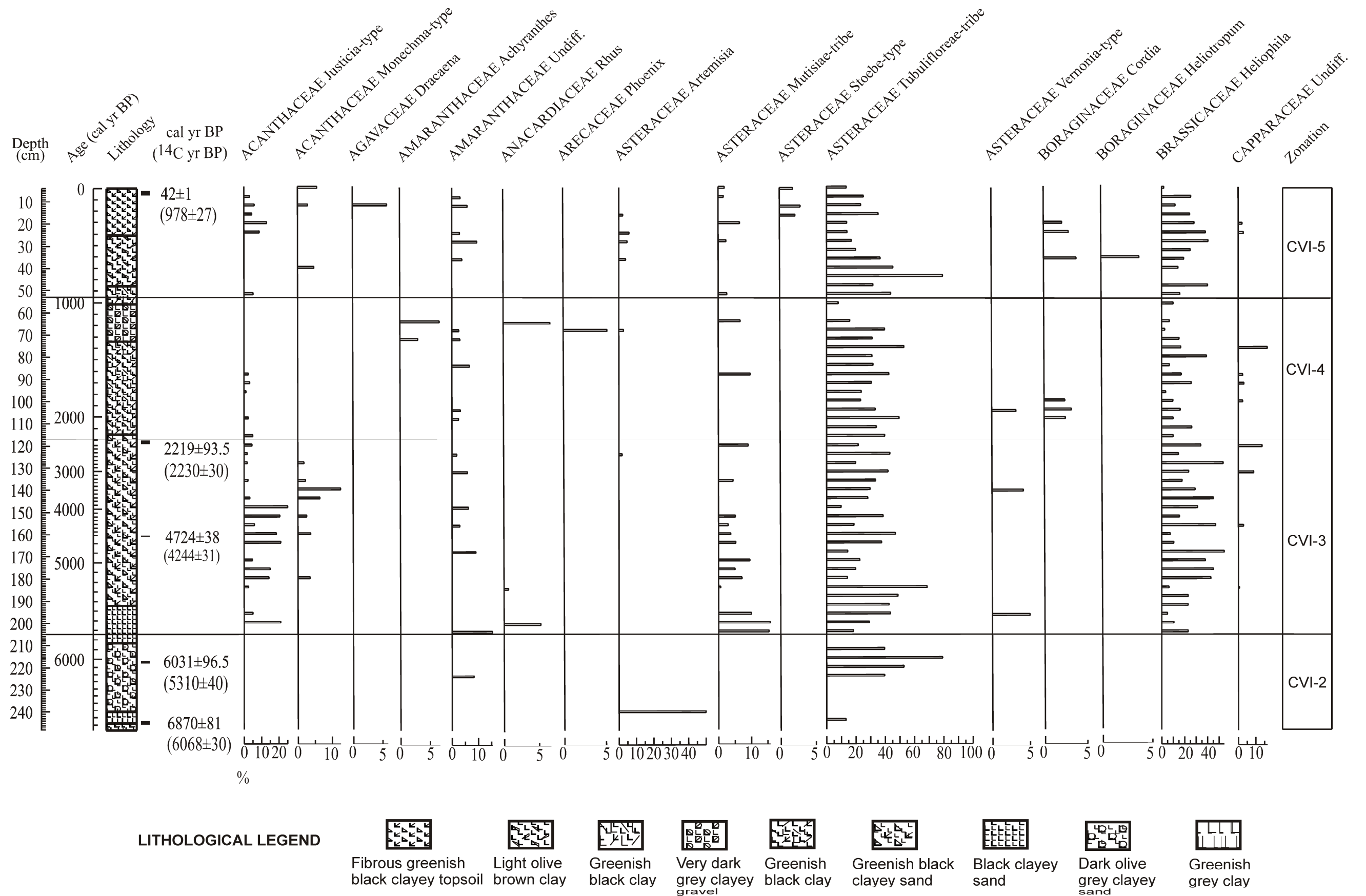


Figure 6.4: 248 cm regional pollen (1 of 3)

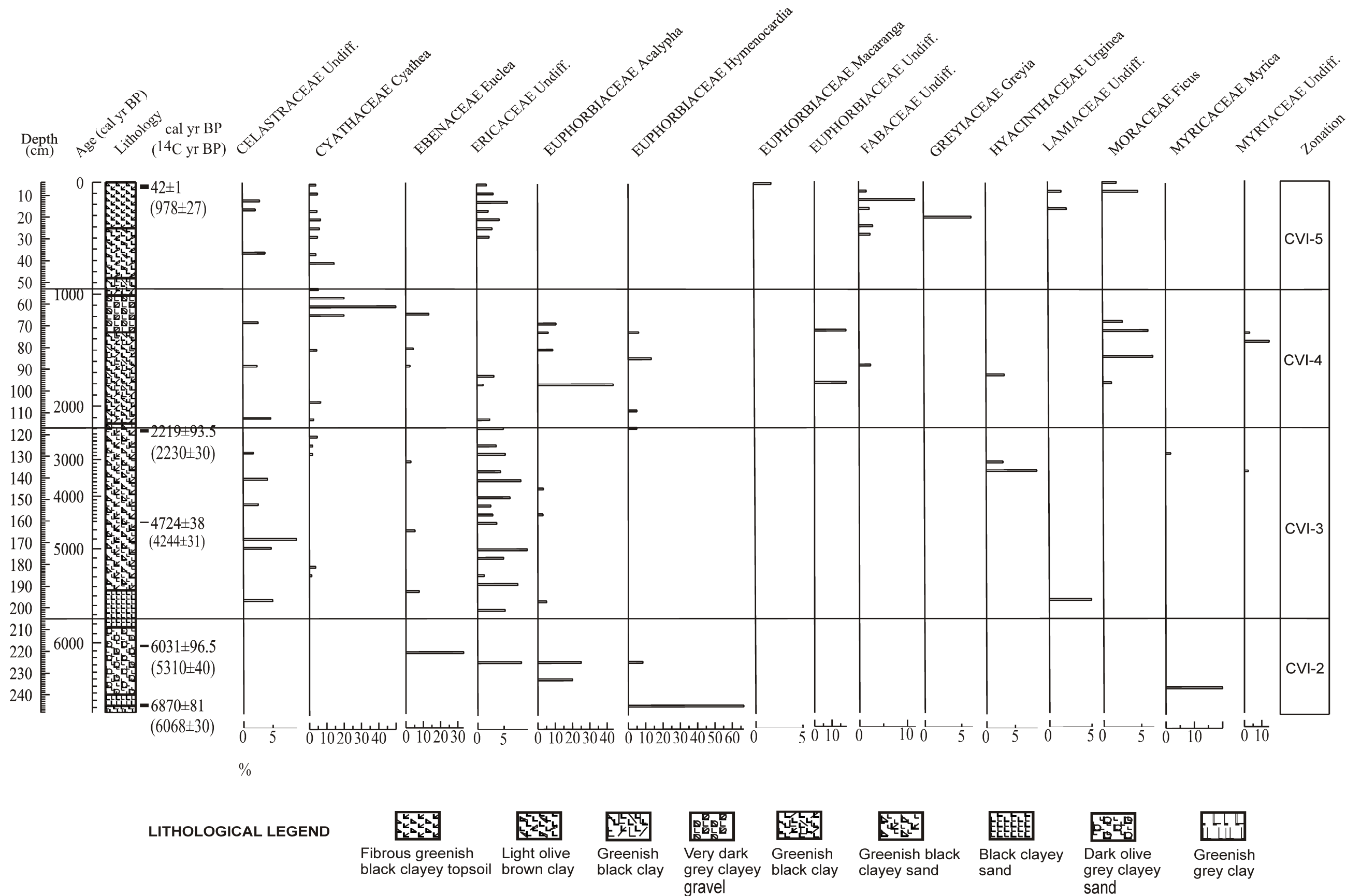


Figure 6.4: 248 cm regional pollen (2 of 3)

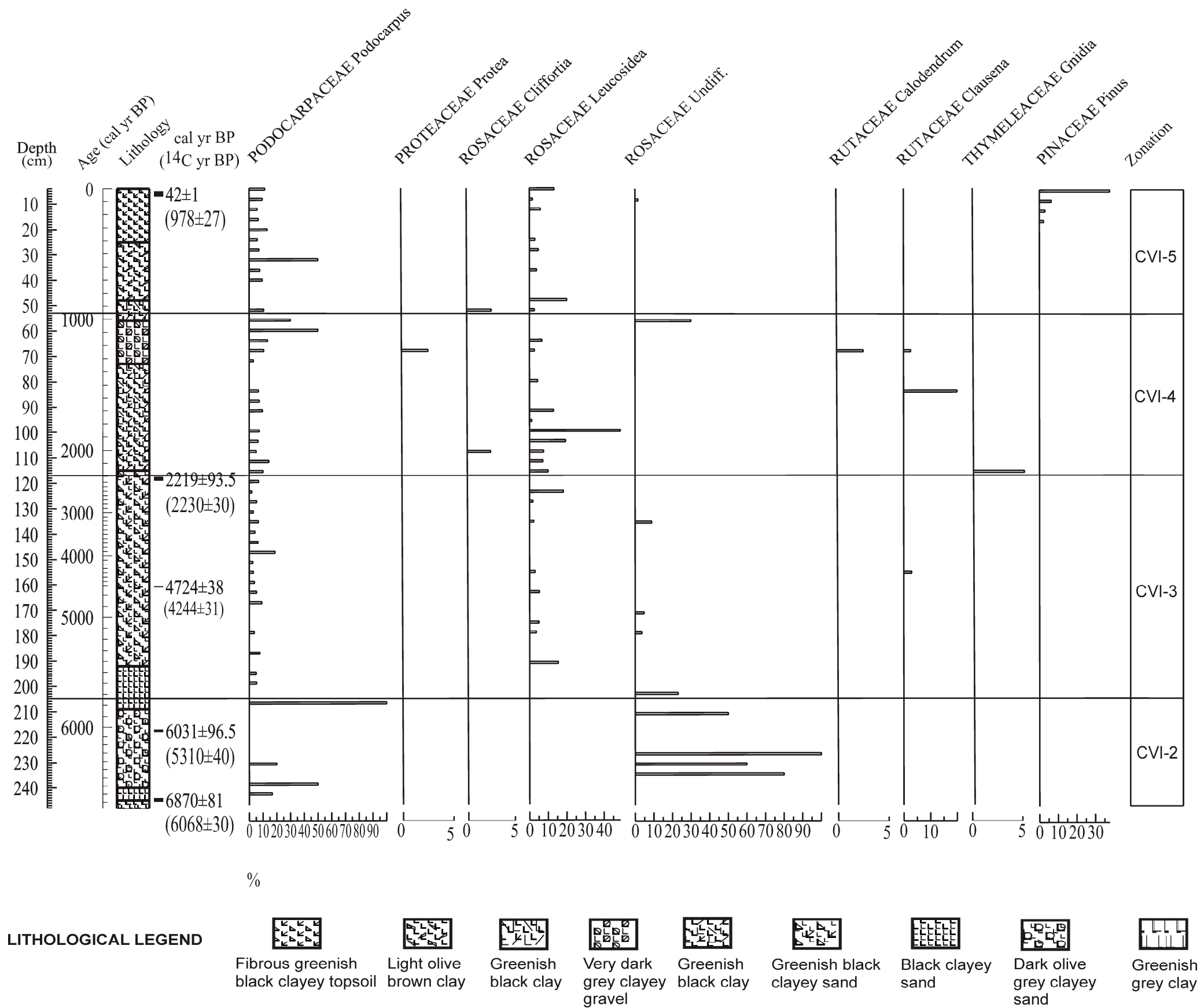


Figure 6.4: 248 cm regional pollen (3 of 3)



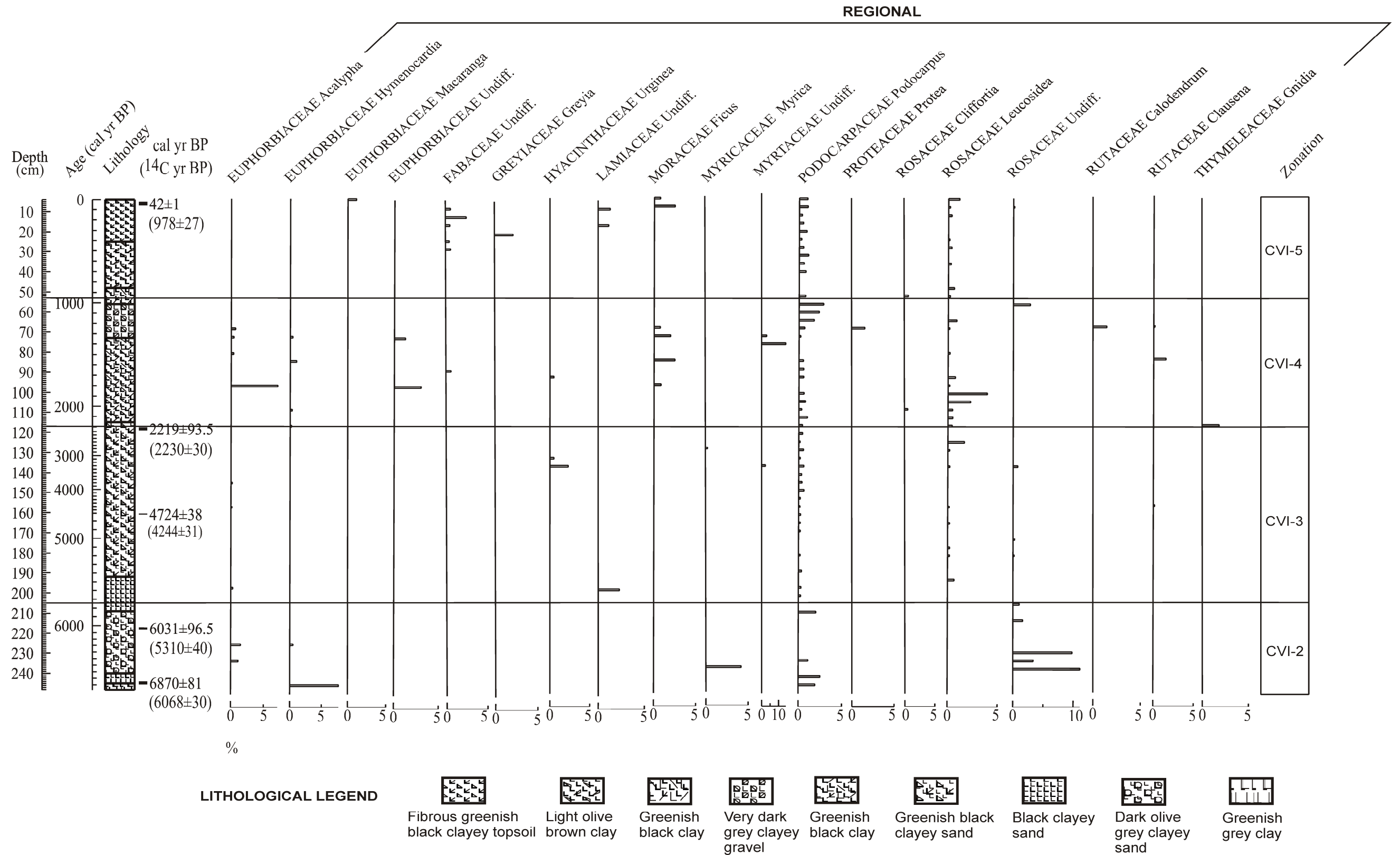


Figure 6.5: 248 cm regional and local pollen (2 of 3)



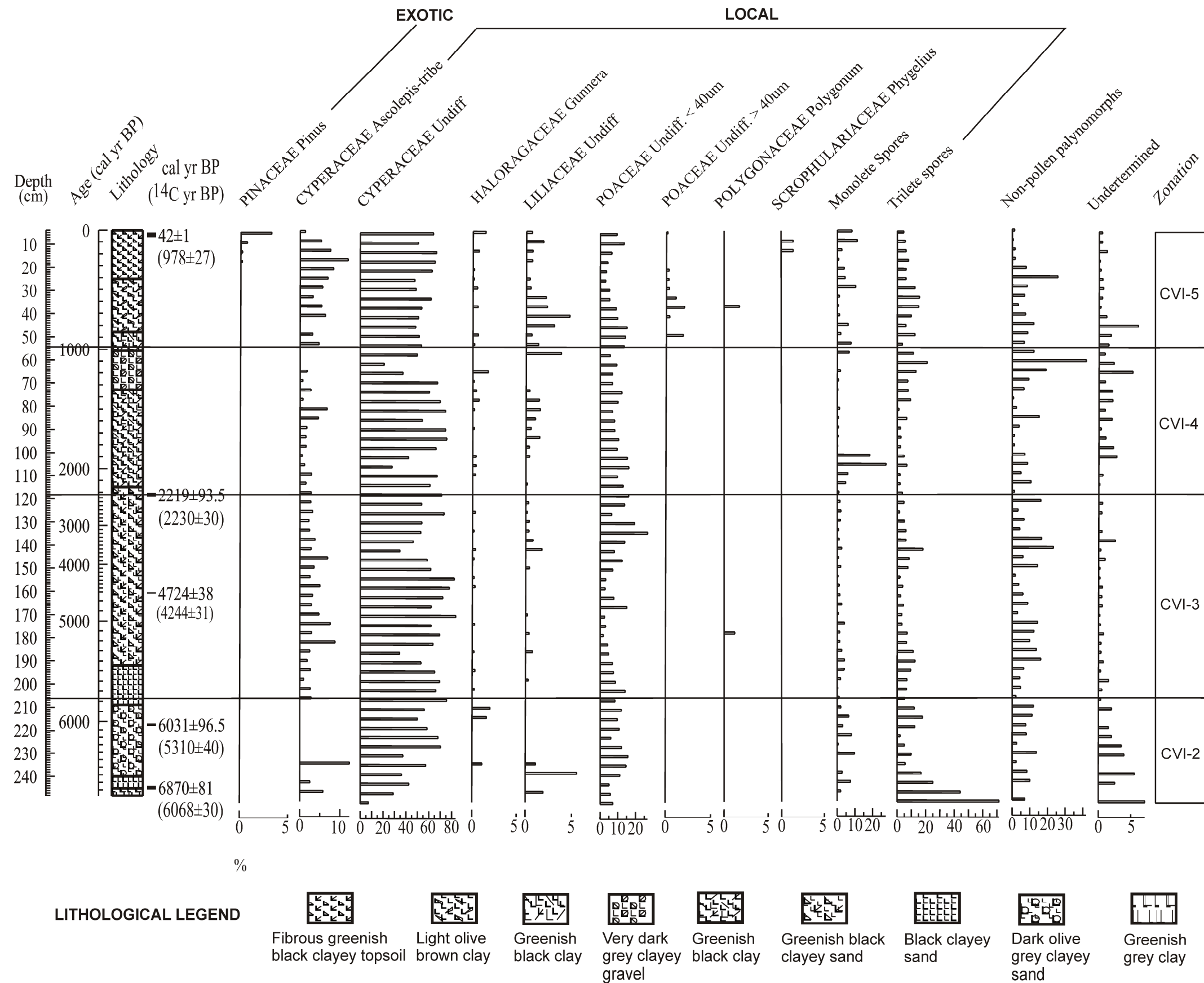


Figure 6.5: 248 cm regional and local pollen (3 of 3)

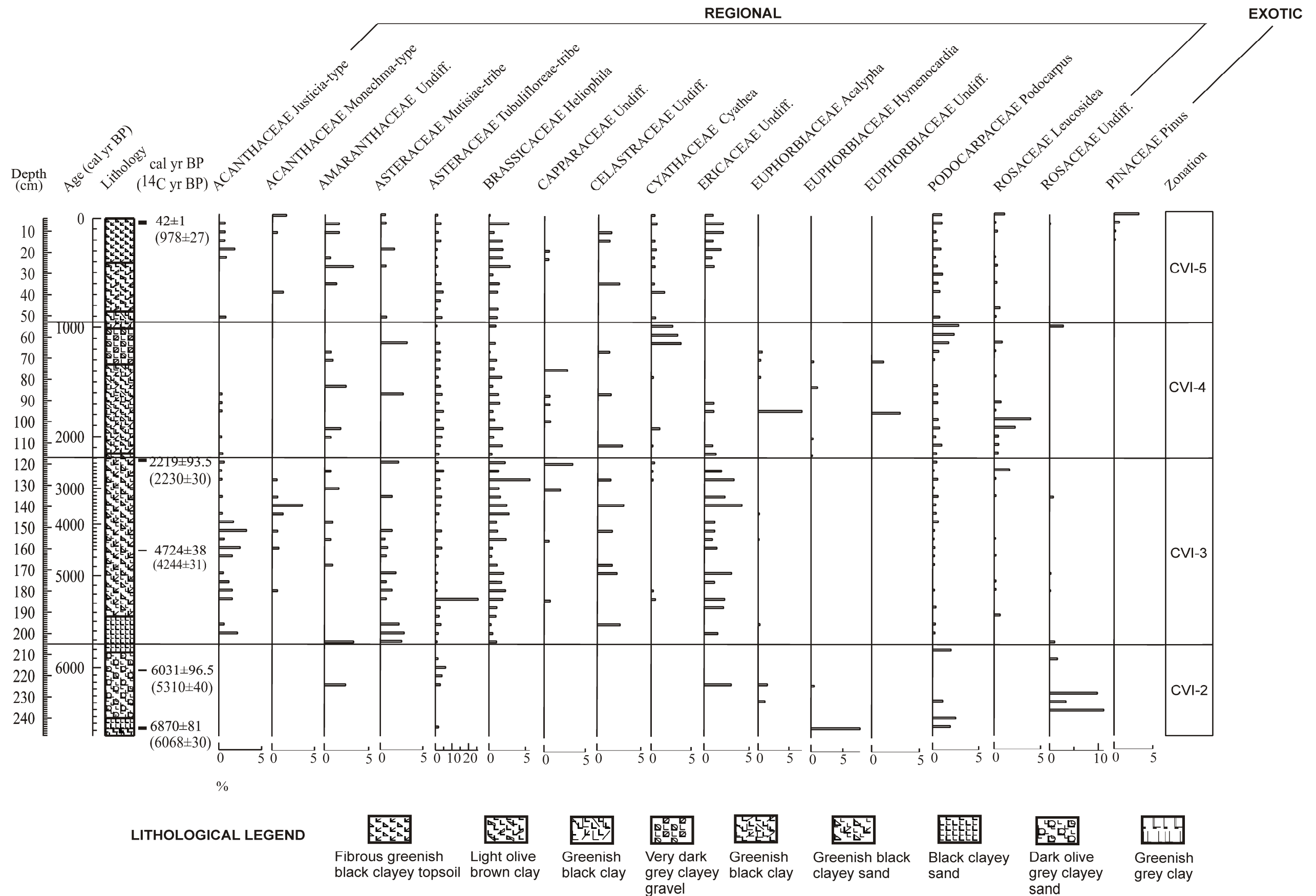


Figure 6.6: 248 cm regional and local pollen summary (1 of 2)

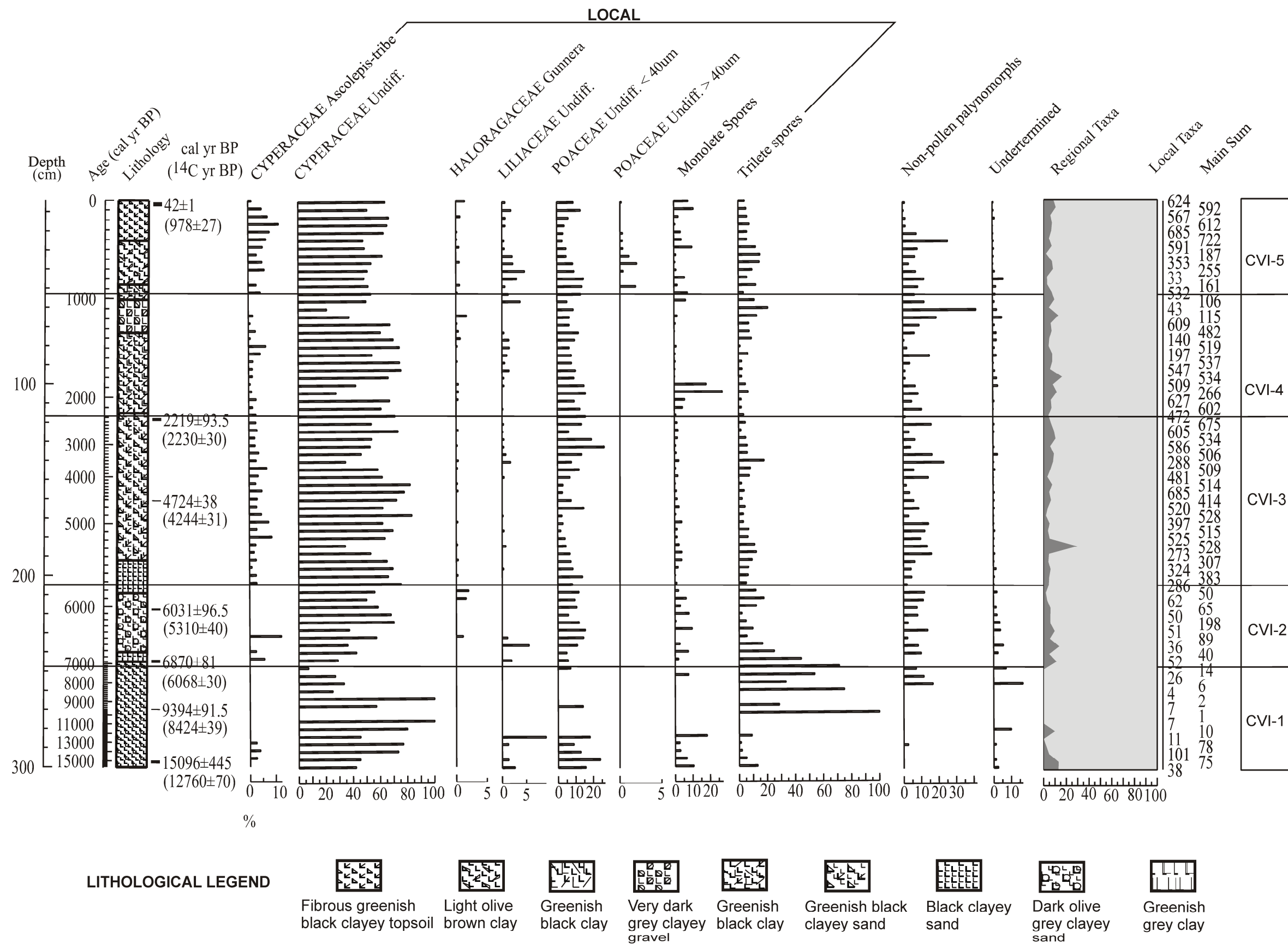


Figure 6.6: 248 cm regional and local pollen summary (2 of 2)

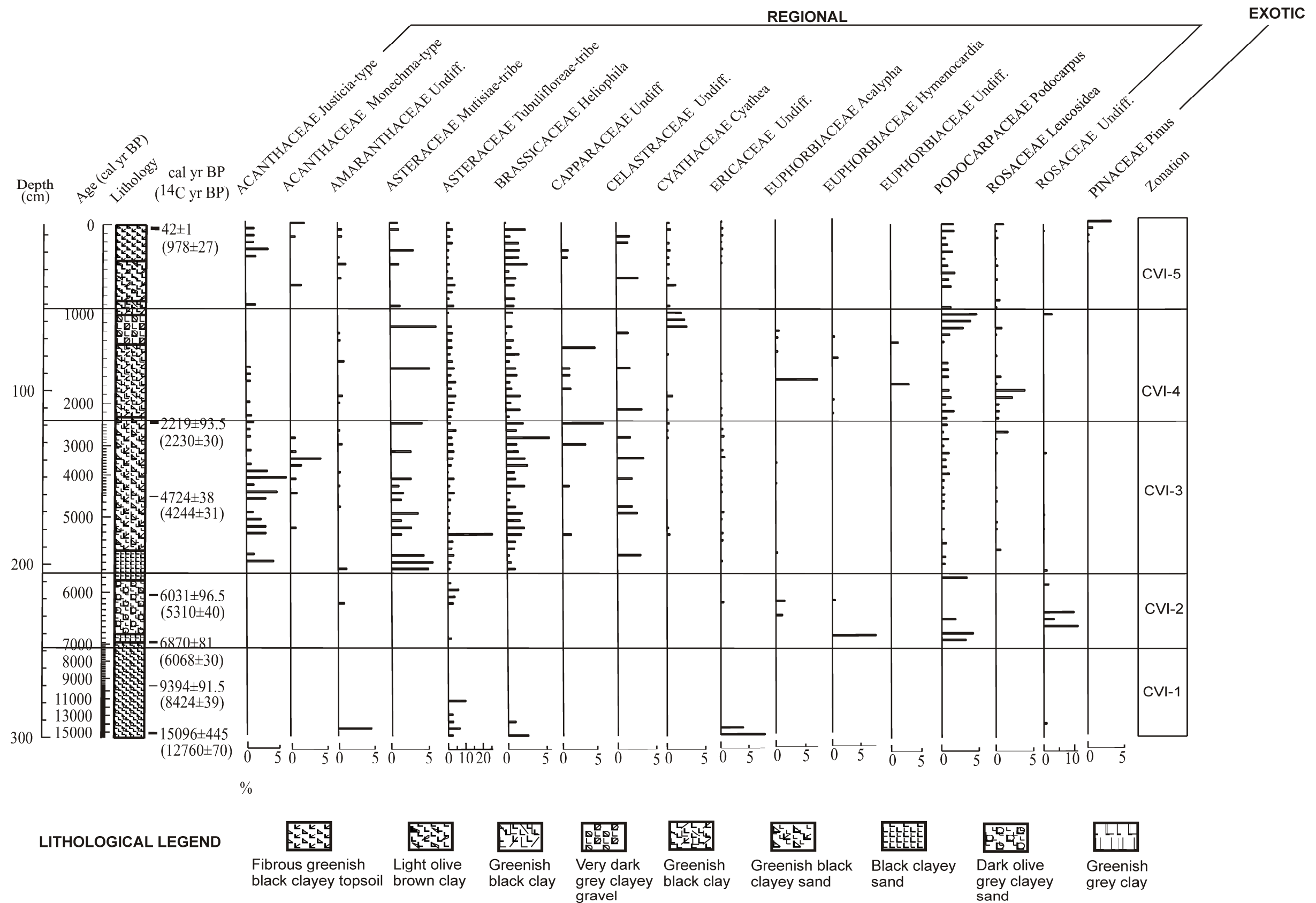


Figure 6.7: 300 cm regional and local pollen summary (1 of 2)

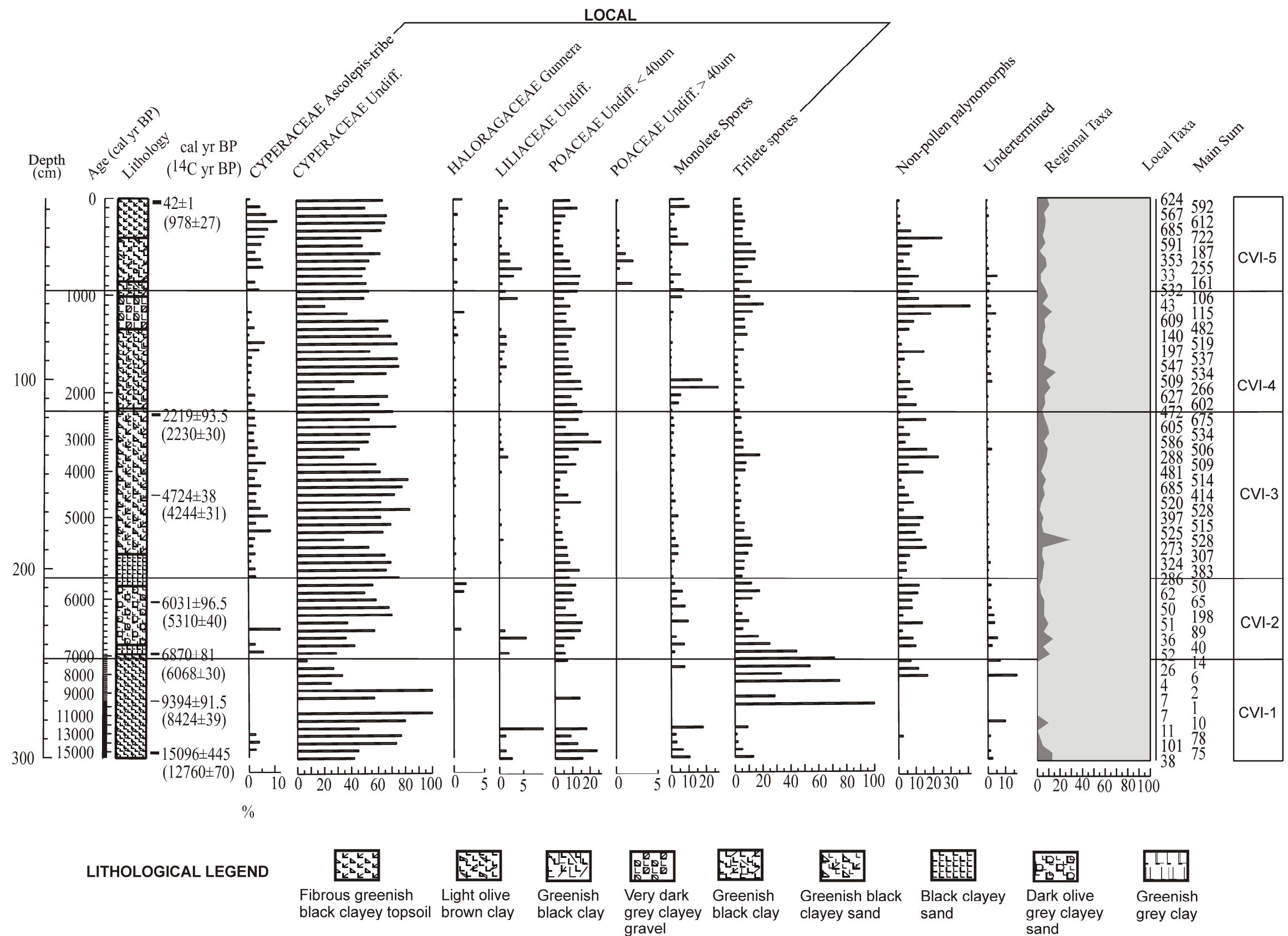


Figure 6.7: 300 cm regional and local pollen summary (2 of 2)

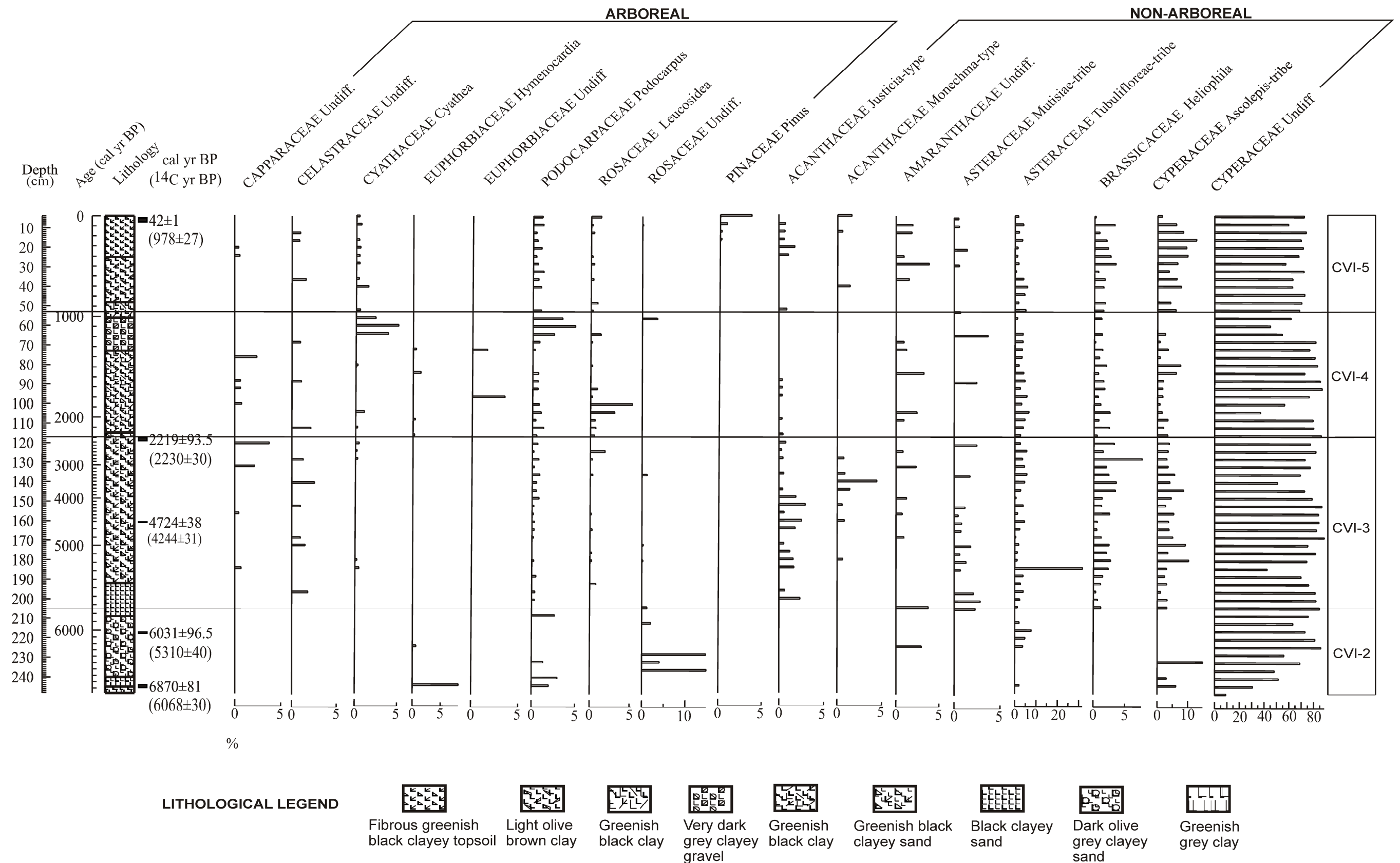
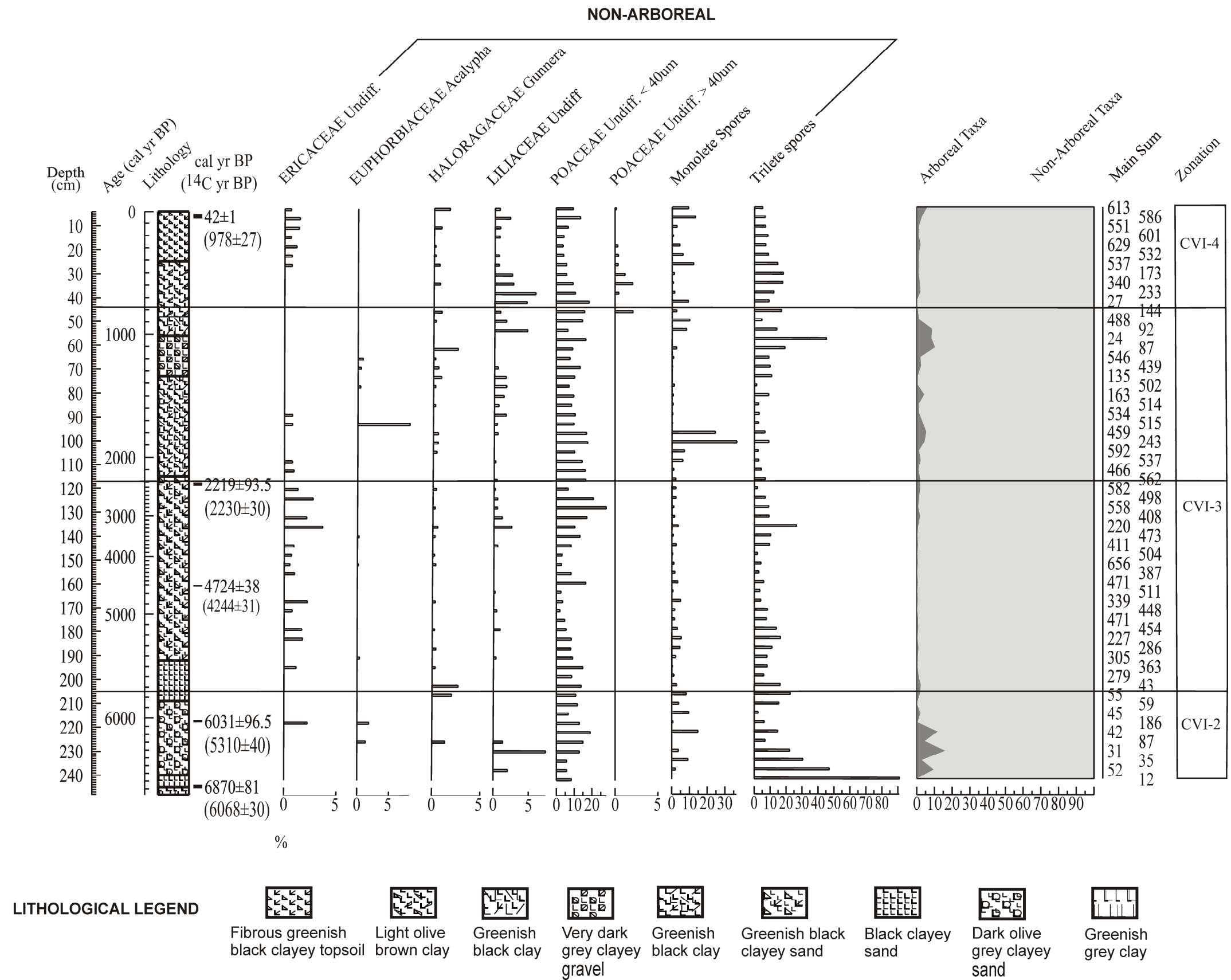


Figure 6.8: 248 cm arboreal and non-arboreal pollen summary (1 of 2)



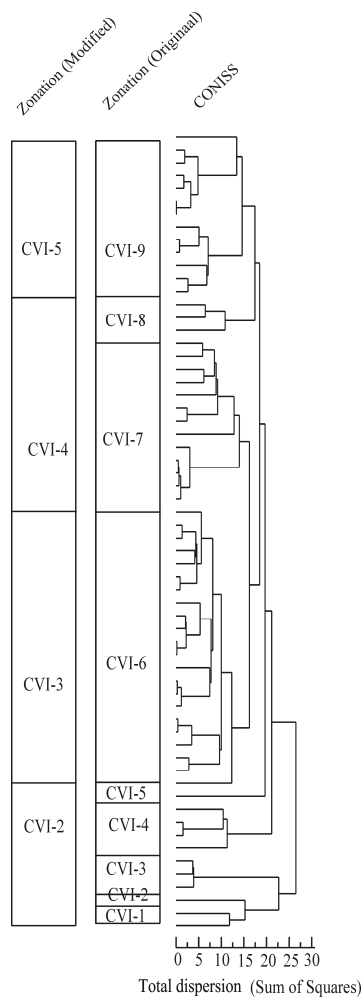
**Figure 6.8: 248 cm arboreal and non-arboreal pollen summary (2 of 2)**



To assist in the interpretation of the pollen data the regional pollen sequence was divided into nine zones and then further condensed into four zones (Table 6.3) using the Constrained Incremental Sum of Squares (CONISS) technique (Figure 6.9) to reduce the influence of the occurrence of the local pollen data on the total pollen dataset.

