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A qualitative study of wood charcoal that is dated to the time of the Toba volcano super-eruption from Sibudu and Border Caves, South Africa

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A qualitative study of wood charcoal that is dated to the time of the Toba volcano super-eruption from Sibudu and Border Caves, South Africa



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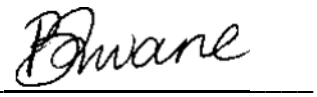
Bongekile Zwane (438320), ORCID number: 0000 0002 3294 4570

A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Signed in Johannesburg, April 2022

DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



(Signature of candidate)

12 day of April 2022 at Wits University, Johannesburg

ABSTRACT

The Toba volcano super-eruption, dated to 74 000 years old (74 ka), is often credited for limiting the contribution of some non- *Homo sapiens* hominins to the contemporary human gene pool. This follows the hypothesis that hominin populations who lived outside Africa perished due to the global 'volcanic winter' that resulted from this event, while *Homo sapiens* populations in Africa decreased drastically. The debate about the impact of the Toba super-eruption on global climate was revived recently following the discovery of its volcanic ash on the south Coast of South Africa.

I, therefore, investigated if devastating 'volcanic winter' conditions that are associated with the Toba super-eruption were present in south-east Africa between 74 and 72 ka. The aim was to test if such conditions affected the growth of woody vegetation, as well as the people who depended on it, using wood charcoal that is preserved at Sibudu and Border Caves, KwaZulu Natal Province. I applied standard archaeobotanical and anthracological procedures while analysing and interpreting charcoal data.

I identified two different types of forested landscapes around the caves, which are located 300 km apart. At Sibudu Cave, there was, predominantly, Afromontane and Scarp Forests with Savanna vegetation, while the Border Cave's landscape had much Savanna, Montane Forest and Grassland woody species. There were warm and humid conditions at Sibudu, which persisted between 73 and 72 ka, based on a range of active fungi in the wood. At Border Cave, there was seasonal fluctuation of unknown environmental conditions, but also warm temperatures that promoted partial silicification of some wood specimens ~ 74 ka.

These results, along with other environmental data, suggest no substantial evidence for extended 'volcanic winter' conditions in KwaZulu Natal. However, more work is needed in other parts of southern Africa because it is suspected that people's movements at this time may be related to unfavourable conditions elsewhere in the subcontinent. The absence of environmental stress in KwaZulu Natal may be due to a stronger influence of local climate drivers which prevented the full impact of the Toba super eruption from overwhelming southern Africa, such that people had resources on which they could depend.

DEDICATION

Kukho konke ukuzikhandla, nokuzimisela nanokuzingabaza.

ACKNOWLEDGEMENTS

I thank Prof. Lyn Wadley for suggesting this research topic in the year 2018, thinking about this event and conducting this research has been more of an adventure from the time I received the question. I also thank my supervisor, Prof. Marion Bamford, for her supervision of this research, specifically, in the identification of the charcoal taxa, none of which were assigned names without her inspection. I would like to also thank my supervisor for providing general guidance throughout the research.

Prof. Lyn Wadley provided access to the charcoal remains that I used to conduct my research. She is specially acknowledged for the direction in the excavation of the samples from Sibudu Cave and permission to study the sample that is discussed in this thesis. She is also acknowledged and thanked for her role as the co-director (along with Prof Lucinda Backwell and Dr Francesco d'Errico) of the excavation (2015-2019) at Border Cave. I thank the excavation teams who participated in excavation seasons at Sibudu (1998 - 2007) and Border Cave (2015 – 2019) for their role in recovering archaeological material that includes the charcoal samples that I studied.

Prof Lucinda Backwell kindly explained the excavation plan of the layers from which charcoal samples at Border Cave were excavated. This was based on the new excavation grid that was laid out at Border Cave in 2015. Her explanations helped me to understand important details related to the thickness and the stratigraphical relationship of the sublayers FEBA and FAAN within 1RGBS.

Dr Sandra Lennox has collected a great amount of comparative wood specimens including in the Sibudu and Border Cave localities. She kindly allowed me to rely on these during my research for comparative analysis and for that I'm grateful.

I acknowledge and thank Dr Paloma de la Pena for explaining the archaeological context of the charcoal samples from Sibudu and Border Caves. I appreciate the conversations I had with her during my research, which made me become aware a lot about the dating of MSA sites and some of the problems involved in getting reliable dates through various techniques.

I would like to also extend my deepest thanks to Ms Prosper Bande who helped me prepare thin sections of charcoal samples for SEM/EDS microchemical analysis. Through this preparation, my samples were properly oriented for further preparation, i.e. with the transverse section oriented correctly. Likewise, I thank the preparation lab at the Geology department, University of the Witwatersrand who completed the preparation of these samples on epoxy blocks. Dr Alexander Ziegler from the Microscopy and Microanalysis Unit at the University of the Witwatersrand is kindly acknowledged for his patience in assisting me with the SEM/EDS analysis of the samples for the third paper of my research.

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Paper 1

Zwane, B. and Bamford, M. (2021) 'A reconstruction of woody vegetation, environment and wooduse at Sibudu Cave, South Africa, based on charcoal that is dated between 73 and 72 ka', *Quaternary International*, 593–594: 95–103.

Paper 2

Zwane, B. and Bamford, M. (2021) 'Wood Charcoal from Border Cave's Member 1RGBS: Evidence for the Environment and Plant Use During MIS 5', *African Archaeological Review*. 38: 657–674.

Paper 3

Zwane, B. and Bamford, M. In Press. Possible avenues for archaeological charcoal studies in southern Africa: Preliminary studies using charcoal remains from Sibudu and Border Caves. *South African Archaeological Bulletin.*

Paper 4

Zwane, B. and Bamford, M. Under Review. When the Toba super eruption reached southern Africa. *Transactions of the Royal Society of South Africa*

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Appendix D Micrographs of some archaeological samples from Border Cave that were identified with certainty. Species are listed in the order of their type numbers.

CHAPTER ONE – INTRODUCTION

1.1 General Introduction

Since the establishment of the magnitude of the 74 000 years old (ka) Toba volcano super eruption, there has been much debate about the possible impact that this event had on the late Pleistocene ecosystem (Rose & Chesner, 1990; Williams, 2012b). This also follows the realisation that it is the only super-eruption that occurred during human history. Shortly after this establishment, Ambrose (1998) inferred that one of the drastic human population decreases during the late Pleistocene was triggered by this event. This explanation, commonly known as the Toba Catastrophe Theory (TCT), assumes that there was an extended period (possibly decades) with unfavourable global climate approximately 74 ka and the years after due to the release of volcanic ash and acidic gases by the Toba super volcano which prompted a chain of negative reactions on the environment leading to a severe scarcity of resources on which people could depend (Rampino & Ambrose, 2000; Rampino & Self, 1993). The ultimate implication of this catastrophic impact, according to this theory, was the near extinction of humans in the late Pleistocene (Ambrose, 1998, 2003; Rampino & Self, 1993).

This idea, however, has been refuted by some researchers, stating that environmental evidence that is dated to the time of the eruption does not support the presence of prolonged 'volcanic winter' conditions (Clarkson et al., 2020a; Gathorne-Hardy & Harcourt-Smith, 2003; Schulz et al., 2002; Timmreck et al., 2012; Williams et al., 2010). In southern Africa, this debate has not received much engagement, notwithstanding a rich archaeological record that spans the time of the super-eruption. However, recently there has been much interest in this topic following the discovery that volcanic debris from this eruption was deposited in the south Coast of South Africa (E. Smith et al., 2018).

This research was designed to contribute to the ongoing need to understand this event by investigating the possible impact that the eruption had on the environment and life in south-east Africa. Wood charcoal from two archaeological sites, Sibudu and Border Caves, was analysed to provide a partial glimpse into life at the end of Marine Isotope Stage (MIS) 5 in two ways, 1) as an environmental proxy and 2) material culture. The sites are in slightly different ecological settings due to their topography, geography and vegetation context. The

sample size of the charcoal remains from each site represents a fraction of the woody vegetation on which people depended during the MIS5/4 transition.

Woody vegetation is a good climate proxy because each woody species is structurally adapted to survive and thrive in places with adequate supply of temperature, water and nutrients due to their evolutionary histories (Carlquist, 2012, 2013; Creber & Chaloner, 1984). It is this same adaptation that determines the contemporary spatial distribution of different woods over a wide range of environments. I have chosen the taxonomic identification of woody vegetation, represented by archaeological charcoal, as the main method of obtaining results, although I used other qualitative methods to describe the environments in the localities of Sibudu and Border Caves. I also used the same charcoal data to derive evidence of wood use at both sites. This is, overall, a qualitative analysis of wood charcoal to determine long-term climate setting (through the growth of woody vegetation taxa/communities) as well as examine possible short-term disturbances that may have affected the development of the woody plants on the landscape (through wood structural change/ecophysiology and the ecology of the plants).

The results of the study are important because woody vegetation is an important component of forests, and it is suspected that many forested areas in the world were affected, and their ecosystems disturbed because of the unfavourable conditions that followed the Toba super-eruption. Although the datasets in this study alone cannot determine this, they will increase evidence about the environmental setting of this period. The results are discussed with respect to the significance of the late Pleistocene environment in southern Africa and the relationship between local ecosystems and global climate.

A careful assessment of the conditions that were hypothesised by the TCT is given and weighed against evidence for the environmental setting of southern Africa during the MIS 5/4 transition as well as the archaeology of this period. Also, woody vegetation in archaeological context is used to reconstruct people's activities in the late Pleistocene. Human behaviour is contextualised with a refined understanding of the environmental and archaeological contexts as derived from other relevant archaeological sites in the subcontinent. The debate about the possible impact of the Toba super-eruption on southern African prehistoric societies is also relevant to the ongoing discussion about the role of

environmental stresses or climate change in human behavioural evolution (Henshilwood & Lombard, 2013; Kandel et al., 2015; Marean et al., 2015). The fact that the Toba volcano super-eruption can be isolated/located chronostratigraphically through its volcanic tuff and ash, at the transition of the MIS 5 to 4, presents an opportunity to evaluate human behavioural changes that may have resulted from its environmental impact.

1.2 Research question, aims and objectives

Research question

This research is designed to address the question: 'Is there evidence for a devastating 'volcanic winter' associated with the Toba super-eruption in KwaZulu Natal, Sibudu and Border Caves localities, based on archaeological woody vegetation that is dated to the estimated time of the super-eruption and a thousand years later?'

Aims and hypotheses

We can accept that people collected wood for fuel use within a close range of their sites but may have ventured farther for specific woods. Therefore, wood charcoal recovered from the sites is a sub-set of the woody vegetation that grew in the area. The composition of the local vegetation is controlled by the local climatic conditions such as rainfall, temperature, seasonality and soils. We can, therefore, use the woody taxa to interpret the local climate as well as wood use.

Aim 1: Investigate if the Toba super-eruption affected the growth of vegetation at Sibudu and Border Caves

H_0: The Toba super-eruption affected the growth of woody vegetation at Sibudu and/or Border Cave

H_1: The Toba super-eruption did not affect the growth of woody vegetation at Sibudu and/or Border Cave

Aim 2: Investigate if the Toba super-eruption affected wood use at Sibudu and Border Cave

H_0: The Toba super-eruption affected wood use at Sibudu and/or Border Cave

H_1: The Toba super-eruption did not affect wood use at Sibudu and/or Border Cave

Objectives

The objectives for this research are to:

a. identify the taxa of the woody species collected by the occupants of Sibudu Cave 1 000 years after the Toba super-eruption, ~73- 72 ka.

b. identify the taxa of the woody species collected by the occupants of Border Cave approximately during the time of the Toba super-eruption, ~74 ka.

c. apply qualitative methods on wood charcoal from Sibudu and Border Caves to investigate if there are any structural changes and/or other indicators, i.e., biological reactions, that occurred due to short term environmental changes during the development of the woody vegetation.

d. use the climatic parameters tolerated by the taxa, other environmental indicators and known uses of the woody taxa identified from Sibudu and Border Caves to:

(i) assess if there were 'volcanic winter' conditions KwaZulu Natal during the time of the Toba super-eruption and a thousand years later.

(ii) assess if the people who interacted with the landscape were affected by the conditions that are hypothesised by the Toba Catastrophe Theory.

1.3 Structure of the thesis

In the second chapter of the thesis, I present the brief background of the debate about the impact of the 74 ka Toba super-eruption on global climate and ecosystem. The chapter introduces the basis for the search of the effects of this event on global climate and the rationale for this study in southern Africa. Along with this brief history, is the regional setting of the study sites- Sibudu and Border Caves- that are used to address the research question, the review of the Middle Stone Age (MSA) archaeology of the MIS 5/4 transition and that of the anthracology methods. A short review of the implication of the MIS5/4 archaeology in the debate about human behavioural evolution is introduced here and will be used when discussing different aspects of the late Pleistocene life and the climatic conditions of the period between 74 and 72 ka in southern Africa.

In chapter 3, I present the methods that I used in this study. I briefly describe the archaeological charcoal samples that were studied, how they were excavated in the field, prepared in the laboratory and analysed using different microscope techniques. Here, I also describe all the methods that were used to obtain results; these are taxonomic identification, wood structural modifications and analysis of miscellaneous inclusions in the wood structure. All the different analytical approaches through which different interpretations were made are also introduced in this section.

Chapter 4 is the first chapter in which I strictly present results of the analysis of archaeological charcoal from Sibudu Cave. In this chapter I outline the anthracology approach that I followed to obtain data from the sample of charcoal remains. I present the results for taxonomic identification and qualitative assessment as well as provide a discussion of the results with respect to the archaeology and environmental setting of Sibudu from 73 to 72 ka. This chapter is composed mostly of the research article which has been published, the pages of which are presented in format of *Quaternary International* journal.

In chapter 5, I present results for the analysis of woody vegetation from Border Cave. This chapter also deals strictly with the results for the taxonomic identification and some qualitative analysis of charcoal remains. The results and their significance are discussed with regards to late Pleistocene archaeology and the 74 ka palaeoenvironment of Border Cave. This discussion was published by the *African Archaeological Review* journal and this section is presented in the format and writing conventions of the same journal.

Chapter 6 presents another set of data that will be published in the *South African Archaeological Bulletin*. In this chapter, I present a short discussion of the methods that have been applied to studying wood charcoal in southern Africa, based on section 2.4, and argue for the application of two qualitative methods of analysis using charcoal remains from both Sibudu and Border Caves. I use the preliminary findings from the two sites to recommend that charcoal studies be developed to rely on more than just the taxonomic and ecophysiological interpretations.

In Chapter 7, I assess if there is evidence for devastating 'volcanic winter' conditions in southern Africa using data from this research and other studies. The goal of this chapter is

to give a carefully thought-out consideration of whether the emerging picture of the environment and human behaviour at the MIS 5/4 transition in southern Africa is consistent with the presence of an unfavourable climate that might be associated with the eruption of Toba. I present the known facts about the 74 ka Toba eruption worldwide, the environmental and archaeological evidence in southern Africa that is dated to the timing of this event and a remark on whether this evidence supports the claims of the TCT. This discussion is given in the writing format of the thesis, however it is currently being reviewed by the *Transactions of the Royal Society of South Africa* journal.

In chapter 8, I highlight the major findings of the research in bullet points, summarising the results with respect to their significance to anthracology/archaeobotany methods and the debate about impact of the Toba super eruption on the late Pleistocene climate and ecosystem in southern Africa. This includes a brief evaluation of how the research successfully accomplished the research aims, the limitations/shortcomings of the methods, the major contribution of this research to our understanding of the impact of Toba in southern Africa and recommendations for future studies investigating similar topics using charcoal remains.

CHAPTER TWO- LITERATURE REVIEW

2.1 Introduction

In this chapter a detailed rationale for the research is given through a series of topics that will be dealt with throughout the thesis, starting with the brief introduction of the Toba Catastrophe Theory (TCT), the introduction of the study region, the review of the archaeology of the Marine Isotope Stage (MIS) 4/5 transition in southern Africa and its importance in the debate about human behavioural evolution as well as the review of anthracology methods and principles. These make up the working framework of this research and will be used or referred to when answering the research question.

2.1.1 Brief background of the Toba Catastrophe Theory

The Toba caldera, commonly known as Lake Toba, in the Sumatra Island of Indonesia is known for being a volcano super-eruption hotspot that could potentially decimate life (Ambrose, 1998). Approximately 74 ka it erupted for the fourth time, since c. 780 ka, and produced the widest ashfall/dispersal in the Quaternary period (Chesner et al., 1991). This eruption was possible because Lake Toba is located on the highly active seismic Sumatran Fault Zone, which is a slip zone between the subducting India-Australian ocean tectonic plate and the overriding Sumatran-Eurasian continental plate (Chesner et al., 1991) (Fig 2.1). The magnitude of the 74 ka eruption was derived from the known amount of pyroclastic material that was ejected which led to the inference that it had a Volcanic Explosivity Index (VEI) of 8, the highest possible rating, thereby given a status of a super-eruption (Williams, 2012b).

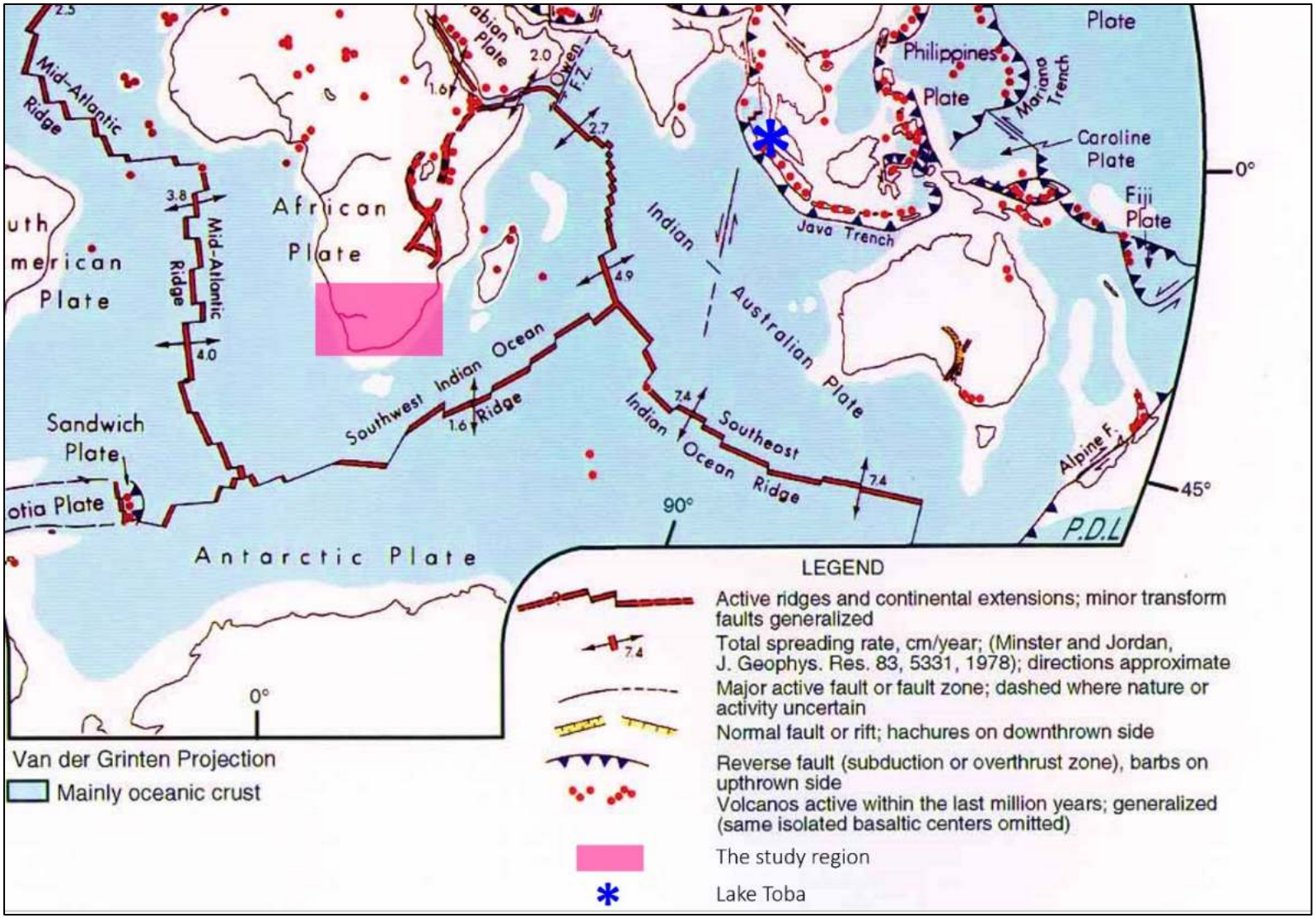


Fig.2.1 The map of continents, tectonic plates and volcanic activity showing the location of the Toba volcanic caldera in Indonesia, as well as the study region, southern Africa (Illustration modified from: geology.com)

By comparison, all other volcano eruptions since then have produced less volcanic debris, however, there is evidence that they affected global climate to some degree. For example, the eruption of Mount Pinatubo in 1991 and that of Mount Tambora in 1815 are known to have lowered global temperatures (English et al., 2013; Kirchner et al., 1999; McCormick et al., 1995; Oppenheimer, 2003). This reduced global temperature record was possible due to the earth's increased planetary albedo following the eruptions. When volcanic aerosols (containing high sulphuric acid gas) are released in large amounts into the stratosphere, their particles scatter the incoming solar radiation back to space and thereby lowering the energy balance of the earth's stratosphere and troposphere (English et al., 2013).

Ultimately, this albedo effect increases the opacity of the atmosphere and cools the surface of the earth. The degree to which these changes occur, however, depends largely on the properties of the volcanic gases such as their size and the concentration of sulphur dioxide (SO_2) contained in the particles (Lamb, 1971; Lanciki et al., 2012; Rampino & Ambrose, 2000). The effects of the increased albedo effect on the ecosystem could also be varied worldwide, depending on geography, altitude, latitude and the weather mechanisms that are generally involved in transporting air between the troposphere and the stratosphere (English et al., 2013; Lamb, 1971). Additionally, the spatially variable connection between the troposphere and stratosphere further determines the geographical extent over which acidic clouds originating from various volcanoes are precipitated (Lamb, 1971; Lanciki et al., 2012; Svensson et al., 2013). After the eruption of Mount Pinatubo, average global temperatures were studied in detail by many studies which indicated that a ~0.5˚C decrease could be credited to the eruption between 1992 and 1993 (Kirchner et al., 1999; McCormick et al., 1995; Stenchikov et al., 1998). Similarly, the aftermath of the eruption of Tambora in 1815 resulted in significant decrease in global temperatures as well as the following year, 1816, having no summer in the northern hemisphere (Oppenheimer, 2003).

The pyroclastic material, termed the Youngest Toba Tuff (YTT), ejected by Toba ~74 ka is estimated between 2500 to 3000 km^3, which is collectively many times larger than that of both Pinatubo (1991) and Tambora (1815). Although the stratospheric SO_2 aerosol loading from this material is not yet fully understood, this event is accepted as a super-eruption with no analogues in recent times (Williams, 2012b). Based on the known climate-volcanism

feedback from eruptions in modern history, the impact of the Toba super-eruption on global climate has been hypothesised to have caused a two-part global climate effect. First, large amounts of ash released into the atmosphere, and their subsequent dispersal over large areas of the globe probably polluted many resources for people and, possibly, lowered atmospheric opacity and hence global temperatures for 6-10 years immediately after the eruption (Rampino & Ambrose, 2000; Rampino & Self, 1993). Secondly, the sulphur aerosol cloud from this eruption contributed to the long term (possibly thousands of years) solar insulation that caused sea surface temperature decreases by deflecting sun rays from the earth (Rampino & Self, 1993). These conditions, some researchers argue, created an inhospitable environment globally called the "volcanic winter," which was responsible for the loss of plant and animal biomass including humans (Ambrose, 1998; Rampino & Ambrose, 2000; Rampino & Self, 1993).

The controversy surrounding the global climate impact of the eruption of Toba, therefore, followed when it was discovered that this is the biggest volcano eruption to occur during human history. This led to the birth of the Toba Catastrophe Theory (TCT), which suggests that the eruption of Toba unleashed an environmental and climatic catastrophe that not only disturbed the ecosystem but caused a near-extinction of human ancestors during the late Pleistocene (Ambrose, 1998, 2003; Rampino & Ambrose, 2000). This idea followed an observation that a genetic bottleneck exists among human populations that dates between 60 and 70 ka in the late Pleistocene (Harpending et al., 1993) and that modern human populations descended from a few thousand people who were isolated from each other for tens of thousands of years in Africa. Ambrose (1998) inferred that this drastic decline in late Pleistocene human population was a result of the aftermath of Toba, which destroyed many habitats and resources on which people depended, leaving a few survivors who found refuge in limited parts of the African continent that were not severely impacted.

One of the effects of the Toba super eruption commonly includes the deterioration of forests in many parts of the world because of the perceived effects of an extended volcanic drought/winter. Forests support many living things including humans and require ideal conditions to flourish. In southern Africa, like in other parts of the world with a tropical climate these requirements include ample water, adequate warmth and nutrients in the soils.

2.2 Regional setting of south-east Africa

Geography and climate

South-east Africa is an area of land that is part of the southern-most end of the African continent and bordered by the Indian Ocean; it features a narrow coastal plain and the Great Escarpment which extend for tens of kilometres to give rise to the plateau in the continental interior. The sub-tropical climate over this landscape is determined by the geographical location of the subcontinent south adjacent of the Tropic of Capricorn, i.e., ~ 23- 35˚S, and the influence of the warm sea surface temperatures (SST) of the Indian Ocean (Tyson, 1999). Rainfall in south-east Africa is promoted by the Indian Oceans' warm SST, which are distributed by the Agulhas Current, the location and intensification of major circulation features such as the Inter Tropical Convergence Zone (ITCZ), trade winds and pressure cells (Landman et al., 2017; Zhao et al., 2016). At present, the interaction of warm moisture from the Indian Ocean, transported by the easterly winds, and the Subtropical High-Pressure Cell promotes a summer rainfall regime over vast areas of the east and interior parts of southern Africa (Fig. 2.2).

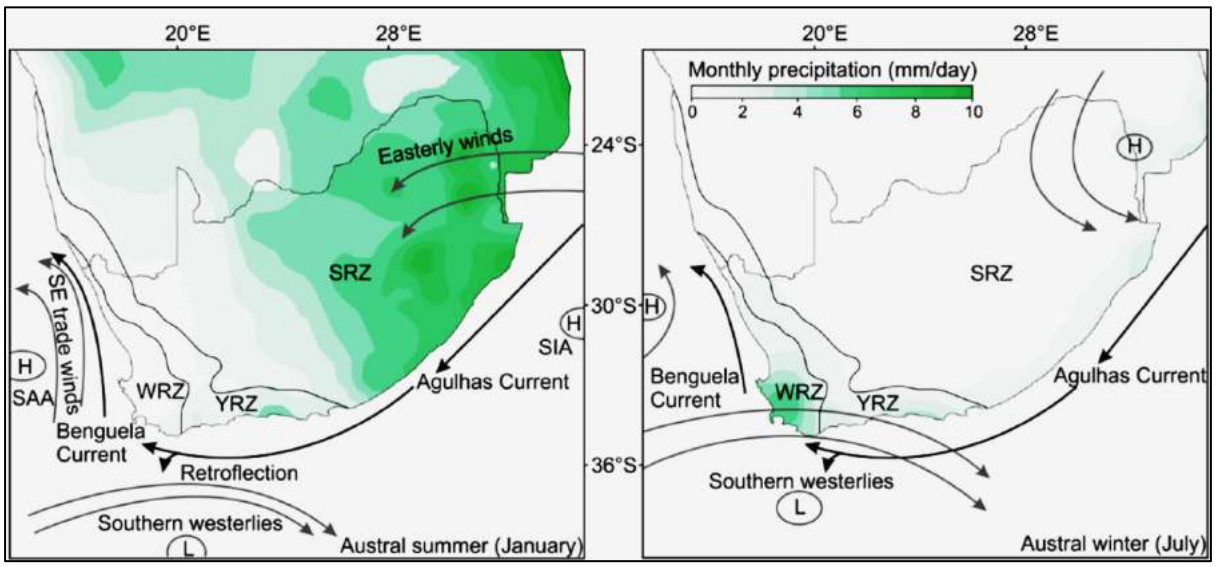


Fig.2.2 A map of climate drivers of southern Africa. The position of the Agulhas and Benguela Ocean Currents, the high- and low-pressure systems and the major trade winds as well as the precipitation variation that they determine on land on a seasonal basis. SRZ= summer rainfall zone, WRZ= winter rainfall zone, YRZ= year-round rainfall zone (Source: Zhao et al 2016).

This system exists permanently with the influence of the polar frontal system which is responsible for the annual supply of most rainfall in the southwestern parts of southern Africa during winter. Polar conditions are transported through the Benguela Upwelling

system and the associated westerly winds (westerlies) which determine the influence of temperate climate in the subcontinent (Blanke et al., 2009). Periodically, according to the Milankovitch's cycles of earth's eccentricity, obliquity and precession of its equinoxes, the intensity of these climate drivers changes and affects temperatures and rainfall patterns over southern Africa (Partridge, 1993; Tyson, 1999).

2.2.1 Sibudu Cave locality- topography and vegetation

Sibudu Cave is located 15 km from the Indian Ocean in KwaZulu Natal province of South Africa. The cave was carved by river erosion on a sandstone and shale cliff that is situated approximately 100 metres above present mean sea level and overlooks uThongathi River (Wadley & Jacobs, 2006). The vegetation near the cave is suited to the tropical climatic conditions. The contemporary vegetation at Sibudu is predominantly that of the Indian Ocean Coastal Belt and Savanna Biome vegetation (Fig. 2.3) (Mucina & Rutherford, 2006). The natural setting of vegetation is currently disturbed by commercial farming and settlement by people, however in undisturbed areas, including that closest to Sibudu Cave, the growth of many woody vegetation forms and species is favoured by the current environment. These occur in patches - dense woody vegetation stands and forest patches - which include the Scarp Forest species (FOz 5), as well as sparsely within the KwaZulu Natal Sandstone Sourveld vegetation unit (SVs 5) described by Mucina & Rutherford (2006) (Fig. 2.3).

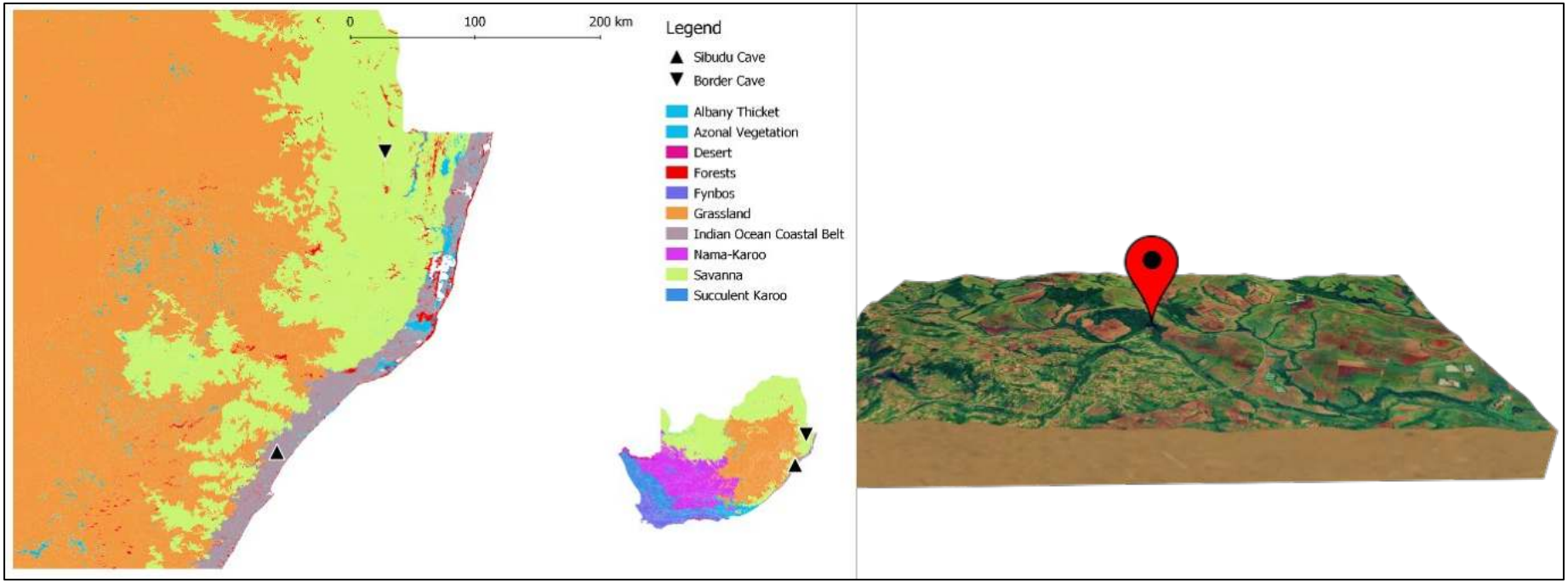


Fig.2.3 Vegetation map and topography of the landscape around Sibudu Cave (Map source: [South African National Biodiversity Institute. 2012 Vegetation Map of South Africa, Lesotho and Swaziland [vector geospatial dataset] 2012. Available from the Biodiversity GIS website, downloaded on 21 October 2021])

2.2.2 Border Cave locality- topography and vegetation

Border Cave is located 82 km from the Indian Ocean in KwaZulu Natal and 2 km north of iNgwavuma River; it was formed on a cliff that towers up to 678 meters above present mean sea level which forms part of the southern Lebombo Mountains (Backwell et al. 2018). The cave was formed in the Lower Jurassic volcanic rocks that are termed the Jozini Formation of the Lebombo Group (Backwell et al. 2018). The vegetation around the cave belongs to the Savanna lowveld (SVl 16 and SVl 17) of the Savanna Biome, the woody components of which dominates the mountainous terrain in the immediate surroundings of the cave and appears like a thick forest; these occur with some species of forests (FOa 1 and FOz 5) in some distant areas (Mucina & Rutherford, 2006) (Fig. 2.4).

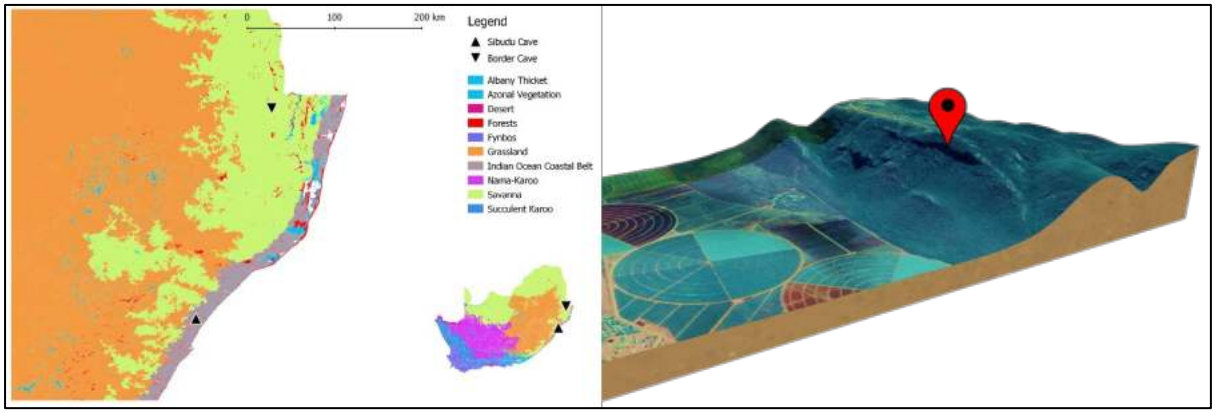


Fig.2.4 Vegetation map and topography of Border Cave (Map source: [South African National Biodiversity Institute. 2012 Vegetation Map of South Africa, Lesotho and Swaziland [vector geospatial dataset] 2012. Available from the Biodiversity GIS website, downloaded on 21 October 2021])

2.3 The archaeology of the MIS 5/4 transition and implication for human evolution

2.3.1 Brief introduction of the archaeology of MIS 5 and 4 in southern Africa

The archaeology of the period that is known as the transition between MIS 5/4 in southern Africa is important for understanding many aspects of human behaviour and cognition. This period is associated, mostly, with the production of the Still Bay lithic technology in South Africa. Important sites that preserve evidence for the making of stone tools in the Still Bay tradition are Blombos Cave (~77-70 ka), Diepkloof Rock Shelter (~73-70 ka), Hollow Rock Shelter (~80-72 ka), Sibudu Cave (~70 ka), Umhlatuzana Rock Shelter (~70 ka) and Apollo 11 (Henshilwood & Lombard, 2013; Lombard et al., 2012; Lombard & Hogberg, 2018). These

lithic tools have a characteristic 'foliate' shape that was made mostly from bifacially shaped and /or retouched stone flakes. The techno tradition was made using both hard- and soft hammer techniques to produce spear points that were hafted for hunting and stone artefacts that served as multipurpose knives (Lombard, 2007; Lombard et al., 2010; Tribolo et al., 2009; Villa et al., 2009; Wadley, 2007).

At Blombos Cave there is evidence that this techno tradition was made using mostly silcrete raw material (although chert and quartzite were also used frequently), which was heated before it was knapped and, in addition to the hard- and soft-hammer techniques, the spear points were finished using a unique pressure flaking technique (Brown et al., 2009, 2012; Mourre et al., 2010). Unlike other known sites with Still Bay lithics, Blombos Cave has been described as a site where hunting points were specially produced at this time (Tribolo et al., 2009; Wadley, 2007).

There is evidence that this tradition at Blombos Cave co-existed with that at Sibudu Cave, 2000 km away north-east of Blombos. At Sibudu Cave, Still Bay points were produced mostly from dolerite raw material although and hornfels and quartzite rocks were also used (Lombard et al., 2019; Wadley, 2007). The morphometric variability of the lithic artefacts of Still Bay industry at Sibudu, Lombard et al. (2019) argues, suggests that this tradition does not represent a drastic innovation because aspects of technological traits of the preceding pre-Still Bay tradition dated to 77 -73 ka were maintained and advanced when the distinct Still Bay tools were produced ~70 ka.

It has also been noted that there is inter-regional variability of this lithic technology across the extended landscape of southern Africa, i.e. that the Sibudu assemblage is more comparable to that found in Apollo 11, in Namibia, while the stylistic tradition of the lithic tradition at Umhlatuzana Rock Shelter in KwaZulu Natal is most similar to that at Hollow Rock Shelter, located in the Western Cape (Lombard et al., 2019). This impression is in contrast with that made by Archer et al. (2016) who concluded that similar traits of this tradition can be seen in archaeological sites on the south-west while a different set of similar tool making conventions are found in the north- east of the subcontinent. Both suggestions, nevertheless, hint that during the MIS 5/4 transition ideas (hence people), such as those of the making of this lithic tradition, spread fast and far across southern Africa. Border Cave is an exception because it preserves evidence for the making of the Howiesons

Poort Industry at this time, i.e. ~74 ka; a blade lithic technology that normally postdates the Still Bay industry at sites such as Diepkloof Rock Shelter (58- 96 ka), Sibudu Cave (61- 64 ka) and Umhlatuzana Rock Shelter (60 ka) (Lombard et al., 2012).

The forethought and action sequence that was generally involved in planning and producing the slightly diverse, yet temporally distinctive Still Bay industry is understood to signify an important evolutionary breakthrough in human behavioural and cognitive development. This innovative capacity has been described to suggest that MSA societies at this time in southern Africa had sophisticated technical skills, a behavioural trait that is consistent with the cognitive development that also capacitated for certain social conventions to be symbolically mediated. Symbolic mediation, according to some researchers, relates the behaviour of late Pleistocene people most to that of contemporary humans (Henshilwood, 2011; Henshilwood & Lombard, 2013; Lombard, 2012; Wadley, 2001). Evidence for this behaviour during this period is based on the discovery of material culture that was, possibly, made to communicate unknown abstract messages through different forms of artistic expressions.

For example, at Blombos Cave there is evidence that tick marine shells (*Nassarius kraussianus*) were perforated and stringed together to form decorative ornaments and worn by some of the occupants or visitors of the cave as early as 72 ka (Henshilwood et al., 2004). Similarly, at Sibudu and Border Caves marine shells were collected by people and used symbolically as ornaments and grave goods, respectively, between 74 and 70 ka (D'Errico et al., 2008; D'Errico & Backwell, 2016). The use of ground ochre colours is also suspected to have been involved in mediating abstract social meaning at Klasies River and Blombos Caves, however, there is evidence that it was also processed and mixed with adhesives to improve hafting techniques at Sibudu Cave (Henshilwood et al., 2009; Hodgskiss, 2020; Wojcieszak & Wadley, 2019).

The role of plants in allowing or easing the developments that are seen across the MIS 5/4 boundary is often understood indirectly from people's activities, apart from their dietary significance (Marean, 2010). For example, the heat treatment of lithic raw material and ochre suggests that a deep knowledge of plants and their properties was common amongst the late Pleistocene people (Bentsen, 2014; Bentsen & Wurz, 2019). Botanical remains from MIS 5/4 sites, generally, show evidence for many uses and wood charcoal is always reported

as an important component of archaeological material. Form these, evidence of wood use and diverse environmental/ climatic settings have been suggested before, in conjunction with other evidence; these are discussed in detail from Chapter 4 to 8.

2.3.2 The implication of MIS 5/4 archaeology for human behavioural evolution

A few theories have been put forward about the origin of behaviour in human ancestors that resembles ours the most. Most of these theories have focused more on the emergence of behavioural attributes that differentiate contemporary human populations from those of other hominin species and, for a long time, engaged on a fierce debate about the suit of characteristics for this differentiation in the archaeological record and its timing in prehistory (Ames et al., 2013).

One of the prominent perceptions about this phenomenon proposed that the defining characteristic for this 'behavioural modernity' was the drastic change in resource exploitation c.40 000 years ago that was exhibited by *Homo neanderthalensis* in Eurasia. This *abrupt change* included many changes in the means and methods of acquiring a diverse range of resources such as new technologies and was accompanied by some production of art and personal adornment (Mellars, 2005; Mellars & Stringer, 1989). Another set of viewpoints focus on the changes that are observed in Africa c. 40 000 - 50 000 and include a longer checklist of behavioural characteristics that demonstrate sophistication in the means and methods of resource exploitation as well as the use of art which emerged *gradually* in African *Homo sapiens* before spreading to Eurasia (Klein, 2000; McBrearty & Brooks, 2000).

Currently, there is much engagement with the idea that focuses mostly on the emergence of symbolic behaviour in *H. sapiens* and the creation of social cognition. Like previous interpretations of the archaeology of human behavioural evolution, this idea improves on past perceptions that human cognition was the driving force behind both technological advances and symbolic expression. However, this approach highlights much of the evidence for this in Africa, and advocates for the recognition that such behaviour originated, possibly, in East or southern Africa (Henshilwood & Marean, 2003).

Henshilwood & Lombard (2013) suggests that the transition between MIS 5/4 contains much evidence, including that stated above in Chapter 2, section 2.3.1, for how we behaviourally 'became human'; this contrasts with the previous suggestion, for example by

Wadley (2001), that 'behavioural modernity' began in Africa much later in the Stone Age i.e. c. 40 000 years ago. This means that the MIS 5/4 boundary is, potentially, the critical period when human ancestors behaved most like present populations based on the material remnants of their lives which were made to display/communicate shared abstract messages or values with members of their society (Henshilwood, 2011).

Although the capacity for this behaviour probably developed/ existed in other non-tangible forms long before it appeared in the material record and our insight into this practice during the MIS 5/4 is incomplete because of the fragmentary nature of the archaeological record, its' significance is unmistakable because it allowed for a 'cognitive niche' among human ancestors (*Homo sapiens*) which provided a competitive socio-economic advantage against other extinct hominin species (Henshilwood & Lombard, 2013). The underlying social and biological mechanisms that were responsible for the development of this 'niche' are not yet fully understood by archaeologists, however, there is an ever-present interest in clarifying the role that climate/environment had in prompting or promoting certain cognitive advances and behavioural changes.

Much of the inference that exists about the relationship between climate and behavioural changes is derived from the lithic technology changes that broadly correlate with the Marine Isotope Stages (Lombard et al., 2012). However, even with such observations, there are many unaccounted inconsistencies that do not fit this relationship, for example, it is completely unknown why some technological innovations such as the Still Bay and Howiesons Poort industry are discontinuous (Jacobs et al., 2008; Lombard et al., 2019).

Researchers such as Roberts (2015), have also noted that the current perception about the relationship between environmental changes and human behaviour in the past is flawed. This flawed perception generally affects the understanding about human cultural development during the Stone Age. For a long time, cultural development was thought of as unilinear ; however, recently there has been increasing support for the notion that, particularly in the MSA, cultural advancement was cumulative yet not unilinear or progressive (Kuhn & Hovers, 2013; Lombard, 2012; Roberts, 2015). This means that knowledge and ideas, such as those concerned with resource exploitation, accumulated as they got developed and transmitted between different people (groups and individuals);

however, people exchanged/adopted ideas depending on the need/want and not at the permanent expense of other forms of knowledge/ideas.

For this reason, the relationship between human behaviour and climatic or environmental factors is complex, especially for the MSA period. In southern Africa, approaches such as those that are proposed by Marean et al. (2015) are seeking to understand the connection between the two by adopting theoretical bases that consider the behaviour of human agents as a product of the relationship between many entities in nature which affect the cost and benefit of foraging under various ecological settings. Derived mostly from the principles of Foraging Theory and Evolutionary ecology, Human Behavioural Ecology in archaeology, may be one of the approaches that can analyse the complexity of the Middle Stone Age because, unlike Darwinian and neo-Darwinian models, it does not assume that human foraging capacity is controlled by either environmental or biological/genetic mechanisms (Belovsky, 1988; Winterhalder & Smith, 1992, 2000). Although this approach is not without flaws, it allows for room to consider the importance of social factors in human behavioural evolution (Winterhalder & Smith, 1992).

The attempt at understanding both social and environmental factors that accompanied foraging habits in archaeology during the Middle Stone Age is worthwhile. This is because, even though archaeological remains do not preserve evidence for many social dynamics concerning short-term production decisions, the resulting long-term material record could indicate some level of group-based subsistence patterns (Winterhalder, 1996). These patterns can be interpreted to suggest many foraging trends including resource exploitation intensities and, perhaps, periods of long-term migrations indicated by pauses in site occupations. The social contexts of these activities is important because environmental conditions do not, independently, trigger/facilitate specific behavioural responses from people. However, they may play a role in influencing the timing of people's movements and, perhaps, other activities because they determine the occurrence and distribution of the biota, i.e. the resources on which people depended.

2.4 Anthracology in southern Africa

Trees and shrubs have a strong relationship with the climate under which they flourish and the same applies to southern African flora. Woodiness is an ecological marker that is used to

describe different vegetation communities and different woody taxa define the floristic profile and the biogeographical boundaries of all vegetation communities (Mucina & Rutherford, 2006; van Wyk & van Wyk, 2013). The diversity of woody flora, therefore, offers a special opportunity to understand the spatial and temporal variability of climate. The complex life cycle and the lengthy life span of woody taxa, generally, allows for a climate record to be stored in the physical cellular structure of wood due to their phylogenetic history (Carlquist, 2012; Creber & Chaloner, 1984; Wiedenhoeft, 2013).

The full potential for interpreting various climatic attributes directly from this wood microstructure has not been thoroughly investigated in southern Africa.

There is more than anthracological evidence that climate can be directly interpreted from the wood produced at different times of tree growth. This has been demonstrated in the subcontinent using wood chemistry, such as with the carbon isotopes of *Adansonia digitata* and *Podocarpus* sp. trees. (Hall et al., 2008; Robertson et al., 2006). Even more convenient, climate signals from the chemistry of wood have been proved possible to obtain from burnt archaeological wood (February & Van der Merwe, 1992; Hall et al., 2008). For archaeobotany, this has potential to answer many questions related to people's interaction with the landscape in the past, including understanding people's preference for different types of wood as well as the implications for the availability wood resources.

2.4.1 Review of principles and methods

The notion that anthracological methods can be used to interpret climate and vegetation histories, including the history of wood use by pre-historic societies of southern Africa, was born in the late 20th century following significant developments in the field of anthracology in other parts of the world, i.e. Europe and America. Archaeological charcoal studies based on this notion were pioneered, notably, by the late Prof. Hillary Deacon in South Africa. Shortly, his ideas were developed by some of his students who laid the groundwork for many ways to study and interpret palaeoclimate and evidence of wood use in the past; their work identified many directions and opportunities for anthracology to contribute to studies of palaeoclimate, palaeoenvironment, vegetation history and archaeobotany of southern Africa (H. Deacon et al., 1983; Scholtz, 1986; Tusenius, 1986).

Along with their scientific breakthroughs, many challenges/obstacles were noted to which caution was advised for future researchers when dealing with archaeological charcoal in the southern African environmental and social context. These challenges directly affect the reliability of results obtained from wood charcoal (Shackleton & Prins, 1992). Charcoal remains recovered from archaeological sites are, in almost all cases, cultural artefacts that have been subjected to many anthropogenic and taphonomic processes. These include, but are not limited to, wood selection process, various degrees of combustion and thermal fragmentation, post-depositional fragmentation of the burnt wood logs as well as site formation processes (Chrzazvez et al., 2014; Dotte-Sarout et al., 2014; Théry-Parisot et al., 2010; Tusenius, 1986). Site formation processes differ significantly and based on the types of sites, i.e. open-air vs closed cave site, the underlying geology as well as site soil conditions.

Wood selection by pre-historic societies is one of the main determinants of the charcoal data recovered by archaeologists following the availability of woody plants in the landscape. Some ethnobotanical work has been done by many researchers on different contemporary southern African communities to record the complexity of the social setting- needs, knowledge, values, beliefs- which must be considered when attempting to understand wood gathering behaviours of pre-historic societies (Chikumbirike, 2014; Gandar, 1982; Pote et al., 2006; Sekhwela, 2003; Shackleton, 1998). Several studies have found that there are many and varied social/cultural beliefs that accompany people's needs and choices for wood resources (Chikumbirike, 2014; Scholtz, 1986; Shackleton & Prins, 1992; Tusenius, 1986). For this reason, the relationship between wood availability- determined by the environment- and wood use by people -guided by cultural rules – is one that is hard to define or standardise in southern Africa.

While there are obvious implications that archaeological charcoal remains are a result of human activity and that the relevance of the woody species they represent is constrained by the value of those species to people, there are equally strong implications that environmental factors must have played the primary role in availing the selected wood or even easing their access (Shackleton & Prins, 1992). This is complicated by instances where the overexploitation of some taxa by people could also affect their availability in the landscape such that there may be changes in the presence and abundance of certain woody

species in absence of environmental or climatic changes (Shackleton, 1998; Shackleton & Prins, 1992). So, while the assumptions of the Principle of Least Effort may hold true in most cases, they should also be held to high scrutiny by researchers because of the complexity of human-environment interaction (Shackleton & Prins, 1992; Tusenius, 1986).

It should also be emphasised that wood gathering behaviours and trends based on contemporary ethnographic studies cannot always be projected directly into the past, without the acknowledgement for unknown social norms and environmental pressures that may have guided historic and pre-historic people's needs and choices for wood resources. This is especially considering that southern Africa has a lengthy archaeological record that is accompanied by significantly different climates as well as different stages of human cultural evolution.

Apart from the complicated dynamic between anthropogenic and environmental factors, many taphonomic processes and sampling strategies by archaeologists, generally, distort the amount and quality of wood charcoal originally produced in the past (Scholtz, 1986; Tusenius, 1986). The real effects of these processes are unknown or have not been investigated in detail in southern Africa, and it is safe to assume that they cannot be simplified according to the time of their deposition, i.e. Early Stone Age, Middle Stone Age, Later stone age, Iron Age and historical times. It has been specially observed during some archaeological investigations that the quality of organic archaeological remains that are dated to the Stone Age differ more according to type of site and its geographical location, than according to the time of the of their deposition (personal observation).

Despite these and many other sources of biases, large scale climate fluctuations/changes have been successfully interpreted from charcoal data and compared favourably to changes interpreted from other biological, sedimentological and isotope data. Deacon *et al.* (1983) was one of the first studies to suggest that anthracological finds be correlated to palynological finds, for example, for a cohesive and reliable palaeoenvironmental reconstruction. He shortly demonstrated this by comparing the anthracological results from Boomplaas Cave in the southern Cape region with pollen, small and big mammal remains, soil sediments, local geomorphology and the carbon isotope signature from a stalagmite of the same cave (Deacon et al., 1984). Scholtz (1986) confirmed the plausibility of this approach using charcoal remains that were recovered from the same site in the southern

Cape coast. In these studies, long term climatic trends indicated by various sources, dated between the late Pleistocene to the Holocene, were correlated to the trends indicated by the woody species preserved in the cave (Deacon et al., 1984; Scholtz, 1986).

Many other anthracological studies have since been conducted similarly, incorporating many aspects of the archaeological landscapes. However, there can exist some contradictions in the environmental conditions interpreted from different sources of palaeoenvironmental data such as those highlighted by Tusenius's (1989) charcoal data. In this study, it was noted that anthracological data from three archaeological sites in the Eastern Cape, South Africa, did not compare perfectly with the Holocene climate data obtained from various other sites and environmental proxies, such as fauna and pollen. This contradiction, however, was not strictly between charcoal data and other environmental evidence (Tusenius, 1989). All palaeoenvironments are prone to misconstruction, though some more than others, due to errors in the techniques, equipment and human observation that are inherent in the different the reconstruction methods.

Many other anthracological results have complemented climate reconstructions in southern Africa (Deacon et al., 1984; Esterhuysen & Smith, 2003; Lennox & Wadley, 2019; Prior & Price Williams, 1985). For example, while correlating environmental interpretation made through charcoal with faunal stable carbon isotope analysis of the same sites (Rose Cottage Cave and Tloutle Rock Shelter), Esterhuysen and Smith (2003) noted that late Pleistocene to Holocene temperature fluctuations interpreted through charcoal remains correlated very well with the $\boldsymbol{\delta}^{13}$C trends obtained from faunal remains. Furthermore, two independent isotope studies proved that $\boldsymbol{\delta}^{13}$C from burnt archaeological charcoal can be used to detect climate signals (February & Van der Merwe, 1992; Hall et al., 2014). The findings of these studies were compared with other climate records and environmental interpretations made from other archaeobotanical and faunal remains (February & Van der Merwe, 1992; Hall et al., 2014). There are many ways in which archaeological charcoal has been used to address questions related to climate, plant growth and plant use. Below are some of the anthracological approaches/methods that have been developed worldwide and an assessment of whether they have been applied in southern Africa.

The taxonomic identification of woody vegetation through wood charcoal

The wood structure of each taxon has, with time, retained an axial and radial cell wood growth pattern that is identical to all trees of the same taxon (Carlquist, 2012; Wiedenhoeft, 2013). This pattern is proof of the evolutionary adaptation of the different species to a defined set of environments (Carlquist, 2012). An accurate study and identification of any taxon using the anatomy of their wood microstructure, therefore, is important in reconstructing and describing past landscapes/environments. This description is extrapolated from the growth distribution of the taxa's extant counterparts and relatives. In principle, this relationship between woody vegetation and their evolutionary histories qualifies the use of the accurate study of wood anatomy as the most relevant and reliable anthracology method to reconstruct past landscapes. In southern Africa, like elsewhere in the world, the high diversity of woody taxa and their distribution is determined mainly by climate variability (Mucina & Rutherford, 2006; van Wyk & van Wyk, 2013). This is highly advantageous because it makes it reasonable to track the climate signals that control tree growth, not only across space but through time.

The identification of woody species using their carbonised microanatomy is possible because wood charcoal retains its cellular structure after incomplete combustion. With an exception of slight wood shrinkage and charring of wood, the anatomical features of the porous and fibrous wood structure are perfectly preserved if the plant it is not burned to ash. These include the unique arrangement, frequency and size of vessel elements, tracheids, axial parenchyma cells, ray parenchyma cells and ground tissue fibres. These wood tissues conduct nutrients and water, store nutrients and strengthen the living plant. Other features used by plants to secrete metabolites, i.e. intercellular canals, secretory elements, etc., and those included in the structure of the living plant, i.e. mineral inclusions, also form a permanent part of the micro-anatomy of different woody species.

Several independent studies have demonstrated the usefulness of this method using archaeological charcoal that was recovered from various sites across the subcontinent. These include studies conducted in South Africa's provinces of Eastern Cape (Tusenius, 1989; Zwane, 2018), Free State (Esterhuysen et al., 1999), KwaZulu Natal (Allott, 2006; House & Bamford, 2019; Lennox, 2016; Lennox & Wadley, 2019; Zwane & Bamford, 2021a), Limpopo (Puech et al., 2021), Northern Cape (Bamford, 2015) and Western Cape

(Cartwright, 2013; Cartwright et al., 2014; Cartwright & Parkington, 1997; Deacon et al., 1983; February, 1990; Scholtz, 1986), as well as the neighbouring countries of eSwatini (Prior, 1983; Prior & Price Williams, 1985), Lesotho (Esterhuysen et al., 1999), Namibia (Eichhorn, 2004; Eichhorn & Jürgens, 2003) and Zimbabwe (Chikumbirike, 2014).

This method is most ideal for interpreting long term climatic changes on a centennial to millennial scale as demonstrated by the above-referenced studies. During these studies, descriptions of the wood anatomy of many different contemporary species were made from across a wide range of environments. Unfortunately, there is no unified atlas of the anatomy of all the comparative woody taxa that were studied during these studies as well as those that have been described by other botanists, independent of archaeobotanical work (Kromhout, 1975; Oskolski & Van Wyk, 2008; van Wyk et al., 1983). As a result, it is not easy to assess many important climate-wood relationships that could refine our interpretation of southern African past environments through the wood structure alone. For example, it is not yet understood how the southern African climate gradient affects the occurrence and variation of different wood microfeatures such as rays and vessel elements across different tree taxa. Similarly, it is not clear if/how the size variation of different wood features within the same taxon can be credited to ontogeny.

Ecophysiology of woody vegetation, dendrochronology and dendroclimatology

Scholtz (1986) was the first in South Africa to propose that smaller fluctuations in climatic measures such as temperature and precipitation are possible to detect using the microstructure of wood charcoal; this is, provided that well preserved, large samples from well dated stratigraphic units are used. This suggestion was based on the accepted notion that different ecological regimes have a direct influence in the development of wood characteristics, such as the vascular tissue of individual plants (Carlquist, 1977). That is, although the different taxa of vascular plants evolved similar wood structural traits, the size and frequency of those traits may vary based on the variable supply of the environmental conditions that each taxon is receiving in their immediate ecological settings (Carlquist, 1977; Creber & Chaloner, 1984). Smaller changes in the environmental conditions such as precipitation can, therefore, be detected spatially and temporally using the same taxa (Creber & Chaloner, 1984).

Scholtz (1986) used this principle to diagnose the short-term climate fluctuations from the late Pleistocene to the Holocene using archaeological charcoal. This method, which he termed Ecologically Diagnostic Xylem Analysis (EDXA) helped identify climatic trends that were comparable to those interpreted through the taxonomic identification of the same charcoal assemblage (Scholtz, 1986). February (1993) used the same understanding to test the commonly held belief that with increased temperatures and precipitation during growth seasons, the wood vessel diameter generally increases while the frequency of the same vessel tissue decreases in a given plant (Carlquist, 1977). After a careful analysis of the wood vessel diameter and frequency of two widely distributed woody species, *Combretum apiculatum* and *Protea caffra*, against the known fluctuation of precipitation and temperature data that was retrieved from weather stations, he concluded that there is a relationship between these vessel attributes and precipitation; no significant results were obtained between the same attributes and temperature (February, 1993).

Unlike Scholtz (1986) who suggested that his EDXA method could be applied to randomly selected samples of unidentified wood, February (1993) cautioned that his 'quantitative xylem analysis' method may only be suited for woody taxa that are known to be sensitive/ highly responsive to different climate measures such as rainfall.

The conclusions reached by February (1993) are related to those reached by a different study in 1977 which sought to determine the possibility of using southern African woody plants for dendrochronology. In this study, Lilly (1977) concluded that out of 108 woody species from southern Africa that were studied then, less than 15 species *may be* suitable for dendrochronological use. This analysis noted many challenges that could discredit such an attempt which attest to the complex nature of tree growth in the subcontinent. Lilly (1977) highlighted, precisely, the constant occurrence of false rings and discontinuous/partial rings in both angiosperm and gymnosperm species. These are credited to many ways in which wood ring clarity is determined and often obscured by both genetic and environmental factors (Lilly, 1977).

Clarifying the role of environmental factors in the development and morphology of wood rings, requires that wood growth be defined- or more precisely, limited- by the variability and seasonality of precipitation; this is crucial to estimate the modality of wood growth and hence the fluctuation of climate variables that control this growth. Related to

ecophysiology, the Principle of Limiting Factors that underlies wood ring clarity and the relevance of dendrochronology is similarly based on the known or hypothesised effects that climate has on the growth of wood (Lilly, 1977). The use of tree rings to determine climate in the past and present, therefore is only possible and plausible provided this principle is satisfied; this has proven to be a complicated task in southern Africa.

The discernability of different wood features such as growth rings in different woody species has wide relevance in archaeobotany. For example, these are important in estimating the log diameter of the wood assemblages that were collected in the past. The average diameter of the wood logs in archaeological sites may be due to two things: (1) functional use of the fires produced by people or (2) ecological factors controlling the availability of the wood resource, trees vs shrubs, young woody plants/ forest vs matured plants (Scholtz, 1986; Tusenius, 1986). Scholtz (1986) was the first to explore the usefulness of reconstructing wood log diameters from disintegrated archaeological charcoal in South Africa. Using the dimensions of the ray parenchyma structure on the transverse section of well-preserved charcoal samples, he determined the minimum variety of the diameter of the wood logs and inferred the pattern of firewood exploitation (Scholtz, 1986). This method, however, relied strictly on big and well-preserved samples from the assemblage and may not be replicable.

There have been significant developments made in the way of this method by international studies which, unfortunately, have not been adopted in southern Africa. These developments focus on the presence and distinctness of ray parenchyma and growth rings to understand the variation of the wood log diameters in a given assemblage (Marguerie & Hunot, 2007; Paradis et al., 2013) or even estimate the true diameter of the different logs in an assemblage (Kabukcu, 2018a; Paradis et al., 2013). Methods that use wood ring morphology to reconstruct wood logs are worth adopting and developing in southern Africa, with a focus on those woody species that are known to reliably form distinct wood ring boundaries.

The ecology and bioecology of woody vegetation

Trees can withstand many conditions that may harm them, strong winds, fire, etc., and generally live with many organisms in their natural growth settings, some of which may be

dangerous to their development. In cases where mechanical injuries and bioecological disturbances occur, they trigger the defences of the trees (Schweingruber, 2007). This is often interpreted from the secretion of protective chemical barriers in the wood microstructure, which function to contain injuries and the spread of harmful microorganisms within the plant (De Micco et al., 2016). This process, termed compartmentalisation, is related to the production of traumatic tyloses or gums by the trees, whereby the conducting tissue (wood vessels) of the sapwood is blocked or occluded in response to external stimuli (De Micco et al., 2016). Tyloses are, otherwise, formed naturally in woody plants when sapwood is converted to heartwood; although, they can also be produced within the sapwood (De Micco et al., 2016; Kabukcu, 2018b). Different unfavourable conditions trigger different types of such hormonal reactions, i.e. gum production, according to the nature of physical damage or biological attack by bacteria and fungi. It is possible, therefore, to reconstruct stressful environmental events using gums or resins (Schweingruber, 2007). However, it is not clear how intense do different stimuli have to be to trigger the protective measures of different plants or if the simple response by trees is, conclusively, an indicator that there were fatal conditions that threatened the development and the life of the plant.

These residues, nonetheless, offer an opportunity to make informed judgements about various aspects of tree growth, plant-environment interactions and even wood use. Firstly, the basic knowledge about the ontogeny of the plants can be deduced from the presence and abundance of tyloses which is useful to understand if people selected young or matured wood (Kabukcu, 2018b). Second, because some secretions such as tyloses are preserved within a specific temperature range when the wood is burned, their preservation in archaeological charcoal remains along with other plant products, such as starch grains, can also be used further to understand the intensity of the fires that were produced in archaeological contexts (Crowther, 2012; Dufraisse et al., 2018). Third, certain gums and resins affect or improve the combustibility of wood and therefore, it is possible that in some cases firewood may have been collected in the past with this knowledge in mind.

Traces of fungal activity (or any other microorganisms) in the deformed structure of wood can be associated with different species (or groups) of wood infesting or wood decomposing organisms and their living conditions because these organisms destroy wood cells in

consistent yet different manners (Schweingruber, 2007). With a secure identification and a known geographical distribution of the concerned organisms, the bioecological context of trees can thus be used to map the precise environmental conditions under which they grew in the past. This interpretation might be limited by the uncertainty as whether these microorganisms represent the microclimate vs the wider subcontinental climate. The above bioecological approaches to studying archaeological wood charcoal have not been fully utilised in southern African anthracology and deserve further attention and development. They can be used, where applicable, to investigate the ecology of a wide range of woody taxa in southern Africa.

2.5 Concluding remarks

Southern African MSA represents one of the most studied and well understood periods of the archaeological (and African) record. In this chapter it was demonstrated that the investigation of the possible impact of the Toba super eruption is warranted because there are many aspects of the MIS 5/4 transition that will improve our understanding of this event, including climate - human relationships. There is also a thorough understanding of many environmental attributes i.e. climate and woody vegetation, that will be useful in suggesting any possible causal relationships that may be used to assess the impact of the 74 ka Toba super eruption on the late Pleistocene ecosystem.

CHAPTER THREE – METHODS AND MATERIALS

3.1 Introduction

In this chapter, all the methods that were used in this study are presented, from the research method to the procedures that were taken to recover/sample charcoal remains, analyse them in the laboratory and interpret the results. These are detailed below.

As stated in Chapter 1 section 1.2, this research is focused on addressing if vegetation in southern Africa and human behaviour (i.e. wood use) responded to the hypothesised catastrophic effects of the Toba super eruption. Archaeological charcoal remains that were used to answer this question were sampled from the relevant archaeological layers of Sibudu and Border Caves. These sites were chosen because:

(a) they preserve evidence for continuous occupation of the caves spanning the estimated time of the Toba super eruption, i.e. 74 to 72 ka.

(b) both caves contain archaeological and environmental evidence from adjacent layers within their stratigraphy which can be used to compare and contextualise the environmental and behavioural interpretations from this study within the wider sequence of events at the two sites respectively.

(c) Sibudu and Border Caves are centres of focus for understanding major evolutionary milestones during the Middle Stone Age (MSA). They have been studied extensively in the past as important sites for investigating people- vegetation-climate interactions; these previous investigations are relevant to understand/ interpret potential effects (or lack thereof) of Toba on the late Pleistocene ecosystem in southern Africa.

The independent variable that is being investigated is the hypothesised effects of Toba and the dependent variables are the late Pleistocene woody vegetation around Sibudu and Border Caves and the needs of people who used it. This will be tested using non-experimental research because the independent variable (effects of climate) cannot be manipulated. The causal relationship between the three variables will, instead, be observed/interpreted from the variables as they occurred in the past through the description of data. A general method of inquiry is presented in figure 3.1.