**Table 6.3: Summary of zonation**

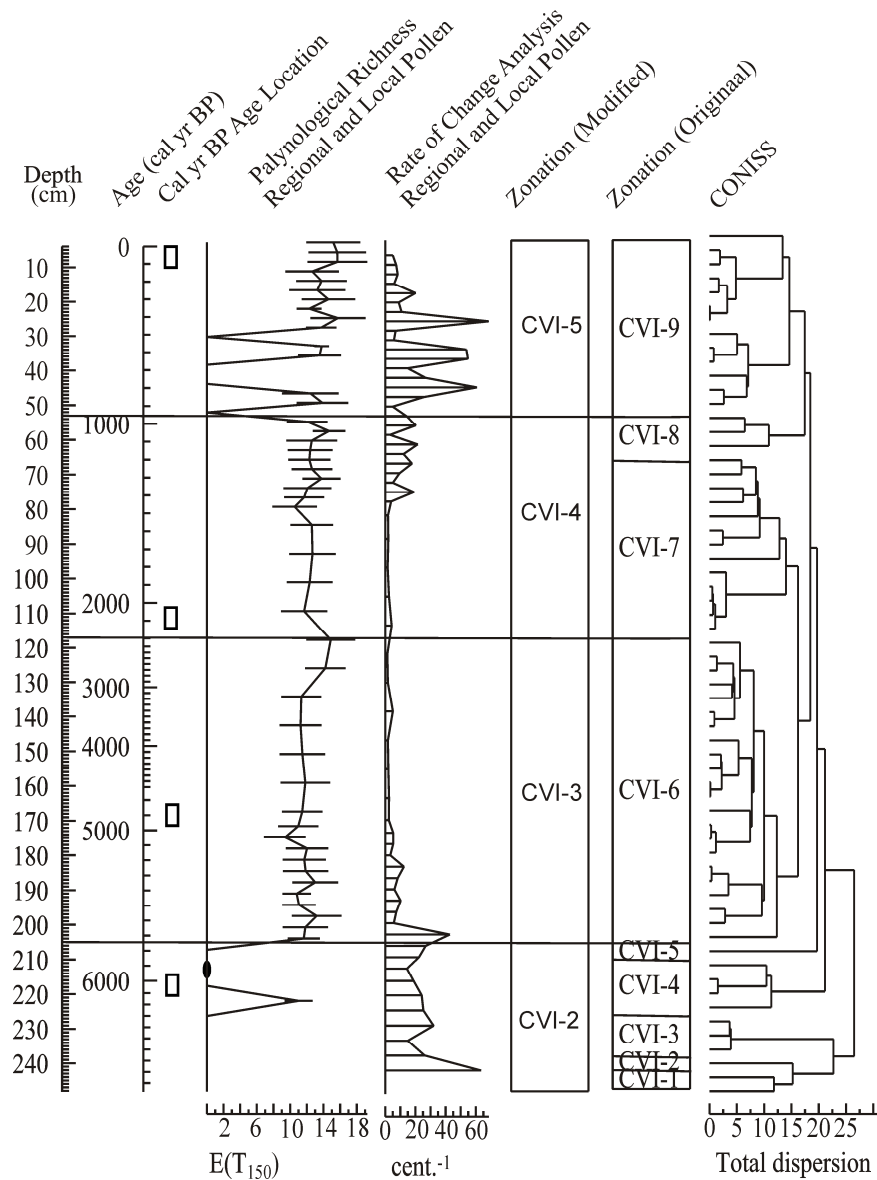
Zone	Depth Range (cm)	Age Range (cal yr BP)	Rounded-off Age Ranges (cal yr BP)
CVI-5	0-53	892-Present	890-Present
CVI-4	53-117	2184-892	2180-890
CVI-3	117-205	5756-2184	5760-2180
CVI-2	205-248	7129-5756	7130-5760
CVI-1	248-300	15,489-7129	15,490-7130



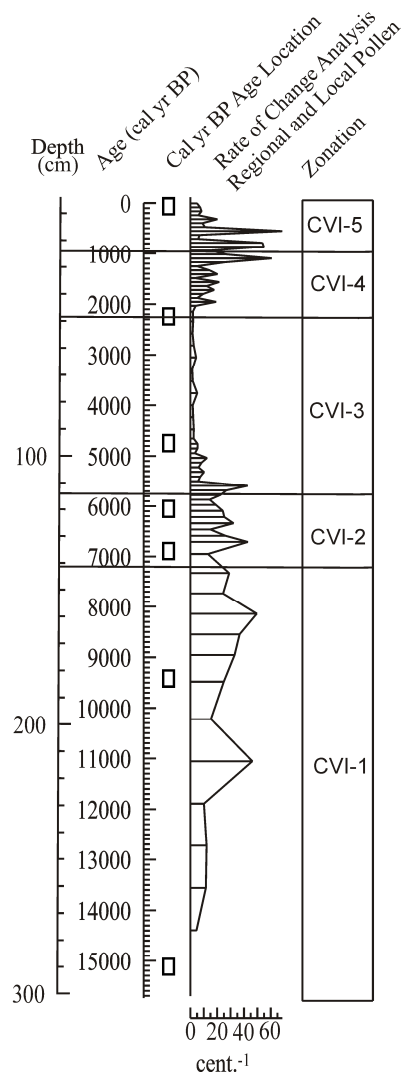
**Figure 6.9: CONISS and zonation of regional pollen data**



Two statistical analyses, viz. palynological richness and rate of change analysis, integrated into Psimpoll were conducted on the regional pollen datasets with both statistical analyses being applied to the 248 cm sequence (Figure 6.10) while the rate of change analysis was applied only to the 300 cm sequence (Figure 6.11).



**Figure 6.10: 248 cm palynological richness and rate of change analysis on regional pollen diagram**



**Figure 6.11: 300 cm rate of change analysis on regional pollen diagram**

A Principle Component Analysis (PCA) was applied to ecologically sensitive pollen to discern temporal trends derived from pollen concentrations (Figure 6.12). The PCA was applied on the following taxa; *Amaranthaceae*, *Cyathea*, *Ericaceae*, fern spores (combined values of monolet and trilete spores), *Gunnera*, *Heliophila*, *Justicia*, *Leucosidea*, *Mutisiae*, *Podocarpus* and *Tubuliflorae*, specifying the following parameters; inter-species correlation, division of standard deviation, square-root transformation and centred by species (Table 6.4).

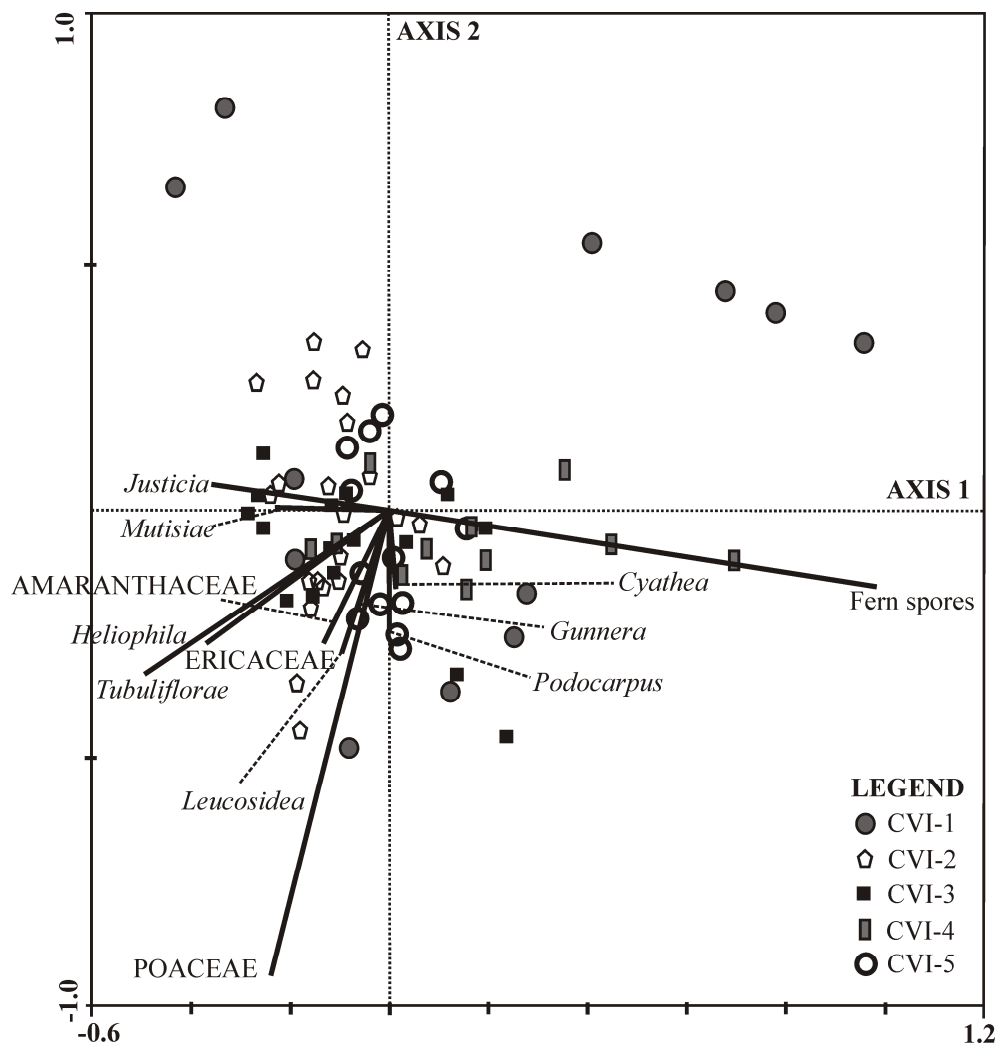


Figure 6.12: PCA of pollen samples

Table 6.4: Pollen PCA results

Axes	1	2	3	4	Total variance
Eigenvalues	0.504	0.21	0.097	0.056	1
Cumulative percentage variance of species data	50.4	71.4	81.1	86.6	
Total sum of squares in species data	5.18634				
Total standard deviation in species data TAU	7.59E-02				

## 6.5. Description of Pollen Results

The pollen results and statistics performed on the pollen data will be described within the five zones delineated from the CONISS application, except for the PCA results, which will be described as a complete entity. The results described hereafter are taken from the 248 cm and 300 cm regional and local pollen diagrams with dates derived from the interpolated calibrated ages.

The results from the PCA indicate that Axis 1 and 2 accounts for *ca.* 50% and *ca.* 20% of the total variability of the dataset and a combined variability of *ca.* 70%. Poaceae, fern spores and *Tubuliflorae* taxa reflect the highest variability compared to the remainder of the taxa. The majority of the taxa are tightly clustered together, which indicates minimal variability exists between these taxa. The lack of variability between the majority of taxa represents a difficulty in the interpretation of the PCA results as the taxa used in the PCA dataset are representative of different habitats and favour different climatic conditions; therefore, reducing the ‘indicative’ ability of these taxa to represent various ecological habitats.

#### **6.5.1. Zone CVI-1: 300-248 cm; 15,490-7130 cal yr BP<sup>34</sup>**

This pollen sequence from 15,490-10,420 cal yr BP commences with a dominance of Cyperaceae, Poaceae, Monolete and Trilete spores and *Tubuliflorae* taxa. Low concentrations of *Ascolepis*, Rosaceae, Ericaceae, Brassicaceae and Amaranthaceae occur during this period. From 10,420-7130 cal yr BP, a sharp increase in Trilete spores occurs with a corresponding decline in Cyperaceae. Cyperaceae continues to decline towards the end of this zone. Monolete spores and Poaceae occur in low concentrations during this period with the exclusion of all other taxa that were previously present during the early stages of this zone. All taxa within this zone are over-represented due to the poor pollen preservation and resultant low pollen counts.

#### **6.5.2. Zone CVI-2: 248-205 cm; 7130-5760 cal yr BP**

The dominant regional taxa within this zone are Rosaceae (10%) and *Tubuliflorae* (5%). Other regional taxa that occur in low concentrations in different periods within this zone include; *Acalypha*, *Hymenocardia* and *Podocarpus* while Amaranthaceae, *Artemisia*, *Euclea*, Ericaceae and *Myrica* all occur as single peaks. The local pollen record reflects that Trilete spores (60%) dominate the early stages of CVI-2 and decline rapidly below 5% *ca.* 6120 cal yr BP. Thereafter Trilete spores increase slightly and concentrations stabilise between 10-20% for the remainder of this zone. Cyperaceae commenced with the lowest concentrations (>10%) recorded throughout all zones; however, this was short-lived with a rapid increase for a short duration occurring reaching a peak by (75%) 5760 cal yr BP. Poaceae concentrations remained consistent throughout this zone with values ranging from 5-15%. Monolete spores were relatively abundant throughout CVI-2. Liliaceae, *Ascolepis* and *Gunnera* were recorded during the first *ca.* 700 cal yr of CVI-2 with *Gunnera* re-appearing during the latter stages of CVI-2.

---

<sup>34</sup> These ages are derived from the interpolated ages attached as Appendix F.

### **6.5.3. Zone CVI-3: 205-117 cm; 5760-2190 cal yr BP**

A number of taxa, viz. *Justicia*, *Monochema*, *Rhus*, *Mutisiae*, *Vernonia*, *Capparaceae*, *Celestraceae*, *Cyathea*, *Leucosidea*, *Urginea*, *Lamiaceae*, *Myrtaceae* and *Clausena* appear for the first time albeit in low concentrations in CVI-3. *Tubuliflorae* dominate the regional pollen record, an abrupt peak of 20% occurred at 5320 cal yr BP. *Podocarpus*, *Brassicaceae* and *Ericaceae* occur with consistent concentrations throughout CVI-3. The local pollen sequence sees the emergence of a single occurrence of *Polygonum ca.* 5320 cal yr BP. *Cyperaceae* remains the dominant local pollen throughout CVI-3 and reaches a maximum peak of 80% by 4930 cal yr BP. *Poaceae* declines steadily from the start of this zone towards the middle period of the zone with the lowest values by 4930 cal yr BP when *Cyperaceae* records its highest values. After an abrupt peak, *Poaceae* increases to a maximum of 25% prior to 2190 cal yr BP. *Asclepis* mirrors the trends of *Poaceae* during this period with low concentrations at the start of the zone with the highest concentrations occurring during the middle of CVI-3. Trilete and Monolete spores remain relatively low throughout this zone.

### **6.5.4. Zone CVI-4: 117-53 cm; 2190-890 cal yr BP**

Zone CVI-4 sees the emergence of *Achyranthes*, *Phoenix*, *Cordia*, *Euphorbiaceae*, *Fabaceae*, *Ficus*, *Protea*, *Cliffortia*, *Calodendrum* and *Gnidia* in the pollen sequence. All these taxa occur in low concentrations. *Leucosidea* spores reach their highest peak by 1820 cal yr BP (4%) and declines with a consistent presence throughout the zone. *Acalypha* and *Euphorbiaceae* both peak at the same time as *Leucosidea* peaks and decline in concentration to >1% and 1% respectively. *Tubuliflorae* and *Brassicaceae* occur throughout CVI-4. *Podocarpus* occurs in low concentrations with a peak of 3% by 890 cal yr BP and *Cyathea* peaks (2%) at the same time. *Ericaceae* occurs in low concentrations from 21890-1640 cal yr BP and does not occur again in this zone. *Justicia* occurs in low concentrations of >1% up to 1800 cal yr BP and thereafter does not occur in this zone. The local pollen record indicates high concentrations of *Cyperaceae* at the start of the zone and then decreases to 25% for a short period. Thereafter, *Cyperaceae* gradually increases to 70% by 1720 cal yr BP whereby concentrations remain high until it decreases to 20% by 1030 cal yr BP. This decrease in *Cyperaceae* is abrupt and is followed by a sharp increase to 50% by 890 cal yr BP. Monolete spores reach its highest peak of 25% by 1920 cal yr BP. Thereafter, monolete spores decline in concentration to >1%. Low concentrations of Trilete spores occur at the start of the zone gradually increase from 1400 cal yr BP to a maximum peak in this zone of 20% prior to the 890 cal yr BP. A single peak of *Liliaceae* occurs by 890 cal yr BP. *Asclepis* is consistently represented from 2190 cal yr BP to 1120 cal yr BP. *Gunnera* also peaks at this time. Thereafter, both *Gunnera* and *Asclepis* does not occur again within CVI-4.

#### **6.5.5. Zone CVI-5: 53-0 cm; 890-present cal yr BP**

There is little change that occurs in the pollen record in CVI-5 with all regional pollen taxa occurring in concentrations of >5%. *Tubuliflorae*, Brassicaceae, *Cyathea*, *Podocarpus* and *Leucosidea* all occur throughout the zone, with Brassicaceae increasing slightly after 390 cal yr BP. *Cliffortia* occurs as a single peak at the start of the zone. A number of pollen taxa occur only after 390 cal yr BP, namely; *Draceana*, *Stoebe*, Capparaceae, Ericaceae, *Macaranga*, Fabaceae, *Greyia*, Lamiaceae and Moraceae. *Justicia* occurs predominately after 390 cal yr BP but a single peak occurs at the start of the zone. *Pinus* is first observed during the latter stages of the zone at ca. 110 cal yr BP. *Pinus* concentrations reach a maximum peak of 2% at the top of the zone. The local pollen record indicates Cyperaceae remain consistently high with concentrations varying between 50-60% throughout this zone. *Ascolepis* commences the zone with low concentrations but gradually increases to a peak at 10% ca. 150 cal yr BP. Thereafter a steady decline to present conditions occurs. *Gunnera* occurs throughout the zone with a peak during present conditions. Liliaceae maintains higher concentrations than the rest of the zone between 790-550 cal yr BP, thereafter it declines but a single peak occurs at ca. 20 cal yr BP. Poaceae follows a similar trend as Liliaceae but is represented continuously throughout the zone. Poaceae >40  $\mu$ m appears for the first time in the pollen record from 790 cal yr BP in low concentrations until 230 cal yr BP. *Polygonum* and *Phygelius* occurs as single and double peaks respectively during this zone. Monolet spores occur throughout this zone in varying concentrations with two main peaks around 390 and 20 cal yr BP. Trilete spores occur throughout this zone in consistent concentrations with little variation.

#### **6.6. Charcoal and Geochemical Diagrams**

The microscopic and digestion-combustion technique results were standardised by the highest value recorded in each dataset and a paired T-test statistical analysis (Appendix I) was applied to the five zones for the microscopic and digestion-combustion charcoal datasets to determine whether the two datasets indicated similar trends.

The geochemical data were analysed using a PCA (Figure 6.13) and the  $\delta^{13}\text{C}$  and C/N values were plotted to identify any trends in the geochemical sequence relating to C<sub>3</sub> / C<sub>4</sub> and wetter / drier conditions (Figure 6.14).

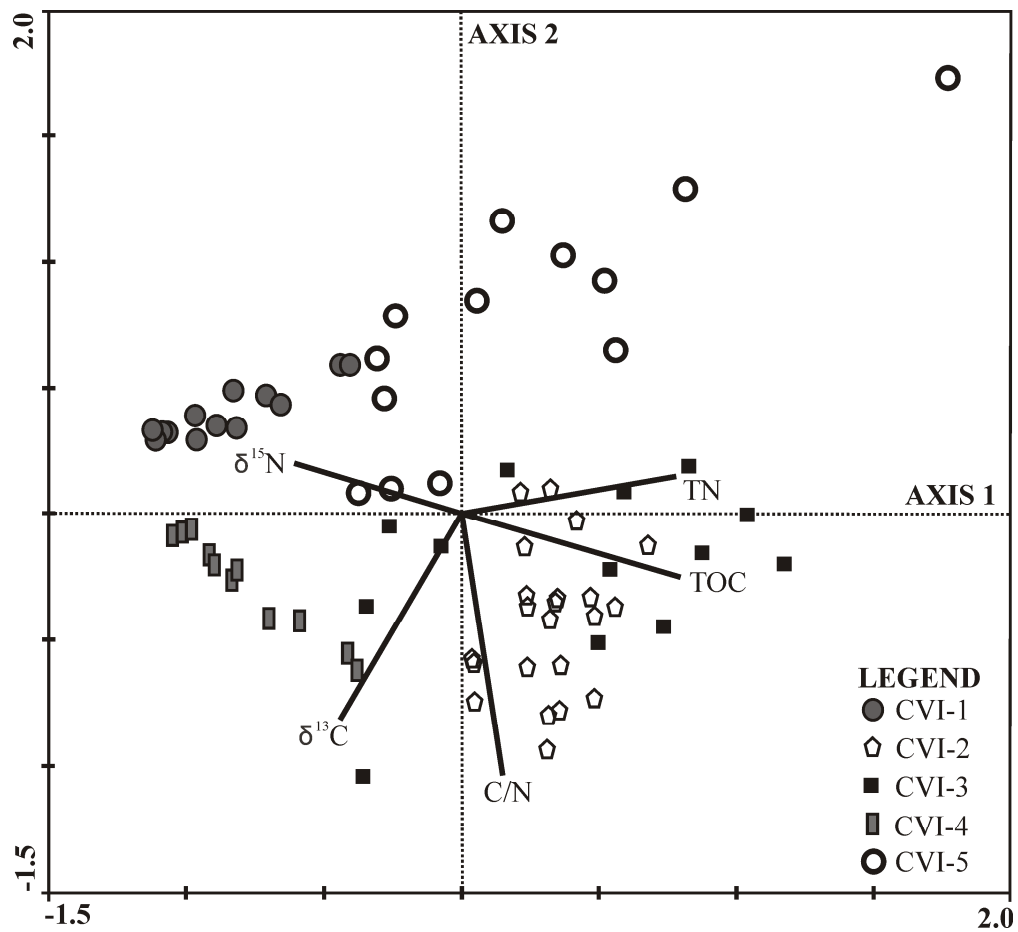
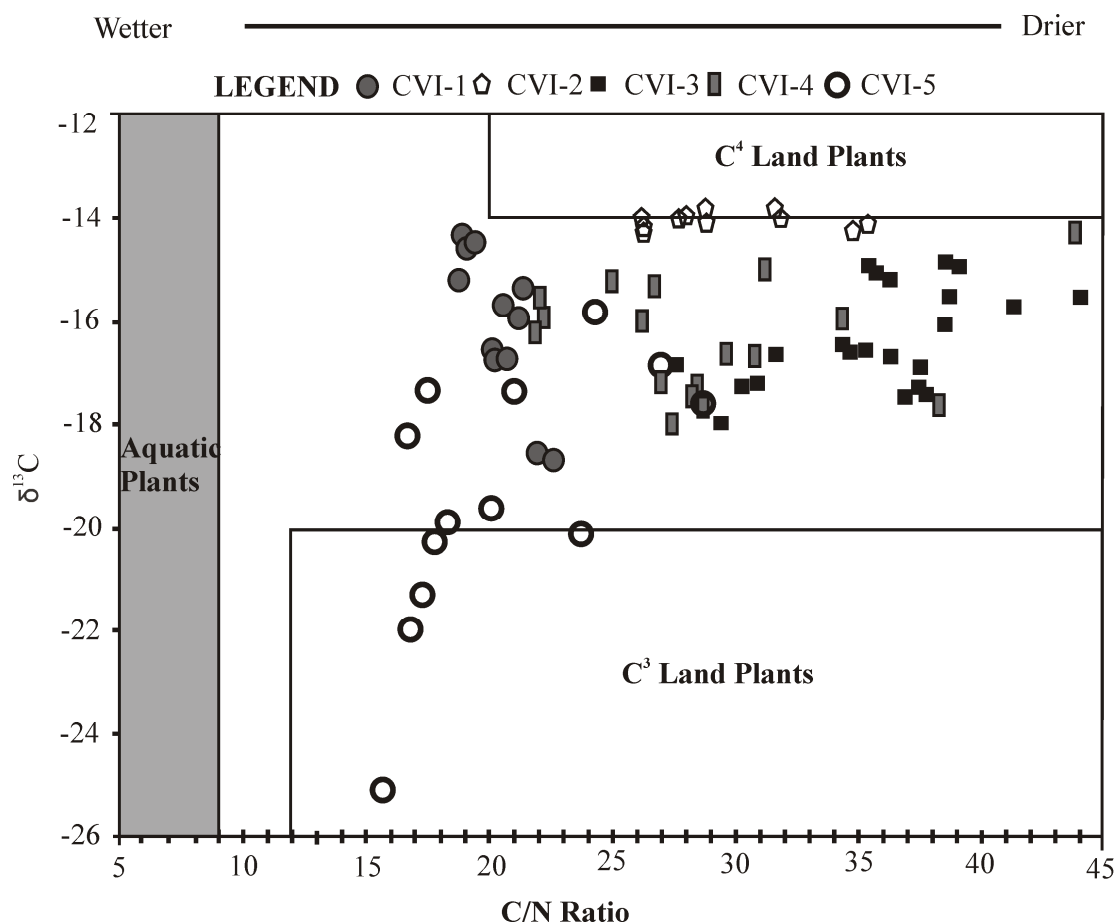


Figure 6.13: PCA of geochemical data

Table 6.5: Geochemical PCA results

Axes	1	2	3	4	Total variance
Eigenvalues:	0.504	0.283	0.122	0.087	1
Cumulative percentage variance of species data:	50.4	78.7	90.9	99.6	
Sum of all eigenvalues					1



The results from the Digestion-Combustion charcoal technique (Appendix J), microscopic charcoal technique (Appendix K) and the geochemical data (Appendix L) were plotted using Psimpoll for the 300 cm sequence dataset (Figure 6.15) and zoned using the same zonation contained in the pollen datasets to assist in the interpretation of results in conjunction with the pollen datasets.

### 6.7. Description of Charcoal and Geochemical Results

The charcoal and geochemical results and statistics, except for the PCA analysis results, will be discussed within the five zones delineated from the CONISS application. The results described hereafter are taken primarily from the 300 cm Geochemical and Charcoal diagram and the dates have been derived from the interpolated calibrated ages.

The PCA results indicate that Axis 1 and 2 account for *ca.* 78% of variability of the data with Axis 1 and Axis 2 contributing *ca.* 50% and 28% variability respectively. Axis 1 may represent a moisture index from wetter to drier conditions (negative to positive values respectively) and Axis 2 may represent a temperature index cooler to warmer conditions (negative to positive



values respectively). These trends are reflected in Figure 6.14 indicating the variation in geochemical data between C<sub>3</sub>- and C<sub>4</sub>-type vegetation.

#### **6.7.1. Zone CVI-1: 300-248 cm; 15,490-7130 cal yr BP**

The Total Organic Carbon (TOC) and Total Nitrogen (TN) content were very low throughout CVI-1. The  $\delta^{13}\text{C}$  content commenced this zone *ca.* -18‰ until 11,430 cal yr BP when it increased to -16‰ and remained for the rest of the zone. The  $\delta^{15}\text{N}$  values decreased initially at the start of the zone and then increased gradually to *ca.* 5‰. C/N remained consistent throughout this zone between 20 and 23. The C/N and  $\delta^{13}\text{C}$  values indicate that the vegetation during this zone reflected a tendency towards both C<sub>3</sub> and C<sub>4</sub>-type vegetation under generally wetter conditions. The results from the charcoal analysis indicate relatively high charcoal percentage from both the techniques at the start of the zone. These values decrease near the zone boundary. The microscopic charcoal indicates three peaks occurring up to 10,420 cal yr BP. The organic and inorganic matter derived from the Digestion-Combustion technique indicate low and high values respectively, correlating with the stratigraphy, TN and TOC values during this zone.

#### **6.7.2. Zone CVI-2: 248-205 cm; 7130-560 cal yr BP**

Similar results occur in this zone as in the previous zone with low TN, TOC values;  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values continue to increase. Organic matter increases gradually with a gradual decrease in inorganic matter and moisture content. The C/N and  $\delta^{13}\text{C}$  values during this zone reflect a dominant presence of C<sub>4</sub>-type vegetation under ameliorated climatic conditions that reflect ambient conditions, neither wet nor dry. Microscopic charcoal show two major peaks at 6410 and 6120 cal yr BP, which are also the highest peaks in charcoal throughout the profile with values of 30% and 45% respectively. Two periods of showing charcoal particles over 100  $\mu\text{m}$  occur at the beginning and end of the zone.

#### **6.7.3. Zone CVI-3: 205-117 cm; 5760-2190 cal yr BP**

The geochemical data from CVI-3 continues along the same trends as in previous zones. The  $\delta^{13}\text{C}$  values reach a peak of *ca.* -12‰ at the zone boundary. The  $\delta^{15}\text{N}$  value peaks a little earlier 2890 cal yr BP before declining. At the same time, TOC and TN start to increase slightly. C/N values, which have been relatively static throughout this zone, start to increase after 3880 cal yr BP and reach a peak of 30 prior to the zone boundary. The C/N and  $\delta^{13}\text{C}$  values reflect increased variability in C<sub>3</sub>- and C<sub>4</sub>-type vegetation and increasingly drier trends during this zone.

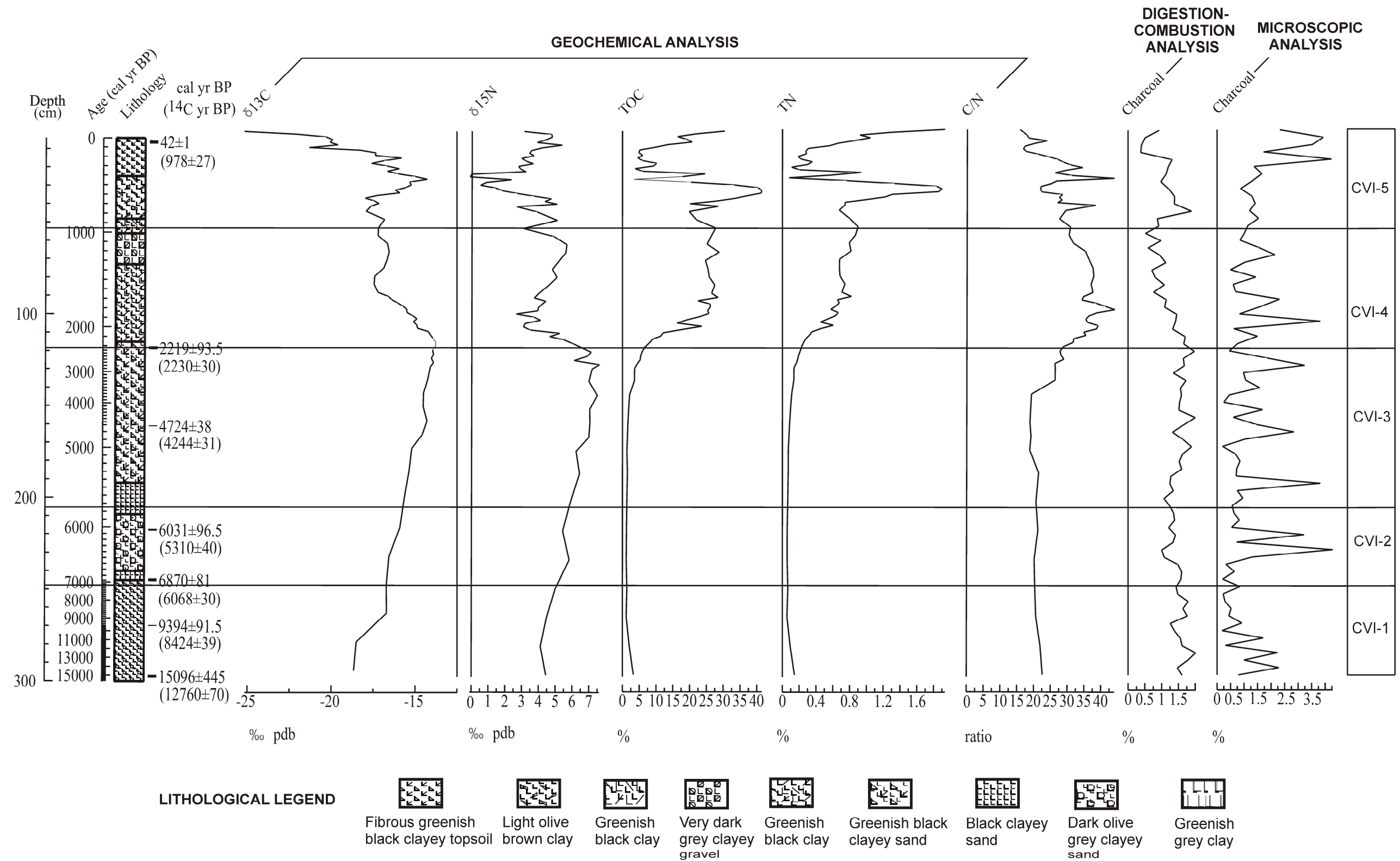


Figure 6.15: 300 cm geochemical and charcoal (1 of 2)

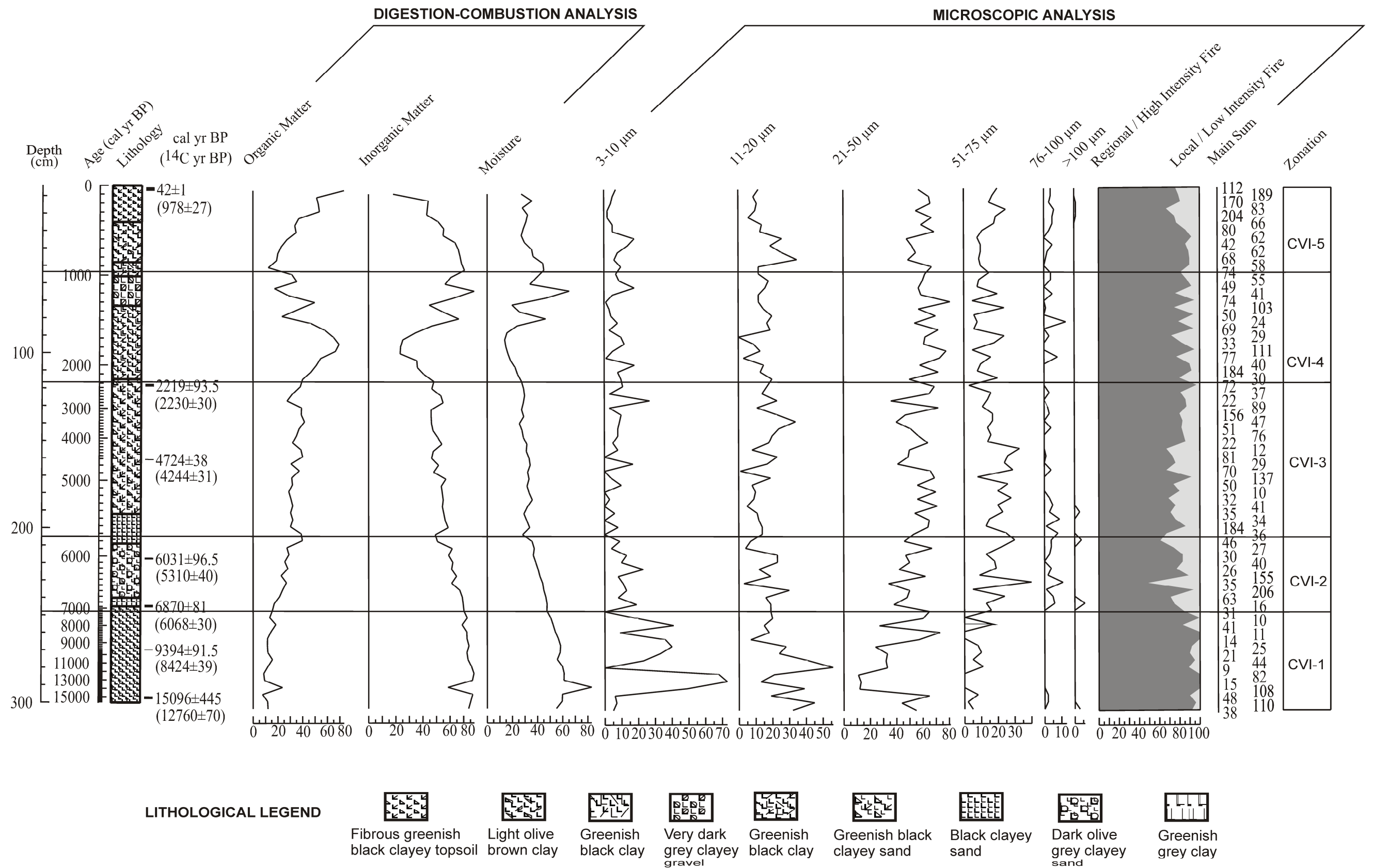


Figure 6.15: 300 cm geochemical and charcoal (2 of 2)

Charcoal concentrations from the Digestion-Combustion technique remain relatively static throughout this zone. The microscopic charcoal has three main peaks, at the start, middle and end of the zone. Organic matter, inorganic matter and moisture from the Digestion-Combustion technique remain relatively consistent throughout the zone. A single event around 5410 cal yr BP reflects charcoal fragments greater than 100  $\mu\text{m}$  from the microscopic charcoal analysis.

#### **6.7.4. Zone CVI-4: 117-53 cm; 2190-890 cal yr BP**

Zone CVI-4 shows increased TOC, TN and C/N values. C/N values peak at 45 and start to decline after 1760 cal yr BP. Both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values decrease initially at the start of the zone and then gradually increase thereafter. Greater variability in the C/N and  $\delta^{13}\text{C}$  values continues from the previous zone; however, climatic conditions appear to become wetter than the trend reflected in CVI-3. Digestion-Combustion charcoal decreases gradually in this zone while microscopic charcoal fluctuate with one main peak occurring *ca.* 1760 cal yr BP. The increase in organic matter is mirrored by the decrease in inorganic matter and moisture content.

#### **6.7.5. Zone CVI-5: 53-0 cm; 890-present cal yr BP**

CVI-5 indicates variable trends throughout the geochemical and charcoal results. Initially,  $\delta^{13}\text{C}$  decreases for a short period and then increases to the second highest peak in the profile to a value of -14.5‰ before declining to its minimum value at the end of the zone. C/N values follow the same trend as the  $\delta^{13}\text{C}$  values during this period. The  $\delta^{15}\text{N}$ , TOC and TN values mirror the  $\delta^{13}\text{C}$  and C/N values with an initial increase, then a decrease and a return to increased values near the end of the zone. The stable carbon isotope results reflect a general trend towards aquatic and  $\text{C}_3$ -type vegetation; however, variability exists as indicated by the values near the  $\text{C}_4$ -type vegetation group. Furthermore, climatic conditions during this zone are variable with wetter conditions being dominant with lesser values near the drier conditions. Charcoal values mirror each other with the Digestion-Combustion charcoal initially increasing and then decreasing for the remainder of the zone, while the microscopic charcoal increased after 430 cal yr BP to reach a peak of 4.5%.

### **6.8. Conclusion**

This chapter presents the results from the multi-proxy analysis, *viz.* pollen, charcoal, geochemical and radiocarbon dating and provides a stratigraphic description of the sediment from which the multi-proxy data have been extracted. These data have been described in terms of fluctuations and trends within the five zones (CVI-1 to CVI-5) as delineated from CONISS.

## CHAPTER SEVEN

### 7. DISCUSSION

#### 7.1. Introduction

A palaeoenvironmental synthesis of the Cathedral Peak region forms the basis of this chapter. The synthesis will be discussed within the five zones (CVI-1 to CVI-5) and will incorporate the findings of all multi-proxy data. To aid in the palaeoenvironmental interpretation, a datasheet of main pollen taxa was compiled providing morphological, ecological and distribution information. Where possible, the palaeoenvironments will be discussed in relation to previous palaeoenvironmental work conducted in southern and eastern Africa to enable the current research to provide additional information for southern and east African palaeoenvironments.

#### 7.2. Palaeoenvironments of the Cathedral Peak Region

Palaeoenvironmental interpretation for the Drakensberg is difficult due to the lack of contemporary climatic data for the region and the lack of palaeoenvironmental research (Mills *et al.* 2009) and these difficulties are evident in the palaeoenvironmental record from Cathedral Peak, which extends back to the last glacial / interglacial transition period. A major influence in the climate of South Africa and the Drakensberg region during the LGM is hypothesized to be the Southern Oscillation pattern, which pushes the southern Indian high-pressure cell northwards (Mills *et al.* 2009). This results in greater seasonal variation with drier summers and wetter winters. Results from previous studies from the Drakensberg suggest conflicting environmental conditions from the LGM; nonetheless, the LGM is characterised as a period of reduced precipitation and temperatures of 30% and 5-7°C, respectively (Mills and Grab 2005). The reduction in precipitation during the LGM is in conflict with the results from the Leqooa glacier in Lesotho, which indicates that precipitation increased to allow for snow accumulation (Mills *et al.* 2009). The effect of the southern Indian high-pressure cell displacement resulted in winter rainfall extending to 30°S in eastern South Africa, which resulted in more frequent cold fronts over the Drakensberg that resulted in increased rainfall (Mills *et al.* 2009). The temperature variation during the LGM over the Drakensberg is challenged with research from Mount Enterprise in the Eastern Cape Drakensberg suggestive of temperatures as low as 17°C cooler with a conservative estimate of 10°C cooler, which is still significantly lower than previously suggested (Lewis and Illgner 2001).

Moisture availability and temperature variations during the LGM prompted previous research throughout the Afromontane region to hypothesize that Afromontane forests expanded and

contracted throughout the late Quaternary (White 1983, 1978). The process of expansion and contraction of these forests were thought to be responsible for the high endemism found in the Afromontane regions and that current forest distribution patterns reflected forest refuge (van Zinderen Bakker 1973). The current research has the ability to provide further insight to the debates regarding temperature and forest expansion / contraction within Afromontane region of South Africa.

#### **7.2.1. Zone CVI-1: 300-248 cm; 15,490-7130 cal yr BP**

The earliest part of the Cathedral Peak pollen record is characterized by poor pollen preservation indicated by the extremely low pollen counts, which results in over-representation of all pollen taxa. Poor pollen preservation could be as the result of the lowering wetlands water table exposing the sediment to air and thus oxidation occurred; however, this is very difficult to discern from this pollen record. The poor pollen preservation results in inconclusive inferences of palaeoenvironmental conditions for this period. The lack of a high-resolution chronology further contributes to the difficulties in palaeoenvironmental interpretation for this period.

The factors that contributed to the poor pollen preservation are likely to have affected the sediment and thus all multi-proxy data from this section indicates a bias towards local vegetation. The geochemical and digestion-combustion results reflect low organic matter concentration during this period and a corresponding high concentration of inorganic matter. The low pollen preservation could be related to the age reversal located at 361 cm of the sediment core, possibly because of weathering, a flood event or similar disturbance mechanism causing sediment to mix and / or the removal of polliniferous sediment. Due to poor pollen preservation and low chronological resolution prior to 7130 cal yr BP, important climatic events such as the Younger Dryas, Pleistocene-Holocene transitional boundary and the 8200 cal yr BP periods cannot be clearly distinguished from the pollen record; therefore, these period are not discussed hereafter.

With all of the above in mind, the pollen record from between 15,490-11,000 cal yr BP indicates regional cool, dry conditions occurred with the presence of *Amaranthaceae*, *Ericaceae* and *Tubuliflorae*. The local pollen taxa dominate the pollen record, suggesting that conditions supported wetland vegetation. An increase in *Cyperaceae* and Trilete spores after *ca.* 11,000 cal yr BP suggests conditions became drier, exposing greater areas of the wetland to be colonised by *Cyperaceae* and ferns. These conditions continued into the early to mid Holocene.

The cool, dry conditions experienced at Cathedral Peak are supported by conditions from East Africa, in the Bale Mountains, Ethiopia where drier conditions occurred after the LGM with

increased Amaranthaceae / Chenopodiaceae, *Artemisia* and Cyperaceae taxa and reduced lake levels from the Ziway-Shella Basin (Mohammed and Bonnefille 1998). Southern African records provide both support (Meadows and Sugden 1991) and contrast to the palaeoenvironmental conditions experienced from Cathedral Peak region during this period (Scott 1982b). After 11,000 cal yr BP, cool, moist and sub-humid conditions prevailed in southern Africa (Scott and Vogel 1983; Meadows and Sugden 1991). Similar conditions were experienced throughout eastern Africa during this period with an increase in moisture recorded from Lake Kimili, Sacred Lake and Lake Rutundu (Umer *et al.* 2007); Lake Albert (Beuning *et al.* 1997); and Mubwindi Swamp (Marchant and Taylor 1997).

The drier conditions suggested by the Cathedral Peak record are in contrast to a number of previous records obtained from East Africa, which suggested an increase in humidity (Garcin *et al.* 2007; Ryner *et al.* 2006) and moisture (Garcin *et al.* 2007; Ryner *et al.* 2006; Beuning *et al.* 1997; Wooller *et al.* 2003) enabling forest expansion to occur (Finch *et al.* 2009; Vincens *et al.* 2007; Wooller *et al.* 2003; Livingstone 1967). Conditions in southern Africa after 11,000 cal yrs BP indicated a change towards drier conditions, supporting the record from Cathedral peak region (Scott 1982b; Scott *et al.* 1995; Meadows and Meadows 1988). Drier conditions were further experienced in some parts of eastern Africa, particularly Rusaka Swamp (Bonnefille *et al.* 1995); Lake Masako (Garcin *et al.* 2007); and the Udzungwa Mountains (Mumbi *et al.* 2008).

### **7.2.2. Zone CVI-2: 248-205 cm; 7130-5760 cal yr BP**

Trilete spores are a disturbance indicator and the high concentration of trilete spores (80%) *ca.* 7100 cal yr BP may suggest a period of local disturbance. The peak in trilete spores was short-lived with a gradual decrease to a minimum of 5% by *ca.* 6200 cal yr BP. During the period 7100-6200 cal yr BP, Cyperaceae increases to its maximum when trilete spores were at their minimum indicating an increase in moisture and a stabilisation of the wetland. *Ascolepis* initially occurred during the development of the wetland and once trilete spores and Cyperaceae reached their minimum and maximum values respectively, *Ascolepis* disappeared from the pollen record for the remainder of CVI-2. This may indicate that conditions during the early development of the wetland were suited to *Ascolepis*; yet, the increased moisture prevented its continual occurrence. *Gunnera* and Liliaceae occurred briefly during this same period of initial wetland development suggesting increased moisture availability during this period (Scott 1999; Scott and Nyakale 2002). A further indication of increased moisture is derived from the *Podocarpus* and Rosaceae signal where Rosaceae occurred in high concentrations (60-90%) between *ca.* 6500-6300 cal yr BP. However, *ca.* 6200 cal yr BP, when Cyperaceae concentrations were at their maximum, *Podocarpus* and later Rosaceae were absent from the pollen record, which is contrary to expectations when increased moisture are generally suitable

for montane forest expansion. During this same period, palaeoenvironmental records from Groenvlei, Cederberg and Wonderkrater all show a decline in arboreal taxa. Conditions from these sites indicate warmer, more humid conditions with greater moisture availability (Martin 1968; Scott and Vogel 1983; Scott 1982b; Meadows and Sugden 1991). Drier conditions experienced in eastern Africa are supported by the record obtained from Rumuiku swamp (Rucina *et al.* 2009).