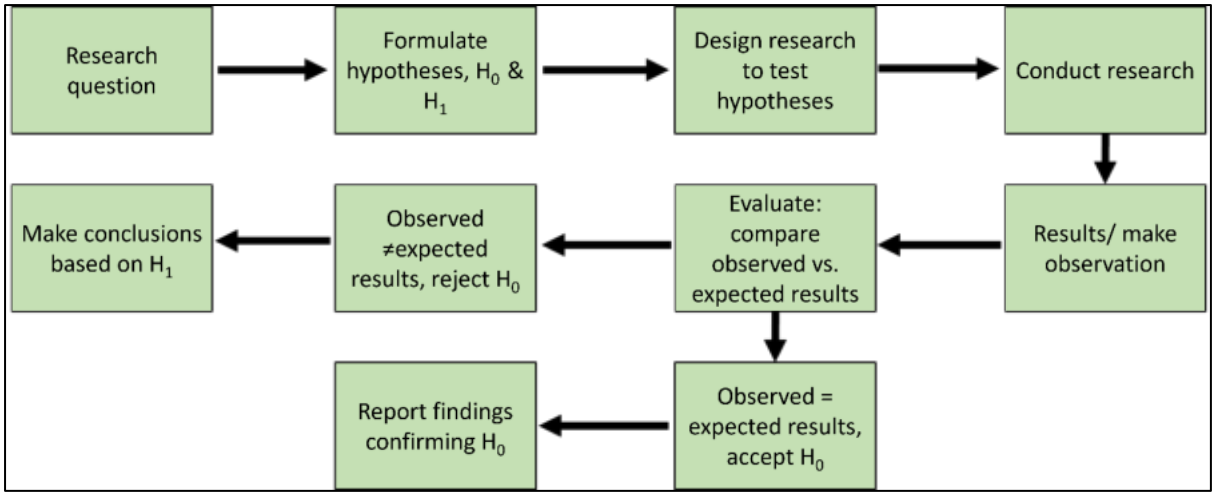


Fig.3.1 The general method of investigation that was adopted to answer the research question.

3.2 Sampling and methods of analysis

3.2.1 Field sampling

Two sets of charcoal assemblages, from Sibudu and Border Caves, were sampled from the field and comparative species/specimens were accessed from those of previous anthracology studies of southern Africa (Fig. 3.2 a).

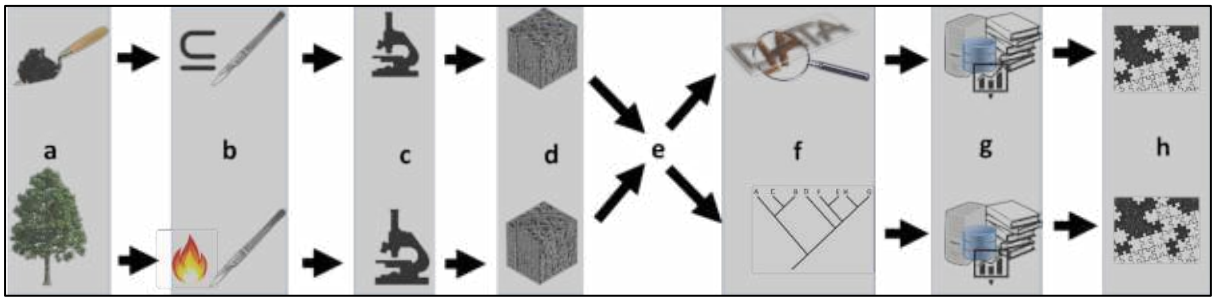


Fig.3.2 The anthracology method detailing the various steps of analysis to obtain data as well as steps to interpret the results. A) = field sampling, b) = laboratory preparation, c) = microscopy techniques and c & d) = the comparative analysis of archaeological charcoal (top) against known contemporary woody vegetation (bottom). From the results, a set of f) = qualitative (top) and taxonomic (bottom) data were obtained. Interpretations were made through g) statistical analyses and environmental/behavioural correlates from books and databases. These were used to h) reconstruct climate and human behaviour. (Picture icons: iconspng.com, pinclipart.com, istockphoto.com).

Archaeological charcoal from Sibudu Cave

The excavations of the MSA at Sibudu Cave under a team led by Professor Wadley, were conducted between 1998 and 2011 (Robinson & Wadley 2018). The deposit was excavated following the natural stratigraphy, however layers that are deeper than 10 cm were arbitrarily split and named respectively after the colour of the dominant matrix of each layer. The stratigraphy of the MSA at Sibudu is clearly defined by different colours and contains ash (Fig. 3.3) (Wadley & Jacobs 2006). Hearths are found in all layers, generally defined by flat circular ash remains, burnt soil sediments at the bottom and with concentrations of charcoal at the centre (Wadley & Jacobs 2006).

Three layers, excavated by Prof. Lyn Wadley, are related to the Toba super-eruption: the Brown Sand (BS) layer is dated through Optically Stimulated Luminescence (OSL) to 77.2 ± 2.1 ka, the Light Brownish-Grey layer (LBG, LBG2, LBG3 and LBG4) is dated between 72.5 ± 2.0 ka and 73.2 ±2.3 ka, and the Reddish-Grey Sand layer (RGS & RGS2) is dated to 70.5±2.0 ka (Wadley & Jacobs 2006). These layers show that the cave was occupied by people before, during as well as after the Toba super-eruption and contain wood charcoal. For this study, charcoal remains from layer LBG only (including its' sub-layers/subdivisions) were analysed (Fig. 3.3).

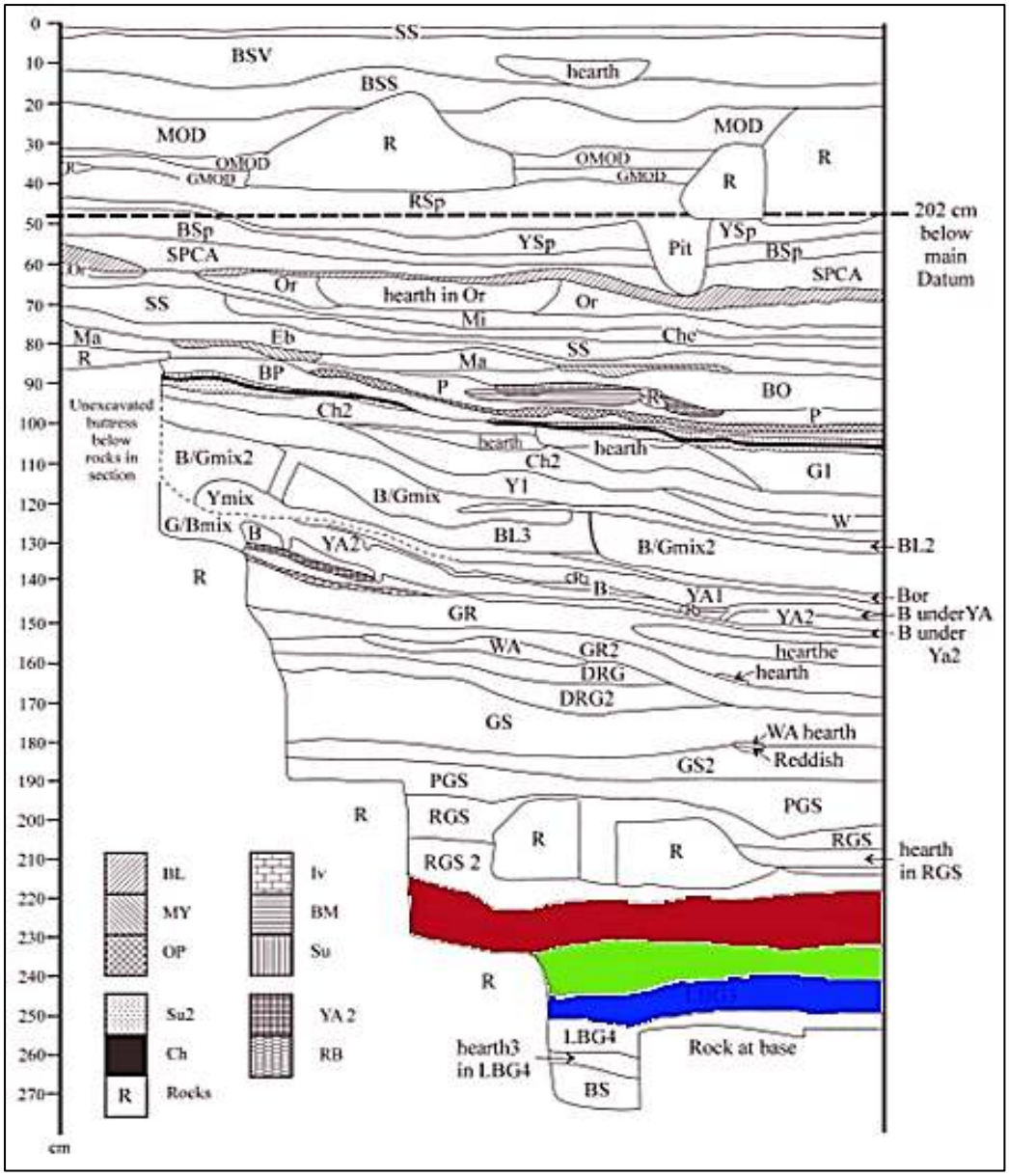


Fig.3.3 Archaeological stratigraphy of Sibudu cave showing layer LBG (red), LBG 2 (green) and LBG3 (blue) in the east wall of square B5 (Illustration after Wadley 2007).

Most of charcoal remains in layer LBG were not recovered from a recognisable combustion feature (i.e. intact hearth); more details about this are presented in Chapter 4. The archaeological material excavated between 1998 and 2011 from these layers was curated separately and the charcoal samples were stored at the Evolutionary Studies Institute, University of the Witwatersrand, where it was obtained for this study.

Archaeological charcoal from Border Cave

Charcoal remains from Border Cave were excavated during the 2018 and 2019 field seasons under the directorship of Profs. Lucinda Backwell, Lyn Wadley and Dr Francesco D'Errico.

These seasons were part of the new expedition of the site that started in 2015 (Backwell et al., 2018). The site was similarly excavated following the stratigraphy of the archaeological layers which is made up of alternating ash and sand layers which were termed 'members.' One layer/ member 1RGBS, is related to the immediate timing of the Toba super eruption and is dated through Electron Spin Resonance to ~74 ± 4 ka (Fig. 3.4). More details about the archaeological context of charcoal from this layer are discussed in Chapter 5. Charcoal fragments that were excavated in the 2018/2019 seasons were curated at the Evolutionary Studies Institute, University of the Witwatersrand, where they were obtained for analysis.



Fig.3.4 Archaeological stratigraphy of Border cave showing the layer 1 RGBS (Courtesy: Lucinda Backwell)

Comparative collections

The reference collections used in this study includes many woody species that have been studied since the 1980s. These specimens/species, although not yet put into one atlas, are a comprehensive record of contemporary woody vegetation because they include a wide range of woody species from many vegetation units that occur in the Indian Ocean Coastal Belt vegetation, Savanna Biome, Grassland areas, Thicket, some Fynbos species and many

indigenous forests. It represents an adequate assemblage for comparative analysis in this study because most of the species were collected from the east parts of southern Africa, predominantly from KwaZulu Natal- including in the of Sibudu and Border Cave localities, Limpopo, Gauteng, Eastern Cape provinces and the neighbouring countries of Lesotho and Zimbabwe.

The main set of comparative species that was mostly used is currently housed at the Evolutionary Studies Institute Herbarium, University of the Witwatersrand. This collection accumulated usually through different archaeological/ anthracological projects focusing on different regions of the subcontinent. There are more than 800 woody specimens- with some duplicated species- that have been incorporated in it. These are burned wood pieces that have been mounted in microscope slides using temporary putty adhesive (Prestik). Fifty of these pieces, although burned by their respective collectors, were mounted by me for this analysis. The wood peices include families, genera and species which were collected for comparative analysis during anthracological studies at Tloutle Rock Shelter and Rose Cottage Cave (Esterhuysen & Mitchell, 1996), Sibudu Cave (Allott, 2005, 2006), Great Zimbabwe (Chikumbirike, 2014), Klasies River main site (Zwane, 2018), Border Cave (Backwell et al., 2018).

Descriptions and microphotographs of comparative species from Bonawe, Colwinton and Ravenscraig Rock Shelters (Tusenius, 1986, 1989) as well as those from Boomplaas Cave (Scholtz, 1986) were used/considered in this research. Published descriptions of woody species from Diepkloof Rock Shelter (Cartwright, 2013; Cartwright & Parkington, 1997) and Elands' Bay Cave (Cartwright et al., 2014; Cartwright & Parkington, 1997) were also consulted along with some woody species from southern Africa that are published independently by botanists (van Wyk et al., 1983; Oskolski and van Wyk, 2008). A collection of micrographs of woody species that were studied by Kromhout (1975) was also frequently referred to for comparative analysis in this study; this work has charcoal micrographs and descriptions of 172 species that were collected from all over southern Africa. In addition to these, an online charcoal database with descriptions and micrographs of woody species collected throughout the world was accessed (InsideWood, 2004-onwards, Wheeler, 2011).

3.2.2 Laboratory analysis and microscopy techniques

Archaeological and comparative charcoal samples were manually broken using fingers/ fingernails and a surgical blade in order to expose a clean (i.e. un-flattened by post-depositional burial and unclogged by sand grains) wood/charcoal microstructure. Breaks were strategically made to reveal the wood cross/transverse section (TS), tangential longitudinal section (TLS) and radial longitudinal section (RLS) of the fragments after charcoal pieces were carefully studied under the microscope to identify the orientation of each section.

The charcoal pieces with these exposed sections were mounted on microscope slides using temporary putty adhesive, i.e. Prestik. These were then studied under an Olympus Light microscope which is fitted with a reflected light source and high magnification objective lenses (Fig. 3.2). A digital camera connected to the microscope and a computer were used along with the Olympus Image Analysis Software to acquire and filter microphotographs. Analysis software is also equipped with digital tools for counting and measuring microfeatures and these were used to analyse charcoal microanatomy for taxonomic identification and quality assessment. A Phenom Scanning Electron Microscope (SEM) was also used to study some charcoal samples mostly for quality assessment.

3.3 Taxonomic identification and quality assessment

The identity of charcoal/woody species was made following the guidelines of the International Association for Wood Anatomist (IAWA). Archaeological wood fragments were taxonomically identified to family, genus and species level using a set of their unique wood anatomical characteristics. The characteristics that were studied for unique sets of descriptions are divided into 162 functional/anatomical and 58 miscellaneous features (Wheeler et al. 2007). The 162 anatomical IAWA features are derived from the presence or absence, arrangement, quantification and measurement of the main elements of the physiological cellular structure of hardwoods (angiosperm) and softwoods (gymnosperm) (Wheeler et al. 2007).

The vascular tissue conducts water from the roots to the leaves of the hardwood plants in the sapwood (Wiedenhoeft, 2013). The cells of this tissue -vessel elements- have a unique yet consistent arrangement is all taxa and appear as pores on the TS, i.e., solitary, radial,

tangential, clustered and dendritic vessel pores. The morphology of the vessel elements develops and adapt to the amount of water that the plant must conduct at different growth seasons, therefore, a variation in the amount and size of vessels is expected within each taxon. These were quantified and according to their observed amounts and compared to the size categories that are established by IAWA. Other vessel attributes, i.e., Intervessel pits, perforation plates, whose occurrence and variation are important descriptors of different species were studied carefully for taxonomic identification. The imperforate tracheary elements, known as tracheids, were also described mainly for softwood taxa; a comprehensive understanding of this tissue was necessary only for the anatomy of species belonging to *Podocarpus*/*Afrocarpus* and *Widdringtonia* genera (Baas et al., 2004).

Wood rays (or ray parenchyma) connect the radial and axial system of vascular plants, mostly, by transporting nutrients axially within the plant. This tissue in softwoods is simple, i.e. always uniseriate on the TLS and with procumbent ray cells on the RLS. In hardwoods, however, wood rays vary in arrangement and their size varies due to ontogeny and environmental factors. The diversity of the ray cell arrangement was documented as seen in the various wood specimens on the TLS and RLS and was used for taxonomic identification, because of their diagnostic nature, following the type categories and size classes of IAWA.

Axial parenchyma is used by plants to store photosynthates and varies widely in hardwoods. The cells of this tissue, as well as their concentration, where they do occur, can be associated with the vessels (paratracheal) or not (apotracheal). Around the vessels paratracheal parenchyma can be scanty, vasicentric, aliform and confluent. Apotracheal parenchyma, on the other hand, is diffuse/scattered or occurs in aggregates and sometimes occurs in bands of different thickness. These patterns vary- and sometimes overlap- within these descriptions and were carefully studied because they are an important descriptor of all hardwood species.

Ground tissue fibres, hard tissue cells of hardwood taxa, provide mechanical support for plants and may vary from one taxon to another as well as based on the growth conditions of the plant. The thickness of the fibre walls, in particular, and the occurrence of pits in the cells walls determines many properties of wood, including density, and defines the unique anatomy of different species. Wood cambial variants, secretory elements and mineral

inclusions were also studied carefully and included in the descriptions of various taxa (Baas et al., 2004; Wheeler et al., 2007; Wiedenhoeft, 2013).

At Sibudu and Border Cave, the taxonomic identification of woody species using the wood anatomy of charred fragments has been done to reconstruct past woody vegetation. Through this method different sets of woody vegetation were reconstructed through which climatic conditions and evidence of wood use were inferred (Allott, 2005, 2006; Backwell et al., 2018; Lennox, 2016; Lennox et al., 2015; Lennox & Bamford, 2015; Lennox & Wadley, 2019).

Qualitative analysis

A qualitative analysis of charcoal was done to (a) study the possible wood ring morphological variation that may be due to environmental fluctuation during the development of some taxa and (b) interpret conditions about the ecology of the plants based on miscellaneous (non-anatomical) features, residues and evidence of non-biological wood modifications. Such changes and/or processes, if they were favoured in the past could inform on the conditions that allowed for their occurrence, persistence and /or intensity.

These microstructural assessments of wood were based on the relationship between plants, and many aspects of their habitats a, i.e., detailed in Chapter 2 section 2.4 and were investigated using different SEM and light microscope techniques. The growth ring morphology was assessed for variation and thickness such as would occur if there were conditions that challenged the normal growth of plants in this dataset, i.e. narrow growth rings indicate stunted wood growth phases (Stahle, 1999; Wimmer, 2002). Wood ring curvature is related to the ontogeny of plants and was also used here to investigate morphological attributes of wood logs or firewood assemblages.

3.4 Method of interpretation

The results of this study were interpreted following archaeobotanical protocols. Charcoal remains were treated both as archaeological artefacts and environmental proxies of Sibudu and Border Cave localities. Vegetation changes interpreted from archaeological charcoal reflect changes in climate and people's wood collection trends. The wood gathering radius of both Sibudu and Border Caves is unknown, however, it can be inferred through the Least

Effort Principle that occupants of the caves procured most of their wood within the immediate surroundings of the cave to utilise minimum energy (Shackleton & Prins, 1992).

3.4.1 Interpretation of the environment

Interpreting environmental conditions from woody taxa

The species identified through charcoal only comprise a fraction of the woody vegetation that was available due to selection bias that is associated with wood gathering. However, the availability of all species and vegetation communities in the environment from which people may gather is a product of natural phenomena. The occurrence and diversity of the taxa and vegetation communities was used as the primary source of inferring environmental conditions (Fig. 3.5). The conditions associated with each taxa and communities of taxa was extrapolated from that of their contemporary analogues and relatives. Various resources, such as digital databases, maps and books, that relate vegetation species to various environmental variables were consulted. These include the South African National Biodiversity's Institute's (SANBI) digital catalogue/website of vegetation which captures species descriptions and their spatial distributions in southern Africa (SANBI 2016). A vegetation atlas that was compiled by Ladislav Mucina and Michael Rutherford and published by SANBI, is a comprehensive description of vegetation of South Africa, Lesotho and eSwatini which includes field survey data that has also been mapped to show the diversity of vegetation and its classification incorporating ~10 000 indigenous species (Mucina & Rutherford, 2006). Additionally, other books that strictly document the distributions of woody species were consulted (Palgrave, 1981; van Wyk & van Wyk, 2013). The quantity of taxa/communities was used for interpretation while considering that archaeological charcoal is highly susceptible to many taphonomic biases introduced by wood combustion and post depositional processes (Asouti & Austin, 2005; Dotte-Sarout et al., 2014; Théry-Parisot et al., 2010, 2008).

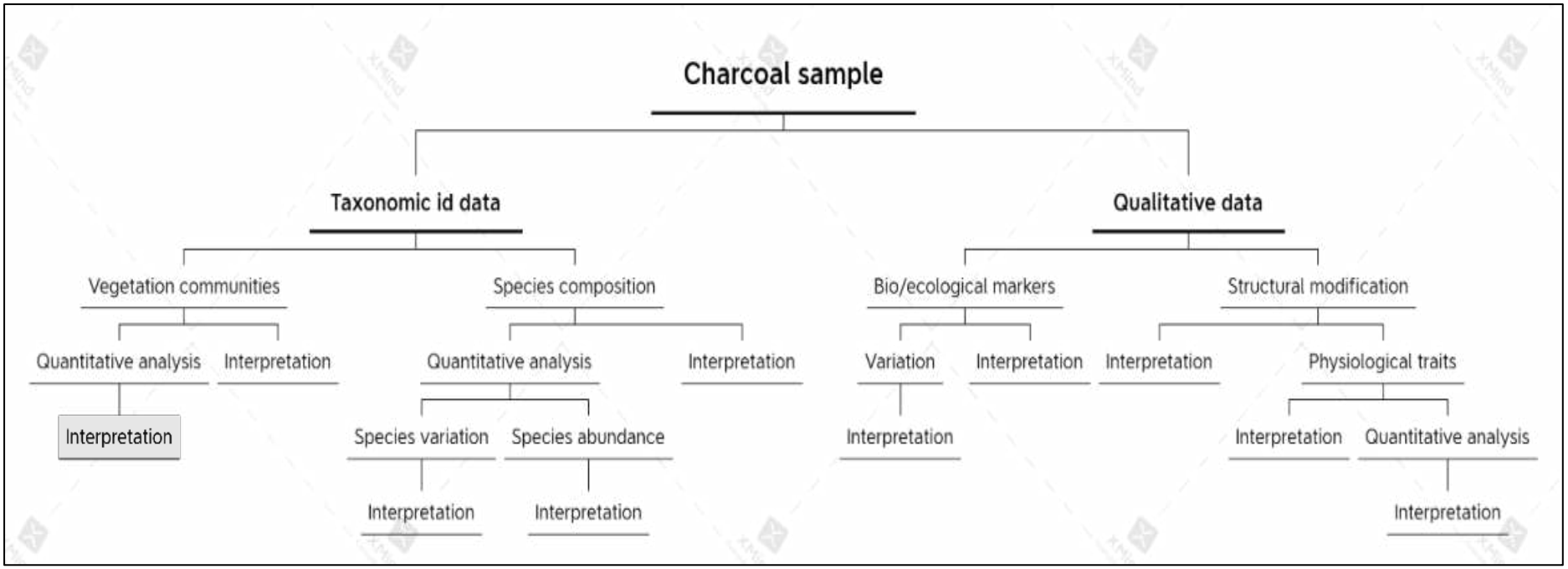


Fig.3.5 Anthracological research approaches generally followed to interpret data that was obtained from archaeological charcoal samples.

Interpreting environmental conditions from the quality of woody vegetation/ taxa

Variations in the structure of growth rings along with modifications in the wood that are related injuries and taphonomic processes was interpreted to understand the finer details about climate and the ecology of the plant's immediate setting. These modifications and the conditions they represent, supplemented details indicated by the interpretation of taxonomic results. The interpretation was based on known environmental factors that control the development and morphology of wood growth rings and determine the occurrence of miscellaneous microprocesses in the ecology of the plants (De Micco et al., 2016; Persiani et al., 2015; Schweingruber, 2007; Wimmer, 2002)

3.4.2 Interpretation of wood use

Anthropogenic wood selection, although subject to unknown social norms and needs may lead to the overrepresentation of some taxa in archaeological sites over many others that were available on the landscape. The presence, variety and abundance of the woody taxa was also interpreted to suggest evidence of wood use, where appropriate (Fig 3.5). This was done by consulting many publications by various ethnobotanists that investigated many aspects of the vegetation use and woody vegetation properties in southern Africa along with many publications documenting prehistoric and archaeological wood use, including those mentioned in Chapter 2, section 2.4 (Palgrave, 1981).

3.5 Concluding remarks

The methods and techniques that are used to obtain archaeological data (charcoal) both in the field and laboratory represent standard archaeobotanical procedures, and will yield results that are comparable to other environmental proxies and archaeological data that was recovered similarly through excavation methods, i.e. the data carries the same amount of sampling bias. The use of taxonomic identification of woody plants has been established to be a useful method of supplementing environmental and archaeological data in many studies. In this research, as stated above, multiple reference (comparative) collection were consulted to increase the chances of identifying as many taxa and to do so accurately. The use of wood quality assessment also has a reliable natural bases, although it has not been applied in southern Africa.

CHAPTER FOUR – RESULTS FOR THE ANALYSIS OF CHARCOAL FROM SIBUDU CAVE

4.1 Introduction

In this chapter, I present the results for the first analysis of charcoal remains from Sibudu Cave. This charcoal assemblage was recovered from a layer that represents a millennium after the Toba super eruption and a millennium before the Still Bay Industry was made at Sibudu. Layer LBG, is characterised by light brownish-gray sediments and its width and extent is spatially variable. The layer was arbitrarily split into 4 sub-divisions of 30 cm thick each, therefore, it is approximately 120 cm thick, however these are not distributed equally over the excavated area. The anthracology methods that were adopted in analysing this assemblage (sample) are presented in the following research article and the anthracological approach taken to interpret results is given in Fig 4.1 below. Appendix A presents the wood anatomical features that were used to identify the taxa in this chapter, while Appendix C has the micrographs of the taxa.

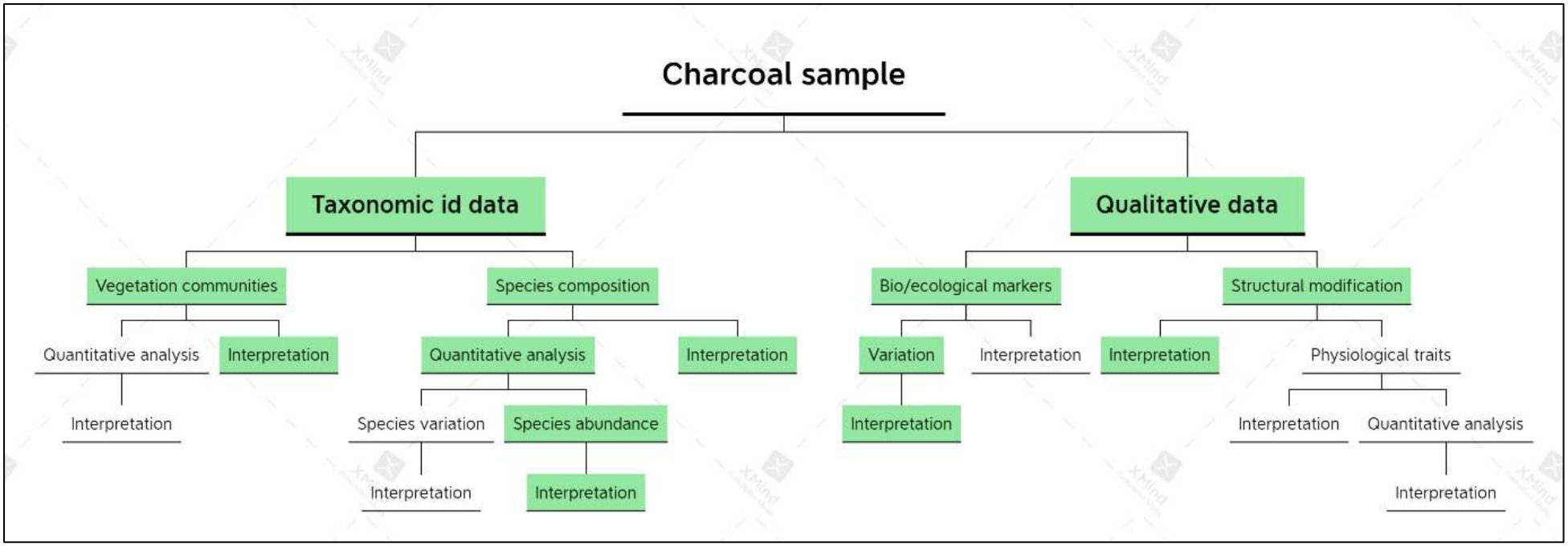


Fig.4.1 The analytical approaches, highlighted in green, that were taken to interpret the data in this chapter.

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A reconstruction of woody vegetation, environment and wood use at Sibudu Cave, South Africa, based on charcoal that is dated between 73 and 72 ka

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ABSTRACT

The aim of this paper is to investigate the Sibudu Cave habitat that is dated to the late Pleistocene using archaeological wood charcoal, in order to reconstruct the environment and the activity of the people who interacted with the landscape. Standard anthracology procedures were applied in this qualitative study to analyse charcoal remains from the cave. A representative subset of charcoal remains was subsampled from a larger assemblage and environmental data, as well as evidence of wood use, are interpreted from 72 charcoal types that include 42 types that we identified taxonomically. We highlight that the environment at Sibudu supported a multi-layered Forest with Savanna vegetation based on the presence of many important taxa of these vegetation communities. The wood of the identified taxa has much rot fungi and was also burrowed by pests; however, it is not possible to infer at this stage if the fungi seen here were pathogenic. The presence of fungi is indicative of an environmental setting with high humidity and warm temperatures, such as is optimal for these types of fungi to flourish. Climatic conditions interpreted here agree with previous interpretations that were made from other environmental proxies. These conditions were only intense enough to disturb the microhabitat at Sibudu and did not change the vegetation near the cave. Also noted during the analysis, is that burning wood logs that were infected with brown rot consistently from c.73 to 72 ka probably produced very warm fires.

1. Introduction

Charcoal remains in archaeological sites are an important source of environmental data that are preserved from the past and provide a means for understanding plant-human-environment interactions throughout prehistory (Esterhuysen and Mitchell, 1996; Asouti and Austin, 2005; Cartwright et al., 2014; Lennox and Wadley, 2019). In southern Africa, studies of archaeological charcoal have contributed to the reconstruction of vegetation history of the subcontinent (Prior and Price Williams, 1985; Scholtz, 1986; Tusenius, 1986; February 1992; Shackleton and Prins, 1993; Esterhuysen and Mitchell, 1996; Cartwright and Parkington, 1997; February, 2000; Allott, 2006; Cartwright et al., 2014; Chikumbirike, 2014; Bamford, 2015; Lennox and Wadley, 2019). The southern African Middle Stone Age record is rich with evidence of the innovative activities that mark important human behavioural evolutionary stages (Lombard et al., 2012). Many Middle Stone Age sites, including Sibudu Cave, contain evidence for behavioural changes through which the transition from one evolutionary milestone to another is understood (Wadley, 2007; Henshilwood et al., 2009; Brown et al., 2012; Lombard et al., 2012). Apart from social factors, one of the things that may have influenced innovation during the Stone Age is the significant change in the environment and consequently the resources on which people depended through time (Deacon, 1992; Ambrose, 1998; Fitzhugh, 2001).

There is a growing need, therefore, to understand the relationship between environmental/climatic drivers and resource fluctuation as well as that between resource fluctuation and human behaviour. Sibudu Cave provides the platform to study the transition from one Stone Age innovation to another due to its' rich archaeological record that spans many important evolutionary stages. As a result, these stages can be easily investigated in relation to potential global climate-influencing incidents, such as the youngest volcano super-eruption of Mount Toba in Indonesia which took place approximately 74 ka, and might have affected local habitats during the late Pleistocene (Ambrose, 1998). This paper is focused on presenting the results for the analysis of charcoal samples from Sibudu Cave that were recovered from an archaeological

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layer dated between c. 73 and 72 ka, a period that represents a transition between the pre-Still Bay and Still Bay lithic industries.

1.1. Site setting

Sibudu Cave is located at 29°31′ 21.50″ S, 31° 5′ 9.20″ E in the province of KwaZulu-Natal, South Africa, on a cliff that, today, is 100 m above mean sea level (a.m.s.l.) (Fig. 1). The cave is situated within an intersection of at least three major vegetation communities of southern Africa c. 15 km from the Indian Ocean (Mucina and Rutherford, 2006). The vegetation in this area grows on the soils that are derived from shale and sandstone rocks near the uThongathi River (Wadley and Jacobs, 2004). Contemporary woody vegetation near the cave has been described and species recorded by various botanists (Mucina and Rutherford, 2006). The current vegetation record at Sibudu, however, may be inaccurate due to sugar cane farming near the cave that has been responsible for the clearance of a large portion of indigenous vegetation. Mucina and Rutherford (2006), for example, mapped three vegetation communities near the cave: Savanna, Indian Ocean Coastal Belt and Forest vegetation communities. At present, there are approximately hundreds of species within these communities and more than 100 indigenous woody species in the vicinity of the cave (Allott, 2005).

The excavation of charcoal specimens discussed here, was done between 1998 and 2011 under the direction of Prof. Lyn Wadley (Wadley and Jacobs, 2004, 2006). The deposit was excavated following the natural stratigraphy, however layers that are deeper than 10 cm were arbitrarily split and named respectively after the colour of the dominant matrix of each layer (Wadley and Jacobs, 2006). The stratigraphy of the Middle Stone Age at Sibudu is clearly defined by different colours and contains ash (Wadley and Jacobs, 2004, 2006). Hearths are found in all layers and are generally defined by flat circular ash remains, burnt soil sediments at the bottom and with concentrations of charcoal at the centre (Wadley and Jacobs, 2006). Botanical remains from their deposit show evidence for the collection of plants for many uses (Allott, 2006; Wadley et al., 2011; Lennox and Bamford, 2015; Lennox et al., 2015; Lennox and Wadley, 2019).

Three layers are discussed here from the Sibudu stratigraphy. The Brown Sand (BS) layer is dated, through single grain Optically Stimulated Luminescence (OSL), to 77.2±2.1 ka. The Light Brownish-Grey (LBG) layer (split into sub-layers LBG(1), LBG2, LBG3 and LBG4) is dated between 72.5±2.0 (LBG1) ka and 73.2±2.3 ka (LBG2), and the Reddish-Grey Sand layer (RGS and RGS2) is dated to 70.5 ± 2.0 ka (Fig. 1) (Jacobs et al., 2008). These layers show that the cave was occupied regularly by people during the late Pleistocene and contain charcoal. The charcoal remains discussed in this paper were recovered from LBG1 to LBG3 along with other archaeological artefacts in four squares: B4, C4, B5 and C5, that are measured at 1 m^2 each (Wadley and Jacobs, 2006). These remains were curated separately, and the charcoal samples were stored temporarily at the Evolutionary Studies Institute, University of the Witwatersrand. Layer LBG contains the pre-Still Bay lithic technology and the light brownish-grey soil sediments of the layer accumulated during a period of low human occupation of the cave compared to the preceding BS layer (Clark, 2019). Volcanic ashes including that of the ~75 ka Toba eruption have not yet been recognised in the Sibudu archaeological deposit; however, such events are temporal markers whose effect can be traced on global climate, ecosystem and maybe even human behaviour. Charcoal remains from Sibudu were, therefore, analysed to understand if the growth of vegetation as well as people's choice of fuelwood was affected by sudden short- or long-term climatic perturbations during the late Pleistocene. The charcoal assemblage is assessed qualitatively for indicators of the environment in which the vegetation grew as well as evidence of wood use with the goal of

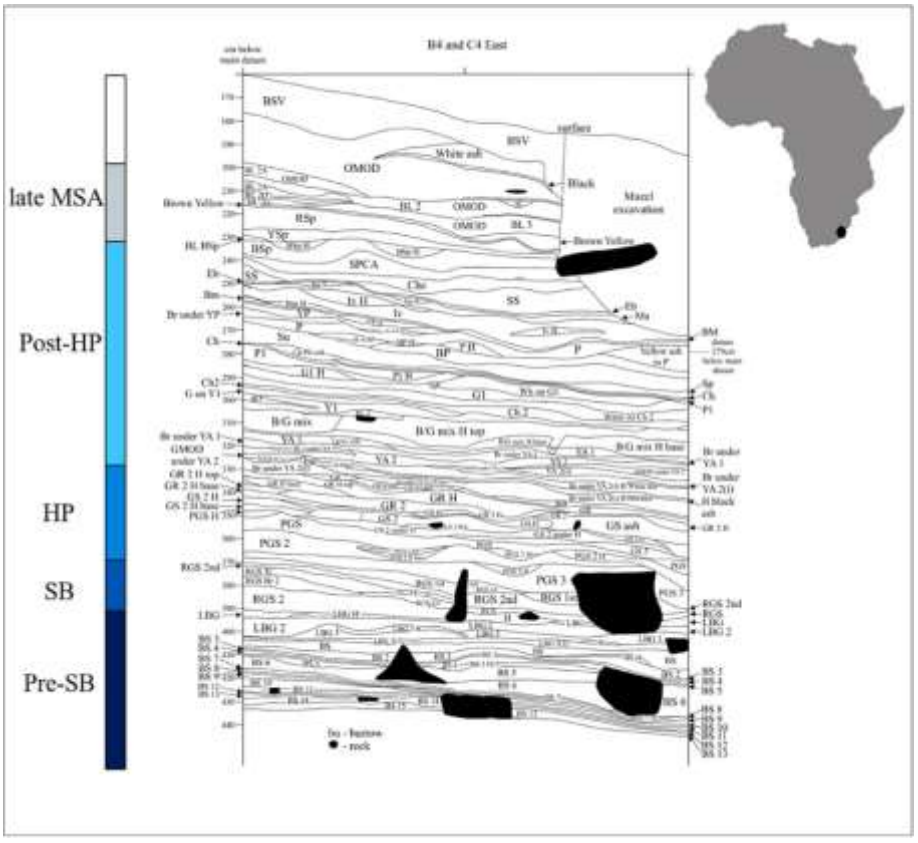


Fig. 1. The east profile of squares B4 and C4 of the archaeological deposit that was excavated at Sibudu Cave as well as the lithic industries contained in the layers. The layer LBG is between the layers BS and RGS and at the end of the Pre-Still Bay (Pre-SB) lithic industry. SB= Still Bay, HP= Howiesons' Poort, MSA = Middle Stone Age (Photo: Lyn Wadley).

describing the finer details of the landscape that accompanied the cultural changes that are documented at this time. This reconstruction will attempt to address the potential intensity of the climatic conditions, the quality -and to a lesser extent quantity-of woody vegetation that was burned as well as a new approach for understanding wood use by considering modifications of wood anatomy related to fungal activity. All charcoal samples analysed here were introduced into the cave anthropogenically (Schiegl and Conard, 2006; Goldberg et al., 2009; Bruch et al., 2012).

2. Materials and methods

A total of c.1800 charcoal remains were excavated from 400 L of archaeological deposit, mostly from areas other than hearths while a few fragments came from Hearths 1 and 3 in squares B4, C4, B5 and C5 (Wadley and Jacobs, 2006). A representative subsample was obtained by categorising charcoal fragments from all squares and quadrants in LBG1, LBG2 and LBG3 into 'small', 'medium' and 'large' size classes. The sizes of charcoal fragments within these classes varied slightly from one quadrant to another, however, charcoals in the 'small' size class were generally <5 mm, 'medium' were ~5 mm and 'large' were >5 mm. Archaeological charcoal fragments were manually broken in order to expose a clean surface. The charcoal fragments, mounted on microscope slides, were then studied under an Olympus Light Stereomicroscope that is fitted with a reflected light source and objective lenses ranging between 50× and 500 × magnification. A Phenom Scanning Electron Microscope (SEM) was also used to study some charcoal samples. These techniques were applied to identify charcoal/woody species, following the International Association for Wood Anatomists (IAWA) terminology and database (Wheeler et al., 2007), against a comprehensive charcoal reference collection created from species in the contemporary Sibudu landscape (Allott, 2005, 2006; Lennox et al., 2015). In addition to this collection, several reference woody species from southern Africa documented in literature (Kromhout, 1975, van Wyk et al., 1983; Oskolski and Wyk, 2008), and those housed in the Evolutionary Studies Institute Palaeobotany Herbarium, University of the Witwatersrand (Zwane, 2018; Lennox and Wadley, 2019), were consulted. The international InsideWood database of modern wood micrographs and descriptions was also consulted (https://insidewood.lib.ncsu.edu).

At Sibudu, the identification of woody species using their charred fragments has been done to reconstruct past woody vegetation near the cave. Through this method, changes from one vegetation community to another were noted at different periods and climatic changes were inferred (Allott, 2006; Lennox et al., 2015; Lennox and Wadley, 2019). The microstructure of all tree and shrub species is similar across space and through time, with very minor variations that may be related to minor fluctuations in the conditions of their habitats. Woody species can, therefore, be used to make hypothetical reconstructions of broader climatic conditions as well as minor fluctuations in some measures of the climate in the past. Woody plants also have a life cycle and life span that captures episodic climate-related incidences (Schweingruber, 2007) and this allows their microanatomy to store the adaptive traits of the plants to seasonal or annual supply of light, heat and precipitation in their habitats. As a result, woody plants can inform on (1) short-term unfavourable changes which have traumatic effects on the plants during their growth and (2) permanent environmental changes which, with every change in climate, may select a range of species that are adapted to the new set of conditions on the landscape (Schweingruber, 2007).

Environmental interpretations, as well as the use of woody vegetation by past societies, can be made based on the presence/absence as well as relative abundance of some species although this interpretation is subject to five main biases: wood selection bias, thermal decomposition, taphonomic factors, sampling bias as well as limited reference materials for taxonomic identification (Prior and Price-Williams, 1985; Shackleton and Prins, 1993; Dotte-Sarout et al., 2014). For example, while some species may not be collected at all for use as firewood (or for any other use), other species may not survive thermal decomposition and post-depositional processes due to their weak mechanical properties (Théry-Parisot et al., 2010). Archaeological excavations may further discriminate against some species that are preserved in caves through insufficient sampling. The scarcity of descriptions of modern woody species' microanatomy for comparative analysis creates an additional challenge when identifying past woody vegetation. In a species-rich region such as southern Africa this challenge is often seen in the number of unidentified charcoal types/species reported in some studies (Allott, 2006; Zwane, 2018; Lennox and Wadley, 2019). Each of these biases minimises the probability of identifying all woody species that were available for past societies to use and thus affect environmental interpretations made through wood charcoal.

3. Results

3.1. Sampling and taphonomy

A third (or 635) of the total number of samples excavated was subsampled, because of time constraints. This subset was reached after it was determined, through plotting the frequency of appearance of new taxa against the analysed fragments (Fig. 2), that the minimum number of taxa was obtained from the assemblage (Dotte-Sarout et al., 2014). Only 316 samples out of 635 could be categorised into different charcoal types representing different taxa. Table 1 presents 72 charcoal types indicating 42 types that were identified taxonomically to genus or species level. These types were identified from all charcoal size classes. Some species such as *Harpephyllum caffrum*, *Englerophytum magalismontanum*, *Vitex rehmannii*, *Commiphora* cf. *marlothii* and *Dombeya kirkii,* were identified with certainty from single "small" fragments, suggesting that species wood composition and their mechanical properties play a greater role than burning temperatures and other post-depositional processes in the recovery of certain archaeological charcoal taxa over others (Shackleton and Prins, 1993; Chrzazvez et al., 2014; Arranz-Otaegui, 2017). Many species or charcoal types were preserved through one or two fragments, i.e. average of 4 fragments per charcoal type; however, Type 6, Type 14 and *Podocarpus* sp., had a totalof 23, 26 and 30 charcoal fragments, respectively, suggesting that perhaps the abundance of some woody species over others in an assemblage is a reflection of selective wood use (Table 1) (Prior and Price Williams, 1985; Shackleton and Prins, 1993; Marston, 2009).

The highest number of species (and charcoal types) was identified from LBG3 and the lowest from LBG2; this is the direct result of sampling bias (Fig. 3). The charcoal data analysed in this study come from an archaeological deposit that was excavated differently across the four squares and through the three sub-layers due to the presence of rock pieces that obstructed parts of the excavated area (Wadley, 2012). Four quadrants of squares B4 and C4 were excavated through the three

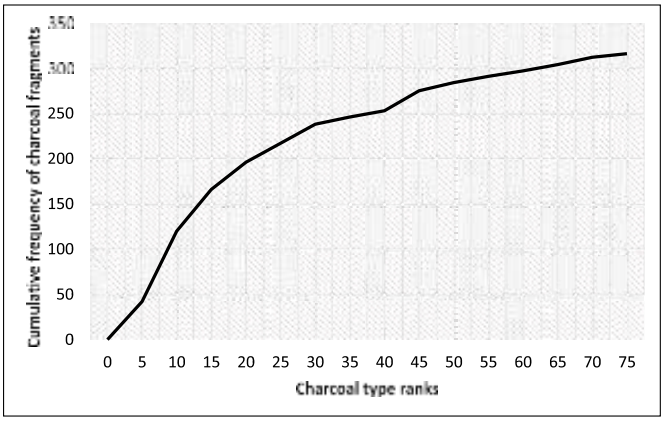


Fig. 2. The cumulative frequency of the charcoal fragments per charcoal types.

Table 1
The list of identified taxa showing the total number of charcoal fragments per taxon, the total in each sub-layer and the number of fragments containing cracks, rot and insect burrows in each taxon. The summary of the data for all unidentified charcoal types is included in the last row.

Taxa		Total no. fragments	Sub-lay rs			Fragments w cracks	Fragments w/ rot	Fragments w/ burrows
Species and authorship	Family		LBG1	LBG2	LBG3			
Allophylus sp.	Sapindaceae	9	0	1	8	0	3	1
cf. *Androstachys johnsonii* Prain	Picrodendraceae	3	0	0	3	0	0	0
Apodytes dimidiata E. Mey. ex Arn.	Icacinaceae	1	0	0	1	0	0	0
cf. *Baphia racemosa* (Hochst.) Baker	Fabaceae	3	0	0	3	0	1	0
cf. *Bolusanthus speciosus* (Bolus) Harms	Fabaceae	3	2	0	1	0	0	0
Buddleja pulchella N.E.Br.	Scrophulariaceae	2	0	0	2	0	0	0
Burkea africana Hook.	Fabaceae	2	0	0	2	1	0	0
Buxus macowanii Oliv.	Buxaceae	6	3	0	3	0	6	0
Canthium sp.	Rubiaceae	1	0	0	1	0	1	0
Catha edulis (Vahl.) Endl.	Celastraceae	2	0	0	2	0	1	1
Chaetachme aristata Planch.	Cannabaceae	1	0	0	1	0	0	0
Commiphora cf. *marlothii* Jacq.	Bursaraceae	1	0	0	1	0	0	0
Cordia caffra Sond.	Boraginaceae	5	0	0	5	1	1	0
Cryptocarya myrtifolia Stapf	Lauraceae	1	0	0	1	0	0	0
Cryptocarya woodii Engl.	Lauraceae	5	4	0	1	0	4	0
cf. *Deinbollia* sp.	Sapindaceae	2	0	0	2	1	0	0
Diospyros austro-africana De Winter	Ebenaceae	8	5	0	3	0	7	1
Dodonea viscosa (L.f) Benth.	Sapindaceae	5	1	0	4	3	0	0
Dombeya burgessiae Gerr. ex Harv.	Malvaceae	1	0	0	1	0	0	0
Dombeya kirkii Mast.	Malvaceae	1	0	0	1	0	0	0
Dombeya tiliaceae (Endl.) Planch.	Malvaceae	11	0	4	7	1	0	1
Englerophytum magalismontanum (Sond.) T. D.Penn.	Sapotaceae	4	1	0	3	0	2	1
Eugenia zeyheri (Harv.) Harv.	Myrtaceae	2	1	1	0	0	1	0
Ficus burkei (Miq.) Miq.	Moraceae	3	2	1	0	0	0	1
Harpephyllum caffrum Bernh.	Anacardiaceae	6	4	0	2	1	2	1
Mimusops obovata Sond.	Sapotaceae	2	0	1	1	0	2	2
Mystroxylon aethiopicum (Thunb.) Loes.	Celastraceae	3	3	0	0	0	2	0
cf. *Olax dissitiflora* Oliv.	Olacaceae	2	2	0	0	0	1	0
Olea capensis L.	Oleaceae	8	5	0	3	1	1	1
cf. *Passerina* sp.	Thymelaceae	2	0	1	1	0	2	0
Podocarpus/Afrocarpus sp.	Podocarpaceae	30	9	7	14	0	3	2
Ptaeroxylon obliquum (Thunb.) Radlk.	Rutaceae	3	0	0	3	0	2	0
cf. *Rauvolfia caffra* Sond.	Apocynaceae	1	0	0	1	0	1	0
Schotia brachypetala Sond.	Fabaceae	8	5	0	3	1	3	1
Searsia chirindensis (Baker f.) Moffett	Anacardiaceae	1	0	0	1	0	0	0
Spirostachys africana Sond.	Euphorbiaceae	1	0	0	1	0	0	0
Strychnos decussata (Pappe) Gilg	Loganiaceae	1	0	0	1	0	0	0
Strychnos sp.	Loganiaceae	5	3	0	2	1	2	
Trema orientalis (L.) Blume	Cannabaceae	4	2	0	2	0	2	0
Vachellia erioloba E. Mey.	Fabaceae	1	0	0	1	0	0	1
Vepris lanceolata (Lam.) G.Don	Rutaceae	13	6	3	4	5	4	1
Vitex rehmannii Gürke	Lamiaceae	1	0	0	1	0	0	0
Unidentified taxa (30)	Unidentified	135	41	19	75	21	48	14

sub-layers, however, in LBG2, two quadrants of square C4 were not excavated because they were covered by large pieces of roof spall (Wadley, 2012). In LBG3, two more squares were excavated (B5 and C5) and charcoal fragments were recovered in all but one quadrant of square B5. This sampling difference contributed significant bias in the presence/absence ratio of archaeological charcoal taxa across the three sub-layers. Moreover, charcoal fragments from squares B5 and C5 were better preserved than those from squares B4 and C4 because archaeological material in the former was generally protected from post-depositional trampling by rock pieces that covered much of the area dug in these squares. Two hundred and eleven specimens (out of 635) were badly preserved (too small and crumbly) or comprised knot and pith wood and therefore could not be identified taxonomically. A further 108 specimens could not be identified taxonomically because their wood microstructure was obscured by rot fungi. The same types of rot fungi were also present in lesser (and varying) degrees in fragments that were categorised into 72 charcoal types (Table 1).

3.2. Vegetation communities represented by the identified species

The identified taxa comprise mostly tall tree species (60%) that are common in the Forest (71%) and Bushveld (Savanna) (69%) vegetation (Fig. 4). Other vegetation communities represented by these taxa are Scrubland (29%) and Grassland (14%) (Fig. 4). Each of the 42 species or genera are currently found in more than one vegetation community, making the environmental tolerances of each tree/shrub fairly wide. However, there are taxa that are important indicators of certain vegetation communities and most taxa are important Forest species followed by Bushveld (Savanna). It should be noted that Scrubland and Grassland species in this dataset are currently found in the margins of Forests and Bushveld and are not important components of Scrublands and Grasslands. This is because the Savanna Biome interdigitates with many vegetation communities the indigenous Forests of southern Africa occur mostly in isolated patches that are enclosed by other vegetation communities (Mucina and Rutherford, 2006).

3.3. Fungi and insects in charcoal samples

The charcoal fragments contained much rot fungi. This was observed under a stereomicroscope as white and brown discoloration of the wood/charcoal cells or tissues that have been infected before the wood was burnt. Sixty three percent of the 72 charcoal types have signs of this infection in varying degrees (Table 1). The white and brown discolouration on the specimens is consistent with the colour of the residual

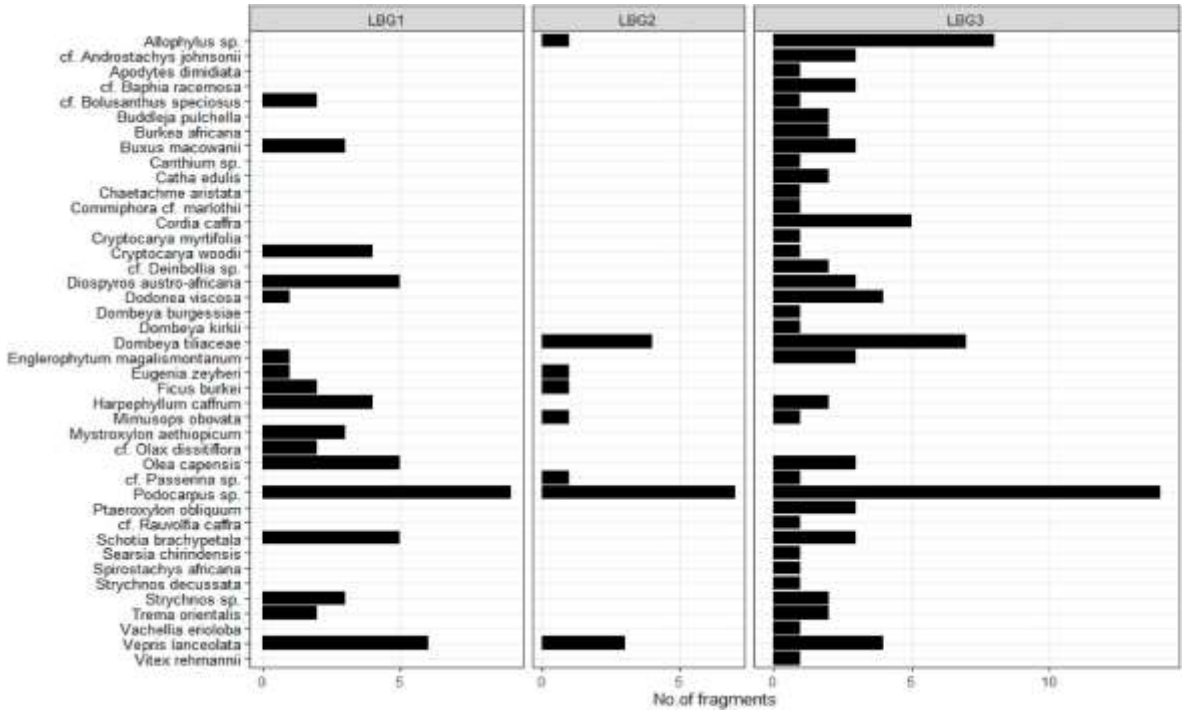


Fig. 3. The anthracological diagram of the identified charcoal species showing the presence and abundance of each species through the three sub-layers LBG1, LBG2 and LBG3.

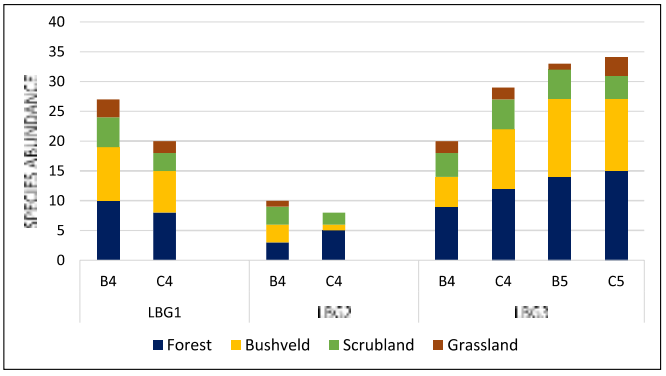


Fig. 4. The vegetation communities in which archaeological charcoal species belong; the abundance of each vegetation community is shown per square and sub-layer.

cellulose and lignin that has been infected by white and brown rot fungi, respectively (Fig. 5a and b) (van Heerden, 2007). Furthermore, when studied under SEM, the microstructure of charcoal with signs of rot fungi, showed clear traces of the hyphal growth of soft rot fungi in the cellular structure of wood at different stages of infection as well as degraded wood cells that have been depleted of lignin and cellulose (Fig. 5c and d) (Martínez et al., 2005; van Heerden, 2007). Wood-rotting fungi survive combustion and post-depositional processes (Moskal-del Hoyo et al., 2010) and are often used to infer that people burnt rotten or dead wood in the past (Théry-Parisot et al., 2008, 2010). Brown, white and soft rots are wood decaying types of Basidiomycete and Ascomycete fungi and generally thrive under very warm and extremely humid conditions, however, some soft rot species live in extreme aridity (Martínez et al., 2005; Watkinson et al., 2016). Fig. 6 shows the abundance of species that had brown rot, a mixture of brown and white rot as well as white rot in all squares and sub-layers. Brown rot and a mixture of brown and white rot were observed in all squares while white rot alone was mostly concentrated over square C4 (Fig. 6).

Evidence of wood-dwelling insects in the archaeological Sibudu landscape was identified in the form of insect burrows in the charcoal specimens (Table 1, Fig. 7a). Approximately 26% of the charcoal types identified have insect burrows; insect frass and carcasses were, however, not found in any of them.

3.4. *Radial cracks in charcoal fragments*

Radial cracks were noted in 26% of the 72 charcoal types (Table 1, Fig. 7b). Cracking in wood is formed along weak zones of stress when water within the wood is lost rapidly as a result of exposure to hot conditions (Hather, 2000). Ray parenchyma cells often form these weak zones and are likely to tear and leave a linear cavity or gash when wood was dried quickly or burnt. The occurrence, frequency and width of these radial cracks depends on several factors, such as the wood species, the amount of moisture retained in the wood and the temperature to which wood is exposed (Théry-Parisot et al., 2010; Arranz-Otaegui, 2017; Caruso Fermé et al., 2018). It was also observed that 73% of the species with cracks, such as *Olea capensis*, *Strychnos* sp. and *Cordia caffra,* also had rot fungi.

4. Discussion: environment, wood uses and climate

At least four Forest types described by Mucina and Rutherford (2006) were identified in the Sibudu archaeological landscape, namely Afrotemperate Forest, Mistbelt Forest, Scarp Forest and Coastal Forest. Six species and genera, *Podocarpus*, *Olea capensis*, *Canthium* sp., *Diospyros*, *Buddleja*, *Cryptocarya* and *Apodytes* are important trees of the Afrotemperate Forest, with some species of *Cryptocarya* and *Apodytes* being endemic to this forest community. Furthermore, some *Cryptocarya* and *Podocarpus* species are palaeoendemics of the Afrotemperate Forest. The Mistbelt Forest is represented by species such as *Apodytes dimidiata*, *Olea capensis*, *Podocarpus* sp., *Ptaeroxylon obliquum*, *Searsia chirindensis*, *Vepris lanceolata*, *Mimusops obovata*, *Mystroxylon aethiopicum*, *Englerophytum magalismontanum*, and genera such as *Vachellia*, *Canthium*, *Eugenia*, *Allophylus*, *Dombeya* and *Diospyros*. Out of these, *Podocarpus*, *Eugenia*,

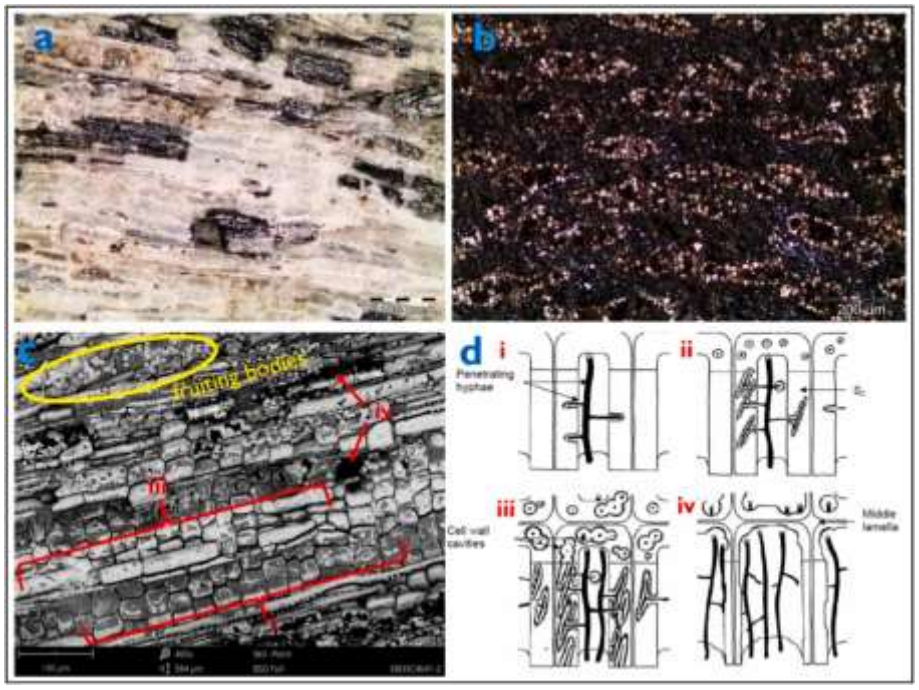


Fig. 5. Examples of a) white residual cellulose infected by white rot fungi inside ray cells; b) brown residual lignin infected by brown rot in vasicentric tracheids. SEM micrograph c) shows soft rot in a charcoal sample from Sibudu and the d) diagram shows the sequential stages of degradation (i-iv) of wood cells by soft rot. Scale bar on micrographs a) & c) = 100 μm, b) = 200μ and diagram d) is modified from Schwarze et al. (2000). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.).

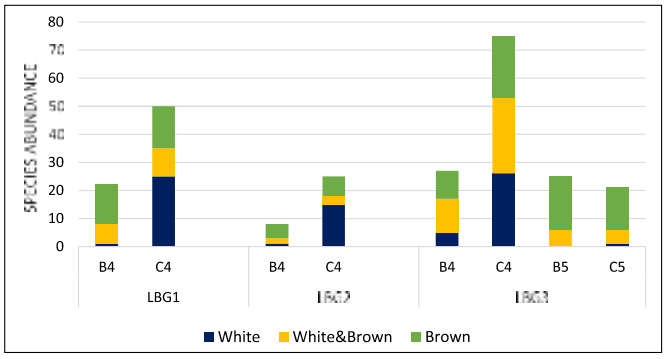


Fig. 6. The spatial and temporal distribution of species (and unidentified fragments) with rot fungi observed in the charcoal samples.

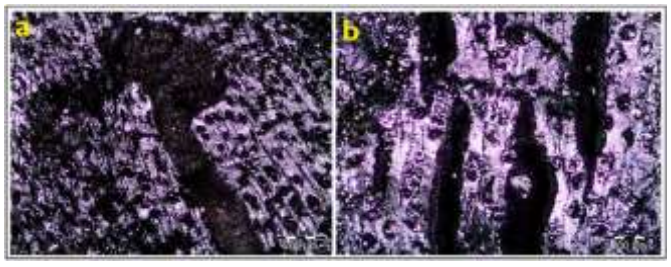


Fig. 7. Examples of a) insect burrowing with sawdust and b) radial cracks on the cross section of charcoal samples. The scale bar on micrographs is 200 μm.

Cryptocarya and *Dombeya*, have species that are endemic to this vegetation type.

The Scarp Forest is represented by nine species and genera, namely *Buxus macowanii*, *Harpephyllum caffrum*, *Ptaeroxylon obliquum*, *Cryptocarya myrtifolia*, *Dombeya*, *Strychnos*, *Eugenia*, *Englerophytum*, *Commiphora* and *Apodytes*. Genera such as *Apodytes*, *Canthium* and *Eugenia* have species that are endemic to the unique conditions of this forest community. Important species belonging to the Coastal Forest are *Ficus burkei*, *Mystroxylon aethiopicum*, *Strychnos decussata*, *Searsia chirindensis* and *Vepris lanceolata*. Important genera include *Allophylus*, *Diospyros*, *Mimusops* and *Schotia*. The above forest taxa, generally, have a narrow distribution over the eastern and southern parts of southern Africa where indigenous forests are currently concentrated (Germishuizen and Meyer, 2003; Coates-Palgrave, 2002; van Wyk and van Wyk, 2013).

Bushveld species were also identified and suggest the presence of Savanna woody vegetation near Sibudu Cave at this time. Species that indicate this vegetation community include five of the Savanna Biome Bushveld types described by Mucina and Rutherford (2006): Central Bushveld, Mopane, Lowveld, sub-escarpment Savanna and the Eastern Kalahari bushveld. The main species of the Central Bushveld identified here are *Vachellia erioloba*, *Vitex rehmannii*, *Mystroxylon aethiopicum*, *Burkea africana* and *Spirostachys africana*. The Mopane vegetation is signified by *Spirostachys africana* and the genus *Commiphora*, while the Lowveld is strongly suggested by eight species: *Burkea africana*, *Ptaeroxylon obliquum*, *Strychnos* sp., *Spirostachys africana*, *Catha edulis*, *Ficus burkei*, *Englerophytum magalismontanum* and *Vepris lanceolata*. *Spirostachys africana*, *Schotia brachypetala* and *Vitex rehmannii* represent the Sub-Escarpment Savanna vegetation. Like many important Savanna species, mentioned above, *Vachellia erioloba* and *Diospyros austro--africana* are widely distributed in southern Africa including in the Eastern Kalahari Bushveld and the Kalahari Duneveld and are no longer distributed in KwaZulu-Natal or in close proximity to Sibudu Cave.

The Afrotemperate Forest of southern Africa comprises tall multi-layered trees and commonly occurs in shallow, sandy humic to acidic soils supported by sandstone and occurs in both summer and winter rainfall regions of the subcontinent (Mucina and Rutherford, 2006). The Mistbelt Forest shares many characteristics with the Afrotemperate and Scarp Forests including a tall multi-layered tree canopy with a dense understorey of shrubs and resembles a scrub forest at low altitudes. This forest often occurs on deep, loamy soils with very high nutrients, derived from sedimentary rocks. The vegetation in this forest contains both Afrotemperate and subtropical elements and currently borders many vegetation communities. The Scarp Forest is a 'biogeographically ancient' set of tall multi-layered trees with an herbaceous understorey (Mucina and Rutherford, 2006, p. 603). Commonly found on nutrient-poor, shallow soils derived from sedimentary rocks, this vege- tation currently occurs in patches mostly at low altitudes, although it is

also found at c. 2000 m a.m.s.l. The Coastal Forest is characterised by low trees that occur specifically on coastal sand dunes at altitudes below 300 m a.m.s.l. This forest vegetation unit grows on sandy and loamy soils and includes many shrubs and herbs.

The Savanna Biome currently covers a wide range of grassland habitats over the eastern and interior of southern Africa. The trees and shrubs of this vegetation are generally short to medium sized and occur entirely in the summer rainfall region of the subcontinent. Generally, the Savanna vegetation occurs on varied altitudes often >1000 m a.m.s.l. and on various soils (Mucina and Rutherford, 2006; van Wyk and van Wyk, 2013). The different types of forests and Savanna identified on the Sibudu archaeological landscape suggests that vegetation around the site has changed constantly over time (Allott, 2005, 2006; Lennox and Wadley, 2019). The contraction and expansion of many species has, with time, formed unique communities and then fragmented due to various climate forcings, leading to the present vegetation which has remnant species of past communities (Allott, 2005).