Palaeoenvironmental records from eastern Africa suggest similar conditions to those recorded in the Cathedral peak region record with increased moisture resulting in forest expansion and decreased fynbos taxa from the Uluguru Mountains (Finch 2009); Sacred lake (Street-Perrott *et al.* 1997; Coetzee 1964).

A different hypothesis for this period could indicate that there was more pronounced summer rainfall season as suggested by the slight increase in Poaceae (Scott *et al.* 2005; Scott and Nyakale 2002). *Artemisia* occurs, as a single peak 6870 cal yr BP suggesting conditions were somewhat drier. The lack of further occurrences in *Artemisia* may be a consequence of this pollen being considered rare in pollen records even though it moderately well dispersed and inhabits a wide range of environments in South Africa (Scott 1982a; Hamilton 1972). However, the occurrence of this taxa does support conditions that were relatively humid with even moisture availability (Scott *et al.* 2005; Scott and Nyakale 2002). The total nitrogen during this period corroborates the increased moisture availability on a local scale with a slight decrease to 4‰ and the  $\delta^{13}\text{C}$  values, which became ‘lighter’<sup>35</sup> from 18.5-17 ‰, which suggests a slight shift towards  $\text{C}_4$  vegetation. The increased moisture and presumably increased biomass could be substantiated with the charcoal records from both the microscopic and digestion-combustion results. Both datasets indicate high concentration of charcoal, relative to CVI-2. The increase in biomass may have lead to increased availability of fuel for fires as recorded in the three distinctive peaks from the microscopic charcoal record. The main component of this charcoal is derived from the size class between 3-20  $\mu\text{m}$ , indicating regional predominance of fires.

The remainder of the CVI-2, between *ca.* 6200-57560 cal yr BP, is static with little pollen to aid in interpretation of prevailing conditions. The most significant aspect of this period is the relatively high concentration of *Tubuliflorae* taxa (80%) and the re-emergence of *Gunnera*, which becomes more prominent in the pollen record *ca.* 5900 cal yr BP. The *Tubuliflorae* signal at the end of CVI-2 suggests greater evaporation and seasonal precipitation as *Tubuliflorae* is a

---

<sup>35</sup> Isotope values are classified as heavier or lighter when the values become less or more negative, respectively.



characteristic component of grasslands, which is further supported by the minor increase in Poaceae. The total nitrogen concentrations increased slightly to a maximum of 5 ‰ from 4 ‰ suggesting reduced moisture availability. As such, conditions between *ca.* 6200-5760 cal yr BP suggest rainfall was slightly reduced, becoming slightly drier.

A number of considerations need to be made in the interpretation of CVI-2. Whilst, this zone represents increased pollen concentration compared to CVI-1, the concentrations are still considerably low. This is reflected in the palynological richness of this zone where a single sub-sample recorded counts over 150, which was used as the minimum number of counts needed for inclusion in the palynological richness analysis. Furthermore, the dominant taxa from this zone are mostly characterised as widely dispersed and / or generally over-represented in pollen records, such as *Artemisia*, *Gunnera*, *Podocarpus* and *Tubuliflorae*; therefore, caution must be taken in inferring palaeoenvironmental conditions between 7130-5760 cal yr BP.

### **7.2.3. Zone CVI-3: 205-117 cm; 5760-2190 cal yr BP**

Pollen diversity increased during CVI-3 with the appearance of non-arboreal and arboreal taxa for the first time; however, the geochemical data does not suggest there was any definite movement between wetter and drier conditions. The  $\delta^{13}\text{C}$  and C/N values indicate a movement towards  $\text{C}_3$ -type vegetation and TN values becoming lighter compared to CVI-2, which support reduced moisture availability. Arboreal taxa of Capparaceae, Celastraceae and *Euclea* indicate conditions that were drier as these taxa are adapted to a range of semi-arid to arid conditions although these taxa are found in a wide variety of habitats (Gil-Romera *et al.* 2007; Finch *et al.* 2009; Dupont *et al.* 2008; Sangu and Bracebridge 2005; Scott 1982a). *Heliophila* appeared for the first time in the pollen sequence. Interpretation of *Heliophila* is inconsistent with suggestions that the presence of these taxa indicates drier condition but it is also commonly found on damp, grassy slopes in the alpine belt. This probably suggests that *Heliophila* is adapted to cooler climates that experiences less precipitation than what is expected from lowland areas (Linder 2003; Court-Picon *et al.* 2005). Furthermore, the presence of *Heliophila* could suggest moister conditions as it is commonly found along lake edges (Darbyshire *et al.* 2003). Moist conditions are reflected in the *Podocarpus* concentrations, which remained below 10% for the entire period, except for a single peak to 20% *ca.* 3960 cal yr BP. The highest concentrations of Ericaceae(>5%) occurred during this zone indicating cooler temperatures with moisture availability remaining relatively constant further suggests that the Ericaceous belt had decreased in altitude by 1000 m (Scott 1982a). The climatic movement towards more xeric conditions as indicated by the relatively high percentages of Ericaceae are supported by similar conditions over a similar temporal scale at the Groenvlei and Cederberg sites (Meadows and Sugden 1991; Martin 1968).

The East African record during this period suggests conditions were favourable to forest expansion (Beuning et al. 1997; Livingstone 1967) and swamp reduction (Mumbi *et al.* 2008). This period is further suggestive of increased disturbance, attributed to human occupation and expansion, with an increase in monolete spores (Meadows 1984).

The local pollen record indicates that Cyperaceae was dominant with Poaceae declining further compared with CVI-2, which could be attributed to the cooler but continued moist conditions prevalent during this period with relatively even seasonal moisture (Scott 1999). The low concentrations of fern spores indicate stable conditions in the wetland. The presence of *Monechma*-type pollen indicates conditions supporting open veld with a reduction in swamp; however this pollen-type is widely dispersed yet poorly deposited and represents a wide range of herbaceous plants (Scott 1982a). This is further supported with the presence of Amaranthaceae which is typically found under drier conditions favouring summer rainfall (Scott *et al.* 2005; Scott 1982a). *Mutisae* and *Tubuliflorae* taxa occur throughout this zone further indicative of summer rainfall with relatively even moisture availability (Scott *et al.* 2005; Scott 1999). Fire regimes appeared to have become more prominent during this zone with the occurring of charcoal particles >100  $\mu\text{m}$  suggesting local fire occurrences. The microscopic charcoal indicate a dramatic increase in fire occurrences between *ca.* 6400-6000 cal yr BP with concentration between 2.5-4.5% which is the highest (4.5%) recorded charcoal concentration from the entire record. The increase in fire may be attributed to the increased biomass and therefore fuel availability resulting from the moister conditions favouring vegetation expansion. The continued drying conditions may have lead to biomass that was conducive to burning.

#### **7.2.4. Zone CVI-4: 117-53 cm; 2190-890 cal yr BP**

Cool, moist conditions persisted until 1680 cal yr BP as indicated by the presence of Ericaceae; thereafter concentrations declined below 5% suggesting that conditions becoming moister and warmer, which is further indicated with the disappearance of Ericaceae for the remainder of CV-4. *Podocarpus* continued throughout the zone with concentrations increasing after 1200 cal yr BP supporting conditions became warmer, more humid and with an increased moisture availability. Near the end of this zone, *Podocarpus* increased dramatically suggesting an expansion of montane forest. A corresponding peak in *Cyathea*, fern spores and Liliaceae may support increasing moisture during this period. Prior to the onset of moister conditions as reflected in the *Podocarpus* record, *Gunnera* peaked *ca.* 3%. The slightly drier conditions and possible wetland disturbance is further supported by the increase in fern spores during this period. The scattered presence of Amaranthaceae throughout CVI-4 may be attributed to the slight decrease in moisture towards drier conditions; however, this pollen is regarded as a

widely dispersed taxa occurring in a wide variety of habitats (Scott 1982a). The TN values at the start of CVI-4 declined rapidly suggesting increased availability of moisture and organic matter from the digestion-combustion reflect increased accumulation, indicative of increased moisture. All other geochemical results suggest increased moisture during the beginning of CVI-4. While this contrast to the Ericaceae record, this may indicate that while temperature became cooler, favouring Ericaceae expansion, moisture levels remained constant and less evaporation occurred; therefore, a greater amount of available moisture was present.

The indicators of drier conditions, Capparaceae and Celastraceae, are largely absent during this zone. *Tubuliflorae* pollen is often associated with open grasslands in karoo and macchia-type vegetation occurring under conditions of stable seasonal moisture, yet it is not normally present in high concentration in summer rainfall areas and is considered well dispersed (Scott 1982a; Scott *et al.* 2005). With this in mind, the Poaceae record shows relatively stable conditions indicating that whilst there may have been a reduced moisture stability, conditions still favoured the existence of open grasslands, which most likely surrounded the wetland (Scott 1982a; Scott *et al.* 2005; Hamilton 1972). From sites in South Africa, the period after *ca.* 2000 cal yr BP have been suggested to indicate the transition into summer-rainfall climatic conditions (Scott and Vogel 1983; Scott 1982b), with drier conditions occurring and these conditions are evident in the Cathedral Peak record. *Cordia* occurred briefly between 1880-1760 cal yr BP indicating forests occurred within the region of the wetland. These forests were probably surrounded by grasslands. *Leucosidea* increased in the first 300 cal yr BP to reach a maximum of 45% suggesting conditions favourable to forest growth in the subalpine region Cathedral Peak. Thereafter *Leucosidea* decreased for the remainder of the pollen zone. The geochemical data support the pollen data during this period as indicated by a transition from slightly drier to slightly wetter condition near the end of this zone.

The palaeoenvironmental record from East Africa is highly suggestive that the period after *ca.* 2000 cal yr BP is highly impacted by human activities with increased disturbance indicators, particularly a reduction in *Podocarpus* (Umer *et al.* 2007), increase in Cyperaceae (Meadows 1984) and monolete and fungal spores (Mumbi *et al.* 2008). Human disturbance indicators continued throughout this zone in East Africa and extended to present conditions where exotic species of *Eucalyptus* and *Pinus*, which are associated with plantations (Ssemmanda *et al.* 2005).

#### **7.2.5. Zone CVI-5: 53-0 cm; 890-present cal yr BP**

The most distinct change in CVI-5 compared with the rest of the profile is the movement towards drier C<sub>3</sub>-type vegetation as reflected by the geochemical results. Non-arboreal, local

pollen dominate the pollen record with Cyperaceae remaining in high concentrations. It is expected that the Poaceae record should reflect the movement towards drier, C<sub>3</sub>-type vegetation; however, this does not occur explicitly as Poaceae declines at the start of the zone. The Ericaceae and *Podocarpus* records do indicate the movement towards more C<sub>3</sub>-type vegetation from 570 cal yr BP. Ericaceae reappears after *ca.* 570 cal yr BP indicative of cooler conditions occurring near the research site. The reduced moisture and possible lowering of the wetland water table reflected with an increase in fern spores, Liliaceae and *Artemisia*. *Justicia* occurs predominantly during the latter stages of CVI-5 indicative of open veld vegetation (Scott 1982a). Amaranthaceae, absent at the start of the zone, occurs throughout the remainder of the zone, further supporting conditions becoming drier (Scott *et al.* 2005; Scott 1982a). Ericaceae and *Stoebe* occur only in the latter stages of CVI-5 suggesting that cooler temperatures occurred under generally drier conditions (Scott *et al.* 2005).

Another significant aspect of this zone is the appearance of *Pinus* and cereal-type Poaceae (>40  $\mu$ m), which are indicative of human occupation. The first cereal Poaceae signal occurs at the boundary between CVI-4 and CVI-5 and continues to the middle of the zone whereby it disappears from the pollen record, only to emerge once again at the end of CVI-5. This may be indicative of agricultural procedures occurring as early as *ca.* 1000 cal yr BP, which corresponds with the time-frame of the early agriculturalists in the area from *ca.* 1800 yr BP. Cathedral was used for *Pinus* plantations from the AD 1950s, which is reflected in the appearance of *Pinus* in the pollen record. *Pinus* appears *ca.* 105 cal yr BP, which may have pre-empted this cultivation practice. Catchment Two of Cathedral Peak was first planted with *Pinus* in 1950 (Lesch and Scott 1997) and by AD 1951, 74% of this catchment, which totalled 190 ha, was under *Pinus* plantations. By AD 1957, Catchment Three was 84% under *Pinus* plantations (Bosch and Hewlett 1982). The discrepancy between the pollen record and the historical data may be due to errors in the dating or due to incorrect identification of *Pinus*. *Stoebe* is also indicative of disturbance which could be attributed to natural events or anthropogenic-induced events (Scott 1982a; Hamilton 1972). The timing of the anthropogenic indicators of *Pinus* and *Stoebe* correspond to the Winterberg escarpment pollen record during the same period, which have an increase in both taxon and the appearance of these taxa are postulated as effects of anthropogenic influences (Meadows and Meadows 1988).

### 7.3. Conclusion

The arboreal pollen record is significantly lower than the non-arboreal record from Cathedral Peak possibly due to the over-representation of local pollen, primarily Cyperaceae, which hinders the interpretation of regional arboreal signals. The arboreal pollen record does not appear to support the prior hypothesis that forests were more widely distributed in the

Afromontane regions prior to human occupation; rather, grasslands appear to have dominated the Cathedral Peak record with an over-representation of local wetland taxa. *Podocarpus* appears to have expanded its range during the last *ca.* 2200 cal yr BP rather than being reduced as originally hypothesized.

The geochemical and pollen records suggest that the last *ca.* 7000 cal yr BP were characterised by fluctuations between wetter / drier and cooler / warmer periods. Gradual shifts between C<sub>3</sub>- and C<sub>4</sub>-type vegetation occurred; however, these results are complicated to interpret especially since grasses and sedges, can be classified as C<sub>3</sub> and C<sub>4</sub> vegetation. Furthermore, Poaceae and Cyperaceae pollen cannot be distinguished below family level and therefore, the distinction between C<sub>3</sub> and C<sub>4</sub>-type grasses and sedges cannot be made.

## CHAPTER EIGHT

### 8. CONCLUSION

#### 8.1. Introduction

With the use of multi-proxy data *viz.* pollen charcoal, geochemical (carbon and nitrogen isotopes) and  $^{14}\text{C}$  dating, this research has developed a palaeoenvironmental record for Cathedral Peak over the last *ca.* 15,490 cal yr BP. To conclude this research, the initial aim and objectives of the research will be critically reviewed to examine the limitations of this research and the future research directions will be explored.

#### 8.2. Review of the Aim and Objectives

**To conduct a wetland depth profile to identify a suitable coring location to extract a minimally disturbed semi-continuous sediment core**

A wetland depth profile was conducted by dividing the wetland into a series of 300 x 600 cm grids. At each point along the grid, flexible, fibreglass rods were pushed into the soil to determine the approximate depth of the wetland. Based on the findings of this profile, a suitable coring site was determined and a minimally disturbed, semi-continuous sediment core of 371 cm was extracted from the wetland for further analysis.

**To map the stratigraphy of the extracted core**

The stratigraphy of the core, conducted during the core extraction process, was purely descriptive. The stratigraphy was further mapped in the laboratory using the Munsell Colour description of soils and the Troels-Smith Sediment Classification system (Troels-Smith 1955). The Troels-Smith classification system was incorporated into the pollen diagrams and the stratigraphy was summarised in Chapter 6, which included the Munsell Colour codes, Munsell description of codes, Troels-Smith Classification codes and Troels-Smith Classification description.

**To create a suitable reference collection for the identification of fossil pollen within the extracted sediment**

Existing pollen reference material was used for this research which included the African Pollen Database (APD 2004), Pollen and Spores of Barro Colorado Island (Roubik and Moreno 1991), and the Neotropical Pollen Key (Bush and Weng 2007) and modern pollen collections from the Drakensberg (Hill 1992). Further sources used for pollen identification included modern

samples collected from the Karkloof Nature Reserve and Mfabeni Swamp (Finch 2005) and the use of pollen reference material (van Zinderen Bakker 1953, 1956; van Zinderen Bakker and Coetzee 1959; van Zinderen Bakker and Welman 1970). Additional reference collection from Cathedral Peak may have improved and assisted the identification process. No charcoal reference material was used and the acquisition a charcoal reference may further improve the charcoal identification process.

**To apply a multi-proxy analysis, which includes; pollen, charcoal, and geochemistry (stable carbon and nitrogen isotope) analyses through a suitable sub-sampling strategy**

Sub-sampling for fossil pollen and charcoal was conducted at a 4 cm resolution. Pollen and charcoal were counted along the same traverses from each depth. The results from the counting procedure indicate very low pollen concentration between 248 cm and 300 cm, while the majority of the 0 cm to 248 cm section contained sufficient pollen concentrations. There are a number of aspects regarding the pollen and charcoal preparation and counting procedure that could have been conducted, if more time was available, to improve the data quality from the counting / identification process. These aspects are detailed below:

- i. A higher resolution sub-sampling strategy could have been implemented between the depths 0 cm and 248 cm based on the poor pollen preservation and resulting low pollen counts found below 248 cm. By focusing on the sediment sections characterised by good pollen preservation results could have been improved, which would have enabled a better interpretation of pollen variations.
- ii. A minimum count of 250 pollen grains and spores should be achieved. Anything less than 250 counts is difficult to quantify and interpret. Samples with less than 250 counts should be re-sampled to determine if the pollen extraction technique may have influenced the pollen concentration.
- iii. Absolute counts with the use of exotic marker spores could have been used as an alternative to relative pollen counts. This could have improved the statistical quantification of the sections with pollen counts below 250 counts.
- iv. Charcoal was counted as a ratio to pollen, but ideally, charcoal should be counted to a minimum of 250 particles. The factors that resulted in the low pollen concentration would also have resulted in low charcoal concentrations. However, if all counts to 250 were conducted, the possibility of an over-representation in charcoal to pollen may have occurred biasing the relationship between vegetation and fire events.
- v. Extensive identification of non-pollen palynomorphs was not conducted. Future research should consider this component especially from young sediments. This identification may

help in providing a better framework of human occupation and influences in the Drakensberg region.

Geochemical analysis were analysed to infer changes vegetation and climatic conditions. Stable carbon isotopes were used to determine changes in C<sub>3</sub>- and C<sub>4</sub>-type vegetation, while stable nitrogen isotopes were used to infer wet-dry variations in the climate. The geochemical analysis was conducted at a 4 cm resolution to enable temporal comparisons between the geochemical data and the pollen / charcoal record.

Overall, stricter methods could have been implemented during the pollen and charcoal procedures to improve data quality.

#### **To establish a chronological framework using radiocarbon dating**

Sub-samples were extracted for radiocarbon analysis based on stratigraphic breaks and as from the CONISS breaks conducted on the Digestion-Combustion charcoal results. Radiocarbon dates were extracted from the top and base of the sediment cores to determine the age range of the core. The final <sup>14</sup>C date used in the chronological record for this research of 15,490 cal yr BP was located at 298 cm due to the age reversal being located at a depth of 361 cm. No further dates were extracted between 300 cm and 361 cm. More radiocarbon dates below 300 cm may have helped determine the start of the age-reversal as well as determine the oldest date of the sediment. However, to do this, is a great financial risk as there was no guarantee of finding the start of the age-reversal, thus funding may have been allocated foolishly. However, seven ‘good’ chronologically stable radiocarbon dates were eventually processed enabling a good chronological history of the sediment core to be determined.

#### **To determine the sediment accumulation rates of the wetland in the Drakensberg**

Sediment accumulation rates were determined using the available radiocarbon dates which were then calibrated using CLAM software (Blaauw 2010) integrated into the open-source statistical development R package (Team 2010). All dates were calibrated using the IntCal09\_bomb calibration curve (Blaauw 2010) with a reservoir effect of 40±40 yr BP to correct for variations through the use of a northern Hemisphere calibration curve in the southern Hemisphere. Sedimentation rates were calculated based on the calibration of the radiocarbon dates. The sedimentation rates indicated moderate to low sedimentation occurring before *ca.* 6000 cal yr BP, with high sedimentation rates occurring during the mid- to late Holocene epoch.



### **To conduct data analysis and interpretation to investigate potential climatic changes and its impact on vegetation distributions**

The possible climatic changes have been discussed and inferences made on the palaeoenvironmental conditions that persisted over the last *ca.* 15,490 cal yr BP. Anthropogenic impacts are difficult to discern; however, some indicators of human occupation in the region of Cathedral Peak have been identified.

### **The overall aim of this research is to use multi-proxy data to investigate and describe the palaeoenvironments of the subalpine belt of Cathedral Peak in the KwaZulu-Natal Drakensberg.**

Multi-proxy data, which included fossil pollen, fossil microscopic charcoal, charcoal percentages derived from the Digestion-Combustion technique, geochemical analysis *viz.* stable carbon and stable nitrogen isotopes and radiocarbon dating were all used during this research. While each proxy dataset deals with understanding different components of palaeoenvironments, they should always be viewed in relation to each other. Analysis of multi-proxy data used in this research enabled an interpretation of climatic events and changes to be understood with greater clarity. The use of the multi-proxy analysis approach has enabled the palaeoenvironments of a sub-alpine wetland, Catchment Six located in the KwaZulu-Natal Drakensberg, to be investigated and described.

### **8.3. Future Research Directions**

Conducting pollen analytical research from research sites within the Drakensberg region has inherent limitations, mainly with the lack of suitable, relatively undisturbed and accessible wetlands. The wetland from Catchment Six is one of a few wetlands that are suitable for palaeoenvironmental research. Further research sites, if possible, should be researched across all vegetation belts of the Drakensberg *viz.* Montane Belt, Subalpine Belt and Alpine Belt, to enable a greater understanding of a region that is phytogeographically important and under-studied. Catchment Six has indicated the suitability of the wetlands located in the Drakensberg to be used for palaeoenvironmental interpretation that extend beyond the Holocene. The potential for other wetlands to provide insight into conditions that existed into the LGM is not impossible and should be kept in mind if more suitable wetlands are identified in the Drakensberg region.

### **8.4. Conclusion**

The palaeoenvironments of Cathedral Peak have been inferred using available multi-proxy data extracted from a subalpine wetland in the Afromontane phytogeographical region of the Cathedral Peak, Drakensberg (White 1983). A synthesis of these palaeoenvironments has been provided and the palaeoenvironmental conditions from other areas in South Africa have been

included where possible to contextualise the current research within the broader framework of Quaternary research. A review of the original aim and objectives that have guided this research and future research directions have been put forward and a critical assessment of this research provided to highlight limitations and to indicate areas of potential improvements.

The Drakensberg region has been largely under-studied and this research indicates the need for continued research, in an important area of biodiversity, cultural history and economic sustainability for South Africa. The protection of these resources is essential to sustain human livelihoods in particular under drivers of current and future climate change, which threaten the sustainability of these resources. To understand the effects of climate change and how the Drakensberg region will be impacted upon by climate change is vital. To provide this information, further palaeoenvironmental research is needed to understand how the region has been impacted upon and how it adapted to climate changes in the past. Future vegetation impacts and responses to climate change can be determined with this knowledge.

## REFERENCES

- Acocks, J. P. H. 1953. *Veld types of South Africa*. Edited by D. J. B. Killick. Vol. 28, *Memoirs of the Botanical Society of South Africa*. Cape Town: Botanical Research Institute and Department of Agricultural Technical Services.
- — —. 1988. *Veld Types of South Africa*. 3<sup>rd</sup> ed. Cape Town: Botanical Research Institute, South Africa.
- Ady, J. 2005. uKhahlamba / Drakensberg Park, KwaZulu-Natal, South Africa. In *World Heritage Sites*, ed. U. Nations, 1-9: United Nations Environment Programme.
- Andrews, J. T. 1998. Abrupt changes (Heinrich events) in late Quaternary North Atlantic marine environments: a history and review of data and concepts. *Journal of Quaternary Science* 13:3-16.
- APD. 2004. African Pollen Database. [<http://medias.obs-mip.fr/apd/>; <http://pass.uonbi.ac.ke/>; <http://www.ncdc.noaa.gov/paleo/apd.html>]
- Aranibar, J. N., I. C. Anderson, H. E. Epstein, C. J. W. Feral, R. J. Swap, J. Ramontsho, and S. A. Macko. 2008. Nitrogen isotope composition of soils, C<sub>3</sub> and C<sub>4</sub> plants along land use gradients in southern Africa. *Journal of Arid Environments* 72 (4):326-337.
- Arnold, T. H., and B. C. de Wet. 1993. *Plants of Southern Africa: Names and Distribution*. Vol. 62, *Memoirs of the Botanical Survey of South Africa*. Pretoria: National Botanical Institute.
- Ascough, P. L., G. T. Cook, and A. J. Dugmore. 2009. North Atlantic marine <sup>14</sup>C reservoir effects: implications for late-Holocene chronological studies. *Quaternary Geochronology* 4 (3):171-180.
- Bard, E., B. Hamelin, R. G. Fairbanks, and A. Zindler. 1990. Calibration of the <sup>14</sup>C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. *Nature* 345:405-410.
- Barkley, F. A. 1934. The Statistical Theory of Pollen Analysis. *Ecology* 15 (3):283-289.
- Bennett, K. D. 2005. *Psimpoll*. Uppsala Universitet, Villavgen.
- Berglund, B. E., M. J. Gaillard, L. Bjorkman, and T. Persson. 2008. Long-term changes in floristic diversity in southern Sweden: palynological richness, vegetation dynamics and land-use. *Vegetation History and Archaeobotany* 17:573-583.
- Beuning, K. R. M., M. R. Talbot, and K. Kelts. 1997. A revised 30,000-year paleoclimatic and paleohydrologic history of Lake Albert, East Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 136 (1):259-279.
- Bews, J. W. 1917. The plant Ecology of the Drakensberg Range. *Annals of the Natal Museum* III (3):511-565.

- Blaauw, M. 2010. Methods and code for 'classical' age-modelling of radiocarbon sequences. *Quaternary Geochronology* 5:512-518.
- Blaauw, M., R. Bakker, J. A. Christen, V. A. Hall, and J. Van der Plicht. 2007. A Bayesian Framework for age modelling of Radiocarbon-dated peat deposits: Case studies from the Netherlands. *Radiocarbon* 49 (2):357-367.
- Blaauw, M., and J. A. Christen. 2005. The Problems of Radiocarbon Dating. *Science* 308:1552-1553.
- Blaauw, M., J. van der Plicht, and B. van Geel. 2004. Radiocarbon dating of bulk peat samples from raised bogs: non-existence of a previously reported 'reservoir effect'? *Quaternary Science Reviews* 23 (1):1537-1542.
- Blackford, J. J. 2000. Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164 (1):33-42.
- Blackwell, P. G., C. E. Buck, and P. J. Reimer. 2006. Important features of the new radiocarbon calibration curves. *Quaternary Science Reviews* 25 (5-6):408-413.
- Blockley, S. P. E., M. Blaauw, C. Bronk Ramsey, and J. van der Plicht. 2007. Building and testing age models for radiocarbon dates in Lateglacial and Early Holocene sediments. *Quaternary Science Reviews* 26 (15-16):1915-1926.
- Bonnefille, R., G. Riollet, G. Buchet, M. Icole, R. Lafont, M. Arnold, and D. Jolly. 1995. Glacial/Interglacial record from intertropical Africa, high resolution pollen and carbon data at Rusaka, Burundi. *Quaternary Science Reviews* 14:917-936.
- Boom, A., R. Marchant, H. Hooghiemstra, and J. S. Sinninghe Damste. 2002. CO<sub>2</sub> and temperature-controlled altitudinal shifts of C<sub>4</sub>- and C<sub>3</sub>-dominated grasslands allow reconstruction of palaeoatmospheric pCO<sub>2</sub>. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177 (1-2):151-168.
- Bosch, J. M., and J. D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55:3-23.
- Brown, A. G. 1999. Biodiversity and pollen analysis: modern pollen studies and the recent history of a floodplain woodland in S. W. Ireland. *Journal of Biogeography* 26 (1):19-32.
- Buck, C. E., T. F. G. Higham, and D. J. Lowe. 2003. Bayesian tools for tephrochronology. *The Holocene* 13 (639-647).
- Bunting, M. J. 2008. Pollen in wetlands: using simulations of pollen dispersal and deposition to better interpret the pollen signal. *Biodiversity and Conservation* 17:2079-2096.
- Bush, M. B., and C. Weng. 2007. Introducing a new (freeware) tool for palynology. *Journal of Biogeography* 34: 377-380.

- Campbell, I. D., W. M. Last, C. Campbell, S. Clare, and J. H. McAndrews. 2000. The late-Holocene paleohydrology of Pine Lake, Alberta: a multiproxy investigation. *Journal of Paleolimnology* 24:427-441.
- Carbutt, C., and T. J. Edwards. 2004. The Flora of the Drakensberg Alpine Centre. *Edinburgh Journal of Botany* 60 (3):581-607.
- — —. 2006. The endemic and near-endemic angiosperms of the Drakensberg Alpine Centre. *South African Journal of Botany* 72:105-132.
- Carcaillet, C. 2007. Charred Particle Analysis. *Paleobotany*:1582-1593.
- Cerling, T. E., J. M. Harris, B. J. MacFadden, M. G. Leakey, J. Quade, V. Eisenmann, and J. R. Ehleringer. 1997. Global vegetation change through the Miocene/Pliocene boundary. *Nature* 389:153-158.
- Cerling, T. E., J. M. Harris, and B. H. Passey. 2003. Diets of East African Bovidae based on stable isotope analysis. *Journal of Mammalogy* 84 (2):456-470.
- Chambers, F. M., D. Mauquoy, S. A. Brain, M. Blaauw, and J. R. G. Daniell. 2007. Globally synchronous climate change 2800 years ago: Proxy data from peat in South America. *Earth and Planetary Science Letters* 253 (3-4):439-444.
- Chase, B., and M. E. Meadows. 2007. Late Quaternary dynamics of southern Africa's winter rainfall zone. *Earth-Science Reviews* 84:103-138.
- Chiu, T.-c., R. G. Fairbanks, R. A. Mortlock, and A. L. Bloom. 2005. Extending the radiocarbon calibration beyond 26,000 years before present using fossil corals. *Quaternary Science Reviews* 24 (16-17):1797-1808.
- Clark, J. S. 1988. Particle Motion and the Theory of Charcoal Analysis: Source Area, Transport, Deposition, and Sampling. *Quaternary Research* 30:67-80.
- Clark, R. L. 1982. Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores* 24 (3-4):523-535.
- — —. 1984. Effects on charcoal of pollen preparation procedures. *Pollen et Spores* 26 (1):560-576.
- Codron, J., D. Codron, J. A. Lee-Thorp, M. Sponheimer, W. J. Bond, D. de Ruiter, and R. Grant. 2005. Taxonomic, anatomical, and spatio-temporal variations in the stable carbon and nitrogen isotopic compositions of plants from an African savanna. *Journal of Archaeological Science* 32:1757-1772.
- Coetzee, J. A. 1955. The morphology of *Acacia* pollen. *South African Journal of Science*.
- — —. 1964. Evidence for a Considerable Depression of Vegetation Belts during the Upper Pleistocene on East African Mountains. *Nature* 204:564-566.
- Coetzee, J. A., and E. M. van Zinderen Bakker. 1952. The pollen spectrum of the southern middle-veld of the Orange Free State. *South African Journal of Science* 48 (1):275-281.
- — —. 1970. Palaeoecological problems of the Quaternary in Africa. *South African Journal of*

*Science* 66 (1):78-84.

- Collin, P. H. 2004. *Dictionary of Environmental and Ecology*. 5th ed. London: Bloomsbury Publishing Plc.
- Conedera, M., W. Tinner, C. Neff, M. Meurer, A. F. Dickens, and P. Krebs. 2009. Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation. *Quaternary Science Reviews* 28:555-576.
- Connor, S. E., I. Thomas, E. V. Kvavadze, G. J. Arabuli, G. S. Avakov, and A. Sagona. 2004. A survey of modern pollen and vegetation along an altitudinal transect in southern Georgia, Caucasus region. *Review of Palaeobotany and Palynology* 129:229-250.
- Court-Picon, M., A. Buttler, and J. L. De Beaulieu. 2005. Modern pollen-vegetation relationships in the Champsaur valley (French Alps) and their potential in the interpretation of fossil pollen records of past cultural landscapes. *Review of Palaeobotany and Palynology* 135:13-39.
- Cowling, S. A., P. M. Cox, C. D. Jones, M. A. Maslin, M. Peros, and S. A. Spall. 2008. Simulated glacial and interglacial vegetation across Africa: implications for species phylogenies and trans-African migration of plants and animals. *Global Change Biology* 14:1-14.
- Daniau, A.-L., S. P. Harrison, and P. J. Bartlein. 2010. Fire regimes during the Last Glacial. *Quaternary Science Reviews* 29:2918-2930.
- Darbyshire, I., H. Lamb, and M. Umer. 2003. Forest clearance and regrowth in northern Ethiopia during the last 3000 years. *The Holocene* 13 (4):537-546.
- Dawson, T. E., S. Mambelli, A. H. Plamboeck, P. H. Templer, and K. P. Tu. 2002. Stable Isotopes in Plant Ecology. *Annual Review of Ecology and Systematics* 33:507-559.
- Deacon, H. J. 1983. An introduction to the fynbos region, time scales and palaeoenvironments. In *Fynbos Palaeoecology: A Preliminary Synthesis*, eds. H. J. Deacon, Q. B. Hendey and J. J. N. Lambrechts. Pretoria: Council for Scientific and Industrial Research.
- Deacon, H. J., Q. B. Hendey, and J. J. N. Lambrechts, eds. 1983. *Fynbos Palaeoecology: a preliminary synthesis*. Vol. 75, *South African National Science Programmes Report*.
- Delwiche, C. C., P. J. Zinke, C. M. Johnson, and R. A. Virginia. 1979. Nitrogen Isotope Distribution as a Presumptive Indicator of Nitrogen Fixation. *Botany Gazette* 140 (Suppl.):S65-S69.
- Dollar, E., and A. Goudie. 2000. Environmental change. In *The Geography of South Africa in a Changing World*, eds. R. Fox and K. Rowntree, 1-509. Cape Town: Oxford University Press.
- Duffin, K. I. 2008. The representation of rainfall and fire intensity in fossil pollen and charcoal records from a South African savanna. *Review of Palaeobotany and Palynology* 151:59-71.

- Duffin, K. I., and M. J. Bunting. 2008. Relative pollen productivity and fall speed estimates for southern African savanna taxa. *Vegetation History and Archaeobotany* 17:507-525.
- Duffin, K. I., L. Gillson, and K. J. Willis. 2008. Testing the sensitivity of charcoal as an indicator of fire events in savanna environments: quantitative predictions of fire proximity, area and intensity. *The Holocene* 18 (2):279-291.
- Dupont, L. M., H. Behling, and J.-H. Kim. 2008. Thirty thousand years of vegetation development and climate change in Angola (Ocean Drilling Program Site 1078). *Climate of the Past* 4:107-124.
- Edwards, D. 1967. A Plant Ecology Survey of the Tugela Basin, 1-285. Pietermaritzburg: Natal Town and Regional Planning Commission Report No 10.
- Esterhuysen, A. 2007. The Earlier Stone Age. In *A Search for Origins: Science, History, and South Africa's 'Cradle of Humankind'*, eds. P. Bonner, A. Esterhuysen and T. Jenkins, 110-121. Johannesburg: Wits University Press.
- Evans, R. D., and J. R. Ehleringer. 1993. A break in the nitrogen cycle in aridlands? Evidence from  $\delta^{15}\text{N}$  of soils. *Oecologia* 94 (3):314-317.
- Everard, D. A. 1986. The effects of fire on the *Podocarpus latifolius* forests of the Royal National Park, Natal Drakensberg. *South African Journal of Botany* 52 (1):60-66.
- Fægri, K., and J. Iversen. 1989. *Textbook of Pollen Analysis*. 4th ed. Chichester: John Wiley & Sons.
- Fairbanks, R. G., R. A. Mortlock, T.-C. Chiu, L. Cao, A. Kaplan, T. P. Guilderson, T. W. Fairbanks, A. L. Bloom, P. M. Grootes, and M.-J. Nadeau. 2005. Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired  $^{230}\text{Th}/^{234}\text{U}/^{238}\text{U}$  and  $^{14}\text{C}$  dates on pristine corals. *Quaternary Science Reviews* 24 (16-17):1781-1796.
- Fairhall, A. W., and A. W. Young. 1973. Methodology of Radiocarbon Dating and Radiocarbon Dates from Nelson Bay Cave. *The South African Archaeological Bulletin* 28 (111/112):90-93.
- Farquhar, G. D., J. R. Ehleringer, and K. T. Hubick. 1989. Carbon Isotope Discrimination and Photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology* 40:503-537.
- Feurdean, A., S. Klotz, S. Brewer, V. Mosbrugger, T. Tămaş, and B. Wohlfarth. 2008. Lateglacial climate development in NW Romania - Comparative results from three quantitative pollen-based methods. *Palaeogeography, Palaeoclimatology, Palaeoecology* 265:121-133.
- Ficken, K. J., F. A. Street-Perrott, R. A. Perrott, D. L. Swain, D. O. Olago, and G. Eglinton. 1998. Glacial/interglacial variations in carbon cycling revealed by molecular and isotope stratigraphy of Lake Nkunga, Mt. Kenya, East Africa. *Organic Chemistry* 29 (5-7):1701-1719.

- Ficken, K. J., M. J. Wooller, D. L. Swain, F. A. Street-Perrot, and G. Eglinton. 2002. Reconstruction of a subalpine grass-dominated ecosystem, Lake Rotunda, Mount Kenya: a novel multi-proxy approach. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177 (1):137-149.
- Figueiral, I., and V. Mosbrugger. 2000. A review of charcoal analysis as a tool for assessing Quaternary and Tertiary environments: achievements and limits. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:397-407.
- Finch, J. 2009. Late Quaternary vegetation dynamics in a biodiversity hotspot, the Uluguru Mountains of Tanzania. *Quaternary Research* 72:111-122.
- Finch, J., and T. R. Hill. 2008. A late Quaternary pollen sequence from Mfabeni Peatland, South Africa: Reconstructing forest history in Maputaland. *Quaternary Research* 70:442-450.
- Finch, J., M. J. Leng, and R. Marchant. 2009. Late Quaternary vegetation dynamics in a biodiversity hotspot, the Uluguru Mountains of Tanzania. *Quaternary Research* 72 (1):111-122.
- Finch, J. M. 2005. Late Quaternary palaeoenvironments of the Mfabeni Peatland, northern KwaZulu-Natal. Unpublished MSc, School of Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg.
- Fiorentino, G., V. Caracuta, L. Calcagnile, M. D'Elia, P. Matthiae, F. Mavelli, and G. Quarta. 2008. Third millennium B.C. climate change in Syria highlighted by Carbon stable isotope analysis of  $^{14}\text{C}$ -AMS dated plant remains from Ebla. *Palaeogeography, Palaeoclimatology, Palaeoecology* 266 (1-2):51-58.
- Flantua, S. G. A., J. H. van Boxel, H. Hooghiemstra, and J. van Smaalen. 2007. Application of GIS and logistic regression to fossil pollen data in modelling present and past spatial distribution: A case study of the Colombian Savanna. *Climate Dynamics* 29:697-712.
- Garcin, Y., A. Vincens, D. Williamson, G. Buchet, and J. Guiot. 2007. Abrupt resumption of the African Monsoon at the Younger Dryas - Holocene climatic transition. *Quaternary Science Reviews* 26 (5-6):690-704.
- Gasse, F., F. Chalie, A. Vincens, M. A. J. Williams, and D. Williamson. 2008. Climatic patterns in equatorial and southern Africa from 30,000 to 10,000 years ago reconstructed from terrestrial and near-shore proxy data. *Quaternary Science Reviews* 27 (25-26):2316-2340.
- Geyh, M. A., U. Schotterer, and M. Grosjean. 1998. Temporal changes of the  $^{14}\text{C}$  reservoir effect in lakes. *Radiocarbon* 40:921-931.
- Gibbard, P. L., M. J. Head, M. J. C. Walker, and T. S. o. Q. Stratigraphy. 2010. Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. *Journal of Quaternary Science* 25 (2):96-102.
- Gil-Romera, G., L. Scott, E. Marais, and G. A. Brook. 2006. Middle- to late-Holocene moisture



- changes in the desert of northwest Namibia derived from fossil hyrax dung pollen. *The Holocene* 16 (8):1073-1084.
- — —. 2007. Late Holocene environmental change in the northwestern Namib Desert margin: New fossil pollen evidence from hyrax middens. *Palaeogeography, Palaeoclimatology, Palaeoecology* 249:1-17.
- Gillson, L., B. H. Walker, and K. J. Willis. 2004. Interpretation of soil  $\delta^{13}\text{C}$  as an indicator of vegetation change in African savannas. *Journal of Vegetation Science* 15 (1):339-350.
- Gillson, L., and K. J. Willis. 2004. 'As Earth's testimonies tell': wilderness conservation in a changing world. *Ecology Letters* 7:990-998.
- Grab, S., L. Scott, L. Rossouw, and S. Meyer. 2005. Holocene palaeoenvironments inferred from a sedimentary sequence in the Tsoaing River Basin, western Lesotho. *Catena* 61 (1):49-62.
- Grenfell, M. C., W. Ellery, and S. E. Grenfell. 2008. Tributary valley impoundment by trunk river floodplain development: a case study from the KwaZulu-Natal Drakensberg foothills, eastern South Africa. *Earth Surface Processes and Landforms* 33 (13):2029-2044.
- Grimm, E. C. 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers and Geosciences* 13 (1):13-35.
- — —. 1992. *TILIA*. Springfield, Illinois, USA: Illinois State Museum.
- Hamilton, A. C. 1972. The interpretation of pollen diagrams from Highland Uganda. *Palaeoecology of Africa* 7 (1):45-149.
- — —. 1981. The Quaternary history of African forests: its relevance to conservation. *African Journal of Ecology* 19 (1):1-6.
- Hamilton, A. C., and D. Taylor. 1991. History of climate and forests in tropical Africa during the last 8 million years. *Climate Change* 19:65-78.
- Hedges, R. E. M., R. E. Stevens, and M. P. Richards. 2004. Bone as a stable isotope archive for local climatic information. *Quaternary Science Reviews* 23 (7-8):959-965.
- Hemp, A. 2005. Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro. *Global Change Biology* 11:1013-1023.
- Hendey, Q. B. 1983. Palaeoecology of the fynbos region: an introduction. In *Fynbos palaeoecology: a preliminary synthesis*, ed. H. J. Deacon, Hendey, Q.B. and Lambrechts, J.J.N. Pretoria: Council for Scientific and Industrial Research.
- Heusser, C. J. 1971. *Spores of Chile: Modern types of the Pteridophyta, Gymnospermae, and Angiospermae*. Tucson: University of Arizona Press.
- Hill, T. R. 1992. Contemporary pollen spectra from the Natal Drakensberg and their relation to associated vegetation communities. Unpublished PhD thesis, Rhodes University.