Species such as *Podocarpus* sp., *Diospyros austro-africana* and *Olea capensis* are known today as valuable sources of firewood that makelong-lasting fires (Coates-Palgrave, 2002; van Wyk and van Wyk, 2013). This may be due to their hard/heavy and durable wood that is also re- ported as good craft wood. Forty-two percent of the species identified here have similar mechanical wood properties and may have been collected in the past as firewood even though there is a scarce record of their use in this way by contemporary southern African societies. Alternatively, woody species with hard and durable wood may have been collected as craft wood and then later burned as firewood. Thesticks of *Cordia caffra* can be rubbed to start a fire as has been demon- strated by contemporary communities of southern Africa and may have been used similarly in the past (van Wyk and van Wyk, 2013).

Approximately, 52% of the species have plant parts (i.e. fruit, root, bark, leaves) with notable nutritional and medicinal properties and may have been collected for food and medicine before their wood was burnt as fuel (van Wyk and Gericke, 2000; Coates-Palgrave, 2002; van Wyk and van Wyk, 2013; Lennox and Wadley, 2019). For example, Lennox and Bamford (2015) argued that *Spirostachys africana* may have been harvested for thousands of years at Sibudu (i.e. from 58 to 49 ka) for its many medicinal properties including laxative properties. Other species such as *Cryptocarya woodii* and *Ptaeroxylon obliquum* may have also been collected for use as insecticides (Wadley et al., 2011; Lennox et al., 2015; Lennox and Wadley, 2019).

Forest and Savanna species collected by the people who visited the cave indicate that this vegetation was available for use throughout the period starting from c. 72 to 73 ka. There is a consistency in the ratio of Forest, Savanna, Scrubland and Grassland vegetation communities, with the forest taxa collected most abundantly over all the squares and from LBG3 to LBG1. Assuming that people preferred to gather most of their resources close to their living spaces, as per the Principle of Least Effort, the observed trend shows the presence of, and to a lesser extent, pro- portion of, the vegetation communities that grew nearest to the cave, from which people selected their fuel resources (Shackleton and Prins, 1992; Asouti and Austin, 2005). Lennox and Wadley (2019) showed that the habitats associated with the layers BS and RGS at Sibudu predominantly were forested based on charcoal analysis. Some charcoal species from their study include *Podocarpus* sp., *Buxus macowanii*, *Canthium* sp., *Cryptocarya woodii*, *Harpephyllum caffrum*, *Mystroxylon aethiopicum*, *Ptaeroxylon obliquum* and *Searsia chirindensis*, and were identified in this charcoal study indicating a forested landscape near Sibudu between c. 77 and 65 ka. Murungi (2017) described the Sibudu landscape dated to the pre-Still Bay industry as having woody and grassy vegetation based on the analysis of phytoliths recovered from BS and LBG layers. Noted in this analysis, was the abundance of Panicoideae C_4 phytoliths belonging to grasses that form an understorey of taller vegetation types such as shrubs and trees. They indicate that there were warm conditions in the vicinity of the cave (Murungi, 2017). Similar warm and wet conditions are also traced through $\delta^{13}C$ isotope signatures in charcoal remains that were recovered from the bottom layers of the Sibudu archaeological deposit including LBG (Hall et al., 2008, 2014). Faunal remains recovered from the layers BS and LBG suggest the presence of small game and forest birds near Sibudu at this time (Val, 2016; Clark, 2019) and stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) from faunal remains indicate that the Sibudu landscape >70 ka generally featured closed, forested habitats (Robinson and Wadley, 2018; Clark, 2019).

The visitors to Sibudu Cave collected dead or dying trees of the Forest and Savanna vegetation communities as indicated by pests and rot fungi in this charcoal data. It is not plausible at this stage to infer that the fungi infected and eventually killed living trees without a taxonomic identification of their species, however, there is compelling evidence to suggest that the rot fungi infected healthy wood, i.e. healthy dead logs or even live trees. First, trees of many different species were infected by the same type of brown, white and soft rots: 63% of the 72 charcoal types plus 106 indeterminate fragments. This suggests that these fungi were not host-specific and many pathogens share this characteristic that is uncommon in southern African indigenous forests (Midgley et al., 1995; Watkinson et al., 2016). Secondly, the cellular structure of these woody species shows the clear development of one of the possible diseases (Fig. 5), consuming the cell contents and eventually destroying the cell walls of the wood, which is a trait that is consistent with phytopathogenic fungi (Martínez et al., 2005; Watkinson et al., 2016). Not all woody taxa, however, were rotted in the same way. While some had only white rot, most seem to have been susceptible to brown rot.

The degree of brown rot fungal infection in all the fragments varied across species; for example, c. 30% of the 72 charcoal types with fungi, including species of mostly Savanna vegetation such as *Ficus burkei*, *Dodonea viscosa* and *Vepris lanceolata,* had very little or negligible amounts of brown rot only. This may indicate that some species had better defence mechanisms or that maybe the fungi were not very virulent on drier slopes around Sibudu where Savanna vegetation grew. If the fungi infected live trees and shrubs, this could explain the discrepancy observed in the species identified across the three layers: BS, LBG and RGS. Only 44% of the species identified in the layer BS were identified here in LBG, whereas 34% of the species identified in the layer RGS occurred in LBG (Lennox and Wadley, 2019). The species in the adjacent layers which also contain brown and white rot, are of similar height to those in LBG (Fig. 8) and were all harvested from the same Forest and Savanna habitats (Lennox and Wadley, 2019). The difference in the taxa collected in BS, LBG and RGS could be that species were favoured less by people when woody vegetation was affected by a biological natural disaster such as a plant disease; however, this cannot be argued with certainty until it is proven that the fungi observed are indeed pathogenic.

The successful development of rot fungi, nevertheless, depends on the favourable environmental conditions including soil pH, nutrients, atmospheric humidity, wind, insolation and atmospheric temperatures

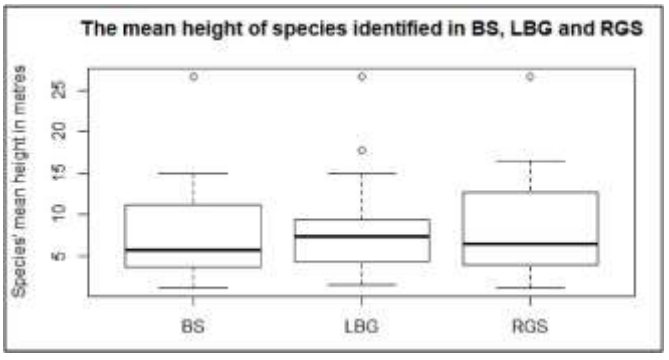


Fig. 8. A box and whiskers plot of the species identified from BS, LBG and RGS showing the species height range, mean, upper and lower quartiles as well as the outliers in each layer.

(Watkinson et al., 2016). For example, optimal conditions for some rot fungi species in southern Africa include very high humidity and temperatures ranging between 20 and 40 °C (Tekere et al., 2001; van Heerden, 2007; Cloete, 2015; Watkinson et al., 2016). Present conditions at Sibudu Cave locality are generally humid and average winter and summer temperatures range between 17 and 20 °C and 22–25 °C, respectively (Wadley and Jacobs, 2004). The rot fungi in the LBG layer, and in the adjacent BS and RGS layers, could suggest an increase in temperatures during the pre-Still Bay and Still Bay at Sibudu. The increase may have caused an outbreak of microorganisms that thrive in very warm and humid conditions. Evidence from sediment and isotope analyses also shows that moister or more humid conditions (relative to the other layers) may have prevailed during the deposition of the basal archaeological layers in the cave including BS, LBG and RGS (Schiegl and Conard, 2006; Hall et al., 2014).

Radial cracks in the fragments of some wood were, most likely, a result of burning green wood (Théry-Parisot and Henry, 2012). Studies conducted in some communities that use firewood today in KwaZulu-Natal (Gandar, 1982), as well as in neighbouring provinces i.e. Eastern Cape (Pote et al., 2006; Shackleton et al., 2007) Limpopo (Madubansi and Shackleton, 2007) and Mpumalanga provinces (Mat- sika et al., 2013) report that dry wood is always preferred for making fire. Some contemporary societies in KwaZulu-Natal only cut green wood of species that can burn while wet (i.e. *Tarchonanthus camphoratus, Vachellia caffra*) or those that are not susceptible to insect attack, which are then stockpiled in huge quantities and burnt only when they are completely dry (Gandar, 1982). Green wood, generally, does not burn well and produces too much smoke (Théry-Parisot and Henry, 2012). Burning green wood, therefore, might be discouraged in most cases unless the smoke of certain plants is purposely sought after, perhaps, to repel pests as has been suggested at Sibudu from c. 77–65 ka (Lennox and Bamford, 2015; Lennox et al., 2015; Lennox, 2016; Lennox and Wadley, 2019). It is possible that people burned green wood in order to release the insecticidal smoke properties of species such as *Ptaeroxylon obliquum* and *Spirostachys africana*. Alternatively, the presence of cracks in the fragments of some species could be a by-product of intentionally burning rotten wood that was affected by brown and white rots that lives under high humidity or green wood. This alternative explanation is more likely, especially since a correlation between species with cracks and rot fungi was noted, i.e. 73% of the charcoal types with cracks also had white and brown rot fungi (Table 1). There is a significant benefit in burning rotten wood. An experiment proved that wood that has been infected by brown rot not only burns well but increases the temperature of the fires compared with burning unaffected wood (Dobry et al., 1986).

5. Conclusions

The period corresponding to approximately a millennium just before the onset of the Still Bay lithic industry at Sibudu was accompanied by unusual environmental conditions and activity by the late Pleistocene communities who visited the cave. The results, along with those of previous studies, showed that the Sibudu landscape had multi-layered forest vegetation with an undergrowth of shrubs, herbs and grasses alongside many Savanna (or Bushveld) woody species at the end of the pre-Still Bay. The visitors of the cave during this time collected a wide range of trees and shrubs that were not collected before and after this period. Warm and humid environmental conditions may have prompted the outbreak of rot fungi. The appearance of rot fungi is related to very warm conditions that may have exceeded present average temperatures. During this time, the people who visited the cave took advantage of the abundant presence of rotten wood which they burned consistently from c. 73 to 72 ka.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CHAPTER FIVE– RESULTS FOR THE ANALYSIS OF CHARCOAL FROM BORDER CAVE

5.1 Introduction

This chapter focuses on the description of the environment and wood use based on the charcoal assemblage (sample) from Border Cave. The analytical approach that was adopted in studying this charcoal dataset is given in Fig. 5.1 and the discussion of the results is presented thereafter in the format of the research journal in which these results appear. The taxa that are discussed in this chapter were identified using the wood anatomical features that are listed in Appendix B. Appendix D has the corresponding micrographs of some taxa that are presented in Appendix B.

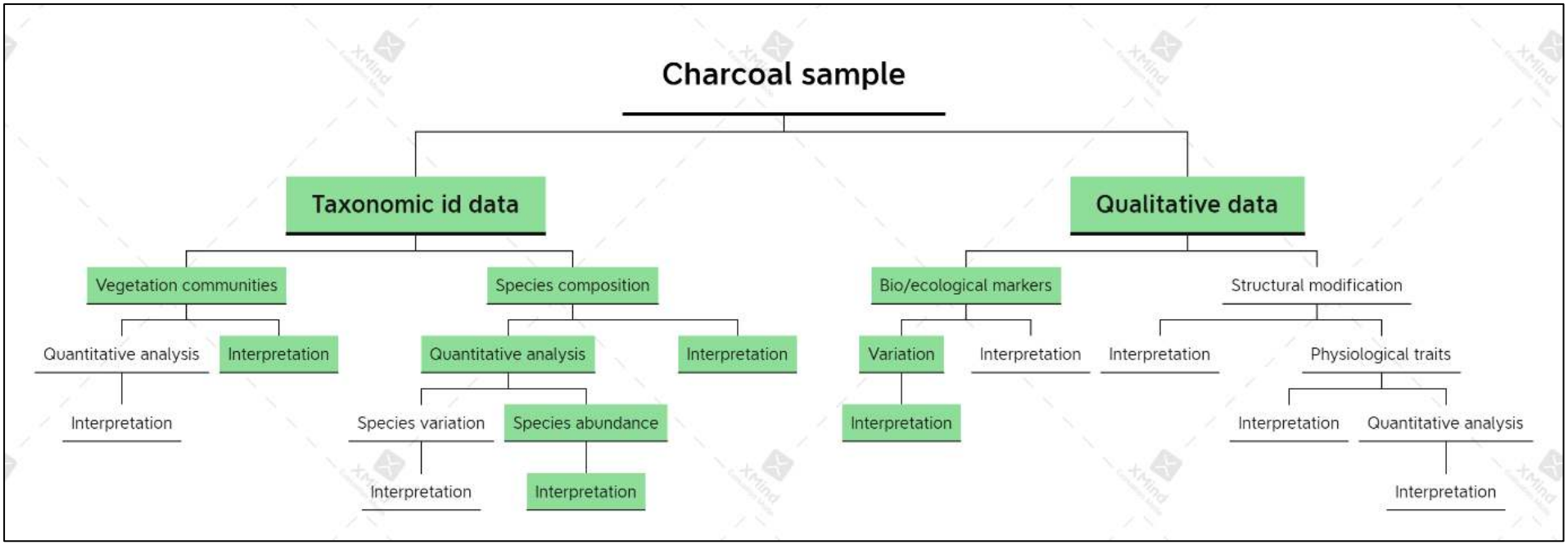


Fig.5.1 The analytical approaches, highlighted in green, that were taken to interpret data in this chapter.

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ORIGINAL ARTICLE

Wood Charcoal from Border Cave's Member 1RGBS: Evidence for the Environment and Plant Use During MIS 5

Bongekile Zwane · Marion Bamford

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Abstract We conducted an anthracological analy-sis of charcoal remains from Border Cave's mem-ber 1RGBS to provide environmental context for the site's occupation ca. 74 ka. Charcoal specimens were analyzed to assess their quality and quantity, and identify their tree taxa to reconstruct the vegetation communities available to the site's occupants. Speci-mens were analyzed using light stereomicroscopy and following standard anthracology methods. We identified the tree taxa that grow predominantly in the savanna, forest, and grassland vegetation communi-ties. Using the current distribution of these communi-ties as a reference, we suggest that the archaeological Border Cave landscape included vegetation types that now grow in southern Africa's interior warm parts. Our data revealed that *Tarchonanthus* sp. was col-lected most abundantly at this time, possibly for its medicinal and cosmetic properties. *Euphorbia* spe-cies were also collected, perhaps for their latex before their wood was burned. Furthermore, green wood logs of *Tarchonanthus* sp. were burned or discarded into the fire; this is evidenced by the high proportion of fragments of this species bearing radial cracks. There may have been unfavorable environmental con-ditions in the archaeological landscape that resulted in the wood vessel occlusion of many trees. These were likely episodic microclimatic conditions around the cave during some growth phases of the trees. These conditions and their intensity, however, were not fatal to the trees in this dataset.

Résumé Nous avons effectué une analyze anthra-cologique des restes de charbon du membre 1RGBS de Border Cave pour fournir un contexte environne-mental pour l'occupation du site ca. 74 ka. Des spéci-mens de charbon de bois ont été analysés pour évaluer leur qualité et leur quantité et identifier leurs taxons d'arbres pour reconstituer les communautés végétales disponibles pour les occupants du site. Les échantil-lons ont été analysés en utilisant la stéréomicroscopie optique et en suivant les méthodes d'anthracologie standard. Nous avons identifié les taxons d'arbres qui poussent principalement dans les communautés végé-tales de savane, de forêt et de prairie. En utilisant la distribution actuelle de ces communautés comme ré-férence, nous suggérons que le paysage archéologique de Border Cave comprenait des types de végétation qui poussent maintenant dans les régions intérieures et chaudes de l'Afrique australe. Nos données ont révélé que *Tarchonanthus* sp. a été récolté le plus abondam-ment à cette époque, peut-être pour ses propriétés mé-

Archaeological time period: Late Pleistocene—74 thousand years ago; Country and region discussed: South Africa, south-east/KwaZulu Natal province

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dicinales et cosmétiques. Les espèces d'*Euphorbia* ont également été récoltées, peut-être pour leur latex avant que leur bois ne soit brûlé. De plus, des bûches de bois vert de *Tarchonanthus* sp. ont été brûlés ou jetés dans le feu ; ceci est mis en évidence par la forte proportion de fragments de cette espèce présentant des fissures radiales. Il peut y avoir eu des conditions environnementales défavorables dans le paysage archéologique qui ont entraîné l'occlusion des vaisseaux en bois de nombreux arbres. Il s'agissait probablement de conditions microclimatiques épisodiques autour de la grotte pendant certaines phases de croissance des arbres. Ces conditions et leur intensité, cependant, n'ont pas été fatales aux arbres de cet ensemble de données.

Keywords *Tarchonanthus* sp. · *Euphorbia* sp. · Climate · Charcoal · Green wood · Vessel occlusion

Introduction

Border Cave is a repository of rare prehistoric finds that have taught us about Middle Stone Age (MSA) human cultural innovations dating back to 200 ka (Backwell et al., 2018). The cave was recently revisited to gain a more refined understanding of the archaeological finds from the excavations conducted between 1940 and 1978 (Backwell et al., 2018). Central to the aim of the current investigation is the need to clarify the spatial and temporal context for the evolutionary milestones and innovations for which the site is known. This paper provides the palaeoenvironmental context and vegetation his-tory of the site's occupation and the introduction of Howiesons Poort lithic technology during a critical point in the late Pleistocene. The Howiesons Poort lithic industry at Border Cave began ca. 74 ka at the time when global climate was undergoing a gradual transition from Marine Isotope Stage (MIS) 5 to MIS 4, a period of many environmental upheav-als, including the super-eruption of Mount Toba in Indonesia (Ambrose, 1998). This period, therefore, begs for a careful assessment of the key elements that played a role in shaping the landscape on which people lived. In this study, wood charcoal is studied to identify the taxa of the remnant trees and inter-pret the environment under which late Pleistocene vegetation grew. In addition, the patterns of use of wood/vegetation by human groups who visited the cave will also be determined.

Charcoal remains are recovered in abundance from many MSA archaeological sites and are used, in conjunction with other environmental prox-ies, to reconstruct past climates, vegetation histo-ries, and evidence of wood use (Cartwright, 2013; Cartwright et al., 2014; Esterhuysen & Mitchell, 1996 ; House & Bamford, 2019; Lennox & Bam-ford, 2015). Anthracological studies have focused intensely on using wood anatomy to describe broad changes in climate and vegetation, taking full advantage of the sensitivity of the species-diverse woody vegetation to the many climatic zones of southern Africa (Allott, 2006; Cartwright et al., 2014; Esterhuysen et al., 1999; Lennox & Wadley, 2019). This is allowed by the adaptive traits of trees that make each species thrive in a limited range of climatic conditions and, therefore, make them excellent climate proxies. Anatomical traits of some species, such as vessel diameter and growth rings, can also be used to understand fluctuations in rain-fall in temperate regions (Limier et al., 2018; Ter-ral & Mengual, 1999). The same method has been recommended in southern Africa using *Combretum apiculatum* and *Protea caffra* (February, 1993).

A qualitative analysis of charcoal in southern Africa was recently conducted by the authors using charcoal from Sibudu Cave (Zwane & Bamford, 2021). This study proved that, apart from wood microfeatures, there are environmental attributes or traces of microorganisms that may have been pre-served in the wood structure. These may inform about tree mortality and the enduring microclimatic condi-tions that did not necessarily alter vegetation makeup. These details are seldom preserved in other botani-cal remains and increase the potential for charcoal to answer a wide range of questions about past human-plant-environment interactions, notwithstanding the biases that are introduced by the wood selection, thermal decomposition, site formation, and tapho-nomic processes. (Chrzazvez et al., 2014; Marston, 2009; Théry-Parisot et al., 2008). Therefore, a quali-tative approach is applied in this study to assess for wood degradation and evidence of wood-dwelling organisms that could inform about the immediate environment of the landscape near the site. These may be interpreted from structural deformation,

non-anatomical residues, and non-organic inclusions in the wood structure of the trees.

Site Setting and Excavation

Border Cave is situated at the bottom of the eastern escarpment of southern Africa at the border of South Africa (KwaZulu Natal Province) and Eswatini (Swaziland). The cave, located 82 km from the Indian Ocean, is carved into a cliff that towers 678 m above sea level (Fig. 1). It was formed in the Lower Juras-sic volcanic rocks, named the Jozini Formation of the Lebombo Group (Backwell et al., 2018). The vegeta-tion near the site is suited to tropical climatic condi-tions (Mucina & Rutherford, 2006). These are mostly trees, shrubs, climbers, and grasses that make up the closed, wooded habitat of the southern Lebombo Mountains. The topography of the cave locality is a steep, leeward slope of the mountains and, therefore, subject to the rain shadow of the orographic precipi-tation that is promoted by the warm currents of the Indian Ocean (Beal et al., 2011). The contemporary vegetation around the cave belongs to the Lowveld unit of the Savanna Biome and currently features small patches of forests at some distance from the cave (Mucina & Rutherford, 2006).

There are approximately 300 woody plant spe-cies that have been noted near Border Cave since the 1970s. These include 214 species identified by John Anderson (Beaumont, 1978) and more than 60 identified by other botanists (Backwell et al., 2018; Mucina & Rutherford, 2006). Some of the most common woods include many species that belong to these families: Fabaceae, Anacardiaceae, Combreta-ceae, Euphorbiaceae, and Ebenaceae (Backwell et al., 2018; Beaumont, 1978; Mucina & Rutherford, 2006). The overrepresentation of the taxa in these families may be driven by the influence of the prevailing cli-matic conditions on the landscape, as is common with many vegetation communities of southern Africa.

Previous excavations (1940–1970) revealed three distinct lithic technologies in the MSA sequence and are originally termed the Pietersburg, Epi-Pieters-burg, and post-Howiesons Poort (Beaumont, 1978; Cooke et al., 1945). These have been re-classified into the early MSA (MSA1), Howiesons Poort, and post-Howiesons Poort Industries (Backwell et al., 2018; Lombard et al., 2012). The industries were recovered from the archaeological deposit with alternating sand

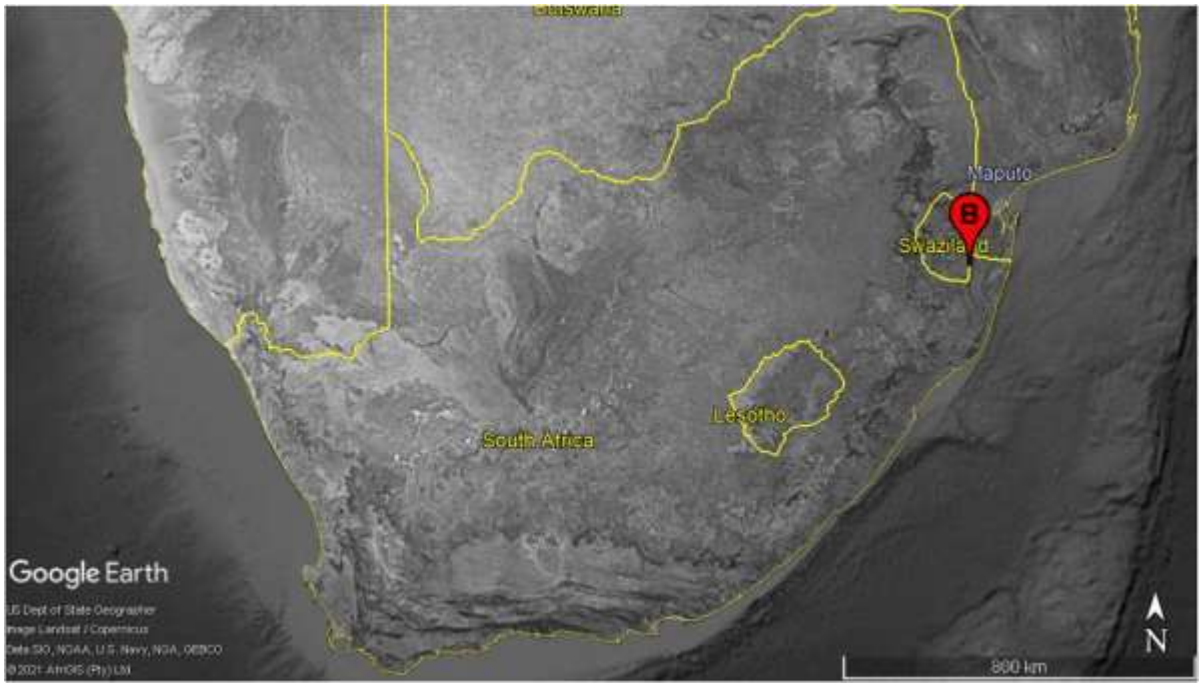


Fig. 1 The location of Border Cave in southern Africa along the border of South Africa and Eswatini (Swaziland)

and ash layers/members dated between 44 and 220 ka (Backwell et al., 2018; Grün & Beaumont, 2001). Since Beaumont's (1978) excavation, these members have been carefully re-excavated following their natural stratigraphy and named after the texture and color of their dominant sediments (Backwell et al., 2018). The first Rubbly Grey-Brown Sand (1RGBS) member is lodged underneath the third White Ash member (3WA) and lies on top of the fourth Brown Sand member (4BS). The sediments of member 1RGBS, dated through Electron Spin Resonance (ESR) to ~ 74 ka, are dominated by brown sand-sized particles that accumulated at a lower rate than those of member 3WA (64 ka) above, however, at a similar rate to the preceding member 4BS (77 ka) (Backwell et al., 2018; Beaumont, 1978; Grün & Beaumont, 2001).

The occupational phase corresponding to mem-ber 1RGBS marks the beginning of Howiesons Poort lithic industry, a technology that continued until 64 ka, i.e., in 3WA (d'Errico & Backwell, 2016). During Cooke et al.'s (1945) excavation of the site, remains of an anatomically modern human infant were recovered with grave goods from member 1RGBS (d'Errico & Backwell, 2016). These repre-sent the earliest known evidence for funerary prac-tices involving symbolic behavior in Africa (Cooke et al., 1945; d'Errico & Backwell, 2016; Rightmire et al., 1979). Despite yielding a well-preserved infant skeleton and the Howiesons Poort lithic industry, lit-tle is known about the environment associated with the deposition of member 1RGBS. The marine gas-tropod shells, *Conus ebraeus*, which were buried with the infant and identified as ornaments/grave goods, suggest the presence of warm ocean waters in the nearby Indian Ocean (d'Errico & Backwell, 2016). These warm conditions complement the warm sea surface temperatures that have been interpreted from $\delta^{18}O$ of the foraminifera from the coast of Mozam-bique (Caley et al., 2011) as well as warm and dry terrestrial conditions at the end of MIS 5a, previously suggested through the analysis of soil sediments from the cave (Butzer et al., 1978).

New excavations at Border Cave, which yielded the charcoal materials discussed in this article, com-menced in 2015 under the directorship of Lucinda Backwell, Francesco d'Errico, and Lyn Wadley. The charcoal remains were recovered from 1RGBS with many artifacts that were deposited anthropogenically, including lithic tools, faunal remains, shell frag-ments, and botanical remains. There are also naturally deposited soil sediments and fragmented cave spall. These are all valuable materials from which cultural and environmental data can be interpreted (Backwell et al., 2018; Beaumont, 1978). These findings indi-cate that, like the occupants at different times during the MSA, the makers of the Howiesons Poort lithic technology foraged over a wide range of habitats and had complex economic, ethical, and esthetic systems (Backwell et al., 2018; Beaumont, 1978).

Evidence for the exploitation of plants at the site date as far back as 200 ka in the form of combus-tion features, including the earliest evidence for the use of grass bedding (Wadley et al., 2020a) and the consumption of cooked geophytes at 170 ka (Wadley et al., 2020b). The transition between the different MSA lithic technologies and their respective foraging strategies provides an important insight into modern human behavioral evolution, comparable with other MSA human activities in Africa (Backwell et al., 2018; Beaumont, 1978; d'Errico & Backwell, 2016). Furthermore, the temporal and environmental settings of these MSA contexts provide a way to understand behavioral trends that may have responded to stresses experienced on a local and global scale, including significant major climatic events.

Methods and Materials

Charcoal fragments were excavated from member 1RGBS in 2018 and 2019. Fragments were sub-sampled into a smaller assemblage, systematically chosen from different size classes ranging from ~ 0.3 to 2.5 cm. The appearance of new taxa was tracked using the cumulative frequency or saturation curve (Fig. 2). Charcoal fragments were manually frac-tured for microscope analysis, carefully exposing the three sections: Transverse section (TS), Tangential Longitudinal Section (TLS), and Radial Longitudi-nal Section (RLS), for a detailed study of the micro-anatomy of wood (Wheeler et al., 2007). The wood microstructure was examined using an Olympus light stereomicroscope fitted with objective lenses, up to 500 × magnification. The Olympus Image Analysis software was used for taking digital photographs, counting, and measuring microfeatures.

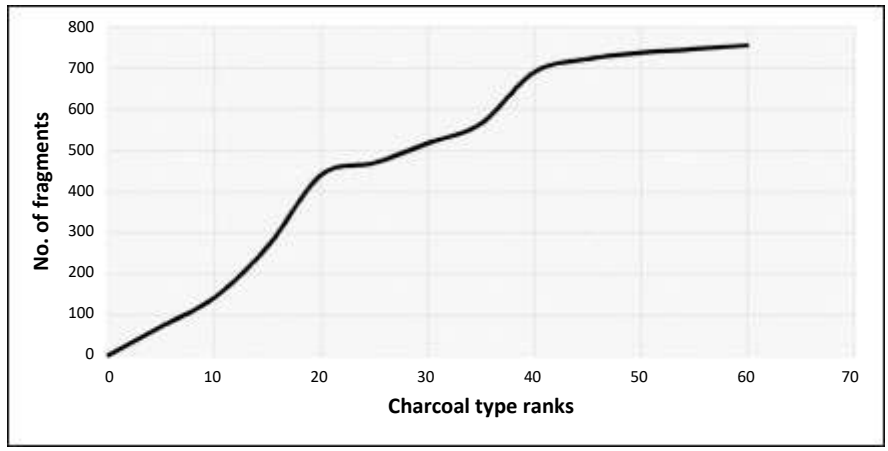


Fig. 2 The cumulative frequency of charcoal fragments against the types/taxa from member 1RGBS of Border Cave

All the charcoal fragments were captured digi-tally, and their micrographs are kept at the Evolu-tionary Studies Institute's database. The taxonomic identification of wood remains was made following the standard procedure recommended by the Inter-national Association for Wood Anatomists (IAWA) as well as by comparison with many different species from southern Africa (Dechamps, 1993; Kromhout, 1975), including those in the InsideWood online data-base (https://insidewood.lib.ncsu.edu). The Evolu-tionary Studies Institute herbarium houses more than 600 woody specimens collected from many parts of southern Africa and representing more than 400 dif-ferent woody species. Most of these species were collected by various researchers from many parts of southern Africa (Allott, 2005; Chikumbirike, 2014; Zwane, 2018) and included more than 30 species recently collected by Sandra Lennox, University of the Witwatersrand, from the vicinity of Border Cave.

Most charcoal studies in southern Africa have refrained from quantifying woody species identified in an assemblage based on the number of charcoal fragments analyzed. Instead, they have opted to use the presence of species (or a group of species) which are indicative of vegetation communities, a method that works best for the diverse flora of southern Africa (Cartwright & Parkington, 1997; Cartwright et al., 2014; Esterhuysen & Mitchell, 1996; Febru-ary, 1992; Lennox & Wadley, 2019). For example, Cartwright has rejected the idea that the number of charcoal fragments can indicate relative abundance of different species present or even collected in the past (Cartwright & Parkington, 1997). The fragment abundance of some species over others can, however, be statistically relevant, as demonstrated by Febru-ary (1992), provided that sampling methods include wood fragments of all sizes in an assemblage (Byrne et al., 2013; Dotte-Sarout et al., 2014). It has been proven that the relative abundance of fragments could reflect the relative abundance of species, regardless of individual species' wood properties. However, this has not been accepted by all researchers. Experi-mental work supporting this suggestion showed that despite differences in physical characteristics of wood, archaeological charcoal assemblages reflect the record of the woody species originally burned, although the least represented/collected woods are most likely preserved through very small fragments (Byrne et al., 2013; Dotte-Sarout et al., 2014). Such studies have contributed toward estimating a mini-mum number of fragments required for analysis to achieve a representative sub-set, especially in regions with a temperate climate.

In southern Africa, the minimum number of frag-ments needed for a representative charcoal sample has not been determined. This problem is compli-cated by the fact that even when using saturation curves to sub-sample a representative assemblage, a clear plateau of the curve is barely reached in south-ern Africa, as in other regions with high species diversity (Fig. 2; Dotte-Sarout et al., 2014; Zwane & Bamford, 2021). Nevertheless, such studies are needed, first, to standardize charcoal analyses with international norms and consider the unique diversity of major vegetation communities in the subcontinent; and second, to determine an accurate measure of eco-logical representativeness of woody vegetation in the past. Overall, these studies are useful for interpreting

the abundance of some taxa over others based on fragment frequencies in archaeological contexts. This quantitative interpretation method is used alongside the species presence/absence approach to interpret the results of the charcoal dataset from Border Cave.