- Hilliard, O. M., and B. L. Burtt. 1987. *The Botany of the Southern Natal Drakensberg*. Edited by J. N. E. DSc. Vol. 15, *Annals of Kirstenbosch Botanic Gardens*. Cape Town: National Botanic Gardens.
- Hilton-Barber, B., and L. R. Berger. 2004. *Field Guide to the Cradle of Humankind*. Cape Town: New Holland Publishing.
- Hogberg, P. 1986. Nitrogen-Fixation and Nutrient Relations in Savanna Woodland Trees (Tanzania). *Journal of Applied Ecology* 23:675-688.
- Hone, J. 2001. *Bushman Art of the Drakensberg: A guide to the art, mythology and culture of the Drakensberg Bushmen*. Durban: Art Publishers.
- Hooghiemstra, H., and B. van Geel. 1998. World list of Quaternary pollen and spore atlases. *Review of Palaeobotany and Palynology* 104 (2):157-182.
- Hopley, P. J., A. G. Latham, and J. D. Marshall. 2006. Palaeoenvironments and palaeodiets of mid-Pliocene micromammals from Makapansgat Limeworks, South Africa: A stable isotope and dental microwear approach. *Palaeogeography, Palaeoclimatology, Palaeoecology* 233 (3-4):235-251.
- Hopley, P. J., G. P. Weedon, J. D. Marshall, A. I. R. Herries, A. G. Latham, and K. L. Kuykendall. 2007. High- and low-altitude orbital forcing of early hominin habitats in South Africa. *Earth and Planetary Science Letters* 256:419-432.
- Huffman, T. N. 2007a. The Early Iron Age at Broederstroom and around the 'Cradle of Humankind'. In *A Search for Origins: Science, History, and South Africa's 'Cradle of Humankind'*, eds. P. Bonner, A. Esterhuysen and T. Jenkins, 148-161. Johannesburg: Wits University Press.
- — —. 2007b. *Handbook to the Iron Age: The Archaeology of Pre-Colonial Farming Societies in Southern Africa*. Pietermaritzburg: University of KwaZulu-Natal Press.
- Hunt, C. O. 1985. Recent advances in pollen extraction techniques: a brief review. In *Palaeobiological Investigations*, eds. N. R. J. Fieller, D. D. Gilbertson and N. G. A. Ralph, 181-187. Oxford: British Archaeological Reports, International Series.
- Hunt, C. O., and G. Rushworth. 2005. Cultivation and human impact at 6000 cal yr B.P. in tropical lowland forest at Niah, Sarawak, Malaysian Borneo. *Quaternary Research* 64:460-468.
- Jain, A. 2009. Global warming and climate change science. In *Atmospheric Science for Environmental Scientists*, eds. C. N. Hewitt and A. V. Jackson. Oxford: Blackwell Publishing Ltd.
- Johnson, M. R., C. J. Van Vuuren, W. F. Hegenberger, R. Key, and U. Shoko. 1996. Stratigraphy of the Karoo Supergroup in southern Africa: an overview. *Journal of African Earth Sciences* 23 (1):3-15.
- Kershaw, A. P., and D. Bulman. 1996. A preliminary application of the analogue approach to

- the interpretation of late Quaternary pollen spectra from southeastern Australia. *Quaternary International* 33:61-71.
- Killick, D. 1990. *A Field Guide to the Flora of the Natal Drakensberg*. Johannesburg: Jonathan Ball and Ad. Donker Publishers.
- Killick, D. J. B. 1963. *An Account of the Plant Ecology of the Cathedral Peak Area of the Drakensberg*. Pretoria: Department of Agricultural Technical Services.
- Kitagawa, H., and J. van der Plicht. 1998. Atmospheric Radiocarbon Calibration to 45,000 yr B.P.: Late Glacial Fluctuations and Cosmogenic Isotope Production. *Science* 279 (5354):1187-1190.
- Krüger, S., and J. Crowson. 2004. uKhahlamba Drakensberg Park World Heritage Site Celebrates 30 years of Wilderness. *International Journal of Wilderness* 10 (2):43 - 46.
- Kuznetsova, T. V., and L. B. Tsirolnik. 2004. Climate oscillations and abrupt changes in C14 data. *Advances in Space Research* 34 (2):426-431.
- Laird, L. D., and I. D. Campbell. 2000. High resolution palaeofire signals from Christina Lake, Alberta: a comparison of the charcoal signals by two different methods. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:111-123.
- Lamb, A. L., G. P. Wilson, and M. J. Leng. 2006. A review of coastal palaeoclimate and relative sea-level reconstructions using  $\delta^{13}\text{C}$  and C/N ratios in organic material. *Earth-Science Reviews* 75 (1-4):29-57.
- Lesch, W., and D. F. Scott. 1997. The response in water yield to the thinning of *Pinus radiata*, *Pinus patula* and *Eucalyptus grandis* plantations. *Forest Ecology and Management* 99:295-307.
- Lewis, C. A., and P. M. Illgner. 2001. Late Quaternary glaciation in southern Africa: moraine ridges and glacial deposits at Mount Enterprise in the Drakensberg of the Eastern Cape Province, South Africa. *Journal of Quaternary Science* 16 (4):365-374.
- Liebenberg, D. P. 1972. *The Drakensberg of Natal*. Cape Town: T.V. Bulpin.
- Linder, H. P. 2003. The radiation of the Cape flora, southern Africa. *Biological Reviews of the Cambridge Philosophical Society* 78:597-638.
- Livingstone, D. A. 1967. Postglacial vegetation of the Ruwenzori mountains in equatorial Africa. *Ecological Monographs* 37 (1):25-52.
- Low, A. B., and A. G. Rebelo. 1996. *Vegetation of South Africa, Lesotho and Swaziland*. Pretoria: Department of Environmental Affairs and Tourism.
- MacDonald, G. M., C. P. S. Larsen, J. M. Szeicz, and K. A. Moser. 1991. The Reconstruction of Boreal Forest Fire History from Lake Sediments: A Comparison of Charcoal, Pollen, Sedimentological, and Geochemical Indices. *Quaternary Science Reviews* 10:53-71.
- Mackie, E. A. V., M. J. Leng, J. M. Lloyd, and C. Arrowsmith. 2005. Bulk organic  $\delta^{13}\text{C}$  and C/N ratios as palaeosalinity indicators within a Scottish isolation basin. *Journal of*

- Quaternary Science* 20 (4):303-312.
- Marchant, R. 2010. Understanding complexity in savannas: climate, biodiversity and people. *Current Opinion in Environmental Sustainability* 2:101-108.
- Marchant, R., and D. Taylor. 1997. Late Pleistocene and Holocene History at Mubwindi Swamp, Southwest Uganda. *Quaternary Research* 47 (1):316-328.
- Martin, A. R. H. 1968. Pollen analysis of Groenvlei lake sediments, Knysna (South Africa). *Review of Palaeobotany and Palynology* 7 (1):107-144.
- McCormac, F. G., A. G. Hogg, P. G. Blackwell, C. E. Buck, T. F. G. Higham, and P. J. Reimer. 2004. SHCal04 Southern Hemisphere Calibration, 0-11.0 Cal Kyr BP. *Radiocarbon* 46:1087-1092.
- McCormac, F. G., P. J. Reimer, A. G. Hogg, T. F. G. Higham, M. G. L. Baillie, J. Palmer, and M. Stuiver. 2002. Calibration of the radiocarbon time scale for the southern hemisphere: AD 1850-950. *Radiocarbon* 44 (3):641-651.
- Meadows, M. E. 1984. Late Quaternary vegetation history of the Nyika Plateau, Malawi. *Journal of Biogeography* 11 (1):209-222.
- Meadows, M. E., and A. J. Baxter. 1999. Late Quaternary Palaeoenvironments of the southwestern Cape, South Africa: a regional synthesis. *Quaternary International* 57/58 (1):193-206.
- Meadows, M. E., A. J. Baxter, and J. Parkington. 1996. Late Holocene environments at Verlorenvlei, Western Cape Province, South Africa. *Quaternary International* 33 (1):81-95.
- Meadows, M. E., and T. R. Hill. 2002. Issues in Biogeography: Diversity in Theory and Practice. *South African Geographical Journal* 84 (1):116-124.
- Meadows, M. E., and H. P. Linder. 1993. A palaeoecological perspective on the origin of Afromontane grasslands. *Journal of Biogeography* 20 (1):345-355.
- Meadows, M. E., and K. F. Meadows. 1988. Late Quaternary vegetation history of the Winterberg Mountains, Eastern Cape, South Africa. *South African Journal of Science* 84 (1):253-259.
- Meadows, M. E., K. F. Meadows, and J. M. Sugden. 1987. The development of vegetation of the Winterberg Escarpment. *The Naturalist* 31 (1):26-32.
- Meadows, M. E., and J. M. Sugden. 1991. A vegetation history of the last 14 000 years on the Cederberg, south-western Cape Province. *South African Journal of Science* 87 (1):34-43.
- Microsoft Office 2003. Microsoft Corporation.
- Mills, S. C., and S. W. Grab. 2005. Debris ridges along the southern Drakensberg escarpment as evidence for Quaternary glaciation in southern Africa. *Quaternary International* 129 (1):61-73.

- Mills, S. C., S. W. Grab, and S. J. Carr. 2009. Recognition and palaeoclimatic implications of late Quaternary niche glaciation in eastern Lesotho. *Journal of Quaternary Science* 24 (7):647-663.
- Mitchell, P. J. 1992. Archaeological research in Lesotho: a review of 120 years. *The African Archaeology Review* 10:3-34.
- — —. 1996. The late Quaternary of the Lesotho highlands, southern Africa: Preliminary results and future potential of ongoing research at Sehonghong shelter. *Quaternary International* 33:35-43.
- Mohammed, M. U., and R. Bonnefille. 1998. A late Glacial / late Holocene pollen record from a highland peat at Tamsaa, Bale Mountains, south Ethiopia. *Global and Planetary Change* 16-17 (1-4):121-129.
- Moore, P. D., J. A. Webb, and M. E. Collinson. 1991. *Pollen Analysis*. 2nd ed. Oxford: Blackwell Scientific Publications.
- Mucina, L., and C. J. Geldenhuys. 2006. Afrotropical, subtropical and azonal forests. In *The vegetation of South Africa, Lesotho and Swaziland*, eds. L. Mucina and M. C. Rutherford. Pretoria, South Africa: South African National Biodiversity Institute.
- Mucina, L., D. B. Hoare, M. C. Lotter, P. J. du Preez, M. C. Rutherford, R. C. Scott-Shaw, G. J. Bredenkamp, L. W. Powrie, L. Scott, K. G. T. Camp, S. S. Cilliers, H. Bezuidenhout, T. H. Mostert, S. J. Siebert, P. J. D. Winter, J. E. Burrows, L. Dobson, R. A. Ward, M. Stalmans, E. G. H. Oliver, F. Siebert, E. Schmidt, K. Kobisi, and L. Kose. 2006. Grassland Biome. In *The vegetation of South Africa, Lesotho, and Swaziland*, eds. L. Mucina and M. C. Rutherford, 349-437. Pretoria: South African National Biodiversity Institute.
- Mucina, L., and M. C. Rutherford, eds. 2006. *The vegetation of South Africa, Lesotho and Swaziland*. Vol. 19, *Strelitzia*. Pretoria: South African National Biodiversity Institute.
- Mullins, J., and J. Emberlin. 1997. Sampling Pollens. *Journal of Aerosol Science* 28 (3):365-370.
- Mumbi, C. T., R. Marchant, H. Hooghiemstra, and M. J. Wooller. 2008. Late Quaternary vegetation reconstruction from the Eastern Arc Mountains, Tanzania. *Quaternary Research* 69 (2):326-341.
- Nakagawa, T. 2007. PolyCounter ver.1.0 & Ergodex DX-1: a cheap and very ergonomic electronic counter board system. . *Quaternary International* 167-168 Supplement (298):doi:i.quaint.2007.04.001.
- Norman, N., and G. Whitfield. 2006. *Geological Journeys: A travellers guide to South Africa's rocks and landforms*. Cape Town: Struik Publishers.
- Norström, E., K. Holmgren, and C.-M. Morth. 2008. A 600-year-long  $\delta^{18}\text{O}$  record from cellulose of *Breonadia salicina* trees, South Africa. *Dendrochronologia* 26:21-33.

- Norström, E., L. Scott, T. C. Partridge, J. Risberg, and K. Holmgren. 2009. Reconstruction of environmental and climate changes at Braamhoek wetland, eastern escarpment South Africa, during the last 16,000 years with emphasis on the Pleistocene-Holocene transition. *Palaeogeography, Palaeoclimatology, Palaeoecology* 271 (3-4):240-258.
- Nyakale, M., and L. Scott. 2002. Interpretation of Late Holocene pollen in channel fills in the eastern Free State, South Africa. *South African Journal of Botany* 68 (1):464-468.
- O'Connor, T. G., and G. J. Bredenkamp. 2003. Grassland. In *Vegetation of Southern Africa*, eds. R. M. Cowling, D. M. Richardson and S. M. Pierce, 215-257. Cape Town: Cambridge University Press.
- Oksanen, J., and E. Ranta. 1992. Plant strategies along mountain vegetation gradients: a test of two theories. *Journal of Vegetation Science* 3 (1):175-186.
- Ortu, E., S. Brewer, and O. Peyron. 2006. Pollen-inferred palaeoclimate reconstructions in mountain areas: problems and perspectives. *Journal of Quaternary Science* 21 (6):615-627.
- Osmaston, H. A., and S. P. Harrison. 2005. The Late Quaternary glaciation of Africa: A regional synthesis. *Quaternary International* 138-139:32-54.
- Patterson, W. A., K. J. Edwards, and D. J. Maguire. 1987. Microscopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews* 6:3-23.
- Peterson, B. J., and B. Fry. 1987. Stable Isotopes in Ecosystem Studies. *Annual Review of Ecology and Systematics* 18:293-320.
- Pooley, E. 2005. *A Field Guide to Wild Flowers: KwaZulu-Natal and the Eastern Region* 2nd ed. Durban: The Flora Publications Trust.
- Porter, S. C. 1981. Pleistocene glaciation in the southern lake district of Chile. *Quaternary Research* 16:263-292.
- Poulson, S. R., C. P. Chamberlain, and A. J. Friedland. 1995. Nitrogen isotope variation of tree rings as a potential indicator of environmental change. *Chemical geology* 125 (3-4):307-315.
- Power, M. J., J. Marlon, N. Ortiz, P. J. Bartlein, S. P. Harrison, F. E. Mayle, A. Ballouche, R. H. W. Bradshaw, C. Carcaillet, C. Cordova, S. Mooney, P. I. Moreno, I. C. Prentice, K. Thonicke, W. Tinner, C. Whitlock, Y. Zhang, Y. Zhao, A. A. Ali, R. S. Anderson, R. Beer, H. Behling, C. Briles, K. J. Brown, A. Brunelle, M. Bush, P. Camill, G. Q. Chu, J. Clark, D. Colombaroli, S. Connor, A.-L. Daniau, M. Daniels, J. Dodson, E. Doughty, M. E. Edwards, W. Finsinger, D. Foster, J. Frechette, M.-J. Gaillard, D. G. Gavin, E. Gobet, S. Haberle, D. J. Hallett, P. Higuera, G. Hope, S. Horn, J. Inoue, P. Kaltenrieder, L. Kennedy, Z. C. Kong, C. Larsen, C. J. Long, J. Lynch, E. A. Lynch, M. McGlone, S. Meeks, S. Mensing, G. Meyer, T. Minckley, J. Mohr, D. M. Nelson, J. New, R. Newnham, R. Noti, W. Oswald, J. Pierce, P. J. H. Richard, C. Rowe, M. F. Sanchez

- Goñi, B. N. Shuman, H. Takahara, J. Toney, C. Turney, D. H. Urrego-Sanchez, C. Umbanhowar, M. Vandergoes, B. Vanniere, E. Vescovi, M. Walsh, X. Wang, N. Williams, J. Wilmshurst, and J. H. Zhang. 2008. Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data. *Climate Dynamics* 30 (7-8):887-907.
- Rafferty, J. D. 2011. Introduction. In *Climate and Climate Change*, ed. J. D. Rafferty, 1-367. New York: Britannica Educational Publishing in association with Rosen Education Services, LLC.
- Ramsey, C. B., J. Van der Plicht, and B. Weninger. 2001. "Wiggle matching" radiocarbon dates. *Radiocarbon* 43 (2A):381-389.
- Reimer, P. J., M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, C. J. H. Bertrand, P. G. Blackwell, C. E. Buck, G. S. Burr, K. B. Cutler, P. E. Damon, R. L. Edwards, R. G. Fairbanks, M. Friedrich, T. P. Guilderson, A. G. Hogg, K. A. Hughen, B. Kromer, G. McCormac, S. Manning, C. B. Ramsey, R. W. Reimer, S. Remmele, J. R. Southon, M. Stuiver, S. Talamo, F. W. Taylor, J. van der Plicht, and C. E. Weyhenmeyer. 2004. IntCal04 Terrestrial Radiocarbon Age Calibration, 0-26 Cal Kyr BP. *Radiocarbon* 46:1029-1058.
- Reimer, P. J., M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, P. G. Blackwell, C. B. Ramsey, C. E. Buck, G. S. Burr, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, I. Hajdas, T. J. Heaton, A. G. Hogg, K. A. Hughen, K. F. Kaiser, B. Kromer, F. G. McCormac, S. W. Manning, R. W. Reimer, D. A. Richards, J. R. Southon, S. Talamo, C. S. M. Turney, J. van der Plicht, and C. E. Weyhenmeyer. 2009. INTCAL09 and MARINE09 Radiocarbon Age Calibration Curves, 0-50,000 Years Cal BP. *Radiocarbon* 51 (4):1111-1150.
- Robinson, D. 2001. D15N as an integrator of the nitrogen cycle. *Trends in Ecology & Evolution* 16 (3):153-162.
- Roubik, D. W., and J. E. Moreno. 1991. Pollen and Spores of Barro Colorado Island. In *Monographs in Systematic Botany*, No. 36, 268. St Louis, Missouri: Missouri Botanical Gardens.
- Rucina, S. M., V. M. Muiruri, R. N. Kinyanjui, K. McGuinness, and R. Marchant. 2009. Late Quaternary vegetation and fire dynamics on Mount Kenya. *Palaeogeography, Palaeoclimatology, Palaeoecology* 283:1-14.
- Ryner, M., K. Holmgren, and D. Taylor. 2008. A record of vegetation dynamics and lake level changes from Lake Emakat, northern Tanzania, during the last c. 1200 years. *Journal of Paleolimnology* 40 (2):583-601.
- Ryner, M. A., R. Bonnefille, K. Holmgren, and A. Muzuka. 2006. Vegetation changes in Empakaai Crater, northern Tanzania, at 14,800–9300 cal yr BP. *Review of*

*Palaeobotany and Palynology* 140:163-174.

- Sandwith, T. S., and M. Pfotenhauer. 2002. *Maloti-Drakensberg: Transfrontier Conservation and Development*. Edited by S. M. Pearce, R. M. Cowling, T. Sandwith and K. MacKinnon, *Mainstreaming Biodiversity Development: Case Studies from South Africa*. Washington D.C.: The World Bank Environment Department.
- Sangu, G., and C. Bracebridge. 2005. Results of Flora. In *Uluguru Component Biodiversity Survey 2005 (Volume II): Uluguru South Forest Reserve.*, eds. C. Bracebridge, E. Fanning, K. M. Howell, P. Rubio and F. A. V. St. John, 25-35. Dar es Salaam: Society for Environmental Exploration and the University of Dar es Salaam: CARE-Tanzania, Conservation and Management of the Eastern Arc Mountain Forests (CMEAMF): Uluguru Component, Forestry and Beekeeping Division of the Ministry of Natural Resources and Tourism.
- Schoeninger, M. J. 1995. Stable Isotope Studies in Human Evolution. *Evolutionary Anthropology: Issues, News, and Reviews* 4 (3):83-98.
- Scott, A. C., J. A. Cripps, M. E. Collinson, and G. J. Nichols. 2000. The taphonomy of charcoal following a recent heathland fire and some implications for the interpretation of fossil charcoal deposits. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:1-31.
- Scott, L. 1982a. Late Quaternary fossil pollen grains from the Transvaal, South Africa. *Review of Palaeobotany and Palynology* 36 (1):241-278.
- . 1982b. A Late Quaternary Pollen Record from the Transvaal Bushveld, South Africa. *Quaternary Research* 17 (1):339-370.
- . 1984. Palynological evidence for Quaternary paleoenvironments in southern Africa. In *Southern African Prehistory and Palaeoenvironments*, ed. R. G. Klein, 65-80. Rotterdam: Balkema.
- . 1989. Late Quaternary vegetation history and climatic change in the eastern Orange Free State, South Africa. *South African Journal of Botany* 55 (1):107-116.
- . 1999. Vegetation history and climate in the savanna biome South Africa since 190,000 ka: a comparison of pollen data from the Tswaing Crater (the Pretoria Saltpan) and Wonderkrater. *Quaternary International* 57/58 (1):215-223.
- . 2002. Grassland development under glacial and interglacial conditions in southern Africa: a review of pollen, phytolith and isotope evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology* 117 (1):47-57.
- Scott, L., C. B. Bousman, and M. Nyakale. 2005. Holocene pollen from swamp, cave and hyrax dung deposits at Blydefontein (Kikvorsberge), Karoo, South Africa. *Quaternary International* 129 (1):49-59.
- Scott, L., and J. S. Brink. 1992. Quaternary palaeoenvironments of pans in central South Africa: palynological and palaeontological evidence. *South African Geographer* 19 (1/2):22-34.



- Scott, L., A. Cadman, and I. McMillan. 2006. Early history of Cainozoic Asteraceae along the Southern African west coast. *Review of Palaeobotany and Palynology* 142 (1-2):47-52.
- Scott, L., and M. Nyakale. 2002. Pollen indications of Holocene palaeoenvironments at Florisbad spring in the central Free State, South Africa. *The Holocene* 12 (4):535-541.
- Scott, L., M. Steenkamp, and P. B. Beaumont. 1995. Palaeoenvironmental conditions in South Africa at the Pleistocene-Holocene transition. *Quaternary Science Reviews* 14 (1):937-947.
- Scott, L., and J. C. Vogel. 1983. Late Quaternary pollen profile from the Transvaal highveld, South Africa. *South African Journal of Science* 79 (1):266-272.
- — —. 2000. Evidence for environmental conditions during the last 20,000 years in Southern Africa from  $^{13}\text{C}$  in fossil hyrax dung. *Global and Planetary Change* 26 (1-3):207-215.
- Seppä, H., and K. D. Bennett. 2003. Quaternary pollen analysis: recent progress in palaeoecology and palaeoecology. *Progress in Physical Geography* 27 (4):548-579.
- Sieben, E. J. J., C. D. Morris, D. C. Kotze, and A. M. Muasya. 2009. Changes in plant form and function across altitudinal and wetness gradients in the wetlands of the Maloti-Drakensberg, South Africa. *Plant Ecology* DOI 10.1007/s11258-009-9657-5.
- Smith, B. N. 1972. Natural Abundance of the Stable Isotopes of Carbon in Biological Systems. *BioScience* 22 (4):226-231.
- Smith, J. M., J. A. Lee-Thorp, and J. C. Sealy. 2002. Stable carbon and oxygen isotope evidence for late Pleistocene to middle Holocene climatic fluctuations in the interior of southern Africa. *Journal of Quaternary Science* 17 (7):683-695.
- Ssemmanda, I., D. B. Ryves, O. Bennike, and P. G. Appleby. 2005. Vegetation history in western Uganda during the last 1200 years: a sediment-based reconstruction from two crater lakes. *The Holocene* 15 (1):119-132.
- Street-Perrott, F. A., Y. Huang, R. A. Perrott, G. Eglinton, P. Barker, L. B. Khelifa, D. D. Harkness, and D. O. Olago. 1997. Impact of lower atmospheric carbon dioxide on tropical mountain ecosystems. *Science* 278:1422-1426.
- Stuiver, M., and P. J. Reimer. 1993. Extended  $^{14}\text{C}$  data base and revised CALIB 3.0  $^{14}\text{C}$  age calibration program. *Radiocarbon* 35:215-230.
- Sugita, S. 2007a. Theory of quantitative reconstruction of vegetation I: pollen from large sites REVEALS regional vegetation. *The Holocene* 17 (2):229-241.
- — —. 2007b. Theory of quantitative reconstruction of vegetation II: all you need is LOVE. *The Holocene* 17 (2):243-257.
- Team, R. D. C. 2010. A Language and Environment for Statistical Computing. Vienna, Austria: <http://www.R-project.org>
- Telford, R., J. E. Heegaard, and H. J. B. Birks. 2004. The intercept is a poor estimate of a calibrated radiocarbon age. *Holocene* 14 (2):296-298.

- Terwilliger, V. J., Z. Eshetu, A. Colman, T. Bekele, A. Gezahgne, and M. L. Fogel. 2008. Reconstructing palaeoenvironment from  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of soil organic matter: A calibration from arid and wetter elevation transects in Ethiopia. *Geoderma* 147:197-210.
- Thode, J. 1893. Die Botanischen Hohenregionen Natal. *Engl. Bot. Jahr* XVIII.
- — —. 1901. *The Botanical Regions of Natal Determined by Altitude*. Durban.
- Thomas, D. S., and P. A. Shaw. 2002. Late Quaternary environmental change in central southern Africa: new data, synthesis, issues and prospects. *Quaternary Science Reviews* 21 (1):783-797.
- Tinner, W., and F. S. Hu. 2003. Size parameters, size-class distribution and area-number relationship of microscopic charcoal: relevance for fire reconstruction. *The Holocene* 13 (4):499-505.
- Tipping, R., and P. Milburn. 2000. Mid-Holocene charcoal fall in southern Scotland - temporal and spatial variability. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:177-193.
- Troels-Smith, J. 1955. Characterization of Unconsolidated Sediments. *D.G.U. IV Rekke* 3 (10):37-82.
- Turner, R., N. Roberts, and M. D. Jones. 2008. Climatic pacing of Mediterranean fire histories from lake sedimentary microcharcoal. *Global and Planetary Change* 63:317-324.
- Tyson, P. D. 1999. Late-Quaternary and Holocene palaeoclimates of southern Africa: a synthesis. *South African Journal of Geology* 102 (4):335-349.
- Tyson, P. D., R. A. Preston-Whyte, and R. E. Schulze. 1976. The Climate of the Drakensberg. In *Natal Town and Regional Planning reports*, 1-82. Pietermaritzburg: Town and Regional Planning Commission.
- Uken, R. 1999. *KwaZulu-Natal*. Edited by M. J. Viljoen and W. U. Reimold, *An Introduction to South Africa's Geological and Mining Heritage*. Randburg: Mintek and Geological Society of South Africa.
- Umer, M., H. F. Lamb, R. Bonnefille, A.-M. Lezine, J.-J. Tiercelin, E. Gibert, J.-P. Cazet, and J. Watrin. 2007. Late Pleistocene and Holocene vegetation history of the Bale Mountains, Ethiopia. *Quaternary Science Reviews* 26 (17-18):2229-2246.
- UNEP. 2005. uKhahlamba / Drakensberg Park, KwaZulu-Natal, South Africa. In *United Nations Environmental Programme - World Conservation Monitoring Centre*, 1 - 9: UNEP.
- van de Mortel, J. E., and M. G. M. Aarts. 2006. Comparative transcriptomics - model species lead the way. *New Phytologist* 170:199-201.
- van Odgaard, B. 1999. Fossil pollen as a record of past biodiversity. *Journal of Biogeography* 26 (1):7-17.
- van Zinderen Bakker, E. M. 1953. *South African pollen grains and spores. Part I*. Amsterdam:

- A.A. Balkema.
- — —. 1956. *South African pollen grains and spores. Part II*. Amsterdam: A.A. Balkema.
- — —. 1973. Ecological investigations of forest communities in the eastern Orange Free State and the adjacent Natal Drakensberg. *Vegetatio* 28 (1):299-334.
- — —. 1995. Archaeology and palynology. *South African Archaeological Bulletin* 50 (1):98-105.
- van Zinderen Bakker, E. M., and J. A. Coetzee. 1959. *South African pollen grains and spores. Part III*. Amsterdam: A.A. Balkema.
- van Zinderen Bakker, E. M., and W. G. Welman. 1970. *South African pollen grains and spores. Part VI*. Cape Town: A.A. Balkema.
- Vincens, A., Y. Garcin, and G. Buchet. 2007. Influence of rainfall seasonality on African lowland vegetation during the Late Quaternary: pollen evidence from Lake Masoko, Tanzania. *Journal of Biogeography* 34:1274-1288.
- Vincens, A., D. Williamson, F. Thevenon, M. Taieb, G. Buchet, M. Decobert, and N. Thouveny. 2003. Pollen-based vegetation changes in southern Tanzania during the last 4200 years: climate change and/or human impact. *Palaeogeography, Palaeoclimatology, Palaeoecology* 198 (1):321-324.
- Wadley, L. 2007. The Middle Stone Age and Later Stone Age. In *A Search for Origins: Science, History, and South Africa's 'Cradle of Humankind'*, eds. P. Bonner, A. Esterhuysen and T. Jenkins, 122-135. Johannesburg: Wits University Press.
- Walker, M. 2005. *Quaternary Dating Methods*. Chichester: John Wiley & Sons Ltd.
- Wang, L., P. D'Odorico, G. S. Okin, and S. A. Macko. 2009. Isotope composition and anion chemistry of soil profiles along the Kalahari Transect. *Journal of Arid Environments* 73 (4-5):480-486.
- Wheeler, J. 2007. The implications of iron-working on the woodlands of Rievaulx and Bilsdale, North Yorkshire, United Kingdom: historical, palaeoecological and palaeoenvironmental perspectives circa 1068-2000, University of Bradford.
- White, F. 1978. The Afromontane region. In *Biogeography of Ecology of Southern Africa*, ed. M. J. A. Werger, 465-513. The Hague: Dr. W. Junk Publications.
- — —. 1983. *The vegetation of Africa*. Paris: UNESCO.
- Whitlock, C., and C. Larsen. 2001. Charcoal as a Fire Proxy. In *Tracking Environmental Change Using Lake Sediments*, eds. J. P. Smol, H. J. B. Birks and W. M. Last, 1-23. Dordrecht: Kluwer Academic Publishers.
- Willis, K. J., and S. A. Bhagwat. 2010. Questions of importance to the conservation of biological diversity: answers from the past. *Climate of the Past* 6:759-769.
- Winkler, M. G. 1985. Charcoal Analysis for Palaeoenvironmental Interpretation: A Chemical Assay. *Quaternary Research* 23:313-326.

- Winslow, J. C., E. R. J. Hunt, and S. C. Piper. 2003. The influence of seasonal water availability on global C<sub>3</sub> versus C<sub>4</sub> grassland biomass and its implications for climate change research. *Ecological Modelling* 3233 (1-21).
- Wooller, M. J., and K. R. Beuning. 2002. Introduction to the reconstruction and modeling of grass-dominated ecosystems. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177 (1):1-3.
- Wooller, M. J., D. L. Swain, K. J. Ficken, A. D. Q. Agnew, F. A. Street-Perrot, and G. Eglinton. 2003. Late Quaternary vegetation changes around Lake Rutundu, Mount Kenya, East Africa: evidence from grass cuticles, pollen and stable carbon isotopes. *Journal of Quaternary Science* 18 (1):3-15.
- Wright, J., and A. Mazel. 2007. *Tracks in a Mountain Range: Exploring the History of the uKhahlamba-Drakensberg*. Johannesburg: Wits University Press.
- Yang, S., and Z. Ding. 2006. Winter-spring precipitation as the principal control on predominance of C<sub>3</sub> plants in Central Asia over the past 1.77 Myr: Evidence from D<sup>13</sup>C of loess organic matter in Tajikistan. *Palaeogeography, Palaeoclimatology, Palaeoecology* 235:330-339.
- Zech, M. 2006. Evidence for Late Pleistocene climate changes from buried soils on the southern slopes of Mt. Kilimanjaro, Tanzania. *Palaeogeography, Palaeoclimatology, Palaeoecology* 242:303-312.

## APPENDICES

### Appendix A: Complete Species List of Cathedral Peak, Drakensberg (Killick 1963; Hill 1992)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ACANTHACEAE	<i>Adhatoda</i>	<i>Andromeda</i>	Killick (1963)	Lindau	
ACANTHACEAE	<i>Barleria</i>	<i>Monticola</i>	Killick (1963)	Oberm	
ACANTHACEAE	<i>Hypoestes</i>	<i>Triflora</i>	Killick (1963)	Foersk. Roem. & Schult	
ACANTHACEAE	<i>Isoglossa</i>	<i>Eckloniana</i>	Killick (1963)	Nees. Lindau	
ACHARIACEAE	<i>Guthriea</i>	<i>capensis</i>	Killick (1963)	H. Bol	
ADIANTACEAE	<i>Adiantum</i>	<i>poiretii</i>	Killick (1963)	Wikstr	
ADIANTACEAE	<i>Cheilanthes</i>	<i>hirta</i>	Killick (1963)	Swartz	
ADIANTACEAE	<i>Notholaena</i>	<i>eckloniana</i>	Killick (1963)	Kunze	<i>Cheilanthes eckloniana</i> (Kunze)
ADIANTACEAE	<i>Pellaea</i>	<i>calomelanos</i>	Killick (1963)	Swartz	<i>Cheilanthes quadripinnata</i> (Prantl)
ADIANTACEAE	<i>Pellaea</i>	<i>quadripinnata</i>	Killick (1963)	Foersk. Prantl	
ADIANTACEAE	<i>Pityrogramma</i>		Killick (1963)	Link	
ADIANTACEAE	<i>Pteris</i>	<i>cretica</i>	Killick (1963)	L.	
ADIANTACEAE	<i>Pteris</i>		Killick (1963)	L.	
AIZOACEAE	<i>Psammotropha</i>	<i>alternifolia</i>	Killick (1963)	Killick	
AIZOACEAE	<i>Psammotropha</i>	<i>mucronata</i>	Killick (1963)	Thunb	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
AIZOACEAE	<i>Psammotropha</i>	<i>myriantha</i>	Killick (1963)	Sond	
ALILIACEAE	<i>Agapanthus</i>	<i>campanulatus</i>	Hill (1992); Killick (1963)	Leighton	
ALLIACEAE	<i>Tulbaghia</i>	<i>acutiloba</i>	Killick (1963)	Harv	
ALLIACEAE	<i>Tulbaghia</i>	<i>alliacea</i>	Killick (1963)	L.f. FP	
AMARANTHACEAE	<i>Achyranthes</i>	<i>argentea</i>	Killick (1963)	Lam	<i>A. aspera</i> var. <i>sicula</i> (Lam)
AMARANTHACEAE	<i>Cyathula</i>	<i>uncinulata</i>	Killick (1963)	Schinz	
AMARYLLIDACEAE	<i>Anoiganthus</i>	<i>breviflorus</i>	Killick (1963)	(Harv) Bak.	<i>Cyrtanthus breviflorus</i> (Bak)
AMARYLLIDACEAE	<i>Anoiganthus</i>	<i>luteus</i>	Killick (1963)	(Bak) Bak	<i>Cyrtanthus breviflorus</i> (Bak)
AMARYLLIDACEAE	<i>Brunsvigia</i>	<i>natalensis</i>	Killick (1963)	Bak	
AMARYLLIDACEAE	<i>Cyrtanthus</i>	<i>erubescens</i>	Killick (1963)	Killick	
AMARYLLIDACEAE	<i>Cyrtanthus</i>	<i>flanagani</i>	Killick (1963)	Bak	
AMARYLLIDACEAE	<i>Haemanthus</i>	<i>hirsutus</i>	Killick (1963)	Bak	<i>Hirsutus humilis</i> subsp. <i>hirsutus</i> (Bak)
ANACARDIACEAE	<i>Rhus</i>	<i>dentata</i>	Killick (1963)	Thunb	
ANACARDIACEAE	<i>Rhus</i>	<i>discolor</i>	Hill (1992); Killick (1963)	E. May ex Sond	
ANACARDIACEAE	<i>Rhus</i>	<i>gerrardii</i>	Killick (1963)	Harv ex Engl	
ANACARDIACEAE	<i>Rhus</i>	<i>tomentosa</i>	Killick (1963)	L	
ANDREAEACEAE	<i>Andreaea</i>	<i>petrophila</i>	Killick (1963)	Fuernr	<i>A. rupestris</i> (Fuernr)
ANTHOCEROTACEAE	<i>Anthoceros</i>	<i>natalensis</i>	Killick (1963)	Steph	
APIACEAE	<i>Alepidea</i>	<i>amatymbica</i>	Killick (1963)	Eckl. & Zeyh	
APIACEAE	<i>Alepidea</i>	<i>capensis</i>	Killick (1963)	R.A. Dyer	
APIACEAE	<i>Alepidea</i>	<i>setifera</i>	Killick (1963)	N.E. Br	
APIACEAE	<i>Alepidea</i>	<i>thodei</i>	Killick (1963)	Dummer	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
APIACEAE	<i>Bupleurum</i>	<i>mundii</i>	Killick (1963)	Cham & Schlecht	
APIACEAE	<i>Peucedanum</i>	<i>caffrum</i>	Killick (1963)	Phill	
APIACEAE	<i>Pimpinella</i>	<i>caffra</i>	Killick (1963)	D. Dietr	
APIACEAE	<i>Pimpinella</i>	<i>stadensis</i>	Killick (1963)	D. Dietr	
APIACEAE	<i>Polemannia</i>	<i>montana</i>	Killick (1963)	Schltr & Wolff	
APIACEAE	<i>Sanicula</i>	<i>europa</i>	Killick (1963)	Sond	<i>S. elata</i> (Sond)
APIACEAE	<i>Sium</i>	<i>thunbergii</i>	Killick (1963)	DC	<i>Berula erecta</i> subsp. <i>Thunbergii</i> (DC)
APOCYNACEAE	<i>Carissa</i>	<i>bispinosa</i>	Killick (1963)	Def ex Brenan	
APONOGETONACEAE	<i>Aponogeton</i>	<i>spathaceus</i>	Killick (1963)	E. Mey ex Hook	<i>A. juncus</i> subsp. <i>junceus</i> (E. Mey ex Hook)
AQUIFOLIACEAE	<i>Ilex</i>	<i>mitis</i>	Hill (1992); Killick (1963)	Radlk	
ARACEAE	<i>Zantedeschia</i>	<i>albomaculata</i>	Killick (1963)	Baill	
ARACEAE	<i>Zantedeschia</i>	<i>oculata</i>	Killick (1963)	Engl	<i>Z. albomaculata</i> subsp. <i>albomaculata</i> (Engl)
ARALIACEAE	<i>Cussonia</i>	<i>paniculata</i>	Killick (1963)	Eckl Zeyh	
ARALIACEAE	<i>Cussonia</i>	<i>spicata</i>	Killick (1963)	Thunb	
ASCLEPIADACEAE	<i>Anisotoma</i>	<i>pedunculata</i>	Killick (1963)	N.E. Br	
ASCLEPIADACEAE	<i>Asclepias</i>	<i>stellifera</i>	Killick (1963)	Schltr	
ASCLEPIADACEAE	<i>Aspidoglossum</i>	<i>woodii</i>	Killick (1963)	Kupicha	
ASCLEPIADACEAE	<i>Pachycarpus</i>	<i>campanulatus</i>	Killick (1963)	N.E. Br	
ASCLEPIADACEAE	<i>Pachycarpus</i>		Killick (1963)	E. Mey	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASCLEPIADACEAE	<i>Riocreuxia</i>	<i>torulosa</i>	Killick (1963)	N.E. Br	
ASCLEPIADACEAE	<i>Riocreuxia</i>	<i>torulosa</i>	Killick (1963)	Decne	
ASCLEPIADACEAE	<i>Schizoglossum</i>	<i>flavum</i>	Killick (1963)	Schltr.	
ASCLEPIADACEAE	<i>Schizoglossum</i>	<i>linifolium</i>	Killick (1963)	Schltr	
ASCLEPIADACEAE	<i>Schizoglossum</i>	<i>montanum</i>	Killick (1963)	R.A. Dyer	
ASCLEPIADACEAE	<i>Schizoglossum</i>	<i>pulchellum</i>	Killick (1963)	Schltr	<i>Miraglossum pulchellum</i> (Schltr)
ASCLEPIADACEAE	<i>Schizoglossum</i>		Killick (1963)	E. Mey	
ASCLEPIADACEAE	<i>Secamone</i>	<i>alpini</i>	Killick (1963)	Schultes	
ASCLEPIADACEAE	<i>Sisyranthus</i>	<i>Imberbis</i>	Killick (1963)	Harv	
ASCLEPIADACEAE	<i>Tylophora</i>	<i>flanaganii</i>	Killick (1963)	Schltr	
ASCLEPIADACEAE	<i>Xysmalobium</i>	<i>parviflorum</i>	Killick (1963)	Harv ex Scott	
				Elliot	
ASPARAGACEAE	<i>Asparagus</i>	<i>asparagoides</i>	Killick (1963)	Wight	<i>Myrsiphyllum asparagoides</i> (Wight)
ASPARAGACEAE	<i>Asparagus</i>	<i>scandens</i>	Killick (1963)	Thunb	<i>Myrsiphyllum scandens</i> (Thunb)
ASPARAGACEAE	<i>Asparagus</i>		Killick (1963)	L	
ASPHODELACEAE	<i>Aloe</i>	<i>arborescens</i>	Killick (1963)	Mill	
ASPHODELACEAE	<i>Aloe</i>	<i>aristata</i>	Killick (1963)	Haw	
ASPHODELACEAE	<i>Aloe</i>	<i>boylei</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Aloe</i>	<i>pratensis</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Aloe</i>	<i>saponaria</i>	Killick (1963)	Haw	A .Maculata (Haw.)
ASPHODELACEAE	<i>Anthericum</i>	<i>longistylum</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Kniphofia</i>	<i>caulescens</i>	Killick (1963)	Bak	



Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASPHODELACEAE	<i>Kniphofia</i>	<i>evansii</i>	Killick (1963)	Bak	<i>Kniphofia typhoides</i> (Bak)
ASPHODELACEAE	<i>Kniphofia</i>	<i>northiae</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Kniphofia</i>	<i>pauciflora</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Kniphofia</i>	<i>porphyrantha</i>	Killick (1963)	Bak	
ASPHODELACEAE	<i>Kniphofia</i>		Killick (1963)	Moench	
ASPHODELACEAE	<i>Notosceptrum</i>	<i>natalense</i>	Killick (1963)	Bak	
ASPIDIACEAE	<i>Dryopteris</i>		Killick (1963)	Adans	
ASPIDIACEAE	<i>Polystichum</i>		Killick (1963)	Roth	
ASPIDIACEAE	<i>Polystichum</i>		Killick (1963)	Roth	
ASPIDIACEAE	<i>Woodsia</i>		Killick (1963)	R. Br	
ASPLENIACEAE	<i>Asplenium</i>	<i>monanthes</i>	Killick (1963)	L	
ASPLENIACEAE	<i>Asplenium</i>	<i>rutaefolium</i>	Killick (1963)	Kunze	
ASPLENIACEAE	<i>Asplenium</i>	<i>splendens</i>	Hill (1992); Killick (1963)	Kunze	
ASPLENIACEAE	<i>Asplenium</i>		Killick (1963)	L	
ASTERACEAE	<i>Artemisia</i>	<i>afra</i>	Killick (1963)	Jacq ex Willd	
ASTERACEAE	<i>Aster</i>	<i>filifolius</i>	Killick (1963)	Vent	<i>Felicia filifolia</i> subsp <i>filifolia</i> (Vent)
ASTERACEAE	<i>Aster</i>	<i>muricatus</i>	same as Hill (1992)	E. Mey ex Harv	<i>Felicia fascicularis</i> (E. Mey ex Harv)
			<i>muricata</i>		
ASTERACEAE	<i>Aster</i>	<i>natalensis</i>	Killick (1963)	Harv	<i>Felicia rosulata</i> (Harv)
ASTERACEAE	<i>Aster</i>	<i>perfoliatus</i>	Hill (1992); Killick (1963)	Oliv	
ASTERACEAE	<i>Aster</i>	<i>pleiocephalus</i>	Killick (1963)	Hutch	
ASTERACEAE	<i>Athanasia</i>	<i>punctata</i>	Killick (1963)	Harv	<i>Inulanthera dregeana</i> (Harv)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Athanasia</i>	<i>thodei</i>	Killick (1963)	H. Bol	<i>Inulanthera thodei</i> (H. Bol)
ASTERACEAE	<i>Athanasia</i>		Killick (1963)	L	
ASTERACEAE	<i>Athrixia</i>	<i>angustissima</i>	Killick (1963)	DC	
ASTERACEAE	<i>Athrixia</i>	<i>arachnoidea</i>	Killick (1963)	Wood and Evans ex Wood	
ASTERACEAE	<i>Athrixia</i>	<i>fontana</i>	Killick (1963)	MacOwan	
ASTERACEAE	<i>Athrixia</i>	<i>phylicaeifolia</i>	Killick (1963)	DC	
ASTERACEAE	<i>Athrixia</i>	<i>pinifolia</i>	Hill (1992); Killick (1963)	N.E. Br	
ASTERACEAE	<i>Berkheya</i>	<i>draco</i>	Killick (1963)	Rossl	
ASTERACEAE	<i>Berkheya</i>	<i>macrocephala</i>	Killick (1963)	J.M. Wood	
ASTERACEAE	<i>Berkheya</i>	<i>montana</i>	Killick (1963)	Wood and Evans	
ASTERACEAE	<i>Berkheya</i>	<i>multijuga</i>	Killick (1963)	DC	
ASTERACEAE	<i>Berkheya</i>	<i>rhapontica</i>	Killick (1963)	DC	
ASTERACEAE	<i>Berkheya</i>	<i>rosulata</i>	Killick (1963)	Rossl	
ASTERACEAE	<i>Berkheya</i>	<i>speciosa</i>	Hill (1992); Killick (1963)	O. Hoffm	
ASTERACEAE	<i>Bojeria</i>	<i>nutans</i>	Killick (1963)	H. Bol	<i>Printzia</i> (H. Bol)
ASTERACEAE	<i>Callilepis</i>	<i>laureola</i>	Killick (1963)	DC	
ASTERACEAE	<i>Cenia</i>		Killick (1963)	Compton	
ASTERACEAE	<i>Chrysanthemoides</i>	<i>monilifera</i>	Hill (1992); Killick (1963)	T. Norl	
ASTERACEAE	<i>Chrysocoma</i>	<i>tenuifolia</i>	Killick (1963)	Berg	<i>Chrysocoma ciliata</i> (Berg)
ASTERACEAE	<i>Cineraria</i>	<i>geraniifolia</i>	Killick (1963)	DC	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Cineraria</i>	<i>lobata</i>	Killick (1963)	L'Herit	
ASTERACEAE	<i>Cirsium</i>	<i>vulgare</i>	Killick (1963)	Savi	
ASTERACEAE	<i>Conyza</i>	<i>gouanii</i>	Killick (1963)	Willd	
ASTERACEAE	<i>Conyza</i>	<i>ivifolia</i>	Killick (1963)	Less	<i>C. scabrida (Less)</i>
ASTERACEAE	<i>Conyza</i>	<i>podocephala</i>	Killick (1963)	DC	
ASTERACEAE	<i>Denekia</i>	<i>capensis</i>	Killick (1963)	Thunb	
ASTERACEAE	<i>Dicoma</i>	<i>anomala</i>	Killick (1963)	Sond	
ASTERACEAE	<i>Eumorphia</i>	<i>sericea</i>	Killick (1963)	Wood and Evans	
ASTERACEAE	<i>Euryops</i>	<i>acraeus</i>	Killick (1963)	M.D. Henderson	
ASTERACEAE	<i>Euryops</i>	<i>evansii</i>	Killick (1963)	Schltr.	
ASTERACEAE	<i>Euryops</i>	<i>laxus</i>	Killick (1963)	Burt Davy	
ASTERACEAE	<i>Euryops</i>	<i>montanus</i>	Killick (1963)	Schltr.	
ASTERACEAE	<i>Euryops</i>	<i>peduncularis</i>	Hill (1992); Killick (1963)	N.E. Br	
ASTERACEAE	<i>Felicia</i>	<i>pinnatifida</i>	Killick (1963)	Wood and Evans	<i>Aster erucifolius (Wood and Evans)</i>
ASTERACEAE	<i>Gazania</i>	<i>krebsiana</i>	Killick (1963)	Rossl	790
ASTERACEAE	<i>Gerbera</i>	<i>natalensis</i>	Killick (1963)	Sch. Bip	<i>G. viridifolia subsp. natalensis (Sch. Bip.)</i>
ASTERACEAE	<i>Gerbera</i>	<i>piloselloides</i>	Killick (1963)	Cass	
ASTERACEAE	<i>Gnaphalium</i>	<i>luteo-album</i>	Killick (1963)	L	<i>Psuedognaphalium luteo-album (L)</i>
ASTERACEAE	<i>Gnaphalium</i>	<i>undulatum</i>	Killick (1963)	L	<i>Psuedognaphalium undulatum (L)</i>
ASTERACEAE	<i>Gymnopentzia</i>	<i>bifurcata</i>	Killick (1963)	Benth	
ASTERACEAE	<i>Gymnopentzia</i>	<i>pilifera</i>	Killick (1963)	N.E. Br	<i>G. bifurcate (N.E. Br)</i>

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Haplocarpha</i>	<i>scaposa</i>	Killick (1963)	Harv	
ASTERACEAE	<i>Haplocarpha</i>		Killick (1963)	Less	
ASTERACEAE	<i>Helichrysum</i>	<i>acutatum</i>	Killick (1963)	DC	
ASTERACEAE	<i>Helichrysum</i>	<i>adenocarpum</i>	Killick (1963)	DC	
ASTERACEAE	<i>Helichrysum</i>	<i>adscendens</i>	Killick (1963)	Moeser	<i>H. cephaloideum</i> (Moeser)
ASTERACEAE	<i>Helichrysum</i>	<i>albirosulatum</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Helichrysum</i>	<i>allioides</i>	Killick (1963)	Less	
ASTERACEAE	<i>Helichrysum</i>	<i>alticolum</i>	Killick (1963)	H. Bol	<i>H. evansii</i> (H. Bol)
ASTERACEAE	<i>Helichrysum</i>	<i>appendiculatum</i>	Killick (1963)	Less	
ASTERACEAE	<i>Helichrysum</i>	<i>argentissimum</i>	Killick (1963)	J.M. Wood	
ASTERACEAE	<i>Helichrysum</i>	<i>aureonitens</i>	Hill (1992); Killick (1963)	Sch. Bip	
ASTERACEAE	<i>Helichrysum</i>	<i>caespitium</i>	Killick (1963)	Harv	
ASTERACEAE	<i>Helichrysum</i>	<i>confertum</i>	Killick (1963)	N.E. Br	
ASTERACEAE	<i>Helichrysum</i>	<i>cooperi</i>	Killick (1963)	Harv	<i>H. rotundatum</i> (Harv)
ASTERACEAE	<i>Helichrysum</i>	<i>drakensbergense</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Helichrysum</i>	<i>flanaganii</i>	Killick (1963)	H. Bol	
ASTERACEAE	<i>Helichrysum</i>	<i>fulvum</i>	Killick (1963)	N.E. Br	
ASTERACEAE	<i>Helichrysum</i>	<i>glomeratum</i>	Killick (1963)	Klatt	
ASTERACEAE	<i>Helichrysum</i>	<i>grandibracteatum</i>	Killick (1963)	M.D. Henderson	
ASTERACEAE	<i>Helichrysum</i>	<i>hypoleucum</i>	Killick (1963)	Harv	
ASTERACEAE	<i>Helichrysum</i>	<i>inerme</i>	Killick (1963)	Moeser	
ASTERACEAE	<i>Helichrysum</i>	<i>infaustum</i>	Killick (1963)	Wood and Evans	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Helichrysum</i>	<i>latifolium</i>	Killick (1963)	Less	<i>H. pilosellum</i> (Lees.)
ASTERACEAE	<i>Helichrysum</i>	<i>milfordiae</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Helichrysum</i>	<i>mundtii</i>	Killick (1963)	Harv	
ASTERACEAE	<i>Helichrysum</i>	<i>nanum</i>	Killick (1963)	Klatt	
ASTERACEAE	<i>Helichrysum</i>	<i>odoratissimum</i>	Killick (1963)	L.	<i>Gnaphalium odoratissimum</i> (L)
ASTERACEAE	<i>Helichrysum</i>	<i>oreophilum</i>	Killick (1963)	Klatt	<i>Troglophyton capillaceum</i> subsp. <i>capillaceum</i> (Harv.)
ASTERACEAE	<i>Helichrysum</i>	<i>pagophilum</i>	Killick (1963)	M.D. Henderson	
ASTERACEAE	<i>Helichrysum</i>	<i>randii</i>	Hill (1992); Killick (1963)	S. Moore	<i>H. chinospaerum</i> (S. Moore)
ASTERACEAE	<i>Helichrysum</i>	<i>retortoides</i>	Killick (1963)	N.E. Br	
ASTERACEAE	<i>Helichrysum</i>	<i>scapiforme</i>	Killick (1963)	Moeser	<i>H. ecklonis</i> (Moeser)
ASTERACEAE	<i>Helichrysum</i>	<i>scopulosum</i>	Killick (1963)	M.D. Henderson	<i>H. aureum</i> (M.D. Henderson)
ASTERACEAE	<i>Helichrysum</i>	<i>sessile</i>	Killick (1963)	DC	
ASTERACEAE	<i>Helichrysum</i>	<i>setigerum</i>	Killick (1963)	H. Bol	<i>H. albo-brunneum</i> (H. Bol.)
ASTERACEAE	<i>Helichrysum</i>	<i>setosum</i>	Hill (1992); Killick (1963)	Harv	
ASTERACEAE	<i>Helichrysum</i>	<i>splendidum</i>	Killick (1963)	Less	<i>H. montanum</i> (Less)
ASTERACEAE	<i>Helichrysum</i>	<i>squamosum</i>	Killick (1963)	Jacq	<i>Edmondia pinifolia</i> (Thunb.)
ASTERACEAE	<i>Helichrysum</i>	<i>subglomeratum</i>	Killick (1963)	Less	
ASTERACEAE	<i>Helichrysum</i>	<i>sutherlandii</i>	Hill (1992); Killick (1963)	Harv	
ASTERACEAE	<i>Helichrysum</i>	<i>tenax</i>	Killick (1963)	M.D. Henderson	
ASTERACEAE	<i>Helichrysum</i>	<i>tenuifolia</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Helichrysum</i>	<i>trilineatum</i>	Killick (1963)	DC	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Helichrysum</i>	<i>trilineatum</i>	Killick (1963)	DC	
ASTERACEAE	<i>Helichrysum</i>	<i>umbraculigerum</i>	Hill (1992); Killick (1963)	Less	
ASTERACEAE	<i>Helichrysum</i>		Killick (1963)	Mill	
ASTERACEAE	<i>Heteromma</i>	<i>decurrens</i>	Killick (1963)	O. Hoffm	
ASTERACEAE	<i>Heteromma</i>		Killick (1963)	Benth	
ASTERACEAE	<i>Hieracium</i>		Killick (1963)	L.	Tolpis capensis (L)
ASTERACEAE	<i>Hirpicium</i>	<i>armeriodes</i>	Killick (1963)	Rossl	
ASTERACEAE	<i>Lactuca</i>	<i>capensis</i>	Killick (1963)	Dinter	L. pallidicoerulea (Dinter)
ASTERACEAE	<i>Leontonyx</i>	<i>coloratus</i>	Killick (1963)	Cass	Helichrysum tinctum (Cass)
ASTERACEAE	<i>Macowania</i>	<i>conferta</i>	Killick (1963)	Benth	
ASTERACEAE	<i>Metalsia</i>	<i>muricata</i>	Killick (1963)	L	
ASTERACEAE	<i>Nidorella</i>		Killick (1963)	Cass	
ASTERACEAE	<i>Osteospermum</i>	<i>juncundum</i>	Killick (1963)	Berg	
ASTERACEAE	<i>Osteospermum</i>	<i>thodei</i>	Killick (1963)	Markotter	
ASTERACEAE	<i>Othonna</i>	<i>natalensis</i>	Killick (1963)	Sch. Bip.	
ASTERACEAE	<i>Pentzia</i>	<i>pinnatifida</i>	Killick (1963)	Oliv	Phymaspermum pinnatifidum (Oliv)
ASTERACEAE	<i>Pentzia</i>	<i>pinnatifida</i>	Killick (1963)	Oliv	Phymaspermum pinnatifidum (Oliv)
ASTERACEAE	<i>Printzia</i>	<i>pyrifolia</i>	Killick (1963)	Less	
ASTERACEAE	<i>Schistostephium</i>	<i>crataegifolium</i>	Killick (1963)	DC	
ASTERACEAE	<i>Schistostephium</i>	<i>hippiifolium</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>achillaefolius</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>barbatus</i>	Killick (1963)	DC	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Senecio</i>	<i>brevidentatus</i>	Killick (1963)	M.D. Henderson	
ASTERACEAE	<i>Senecio</i>	<i>bupleuroides</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>caudatus</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>cryptolanatus</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Senecio</i>	<i>deltoideus</i>	Killick (1963)	Less	
ASTERACEAE	<i>Senecio</i>	<i>dregeanus</i>	Killick (1963)	DC	<i>S. discodregeanus</i> (DC)
ASTERACEAE	<i>Senecio</i>	<i>erubescens</i>	Hill (1992); Killick (1963)	Ait	
ASTERACEAE	<i>Senecio</i>	<i>gramineus</i>	Killick (1963)	Harv	
ASTERACEAE	<i>Senecio</i>	<i>harveianus</i>	Killick (1963)	MacOwan	
ASTERACEAE	<i>Senecio</i>	<i>haygarthii</i>	Killick (1963)	Hilliard	
ASTERACEAE	<i>Senecio</i>	<i>hieraciodes</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>inaequidens</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>inornatus</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>isatideus</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>macroalatus</i>	Killick (1963)	M.D. Henderson	<i>S. inornatus</i> (M.D. Henderson)
ASTERACEAE	<i>Senecio</i>	<i>macrocephallus</i>	Killick (1963)	DC	<i>S. isatidioides</i> (Phill.)
ASTERACEAE	<i>Senecio</i>	<i>oxyriifolius</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>praeteritus</i>	Killick (1963)	Killick	
ASTERACEAE	<i>Senecio</i>	<i>serratuloides</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>tamoides</i>	Killick (1963)	DC	
ASTERACEAE	<i>Senecio</i>	<i>tugelensis</i>	Killick (1963)	Wood and Evans	
ASTERACEAE	<i>Senecio</i>		Killick (1963)	L	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ASTERACEAE	<i>Stoebe</i>	<i>vulgaris</i>	Killick (1963)	Levyns	
ASTERACEAE	<i>Ursinia</i>	<i>alpina</i>	Killick (1963)	N.E. Br	U. paleacea (N.E. Br)
ASTERACEAE	<i>Ursinia</i>	<i>apiculata</i>	Killick (1963)	DC	U. Montana subsp. apiculata (DC.)
ASTERACEAE	<i>Ursinia</i>	<i>montana</i>	Killick (1963)	DC	
ASTERACEAE	<i>Vernonia</i>	<i>hirsuta</i>	Killick (1963)	Sch. Bip	
ASTERACEAE	<i>Vernonia</i>	<i>pinifolia</i>	Killick (1963)	Less	V. capensis (Less)
ASTERACEAE	<i>Vernonia</i>		Killick (1963)	Schrb	
ATHYRIACEAE	<i>Athyrium</i>	<i>schimperi</i>	Killick (1963)	Moug. Ex Fee	
ATHYRIACEAE	<i>Cystopteris</i>	<i>fragilis</i>	Killick (1963)	Bernh.	
AYTONIACEAE	<i>Plagiochasma</i>	<i>rupestre</i>	Killick (1963)	Steph.	
AYTONIACEAE	<i>Plagiochasma</i>		Killick (1963)	Lehm. And Lindenb	
BALSAMINACEAE	<i>Impatiens</i>	<i>dutheiae</i>	Killick (1963)	L. Bol	I. hochstetteri (L. Bol)
BARTRAMIACEAE	<i>Bartramia</i>	<i>hampeana</i>	Killick (1963)	C. Mull	
BARTRAMIACEAE	<i>Philonotis</i>	<i>afrofontana</i>	Killick (1963)	Par.	
BARTRAMIACEAE	<i>Philonotis</i>		Killick (1963)	Brid	
BEGONIACEAE	<i>Begonia</i>	<i>sutherlandii</i>	Killick (1963)	Hook	
BLECNACEAE	<i>Blechnum</i>	<i>attenuatum</i>	Killick (1963)	Mett	
BLECNACEAE	<i>Blechnum</i>	<i>punctulatum</i>	Hill (1992); Killick (1963)	Swartz	
BORAGINACEAE	<i>Cynoglossum</i>	<i>enerve</i>	Killick (1963)	Turcz	C. hispidum (Turcz)
BORAGINACEAE	<i>Lithospermum</i>	<i>afromontanum</i>	Killick (1963)	Weim	
BORAGINACEAE	<i>Myosotis</i>	<i>sylvatica</i>	Killick (1963)	Sm.	



Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
BORAGINACEAE	<i>Tysonia</i>	<i>africana</i>	Killick (1963)	H. Bol	Afrotysonia Africana (H. Bol)
BRACHYTHECIACEAE	<i>Brachythecium</i>	<i>subrutabulum</i>	Killick (1963)	Jaeg	
BRACHYTHECIACEAE	<i>Pleuropus</i>	<i>sericeus</i>	Killick (1963)	Broth	Homalothecium afrostriatum (Broth)
BRASSICACEAE	<i>Heliophila</i>	<i>rigidiuscula</i>	Killick (1963)	Eckl. And Zeyh.	
BRASSICACEAE	<i>Heliophila</i>	<i>suavissima</i>	Killick (1963)	Burch ex DC	
BRASSICACEAE	<i>Heliophila</i>		Killick (1963)	L.	
BRYACEAE	<i>Brachhymenium</i>	<i>dicranoides</i>	Killick (1963)	Hornsch	
BRYACEAE	<i>Brachhymenium</i>	<i>pulchrum</i>	Killick (1963)	Hook	
BRYACEAE	<i>Bryum</i>	<i>alpinum</i>	Killick (1963)	Huds ex With	
BRYACEAE	<i>Bryum</i>	<i>argenteum</i>	Killick (1963)	Hedw	
BRYACEAE	<i>Bryum</i>	<i>aulacomnoides</i>	Killick (1963)	Sim	B. psuedotriquetrum (C. Mull)
BRYACEAE	<i>Bryum</i>	<i>capillare</i>	Killick (1963)	Hedw	
BRYACEAE	<i>Bryum</i>	<i>truncorum</i>	Killick (1963)	Brid	
BRYACEAE	<i>Rhodobryum</i>	<i>umbraculum</i>	Killick (1963)	Schimp. Ex Par	
BRYACEAE	<i>Webera</i>		Killick (1963)	Hedw	Pohlia spp (Hedw)
CAMPANULACEAE	<i>Wahlenbergia</i>	<i>fasciculata</i>	Killick (1963)	V. Brehm	
CAMPANULACEAE	<i>Wahlenbergia</i>	<i>montana</i>	Killick (1963)	A. DC	
CAMPANULACEAE	<i>Wahlenbergia</i>	<i>squamifolia</i>	Killick (1963)	V. Brehm	
CAMPANULACEAE	<i>Wahlenbergia</i>	<i>undulata</i>	Hill (1992); Killick (1963)	A. DC	
CAMPANULACEAE	<i>Wahlenbergia</i>		Killick (1963)	Schrad. Ex Roth	
CARYOPHYLLACEAE	<i>Cerastium</i>	<i>dregeanum</i>	Killick (1963)	Fenzl	C. arabis (Fenzl)
CARYOPHYLLACEAE	<i>Dianthus</i>	<i>basuticus</i>	Killick (1963)	Burt Davy	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
CARYOPHYLLACEAE	<i>Silene</i>	<i>burchellii</i>	Killick (1963)	Oth	
CARYOPHYLLACEAE	<i>Silene</i>	<i>capensis</i>	Killick (1963)	Oth	<i>S. undulate</i> (Oth)
CELASTRACEAE	<i>cassine</i>	<i>tetragona</i>	Killick (1963)	Loes	
CELASTRACEAE	<i>Maytenus</i>	<i>acuminatus</i>	Killick (1963)	Loes	
CELASTRACEAE	<i>Maytenus</i>	<i>mossambicensis</i>	Killick (1963)	Blakelock	
CELASTRACEAE	<i>Maytenus</i>	<i>peduncularis</i>	Killick (1963)	Loes	
CELASTRACEAE	<i>Maytenus</i>	<i>undata</i>	Killick (1963)	Blakelock	
CELASTRACEAE	<i>Pterocelastrus</i>	<i>galpinii</i>	Killick (1963)	Loes	<i>Pterocelastrus echinatus</i> (Loes)
CELASTRACEAE	<i>Pterocelastrus</i>		Killick (1963)	Meisn.	
CHENOPODIACEAE	<i>Chenopodium</i>	<i>schraderianum</i>	Killick (1963)	Roem and Schult	
CLUSIACEAE	<i>Hypericum</i>	<i>lalandii</i>	Killick (1963)	Choisy	
COLCHICACEAE	<i>Wurmbea</i>	<i>kraussii</i>	Killick (1963)	Bak. FP	
CORNACEAE	<i>Curtisia</i>	<i>dentata</i>	Killick (1963)	C.A. Sm	
CRASSULACEAE	<i>Crassula</i>	<i>filamentosa</i>	Killick (1963)	Schonl	<i>C. lanceolata</i> subsp. <i>lanceolata</i> (Schonl)
CRASSULACEAE	<i>Crassula</i>	<i>filiformis</i>	Killick (1963)	Dietr	
CRASSULACEAE	<i>Crassula</i>	<i>harveyii</i>	Killick (1963)	Britt and Bak. F.	<i>C. dependens</i> (Britt & Bak)
CRASSULACEAE	<i>Crassula</i>	<i>lineolata</i>	Killick (1963)	Dryand	<i>C. pellucida</i> subsp. <i>marginalis</i> (Dryand)
CRASSULACEAE	<i>Crassula</i>	<i>muscosa</i>	Killick (1963)	L	
CRASSULACEAE	<i>Crassula</i>	<i>natans</i>	Killick (1963)	Thunb	
CRASSULACEAE	<i>Crassula</i>	<i>platyphylla</i>	Killick (1963)	Harv	<i>C. nudicaulis</i> var. <i>nudicaulis</i> (Schonl)
CRASSULACEAE	<i>Crassula</i>	<i>rubicunda</i>	Killick (1963)	Schonl	<i>C. alba</i> var. <i>alba</i> (Drege ex Harv)
CRASSULACEAE	<i>Crassula</i>	<i>sarcocaulis</i>	Killick (1963)	Eckl. And Zeyh.	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
CRASSULACEAE	<i>Crassula</i>	<i>setulosa</i>	Killick (1963)	N.E. Br	
CRASSULACEAE	<i>Crassula</i>	<i>setulosa</i>	Killick (1963)	Harv	
CRASSULACEAE	<i>Crassula</i>	<i>umbraticola</i>	Killick (1963)	N.E. Br	
CRASSULACEAE	<i>Crassula</i>	<i>vaginata</i>	Hill (1992); Killick (1963)	Eckl. And Zeyh.	
CRASSULACEAE	<i>Crassula</i>		Killick (1963)	L	
CRASSULACEAE	<i>Kalanchoe</i>	<i>thyrsiflora</i>	Killick (1963)	Harv. FP	
CUCURBITACEAE	<i>Melothria</i>	<i>cordata</i>	Killick (1963)	Cogn	<i>Zehneria scabra (Cogn)</i>
CUPRESSACEAE	<i>Widdringtonia</i>	<i>dracomontana</i>	Killick (1963)	Stapf	<i>W. nodiflora (Stapf)</i>
CYATHACEAE	<i>Cyathea</i>	<i>dregei</i>	Killick (1963)	Kunze	
CYPERACEAE	<i>Ascolepis</i>	<i>capensis</i>	Killick (1963)	Ridley	
CYPERACEAE	<i>Bulbostylis</i>	<i>densa</i>	Killick (1963)	Hand. Mazz	
CYPERACEAE	<i>Bulbostylis</i>		Hill (1992); Killick (1963)	Kunth	
CYPERACEAE	<i>Bulbostylis</i>	<i>schoenoides</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Carex</i>	<i>cernua</i>	Killick (1963)	Kuekenth	<i>C. austro-africana (Kuekenth)</i>
CYPERACEAE	<i>Carex</i>	<i>killickii</i>	Killick (1963)	Nelmes	
CYPERACEAE	<i>Carex</i>	<i>monotropa</i>	Killick (1963)	Nelmes	
CYPERACEAE	<i>Carex</i>	<i>spicato-paniculata</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Carex</i>	<i>zuluensis</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Cyperus</i>	<i>compactus</i>	Killick (1963)	Lam	<i>Cyperus obtusiflorus var. obtusiflorus (Lam)</i>
CYPERACEAE	<i>Cyperus</i>	<i>semitrifidus</i>	Killick (1963)	Schrad	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
CYPERACEAE	<i>Eleocharis</i>	<i>palustris</i>	Killick (1963)	R. Br	
CYPERACEAE	<i>Ficina</i>	<i>stolonifera</i>	Killick (1963)	Boeck	
CYPERACEAE	<i>Ficina</i>		Killick (1963)	Schrad	
CYPERACEAE	<i>Ficinia</i>	<i>cinnamomea</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Fimbristylis</i>	<i>dichotoma</i>	Killick (1963)	Roem and Schult	
CYPERACEAE	<i>Fuirena</i>	<i>pubescens</i>	Hill (1992); Killick (1963)	Kuekenth	
CYPERACEAE	<i>Kyllinga</i>	<i>erecta</i>	Killick (1963)	Schumach	
CYPERACEAE	<i>Mariscus</i>	<i>congestus</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Mariscus</i>		Killick (1963)	Gaertn	
CYPERACEAE	<i>Pycnus</i>	<i>oakfortensis</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Pycnus</i>	<i>rehmannianus</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Pycnus</i>		Killick (1963)	Beauv	
CYPERACEAE	<i>Rhynchospora</i>	<i>brownii</i>	Killick (1963)	Roem and Schult	
CYPERACEAE	<i>Schoenoxiphium</i>	<i>filiforme</i>	Killick (1963)	Kuekenth	
CYPERACEAE	<i>Schoenoxiphium</i>		Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Scirpus</i>	<i>falsus</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Scirpus</i>	<i>ficinioides</i>	Killick (1963)	Kunth	
CYPERACEAE	<i>Scirpus</i>	<i>fluitans</i>	Killick (1963)	L	Isolepis fluitans (L)
CYPERACEAE	<i>Scirpus</i>	<i>hystrix</i>	Killick (1963)	Thunb	Isolepis hystrix (Thunb.)
CYPERACEAE	<i>Scirpus</i>	<i>macer</i>	Killick (1963)	Boeck	Isolepis costata var. macra (Boeck.)
CYPERACEAE	<i>Scleria</i>	<i>bulbifera</i>	Killick (1963)	Hochst	
CYPERACEAE	<i>Scleria</i>	<i>welwitschii</i>	Killick (1963)	C.B. Cl.	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
CYPERACEAE	<i>Scleria</i>	<i>woodii</i>	Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Tetraria</i>	<i>cuspidata</i>	Hill (1992); Killick (1963)	C.B. Cl.	
CYPERACEAE	<i>Tetraria</i>		Killick (1963)	Beauv	
DICRANACEAE	<i>Campylopus</i>	<i>trichodes</i>	Killick (1963)	Dix	C. pilfer (Lor)
DIOSCOREACEAE	<i>Dioscorea</i>	<i>sylvatica</i>	Killick (1963)	Kunth	
DIPSACACEAE	<i>Cephalaria</i>	<i>natalensis</i>	Killick (1963)	Kuntze	
DIPSACACEAE	<i>Scabiosa</i>	<i>columbaria</i>	Killick (1963)	L	
DIPSACACEAE	<i>Scabiosa</i>	<i>drakensbergensis</i>	Killick (1963)	B.L. Burtt	
DROSERACEAE	<i>Drosera</i>	<i>natalensis</i>	Killick (1963)	Diels	
EBENACEAE	<i>Diospyros</i>	<i>austroafricana</i>	Killick (1963)	L	
EBENACEAE	<i>Diospyros</i>	<i>lycioides</i>	Killick (1963)	Desf	
EBENACEAE	<i>Diospyros</i>	<i>whyteana</i>	Killick (1963)	F. White	
EBENACEAE	<i>Euclea</i>	<i>lancea</i>	Hill (1992); Killick (1963)	Thunb	
EBENACEAE	<i>Euclea</i>		Killick (1963)	Murray	
EBENACEAE	<i>Royena</i>	<i>hirsuta</i>	Killick (1963)	De Winter	Diospyros austro-africana (De Winter)
ENCALYPTACEAE	<i>Encalypta</i>	<i>ciliata</i>	Killick (1963)	Hedw	
ENTODONTACEAE	<i>Entodon</i>	<i>dregeanus</i>	Killick (1963)	C. Mull	E. macropodus (C Mull)
EQUISETACEAE	<i>Equisetum</i>	<i>ramosissimum</i>	Killick (1963)	Desf	
ERICACEAE	<i>Erica</i>	<i>aestiva</i>	Killick (1963)	Markotter	
ERICACEAE	<i>Erica</i>	<i>alopecurus</i>	Killick (1963)	Harv	
ERICACEAE	<i>Erica</i>	<i>cerinthoides</i>	Killick (1963)	L	
ERICACEAE	<i>Erica</i>	<i>drakensbergensis</i>	Killick (1963)	Guth and Bol	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ERICACEAE	<i>Erica</i>	<i>ebracteata</i>	Killick (1963)	H. Bol	
ERICACEAE	<i>Erica</i>	<i>flanaganii</i>	Killick (1963)	H. Bol	
ERICACEAE	<i>Erica</i>	<i>frigida</i>	Killick (1963)	H. Bol	
ERICACEAE	<i>Erica</i>	<i>oatesii</i>	Killick (1963)	Rolfe	
ERICACEAE	<i>Erica</i>		Killick (1963)	L	
ERICACEAE	<i>Erica</i>	<i>thodei</i>	Killick (1963)	Guth and Bol	
ERICACEAE	<i>Erica</i>	<i>westii</i>	Killick (1963)	L. Bol	<i>E. straussiana</i> (L. Bol)
ERICACEAE	<i>Erica</i>	<i>woodii</i>	Killick (1963)	H. Bol	
ERICACEAE	<i>Erica</i>		Killick (1963)	L	
ERICACEAE	<i>Philippia</i>	<i>evansii</i>	Killick (1963)	N.E. Br	<i>Erica evansii</i> (N.E. Br)
ERIOCAULACEAE	<i>Eriocaulon</i>	<i>abyssinicum</i>	Killick (1963)	Hochst	
ERIOCAULACEAE	<i>Eriocaulon</i>	<i>dregei</i>	Killick (1963)	Hochst	
ERIOSPERMACEAE	<i>Eriospermum</i>	<i>cooperi</i>	Hill (1992); Killick (1963)	Bak	
EUPHORBIACEAE	<i>Acalypha</i>	<i>depressinerva</i>	Killick (1963)	K. Schum	<i>A. schinzii</i> (Kuntze)
EUPHORBIACEAE	<i>Acalypha</i>	<i>punctata</i>	Hill (1992); Killick (1963)	Meisn	
EUPHORBIACEAE	<i>Adenocline</i>	<i>mercurialis</i>	Killick (1963)	Turcz	<i>A. acuta</i> (Turcz.)
EUPHORBIACEAE	<i>Clutia</i>	<i>monticola</i>	Killick (1963)	S. Moore	
EUPHORBIACEAE	<i>Clutia</i>	<i>nana</i>	Killick (1963)	Prain	
EUPHORBIACEAE	<i>Clutia</i>	<i>natalensis</i>	Killick (1963)	Bernh. ex Krauss	
EUPHORBIACEAE	<i>Euphorbia</i>	<i>epicyparissias</i>	Killick (1963)	E. May. Ex Boiss	
EUPHORBIACEAE	<i>Euphorbia</i>	<i>ericoides</i>	Killick (1963)	Lam	
EUPHORBIACEAE	<i>Euphorbia</i>	<i>guenzii</i>	Killick (1963)	Boiss	

Family	Genus	Species	Cited Author	Author	Current Species Name and Author
EUSTICHIACEAE	<i>Eustichia</i>	<i>longirostis</i>	Killick (1963)	Brid	
FABACEAE	<i>Argyrolobium</i>	<i>collinum</i>	Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Argyrolobium</i>	<i>tuberosum</i>	Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Buchenroedera</i>	<i>lotononoides</i>	Hill (1992); Killick (1963)	Scott Elliot	Lotonotis lotonoides(B-E. van Wyk)
FABACEAE	<i>Calpurnia</i>	<i>intrusa</i>	Hill (1992); Killick (1963)	E. Mey	Calpurina villosa var. intrusa (E. Mey)
FABACEAE	<i>Desmodium</i>	<i>repandum</i>	Killick (1963)	(Vahl) DC.	
FABACEAE	<i>Dumasia</i>	<i>villosa</i>	Killick (1963)	DC	
FABACEAE	<i>Eriosema</i>	<i>kraussianum</i>	Killick (1963)	Meisn	
FABACEAE	<i>Indigofera</i>	<i>cuneifolia</i>	Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Indigofera</i>	<i>hedyantha</i>	Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Indigofera</i>	<i>longebarbata</i>	Hill (1992); Killick (1963)	Enbgl.	
FABACEAE	<i>Indigofera</i>	<i>woodii</i>	Killick (1963)	H. Bol	
FABACEAE	<i>Lessertia</i>	<i>perannans</i>	Killick (1963)	DC	
FABACEAE	<i>Lessertia</i>	<i>thodei</i>	Killick (1963)	L. Bol	
FABACEAE	<i>Lotononis</i>	<i>eriantha</i>	Killick (1963)	Benth	
FABACEAE	<i>Lotononis</i>	<i>galpinii</i>	Killick (1963)	Dummer	
FABACEAE	<i>Lotononis</i>	<i>trisegmentata</i>	Killick (1963)	Phill	
FABACEAE	<i>Lotononis</i>		Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Melolobium</i>		Killick (1963)	Eckl. & Zeyh	
FABACEAE	<i>Psoralea</i>		Killick (1963)	L	
FABACEAE	<i>Rhynchosia</i>	<i>caribaea</i>	Killick (1963)	DC	
FABACEAE	<i>Sutherlandia</i>	<i>montana</i>	Killick (1963)	Phill & R.A. Dyer	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
FABACEAE	<i>Tephrosia</i>	<i>polystachya</i>	Killick (1963)	E. Mey	
FABACEAE	<i>Trifolium</i>	<i>burchellianum</i>	Killick (1963)	Ser	
FABRONIACEAE	<i>Fabronia</i>	<i>abyssinica</i>	Killick (1963)	C. Mull	
FABRONIACEAE	<i>Fabronia</i>	<i>perciliata</i>	Killick (1963)	C. Mull	
FISSIDENTACEAE	<i>Fissidens</i>	<i>amblyophyllus</i>	Killick (1963)	C. Mull	<i>F. asplenoides</i> (C. Mull)
FISSIDENTACEAE	<i>Fissidens</i>	<i>glaucescens</i>	Killick (1963)	Hornsch	
FISSIDENTACEAE	<i>Fissidens</i>	<i>laxifolius</i>	Killick (1963)	Hornsch	<i>F. curvatus</i> (Hornsch.)
FLACOURTIACEAE	<i>Dovyalis</i>	<i>zeyheri</i>	Killick (1963)	Warb	
FLACOURTIACEAE	<i>Kiggelaria</i>	<i>africana</i>	Killick (1963)	L	
FLACOURTIACEAE	<i>Scolopia</i>	<i>mundii</i>	Killick (1963)	Warb	
FLACOURTIACEAE	<i>Trimera</i>	<i>grandiflora</i>	Killick (1963)	Warb	
FUMARIACEAE	<i>Fumaria</i>	<i>officinalis</i>	Killick (1963)	Harv	
FUNARIACEAE	<i>Funaria</i>	<i>hygrometrica</i>	Killick (1963)	Hedw	
GENTIANACEAE	<i>Chironia</i>	<i>krebsii</i>	Killick (1963)	Griseb	
GENTIANACEAE	<i>Chironia</i>	<i>peglerae</i>	Killick (1963)	Prain	
GENTIANACEAE	<i>Sebaea</i>	<i>filiformis</i>	Killick (1963)	Schinz	
GENTIANACEAE	<i>Sebaea</i>	<i>macrophylla</i>	Killick (1963)	Gilg	
GENTIANACEAE	<i>Sebaea</i>	<i>natalensis</i>	Killick (1963)	Schinz	
GENTIANACEAE	<i>Sebaea</i>	<i>procumbens</i>	Killick (1963)	A.W. Hill	
GENTIANACEAE	<i>Sebaea</i>	<i>repens</i>	Killick (1963)	Schinz	
GENTIANACEAE	<i>Sebaea</i>	<i>thodeana</i>	Killick (1963)	Gilg	
GENTIANACEAE	<i>Sebaea</i>		Killick (1963)	Soland. ex Br.	



Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
GENTIANACEAE	<i>Swertia</i>	<i>welwitschii</i>	Killick (1963)	Engl	
GERANIACEAE	<i>Geranium</i>	<i>caffrum</i>	Killick (1963)	Eckl. & Zeyh	
GERANIACEAE	<i>Geranium</i>		Killick (1963)	Burm	
GERANIACEAE	<i>Geranium</i>	<i>ornithopodum</i>	Killick (1963)	Hilliard & Burt	
GERANIACEAE	<i>Geranium</i>	<i>pulchrum</i>	Killick (1963)	N.E. Br	
GERANIACEAE	<i>Monsonia</i>	<i>attenuata</i>	Killick (1963)	Harv	
GERANIACEAE	<i>Pelargonium</i>	<i>alchemilloides</i>	Killick (1963)	L'Herit	
GERANIACEAE	<i>Pelargonium</i>	<i>flabellifolium</i>	Killick (1963)	Harv	<i>P. luridum</i> (Harv.)
GESNERIACEAE	<i>Streptocarpus</i>	<i>gardenii</i>	Killick (1963)	Hook	
GLEICHENIACEAE	<i>Sticherus</i>	<i>umbraculiferus</i>	Killick (1963)	Presl	<i>Gleivhenia umbraculifera</i> (Ching)
GREYIACEAE	<i>Greyia</i>	<i>sutherlandii</i>	Killick (1963)	Hook & Harv	
GRIMMIACEAE	<i>Grimmia</i>	<i>apocarpa</i>	Killick (1963)	Hedw	<i>Schistidium apocarpum</i> (Hedw.)
GRIMMIACEAE	<i>Grimmia</i>	<i>commutata</i>	Killick (1963)	Hueb	<i>G. ovalis</i> (Hueb.)
GRIMMIACEAE	<i>Grimmia</i>	<i>drakensbergensis</i>	Killick (1963)	Sim	<i>G. pulvinata</i> (Sim)
GRIMMIACEAE	<i>Grimmia</i>	<i>pulvinata</i>	Killick (1963)	J.E. Sm	
HALORAGACEAE	<i>Gunnera</i>	<i>perpensa</i>	Killick (1963)	L	
HOOKERIACEAE	<i>Hypopterygium</i>	<i>laricinum</i>	Killick (1963)	Brid	
HYACINTHACEAE	<i>Albuca</i>	<i>baurii</i>	Killick (1963)	Bak	<i>A. etosa</i> (Bak.)
HYACINTHACEAE	<i>Albuca</i>	<i>trichophylla</i>	Killick (1963)	Bak	<i>A. shawii</i> (Bak.)
HYACINTHACEAE	<i>Dipcadi</i>	<i>gracillimum</i>	Killick (1963)	Bak	
HYACINTHACEAE	<i>Drimia</i>	<i>neriniformis</i>	Killick (1963)	Bak	
HYACINTHACEAE	<i>Elsiea</i>	<i>flanaganii</i>	Killick (1963)	Leighton	<i>Ornithogalum paludosum</i> (Leighton)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
HYACINTHACEAE	<i>Elsiea</i>		Killick (1963)	Leighton	
HYACINTHACEAE	<i>Eucomis</i>	<i>bicolor</i>	Killick (1963)	Bak	
HYACINTHACEAE	<i>Eucomis</i>	<i>humilis</i>	Killick (1963)	Bak	
HYACINTHACEAE	<i>Galtonia</i>	<i>viridiflorum</i>	Killick (1963)	Verdoorn	
HYACINTHACEAE	<i>Schizocarphus</i>	<i>rigidifolius</i>	Killick (1963)	v.d. Merwe	<i>Scilla nervosa</i> (v.d. Merwe)
HYACINTHACEAE	<i>Schizocarphus</i>		Killick (1963)	v.d. Merwe	
HYACINTHACEAE	<i>Scilla</i>	<i>natalensis</i>	Killick (1963)	Planch	
HYACINTHACEAE	<i>Scilla</i>	<i>saturata</i>	Killick (1963)	Bak	<i>Ledebouria cooperi</i> (Bak.)
HYACINTHACEAE	<i>Scilla</i>		Killick (1963)	L	
HYACINTHACEAE	<i>Urginea</i>	<i>macrocentra</i>	Killick (1963)	Bak	
HYACINTHACEAE	<i>Urginea</i>	<i>tenella</i>	Killick (1963)	Bak	
HYMENOPHYLLACEAE	<i>Trichomanes</i>	<i>melanotrichum</i>	Killick (1963)	Schlechtd	
HYPNACEAE	<i>Hypnum</i>		Killick (1963)	Hedw	
HYPNACEAE	<i>Microthamnion</i>		Killick (1963)	Hedw	
HYPOXIDACEAE	<i>Hypoxis</i>	<i>membranacea</i>	Killick (1963)	Bak	
HYPOXIDACEAE	<i>Hypoxis</i>	<i>multiceps</i>	Killick (1963)	Buchinger ex Bak	
HYPOXIDACEAE	<i>Hypoxis</i>		Killick (1963)	L	
HYPOXIDACEAE	<i>Rhodohypoxis</i>	<i>baurii</i>	Killick (1963)	Nel	
HYPOXIDACEAE	<i>Rhodohypoxis</i>	<i>palustris</i>	Killick (1963)	Killick	<i>R. milloides</i> (Killick)
HYPOXIDACEAE	<i>Rhodohypoxis</i>	<i>rubella</i>	Killick (1963)	Nel	
ICANINACEAE	<i>Apodytes</i>	<i>dimidiata</i>	Killick (1963)	E. May. ex Arn	
ICANINACEAE	<i>Cassinopsis</i>	<i>ilicifolia</i>	Killick (1963)	Hochst	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
IRIDACEAE	<i>Aristea</i>	<i>angolensis</i>	Killick (1963)	Bak	
IRIDACEAE	<i>Aristea</i>	<i>cognata</i>	Killick (1963)	N.E. Br	
IRIDACEAE	<i>Curtonus</i>	<i>paniculatus</i>	Killick (1963)	N.E. Br	<i>Crocoshia paniculata</i> (N.E. Br.)
IRIDACEAE	<i>Dierama</i>	<i>igneum</i>	Killick (1963)	Klatt	
IRIDACEAE	<i>Dierama</i>	<i>robustum</i>	Killick (1963)	N.E. Br	
IRIDACEAE	<i>Dietes</i>	<i>vegeta</i>	Killick (1963)	N.E. Br	<i>D. iridioides</i> (N.E. Br.)
IRIDACEAE	<i>Gladiolus</i>	<i>flanaganii</i>	Killick (1963)	Bak	
IRIDACEAE	<i>Gladiolus</i>	<i>longicollis</i>	Killick (1963)	Bak	
IRIDACEAE	<i>Gladiolus</i>	<i>psittacinus</i>	Killick (1963)	Hook	<i>G. dalenii</i> (Hook)
IRIDACEAE	<i>Gladiolus</i>	<i>subaphyllus</i>	Killick (1963)	G.J. Lewis	<i>G. parvulus</i> (N.E. Br.)
IRIDACEAE	<i>Gladiolus</i>	<i>woodii</i>	Killick (1963)	Bak	
IRIDACEAE	<i>Hesperantha</i>		Killick (1963)	Ker-Gawl	
IRIDACEAE	<i>Moraea</i>	<i>culmea</i>	Killick (1963)	Killick	<i>M. trifida</i> (Killick)
IRIDACEAE	<i>Moraea</i>	<i>modesta</i>	Killick (1963)	Killick	
IRIDACEAE	<i>Moraea</i>	<i>mossii</i>	Killick (1963)	N.E. Br	<i>M. stricta</i> (N.E. Br.)
IRIDACEAE	<i>Moraea</i>	<i>pubiflora</i>	Killick (1963)	N.E. Br	
IRIDACEAE	<i>Moraea</i>	<i>spathulata</i>	Killick (1963)	Klatt	
IRIDACEAE	<i>Moraea</i>		Killick (1963)	Mill	
IRIDACEAE	<i>Tritonia</i>	<i>lineata</i>	Killick (1963)	Ker-Gawl	
IRIDACEAE	<i>Watsonia</i>	<i>lepida</i>	Killick (1963)	N.E. Br	
IRIDACEAE	<i>Watsonia</i>	<i>socium</i>	Killick (1963)	J.W. Mathews	<i>W. pillansii</i> (J. W. Mathews & L. Bol.)
JUBULACEAE	<i>Frullania</i>	<i>ecklonii</i>	Killick (1963)	Gott & Lindeb	<i>F. arecae</i> (Gott. & Lindenb.)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
JUBULACEAE	<i>Frullania</i>	<i>natalensis</i>	Killick (1963)	Sim	<i>F. depressa</i> (Sim)
JUBULACEAE	<i>Frullania</i>		Killick (1963)	Raddi	
JUNCACEAE	<i>Juncus</i>	<i>dregeanus</i>	Killick (1963)	Kunth	
JUNCACEAE	<i>Juncus</i>	<i>exsertus</i>	Killick (1963)	Buchen	
JUNCACEAE	<i>Juncus</i>	<i>oxycarpus</i>	Killick (1963)	E. May ex Kunth	
JUNCACEAE	<i>Juncus</i>	<i>Punctorius</i>	Killick (1963)	L	
JUNCACEAE	<i>Juncus</i>	<i>rostratus</i>	Killick (1963)	Buchen	<i>J. exsertus</i> subsp. <i>exsertus</i> (Buchen.)
JUNCACEAE	<i>Luzula</i>	<i>africana</i>	Killick (1963)	Drege ex Steud	
LAMIACEAE	<i>Aeolanthus</i>	<i>canescens</i>	Killick (1963)	Guerke	<i>A. buchnerianus</i> (Guerke)
LAMIACEAE	<i>Ajuga</i>	<i>ophrydis</i>	Killick (1963)	Burch. ex Benth	
LAMIACEAE	<i>Becium</i>		Killick (1963)	Lindl.	
LAMIACEAE	<i>Hemizygia</i>	<i>elliottii</i>	Killick (1963)	Ashby	
LAMIACEAE	<i>Leonotis</i>	<i>dysophylla</i>	Killick (1963)	Benth	<i>L. ocymifolia</i> var. <i>ocymifolia</i> (Benth.)
LAMIACEAE	<i>Leonotis</i>	<i>ocymifolia</i>		Burm. F.	
LAMIACEAE	<i>Plectranthus</i>	<i>calycinus</i>		Benth	<i>Rabdosiella calycina</i> (T. Cooke)
LAMIACEAE	<i>Plectranthus</i>	<i>dolichopodus</i>	Killick (1963)	Briq	
LAMIACEAE	<i>Plectranthus</i>	<i>grallatus</i>	Hill (1992); Killick (1963)	Briq	
LAMIACEAE	<i>Plectranthus</i>		Killick (1963)	L'Herit	
LAMIACEAE	<i>Pycnostachys</i>	<i>reticulata</i>	Killick (1963)	Benth	
LAMIACEAE	<i>Rabdosiella</i>	<i>calycina</i>	Killick (1963)	Codd	
LAMIACEAE	<i>Satureja</i>	<i>compacta</i>	Killick (1963)	Killick	
LAMIACEAE	<i>Satureja</i>	<i>grandibracteata</i>	Killick (1963)	Killick	