Results

Sample Reliability and Taphonomy

So far, new excavations have removed about 77 L of archaeological sediments from 1RGBS and yielded more than 3000 charcoal fragments from which the assemblage in this study was subsampled. These fragments come from three squares (N108 E117; N108 E116, and N109 E117), each measuring approximately 1×0.5 m. The member 1RGBS comprises two sub-layers: FAAN, from which 68.5 L of archaeological deposit were removed, and lies stratigraphically below FEBA, whose deposit comprises only 8.5 L (Lucinda Backwell, email corre-spondence, 18 November 2020). Layer FEBA had 942 charcoal fragments from which 296 were subsampled; while 600 were subsampled in layer FAAN with a total of 2,252. Most charcoal fragments were very well preserved and could be studied in detail for taxonomic identification. Only 141 samples were too small, or pith, knot, and crum-bly fragments, and could not be identified taxonomically. The remaining 755 samples were grouped into 57 taxa/ types based on the similarities in their wood microstruc-ture. Approximately, 65% (n =37) of these types were identified to genus or species (Table 1 and Supplemen-tary Material). Charcoal fragments in this study were not recovered from hearths or fireplaces; instead, they repre-sent disturbed hearth debris from many burning events in the cave scattered over the excavated area (Théry-Parisot et al., 2008). This assemblage gives a more representa-tive subset of woody vegetation that was collected and burned during many different occupational periods, prob-ably across several decades leading to 74 ka, rather than a few burning events that are commonly marked by intact hearths (Dotte-Sarout et al., 2014; Théry-Parisot et al., 2008).

Charcoal fragments per type/taxa ranged between 1 and 123 and had a mean of 13 fragments per type/ taxon (Table 1). Two outliers stood out: *Tarchonanthus* sp. and *Euphorbia* sp. 1 with 123 and 80 fragments, respectively. The over-representation of the two species suggests that they were collected more than others in the past. Six species: *Brachylaena huillensis*, *Colophospermum mopane*, *Combretum krausii*, *Euphorbia* sp. 2, *Ozoroa paniculosa*, and *Searsia lancea* were identified only from sub-layer FAAN, while *Protea* sp. 1 and *Sterculia rogersii* were restricted to FEBA (Fig. 3). This distribution pat-tern could be a direct consequence of the duration or rate of sediment accumulation of the sub-layers since FAAN is significantly thicker than FEBA (Lucinda Backwell, email correspondence, 18 November 2020). The implication of this is that the cave was occupied more frequently or over a longer period during the deposition of FAAN than FEBA. There were 29 species that were common to both FEBA and FAAN sub-layers, but more fragments within each species were found in FAAN than in FEBA, perhaps, due to depositional bias (Fig. 3).

The Identification of Euphorbia Species

Comparative Euphorbia tirucalli and Archaeological Euphorbia sp. 1 (Type 37)

Wood samples of *E. tirucalli* were collected by Lennox (SJL171) near Border Cave and, with permission, carbonized by the authors. The description of wood anatomical features of this specimen compares very well with a description of the same species on InsideWood. On the Traverse Section (TS), the vessel arrangement is mostly solitary and has few short radial multiples; the fibers are distinctly thin, and the parenchyma cells are diffuse (Fig. 4a). On the Radial Longitudinal Sec-tion (RLS), the ray cells of this species are mixed throughout (Fig. 4b). When observed from the Tan-gential Longitudinal Section (TLS), the rays are uni-seriate to triseriate, and the width of the biseriate and triseriate portions is the same as that of the uniseriate cells (Fig. 4d). The length of these rays varies; how-ever, they are generally less than 1 mm. The character-istic presence of laticifers or latex tubes was noted in the enlarged parts of the rays, indicated by an arrow in Fig. 4c, a common phenomenon in species belonging to the genus *Euphorbia* (Mennega, 2005).

In archaeological charcoal fragments identified to *Euphorbia* sp. 1 (Type 37), vessels are arranged more often in short radial multiples than solitarily on the TS (Fig. 5a). The TS surface is also distinctly defined by thin fibers and diffuse parenchyma cells. The upright, procumbent, and square ray cells of

Table 1 The list of species identified from Border Cave show-ing the taxa and number of the identified types, the total num-ber of charcoal fragments per taxon, the number of fragments in each sub-layer; as well as fragments with radial cracks, brown deposits, white deposits, and blue-yellow stains in the wood structure per taxon. Cf. marks the species or genera that were identified with less certainty

Taxa		Type no	Total no. fragments	Sub-layers		Frag-ments w/ cracks	Fragments w/ brown deposits	Fragments w/ white deposits	Frag-ments w/ stains
Species and author-ship	Family			FEBA	FAAN				
Allophylus sp.	Sapindaceae	39	3	2	1	0	1	0	0
Apodytes dimidiata E.Mey. ex Arn	Icacinaceae	26	10	4	6	1	2	0	0
Brachylaena cf. *discolor* DC	Asteraceae	34	11	3	8	8	0	0	0
Brachylaena huil-lensis O.Hoffm	Asteraceae	50	2	0	2	0	2	0	0
Chionanthus bat-tiscombei (Hutch.) Stearn	Oleaceae	19	24	12	12	1	8	0	3
cf. *Chionan-thus foveolatus* (E.Mey.) Stearn	Oleaceae	4	5	2	3	2	0	0	0
Colophospermum mopane (J.Kirk ex Benth.) J.Kirk ex J.Léonard	Fabaceae	57	2	0	2	1	1	0	1
Combretum krausii Hochst	Combretaceae	56	7	0	7	0	1	1	2
Dichrostachys cinerea (L.) Wight & Arn	Fabaceae	43	7	2	5	1	1	0	0
Diospyros dichro-phylla (Gand.) De Winter	Ebenaceae	9	35	13	22	2	19	1	8
Diospyros natalensis (Harv.) Brenan	Ebenaceae	46	4	1	3	1	0	0	0
Euphorbia sp. 1	Euphorbiaceae	37	80	13	67	1	51	5	15
Euphorbia sp. 2	Euphorbiaceae	48	2	0	2	0	0	0	1
Gymnosporia nemorosa (Eckl. & Zeyh.) Szyszyl	Celastraceae	33	3	1	2	0	0	0	1
cf. *Heywoodia lus-cens* Sim	Phyllanthaceae	2	19	7	12	0	3	0	1
Lannea discolor (Sond.) Engl	Anacardiaceae	38	9	3	6	0	3	0	4
Maytenus sp.	Celastraceae	36	24	13	11	7	2		2
Mystroxylon aethi-opicum (Thunb.) Loes	Celastraceae	14	6	3	3	0	1	0	0
Ozoroa cf. *panicu-losa* (Sond.) R.Fern. & A.Fern	Anacardiaceae	44	6	0	6	2	0	0	1
Podocarpus/ Afro-carpus sp.	Podocarpaceae	20	14	7	7	0	0	0	2

Table 1 (continued)

Taxa		Type no	Total no. fragments	Sub-layers		Frag-ments w/ cracks	Fragments w/ brown deposits	Fragments w/ white deposits	Frag-ments w/ stains
Species and author-ship	Family			FEBA	FAAN				
Protea cf. *roupelliae* Meisn	Proteaceae	41	3	2	1	0	0	0	0
Protea sp. 1	Proteaceae	22	1	1	0	0	0	0	0
cf. *Protea* sp. 2	Proteaceae	49	2	1	1	0	0	0	2
cf. *Rauvolfia caffra* Sond	Apocynaceae	5	19	8	11	3	6	3	2
Sclerocarya birrea (A.Rich.) Hochst	Anacardiaceae	32	11	4	7	3	1	1	6
Searsia chirindensis (Baker f.) Moffett	Anacardiaceae	55	2	1	1	0	0	0	0
Searsia lancea (L.f.) F.A.Barkley	Anacardiaceae	47	4	0	4	1	2	0	2
Senegalia ataxacan-tha (DC.) Kyalan-galiwa & Boatwr	Fabaceae	25	9	2	7	0	3	0	2
Senegalia caf-fra (Thunb.) P.J.H.Hurter &Mabb	Fabaceae	42	8	1	7	1	1	1	1
Senegalia sp.	Fabaceae	3	17	4	13	2	0	3	1
Sterculia sp.	Sterculiaceae	24	1	1	0	0	1	0	0
Tarchonanthus sp.	Asteraceae	18	123	38	85	59	4	5	13
Vachellia robusta (Burch.) Kyalan-galilwa & Boat-wright	Fabaceae	40	9	2	7	1	1	0	1
Vachellia sieberiana (DC.) Kyal. & Boatwr	Fabaceae	1	11	5	6	1	5	1	1
Vachellia sp. 1	Fabaceae	12	4	3	1	0	3	0	1
Vachellia sp. 2	Fabaceae	23	6	2	4	0	4	1	3
Vachellia tortilis (Forssk.) Gallaso & Banfi	Fabaceae	31	10	1	9	0	3	1	0
Undetermined types/ fragments	Undetermined	-	231	107	135	47	37	14	39

this specimen on the RLS are mixed, i.e., irregu-lar cell arrangement throughout the rays (Fig. 5b). These rays appear mostly uniseriate and biseriate on the TLS; and similar to *E. tirucalli*, the widths of biseriate portions are equal to the uniseriate cells of the rays (Fig. 5d). Laticifers or latex tubes (arrow in Fig. 5c) were also noted in the fragments belonging to this type in the archaeological assemblage.

Three dissimilarities were noted between the comparative sample of *E. tirucalli* and the archaeological *Euphorbia* sp. 1. The first is the vessel arrangement on the TS (i.e., abundance of solitary vs. short radial multi-ple). Secondly, the average ray length (i.e., the ray height in both samples) varies from<0.5 to 1 mm (Figs. 4d and 5d). In contrast, a reliable description of *E. tirucalli* on InsideWood records that the ray height of this species

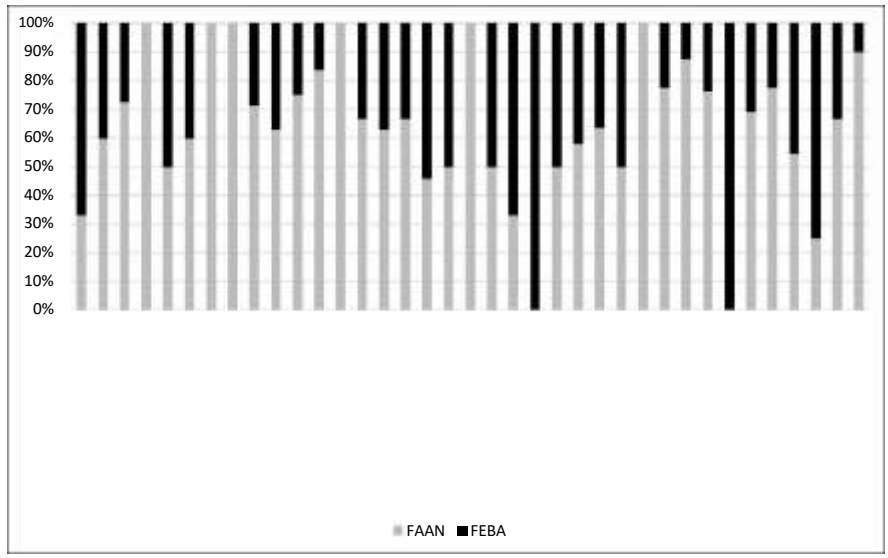


Fig. 3 The abundance of species in sub-layers FAAN and FEBA within member 1RGBS

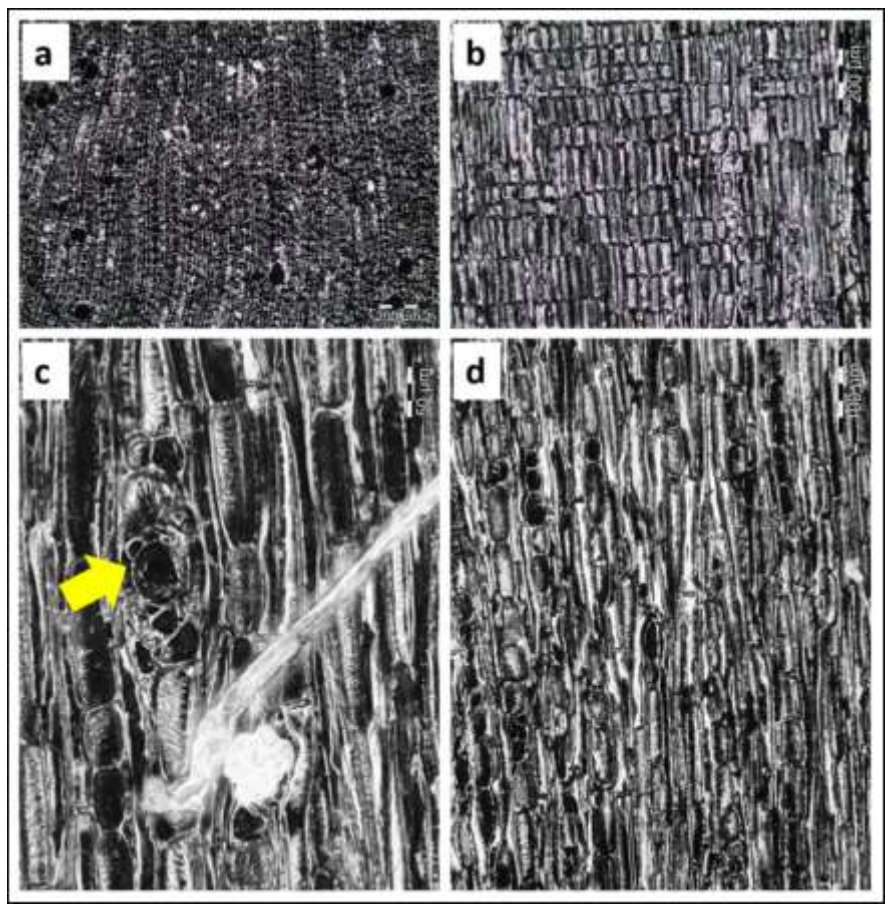


Fig. 4 The micrographs of *Euphorbia tirucalli* from the modern Border Cave landscape showing the wood anatomy along the TS (**a**), TLS (**b**), and RLS (**c**, **d**). Scale bar on (**a**) and (**b**) = 200 µm, (**c**) = 50 µm, and (**d**) = 100 µm

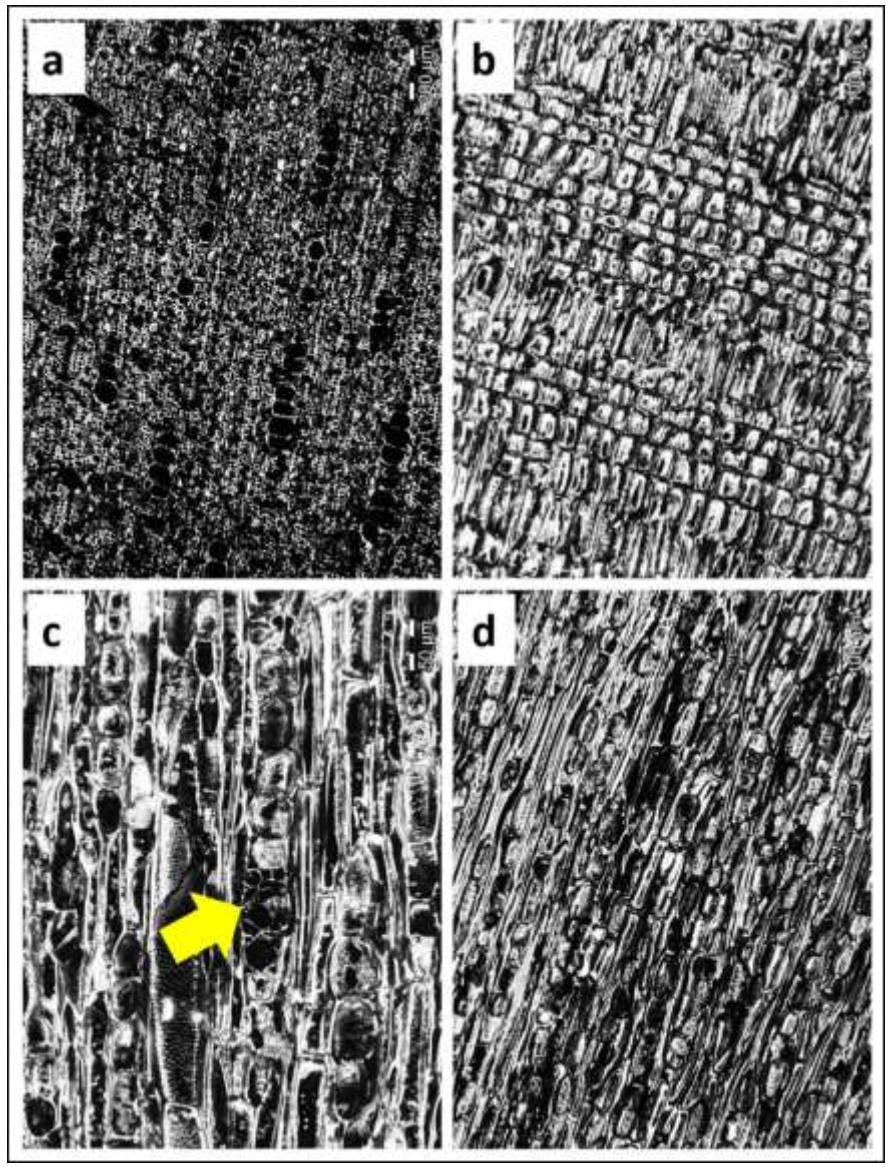


Fig. 5 The micrographs of *Euphorbia* sp. 1 from the archaeological Border Cave landscape showing the wood anatomy along the TS (**a**), RLS (**b**), and TLS (**c**, **d**). Scale bar on (**a**) = 200 µm, (**b**) and (**d**) = 100 µm, and (**c**) = 50 µm

may reach up to>1 mm. The third dissimilarity was the presence of prismatic crystals in the fibers of *E. tirucalli*, not noted in the archaeological specimens of *Euphorbia* sp. Prismatic crystals occur in many genera of Euphor-biaceae, including *Spirostachys* (Lennox & Bamford, 2015), but they were not visible in the archaeological specimens in question. Nevertheless, this taxonomic identity was confirmed based on many similarities that the archaeological fragments of this second most abun-dant archaeological type share with the general descrip-tion of some *Euphorbia* species.

Euphorbia sp. 2 (Type 48) in Archaeological Assemblages

The 48th type in the archaeological assemblage was identified to *Euphorbia* sp. 2 following the description of *E. candelabrum* on InsideWood and Mennega (2005). The most important wood microfeatures found in this species include less frequent (5–20/mm^2), wide (100–200 µm), and long vessels (350–800 µm), which have large gash-like or scalariform inter-vessel pits (Fig. 6a–c). These occur

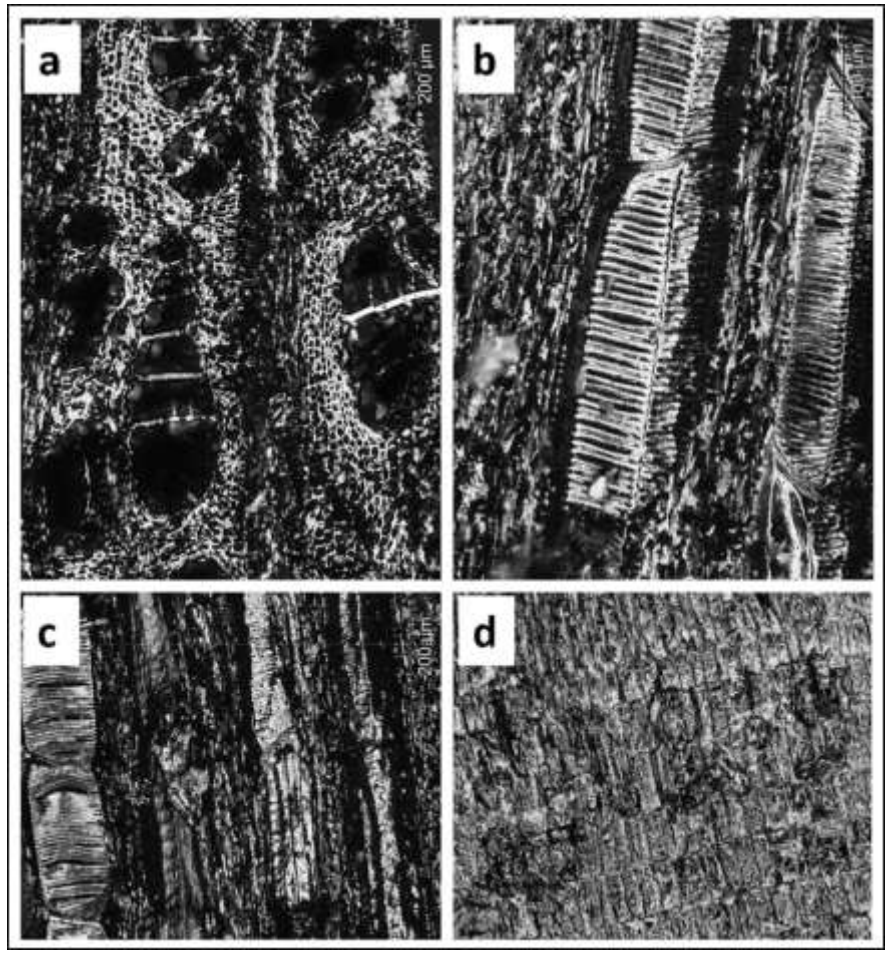


Fig. 6 The wood anatomy of archaeological fragment belonging to *Euphorbia* sp. 2 showing the TS (**a**, **c**), TLS (**b**), and RLS (**d**). Scale bar on (**a**, **c**) = 200 µm and (**b**, **d**) = 100 µm

with exclusively uniseriate and short rays (< 0.5 mm) whose cells are homocellular upright on the RLS (Fig. 6d). The authors did not study comparative specimens of this species. However, the descriptions published by the two sources were enough to confirm that there may be a second *Euphorbia* species in the archaeological dataset. This is based on the presence of important vessel and ray characteristics, including scalariform inter-vessel pits similar to those found in some *Euphorbia* species such as *E. ingens*.

Vegetation Communities Represented by the Species

Four vegetation communities were identified from the charcoal types/species in the archaeological Border Cave landscape. These are, in the order of dominance, Bushveld (43.5%), Forest (36%), Grassland (18%), and Scrubland (2.5%) communities (Fig. 7). These communities are based on the modern distribution of the species. Therefore, it is possible that scrubland vegetation did not comprise a significant portion of the vegetation near the cave because it is so scarcely represented in this fraction of archaeological woody vegetation.

Wood Vessel Occlusion by Unknown Residues

A significant proportion of fragments in many different charcoal types had strange residues of different colors and textures, mostly inside vessel elements. These residues were recorded in three categories: brown deposits, white deposits, and blue-yellow stains (Table 1). Brown residues are always found deposited inside wood vessels where they appear like a stringy mass and sometimes granular. These residues were observed in 166 frag-ments belonging to 39 types/species (Fig. 8). Most of the fragments (63%) belonging to *Euphorbia*

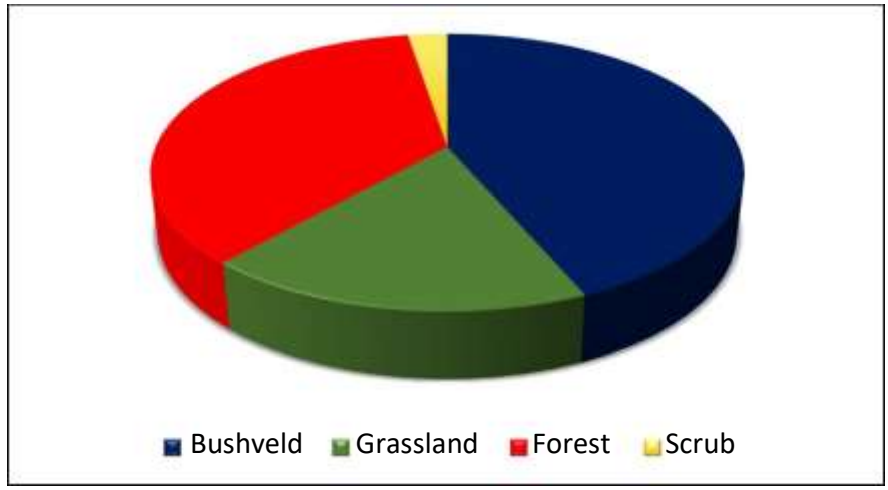


Fig. 7 The proportions of all vegetation communities in member 1RGBS

sp. (Type 37) contained much of the brown depos-its (Fig. 9a). White residues were noted and often appear like a solid mass inside the vessels of 32% of all 57 taxa (Figs. 8 and 9b) . Blue-yellow stains were also seen in the vessels and tyloses of spe-cies such as *Sclerocarya birrea*, and in the phloem of *Combretum krausii* (Fig. 9c). Except for blue-yellow stains, the brown and white residues were restricted to some growth rings/growth phases of the woody vegetation in this assemblage (Fig. 9a and b). The nature of these deposits in the wood is not yet fully understood, but it is possible that they were produced sporadically by the trees and shrubs or by other unknown organisms in the habitats of the different species. Insect burrows containing insect frass were also present in seven fragments that belong to four types/species in this dataset.

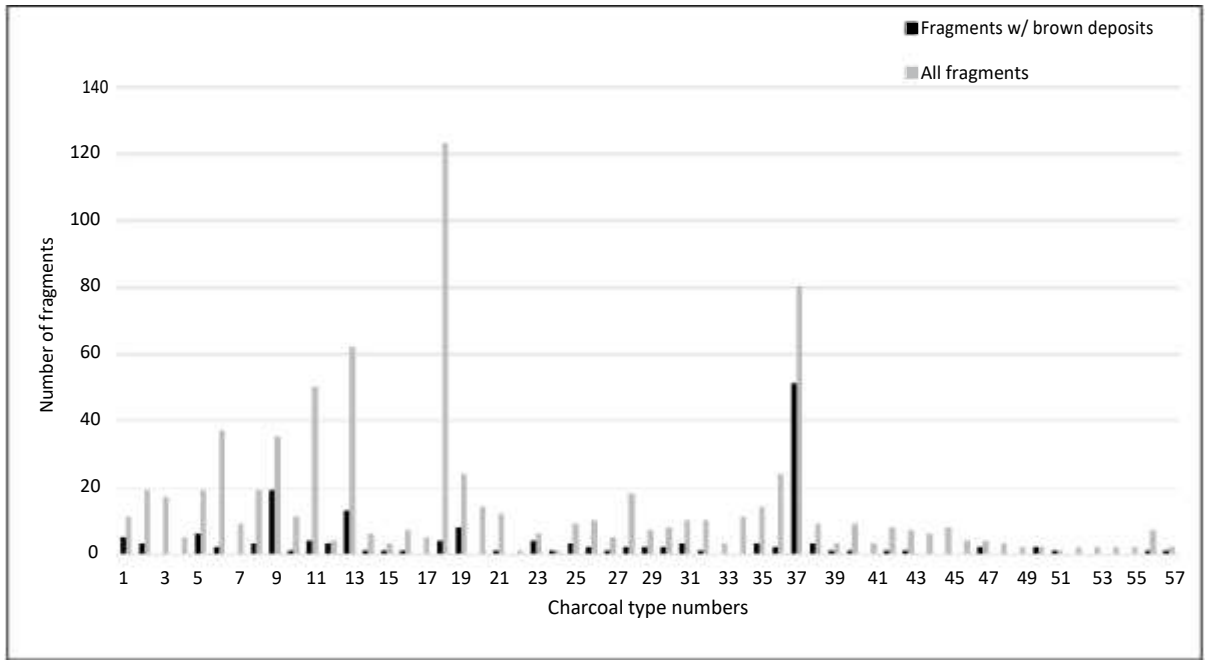


Fig. 8 The abundance of fragments with brown deposits inside vessels and the total number of fragments per type

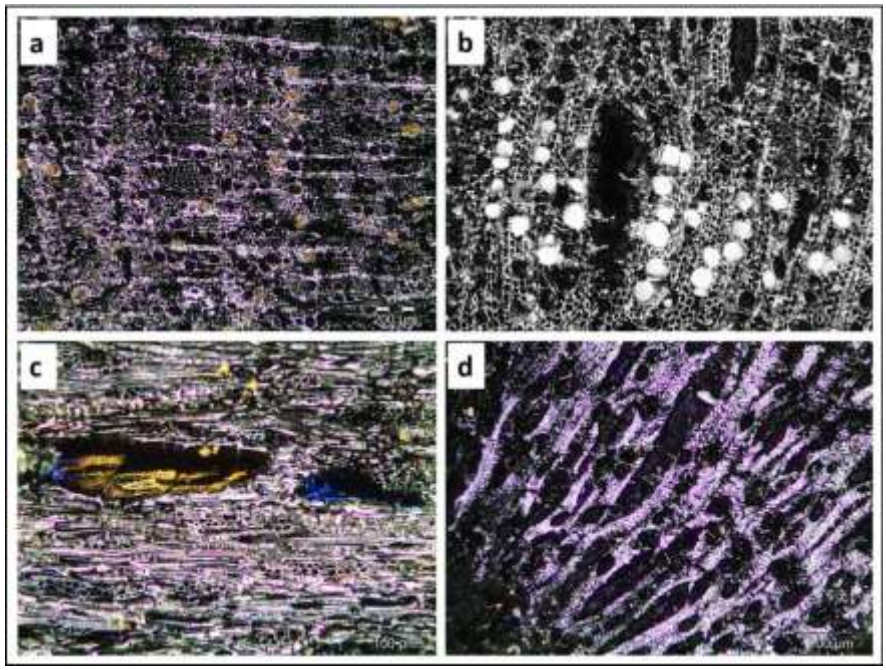


Fig. 9 Examples of wood fragments containing brown deposits (**a**), white deposits (**b**), and blue-yellow stains (**c**) in vessels of the wood, and an example (**d**) of radial cracks viewed on the TS. Scale bar on (**a**) = 200 µm, (**b**, **c**), and (**d**) = 100 µm

Radial Cracks

Radial cracks were also noted in the fragments of 26% of the 57 taxa (Fig. 9d). These linear openings/cracks along wood rays are formed under unique conditions that possibly depended on many factors, such as exposure to heat, but are always directly related to moisture contained in the wood (Caruso Fermé et al.,

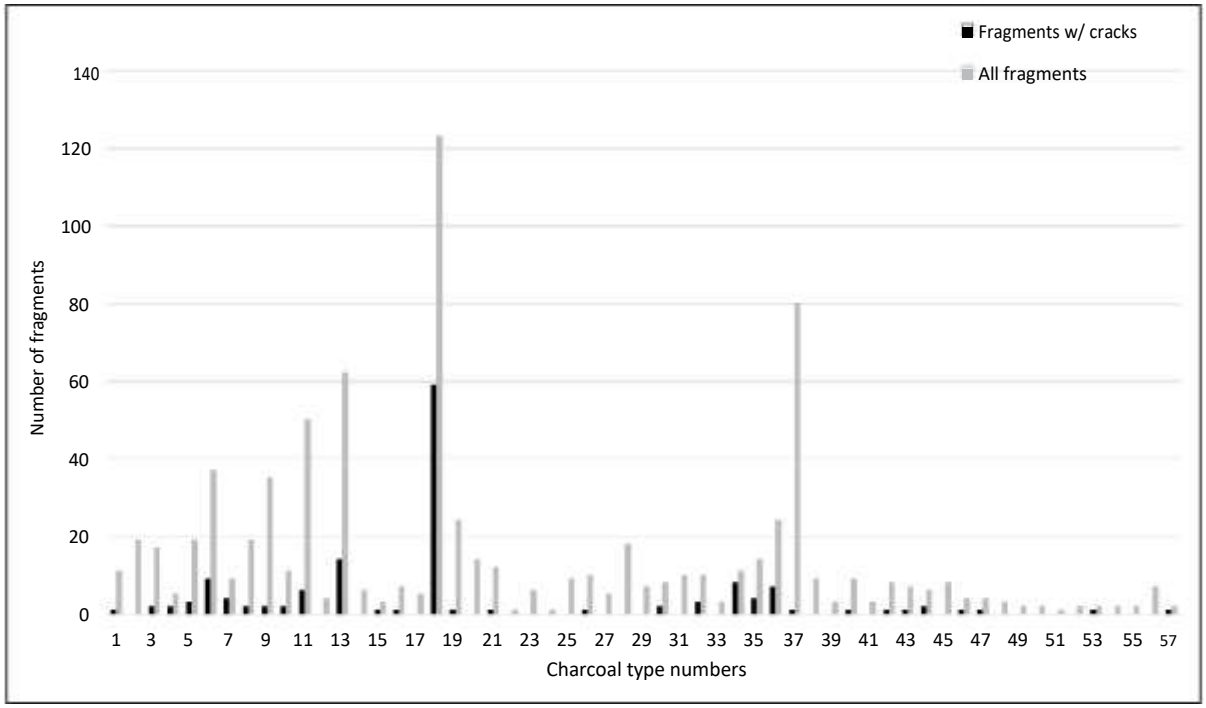


Fig. 10 The abundance of fragments with cracks and the total number of fragments per type

2018). When moisture is heated in the wood, there is a rapid increase in temperatures; pressure builds within and is released through the weak zones, commonly through ray parenchyma (Caruso Fermé et al., 2018; Théry-Parisot et al., 2010). This phenomenon is commonly associated with wood containing high amounts of moisture, such as freshly harvested or greenwood. Some species in this assemblage, including *Tarchonanthus* sp., have fragments whose wood logs were possibly burned as greenwood (Fig. 10).

Discussion

The Bushveld vegetation, otherwise known as Savanna Biome vegetation, grows on diverse habitats and soil substrates that receive varying amounts of precipitation. These vegetation communities are divided into many units and are described by Mucina and Rutherford (2006). At Border Cave, two Lowveld Savanna units (SVl 16 and 17) domi-nate the modern landscape, but there is also some montane forest vegetation. It appears that more Savanna vegetation communities are present due to many changes in the climate, which allowed for the growth and expansion of different species. Approximately 43% of the species identified at Border Cave 74 ka, including seven different *Senegalia* and *Vachellia* species (formerly known as *Acacia*), are characteristic Savanna woods. Through these species, three Savanna vegetation units were recognized: Mopane, Sub -escarpment, and Lowveld. The Mopane (SVmp 2) unit, currently found several kilometers west of the site, is represented by *Sclerocarya birrea*, *Colophospermum mopane*, *Vachellia tortilis*, and *Sterculia rogersii*. The Sub -escarpment (SVs) is signified by *Vachellia tortilis*, *Sclerocarya birrea, Dichrostachys cinerea*, *Combretum* species, and several *Euphorbia* species (Mucina & Rutherford, 2006). They suggest that favorable conditions for these taxa were much closer to the cave than today.