Family	Genus	Species	Cited Author	Author	Current Species Name and Author
LAMIACEAE	<i>Satureja</i>	<i>reptans</i>	Killick (1963)	Killick	
LAMIACEAE	<i>Stachys</i>	<i>albiflora</i>	Killick (1963)	N.E. Br	
LAMIACEAE	<i>Stachys</i>	<i>caffra</i>	Killick (1963)	E. May	
LAMIACEAE	<i>Stachys</i>	<i>dregeana</i>	Killick (1963)	Benth	
LAMIACEAE	<i>Stachys</i>		Killick (1963)	L	
LAMIACEAE	<i>Syncolostemon</i>	<i>macranthus</i>	Killick (1963)	Ashby	
LAURACEAE	<i>Ocotea</i>	<i>bullata</i>	Killick (1963)	Baill	
LEJEUNEACEAE	<i>Archilejeunea</i>		Killick (1963)	Steph	
LEJEUNEACEAE	<i>Archilejeunea</i>		Killick (1963)	Steph	
LEJEUNEACEAE	<i>Ptychanthus</i>	<i>striatus</i>	Killick (1963)	Nees	
LINACEAE	<i>Linum</i>	<i>thunbergii</i>	Killick (1963)	Eckl. & Zeyh	
LOBELIACEAE	<i>Cyphia</i>	<i>elata</i>	Killick (1963)	Harv	
LOBELIACEAE	<i>Lobelia</i>	<i>decipiens</i>	Killick (1963)	Sond	Monopsis decipiens (Sond.)
LOBELIACEAE	<i>Lobelia</i>		Killick (1963)	Lam	
LOBELIACEAE	<i>Lobelia</i>	<i>flaccida</i>	Killick (1963)	A. DC	
LOBELIACEAE	<i>Lobelia</i>	<i>patula</i>	Killick (1963)	L	
LOBELIACEAE	<i>Lobelia</i>	<i>preslii</i>	Killick (1963)	A. DC	
LOGANIACEAE	<i>Buddleja</i>	<i>auriculata</i>		Prain	B. auriculata (Prain)
		<i>euryfolia</i>			
LOGANIACEAE	<i>Buddleja</i>	<i>corrugata</i>	Killick (1963)	Phill	Buddleja loricata (Phill)
LOGANIACEAE	<i>Buddleja</i>	<i>salviifolia</i>	Killick (1963)	Lam	
LOGANIACEAE	<i>Gomphostigma</i>	<i>virgatum</i>	Killick (1963)	Baill	

Family	Genus	Species	Cited Author	Author	Current Species Name and Author
LOMARIOPSIDACEAE	<i>Elaphoglossum</i>	<i>angustatum</i>	Killick (1963)	Hieron	
LOPHOCOLEACEAE	<i>Chiloscyphus</i>		Killick (1963)	Corda	
LOPHOCOLEACEAE	<i>Lophocolea</i>		Killick (1963)	Dum	
LYCOPODIACEAE	<i>Lycopodium</i>	<i>saururus</i>	Killick (1963)	Lam	
LYCOPODIACEAE	<i>Lycopodium</i>	<i>verticillatum</i>	Killick (1963)	L	
MALVACEAE	<i>Hibiscus</i>	<i>trionum</i>	Killick (1963)	L	
MALVACEAE	<i>Hibiscus</i>		Killick (1963)	L	
MALVACEAE	<i>Sphaeralcea</i>	<i>pannosa</i>	Killick (1963)	H. Bol	<i>Anisodonteia julii</i> subsp. <i>pannosa</i> (H. Bol.)
MARCHANTACEAE	<i>Marchantia</i>	<i>wilmsii</i>	Killick (1963)	Steph	
MELIACEAE	<i>Ekebergia</i>	<i>meyeri</i>	Killick (1963)	Presl & C. DC	<i>E. capensis</i> (Presl. & C. DC)
MELIANTHACEAE	<i>Melianthus</i>	<i>villosus</i>	Killick (1963)	H. Bol	
MESEMBRYANTHEACEAE	<i>Delosperma</i>	<i>obtusum</i>	Killick (1963)	L. Bol	
METEORACEAE	<i>Squamidium</i>	<i>rehmannii</i>	Killick (1963)	Broth	<i>S. brasilense</i> (Broth.)
METZGERIACEAE	<i>Metzgeria</i>		Killick (1963)	Raddi	
MNIACEAE	<i>Mnium</i>	<i>rostratum</i>	Killick (1963)	Schrad	<i>Plagiomnium rhynchophorum</i> (Dix.)
MORACEAE	<i>Ficus</i>	<i>ingens</i>	Killick (1963)	Miq	
MYRICACEAE	<i>Myrica</i>	<i>pilulifera</i>		Rendle	
MYRICACEAE	<i>Myrica</i>	<i>serrata</i>	Hill (1992); Killick (1963)	Lam	
MYRSINACEAE	<i>Myrsine</i>	<i>africana</i>	Hill (1992); Killick (1963)	L	
MYRSINACEAE	<i>Rapanea</i>	<i>melanophloeos</i>	Killick (1963)	Mez	
OLINACEAE	<i>Olinia</i>	<i>emarginata</i>	Killick (1963)	Burt Davy	
ONAGRACEAE	<i>Epilobium</i>	<i>flavescens</i>	Killick (1963)	E. Mey ex Sond	<i>E. capense</i> (E. Mey. Ex. Sond.)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ONAGRACEAE	<i>Epilobium</i>	<i>hirsutum</i>	Killick (1963)	L	
ONAGRACEAE	<i>Epilobium</i>	<i>salignum</i>	Hill (1992); Killick (1963)	Hauskn	
ONAGRACEAE	<i>Oenothera</i>	<i>laciniata</i>	Killick (1963)	Hill	
ONAGRACEAE	<i>Oenothera</i>	<i>rosea</i>	Killick (1963)	L'Herit	
OPHIOGLOSSACEAE	<i>Ophioglossum</i>	<i>reticulatum</i>	Killick (1963)	L	
OPHIOGLOSSACEAE	<i>Ophioglossum</i>		Killick (1963)	L	
ORCHIDACEAE	<i>Brownleea</i>	<i>macroceras</i>	Killick (1963)	Sond	
ORCHIDACEAE	<i>Corycium</i>	<i>nigrescens</i>	Killick (1963)	Sond	
ORCHIDACEAE	<i>Disa</i>	<i>fragrans</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Disa</i>	<i>macowanii</i>	Killick (1963)	Reichb	<i>D. versicolor</i> ( Reichb.)
ORCHIDACEAE	<i>Disa</i>	<i>stachyoides</i>	Killick (1963)	Reichb	
ORCHIDACEAE	<i>Disa</i>		Killick (1963)	Berg	
ORCHIDACEAE	<i>Disperis</i>	<i>cardiophora</i>	Killick (1963)	Harv	
ORCHIDACEAE	<i>Disperis</i>	<i>fanniniae</i>	Killick (1963)	Harv	
ORCHIDACEAE	<i>Disperis</i>	<i>stenoplectron</i>	Killick (1963)	Reichb	
ORCHIDACEAE	<i>Disperis</i>	<i>thorncroftii</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Disperis</i>	<i>tysonii</i>	Killick (1963)	H. Bol	
ORCHIDACEAE	<i>Eulophia</i>	<i>calanthoides</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Eulophia</i>	<i>foliosa</i>	Killick (1963)	H. Bol	
ORCHIDACEAE	<i>Eulophia</i>	<i>hians</i>	Killick (1963)	Rolfe	<i>E. clavicornis</i> var. <i>clavicornis</i> (Spreng.)
ORCHIDACEAE	<i>Eulophia</i>	<i>leontoglossa</i>	Killick (1963)	Reichb	
ORCHIDACEAE	<i>Eulophia</i>	<i>zeyheri</i>	Killick (1963)	Hook	<i>E. welwitschii</i> (Hook.)

Family	Genus	Species	Cited Author	Author	Current Species Name and Author
ORCHIDACEAE	<i>Eulophia</i>		Killick (1963)	R. Br ex Lindl	
ORCHIDACEAE	<i>Habernaria</i>	<i>dregeana</i>	Hill (1992); Killick (1963)	Lindl. FP	
ORCHIDACEAE	<i>Habernaria</i>	<i>orangana</i>	Killick (1963)	Reichb. F.	<i>H. dives</i> (Reichb)
ORCHIDACEAE	<i>Habernaria</i>	<i>petri</i>	Killick (1963)	Schltr	<i>H. lithophila</i> (Schltr.)
ORCHIDACEAE	<i>Habernaria</i>	<i>tridens</i>	Killick (1963)	Lindl	
ORCHIDACEAE	<i>Holothrix</i>	<i>orthoceros</i>	Killick (1963)	Reichb. F.	
ORCHIDACEAE	<i>Holothrix</i>	<i>scopularia</i>	Killick (1963)	Reichb. F.	
ORCHIDACEAE	<i>Holothrix</i>	<i>thodei</i>	Killick (1963)	Rolfe	
ORCHIDACEAE	<i>Huttonaea</i>	<i>grandiflora</i>	Killick (1963)	Rolfe	
ORCHIDACEAE	<i>Huttonaea</i>	<i>pulchra</i>	Killick (1963)	Harv. FP	
ORCHIDACEAE	<i>Liparis</i>	<i>bowkeri</i>	Killick (1963)	Harv. FP	
ORCHIDACEAE	<i>Monadenia</i>	<i>basutorum</i>	Killick (1963)	Rolfe	<i>Disa basutorum</i> (Rolfe)
ORCHIDACEAE	<i>Neobolusia</i>	<i>tysonii</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Neobolusia</i>	<i>virginea</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Neobolusia</i>		Killick (1963)	Schltr	
ORCHIDACEAE	<i>Polystachya</i>	<i>ottoniana</i>	Killick (1963)	Reichb	
ORCHIDACEAE	<i>Pterygodium</i>	<i>hastatum</i>	Killick (1963)	H. Bol	
ORCHIDACEAE	<i>Satyrium</i>	<i>longicauda</i>	Killick (1963)	Lindl	
ORCHIDACEAE	<i>Satyrium</i>	<i>neglectum</i>	Killick (1963)	Schltr	
ORCHIDACEAE	<i>Satyrium</i>		Killick (1963)	Swartz	
ORCHIDACEAE	<i>Schizochilus</i>		Killick (1963)	Sond	
ORCHIDACEAE	<i>Stenoglottis</i>	<i>fimbriata</i>	Killick (1963)	Lindl	



Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
ORTHOTRICHACEAE	<i>Macromitrium</i>		Killick (1963)	Brid	
ORTHOTRICHACEAE	<i>Schlotheimia</i>	<i>rufo-aeruginosa</i>	Killick (1963)	C. Mull	Species insufficiently known
OXALIDACEAE	<i>Oxalis</i>	<i>obliquifolia</i>	Killick (1963)	Steud ex Rich	
PAPAVERACEAE	<i>Papaver</i>	<i>aculeatum</i>	Killick (1963)	Thunb	
PERIPLOCACEAE	<i>Raphionacme</i>	<i>hirsuta</i>	Killick (1963)	R.A. Dyer ex Phill	
PHYTOLACCACEAE	<i>Phytolacca</i>		Killick (1963)	L	
PIPERACEAE	<i>Peperomia</i>	<i>reflexa</i>	Killick (1963)	A Dietra	<i>P. tetraphylla</i> (A. Dietr.)
PITTOSPARACEAE	<i>Pittosporum</i>	<i>viridiflorum</i>	Killick (1963)	Sims	
PLAGIOCHILACEAE	<i>Plagiochila</i>	<i>natalensis</i>	Killick (1963)	Pears	<i>P. heterostipa</i> (Pears.)
POACEAE	<i>Agrostis</i>	<i>barbuligera</i>	Killick (1963)	Stapf	
POACEAE	<i>Agrostis</i>	<i>huttoniae</i>	Killick (1963)	C.E.Hubb	<i>A. lachnatha</i> var. <i>lachnatha</i> (C.E. Hubb.)
POACEAE	<i>Aira</i>	<i>caryophyllea</i>	Killick (1963)	L	<i>A. cupaniana</i> (L.)
POACEAE	<i>Alloteropsis</i>	<i>semialata</i>	Killick (1963)	R. Br	
POACEAE	<i>Andropogon</i>	<i>appendiculatus</i>	Killick (1963)	Nees	
POACEAE	<i>Andropogon</i>	<i>eucomus</i>	Killick (1963)	Nees	
POACEAE	<i>Andropogon</i>	<i>filifolius</i>	Hill (1992); Killick (1963)	Steud	<i>Diheteropogon filifolius</i> (Steud)
POACEAE	<i>Andropogon</i>	<i>ravus</i>	Killick (1963)	J.G. Anders	
POACEAE	<i>Anthoxanthum</i>	<i>ecklonii</i>	Killick (1963)	Stapf	
POACEAE	<i>Aristida</i>	<i>galpinii</i>	Hill (1992); Killick (1963)	Stapf	<i>A. junctiformis</i> subsp. <i>galpinii</i> (Stapf.)
POACEAE	<i>Aristida</i>	<i>monticola</i>	Hill (1992); Killick (1963)	Henr	
POACEAE	<i>Arundinaria</i>	<i>tesselata</i>	Killick (1963)	Munro	<i>Thamnocalamus tessellatus</i> (Munro)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
POACEAE	<i>Arundinella</i>	<i>nepalensis</i>	Killick (1963)	Trin	
POACEAE	<i>Brachiaria</i>	<i>marlothii</i>	Killick (1963)	Stent	
POACEAE	<i>Brachiaria</i>	<i>serrata</i>	Killick (1963)	Stapf	
POACEAE	<i>Brachypodium</i>	<i>bolusii</i>	Killick (1963)	Stapf	
POACEAE	<i>Brachypodium</i>	<i>flexum</i>	Killick (1963)	Nees	
POACEAE	<i>Bromus</i>	<i>speciosus</i>	Killick (1963)	Nees	
POACEAE	<i>Catalepis</i>	<i>gracilis</i>	Killick (1963)	Stapf & Stent	
POACEAE	<i>Crinipes</i>	<i>gynoglossa</i>	Hill (1992); Killick (1963)	Goossens	<i>Styppeiochloa gynpglossa</i> (Goossens)
POACEAE	<i>Cymbopogon</i>	<i>validus</i>	Hill (1992); Killick (1963)	Stapf ex Burt Davy	
POACEAE	<i>Cynodon</i>	<i>hirsutus</i>	Killick (1963)	Stent	
POACEAE	<i>Danthonia</i>	<i>disticha</i>	Killick (1963)	Nees	<i>Merxmeullera disticha</i> (Nees)
POACEAE	<i>Danthonia</i>	<i>drakensbergensis</i>	Killick (1963)	Schweick	<i>Merxmeullera drakensbergensis</i> (Schweick.)
POACEAE	<i>Danthonia</i>	<i>macowanii</i>	Killick (1963)	Stapf	<i>Merxmeullera macowanii</i> (Stapf.)
POACEAE	<i>Danthonia</i>	<i>stereophylla</i>	Killick (1963)	J.G. Anders	<i>Merxmuellera stereophylla</i> (J.G. Anders)
POACEAE	<i>Danthonia</i>	<i>stricta</i>	Killick (1963)	Schrad	<i>Merxmeullera stricta</i> (Schrad.)
POACEAE	<i>Danthonia</i>		Killick (1963)	DC	
POACEAE	<i>Digitaria</i>	<i>diagonalis</i>	Killick (1963)	Stapf	
POACEAE	<i>Digitaria</i>	<i>flaccida</i>	Killick (1963)	Stapf	
POACEAE	<i>Digitaria</i>	<i>monodactyla</i>	Hill (1992); Killick (1963)	Stapf	
POACEAE	<i>Digitaria</i>	<i>ternata</i>	Killick (1963)	Stapf	
POACEAE	<i>Digitaria</i>	<i>tricholaenoides</i>	Killick (1963)	Stapf	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
POACEAE	<i>Ehrharta</i>	<i>longigluma</i>	Killick (1963)	C.E.Hubb	
POACEAE	<i>Eleusine</i>	<i>africana</i>	Killick (1963)	K.-O.Byrne	<i>E. coracana subsp. Africana</i> (K.-O. Byrne)
POACEAE	<i>Elionurus</i>	<i>argenteus</i>		Kunth ex Willd	<i>Elionurus muticus</i> (Kunth)
POACEAE	<i>Eragrostis</i>	<i>caesis</i>	Killick (1963)	Stapf	
POACEAE	<i>Eragrostis</i>	<i>capensis</i>	Killick (1963)	Trin	
POACEAE	<i>Eragrostis</i>	<i>curvula</i>	Killick (1963)	Nees	
POACEAE	<i>Eragrostis</i>	<i>curvula forme</i>	Killick (1963)	Nees	
POACEAE	<i>Eragrostis</i>	<i>nebulosa</i>	Killick (1963)	Stapf	<i>E. planiculmis</i> (Stapf)
POACEAE	<i>Eragrostis</i>	<i>plana</i>	Killick (1963)	Nees	
POACEAE	<i>Eragrostis</i>	<i>planiculmis</i>	Killick (1963)	Nees	
POACEAE	<i>Eragrostis</i>	<i>racemosa</i>	Killick (1963)	Steud	
POACEAE	<i>Eragrostis</i>		Hill (1992); Killick (1963)	Wolf	
POACEAE	<i>Eulalia</i>	<i>villosa</i>	Hill (1992); Killick (1963)	Nees	
POACEAE	<i>Festuca</i>	<i>caprina</i>	Killick (1963)	Nees	
POACEAE	<i>Festuca</i>	<i>costata</i>	Killick (1963)	Nees	
POACEAE	<i>Festuca</i>	<i>scabra</i>	Killick (1963)	Vahl	
POACEAE	<i>Festuca</i>		Killick (1963)	L	
POACEAE	<i>Harpochloa</i>	<i>falx</i>	Killick (1963)	Kuntze	
POACEAE	<i>Helictotrichon</i>	<i>hirtulum</i>	Killick (1963)	(Steud). Schweick	
POACEAE	<i>Helictotrichon</i>	<i>turgidulum</i>	Killick (1963)	(Steud). Schweick	
POACEAE	<i>Heteropogon</i>	<i>contortus</i>	Killick (1963)	Roem & Schult	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
POACEAE	<i>Hyparrhenia</i>	<i>aucta</i>	Killick (1963)	Stapf ex Stent	
POACEAE	<i>Hyparrhenia</i>	<i>dregeana</i>	Hill (1992); Killick (1963)	Stapf	
POACEAE	<i>Hyparrhenia</i>	<i>glauca</i>	Killick (1963)	Stent	H. tamba (Stent.)
POACEAE	<i>Hyparrhenia</i>	<i>hirta</i>	Hill (1992); Killick (1963)	Stapf	
POACEAE	<i>Hyparrhenia</i>	<i>tamba</i>	Killick (1963)	Stapf	
POACEAE	<i>Imperata</i>	<i>cylindrica</i>	Killick (1963)	Raeuschel	
POACEAE	<i>Ischaemum</i>	<i>arcuatum</i>	Killick (1963)	Stapf	I. fasciculatum (Stapf)
POACEAE	<i>Ischaemum</i>	<i>franksae</i>	Hill (1992); Killick (1963)	J.M. Wood	Phacelurus franksiae (J.M. Wood)
POACEAE	<i>Koeleria</i>	<i>cristata</i>	Killick (1963)	Pers	Koeleria capensis (C.E. Hubb.)
POACEAE	<i>Loudetia</i>	<i>simplex</i>	Hill (1992); Killick (1963)	Steud	
POACEAE	<i>Microchloa</i>	<i>caffra</i>	Killick (1963)	Nees	
POACEAE	<i>Miscanthidium</i>	<i>capensis</i>	Killick (1963)	Nees	Miscanthus capensis (Nees)
POACEAE	<i>Monocymbium</i>	<i>ceresiiforme</i>	Killick (1963)	Stapf	
POACEAE	<i>Oplismenus</i>	<i>hirtellus</i>	Killick (1963)	Beauv	
POACEAE	<i>Panicum</i>	<i>ecklonii</i>	Killick (1963)	Nees	
POACEAE	<i>Panicum</i>		Killick (1963)	L	
POACEAE	<i>Panicum</i>	<i>natalense</i>	Killick (1963)	Hoschst	
POACEAE	<i>Paspalum</i>	<i>dilatatum</i>	Hill (1992); Killick (1963)	Poir	
POACEAE	<i>Pennisetum</i>	<i>natalense</i>	Killick (1963)	Stapf	
POACEAE	<i>Pennisetum</i>	<i>sphacelatum</i>	Killick (1963)	Dur & Schinz	
POACEAE	<i>Pennisetum</i>	<i>thunbergii</i>	Hill (1992); Killick (1963)	Kunth	
POACEAE	<i>Pentaschistis</i>	<i>aurea pilosoguma</i>	Killick (1963)	McClean	Pentaschistis aurea (McClean)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
POACEAE	<i>Pentaschistis</i>	<i>tysonii</i>	Killick (1963)	Stapf	
POACEAE	<i>Penthaschistis</i>	<i>oreodoxa</i>	Killick (1963)	Schweick	
POACEAE	<i>Phragmites</i>	<i>communis</i>	Killick (1963)	Trin	P australis (Trin.)
POACEAE	<i>Poa</i>	<i>binata</i>	Killick (1963)	Nees	
POACEAE	<i>Pseudobromus</i>	<i>africanus</i>	Killick (1963)	Stapf	Festuca africana (Stapf)
POACEAE	<i>Rendlia</i>	<i>altera</i>	Hill (1992); Killick (1963)	Chiov	
POACEAE	<i>Rhynchelytrum</i>	<i>setifolium</i>	Hill (1992); Killick (1963)	Chiov	Melinis nerviglumis (Chiov.)
POACEAE	<i>Setaria</i>	<i>pallide-fusca</i>	Killick (1963)	Stapf & C.E. Hubb	
POACEAE	<i>Sporobolus</i>	<i>centrifugus</i>	Killick (1963)	Nees	
POACEAE	<i>Sporobolus</i>	<i>pyramidalis</i>	Killick (1963)	Beauv	
POACEAE	<i>Stiburus</i>	<i>alopeкуроoides</i>	Killick (1963)	Stapf	
POACEAE	<i>Stiburus</i>	<i>conrathii</i>	Killick (1963)	Hack	
POACEAE	<i>Stipa</i>	<i>dregeana</i>	Killick (1963)	Steud	
POACEAE	<i>Themeda</i>	<i>triandra</i>	Hill (1992); Killick (1963)	Forssk	
POACEAE	<i>Trachypogon</i>	<i>spicatus</i>	Hill (1992); Killick (1963)	Kuntze	
POACEAE	<i>Tristachya</i>	<i>hispida</i>	Killick (1963)	K. Schum	Tristachya leucothrix (K. Schum)
PODOCARPACEAE	<i>Podocarpus</i>	<i>falcatus</i>	Killick (1963)	R. Br ex Pers	
PODOCARPACEAE	<i>Podocarpus</i>	<i>henkelii</i>	Killick (1963)	Stapf ex Dallim & Jacks	
PODOCARPACEAE	<i>Podocarpus</i>	<i>latifolius</i>	Killick (1963)	R. Br ex Mirb	
POLYGALACEAE	<i>Muraltia</i>	<i>lancifolia</i>	Killick (1963)	Harv	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
POLYGALACEAE	<i>Muraltia</i>	<i>saxicola</i>	Killick (1963)	Chod	
POLYGALACEAE	<i>Polygala</i>	<i>hispidula</i>	Killick (1963)	Burch	
POLYGALACEAE	<i>Polygala</i>	<i>hottentota</i>	Killick (1963)	Presl	
POLYGALACEAE	<i>Polygala</i>	<i>myrtifolia</i>	Hill (1992); Killick (1963)	L. FP	
POLYGALACEAE	<i>Polygala</i>	<i>rehmannii</i>	Killick (1963)	Chod	
POLYGALACEAE	<i>Polygala</i>	<i>virgata</i>	Hill (1992); Killick (1963)	Thunb	
POLYGONACEAE	<i>Polygonum</i>		Killick (1963)	L	
POLYGONACEAE	<i>Rumex</i>	<i>woodii</i>	Killick (1963)	N.E. Br	
POLYPODIACEAE	<i>Pleopeltis</i>		Killick (1963)	NH.B.K. ex Willd	
POLYPODIACEAE	<i>Polypodium</i>		Killick (1963)	L	
POLYPODIACEAE	<i>Polypodium</i>	<i>vulgaris</i>	Killick (1963)	L	
POLYTRICHACEAE	<i>Pogonatum</i>	<i>simense</i>	Killick (1963)	Jaeg	P. oligodus (Jaeg.)
POLYTRICHACEAE	<i>Polytrichum</i>	<i>commune</i>	Killick (1963)	Hedw	
POTAMOGETONACEAE	<i>Potamogeton</i>	<i>pusillus</i>	Killick (1963)	L	
POTTIACEAE	<i>Anoetangium</i>	<i>wilmsianum</i>	Killick (1963)	Par	
POTTIACEAE	<i>Hyophila</i>	<i>zeyheri</i>	Killick (1963)	Jaeg	Trichostomum brachydontium (Jaeg.)
POTTIACEAE	<i>Tortula</i>	<i>brevimucronata</i>	Killick (1963)	Broth	T. fragilis (Broth.)
PRIMULACEAE	<i>Anagallis</i>	<i>huttonii</i>	Killick (1963)	Harv	
PRIMULACEAE	<i>Lysimachia</i>	<i>ruhmeriana</i>	Killick (1963)	Vatke	
PROTEACEAE	<i>Protea</i>	<i>dracomontana</i>	Killick (1963)	Beard	
PROTEACEAE	<i>Protea</i>	<i>multibracteata</i>	Killick (1963)	Phill	Protea caffra subspecies caffra (Phill)

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
PROTEACEAE	<i>Protea</i>	<i>roupelliae</i>	Hill (1992); Killick (1963)	Meisn	
PROTEACEAE	<i>Protea</i>	<i>subvestita</i>	Killick (1963)	N.E. Br FP	
PTERIDOPHYTA	<i>Pteridium</i>	<i>aquilinum</i>	Killick (1963)	Kuhn	
PTYCHOMITRIACEAE	<i>Ptychomitrium</i>	<i>cucullatifolium</i>	Killick (1963)	Jaeg	
RACOPILACEAE	<i>Racopilum</i>	<i>capense</i>	Killick (1963)	C Mull	
RADULACEAE	<i>Radula</i>	<i>boryana</i>	Killick (1963)	Nees	
RANUNCULACEAE	<i>Anemone</i>	<i>fanninii</i>	Killick (1963)	Harv. ex Mast	
RANUNCULACEAE	<i>Clematis</i>	<i>brachiata</i>	Killick (1963)	Thunb	
RANUNCULACEAE	<i>Ranunculus</i>	<i>baurii</i>	Killick (1963)	Macowan	
RANUNCULACEAE	<i>Ranunculus</i>	<i>multifidus</i>	Killick (1963)	Forssk	
RANUNCULACEAE	<i>Ranunculus</i>		Killick (1963)	L	
RANUNCULACEAE	<i>Thalictrum</i>	<i>rhynchocarpum</i>	Killick (1963)	Dill & Rich	
RESTIONACEAE	<i>Restio</i>	<i>fruticosus</i>	Killick (1963)	Thunb	Rhodocoma fruticosa (Thunb.)
RESTIONACEAE	<i>Restio</i>	<i>sieberi</i>	Killick (1963)	Kunth	Ischyrolepis sieberi (Kunth)
RHAMNACEAE	<i>Rhamnus</i>	<i>prinoides</i>	Killick (1963)	L'Herit	
RHAMNACEAE	<i>Scutia</i>	<i>myrtina</i>	Killick (1963)	Kurz	
ROSACEAE	<i>Agrimonia</i>	<i>eupatoria</i>	Killick (1963)	L	A. bracteata (L.)
ROSACEAE	<i>Alchemilla</i>	<i>natalensis</i>	Killick (1963)	Engl	
ROSACEAE	<i>Cliffortia</i>	<i>browniana</i>	Killick (1963)	Burt Davy	
ROSACEAE	<i>Cliffortia</i>	<i>filicauloides</i>	Killick (1963)	Weim	
ROSACEAE	<i>Cliffortia</i>	<i>linearifolia</i>	Hill (1992); Killick (1963)	Eckl. & Zeyh	
ROSACEAE	<i>Cliffortia</i>	<i>repens</i>	Killick (1963)	Schltr	

Family	Genus	Species	Cited Author	Author	Current Species Name and Author
ROSACEAE	<i>Cliffortia</i>	<i>spathulata</i>	Killick (1963)	Weim	
ROSACEAE	<i>Geum</i>	<i>capense</i>	Killick (1963)	Thunb	
ROSACEAE	<i>Leucosidea</i>	<i>sericea</i>	Hill (1992); Killick (1963)	Eckl. & Zeyh	
ROSACEAE	<i>Rubus</i>	<i>ludwigii</i>	Killick (1963)	Eckl. & Zeyh	
RUBIACEAE	<i>Anthospermum</i>	<i>hedyotideum</i>	Killick (1963)	Sond	A. Herbaceum (Sond.)
RUBIACEAE	<i>Anthospermum</i>	<i>herbaceum</i>	Killick (1963)	L.f	
RUBIACEAE	<i>Anthospermum</i>	<i>hispidulum</i>	Killick (1963)	E. May. ex Sond	
RUBIACEAE	<i>Anthospermum</i>	<i>rigidum</i>	Killick (1963)	Eckl. & Zeyh	
RUBIACEAE	<i>Burchellia</i>	<i>bubalina</i>	Killick (1963)	Sims FP	
RUBIACEAE	<i>Canthium</i>	<i>ciliatum</i>	Killick (1963)	Kuntze	
RUBIACEAE	<i>Canthium</i>	<i>pauciflorum</i>	Killick (1963)	Kuntze	
RUBIACEAE	<i>Conostomium</i>	<i>natalense</i>	Killick (1963)	Brem	
RUBIACEAE	<i>Galium</i>	<i>rotundifolium</i>	Killick (1963)	L	<i>G. thundergianum</i> var <i>thunbergianum</i> (L.)
RUBIACEAE	<i>Galium</i>		Killick (1963)	L	
RUBIACEAE	<i>Kohautia</i>	<i>amatymbica</i>	Killick (1963)	Eckl. & Zeyh	
RUBIACEAE	<i>Pavetta</i>	<i>cooperi</i>	Killick (1963)	Harv & Sond	
RUBIACEAE	<i>Pentanisia</i>	<i>prunelloides</i>	Hill (1992); Killick (1963)	Walp	
RUBIACEAE	<i>Pygmaeothamnus</i>	<i>chamaedendrum</i>	Killick (1963)	Robyns	
RUTACEAE	<i>Calodendrum</i>	<i>capense</i>	Killick (1963)	Thunb	



Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
RUTACEAE	<i>Clausena</i>	<i>anisata</i>	Killick (1963)	Hook f ex Bernth	
SALICACEAE	<i>Salix</i>	<i>woodii</i>	Killick (1963)	Seemen	S. mucronata subsp. woodii (Seemen)
SANTALACEAE	<i>Osyris</i>		Killick (1963)	L	
SANTALACEAE	<i>Thesium</i>	<i>imbricatum</i>	Killick (1963)	Thunb	
SANTALACEAE	<i>Thesium</i>	<i>racemosum</i>	Killick (1963)	Bernh	
SANTALACEAE	<i>Thesium</i>	<i>scirpioides</i>	Killick (1963)	A.W. Hill	
SANTALACEAE	<i>Thesium</i>		Killick (1963)	L	
SAPINDACEAE	<i>Allophylus</i>	<i>melanocarpus</i>	Killick (1963)	Radlk	
SCHIZAECEAE	<i>Mohria</i>	<i>caffrorum</i>	Hill (1992); Killick (1963)	Desv	
SCROPHULARIACEAE	<i>Alectra</i>		Killick (1963)	Thunb	
SCROPHULARIACEAE	<i>Bowkeria</i>	<i>verticillata</i>	Hill (1992); Killick (1963)	Eckl. & Zeyh	
SCROPHULARIACEAE	<i>Buchnera</i>	<i>dura</i>	Killick (1963)	Benth	
SCROPHULARIACEAE	<i>Cycnium</i>	<i>racemosum</i>	Killick (1963)	Benth	
SCROPHULARIACEAE	<i>Diascia</i>		Killick (1963)	Link & Otto	
SCROPHULARIACEAE	<i>Diclis</i>	<i>reptans</i>	Hill (1992); Killick (1963)	Benth	
SCROPHULARIACEAE	<i>Glumicalyx</i>	<i>montanus</i>	Killick (1963)	Hiern	
SCROPHULARIACEAE	<i>Graderia</i>	<i>scabra</i>	Killick (1963)	Benth	
SCROPHULARIACEAE	<i>Halleria</i>	<i>lucida</i>	Hill (1992); Killick (1963)	L. FP	
SCROPHULARIACEAE	<i>Limosella</i>	<i>capensis</i>	Killick (1963)	Thunb	L. grandiflora (Thunb.)
SCROPHULARIACEAE	<i>Limosella</i>	<i>longiflora</i>	Killick (1963)	Kuntze	
SCROPHULARIACEAE	<i>Limosella</i>	<i>maior</i>	Killick (1963)	Diels FP	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
SCROPHULARIACEAE	<i>Manulea</i>	<i>thodeana</i>	Killick (1963)	Diels	M. crassifolia subsp. thodeana (Diels)
SCROPHULARIACEAE	<i>Melasma</i>	<i>scabrum</i>	Killick (1963)	Berg	
SCROPHULARIACEAE	<i>Mimulus</i>	<i>gracilis</i>	Killick (1963)	R. Br	
SCROPHULARIACEAE	<i>Nemesia</i>	<i>cynanchifolia</i>	Killick (1963)	Benth FP	
SCROPHULARIACEAE	<i>Nemesia</i>	<i>denticulata</i>	Killick (1963)	Fourc	
SCROPHULARIACEAE	<i>Phygellus</i>	<i>capensis</i>	Killick (1963)	E. Mey ex Benth	
SCROPHULARIACEAE	<i>Sopubia</i>	<i>cana</i>	Killick (1963)	Buch-ham ex D. Don	
SCROPHULARIACEAE	<i>Striga</i>	<i>elegans</i>	Killick (1963)	Benth	
SCROPHULARIACEAE	<i>Sutera</i>	<i>breviflora</i>	Killick (1963)	N.E. Br	
SCROPHULARIACEAE	<i>Sutera</i>	<i>dentatisepala</i>	Killick (1963)	Overk	
SCROPHULARIACEAE	<i>Sutera</i>	<i>floribunda</i>	Killick (1963)	Kuntze	
SCROPHULARIACEAE	<i>Sutera</i>	<i>pristisepala</i>	Killick (1963)	Hiern	
SCROPHULARIACEAE	<i>Veronica</i>	<i>anagallis- aquatica</i>	Killick (1963)	L	
SCROPHULARIACEAE	<i>Zaluzianskya</i>	<i>capensis</i>	Hill (1992); Killick (1963)	Walp	
SCROPHULARIACEAE	<i>Zaluzianskya</i>	<i>goseloides</i>	Killick (1963)	Diels	Glumicaly flanganii (Diels)
SCROPHULARIACEAE	<i>Zaluzianskya</i>	<i>maritima</i>	Killick (1963)	Walp	
SCROPHULARIACEAE	<i>Zaluzianskya</i>		Killick (1963)	F.W. Schmidt	
SCROPHULARIACEAE	<i>Zaluzianskya</i>	<i>longiflora</i>	Killick (1963)	Walp	Z. capensis (Walp)
SELAGINACEAE	<i>Hebenstretia</i>	<i>comosa</i>	Killick (1963)	Hochst	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
SELAGINACEAE	<i>Hebenstretia</i>	<i>dentata</i>	Killick (1963)	L	
SELAGINACEAE	<i>Hebenstretia</i>	<i>sutherlandii</i>	Killick (1963)	H. Bol ex Rolfe	H. dura (Rolfe)
SELAGINACEAE	<i>Selago</i>	<i>flanaganii</i>	Killick (1963)	Rolfe	
SELAGINACEAE	<i>Selago</i>	<i>monticola</i>	Killick (1963)	Wood & Evans	
SELAGINACEAE	<i>Selago</i>		Killick (1963)	L	
SELAGINELLACEAE	<i>Selaginella</i>	<i>imbricata</i>	Killick (1963)	Spring ex Decne	
SOLANACEAE	<i>Physalis</i>	<i>peruviana</i>	Killick (1963)	L	
SOLANACEAE	<i>Solanum</i>	<i>giganteum</i>	Killick (1963)	Jacq	
STERCULIACEAE	<i>Hermannia</i>	<i>woodii</i>	Killick (1963)	Schinz	
THAMNOBRYACEAE	<i>Porothamnium</i>	<i>natalense</i>	Killick (1963)	Fleisch	Porotrichum molliculum (Fleisch.)
THUDIACEAE	<i>Thuidium</i>	<i>promontorii</i>	Killick (1963)	Par	T. matarumense (Par.)
THYMELAEACEAE	<i>Dais</i>	<i>cotinifolia</i>	Killick (1963)	L. FP	
THYMELAEACEAE	<i>Gnidia</i>	<i>aberrans</i>	Killick (1963)	C.H. Wr	
THYMELAEACEAE	<i>Gnidia</i>	<i>baurii</i>	Killick (1963)	C.H. Wr	
THYMELAEACEAE	<i>Gnidia</i>	<i>compacta</i>	Killick (1963)	J.H. Ross	
THYMELAEACEAE	<i>Gnidia</i>	<i>polystachya</i>	Killick (1963)	Berg	
THYMELAEACEAE	<i>Lasiosiphon</i>	<i>anthylloides</i>	Killick (1963)	Meisn	Gnidia anthylloides (Meisn.)
THYMELAEACEAE	<i>Lasiosiphon</i>	<i>caffer</i>	Killick (1963)	Meisn	Gnidia caffra (Meisn.)
THYMELAEACEAE	<i>Lasiosiphon</i>	<i>polyanthus</i>	Killick (1963)	Gilg	Gnidia polyantha (Gilg)
THYMELAEACEAE	<i>Lasiosiphon</i>		Killick (1963)	Fresen	Gnidia spp. (Fresen)
THYMELAEACEAE	<i>Passerina</i>	<i>filiformis</i>	Killick (1963)	L	

Family	Genus	Species	Cited Author	Authority	Current Species Name and Authority
THYMELAEACEAE	<i>Passerina</i>	<i>montana</i>	Killick (1963)	Thoday	
TILIACEAE	<i>Sparrmannia</i>	<i>ricinocarpa</i>	Killick (1963)	Kuntze	
ULMACEAE	<i>Celtis</i>	<i>africana</i>	Killick (1963)	Burm	
URTICACEAE	<i>Parietaria</i>	<i>debilis</i>	Killick (1963)	G. Forst	<i>P. micrantha</i> (G. Forst.)
VALERIANACEAE	<i>Valeriana</i>	<i>capensis</i>	Killick (1963)	Thunb	
VELLOZIACEAE	<i>Vellozia</i>	<i>talbotii</i>	Killick (1963)	Balf	<i>Talbotia elegans</i> (Balf)
VELLOZIACEAE	<i>Vellozia</i>	<i>viscosa</i>	Killick (1963)	Bak	<i>Xerophyta viscosa</i> (Bak)
VITACEAE	<i>Rhoicissus</i>	<i>revoilii</i>	Killick (1963)	Planch	
XYRIDACEAE	<i>Xyris</i>	<i>capensis</i>	Killick (1963)	Thunb	
ZAMIACEAE	<i>Encephalartos</i>	<i>ghellinckii</i>	Killick (1963)	Lem	

## **Appendix B: Gravitational ‘Swirling’ Separation Technique (Hunt 1985; Wheeler 2007)**

1. 1 cm<sup>3</sup> sub-samples are dissected from the core at 5 cm intervals.
2. Sub-samples are placed into vials, labelled, sealed, and stored in a refrigerator until the chemical process is ready to begin.
3. The sub-samples are placed into labelled beakers.
4. 40 ml of 10% KOH and 5 mg of Na<sub>4</sub>O<sub>7</sub>P<sub>2</sub> is added to the sub-sample in the beaker. The beaker contents are stirred well with stirring rods and the beakers are placed into a water bath at a temperature of 100°C for ± 30 minutes, stirring regularly to ensure the sub-sample is digests.
5. The solution from the beakers is poured through a 150 µm sieve into the ‘swirling dish’. Any remaining contents from the beakers are extracted using distilled water and poured through the 150 µm sieve.
6. The contents of the sieve need to be blasted to into the ‘swirling dish’.
7. The diluted solution in the ‘swirling dish’ is gently swirled for ± 10 minutes to separate the larger residual material from the macro pollen and charcoal contained in the clear solution through gravitation.
8. The clear solution is gently poured into a beaker. The dark residual material is disposed of.
9. The solution in the beaker is put through the 150 µm beaker once more, into the ‘swirling dish and blasted with water. The solution in the ‘swirling dish’ is again swirled to separate the larger residual material from the macro pollen and charcoal remains. The clear solution is again poured gently off into a beaker.
10. The solution in the beaker is poured through the 6µm sieve. Macro pollen and charcoal should remain on the sieve. These contents are blasted with water until the soapy smell and texture of the water is removed. This takes approximately four times of blasting. On the last time, five drops of Safrannin O solution is added to the macro remains. The remains are again blasted.
11. Using distilled water and plastic pipettes, the macro remains are transferred into labelled vials.
12. The vials are placed into the refrigerator for 12 hours. Approximately half of the solution is removed with a plastic pipette, ensuring the macro remains are still covered in liquid and placed in the refrigerator until mounting can occur.

## Appendix C: Morphological, preservation and dispersal characteristics of major palynomorphs

Morphological, preservation and dispersal characteristics of major palynomorphs encountered in Cathedral Peak, Drakensberg, South Africa, palaeoecological records and associated ecological and indicator values of likely parent taxa.

### ACANTHACEAE

Identified as: *Achanthus*

Genus found in Cathedral Peak: *Adhatoda*, *Barleria*, *Hypoestes*, *Isoglossa*

Likely parent taxa: *Monechma*-type

Pollen morphological characteristics (on Family level): Acanthaceae pollen can be divided up into six morphological types; i) *Blepharis*, ii) *Justicia*-type, iii) *Monechma*-type, iv) *Macrorungia*-type, v) *Dicliptera*-type, vi) Acanthaceae no 462, vii) Acanthaceae no 452. Types vi and vii are rare and recorded only in the Rietvlei deposits, and no herbarium reference material of such grains is available; they are tentatively identified as Acanthaceae (Scott 1982a).

Ecology: Acanthaceae is a large family of herbs with 43 genera found in South Africa (Pooley 2005) usually indicative of open veld environments rather than swamp environments (Scott 1982a).

Dispersal and preservation characteristics: Acanthaceae is considered to be widely distributed (Scott 1982a) but poorly dispersed (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Justicia*

Genera found in Cathedral Peak: *Adhatoda*, *Barleria*, *Hypoestes*, *Isoglossa*

Likely parent taxa: *Justicia*-type

Pollen morphological characteristics (on Family level): Acanthaceae pollen can be divided up into 6 morphological types; i) *Blepharis*, ii) *Justicia*-type, iii) *Monechma*-type, iv) *Macrorungia*-type, v) *Dicliptera*-type, vi) Acanthaceae no 462, vii) Acanthaceae no 452. Types vi and vii are rare and recorded only in the Rietvlei deposits, and no herbarium reference material of such grains is available; they are tentatively identified as Acanthaceae (Scott 1982a).

Ecology: Acanthaceae is a large family of herbs with 43 genera found in South Africa (Pooley 2005) usually indicative of open veld environments rather than swamp environments (Scott 1982a).

Dispersal and preservation characteristics: Acanthaceae is considered to be widely distributed (Scott 1982a) but poorly dispersed (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## AMARANTHACEAE

Identified as: *Aerva*

Genera found in Cathedral Peak: *Achyranthes*, *Cyathula*

Likely parent taxa: Amaranthaceae undifferentiated

Pollen morphological characteristics (on Family level): cribellate; spherical; ellipsoidal or polyhedral with rounded edges; 12-35  $\mu\text{m}$  diameter. Foramina: 12-60  $\mu\text{m}$ ; circular, sometimes wavy margins; 2.5-8.6  $\mu\text{m}$  diameter, sometimes situated in deep, straight or funnel shaped depressions; membrane has the same sculpturing as rest of exine or is flecked with granules which tend to aggregate towards centre and fuse; or with operculum; Exine: 1-5.7  $\mu\text{m}$ ; thick; granulate; sexine baculate; sometimes tegillate; nexine only 0.5-1.5  $\mu\text{m}$  thick (van Zinderen Bakker 1953).

Ecology: Amaranthaceae are halophytes favouring dry, saline conditions with summer rainfall and evaporative conditions (Scott *et al.* 2005; Scott 1982a)

Dispersal and preservation characteristics: Amaranthaceae are wind-pollinated (van Zinderen Bakker 1953), dispersed over long distances (Hamilton 1972) and occur in most parts of the country in a wide-range of habitats (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Celosia*

Genera found in Cathedral Peak: *Achyranthes*, *Cyathula*

Likely parent taxa: *Achyranthes*

Pollen morphological characteristics (on Family level): cribellate; spherical; ellipsoidal or polyhedral with rounded edges; 12-35  $\mu\text{m}$  diameter. Foramina: 12-60  $\mu\text{m}$ ; circular, sometimes wavy margins; 2.5-8.6  $\mu\text{m}$  diameter, sometimes situated in deep, straight or funnel shaped depressions; membrane has the same sculpturing as rest of exine or is flecked with granules which tend to aggregate towards centre and fuse; or with operculum; Exine: 1-5.7  $\mu\text{m}$ ; thick; granulate; sexine baculate; sometimes tegillate; nexine only 0.5-1.5  $\mu\text{m}$  thick (van Zinderen Bakker 1953).

Ecology: Amaranthaceae are halophytes favouring dry, saline conditions with summer rainfall and evaporative conditions (Scott *et al.* 2005; Scott 1982a)

Dispersal and preservation characteristics: Amaranthaceae are wind-pollinated (van Zinderen Bakker 1953), dispersed over long distances (Hamilton 1972) and occur in most parts of the country in a wide-range of habitats (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## ANACARDIACEAE

Identified as: *Rhus*

Genera found in Cathedral Peak: *Rhus* spp.

Likely parent taxa: *Rhus*

Pollen morphological characteristics: No morphological features are available for this research.

Ecology: *Rhus* are found in Cathedral Peak in montane and subalpine grasslands (Killick 1963).

Dispersal and preservation characteristics: There are over 20 species of trees and shrubs belonging to the genera *Rhus* occupying a wide range of habitats. While the genus is insect pollinated, it does produce pollen in large numbers. It is considered to be moderately to well dispersed over long distances, often found in pollen samples although not in high numbers (Scott 1982a; Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## ARECACEAE

Identified as: *Phoenix*

Genera found in Cathedral Peak: Not found according to Killick (1963) and Hill (1992).

Pollen morphological characteristics (on Genus level): monosulcate; in dry conditions oblate; ambit elliptical with rounded ends; uniform shape and size; 20-22.9  $\mu\text{m}$ ; lengthwise sulcus, deeply invaginated in dry conditions and closed; sulcus membrane is psilate; exine 1.2  $\mu\text{m}$ ; finely scrobiculate (van Zinderen Bakker 1953).

Ecology: *Phoenix* is found from the Eastern Cape into KwaZulu-Natal and up into the eastern sub-tropical belt into tropical Africa growing mostly along watercourses (van Zinderen Bakker 1953).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal



## ASTERACEAE

Identified as: *Artemisia*

Genera found in Cathedral Peak: *Artemisia afra*

Likely parent taxa: *Artemisia afra*

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.* 2006).

Ecology: *Artemisia* is found in grasslands (Scott 1982a), sandy areas under local sub-humid conditions (Scott and Nyakale 2002) with relatively even seasonal moisture distribution (Scott 1999). It is an indication of somewhat drier conditions (Scott 1982a).

Dispersal and preservation characteristics: *Artemisia* occurs in a wide range of habitats in eastern South Africa. It is often rare in pollen samples although it is considered moderately well dispersed (Scott 1982a; Hamilton 1972) over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Mutiseae*-tribe

Genera found in Cathedral Peak: a variety of Asteraceae species fall within the *Mutiseae*-tribe

Likely parent taxa: Asteraceae falling within the *Mutiseae* tribe

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.* 2006); short spined (Scott 2008); Monad, isopolar, radiosymmetric, tricolporate, colpi long, pores large 4-6µm wide, margins attenuating equatorially; subprolate, ambit subcircular, exine thick, 5µm across, tectate, subtectum more / less reticulate (Heusser 1971).

Ecology: *Mutiseae*-tribe form shrublands in dry karroid veld under less summer rainfall (Scott and Nyakale 2002). Its presence is indicative of different seasonal climatic distribution with weaker summer rains. It is not usually dominant in summer rain regions (Scott *et al.* 2005). It favours relatively even seasonal moisture distributions (Scott 1999).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Stoebe*-type

Genera found in Cathedral Peak: *Stoebe vulgaris*

Likely parent taxa: *Stoebe vulgaris*

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.* 2006).

Ecology: *Stoebe* occurs in grasslands (Scott 1982a), shrubland, and dry karroid veld under conditions of less summer rain (Scott and Nyakale 2002) but with a relatively even seasonal

moisture distribution (Scott 1999). It is indicative of different seasonal climatic distributions with weaker summer rainfall. It is not usually dominant in summer rain regions (Scott *et al.* 2005).

Dispersal and preservation characteristics: *Stoebe* is common in disturbed habitats and suggest cooler, drier conditions. It is considered a moderately well dispersed pollen (Scott 1982a; Hamilton 1972) being dispersed over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Tubuliflorae*-tribe

Genera found in Cathedral Peak: a variety of Asteraceae belong to this tribe

Likely parent taxa: Asteraceae falling within the *Tubuliflorae*-tribe

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.* 2006).

Ecology: *Tubuliflorae* often found in shrublands and dry karroid veld with less summer rainfall (Scott and Nyakale 2002) but with a relatively even seasonal moisture distribution (Scott 1999). It is indicative of different seasonal climatic distributions with weaker summer rainfall. It is not usually dominant in summer rainfall regions (Scott *et al.* 2005). *Tubuliflorae* occurs over a wide range of habitats. It is an important constituent of grasslands especially in karoo and macchia vegetation (Scott 1982a).

Dispersal and preservation characteristics: *Tubuliflorae* is considered to be moderately well dispersed (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Vernonia*-type

Genera found in Cathedral Peak: *Vernonia hirsuta*, *Vernonia pinifolia*

Likely parent taxa: *Vernonia* species

Pollen morphological characteristics (on Genus level): highly distinctive palynomorph. Trizonocolporate, echinate, fenestrate. 25-48 µm (Finch *et al.* 2009).

Ecology: A well represented genus of herbs, shrubs and small trees commonly occurring within secondary or disturbed forest types between 2000 and 3200 m. Ecology is variable due to a large number of potential parent taxa; nevertheless, *Vernonia* pollen has been viewed as indicative of agriculturally-related disturbance (Finch *et al.* 2009).

Dispersal and preservation characteristics: This pollen type is dispersed over long distances but is considered poorly dispersed (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## BORAGINACEAE

Identified as: *Cordia*

Genera found in Cathedral Peak: *Cynoglossum, Lithospermum, Myosotis, Tysonia*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Cordia* is found typically in lowland forest (Finch *et al.* 2009) and as forest patches in edaphic grasslands (Mumbi *et al.* 2008)

Dispersal and preservation characteristics: *Cordia* is typically insect pollinated and thus produce pollen in relatively low concentrations, as a result it is generally under-represented in pollen record (Connor *et al.* 2004).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Heliotropum*

Genera found in Cathedral Peak: *Cynoglossum, Lithospermum, Myosotis, Tysonia*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Heliotropum* occurs in Lowland forest (Finch *et al.* 2009)

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## BRASSICACEAE

Identified as: Brassicaceae undifferentiated

Genera found in Cathedral Peak: *Heliophila*

Likely parent taxa: *Heliophila*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: Brassicaceae can occur along lake edges (Darbyshire *et al.* 2003) and in the Cape Florsitic Region it is found along arid northern margins (Linder 2003). It is adapted to tolerate salt and cold conditions (van de Mortel and Aarts 2006). It commonly found on damp grassy scree slopes of in the alpine belt (Court-Picon *et al.* 2005).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## CAPPARACEAE

Identified as: Capparaceae undifferentiated

Genera found in Cathedral Peak: Not found in the Cathedral Peak according to Killick (1963) and Hill (1992).

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): 3-colporate, prolate to subprolate, ambit fossaperturate; polar axis 14-42 um; long colpi; exine tegillate, sometimes c. punctitegillate, or with LO- to OL-pattern, faintly granulate, or with minute spinules.

Ecology: Capparaceae are generally well adapted to arid conditions (Gil-Romera *et al.* 2007) often being found in warm, low-land savanna, occurs within the Kalahari Thornveld vegetation and in steppe, semi-desert to desert conditions. As such, Capparaceae is indicative of drier conditions with less rainfall (Scott 1999; Dupont *et al.* 2008; Gil-Romera *et al.* 2006).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## CELASTRACEAE

Identified as: Celastraceae undifferentiated

Genera found in Cathedral Peak: *Cassine tetragonal*, *Maytenus acuminatus*, *M. mossambicensis*, *M. peduncularis*, *M. undata*, *Pterocelastrus galpini*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: Celastraceae is commonly found in montane forests, woodlands, riverine forest, evergreen and coastal bushland as well as dry forest and savanna. Celastraceae are well adapted to arid conditions and thus reflect suggest drier conditions with lower precipitation (Gil-Romera *et al.* 2007; Finch *et al.* 2009; Dupont *et al.* 2008; Sangu and Bracebridge 2005).

Dispersal and preservation characteristics: This pollen is considered to be dispersed over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## CYATHACEAE

Identified as: *Cyathea*

Genera found in Cathedral Peak: *Cyathea dregei*

Likely parent taxa: *Cyathea dregei*

Pollen morphological characteristics (on Genus level): actinomorphic; trilete; tetrahedral; ambit triangular concave; proximal oar flatly pyramidal; distal part conical; Distal part semicircular; 40x51 $\mu$ m; laesura 16  $\mu$ m, margo broad; Sporoderm: exine 2.5  $\mu$ m thick, 1  $\mu$ m thick perine often present, there is a space of 0.5  $\mu$ m between perine and exine, this psilate perine is often cracked and appears as flakes (van Zinderen Bakker and Welman 1970)

Ecology: Five species of *Cyathea* occur in southern Africa with only one species found in the subalpine belt of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## CYPERACEAE

Identified as: *Ascolepis*-tribe

Genera found in Cathedral Peak: *Ascolepis capensis*

Likely parent taxa: *Ascolepis capensis*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Ascolepis*-tribe is typically found in wetlands in aquatic (Scott 1982a), semi-aquatic and swamp-like environments (Scott 1999) with shallow water or damp soil (Scott and Nyakale 2002).

Dispersal and preservation characteristics: This pollen is considered to be moderately well dispersed (Hamilton 1972)

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: Cyperaceae undifferentiated

Genera found in Cathedral Peak: Large array of Cyperaceae genera and species occur

Likely parent taxa: members of the Cyperaceae family

Pollen morphological characteristics (on Family level): Pseudomonads of subglobose, ovoid / elongated ovoid shape; wedge / gourd-shaped; one irregularly defined germ spore situated on a slightly elevated or flat area in the middle of the broader end; aperture sometimes irregularly perforated; 21-76 $\mu$ m; dry conditions cause 3-4 concavities to originate on the sides and on a broad end causing grain to become polyhedral, varying from elongated tetrahedral to more irregular shapes; after acetolysis it shows folds when supporting intine is lost; exine thin 1-2.5 $\mu$ m; granulate, scrobiculate or reticulate sculpturing (van Zinderen Bakker 1953).

Ecology: Cyperaceae are herbaceous plants found in aquatic (Scott 1982a) moist environments including forest margins, streamsides or swamps (Finch *et al.* 2009).

Dispersal and preservation characteristics: Due to the local nature of the parent vegetation Cyperaceae pollen often dominates the pollen sum (Finch *et al.* 2009).

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

## EBENACEAE

Identified as: *Euclea*

Genera found in Cathedral Peak: *Euclea mispathulata*, *E. hirsuta*

Likely parent taxa: *Euclea mispathulata*, *E. hirsuta*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Euclea* are found in montane and subalpine grasslands of Cathedral peak (Killick 1963).

Dispersal and preservation characteristics: *Euclea* are regarded as rare to common in fossil and surface samples often occurring in dry bushveld where grass pollen production is apparently low (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## ERICACEAE

Identified as: Ericaceae undifferentiated

Genera found in Cathedral Peak: *Erica*, *Phyllipia*

Likely parent taxa: *Erica*, *Phyllipia*

Pollen morphological characteristics (on Genus level): An unmistakable palynomorph. Inaperturate, psilate, scabrate, fossulate, rugulate tetrad. 28-55  $\mu$ m (Coetzee 1955).

Ecology: Ericaceae are found in montane and subalpine grasslands and the alpine heath environments of Cathedral Peak (Scott 1982a; Killick 1963). The presence of >5% of this taxa indicates the lowering of vegetation belts. At 23°S Ericaceae usually occurs up to

1000m (Scott 1982a). It is often associated with fynbos environments that have cool, sub-humid conditions with a relatively even seasonal moisture distribution (Scott 1999).

Dispersal and preservation characteristics: Ericaceae is considered to be moderately well dispersed (Hamilton 1972)

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## EUPHORBIACEAE

Identified as: *Acalypha*

Genera found in Cathedral Peak: *Acalypha depressinervia*, *E. punctata*

Likely parent taxa: *Acalypha depressinervia*, *E. punctata*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Acalypha* spp. are herbaceous found in the sub-alpine grasslands (Scott 1982a; Killick 1963).

Dispersal and preservation characteristics: *Acalypha* are herbaceous, have very well, long distance dispersal pollen (Hamilton 1972) which occur as montane forests in East Africa. They can have unrealistic over-representation and should be considered excluded from pollen sum (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Macaranga*

Genera found in Cathedral Peak: *Adenocline*, *Clutia*, *Euphorbia*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: *Macaranga* is an under-story tree abundant in wetter montane forests between 1400 and 2500 m. Characteristic of secondary and regenerating forest where it is a fast growing gap coloniser (Finch *et al.* 2009).

Dispersal and preservation characteristics: *Macaranga* is classified as a well dispersed pollen over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## GREYIACEAE

Identified as: *Greyia*

Genera found in Cathedral Peak:

Likely parent taxa: *Greyia sutherlandii*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Greyia* are found in montane grasslands and montane forests of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## HALORAGACEAE

Identified as: *Gunnera*

Genera found in Cathedral Peak: *Gunnera perpensa*

Likely parent taxa: *Gunnera perpensa*

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: *Gunnera* are found in the subalpine grasslands of Cathedral Peak (Killick 1963) under aquatic conditions (Scott 1982a); *Gunnera* is a large semi-aquatic, perennial herb common in marshy environments up to 2400 m growing typically on the edge of wetlands and in drier areas of the wetland. This species is thought to be highly responsive to changes in the hydrological budget (Finch *et al.* 2009).

Dispersal and preservation characteristics: Pollen is considered to be over-represented due to its local dominance at the swamp site (Finch *et al.* 2009).

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

## HYACINTHACEAE

Identified as: *Urginea*

Genera found in Cathedral Peak: *Urginea macrocentra*, *U. tenella*

Likely parent taxa: *Urginea macrocentra*, *U. tenella*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Urginea* is found in montane and subalpine grasslands and alpine heath environments of Cathedral Peak (Killick 1963).



Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## LAMIACEAE

Identified as: *Undifferentiated*

Genera found in Cathedral Peak: *Aeolanthus, Ajuga, Becium, Hemizygia, Leonotis, Plectranthus, Pycnostachys, Satureja, Stachys, Syncolostemon*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: No ecological data is available for this research.

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## LILIACEAE

Identified as: *Undifferentiated*

Genera found in Cathedral Peak: *Agapanthus, Aloe, Eriospermum, Kniphofia, Scilla*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): mostly monosulcate, sometimes anaperturate or trichotomosulcate; exine psilate, pitted, granulate or reticulate, subchinate or echinate (van Zinderen Bakker 1953).

Ecology: Liliaceae are insect pollinated with low concentrations of pollen being produced; therefore the pollen may be under-represented in pollen rain and sediment records (van Zinderen Bakker 1953).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

## MORACEAE

Identified as: *Ficus*

Genera found in Cathedral Peak: *Ficus ingens*

Likely parent taxa: *Ficus ingens*

Pollen morphological characteristics (on Family level): 2-4 proate; spherical; mostly aspidate; sometimes very small size; very little ornamentation or granulate surface (van Zinderen Bakker 1953).

Ecology: *Ficus* is found in the montane grasslands of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## MYRICACEAE

Identified as: *Myrica*

Genera found in Cathedral Peak: *Myrica pilulifera*, *M. serrata*,

Likely parent taxa: *Myrica pilulifera*, *M. serrata*

Pollen morphological characteristics (on Genus level): usually triporate, aspidate, oblate, with equatorial diameter 22-36  $\mu\text{m}$ ; 2, 4, or 6 pores; ambit triangular with convex sides; irregular arrangement pores; mostly circular, sometime elliptical; thickening of exine under aspis is of tarsus pattern or transition between this and club-shaped pattern; exine is two layers surface slightly roughened or minutely granulate (van Zinderen Bakker 1953).

Ecology: *Myrica* is found in montane grasslands and forests of Cathedral Peak (Killick 1963) occurring within and on the forest margins under sub-humid conditions (Scott 1982a, 1999).

Dispersal and preservation characteristics: This pollen is considered moderately well dispersed over long distances in East Africa (Scott 1982a; Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

## MYRTACEAE

Identified as: Myrtaceae undifferentiated

Genera found in Cathedral Peak: Not found in Cathedral Peak according to Killick (1963) and Hill (1992)

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): No morphological description available for this research.

Ecology: Eucalyptus is an exotic neophyte associated with human activity but also occurring within montane forest types (Finch *et al.* 2009).

Dispersal and preservation characteristics: The pollen is moderately well dispersed (Finch *et al.* 2009).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## PINACEAE

Identified as: *Pinus*

Genera found in Cathedral Peak: Not native; introduced

Likely parent taxa: *Pinus*

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: Exotic neophyte associated with human activity (Finch *et al.* 2009).

Dispersal and preservation characteristic: *Pinus* is anemophilous and therefore extremely well dispersed, contributing to over-representation in the pollen signal (Finch *et al.* 2009) .

Local / Regional: Regional (exotic)

Arboreal / Non-Arboreal: Arboreal

## POACEAE

Identified as: *Undifferentiated <40μm*

Genera found in Cathedral Peak:

Likely parent taxa: Members of the Poaceae family

Pollen morphological characteristics (on Family level): spheroidal or more or less ovoidal; 22-little +100μm; single germ spore surrounded by thickened rim; psilate; wild grass usually 20-25μm; spherical / ellipsoidal; less 1μm exine; ulcus lee 2μm across; impossible to ID different grasses spp based on size (van Zinderen Bakker 1953).

Ecology: *Poaceae* are found in regional humid conditions with summer rainfall (Scott and Nyakale 2002) under strong evaporative conditions (Scott *et al.* 2005).

Dispersal and preservation characteristic: Poaceae are well dispersed (Hamilton 1972).

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Undifferentiated >40μm*

Genera found in Cathedral Peak:

Likely parent taxa: Members of the Poaceae family

Pollen morphological characteristics (on Family level): spheroidal or more or less ovoidal; cereal grass 35-40μm; exine 1-2μm; uluc 2-7μm across; most SA grass could be classified as cereal probably due to polypoidy; impossible to ID different grasses spp based on size (van Zinderen Bakker 1953).

Ecology: *Poaceae* are found in regional humid conditions with summer rainfall (Scott and Nyakale 2002) under strong evaporative conditions (Scott *et al.* 2005).

Dispersal and preservation characteristic: Poaceae are well dispersed (Hamilton 1972)

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

## PODOCARPACEAE

Identified as: *Podocarpus*

Genera found in Cathedral Peak: *Podocarpus falcatus*, *P. henkelii*, *P. latifolius*

Likely parent taxa: *Podocarpus falcatus*, *P. henkelii*, *P. latifolius*

Pollen morphological characteristics (on Genus level): Six species in South Africa occur in mountainous regions from the Cape Peninsula coastal belt to KwaZulu-Natal and into Mpumalanga; wind pollinated; grains: monosulcate, spherical to ellipsoidal, saccate, provided with 2,3 and exceptionally 4 air-sacs; 2 sac grains range 23-45 $\mu$ m diameter; proximal side arched; thick exine; sulcus on distal face, sharply defined, surrounded air-sacs,; Bladders: at the inside with reticulate thickenings, which merge with structure of proximal face; large, but mostly weak and flaccid (van Zinderen Bakker 1953).

Ecology: *Podocarpus* are found in the montane forests and subalpine grasslands of Cathedral Peak (Killick 1963). It is often a forest-dweller (Scott 1982a) favouring relatively moist conditions (Scott 1999).

Dispersal and preservation characteristic: Pollen grains produced large numbers, each with air bladders making the grains very buoyant with the ability to be well dispersed by wind over long distances (Scott 1982a; Hamilton 1972). As such they can be easily overrepresented in pollen sums (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## POLYGONACEAE

Identified as: *Polygonum*

Genera found in Cathedral Peak: *Rumex*

Likely parent taxa: *Polygonum*

Pollen morphological characteristics (on Family level): 18 species occur in South Africa; grains: tricolporate; forate; prolate; sometimes subprolate; ambit fossaperturate; spheroidal; ellipsoidal; sometimes cylindrical; uniform; 22.9-58.6 $\mu$ m; depressed colpi; exine: zonorate; reticulum with lumina; granulate (van Zinderen Bakker 1953).

Ecology: Aquatic vegetation (Scott 1982a).

Dispersal and preservation characteristic: *Polygonum* is partly insect partly wind pollinated. The pollen grains are extremely various. They are widely distributed species (van Zinderen Bakker 1953).

Local / Regional: Local

Arboreal / Non-Arboreal: Arboreal

## PROTEACEAE

Identified as: *Protea*

Genera found in Cathedral Peak: *Protea dracomontana*, *P. multibracteata*, *P. Roupelliae*, *P. subvestita*

Likely parent taxa: *Protea dracomontana*, *P. multibracteata*, *P. Roupelliae*, *P. subvestita*

Pollen morphological characteristics (on Genus level): triporate, oblate, disc-shaped, 23-39 $\mu$ m equatorial diameter; ambit triangular with rounded angles; angles slightly bent towards proximal side; pores at angles slightly elliptical; thin exine 1.1-1.5 $\mu$ m; two layers, nearly devoid of sculpturing; some scattered granules or scrobiculate (van Zinderen Bakker 1953).

Ecology: *Protea* is found in the montane and sub-alpine grasslands and montane forests of Cathedral Peak (Killick 1963). Its also found in upland and mesic savanna under sub-humid conditions (Scott 1999).

Dispersal and preservation characteristic: *Protea* is found under wide range temperatures (Scott 1999); 100-130 spp in SA mostly SW districts of Cape province, but extending into Natal Transvaal Basutoland, Swaziland (van Zinderen Bakker 1953).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## ROSACEAE

Identified as: *Cliffortia*

Genera found in Cathedral Peak: *Cliffortia browniana*, *C. filicauloides*, *C. linearifolia*, *C. repens*, *C. spathulata*

Likely parent taxa: *Cliffortia browniana*, *C. filicauloides*, *C. linearifolia*, *C. repens*, *C. spathulata*

Pollen morphological characteristics (on Genus level): grains 3-4 porate; spheroidal to suboblate; ambit circular; medium sized; pori: protruding; surrounded thick collar; often irregular outline; surrounded granules and small cracks in exine; exine: 2-3 $\mu$ m thick; nexine 0.5 $\mu$ m; baculate; crassitegillate; punctitegillate (van Zinderen Bakker and Coetzee 1959).

Ecology: *Cliffortia* is found in montane and sub-alpine grasslands and alpine heath environments of Cathedral Peak (Killick 1963), usually under moist but also drier conditions (Scott 1982a).

Dispersal and preservation characteristic: There are 78 species of *Cliffortia* occurring mostly in the south-west Cape but with a few species extending eastwards along the coastal belt (van Zinderen Bakker and Coetzee 1959).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Identified as: *Leucosidea*

Genera found in Cathedral Peak: *Leucosidea sericea*

Likely parent taxa: *Leucosidea sericea*

Pollen morphological characteristics (on Genus level): 3 colpate; prolate to prolate spheroidal; sometimes slightly constricted at equator; fossaperturate; size: 22.4-28 $\mu$ m; Apertures: long, pointed end at poles; 5.5 $\mu$ m apart; membrane psilate; constricted at equator over distance of 4-5.5 $\mu$ m; equatorial area sometimes protruding;; ora oblongata; exine: 2-2.5 $\mu$ m thick; stratification obscure; with regular striate pattern (van Zinderen Bakker and Coetzee 1959).

Ecology: *Leucosidea* is found in the montane and sub-alpine grasslands of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristic: *Leucosidea* is endemic with one species occurring from Limpopo through to the mountains of the eastern escarpment as far south as Queenstown in the Eastern Cape (van Zinderen Bakker and Coetzee 1959).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Arboreal / Non-Arboreal: Arboreal

Identified as: Undifferentiated

Genera found in Cathedral Peak: *Agrimonia eupatoria*, *Alchemilla natalensis*, *Cliffortia browniana*, *C. filicauloides*, *C. linearfolia*, *C. repens*, *C. spathulata*, *Geum capense*, *Leucosidea sericea*, *Rubus, ludwigii*.

Likely parent taxa:

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: No ecological description is found for this research.

Dispersal and preservation characteristic: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## RUTACEAE

Identified as: *Calodendrum*

Genera found in Cathedral Peak: *Calodendrum capense*

Likely parent taxa: *Calodendrum capense*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: Montane forests of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristic: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Identified as: *Clausena*

Genera found in Cathedral Peak: *Clausena anisata*

Likely parent taxa: *Clausena anisata*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: Montane forests of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristic: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

## SCROPHULARIACEAE

Identified as: *Phygellus*

Genera found in Cathedral Peak: *Phygellus capensis*

Likely parent taxa: *Phygellus capensis*

Pollen morphological characteristics: No morphological description available for this research.

Ecology:

Dispersal and preservation characteristic: insect pollinated; generally under-represented in pollen record (Connor *et al.* 2004)

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

## THYMELEACEAE

Identified as: *Gnidia*

Genera found in Cathedral Peak: *Dias*, *Lasiosiphon*, *Passerina*

Likely parent taxa: *Gnidia baurii*, *G. compacta*, *G. polystachya*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: Grasslands (Scott 1982)

Dispersal and preservation characteristic: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal



## **Appendix D: Combustion-Digestion Technique (Adapted from Winkler, 1985)**

1. Dry, clean crucibles are weighed and labelled
2. Each sub-sample is placed inside the crucible and weighed to determine the wet/moist weight of the sample.
3. Crucibles with sub-samples are placed into the oven at 85°C and dried overnight.
4. The dried crucibles are taken out of the oven and placed into desiccators for 30 minutes to one hour to cool.
5. The cooled sub-samples are weighed in the crucible to obtain the dry weight (DW).
6. After the sub-samples are weighed, they are placed into beakers and 20ml of concentrated nitric acid (HNO<sub>3</sub>) is added to each sub-sample.
7. The beakers are then placed in a heating block 100°C for up to three hours, or until there is no more yellow gas being emitted, which is indicative of the digestion process.
8. After the digestion process is completed the sub-samples are decanted into test tubes and placed in a centrifuge for five minutes at 3.5 (x1000) rpm.
9. The supernatant is decanted and the remaining sample is placed into a crucible. The crucible is then placed overnight in an oven at 85°C.
10. The crucibles are taken out of the oven and placed in desiccators to cool for 30 minutes to one hour.
11. Once the crucibles are cooled, they are weighed to determine the weight after nitric acid digestion (NW).
12. Once weighed the sub-samples are placed into a furnace for three hours at 450°C.
13. The crucibles are cooled for 30 minutes to one hour in desiccators and then weighed to determine the ignition weight (IW).

## Appendix E: Catchment Six Calibrated Ages

Depth (cm)	Cal Min Date	Cal Max Date	Probability (%)	Median Date	Median Error
7	-43.5	-41.5	67.4*	-42.5	1
7	-8.5	-8.5	22.7	-8.5	0
119	2125.5	2312.5	100*	2219	93.5
161	4627.5	4638.5	1.9	4633	5.5
161	4641.5	4683.5	15.7	4662.5	21
161	4685.5	4761.5	48.4*	4723.5	38
161	4789.5	4793.5	0.7	4791.5	2
161	4796.5	4844.5	28.6	4820.5	24
218	5934.5	6127.5	78.8*	6031	96.5
218	6139.5	6180.5	16.7	6160	20.5
245.5	6788.5	6950.5	100*	6869.5	81
270	9302.5	9485.5	100*	9394	91.5
298	14651.5	15541.5	100*	15096.5	445
361	5994.5	6183.5	100	6089	94.5

\* denotes the data used in the analysis process

## Appendix F: Interpolated Calibrated Ages

Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
7	-44.139	-8.139	-39.691	25	303.832	363.832	327.901	43	654.400	732.400	691.314
8	-28.958	13.042	-15.201	26	322.947	383.947	348.090	44	673.591	752.591	711.504
9	-5.789	33.211	4.786	27	343.085	405.085	368.280	45	692.779	772.779	731.693
10	13.297	53.297	25.063	28	362.214	425.214	388.470	46	711.965	793.965	751.883
11	33.343	74.343	45.242	29	381.391	446.391	408.659	47	731.149	814.149	772.072
12	52.375	95.375	65.435	30	400.616	466.616	428.849	48	751.330	835.330	792.263
13	72.402	115.402	85.626	31	419.855	486.855	449.039	49	770.509	855.509	812.452
14	91.425	136.425	105.814	32	440.090	507.090	469.228	50	789.687	876.687	832.641
15	110.460	156.460	126.004	33	459.319	528.319	489.418	51	808.863	896.863	852.831
16	129.484	177.484	146.194	34	478.544	547.544	509.607	52	828.037	917.037	873.021
17	149.524	198.524	166.384	35	498.765	567.765	529.797	53	848.209	938.209	893.211
18	168.564	218.564	186.573	36	517.982	587.982	549.987	54	867.380	959.380	913.400
19	187.589	239.589	206.763	37	538.194	609.194	570.176	55	886.549	979.549	933.590
20	207.635	260.635	226.953	38	557.404	629.404	590.366	56	906.717	1000.717	953.779
21	226.670	280.670	247.142	39	576.609	649.609	610.556	57	924.884	1020.884	973.969
22	245.683	301.683	267.332	40	595.811	669.811	630.745	58	945.050	1042.050	994.159
23	265.694	321.694	287.521	41	615.011	691.011	650.935	59	964.214	1062.214	1014.348
24	284.735	342.735	307.711	42	635.207	712.207	671.124	60	984.377	1083.377	1034.538

Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
61	1003.539	1104.539	1054.728	82	1410.759	1541.759	1478.710	103	1816.781	1981.781	1902.692
62	1022.700	1124.700	1074.917	83	1430.907	1562.907	1498.900	104	1835.922	2002.922	1922.882
63	1042.860	1145.860	1095.107	84	1450.053	1584.053	1519.089	105	1855.063	2023.063	1943.072
64	1062.019	1167.019	1115.297	85	1469.200	1605.200	1539.279	106	1874.203	2044.203	1963.261
65	1081.177	1187.177	1135.486	86	1488.346	1625.346	1559.469	107	1893.344	2065.344	1983.451
66	1100.334	1208.334	1155.676	87	1507.491	1646.491	1579.658	108	1913.484	2086.484	2003.641
67	1120.491	1229.491	1175.865	88	1527.637	1667.637	1599.848	109	1932.624	2107.624	2023.830
68	1139.646	1249.646	1196.055	89	1545.781	1687.781	1620.037	110	1951.764	2128.764	2044.020
69	1158.801	1270.801	1216.245	90	1564.926	1708.926	1640.227	111	1970.904	2148.904	2064.209
70	1177.955	1290.955	1236.434	91	1585.070	1730.070	1660.417	112	1990.043	2170.043	2084.399
71	1197.109	1312.109	1256.624	92	1604.214	1751.214	1680.606	113	2009.183	2191.183	2104.589
72	1217.262	1333.262	1276.814	93	1623.358	1771.358	1700.796	114	2028.322	2212.322	2124.778
73	1236.414	1353.414	1297.003	94	1642.501	1792.501	1720.986	115	2048.461	2233.461	2144.968
74	1255.566	1374.566	1317.194	95	1661.645	1813.645	1741.175	116	2067.600	2254.600	2165.158
75	1275.717	1395.717	1337.382	96	1681.787	1834.787	1761.365	117	2086.739	2275.739	2185.347
76	1294.867	1416.867	1357.573	97	1700.930	1855.930	1781.555	118	2105.878	2295.878	2205.537
77	1314.017	1437.017	1377.762	98	1720.072	1877.072	1801.744	119	2125.016	2317.016	2225.727
78	1333.166	1458.166	1397.952	99	1739.215	1897.215	1821.934	120	2187.575	2375.575	2285.668
79	1353.315	1479.315	1418.141	100	1758.356	1918.356	1842.123	121	2250.116	2433.116	2345.610
80	1372.464	1500.464	1438.331	101	1777.498	1939.498	1862.313	122	2311.637	2490.637	2405.551
81	1391.612	1520.612	1458.520	102	1797.640	1960.640	1882.503	123	2374.137	2550.137	2465.493

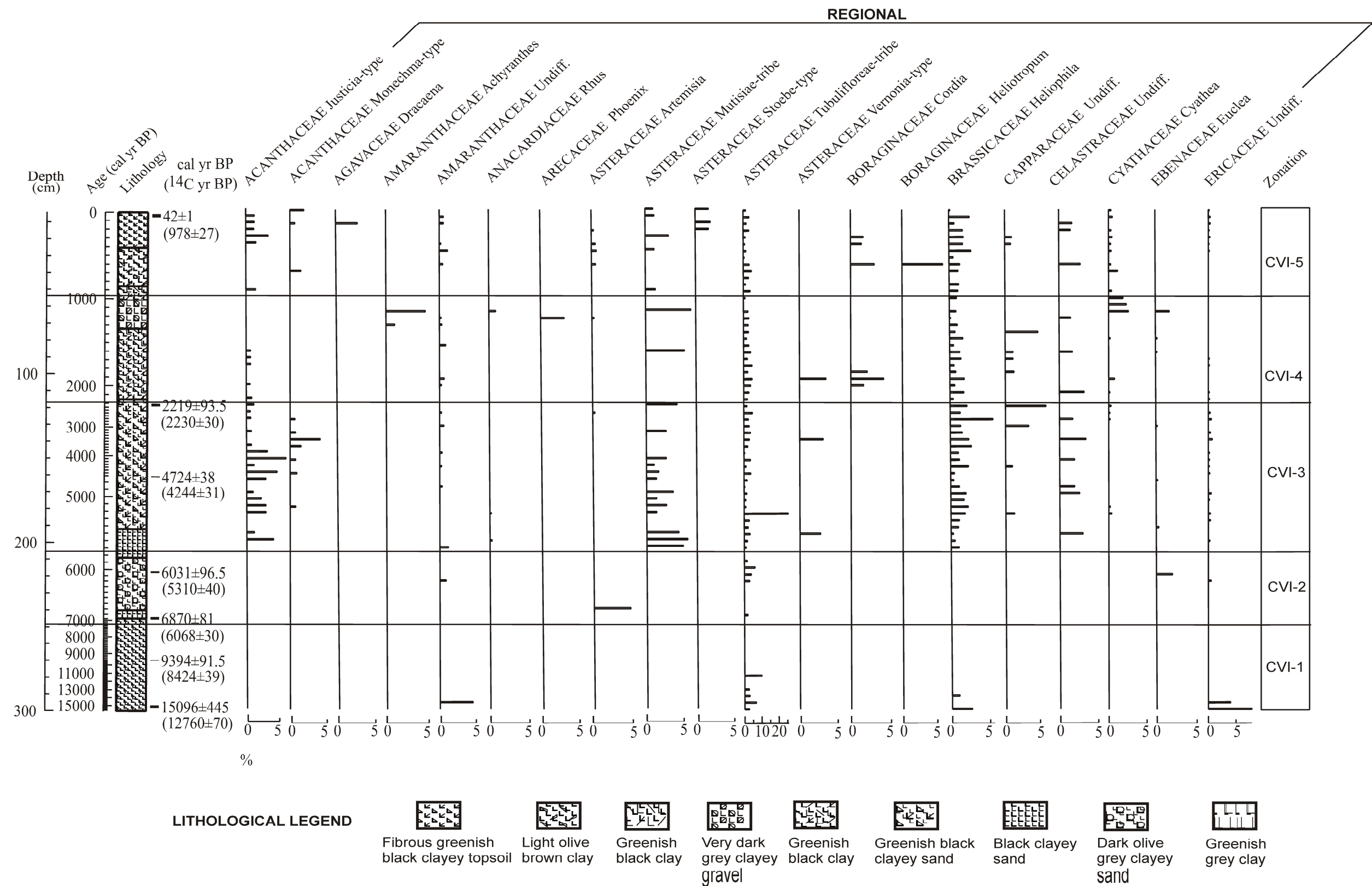
Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
124	2435.615	2608.615	2525.435	145	3701.709	3867.709	3784.209	166	4752.153	4958.153	4858.581
125	2497.069	2667.069	2585.376	146	3760.457	3928.457	3844.150	167	4778.043	4980.043	4881.642
126	2558.498	2726.498	2645.318	147	3820.172	3989.172	3904.092	168	4803.918	5001.918	4904.703
127	2619.898	2785.898	2705.260	148	3878.854	4049.854	3964.034	169	4829.778	5022.778	4927.764
128	2681.270	2845.270	2765.201	149	3937.505	4110.505	4023.975	170	4855.621	5044.621	4950.825
129	2741.611	2904.611	2825.143	150	3996.865	4171.865	4083.917	171	4879.448	5067.448	4973.886
130	2801.919	2963.919	2885.084	151	4055.484	4232.484	4143.859	172	4903.257	5090.257	4996.948
131	2863.193	3024.193	2945.026	152	4113.077	4293.077	4203.800	173	4926.047	5112.047	5020.009
132	2923.431	3083.431	3004.968	153	4172.646	4354.646	4263.742	174	4949.818	5134.818	5043.070
133	2983.632	3143.632	3064.909	154	4229.192	4416.192	4323.683	175	4973.569	5158.569	5066.131
134	3043.794	3203.794	3124.851	155	4284.718	4478.718	4383.626	176	4997.298	5181.298	5089.192
135	3104.915	3264.915	3184.793	156	4341.224	4540.224	4443.567	177	5020.006	5204.006	5112.253
136	3164.996	3324.996	3244.734	157	4398.713	4602.713	4503.508	178	5043.692	5226.692	5135.314
137	3225.035	3385.035	3304.676	158	4455.184	4664.184	4563.450	179	5067.144	5250.144	5158.376
138	3284.031	3445.031	3364.617	159	4512.640	4725.640	4623.392	180	5090.659	5273.659	5181.437
139	3343.986	3504.986	3424.559	160	4570.081	4788.081	4683.333	181	5114.151	5297.151	5204.498
140	3403.398	3565.398	3484.501	161	4626.508	4850.508	4743.275	182	5137.617	5320.617	5227.559
141	3464.340	3626.340	3544.442	162	4652.461	4871.461	4766.336	183	5161.058	5344.058	5250.620
142	3523.241	3686.241	3604.384	163	4677.403	4893.403	4789.397	184	5185.474	5368.474	5273.682
143	3583.102	3747.102	3664.326	164	4702.332	4914.332	4812.458	185	5208.863	5391.863	5296.743
144	3641.924	3806.924	3724.267	165	4727.249	4936.249	4835.519	186	5232.227	5415.227	5319.804

Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
187	5254.564	5438.564	5342.865	208	5723.406	5933.406	5827.149	229	6297.058	6471.058	6382.772
188	5278.876	5462.876	5365.926	209	5744.599	5957.599	5850.210	230	6328.546	6498.546	6412.318
189	5302.161	5486.161	5388.987	210	5766.780	5982.780	5873.272	231	6359.968	6525.968	6441.865
190	5324.421	5509.421	5412.048	211	5787.950	6006.950	5896.333	232	6390.316	6553.316	6471.411
191	5346.656	5532.656	5435.110	212	5810.109	6032.109	5919.394	233	6420.764	6580.764	6500.957
192	5369.865	5555.865	5458.171	213	5831.258	6056.258	5942.455	234	6451.889	6608.889	6530.504
193	5393.051	5580.051	5481.232	214	5852.397	6081.397	5965.516	235	6481.919	6635.919	6560.050
194	5415.212	5603.212	5504.293	215	5874.528	6106.528	5988.578	236	6511.978	6664.978	6589.597
195	5437.350	5626.350	5527.354	216	5894.649	6130.649	6011.639	237	6542.425	6693.425	6619.143
196	5459.466	5649.466	5550.415	217	5916.359	6156.359	6034.700	238	6571.767	6721.767	6648.690
197	5481.561	5672.561	5573.477	218	5936.869	6181.869	6057.761	239	6602.005	6751.005	6678.236
198	5503.634	5696.634	5596.538	219	5970.406	6206.406	6087.307	240	6631.140	6781.140	6707.783
199	5525.687	5719.687	5619.599	220	6003.925	6231.925	6116.854	241	6661.176	6811.176	6737.329
200	5547.721	5742.721	5642.660	221	6037.313	6257.313	6146.400	242	6690.119	6842.119	6766.875
201	5569.736	5766.736	5665.721	222	6070.751	6283.751	6175.947	243	6718.974	6872.974	6796.422
202	5591.733	5789.733	5688.782	223	6104.071	6310.071	6205.493	244	6746.749	6903.749	6825.968
203	5613.240	5813.240	5711.844	224	6136.635	6336.635	6235.040	245	6774.450	6935.450	6855.517
204	5635.503	5837.503	5734.905	225	6169.165	6363.165	6264.586	246	6841.175	7001.175	6922.040
205	5657.750	5861.750	5757.966	226	6201.257	6389.257	6294.132	247	6947.936	7102.936	7025.541
206	5678.982	5884.982	5781.027	227	6233.907	6416.907	6323.679	248	7053.639	7203.639	7129.044
207	5701.201	5909.201	5804.088	228	6265.509	6443.509	6353.225	249	7159.278	7305.278	7232.546