Taxa such as *Brachylaena discolor*, *Diospy-ros dichrophylla*, *Dichrostachys cinerea*, *Sclero-carya birrea*, and *Sterculia rogersii*, as well as spe-cies belonging to *Vachellia*, *Senegalia*, *Combretum*, *Euphorbia*, *Ozoroa*, and *Lannea* genera, are commonly found in many Lowveld (SVl) units as currently seen today (Mucina & Rutherford, 2006).

Forest vegetation types, Scarp and Lowveld river-ine forest, were noted in the Border Cave landscape. The Scarp Forest (FOz 5), which currently borders some Lowveld units of the Savanna Biome, was pre-sent in the archaeological landscape, as indicated by *Podocarpus*/*Afrocarpus* sp. and cf. *Heywoodia lucens* (Mucina & Rutherford, 2006). The Lowveld riverine forest (FOa1) is represented by cf. *Rauvolfia caffra* and has many species within the *Combretum*, *Vachellia*, *Senegalia*, and *Diospyros* genera (Mucina & Rutherford, 2006).

There was also a significant proportion of Grassland woods near Border Cave. *Tarchonanthus* sp., *Vachellia sieberiana*, and *Protea* cf. *roupelliae* are very important constituents of two Grassland units (i.e., Mesic Highveld Grassland, Sub-Escarpment Grassland) as well as the Savanna Biome (Central Bushveld and Lowveld) of southern Africa. The presence and abundance of these species in the archaeological landscape of Border Cave place the grassland vegetation a few kilometers closer to the cave in the past than it is today (Mucina & Rutherford, 2006). The vegetation in the lower sub-layer of 1RGBS, namely FAAN, has six taxa: *Brachylaena huillen-sis*, *Colophospermum mopane*, *Combretum krausii*, *Euphorbia* sp. 2, *Ozoroa paniculosa*, and *Searsia lancea* that are widely distributed over inland areas of the subcontinent. Most of these taxa are still found near the cave; however, they collectively suggest that the environment most favorable for their growth prevailed during the deposition of the lower parts of member 1RGBS.

Moreover, *Euphorbia* species are widespread in southern Africa and indicate that a wide range of species grew during the accumulation of FAAN sedi-ments but not during FEBA. Other species found in both sub-layers with a wide distribution in South Africa and the neighboring countries of Zimba-bwe, Botswana, Angola, Namibia, and Mozambique include *Dichrostachys cinerea*, *Lannea discolor*, *Vachellia sieberiana*, *Vachellia tortillis*, and *Sclero-carya birrea*. In total, more than 60% of the species in this dataset are distributed similarly on and above the escarpment. Thus, they signify that the vegetation cover of the archaeological landscape was more com-parable to that of the modern escarpment and plateau regions of the sub-continent than the coastal plain, which is represented by less than 20% of species, such as *Podocarpus/Afrocarpus* sp., cf. *Heywoodia lucens*,

Diospyros spp., and *Searsia chirindensis* (Mucina & Rutherford, 2006; van Wyk & van Wyk, 2013).

The above implies that there was more Savanna mixed with Grassland vegetation that grew within the foraging distance of the site, according to the Prin-ciple of Least Effort (Asouti & Austin, 2005). Most of the tree/shrub species in the dataset are known for the usefulness of their wood more than the other plant parts. For example, *Dichrostachys cinerea* is used today for firewood; and it has hardwood, a char-acteristic it shares with many other species in this dataset, such as *Colophospermum mopane*, *Searsia lancea*, and *Brachylaena discolor* (Coates-Palgrave, 1981; van Wyk & van Wyk, 2013). The hardness and durability qualities of these species make them good timber wood today and suggest that the MSA people favored these trees, perhaps, for making wooden arti-facts. Nine species identified in this dataset, includ-ing *Lannea discolor*, *Senegalia caffra*, and *Searsia chirindensis*, have known medicinal properties, while three species: *Sclerocarya birrea*, *Lannea discolor*, and *Vachellia tortilis* have nutritional value for which they are still harvested by people today (Coates-Pal-grave, 1981; van Wyk & van Wyk, 2013).

Many different types of camphorbush trees (*Tarchonanthus* sp.) are known for their strong medici-nal properties that are commonly extracted from the leaves, bark, and wood of these plants (Coates-Palgrave, 1981; van Wyk & van Wyk, 2013). The leaves are used medicinally and for cosmetics, and burning the leaves releases perfumed smoke that can repel insects (Lennox, 2016; van Wyk & van Wyk, 2013). Their wood is hard and durable; it is used to make wooden artifacts and can burn while wet. However, they are scarcely recorded as good fuelwood today (Gandar, 1982; van Wyk & van Wyk, 2013). The knowledge about the usefulness of these trees may indeed date back to the MSA in southern Africa, based on the presence of wood charcoal remains of *Tarchonanthus parvicapitulatus* in a hearth at Sibudu Cave, dated to 50–60 ka (Lennox, 2016). The abundance of the camphor bush tree fragments at Border Cave sug-gests that it was harvested/collected for many uses and hence was constantly sought after more than other spe-cies. It is also likely that it was burned/discarded in the fire as greenwood, perhaps after different plant parts were used, based on the presence of radial cracks in wood fragments of this plant.

Almost half of the total number of fragments (ratio = 0.48) of *Tarchonanthus* sp. have radial cracks and comprise some of the widest and most frequent cracks, indicating that most of the wood from this dataset plant was burned green. This high ratio is surpassed only by *B.* cf. *discolor*. However, this observa-tion and comparison may not be statistically signifi-cant since the fragments per taxa in this assemblage had a very wide range, possibly due to such factors as taphonomy and the thermal decomposition of wood logs originally collected in the past. Similarly, *Euphorbia* species generally have known medicinal uses. The latex of many *Euphorbia* species is poison-ous, has medicinal properties, and can repel or kill insects (d'Errico et al., 2012; van Wyk & van Wyk, 2013). However, like *Tarchonanthus* sp., this plant may have had uses in the MSA that are unknown today. For example, it is thought that the resin from *E. tirucalli* was used to bind a hafting material discov-ered in member 1BS-Lower during the Later Stone Age occupation of Border Cave (Beaumont, 1978; d'Errico, et al., 2012). Therefore, the use of this type of plant may have its origins in the MSA, and sug-gests the vast knowledge of it by the people and the availability of many different *Euphorbia* species close to the site.

The abundant presence of *Tarchonanthus* sp. and *Euphorbia* sp. 1 may hint at the need for these plants and their availability, favored by the environmen-tal conditions that allowed them to grow and mature enough for use. These and several others in this data-set are important trees of the Savanna and Grassland Biomes. Moisture regime, soil substrates, and tem-perature variation on the escarpment and plateau of the sub-continent, determining factors for the distri-bution of vegetation forms and taxa, are very variable in both Savanna and Grasslands today. The Mesic Highveld Grassland, Mopane, Sub-Escarpment, and some Lowveld Savanna vegetation units thrive in the interior parts of southern Africa, where they tol-erate extreme seasonality, including very high sum-mer temperatures, cold winters, and low precipitation levels. These conditions contrast with those found below the escarpment in the coastal areas (Mucina & Rutherford, 2006). The mountainous terrain of the Border Cave landscape experiences orographic pre-cipitation that promotes the growth of forest vegeta-tion on the Lebombo Mountains; therefore, the pres-ence of the montane forest at any period near the cave can be expected.

Despite the variable conditions to which the trees were suited at Border Cave, there may have been some unfavorable, or even hostile, conditions that resulted in the episodic or sporadic occurrence of vessel occlusion during certain growth phases of the woods in this dataset. These vessel deposits could be tyloses formed within the wood or even gums of organic origin that the plants secrete against aging or in response to freezing, drought, mechanical wounding, flooding, insect attack, or pathogen infection (De Micco et al., 2016; Schweingruber, 2007). Alternatively, they could be foreign substances, perhaps fungal remains, left in the wood cells only during the growing seasons when conditions were conducive for the associated unknown organisms to thrive in the habitats of the trees. The environmental conditions related to the production of these vessel deposits, however unknown, were not fatal to the trees because the growth phases (growth rings) with occluded vessels were followed by normal growth. There is also no clear relationship between vessel occlusion and vegetation communities; however, species such as *Euphorbia sp*. 1 and Type 9 had high ratios (0.64 and 0.54, respectively) of fragments occluded by brown vessel deposits.

Conclusion

During the deposition of member 1RGBS, the Bor-der Cave landscape featured a warm climate with variability in some microenvironmental parameters, which differed from one rainy season to another and were responsible for periodic vessel occlusion in some taxa in this dataset. The vegetation mosaic in this archaeological landscape featured the ever-present montane forest of the Lebombo Mountains, along with Savanna Biome and Grassland Biome vegetation types. The presence of grasslands implies that the environmental conditions near Border Cave were generally more comparable to those found in the inland areas of southern Africa—warmer and drier than the coastal areas below the escarpment. These conditions may have attracted many species that are currently not very common close to the cave today, including two *Euphorbia* species. *Tarchonanthus* sp., an important species of some Grassland and Savanna vegetation types in southern Africa, was collected most abundantly, presumably for many medicinal and cosmetic uses. This is also, most likely, because it was available in abundance. The woods of this species were also discarded into fires or burned as greenwood because they can burn while damp. Whether inten-tional or not, this practice allowed the MSA people to exploit the medicinal properties of this plant that are released through its fumes. Similarly, it appears the MSA occupants of Border Cave harvested *Euphorbia* species for uses unknown to us.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10437-021-09448-4.

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CHAPTER SIX – RESULTS FOR THE QUALITATIVE ASSESSMENT OF SELECTED SAMPLES FROM SIBUDU AND BORDER CAVES

6.1 Introduction

In this chapter, alternative approaches to analysing charcoal using the qualitative attributes of wood were attempted or expanded on from those presented in Chapter 4 and Chapter 5. This was done to supplement the results and interpretations that were achieved using a taxonomic identification of woody vegetation as presented in Chapters 4 and 5. This attempt was made to test whether there is additional data about the environment, wood growth and wood use both at Sibudu and Border Caves that could improve the results of the study.

The initial attempt sought to determine if wood structural changes could inform on unfavourable conditions that may have been experienced by the woody vegetation at anytime between 74 and 72 ka. This was investigated using the premise that the Toba volcano super eruption may have had negative effects on vegetation growth globally, as hypothesised by the Toba Catastrophe Theory, i.e. see Chapter 2, Section 2.1. If these conditions were present in southern Africa, woody vegetation would be stunted from developing properly, i.e., will exhibit reduced widths of wood logs due to slowed growth rate of the vegetation for the duration of the unfavourable effects that the volcanic event has on climate and local weather systems.

When woody vegetation is subjected to extreme reduction in the annual supply of adequate temperatures and precipitation and photoperiodism, such as a prolonged 'volcanic winter' is expected to do, wood production or wood cell division is also slowed down significantly (Creber & Chaloner, 1984). This would be apparent in the wood microanatomy through reduced development of wood growth rings during the period of the affected climate versus the times when there is favourable growth conditions; the growth rings under such climates would appear narrowly versus broadly spaced, respectively (Creber & Chaloner, 1984; Schweingruber, 2007).

After a careful consideration for applying this understanding in studying southern African woody vegetation through archaeological charcoal, several problems were noted with this approach. First, the archaeological remains that were studied here, like most organic

artefacts, was preserved through small fragments that often did not preserve enough surface area of the transverse section of different woody species/ specimens where the growth phases/rings could be studied properly.

Secondly, the occurrence of growth rings in many woody taxa is not reliable under the tropical climate of south-east Africa that includes the Sibudu and Border Caves' localities. This problem is accentuated by the reality that the taxa range represented by archaeological fragments may, on account of being material culture, not include the limited number of species whose wood ring morphology/boundaries occur reliably in response to the climatic setting of their growth sites. Although the investigation of the direct influence of the hypothesised aftermath of Toba on woody vegetation growth was not impossible, it was decided to refocus the investigation of the relationship between woody vegetation growth and the qualitative anatomical attributes of the plants to answer more important questions regarding the dataset of the two sites.

Following the notion that the woody vegetation at Sibudu Cave was infected by fungi, see Chapter 4 section 4.2.3, the first phenomenon that this chapter investigates is the variability of wood log sizes of the charcoal remains. This was done to understand whether the fungi in the wood were pathogenic or endophytic or decomposing species. The investigation was based on the understanding that, in southern Africa, pathogenic fungi attack old trees with weak defences. If this is true for the dataset from Sibudu Cave, there may be a pattern in the maturity of the wood logs that were, possibly, infested and killed by fungi and thus their dead, rotten wood favoured for fuel.

The second analysis followed the notion of foreign-looking residues in the wood structure of the charcoal remains from Border Cave (Chapter 5 section 5.2.4). While it seemed that some of the residues included in the wood vessels are ordinary, i.e. stringy mass deposit is fungal hyphae in many fragments, there were some unexpected and unknown inclusions which do not fit the scope of anthracology/ wood anatomy. These were further investigated through a chemical microanalysis to see if their chemistry could help determine their origin. The analytical approach for interpreting the results is given in Figure 6.1. There are many factors that affected the reliability of the results obtained here (which are discussed in the chapter) and the sample size for both analyses is small, therefore the interpretations made in this chapter are suggestive rather than conclusive.

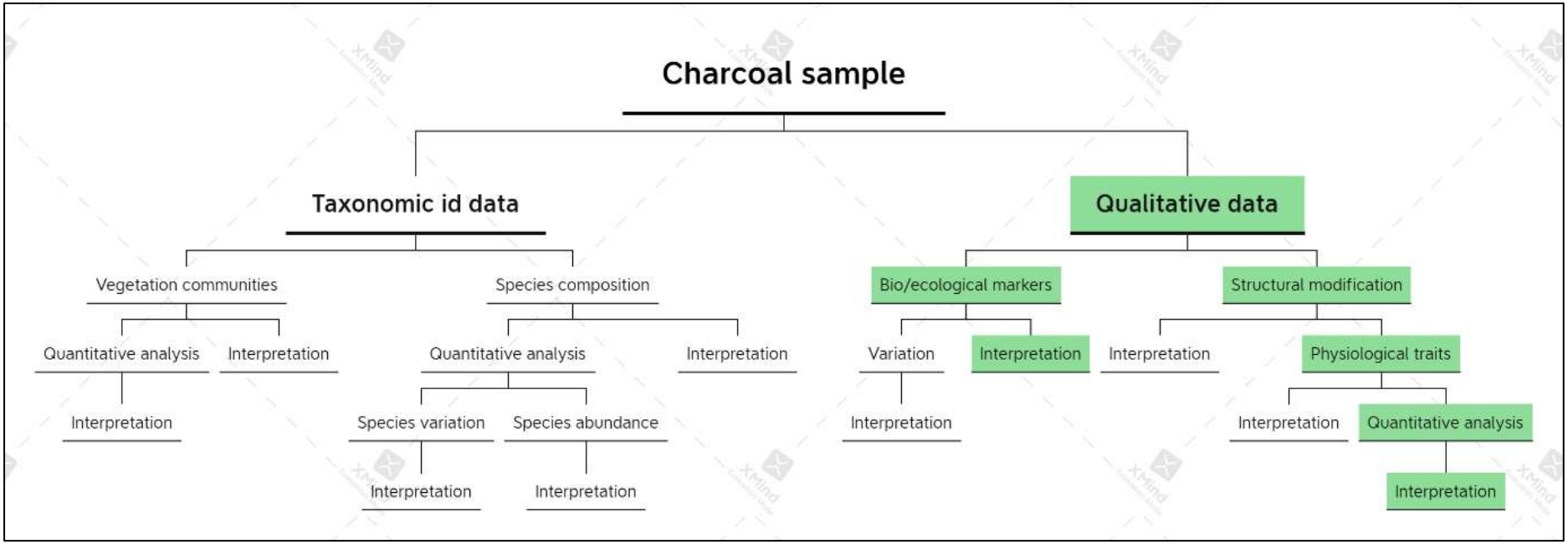


Fig.6.1 The analytical approaches, highlighted in green, that were used to interpret the data in this chapter

Field and Technical Report

POSSIBLE AVENUES FOR ARCHAEOLOGICAL CHARCOAL STUDIES IN SOUTHERN AFRICA: PRELIMINARY STUDIES USING CHARCOAL REMAINS FROM SIBUDU AND BORDER CAVES

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ABSTRACT

In this paper, we review anthracology methods that have been employed in southern Africa. We note that methods such as ecophysiology have not been fully adopted because of the complex nature of tree growth under most parts of the subcontinent which experience a sub-tropical climate. The limited use of wood ecophysiology methods affects the application of other methods in archaeobotany, notably, those that rely on the distinctness of wood growth rings. Here, we attempted to use the curvature of wood growth rings to determine the variation in the diameter of wood logs from Sibudu Cave; this was based on disintegrated charcoal fragments. The successful application of this method was significantly challenged by the indiscernibility of growth ring boundaries. However, the method must be developed, and future studies must establish a reliable sample size of the wood fragments that form distinct growth ring boundaries for a more accurate interpretation. We also recommend the analysis of inclusions that are preserved in the wood structure using a charcoal dataset from Border Cave. We, therefore, conducted a preliminary chemical microanalysis on unknown residues that were embedded in wood vessels to obtain a better indication of the environment that resulted in their occurrence in the past. This analysis proved only useful in suggesting the partial silicification of some wood. We argue that this approach can provide reliable additional data about palaeoenvironments in as far as it complements the scope of anthracology.

KEYWORDS: charcoal, wood ring curvature estimation, chemical microanalysis, landscape

INTRODUCTION

Charred wood remains in archaeological sites represent a good proportion of woody vegetation that grew near any site at various points of occupation. Although these remains were collected as a source of fuel or for other purposes by people, they are also an environmental record of any given locality. The full potential for interpreting various aspects of tree/shrub life directly from the wood microstructure is needed in southern Africa, to better understand people's interaction with the

landscape, including people's preference for different types of wood as well as the implications for the availability wood resources to prehistoric societies. This paper explores the potential for using wood features such as tree growth rings and chemical/mineral inclusions in the wood structure to understand the quality of wood that was used by people at Sibudu and Border Caves, two archaeological sites in KwaZulu Natal, South Africa (Fig. 1).

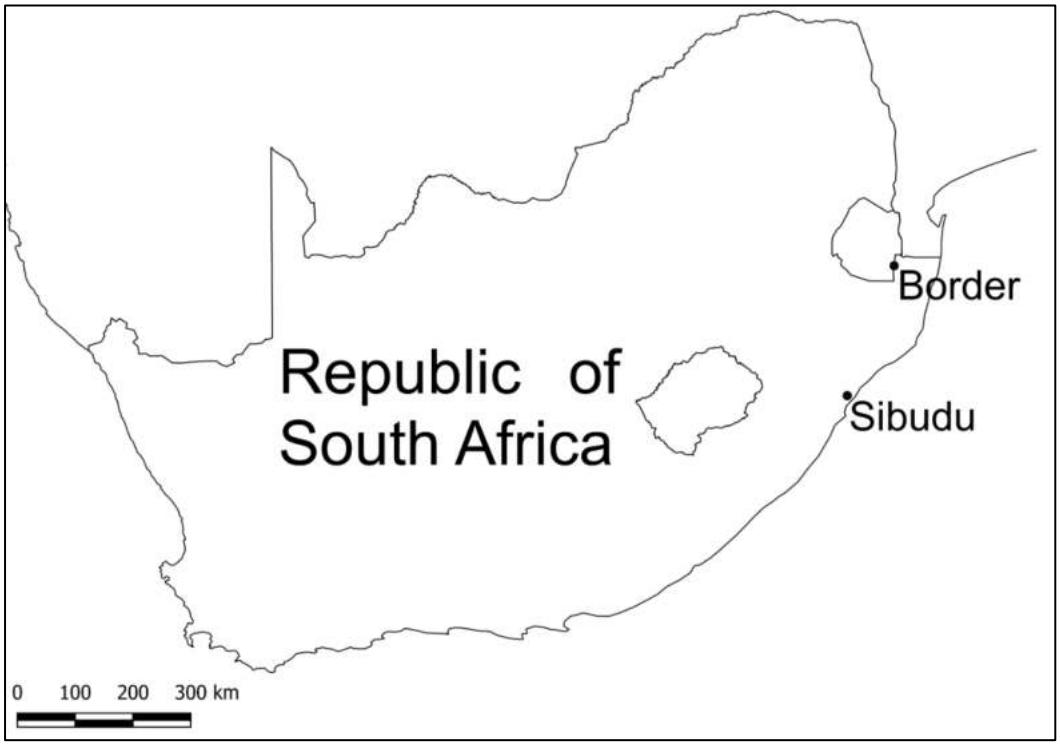


Fig.6.2 (Fig. 1) The location of Border and Sibudu Caves in South Africa

ARCHAEOLOGICAL CHARCOAL STUDIES IN SOUTH AFRICA: A REVIEW OF SOME METHODS OF ANALYSIS

When charcoal studies were first conducted in southern Africa during the late 20th century, many opportunities were identified for anthracology to contribute to studies of palaeoclimate, palaeoenvironment, vegetation history and archaeobotany (Deacon *et al.* 1983; Scholtz 1986; Tusenius 1986). Below, is the review of the methods that that have been developed worldwide and a brief evaluation of whether they have been applied in southern Africa.

THE TAXONOMIC IDENTIFICATION OF WOODY PLANTS

The relationship between trees/shrubs and their evolutionary histories qualifies the use of the accurate study of wood anatomy as the most relevant and reliable anthracology method to reconstruct the woody component of past landscapes; this is advantageous to track the climate signals that control woody vegetation growth across space and through time (Carlquist 2012). In southern Africa, like elsewhere in the world, various tree/shrubs habitats are extrapolated from the growth distribution of

their extant counterparts or relatives according to their adaptation to a defined set of environments (Mucina & Rutherford 2006; van Wyk & van Wyk 2013). Both the diversity and, sometimes, abundance of woody taxa are good measures of climate variability.

Several studies have demonstrated this using archaeological charcoal that was recovered from various sites in South Africa's provinces of Eastern Cape (Tusenius 1986, 1989; Zwane 2018), Free State (Esterhuysen *et al.*1999), KwaZulu Natal (Allott 2006; Lennox 2016; House & Bamford 2019; Lennox & Wadley 2019; Zwane & Bamford 2021), Limpopo (Puech *et al.* 2021), Northern Cape (Bamford 2015) and Western Cape (Deacon *et al.*1983; Scholtz 1986; February 1990; Cartwright & Parkington 1997; Cartwright 2013; Cartwright *et al.* 2014), as well as the neighbouring countries of Botswana (Mvimi 2019), eSwatini (Prior 1983; Prior & Price-Williams 1985), Lesotho (Esterhuysen *et al.* 1999), Namibia (Eichhorn 2004; Mvimi 2019) and Zimbabwe (Chikumbirike 2014). This method is ideal for interpreting long term climatic changes on a centennial to millennial scale.

THE ECOPHYSIOLOGY OF WOODY PLANTS

Scholtz (1986) was the first in South Africa to propose that smaller fluctuations in climatic measures are possible to detect from anatomical features whose morphology varies with the seasonal supply of precipitation and temperature in their habitats (Carlquist 1977). He and February (1990) adopted this concept to diagnose the short-term climate fluctuations at Boomplaas and Elands Bay Caves, respectively, using a method called Ecologically Diagnostic Xylem Analysis (EDXA). February (1993) further used the same understanding to thoroughly test the relationship between changes in wood vessel diameter and frequency, and changes in precipitation and temperature (Carlquist 1977). He found a relationship between the vessel attributes of *Combretum apiculatum* and *Protea caffra,* and precipitation; however, no significant results were obtained between the same attributes and temperature (February 1993).

February's (1993) conclusions can be related to those reached by Lilly (1977), who concluded that only a few species are suitable for dendrochronology in southern Africa. Both studies suggest that in most parts of the subcontinent where there is a sub-tropical climate, distinct wood growth phases, and their related growth conditions, are difficult to detect from the morphology of the vascular tissue and growth rings due to climate and genetic predisposition of most taxa. Lilly (1977) highlighted that false rings and discontinuous/partial rings in both angiosperm and gymnosperm species obscure the modality of wood growth, hence the fluctuation of climate.

The discernibility of growth rings in archaeobotany is important in estimating the log diameter of the wood assemblages that were collected in the past. Scholtz (1986) explored this idea by reconstructing wood log diameters using the ray parenchyma structure of charcoal from Boomplaas Cave (Scholtz 1986). His method, however, relied on exceptionally well-preserved samples and may be nonreplicable. There have been significant developments made in this method by international studies

which use the presence and distinctness of ray parenchyma and curvature of growth rings to understand the variation of the wood logs or even estimate the true diameter of the wood logs (Marguerie & Hunot 2007; Paradis *et al.* 2013). Both methods are worth adopting and developing in southern Africa, with a focus on woody species that are known to reliably form distinct wood ring boundaries.

THE ECOLOGY AND BIOECOLOGY OF WOODY PLANTS

Woody plants can withstand many conditions that may harm them, strong winds, fire, etc., and generally live with many organisms that might be dangerous to their development. In cases where mechanical injuries and bioecological disturbances occur, they trigger the secretion of traumatic tyloses or gums which serve to contain injuries and the spread of harmful microorganisms within the plant (Schweingruber 2007; De Micco *et al.* 2016). Tyloses are, otherwise, formed naturally in woody plants when sapwood is converted to heartwood and sometimes within sapwood. Different unfavourable conditions can thus be interpreted from such hormonal reactions.

Fungal activity (and other microorganisms) in the deformed structure of wood can also be associated with specific species (or groups) of wood infesting or wood decomposing organisms and their living conditions because these organisms destroy wood cells in consistent yet different manners (Schweingruber 2007; Zwane & Bamford 2021). Furthermore, post-mortem reactions can preserve details about the environment of deadwood from the past, which can be used to investigate the wider environment of the plant's ecology. These reactions can be interpreted, where applicable, from chemicals/minerals in the wood; this method has not been applied in southern Africa (Mustoe 2017).

AIMS AND METHODS

In this study, we used the discernibility of wood growth rings and unknown wood inclusions to conduct two investigations. Firstly, we investigated the diversity (and possibly accurate measure) of the wood log sizes of the wood that was collected at Sibudu Cave between 72.5 ± 2.0 ka and 73.2 ± 2.3 ka. It is assumed that the quantity of archaeological charcoal fragments preserved today represents the diversity of the different wood resources that were available for people in the past. If this is true, then the characteristics of that wood assemblage, i.e. species diversity and wood log sizes, will be reflected in the charcoal data (Shackleton & Prins 1992; Asouti & Austin 2005; Dotte-Sarout *et al.* 2014). It is also assumed that the quantitative attributes of those characteristics will be, somewhat, reflected in the same proportion to those of the original assemblage despite the combustion of wood and many unknown taphonomic processes. If more big logs of wood were collected, then the archaeological charcoal assemblage will reflect this trend and signify the abundant availability of such logs and vice versa. It is, however, acknowledged that the estimation/measurements for big and small wood logs of trees vs shrubs may overlap because these growth forms mature differently. The collection strategies will, nevertheless, be made based on other ecological and cultural evidence from

the site. The estimated wood log variation of the Border Cave dataset is used to control this interpretation.

A second assessment investigated the chemistry of biological or mineral inclusions that were observed in the wood vessels of trees that were collected at Border Cave approximately 74 ± 4 ka (Zwane & Bamford 2021b). It was hypothesised that if they are composed of chemical elements or compounds that are rare in trees, then they might be related to the growth or burial conditions of the 74 ka Border Cave landscape. If these residues are made up of chemical compounds that are common in trees, i.e., associated defensive compounds, then their occurrence might be ordinary. We included charred wood samples of contemporary woody plants with similar vessel inclusions for comparative analysis.

METHOD 1

Two techniques of reconstructing wood log diameters were attempted in this study, namely: the Ring Curvature Estimation and Wood log Diameter Reconstruction; both techniques rely on the distinctness and curvature of wood growth rings. The Ring Curvature Estimation is based on the accepted notion that, when assessed in incomplete wood/charcoal pieces under the same resolution, wide wood ring structures are weakly angled/curved while narrow rings are strongly curved. Standard procedures were followed in this study (Paradis *et al.* 2013). The samples were assessed using a constant magnification lens of 50X of an Olympus light microscope on the transverse section, to identify ring clarity in each charcoal fragment. Three categories of ring curvatures were created for which ‘strongly’, ‘moderately’ and ‘weakly’ curved rings were defined numerically (Fig 2); the samples under each category were interpreted to suggest the relative abundance of wood logs with ‘small’, ‘medium’ and ‘large’ diameters, respectively.

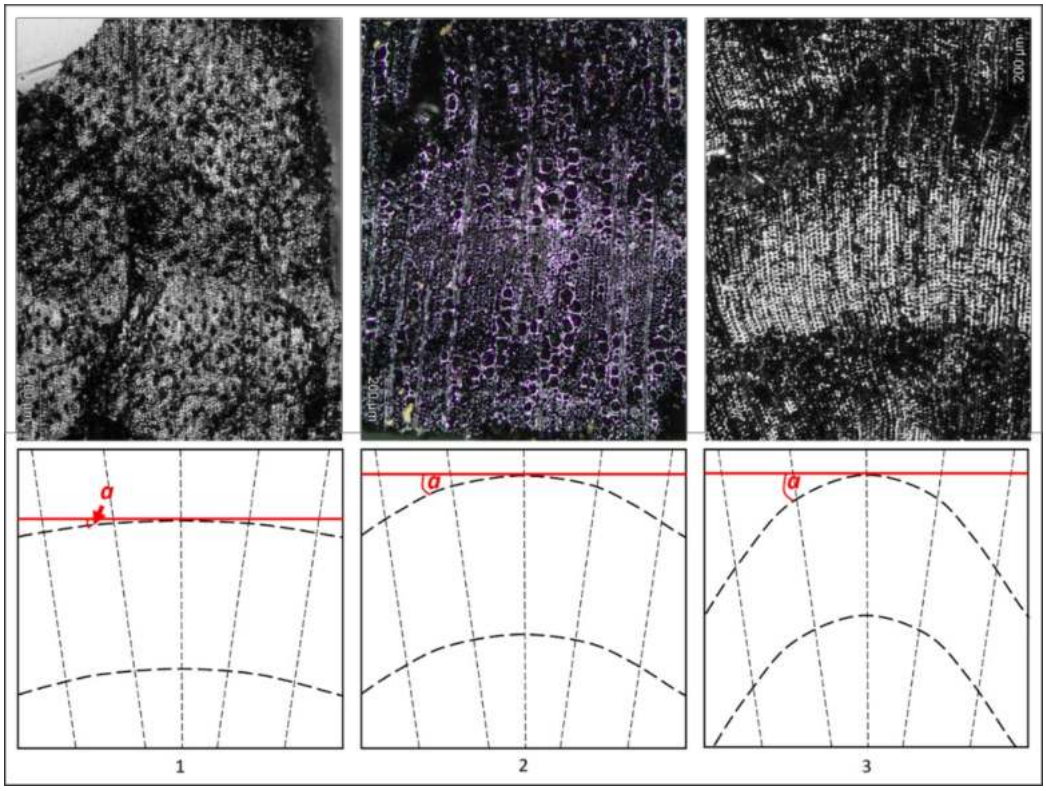


Fig.6.3 (Fig. 2) *Illustration of the method of measuring (1) weakly curved, (2) moderately curved and (3) strongly curved wood growth rings in each wood fragment with discernible growth rings using the curvature angle (a).*

Wood log Diameter Reconstruction was attempted to quantify the wood log categories based on the samples with distinct growth ring boundaries as well as two discernible rays on the transverse section that are located ideally 4 mm apart at their intersection with the outermost preserved ring of each charcoal fragment. The radius of the charcoal fragments was calculated following Kabukcu (2018) and Paradis *et al.* (2013). The necessary measurements for the application of the two reconstructions were obtained using ImageJ software (Fig. 2) (Rueden *et al.* 2017).

METHOD 2

For microchemical analysis, samples were mounted into epoxy resin blocks, polished along the transverse sections of the wood and coated with carbon. These included archaeological and comparative samples containing similar-looking residues in their wood. A chemical microanalysis was done using a Tescan Vega Scanning Electron Microscope (SEM) equipment coupled with Energy-Dispersive Spectroscopy (EDS) to obtain the elemental composition data of different phases of the charcoal samples. This technique identifies petrogenetically significant phases based on their backscattered electron (BSE) illumination as well as giving the relative concentration of different elements in each charcoal sample. It does not provide an exact quantitative measure of elements;

however, the BSE ratio of all detected elements is proportional to their average relative atomic mass in different parts of the charcoal sample.

RESULTS

WOOD RING CURVATURE ESTIMATION

The size of the fragments from Sibudu Cave ranged from ~ 0.2 to barely over 1 cm^2 and that of Border Cave between ~0.3 and 2.5 cm^2. Although having significantly wide size ranges, most fragments within both datasets measured on the lower end of their respective ranges. The surface area of these mostly small fragments after manual fracture for anthracological assessment was often even smaller. There were 31 fragments (representing 18 species) at Sibudu whose growth ring boundaries were defined by ring porous or semi-ring porous; these were taken from a larger dataset of 316 identifiable fragments that were classified into 72 species. Similarly, 24 charcoal fragments (representing 11 woody species) were obtained from 755 identifiable samples (representing 57 species) from Border Cave could be analysed for ring curvature variation and log diameter reconstruction. A description of taxa represented by these charcoal assemblages is discussed elsewhere (Zwane & Bamford 2021a; 2021b).