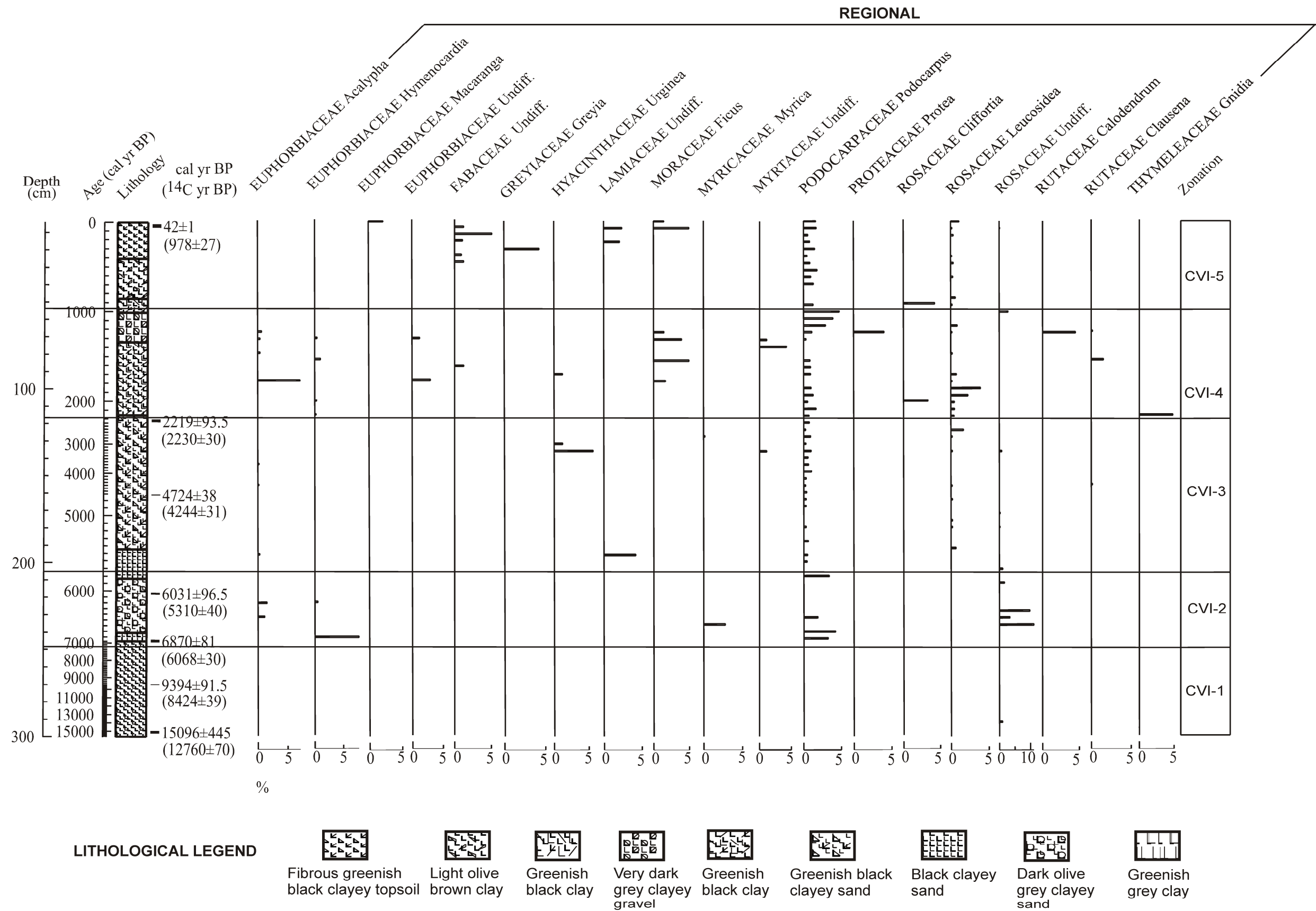
Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
250	7263.846	7406.846	7336.049	271	9503.904	9690.904	9608.885	292	13525.429	14226.429	13867.414
251	7367.335	7508.335	7439.551	272	9706.526	9898.526	9811.673	293	13712.014	14445.014	14070.201
252	7471.738	7610.738	7543.054	273	9905.633	10107.633	10014.460	294	13899.256	14663.256	14272.988
253	7575.456	7713.456	7646.556	274	10104.252	10321.252	10217.247	295	14086.549	14882.549	14475.776
254	7678.381	7815.381	7750.059	275	10300.434	10536.434	10420.034	296	14272.888	15100.888	14678.563
255	7782.857	7918.857	7853.561	276	10496.240	10753.240	10622.821	297	14460.079	15320.079	14881.350
256	7886.227	8022.227	7957.064	277	10692.748	10969.748	10825.608	298	14646.201	15538.201	15084.137
257	7989.492	8125.492	8060.566	278	10886.423	11186.423	11028.395	299	14833.608	15757.608	15286.924
258	8091.655	8228.655	8164.069	279	11077.213	11401.213	11231.182	300	15019.696	15975.696	15489.711
259	8193.718	8332.718	8267.571	280	11268.626	11617.626	11433.969	301	15206.705	16194.705	15692.498
260	8295.688	8435.688	8371.074	281	11459.073	11834.073	11636.756	302	15393.781	16413.781	15895.285
261	8397.571	8540.571	8474.576	282	11647.624	12050.624	11839.543	303	15579.972	16632.972	16098.072
262	8499.374	8644.374	8578.079	283	11837.122	12268.122	12042.331	304	15767.106	16852.106	16300.859
263	8600.106	8748.106	8681.581	284	12026.438	12485.438	12245.118	305	15953.496	17071.496	16503.646
264	8700.774	8852.774	8785.084	285	12214.732	12702.732	12447.905	306	16140.755	17290.755	16706.434
265	8801.384	8958.384	8888.586	286	12402.774	12920.774	12650.692	307	16327.748	17510.748	16909.221
266	8901.942	9063.942	8992.089	287	12589.874	13137.874	12853.479	308	16514.729	17729.729	17112.008
267	9001.314	9169.314	9095.591	288	12777.108	13355.108	13056.266	309	16701.670	17949.670	17314.795
268	9101.380	9275.380	9199.093	289	12964.795	13572.795	13259.053	310	16888.611	18169.611	17517.582
269	9200.594	9381.594	9302.596	290	13151.968	13790.968	13461.840	311	17075.449	18388.449	17720.369
270	9299.778	9488.778	9406.098	291	13338.467	14008.467	13664.627	312	17262.493	18608.493	17923.156

Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date	Depth (cm)	Cal Min Date	Cal Max Date	Best Date
313	17448.684	18827.684	18125.943	334	21369.487	23442.487	22384.472	355	25285.600	28058.600	26643.001
314	17635.443	19047.443	18328.730	335	21555.474	23662.474	22587.259	356	25472.376	28278.376	26845.788
315	17822.196	19267.196	18531.517	336	21742.369	23882.369	22790.046	357	25659.083	28498.083	27048.575
316	18009.382	19487.382	18734.304	337	21929.242	24102.242	22992.833	358	25844.790	28717.790	27251.362
317	18196.283	19707.283	18937.092	338	22115.977	24321.977	23195.620	359	26031.605	28937.605	27454.149
318	18383.321	19926.321	19139.879	339	22301.947	24541.947	23398.407	360	26218.410	29157.410	27656.936
319	18570.199	20146.199	19342.666	340	22488.723	24761.723	23601.195	361	26404.208	29377.208	27859.723
320	18757.066	20366.066	19545.453	341	22675.555	24981.555	23803.982				
321	18942.916	20584.916	19748.240	342	22862.513	25201.513	24006.769				
322	19129.697	20805.697	19951.027	343	23048.631	25421.631	24209.556				
323	19316.421	21025.421	20153.814	344	23235.247	25641.247	24412.343				
324	19503.465	21245.465	20356.601	345	23421.994	25860.994	24615.130				
325	19689.372	21464.372	20559.388	346	23607.798	26080.798	24817.917				
326	19876.187	21684.187	20762.175	347	23794.591	26300.591	25020.704				
327	20063.066	21904.066	20964.962	348	23980.612	26519.612	25223.491				
328	20250.001	22124.001	21167.749	349	24167.473	26740.473	25426.278				
329	20436.868	22343.868	21370.537	350	24353.311	26959.311	25629.065				
330	20622.837	22563.837	21573.324	351	24540.224	27179.224	25831.852				
331	20809.704	22783.704	21776.111	352	24726.079	27399.079	26034.640				
332	20996.628	23003.628	21978.898	353	24912.952	27618.952	26237.427				
333	21183.575	23223.575	22181.685	354	25099.619	27838.619	26440.214				

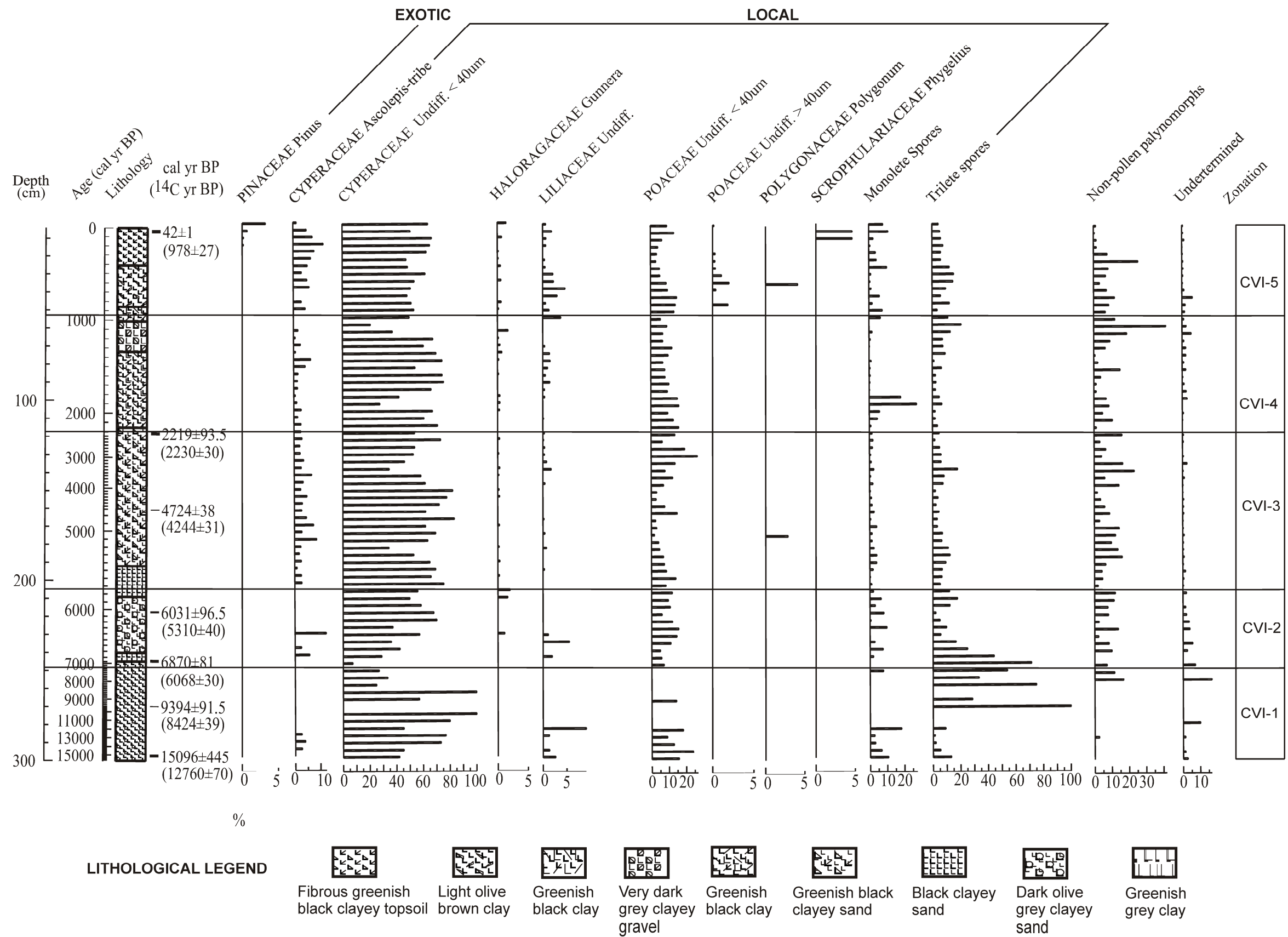




Appendix G: 300 cm Regional and Local Pollen Diagram (1 of 3)



Appendix G: 300 cm Regional and Local Pollen (2 of 3)



Appendix G: 300 cm Regional and Local Pollen (3 of 3)

## Appendix H: Raw Pollen Counts

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
ACANTHACEAE <i>Justicia</i> -type	-	2	2	2	6	3	-	-	-	-	-	-	2	-	-	-	-	-	-	-
ACANTHACEAE <i>Monechma</i> -type	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AGAVACEAE <i>Dracaena</i>	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE <i>Achyranthes</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-
AMARANTHACEAE Undiff.	-	2	2	-	-	1	4	-	1	-	-	-	-	-	-	-	1	1	-	-
ANACARDIACEAE <i>Rhus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	-	-	-
ARECACEAE <i>Phoenix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
ASTERACEAE <i>Artemisia</i>	-	-	-	1	-	2	2	-	1	-	-	-	-	-	-	-	1	-	-	-
ASTERACEAE <i>Mutisiae</i> -tribe	1	1	-	-	3	-	1	-	-	-	-	-	1	-	-	1	-	-	-	-
ASTERACEAE <i>Stoebe</i> -type	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Tubulifloreae</i> -tribe	9	20	10	20	8	6	9	1	12	12	1	2	21	1	-	3	19	13	4	9
ASTERACEAE <i>Vernonia</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Cordia</i>	-	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Heliotropum</i>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
BRASSICACEAE Undiff	1	16	4	11	13	13	17	1	5	3	0	2	6	1	-	1	1	5	1	9
CAPPARACEAE Undiff	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-
CELASTRACEAE Undiff	-	-	1	1	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-
CYATHACEAE <i>Cyathea</i>	2	3	-	2	3	2	2	-	1	3	-	-	2	2	1	3	-	-	-	1
EBENACEAE <i>Euclea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1
ERICACEAE Undiff	1	2	2	1	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
<b>EUPHORBIACEAE</b> <i>Acalypha</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2	-	2
<b>EUPHORBIACEAE</b> <i>Hymenocardia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
<b>EUPHORBIACEAE</b> <i>Macaranga</i>	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>EUPHORBIACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-
<b>FABACEAE</b> Undiff	-	1	4	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>GREYIACEAE</b> <i>Greyia</i>	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>HYACINTHACEAE</b> <i>Urginea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>LAMIACEAE</b> Undiff	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MORACEAE</b> <i>Ficus</i>	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-
<b>MYRICACEAE</b> <i>Myrica</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MYRTACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-
<b>PODOCARPACEAE</b> <i>Podocarpus</i>	6	6	2	3	6	2	3	2	2	2	-	-	4	3	1	2	4	1	-	-
<b>PROTEACEAE</b> <i>Protea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
<b>ROSACEAE</b> <i>Cliffortia</i>	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Leucosidea</i>	7	1	2	-	-	1	2	-	1	-	-	1	1	-	-	1	1	-	-	1
<b>ROSACEAE</b> <i>Rubus</i>	-	1	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Calodendrum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
<b>RUTACEAE</b> <i>Clausena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
<b>THYMELEACEAE</b> <i>Gnidia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>PINACEAE</b> <i>Pinus</i>	20	4	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>CYPERACEAE</b> <i>Ascolepis</i> -tribe	8	31	43	73	57	50	33	6	19	16	-	5	25	-	-	2	4	13	1	35
<b>CYPERACEAE</b> Undiff	400	301	379	401	431	345	289	116	190	130	16	83	285	53	9	43	412	292	98	387

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
<b>HALORAGACEAE <i>Gunnera</i></b>	9	-	4	-	1	1	3	-	2	-	-	1	1	-	-	2	1	2	1	1
<b>LILIACEAE Undiff</b>	4	11	4	4	-	3	3	4	8	12	1	1	7	4	-	-	-	2	2	8
<b>POACEAE Undiff &lt; 40um</b>	59	80	37	26	24	22	31	10	32	25	5	23	72	6	4	8	42	59	14	36
<b>POACEAE Undiff &gt; 40um</b>	1	-	-	-	2	2	2	2	7	1	0	3	-	-	-	-	-	-	-	-
<b>POLYGONACEAE <i>Polygonum</i></b>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<b>SCROPHULARIACEAE <i>Phygelius</i></b>	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Monolete Spores</b>	51	66	14	4	26	31	61	2	2	3	2	3	41	7	-	2	4	1	-	6
<b>Trilete spores</b>	28	33	35	48	42	44	73	29	53	25	2	20	19	12	9	15	45	37	13	6
<b>Non-pollen palynomorphs</b>	8	3	9	10	54	186	50	13	12	19	4	14	36	13	18	22	57	32	1	12
<b>Undertermined</b>	3	3	7	1	2	4	4	1	1	3	2	3	8	1	1	6	6	10	3	5
<b>TOTAL COUNTS</b>	<b>624</b>	<b>592</b>	<b>567</b>	<b>612</b>	<b>685</b>	<b>722</b>	<b>591</b>	<b>187</b>	<b>353</b>	<b>255</b>	<b>33</b>	<b>161</b>	<b>532</b>	<b>106</b>	<b>43</b>	<b>115</b>	<b>609</b>	<b>482</b>	<b>140</b>	<b>519</b>

Depth (cm)	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	148	152	156	160
ACANTHACEAE <i>Justicia</i> -type	-	1	1	1	-	-	1	-	1	2	1	1	-	1	-	1	4	8	2	5
ACANTHACEAE <i>Monechma</i> -type	-	-	-	-	-	-	-	-	-	-	-	1	-	1	3	2	-	1	-	1
AGAVACEAE <i>Dracaena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE <i>Achyranthes</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE Undiff.	1	-	-	-	-	1	1	-	-	-	1	-	2	-	-	-	1	-	1	-
ANACARDIACEAE <i>Rhus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARECACEAE <i>Phoenix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Artemisia</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Mutisiae</i> -tribe	-	4	-	-	-	-	-	-	-	4	-	-	-	2	-	-	-	2	1	1
ASTERACEAE <i>Stoebe</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Tubulifloreae</i> -tribe	6	22	12	26	12	13	25	18	10	12	30	14	18	19	9	11	2	19	8	16
ASTERACEAE <i>Vernonia</i> -type	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-
BORAGINACEAE <i>Cordia</i>	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Heliotropum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRASSICACEAE Undiff	1	7	8	3	4	5	4	11	2	15	8	30	8	8	7	14	5	6	16	2
CAPPARACEAE Undiff	-	1	1	-	1	-	-	-	-	6	-	-	3	-	-	-	-	-	1	-
CELASTRACEAE Undiff	-	1	-	-	-	-	-	2	-	-	-	1	-	-	1	-	-	1	-	-
CYATHACEAE <i>Cyathea</i>	-	-	-	-	-	2	-	1	-	2	1	1	-	-	-	-	-	-	-	-
EBENACEAE <i>Euclea</i>	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
ERICACEAE Undiff	-	-	1	1	-	-	-	1	1	-	2	3	-	2	2	-	1	1	1	1
EUPHORBIACEAE <i>Acalypha</i>	-	0	0	38	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-
EUPHORBIACEAE <i>Hymenocardia</i>	2	0	0	0	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-

Depth (cm)	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	148	152	156	160
<b>EUPHORBIACEAE</b> <i>Macaranga</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>EUPHORBIACEAE</b> Undiff	-	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>FABACEAE</b> Undiff	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>GREYIACEAE</b> <i>Greyia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>HYACINTHACEAE</b> <i>Urginea</i>	-	-	1	-	-	-	-	-	-	-	-	-	1	4	-	-	-	-	-	-
<b>LAMIACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MORACEAE</b> <i>Ficus</i>	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MYRICACEAE</b> <i>Myrica</i>	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
<b>MYRTACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
<b>PODOCARPACEAE</b> <i>Podocarpus</i>	1	3	3	-	3	2	2	6	2	3	1	3	1	3	1	2	3	1	1	1
<b>PROTEACEAE</b> <i>Protea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Cliffortia</i>	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Leucosidea</i>	-	-	4	1	20	6	3	3	2	-	10	1	-	1	-	-	-	-	1	-
<b>ROSACEAE</b> <i>Rubus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Calodendrum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Clausena</i>	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
<b>THYMELEACEAE</b> <i>Gnidia</i>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<b>PINACEAE</b> <i>Pinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>CYPERACEAE</b> <i>Ascolepis</i> -tribe	9	9	8	8	3	3	18	9	13	18	19	12	14	19	8	35	17	13	34	13
<b>CYPERACEAE</b> Undiff	107	401	414	354	215	74	422	367	336	363	444	288	310	234	100	298	297	423	534	299
<b>HALORAGACEAE</b> <i>Gunnera</i>	-	1	-	-	2	1	2	-	-	-	2	-	1	-	1	1	-	1	2	-
<b>LILIACEAE</b> Undiff	2	3	8	2	2	-	-	1	-	2	1	2	2	4	5	-	2	-	-	-



Depth (cm)	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	148	152	156	160
<b>POACEAE Undiff &lt; 40um</b>	16	44	57	51	78	43	61	78	76	93	39	104	157	70	23	63	34	16	19	32
<b>POACEAE Undiff &gt; 40um</b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>POLYGONACEAE <i>Polygonum</i></b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>SCROPHULARIACEAE <i>Phygelius</i></b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Monolete Spores</b>	1	3	2	1	93	73	37	28	4	10	12	9	4	5	7	3	9	2	7	6
<b>Trilete spores</b>	13	12	14	12	25	18	12	12	17	32	10	27	36	31	52	42	36	10	26	10
<b>Non-pollen palynomorphs</b>	30	21	7	7	36	23	31	64	6	109	20	36	25	84	67	31	69	9	25	25
<b>Undertermined</b>	4	2	6	12	14	-	4	1	-	4	3	-	3	13	1	5	1	1	4	2
<b>TOTAL COUNTS</b>	<b>197</b>	<b>537</b>	<b>547</b>	<b>534</b>	<b>509</b>	<b>266</b>	<b>627</b>	<b>602</b>	<b>472</b>	<b>675</b>	<b>605</b>	<b>534</b>	<b>586</b>	<b>506</b>	<b>288</b>	<b>509</b>	<b>481</b>	<b>514</b>	<b>685</b>	<b>414</b>

Depth (cm)	164	168	172	176	180	184	188	192	196	200	204	208	212	216	220	224	228	232	236	240
ACANTHACEAE <i>Justicia</i> -type	4	-	1	3	4	4	-	-	1	4	-	-	-	-	-	-	-	-	-	-
ACANTHACEAE <i>Monechma</i> -type	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AGAVACEAE <i>Dracaena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE <i>Achyranthes</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE Undiff	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-
ANACARDIACEAE <i>Rhus</i>	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
ARECACEAE <i>Phoenix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Artemisia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
ASTERACEAE <i>Mutisiae</i> -tribe	1	-	2	1	2	1	-	-	2	3	2	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Stoebe</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Tubulifloreae</i> -tribe	9	2	6	5	5	136	8	7	11	7	3	-	1	4	2	6	-	-	-	-
ASTERACEAE <i>Vernonia</i> -type	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Cordia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Heliotropum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRASSICACEAE Undiff	2	6	8	9	12	10	3	3	1	2	3	-	-	-	-	-	-	-	-	-
CAPPARACEAE Undiff	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CELASTRACEAE Undiff	-	1	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
CYATHACEAE <i>Cyathea</i>	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EBENACEAE <i>Euclea</i>	1	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-
ERICACEAE Undiff	-	-	2	1	-	2	1	-	-	1	-	-	-	-	-	1	-	-	-	-
EUPHORBIACEAE <i>Acalypha</i>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	3	-	1	-	-
EUPHORBIACEAE <i>Hymenocardia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-

Depth (cm)	164	168	172	176	180	184	188	192	196	200	204	208	212	216	220	224	228	232	236	240
<b>EUPHORBIACEAE</b> <i>Macaranga</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>EUPHORBIACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>FABACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>GREYIACEAE</b> <i>Greyia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>HYACINTHACEAE</b> <i>Urginea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>LAMIACEAE</b> Undiff	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<b>MORACEAE</b> <i>Ficus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MYRICACEAE</b> <i>Myrica</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
<b>MYRTACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1
<b>PODOCARPACEAE</b> <i>Podocarpus</i>	1	1	-	-	1	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-
<b>PROTEACEAE</b> <i>Protea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Cliffortia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Leucosidea</i>	1	-	-	1	1	-	-	2	-	-	3	-	1	-	-	-	5	3	4	0
<b>ROSACEAE</b> <i>Rubus</i>	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Calodendrum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Clausena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>THYMELEACEAE</b> <i>Gnidia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>PINACEAE</b> <i>Pinus</i>	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	-	11	-	1
<b>CYPERACEAE</b> <i>Ascolepis</i> -tribe	15	25	30	15	46	13	5	8	3	10	216	28	31	38	34	139	19	51	13	17
<b>CYPERACEAE</b> Undiff	323	441	246	358	334	182	145	200	225	253	-	1	1	-	-	-	-	1	-	-
<b>HALORAGACEAE</b> <i>Gunnera</i>	-	-	1	-	-	1	-	1	-	1	-	-	-	-	-	-	-	1	2	0
<b>LILIACEAE</b> Undiff	-	1	0	2	-	4	-	-	1	-	-	-	-	-	-	-	-	-	-	-

Depth (cm)	164	168	172	176	180	184	188	192	196	200	204	208	212	216	220	224	228	232	236	240
<b>POACEAE Undiff &lt; 40um</b>	78	13	12	9	22	25	19	23	28	54	24	6	6	7	3	24	8	13	4	2
<b>POACEAE Undiff &gt; 40um</b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>POLYGONACEAE <i>Polygonum</i></b>	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>SCROPHULARIACEAE <i>Phygelius</i></b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Monolete Spores</b>	13	3	16	7	7	13	11	12	6	1	3	1	4	2	4	1	5	-	1	3
<b>Trilete spores</b>	23	17	13	36	34	59	34	29	22	25	15	6	11	8	1	10	5	5	6	10
<b>Non-pollen palynomorphs</b>	46	16	57	63	52	72	44	20	14	18	6	6	7	5	4	5	7	2	3	4
<b>Undertermined</b>	3	1	1	4	2	2	2	1	5	2	1	1	-	1	1	7	2	-	2	1
<b>TOTAL COUNTS</b>	<b>520</b>	<b>528</b>	<b>397</b>	<b>515</b>	<b>525</b>	<b>528</b>	<b>273</b>	<b>307</b>	<b>324</b>	<b>383</b>	<b>286</b>	<b>50</b>	<b>62</b>	<b>65</b>	<b>50</b>	<b>198</b>	<b>51</b>	<b>89</b>	<b>36</b>	<b>40</b>

Depth (cm)	244	248	252	256	260	264	268	272	276	280	284	288	292	296	300
ACANTHACEAE <i>Justicia</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACANTHACEAE <i>Monechma</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AGAVACEAE <i>Dracaena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE <i>Achyranthes</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMARANTHACEAE Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
ANACARDIACEAE <i>Rhus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARECACEAE <i>Phoenix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Artemisia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Mutisiae</i> -tribe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Stoebe</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASTERACEAE <i>Tubulifloreae</i> -tribe	1	-	-	-	-	-	-	-	-	1	-	2	3	5	1
ASTERACEAE <i>Vernonia</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Cordia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BORAGINACEAE <i>Heliotropum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BRASSICACEAE Undiff	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
CAPPARACEAE Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CELASTRACEAE Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CYATHACEAE <i>Cyathea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EBENACEAE <i>Euclea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ERICACEAE Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3
EUPHORBIACEAE <i>Acalypha</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EUPHORBIACEAE <i>Hymenocardia</i>	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth (cm)	244	248	252	256	260	264	268	272	276	280	284	288	292	296	300
<b>EUPHORBIACEAE</b> <i>Macaranga</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>EUPHORBIACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>FABACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>GREYIACEAE</b> <i>Greyia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>HYACINTHACEAE</b> <i>Urginea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>LAMIACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MORACEAE</b> <i>Ficus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>MYRICACEAE</b> <i>Myrica</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>PODOCARPACEAE</b> <i>Podocarpus</i>	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>PROTEACEAE</b> <i>Protea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Cliffortia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Leucosidea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>ROSACEAE</b> <i>Rubus</i>	0	-	-	-	-	-	-	-	-	-	-	-	1	-	-
<b>RUTACEAE</b> <i>Calodendrum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>RUTACEAE</b> <i>Clausena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>THYMELEACEAE</b> <i>Gnidia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>PINACEAE</b> <i>Pinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>CYPERACEAE</b> <i>Ascolepis</i> -tribe	3	-	-	-	-	-	-	-	-	-	-	2	4	2	-
<b>CYPERACEAE</b> Undiff	15	1	7	2	1	2	4	-	7	8	5	60	74	34	16
<b>HALORAGACEAE</b> <i>Gunnera</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>LILIACEAE</b> Undiff	1	-	-	-	-	-	-	-	-	-	1	1	-	1	1
<b>MYRTACEAE</b> Undiff	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth (cm)	244	248	252	256	260	264	268	272	276	280	284	288	292	296	300
<b>POACEAE Undiff &lt; 40um</b>	3	1	-	-	-	-	1	-	-	-	2	7	13	18	6
<b>POACEAE Undiff &gt; 40um</b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>POLYGONACEAE <i>Polygonum</i></b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>SCROPHULARIACEAE <i>Phygelius</i></b>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Monolete Spores</b>	1	-	2	-	-	-	-	-	-	-	2	2	3	5	4
<b>Trilete spores</b>	23	10	14	2	3	-	2	1	-	-	1	1	2	4	5
<b>Non-pollen palynomorphs</b>	-	1	3	1	-	-	-	-	-	-	-	2	-	-	-
<b>Undertermined</b>	-	1	-	1	-	-	-	-	-	1	-	1	-	1	1
<b>TOTAL COUNTS</b>	<b>52</b>	<b>14</b>	<b>26</b>	<b>6</b>	<b>4</b>	<b>2</b>	<b>7</b>	<b>1</b>	<b>7</b>	<b>10</b>	<b>11</b>	<b>78</b>	<b>101</b>	<b>75</b>	<b>38</b>

## Appendix I: Paired T-Test Statistical Results from Charcoal Technique Comparison

Zone	CVI-5		CVI-4		CVI-3		CVI-2		CVI-1	
	Microscopic	Digestion- Combustion	Microscopic	Digestion- Combustion	Microscopic	Digestion- Combustion	Microscopic	Digestion- Combustion	Microscopic	Digestion- Combustion
Mean	0.474	0.519	0.316	0.515	0.286	0.778	0.282	0.664	0.211	0.794
Variance	0.069	0.047	0.039	0.026	0.050	0.013	0.094	0.009	0.029	0.010
Observations	13.000	13.000	16.000	16.000	22.000	22.000	11.000	11.000	13.000	13.000
Pearson										
Correlation	-0.440		0.281		-0.328		-0.521		0.216	
Hypothesized										
Mean										
Difference	0.000		0.000		0.000		0.000		0.000	
Df	12.000		15.000		21.000		10.000		12.000	
t Stat	-0.398		-3.659		-8.126		-3.475		-11.755	
P(T<=t) one-										
tail	0.349		0.001		0.000		0.003		0.000	
t Critical one-										
tail	1.782		1.753		1.721		1.812		1.782	
P(T<=t) two-										
tail	0.697		0.002		0.000		0.006		0.000	
t Critical two-										
tail	2.179		2.131		2.080		2.228		2.179	



## Appendix J: Raw Digestion-Combustion Charcoal Values

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44	48	52	56
Charcoal (%)	8.24	4.48	3.56	3.35	11.65	10.62	10.05	8.67	10.85	12.32	12.25	16.78	7.75	8.12
Organic Matter (%)	73.56	51.45	52.91	53.71	36.99	33.84	34.91	27.48	22.88	20.12	19.11	12.43	31.52	35.41
Inorganic Matter (%)	18.20	44.07	43.53	42.94	51.36	55.54	55.04	63.85	66.27	67.56	68.64	70.80	60.73	56.48
Moisture (%)	27.18	35.65	28.02	32.19	30.90	28.76	27.15	29.70	35.43	36.55	44.37	45.11	39.44	34.01

Depth (cm)	60	64	68	72	76	80	84	88	92	96	100	104	108	112
Charcoal (%)	4.61	8.70	5.31	8.42	9.98	6.30	7.21	9.61	6.77	10.12	9.66	12.88	12.55	11.81
Organic Matter (%)	17.47	28.63	49.89	36.49	23.41	46.94	58.21	65.13	69.57	66.58	54.72	51.12	46.55	40.03
Inorganic Matter (%)	77.92	62.67	44.79	55.09	66.61	46.76	34.59	25.26	23.66	23.30	35.62	36.00	40.91	48.16
Moisture (%)	65.32	46.85	19.75	25.76	46.51	23.90	15.76	13.95	14.84	16.50	18.63	22.26	24.20	27.31

Depth (cm)	116	120	124	128	132	136	140	144	148	152	156	160	164	168
Charcoal (%)	15.13	14.74	17.52	14.63	14.87	11.98	15.32	13.86	14.11	13.61	13.46	17.76	14.67	11.75
Organic Matter (%)	38.20	31.92	27.52	39.19	38.98	41.60	37.19	35.07	31.90	38.70	40.08	30.64	37.38	31.26
Inorganic Matter (%)	46.67	53.34	54.95	46.17	46.15	46.42	47.49	51.07	53.99	47.69	46.46	51.60	47.95	56.99
Moisture (%)	28.99	29.76	28.75	27.33	29.05	25.61	27.71	28.75	31.57	31.09	33.35	34.17	32.16	33.27

Depth (cm)	172	176	180	184	188	192	196	200	204	208	212	216	220	224
Charcoal (%)	14.55	16.80	14.41	13.53	14.18	11.32	11.07	11.97	9.49	11.03	12.06	12.31	10.72	12.55
Organic Matter (%)	31.84	28.87	30.58	32.07	30.35	32.12	30.25	38.87	39.80	27.34	28.97	25.62	28.10	22.62
Inorganic Matter (%)	53.61	54.33	55.00	54.40	55.48	56.55	58.68	49.16	50.71	61.62	58.98	62.07	61.18	64.83
Moisture (%)	31.70	33.35	35.86	31.99	29.20	31.54	33.77	28.15	35.68	37.40	36.63	38.57	40.44	41.88

Depth (cm)	228	232	236	240	244	248	252	256	260	264	268	272	276	280
Charcoal (%)	11.89	8.91	9.55	13.21	14.17	13.96	12.70	13.14	15.88	14.51	15.67	11.17	12.28	13.84
Organic Matter (%)	26.92	23.92	21.37	17.07	15.55	13.33	18.38	14.52	11.59	11.54	11.87	15.60	11.90	8.54
Inorganic Matter (%)	61.19	67.17	69.07	69.72	70.28	72.71	68.92	72.34	72.53	73.95	72.46	73.23	75.82	77.62
Moisture (%)	44.11	44.99	46.66	47.59	47.49	50.51	52.38	54.13	56.58	58.35	58.01	55.74	59.84	61.18

Depth (cm)	284	288	292	296	300
Charcoal (%)	14.26	17.86	15.74	13.02	14.26
Organic Matter (%)	9.27	23.67	7.58	11.70	12.02
Inorganic Matter (%)	76.47	58.47	76.69	75.27	73.72
Moisture (%)	61.03	83.10	59.80	59.67	55.10

## Appendix K: Raw Microscopic Charcoal Counts

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	100
<b>3-10 <math>\mu\text{m}</math></b>	8	9	7	2	5	3	4	11	6	5	4	6	5	5	9	2	1	3	2	2	2	3	4	5	1
<b>11-20 <math>\mu\text{m}</math></b>	13	17	18	8	13	9	10	16	8	16	24	7	9	10	8	5	9	15	10	4	13	0	3	14	2
<b>21-50 <math>\mu\text{m}</math></b>	64	123	113	46	136	39	55	30	22	34	33	39	46	33	28	24	60	59	35	13	50	18	20	87	56
<b>51-75 <math>\mu\text{m}</math></b>	22	32	26	21	38	12	9	5	4	6	6	6	11	5	4	8	4	25	3	2	4	7	6	5	12
<b>76-100 <math>\mu\text{m}</math></b>	5	8	5	5	10	3	2	0	2	1	1	0	3	2	0	2	0	1	0	3	0	1	0	0	6
<b>&gt;100 <math>\mu\text{m}</math></b>	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>112</b>	<b>189</b>	<b>170</b>	<b>83</b>	<b>204</b>	<b>66</b>	<b>80</b>	<b>62</b>	<b>42</b>	<b>62</b>	<b>68</b>	<b>58</b>	<b>74</b>	<b>55</b>	<b>49</b>	<b>41</b>	<b>74</b>	<b>103</b>	<b>50</b>	<b>24</b>	<b>69</b>	<b>29</b>	<b>33</b>	<b>111</b>	<b>77</b>

Depth (cm)	104	108	112	116	120	124	128	132	136	140	144	148	152	156	160	164	168	172	176	180	184	188	192	196	200
<b>3-10 <math>\mu\text{m}</math></b>	7	15	3	8	1	6	3	16	4	4	6	1	1	0	5	0	5	5	0	1	0	2	0	15	0
<b>11-20 <math>\mu\text{m}</math></b>	6	23	6	12	5	5	10	36	16	12	15	4	1	19	5	1	26	4	1	3	2	4	4	25	5
<b>21-50 <math>\mu\text{m}</math></b>	23	132	15	50	24	8	64	73	19	26	43	14	6	40	12	46	95	28	7	18	29	19	22	118	19
<b>51-75 <math>\mu\text{m}</math></b>	4	14	6	2	6	3	10	27	8	7	12	3	4	21	7	20	11	13	2	9	8	8	5	24	9
<b>76-100 <math>\mu\text{m}</math></b>	0	0	0	0	1	0	2	4	0	2	0	0	0	1	0	3	0	0	0	1	2	1	3	2	3
<b>&gt;100 <math>\mu\text{m}</math></b>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<b>Total</b>	<b>40</b>	<b>184</b>	<b>30</b>	<b>72</b>	<b>37</b>	<b>22</b>	<b>89</b>	<b>156</b>	<b>47</b>	<b>51</b>	<b>76</b>	<b>22</b>	<b>12</b>	<b>81</b>	<b>29</b>	<b>70</b>	<b>137</b>	<b>50</b>	<b>10</b>	<b>32</b>	<b>41</b>	<b>35</b>	<b>34</b>	<b>184</b>	<b>36</b>

Depth (cm)	204	208	212	216	220	224	228	232	236	240	244	248	252	256	260	264	268	272	276	280	284	288	292	296	300
<b>3-10 <math>\mu\text{m}</math></b>	4	1	4	4	6	12	4	27	5	3	0	2	17	1	5	10	7	10	0	56	11	53	3	8	2
<b>11-20 <math>\mu\text{m}</math></b>	3	1	7	9	3	30	1	62	10	3	6	2	6	2	1	7	5	18	5	17	2	42	9	50	12
<b>21-50 <math>\mu\text{m}</math></b>	21	18	14	20	11	96	12	104	30	6	20	6	11	8	8	6	7	14	3	9	2	13	31	48	21
<b>51-75 <math>\mu\text{m}</math></b>	14	6	4	7	5	14	14	11	15	2	5	0	7	0	0	2	2	2	1	0	0	0	4	2	2
<b>76-100 <math>\mu\text{m}</math></b>	2	1	1	0	1	3	4	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
<b>&gt;100 <math>\mu\text{m}</math></b>	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<b>Total</b>	<b>46</b>	<b>27</b>	<b>30</b>	<b>40</b>	<b>26</b>	<b>155</b>	<b>35</b>	<b>206</b>	<b>63</b>	<b>16</b>	<b>31</b>	<b>10</b>	<b>41</b>	<b>11</b>	<b>14</b>	<b>25</b>	<b>21</b>	<b>44</b>	<b>9</b>	<b>82</b>	<b>15</b>	<b>108</b>	<b>48</b>	<b>110</b>	<b>38</b>

## Appendix L: Raw Geochemical Values

Depth (cm)	4	8	12	16	20	24	28	32	36	40	44
<b>ID#</b>	10	11	12	13	14	18	19	20	21	22	23
<b>Total Nitrogen (TN ‰ pdb)</b>	1.936	1.294	0.924	1.047	0.870	0.670	0.558	0.307	0.278	0.286	0.187
<b>δ<sup>15</sup>N (‰ pdb)</b>	3.110	4.735	4.772	4.404	3.878	5.362	4.181	3.552	3.420	3.677	2.965
<b>Total Organic Carbon (TOC ‰ pdb)</b>	30.460	21.790	16.460	19.160	20.680	13.460	9.657	5.122	4.883	6.029	4.545
<b>δ<sup>13</sup>C (‰ pdb)</b>	-25.150	-21.993	-20.286	-19.898	-20.047	-19.591	-21.292	-18.252	-17.331	-17.360	-15.804
<b>Carbon:Nitrogen Ratio (C/N)</b>	15.733	16.839	17.816	18.300	23.765	20.102	17.300	16.679	17.546	21.080	24.292
Depth (cm)	48	52	56	60	64	68	72	76	80	84	88
<b>ID#</b>	24	27	28	29	30	31	32	36	37	38	39
<b>Total Nitrogen (TN ‰ pdb)</b>	0.221	0.355	0.302	0.110	0.204	0.938	0.576	0.079	0.764	1.336	1.837
<b>δ<sup>15</sup>N (‰ pdb)</b>	3.196	3.638	2.772	2.890	3.212	-0.017	-0.110	2.339	0.855	0.513	1.404
<b>Total Organic Carbon (TOC ‰ pdb)</b>	5.971	10.140	9.287	3.779	6.037	24.570	17.940	3.446	20.380	33.350	40.390
<b>δ<sup>13</sup>C (‰ pdb)</b>	-16.852	-17.582	-16.662	-15.941	-16.637	-15.985	-14.978	-14.274	-15.319	-15.216	-15.547
<b>Carbon:Nitrogen Ratio (C/N)</b>	27.006	28.604	30.752	34.355	29.579	26.197	31.173	43.831	26.668	24.963	21.987

Depth (cm)	92	96	100	104	108	112	116	120	124	128	132
ID#	40	41	42	45	46	47	48	49	50	53	54
Total Nitrogen (TN ‰ pdb)	1.901	1.858	1.310	1.220	0.991	0.747	0.746	0.677	0.802	0.901	0.870
δ <sup>15</sup> N (‰ pdb)	1.793	2.678	3.694	4.724	4.340	5.067	2.671	3.879	5.081	3.066	4.890
Total Organic Carbon (TOC ‰ pdb)	41.450	41.260	37.210	33.450	28.010	20.100	28.540	19.880	22.060	27.740	26.410
δ <sup>13</sup> C (‰ pdb)	-16.168	-15.912	-17.260	-17.963	-17.443	-17.152	-17.615	-17.911	-16.812	-17.174	-17.200
Carbon:Nitrogen Ratio (C/N)	21.804	22.207	28.405	27.418	28.256	26.922	38.237	29.387	27.496	30.781	30.356
Depth (cm)	136	140	144	148	152	156	160	164	168	172	176
ID#	55	56	57	58	62	63	64	65	66	67	68
Total Nitrogen (TN ‰ pdb)	0.797	0.817	0.681	0.679	0.685	0.744	0.709	0.820	0.656	0.677	0.634
δ <sup>15</sup> N (‰ pdb)	5.653	5.589	5.194	4.791	5.072	4.557	3.969	3.718	4.397	4.155	3.957
Total Organic Carbon (TOC ‰ pdb)	25.200	28.780	24.700	25.440	25.840	27.480	26.560	28.440	22.480	26.060	26.160
δ <sup>13</sup> C (‰ pdb)	-16.643	-16.539	-16.662	-16.861	-17.401	-17.441	-17.213	-16.590	-16.378	-16.038	-15.717
Carbon:Nitrogen Ratio (C/N)	31.634	35.248	36.297	37.489	37.739	36.921	37.482	34.666	34.258	38.516	41.275
Depth (cm)	180	184	188	192	196	200	204	208	212	216	220
ID#	71	72	73	74	75	76	80	81	82	83	84
Total Nitrogen (TN ‰ pdb)	0.577	0.664	0.631	0.542	0.453	0.605	0.459	0.349	0.322	0.282	0.253
δ <sup>15</sup> N (‰ pdb)	3.929	2.649	3.715	4.088	3.184	3.068	3.465	5.228	4.637	5.485	6.023
Total Organic Carbon (TOC ‰ pdb)	25.370	25.680	22.860	19.170	16.240	23.610	17.700	12.150	11.400	8.977	8.010
δ <sup>13</sup> C (‰ pdb)	-15.502	-15.488	-15.165	-14.886	-15.104	-14.904	-14.857	-14.216	-14.091	-13.954	-13.782
Carbon:Nitrogen Ratio (C/N)	44.007	38.675	36.234	35.395	35.850	39.005	38.604	34.784	35.393	31.822	31.610

Depth (cm)	224	228	232	236	240	244	248	252	256	260	264
ID#	85	89	90	91	92	93	94	10	11	12	13
Total Nitrogen (TN ‰ pdb)	0.230	0.212	0.194	0.183	0.166	0.138	0.136	0.111	0.098	0.087	0.078
δ <sup>15</sup> N (‰ pdb)	6.565	7.112	6.869	6.097	7.603	7.170	6.976	7.483	7.026	7.044	6.976
Total Organic Carbon (TOC ‰ pdb)	6.627	5.883	5.431	5.263	4.346	3.623	3.571	2.132	1.858	1.634	1.493
δ <sup>13</sup> C (‰ pdb)	-13.782	-13.962	-13.899	-14.031	-13.902	-14.093	-14.237	-14.498	-14.525	-14.291	-14.582
Carbon:Nitrogen Ratio (C/N)	28.776	27.698	28.009	28.838	26.212	26.311	26.277	19.259	19.029	18.814	19.126

Depth (cm)	268	272	276	280	284	288	292	296	300
ID#	14	18	19	20	21	22	23	24	27
Total Nitrogen (TN ‰ pdb)	0.071	0.069	0.064	0.057	0.057	0.065	0.055	0.093	0.144
δ <sup>15</sup> N (‰ pdb)	6.219	6.431	5.880	5.434	5.816	4.995	4.479	4.107	4.436
Total Organic Carbon (TOC ‰ pdb)	1.326	1.486	1.320	1.213	1.141	1.317	1.135	2.029	3.256
δ <sup>13</sup> C (‰ pdb)	-15.198	-15.360	-15.658	-15.910	-16.556	-16.724	-16.711	-18.511	-18.672
Carbon:Nitrogen Ratio (C/N)	18.750	21.412	20.651	21.232	20.127	20.330	20.640	21.933	22.611