Table 6.1 (TABLE 1.) *Summary of the result of ring curvature measurements/estimations from Sibudu and Border Caves.*

Sites	**Curvature angle**			**Total**
	Weak	Moderate	Strong	
Sibudu Cave	5	18	8	31
Border Cave	5	9	10	24

The results for the Ring Curvature Estimation showed that the curvature angle of the samples from Sibudu Cave ranged from 0.5˚ to 16.4˚ and had an average of 8.3˚, while those from Border Cave ranged between 1.9˚ and 16.8˚ with an average of 9.4˚. Three angle categories were thus set at 0-5˚, 5-10˚ and more than 10˚, representing classes of weakly, moderately and strongly curved growth rings, respectively, for both datasets (Table 1). The Sibudu Cave logs were normally distributed, according to the size classes that were artificially set whereas the Border Cave logs were slightly skewed to the right, i.e., towards strongly curved rings representing ‘small’ logs (Fig. 3, 4, 5). Figures 3 and 4 show that at Sibudu there were more wood fragments with moderately curved growth rings than both weakly and strongly curved ring classes combined.

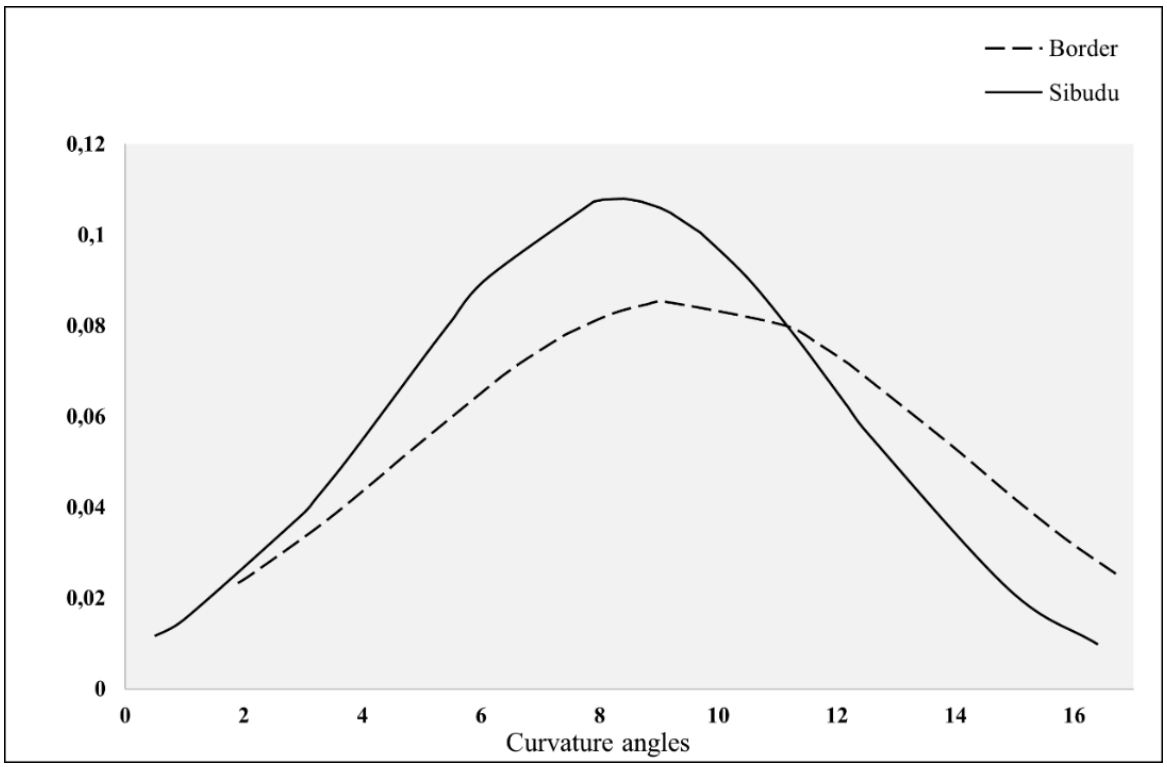


Fig.6.4 (Fig. 3) *The normal distribution curves of the curvature angle results obtained at Sibudu vs at Border Caves.*

At Border Cave wood logs with strongly curved, i.e., 'small' diameter, were collected slightly more abundantly than 'medium' sized logs in this dataset and the logs with a 'large' diameter were collected the least (Fig. 3, 5). *Podocarpus* spp., common plant to both datasets, was collected mostly in 'large' (n= 3) sized logs than 'small' (n= 1) and 'medium' (n= 1) sized at Sibudu, while it was collected mostly in 'small' (n= 3) followed by 'medium' (n= 3) sized logs at Border Cave.

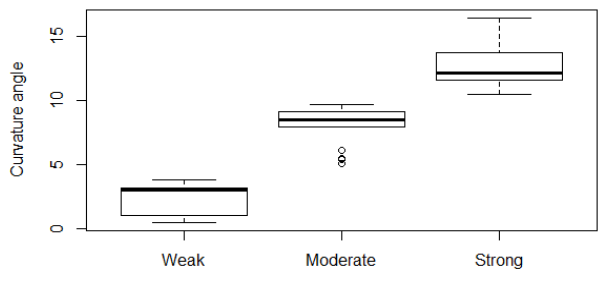


Fig.6.5 (Fig. 4) *The curvature variation of the wood logs from Sibudu Cave, showing the range, interquartile range and average angle (a in Figure 2) measurements for weakly, moderately and strongly curved ring boundaries.*

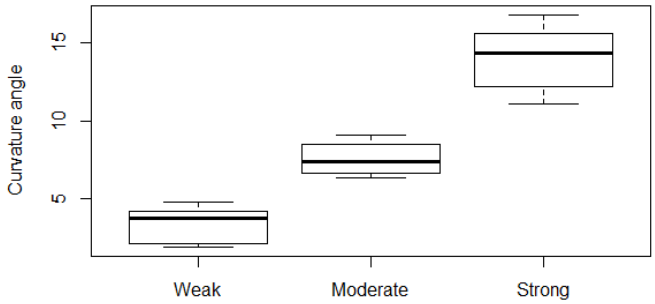


Fig.6.6 (Fig. 5) *The curvature variation of the wood logs from Border Cave, showing the range, interquartile range and average angle (a in Figure 2) measurements for weakly, moderately and strongly curved ring boundaries.*

The reconstruction of the wood log diameter of samples from both caves yielded unreliable results due to the poor condition and the small nature of many samples. It was, therefore, not possible to quantify the observed size ranges.

CHEMICAL ANALYSIS

The chemical analyses showed that all the charcoal samples, including both comparative and archaeological samples, contained the same elements however in different ratios and all charcoal fragments were not chemically homogeneous (Table 2). A chemical composition of the unknown residues that are noted in the archaeological plants, however, could be suggested. The electron microanalysis of the archaeological samples with brown deposits included in the vessels were rich in silicon (Si) and oxygen (O). Figure 6 shows the wood structure of sample 1 (*Euphorbia* sp.) with a stringy or granular mass inside the wood vessels as well as the mapped phases showing high silicon content in and around the vessels.

Table 6.2 (TABLE 2.) *List of the samples analysed for elemental composition. Main elements detected in each sample are indicated in the last column in the order of abundance; the investigated residues are composed mostly of the element indicated in bold & underline, except for samples 6 and 7.*

Sample #	Data type	Species	Residue type	Main elements
1	Archaeological	*Euphorbia* sp. (Type 37)	Brown deposits	C, **Si, O**, Ca, Cl, Mg, S
2	Archaeological	Undetermined (Type 31)	White deposits	C, **Ca**, Cl, S, O, Si, Mg,
3	Archaeological	Undetermined (Type 7)	White deposits	C, **Ca**, O, Si, Cl, Mg, S
4	Archaeological	*Colophospermum mopane* (Type 57)	Blue-yellow stain	C, **Si, O**, Ca Cl, Mg, Na
5	Archaeological	*Lannea discolor* (Type 38)	Blue-yellow stain	C, O, **Si,** Cl, K, Mg, Na
6	Contemporary	*Combretum molle* (BPI/20/18)	Blue-yellow stain	C, O, Si**,** K, Ca, Cl, Mg, S
7	Contemporary	*Combretum collinum* (BPI/20/33)	Blue-yellow stain	C, O, Si, K, Cl, P, Ca, Mg
8	Contemporary	*Sclerocarya birrea* (BPI/20/ 176)	Blue-yellow stain	**C, Si, O**, K, P, Cl, Ca, Mg, S
9	Contemporary	*Sclerocarya birrea* (BPI/20/30)	Blue-yellow stain	C, **O, Si,** Cl, K, Ca, S, Mg
10	Contemporary	*Terminalia phanerophlebia* (BPI/20/255)	White deposits	C, **Ca**, O, Cl, K

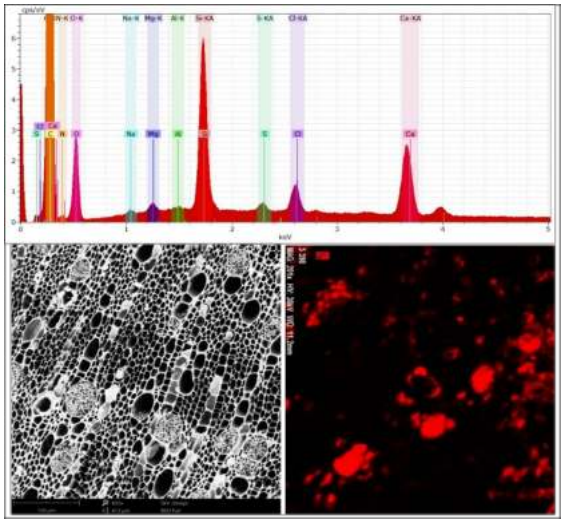


Fig.6.7 (Fig. 6) *The spectrum of the elements detected in sample 1 as well as their relative abundance. The SEM image of sample 1 with the brown stringy deposits (below the spectrum, left) and the SEM/EDS map (right) results showing the concentration of silicon (Si) mostly in and around the wood vessels.*

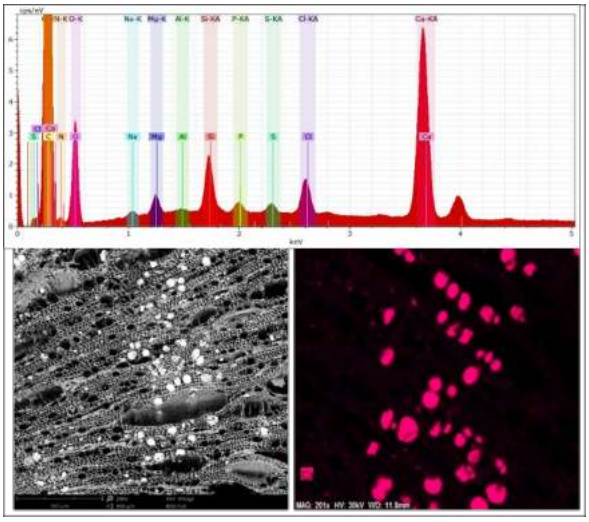


Fig.6.8 (Fig. 7) *The spectrum of the elements detected in sample 6 as well as their relative abundance. Below the spectrum, the SEM image of the TS surface of sample 9 with solid white deposits (left) and the corresponding SEM/EDS map (right) showing the concentration of calcium (Ca) mostly inside the vessels.*

The chemical microanalysis of white residues in the vessels of archaeological charcoal showed that these are made up almost completely of calcium (Ca), however they had oxygen and magnesium (Mg) as well (Fig. 7). The chemical composition of the archaeological samples 2 and 3 compared well to that of sample 10 (comparative *Terminalia phanerophlebia*), i.e., contained high levels of calcium among other elements (Fig. 8).

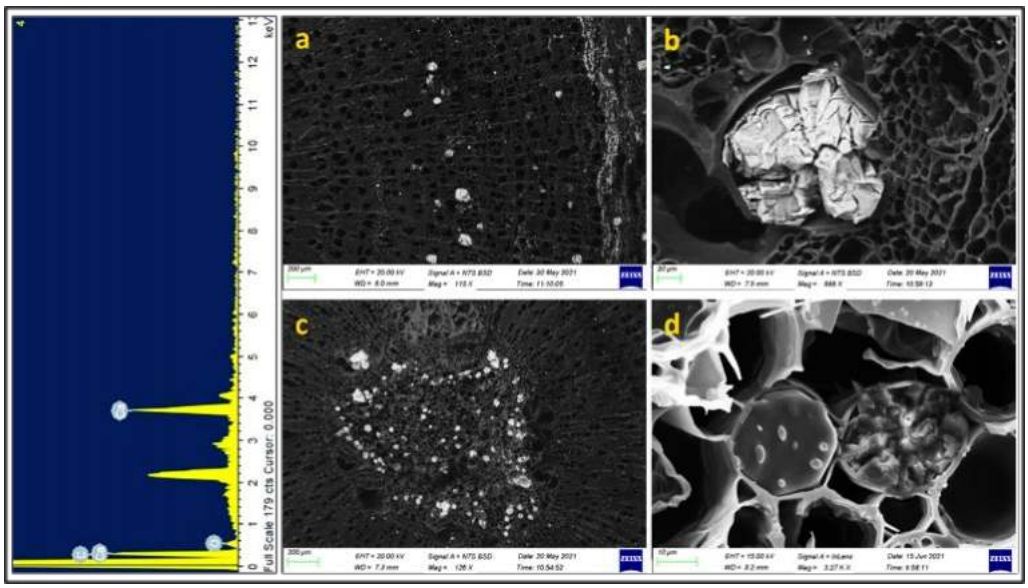


Fig.6.9 (Fig. 8) *The microphotographs of sample 10 (Terminalia phanerophlebia) showing the distribution of calcium rich mineral inclusions in a) & b) selected growth phases as well as in c) & d)*

the pith of the charred wood piece. This sample was analysed through a similar EDS technique however a Ziess microscope was used.

The chemistry of the blue-yellow stains could only be detected in the vessel walls of sample 4 (*Colophospermum mopane*), 5 (*Lannea discolor*) 8 and 9 (*Sclerocarya birrea*) - due to the sparse nature of this staining - and composed mostly carbon (i.e. the organic tyloses) while some vessels had very high levels of Si and O in their walls (Fig. 9). The chemistry of the similarly stained phloem regions of the *Combretum* species (samples 6&7) was not obvious.

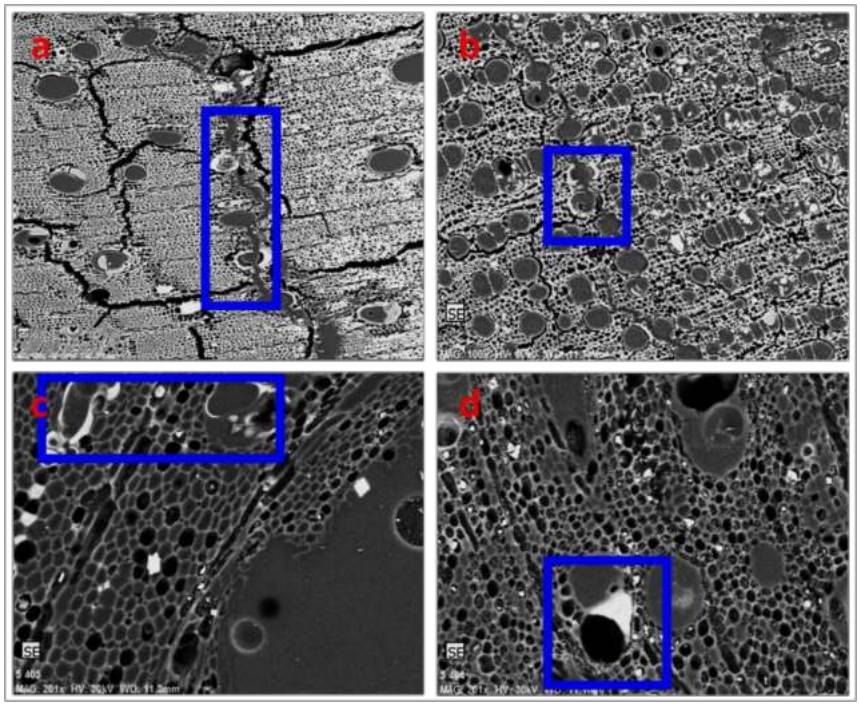


Fig.6.10 (Fig. 9) *The BSE images of a)* Colophospermum mopane*, b)* Lannea discolor*, c) and d)* Sclerocarya birrea *showing the silicon-rich phases in the vessel walls that were often stained blue-yellow.*

DISCUSSION

The sample size for the estimation of ring curvature was small for both Sibudu and Border Caves and more work is recommended to improve the interpretation made in this study. The visibility of the growth ring boundaries affected the adequate sample for this method. In most cases the ring boundaries were determined through wood porosity, except for *Podocarpus* spp. which had the boundary of its growth rings marked by the thickening of the tracheid walls. The application of Ring Curvature Estimation and Wood log Diameter Reconstruction was further limited by the size of the charcoal fragments. Charcoal fragments from Sibudu Cave were excavated from as deep as three metres below the surface of the cave floor and dated between 73 and 72 ka. The depositional context and age of the samples that implies many taphonomic factors contributed to the uncontrolled fragmentation of burnt wood logs from Sibudu and resulted in the small charcoal samples that were eventually studied. The small nature of these archaeological charcoal fragments made it difficult to

obtain reliable measurements to reconstruct the log diameter as most of the fragments measured below 4 mm after laboratory preparation.

Despite the biases listed above, some trends in the wood log representation can be read. If the assumptions made earlier concerning the representation of the original wood assemblage with its characteristics hold true (Shackleton & Prins 1992; Asouti & Austin 2005), then the observed trends reflect the original wood log assemblages. These firewood collecting trends could have both social and ecological explanations. The occupants of Sibudu Cave may have preferred an ideal wood thickness, such as is represented by the 'medium' sized logs in this study and, therefore, collected their wood resources consistently with this target in mind. This way, it is reasonable that few samples fall outside the range of the preferred log thickness.

Ecologically, the observed trend could mean that the Sibudu occupants had more access to similar-sized wood logs. This is, however, unlikely because it has been suggested that between 73 and 72 ka there was a closed, multi-layered forest consisting of a wide range of trees, from small shrubs such as *Dombeya burgessiae* to very big trees such as *Podocarpus* sp. (Zwane & Bamford 2021a). If the occupants of Sibudu collected dead wood indiscriminately, then there should be wood pieces of a very wide range in equal proportions. It is, therefore, unlikely that the fragments studied here represent the log fragments of such a forest in its entirety.

The trend indicated by *Podocarpus* at Border Cave agrees with that suggested by all 24 fragments and shows that more 'small' and 'medium' sized logs were collected in the cave's locality. Unlike the Sibudu Cave landscape, Border Cave featured a slightly drier type of forest which consisted mostly of Savanna and Grassland woody species (Zwane & Bamford 2021b). The interpretation of the trend suggested by the abundance of 'small'- sized wood logs over others, can mean that these were either available more abundantly or were preferred by the occupants of the Border Cave over others. It is difficult to argue with certainty if the trend represents ecological or social factors.

Most elements identified through microchemical analysis are common in plants (Rowell *et al.* 2013). Silicon and calcium bearing minerals/products, however, were found most-noticeably in the unknown residues of interest in the wood vessels and fibres. White inclusions are found strictly inside wood vessels and are not part of the wood structure. They, possibly, represent calcium carbonate/oxalate compounds whose occurrence is ordinary for some species of woody vegetation. Parts of the wood of samples with brown inclusions were altered by high amounts of silica in and around vessel walls of charcoal fragments from Border Cave. These compounds indicate the incipient stages of silicification of the wood, along with those of the stained samples whose vessel walls that are rich in silicon. This reaction is commonly favoured by warm conditions (Buurman 1972; Mustoe 2017) and suggests that c. 74 ka (or before then) temperatures at Border Cave were warm enough for some logs of dead wood to be partially silicified.

CONCLUSIONS

The traditional applications of the taxonomic identification of charcoal assemblages to reconstruct the past vegetation and climate can be enhanced by looking at the growth rings and the chemical composition of the charcoal. If growth rings are present, then their curvature can be used to estimate the variation of log wood sizes and if the charcoal fragments are at least 4 mm wide then sizes of wood logs can be reconstructed. Preliminary results indicate that wood exploitation trends from the estimation of wood log sizes can be interpreted, however, future studies must determine the adequate sample size of charcoal fragments exhibiting distinct growth ring boundaries to confirm such interpretation. It is suspected that the trends identified here, although through a small assemblage, could hint at cultural behaviour at Sibudu. The SEM/EDS chemical analysis of charcoal remains from Border Cave showed that silica-rich chemical compounds that are now part of the wood structure (vessels, fibres and vessel walls) formed because of post-mortem silicification of wood, a reaction that is associated with warm temperatures.

ACKNOWLEDGEMENTS

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CHAPTER SEVEN- DISCUSSION

7.1 General introduction

In this chapter, I address the research question by considering environmental evidence that is available about the late Pleistocene. I first present a discussion of the evidence that exists for the dispersal of the Youngest Toba Tuff (YTT) and the relevant paleoclimatic/ environmental evidence of the late Pleistocene at the MIS 5/4 transition globally that accompanied this deposition. I then discuss the environmental or climatic evidence for the same period in southern Africa, considering the influence of the different climate drivers that could determine the full impact of the conditions that were hypothesised by the TCT on the ecosystem of the subcontinent. The chapter is completed by a careful analysis of the archaeological evidence in southern Africa which is used to suggest if there is evidence for an environmental stress of the magnitude that was hypothesized by the TCT that people lived through. The following section is a draft of a manuscript that has been submitted for publication. The section is presented in the writing format of the thesis.

When the Toba super-eruption reached South Africa

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Southern Africa's Middle Stone Age period offers a special opportunity to answer important questions about the interaction of people and the environment, however detected partially, in the archaeological record. People's responses to different climatic changes are not always obvious because human behaviour is both diverse and versatile. In this review article, we argue that different groups of people in southern Africa were impacted differently by the aftermath 74 ka Toba volcano super eruption, which originated in Indonesia, due to many factors. First, the proximity of the subcontinent and the dominance of major air circulation systems, along with its' varied topography provided many habitable environments for people. Secondly, human behaviour is flexible because it is guided by different group-specific cultural norms as well as accumulated social knowledge which is adaptable to varied resources on the landscape. Therefore, the severity of this super eruption was mitigated by

cultural resilience emanating from both pre-existing survival strategies and the innate potential to develop them. We conclude that, while the Toba super eruption may have been catastrophic in some parts of the world, there were many ecological factors that prevented it from devastating the southern African ecosystem; and while it may have affected people, it's real impact might be better understood independent of the assumptions of the Toba Catastrophe Theory.

Keywords: human cultural evolution; adaptation; environmental stress; Toba super eruption

Introduction

When thinking about the possible impact that the c. 74 000 years (74 ka) Toba volcano super-eruption may have had on the late Pleistocene ecosystem, it is often difficult to fathom the level of agency that people had in the face of this cataclysmic danger. The Toba Catastrophe Theory (TCT) claimed that the eruption of Toba unleashed an environmental and climatic catastrophe that not only disturbed the ecosystem but caused a near extinction of human ancestors during the late Pleistocene (Ambrose, 1998, 2003; Rampino & Ambrose, 2000). For two decades, since the hypothesised devastating impact of Toba was related to the near extinction of humans, there has been debates about the impact of this event on global climate and about how late Pleistocene populations survived this event (Williams, 2012b). Recently, the idea of persistent and devastating winter conditions, originally hypothesised by the supporters of the TCT, has been challenged by different researchers. This follows the discovery of the ash debris from this event as far as East and southern Africa, that is accompanied by less evidence for a severe impact on human activity at some relevant archaeological sites (Smith et al., 2018; Yost et al., 2018).

The role of this undoubtedly sizeable event in influencing late Pleistocene life, therefore, begs for a different perspective to understand its' true impact on the ecosystem and human history. Considering the environmental and archaeological data in southern Africa, we propose that the effect of this eruption on prehistoric life is much more complex than has been overly simplified by the TCT. Here, we use evidence from some palaeoenvironmental archives and archaeological sites from South Africa to demonstrate this.

7.2 The youngest Toba super-eruption: general facts and perceptions

7.2.1 The Youngest Toba Tuff (YTT)

More than 70 ka ago, a volcano eruption occurred on the Sumatra Island of Indonesia, almost 9 000 kilometres (km) north-east of southern Africa (Fig. 7.1). This event, dated between c. 73 ka (Chesner et al., 1991; Storey et al., 2012) and c. 75 ka (Mark et al., 2013; Westgate et al., 1998), left a 1 130 km^2 caldera known as Lake Toba. Lake Toba is located on the Sumatran Fault Zone which is a slip zone between the subducting India-Australian ocean tectonic plate and the overriding Sumatran-Eurasian continental plate (Chesner et al., 1991; Rose & Chesner, 1990). This highly active seismic fault zone has produced at least four eruptions from the Toba caldera in the last 1.2 million years (Chesner et al., 1991; Matthews et al., 2012; Rampino & Self, 1993). The c. 74 ka eruption, is the youngest and the only super-eruption to occur during human history (Chesner et al., 1991; Costa et al., 2014; Matthews et al., 2012). It is estimated that the Youngest Toba super-eruption released ~3000 km^3 of magma, ash and gases through a ~35 km eruption column (Chesner et al., 1991; Rose & Chesner, 1990). Most of the thick pyroclastic deposits, termed the Youngest Toba Tuff (YTT), have been traced in ocean sediments and on land mostly within 40 000 km^2 of the caldera (Costa et al., 2014; Rose & Chesner, 1990). Additionally, 'co-ignimbrite' ash and sulphuric gases from the eruption were injected into the stratosphere and distributed by dominant trade winds across the globe, possibly affecting the late Pleistocene climate significantly (Costa et al., 2014; Matthews et al., 2012; Rose & Chesner, 1990).

To date, most of the YTT has been identified to the west outside of Sumatra in the marine cores of water bodies such as the Andaman Sea, Arabian Sea and Bay of Bengal, as well as on land in the Indian subcontinent and the African continent where distinct layers of YTT ash remains and the surrounding matrix have been dated to the approximate age of the eruption (Buhring & Sarnthein, 2000; Matthews et al., 2012; Robock et al., 2009; Schulz et al., 2002; E. Smith et al., 2018; Westgate et al., 1998). However, Buhring and Sarnthein (2000) confirmed that the YTT was also distributed to the east of the caldera by south-westerly summer monsoon winds, following the recovery of the YTT from a marine core in the South China Sea in a transition layer of Marine Isotope Stage (MIS) 5-4, i.e. 75 ka (Liu et al., 2006)

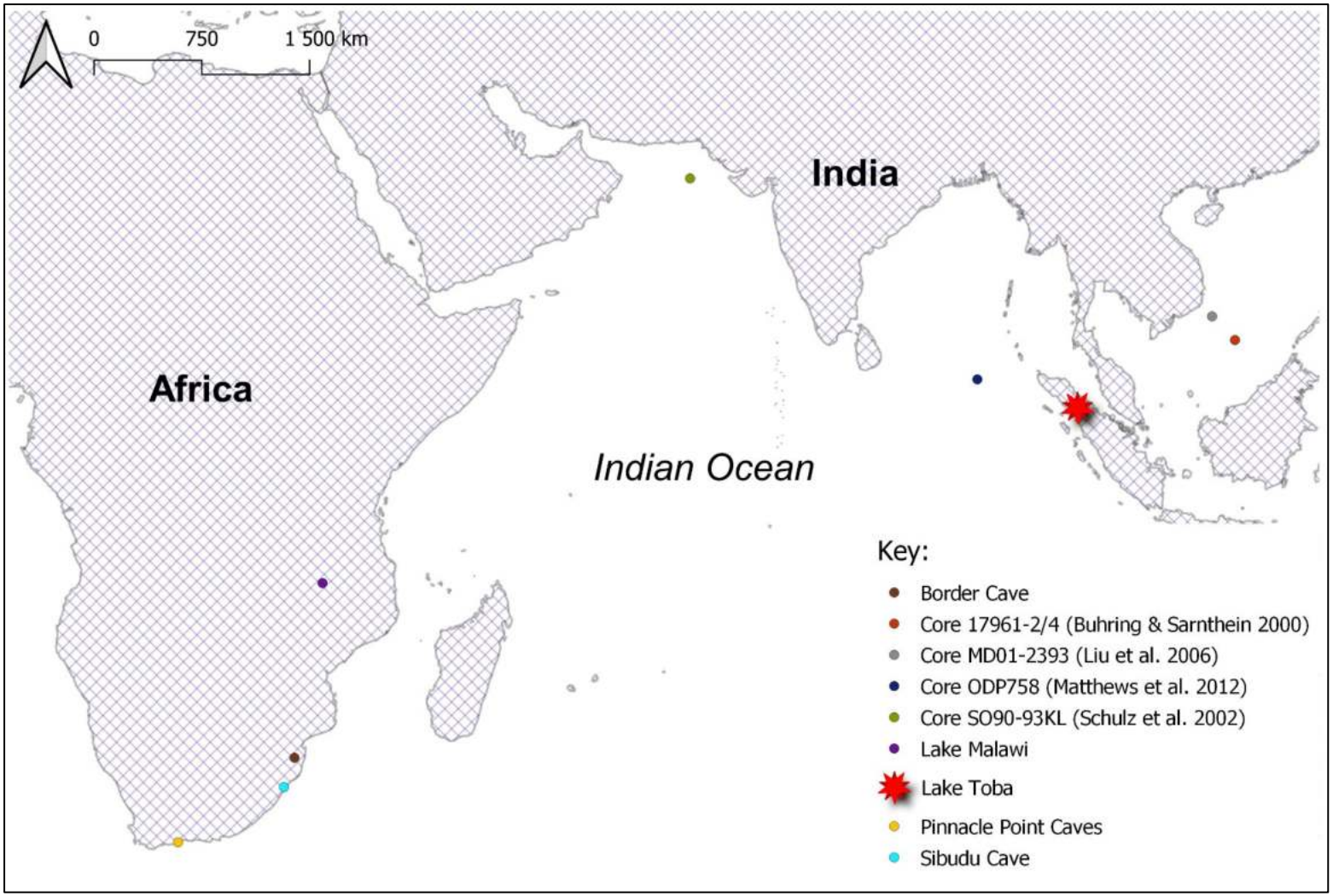


Fig.7.1 The location of two sites, Lake Malawi and Pinnacle Point Caves, from which the YTT has been recovered in Africa in relation to the Toba caldera, the study sites (Sibudu & Border caves) as well as some of the marine core sites in the Indian Ocean, Arabian Sea and South China Sea from which the YTT was recovered.

In the Arabian Sea, 3 900 km west of the Toba caldera, rhyolitic volcanic shards with a chemical signature of the YTT were recovered from marine sediment cores near the MIS 5-4 transition (Schulz et al., 2002). On the African continent the YTT crypto tephra volcanic glass shards from Lake Malawi sediments, East Africa, were confirmed to be morphologically and chemically distinct from the local Rungwe Volcanic Province; these results extend the Toba ash dispersal radius to approximately 7 300 km west of the Toba caldera (Lane et al., 2013). Most recently, the ash dispersal radius of the YTT has been expanded to southern Africa where microscopic 'cryptotephra' glass shards from the c. 74 ka Toba eruption were discovered on the south coast of South Africa (Smith et al., 2018). These were found in two archaeological sites, Pinnacle Point site 5-6 and the Vleesbaai Area B, located nine km from each other and, together, ~ 8 937 km from the Toba caldera.

7.2.2 The global environmental impact of the Toba super-eruption

The impact of the Toba super-eruption on regional and global climate is much debated. The TCT hypothesised that, based on the large amounts of magma and sulphur aerosols, this single incident could lower atmospheric opacity and trigger a ~3˚C global temperature reduction (Ambrose, 1998; Rampino & Self, 1993). The ash and sulphuric gas component from this eruption contributed to the solar insolation and pollution of the resources on which late Pleistocene human populations depended. The particles of the sulphuric gas cloud, that was ejected into the stratosphere, scattered the incoming solar radiation back to space and thus increased the planetary albedo effect. This caused a long term (possibly decadal) reduction of sea surface temperatures(Rampino & Self, 1993; Robock et al., 2009). These conditions, collectively, created an inhospitable environment globally, called the "volcanic winter," which resulted in a loss of plant and animal biomass on which late Pleistocene populations depended (Ambrose, 2003; Rampino & Ambrose, 2000). Consequently, human populations were also reduced drastically.

This, according to Ambrose (1998), explains one of the late Pleistocene human demographic bottlenecks that are dated between 60 and 70 ka through a significantly reduced genetic pool (Harpending et al., 1993). If a cataclysmic event, such as the Toba super eruption, occurred >70 ka and caused a significant human population decrease, the recovery from these conditions (and those of the of the onset of glacial MIS 4) could lag by 1000 to 10 000 years, depending on the mutation rates of surviving reproductive individuals. This, Ambrose

(1998) argued, is supported by genetic and archaeological evidence in Africa where a human genetic bottleneck release is observed ~60 ka followed by a technological advancement that would have aided in recovering human population growth based on its' adaptive advantage (Ambrose, 1998). This implies that the eruption of Mount Toba unleashed an environmental and climatic catastrophe that devastated the ecosystem (Ambrose, 2003; Robock et al., 2009; Williams et al., 2009).

Some evidence in south Asia does indicate an abrupt animal and plant die-out in some regions closer to the Toba caldera, however it is difficult to establish Toba's role as the long-term accelerant of the conditions that are observed towards the end of MIS 5. For example, in India it was noted that dry and cold climatic conditions were gradually underway in the area when the YTT was deposited in the Jerreru Valley, located ~3 000 km from Sumatra, replacing a grassy woodland with wooded grasslands (Haslam et al., 2010). The short lived ashfall event resulted in a sudden reduction of woodland and a human occupation hiatus in the valley; however, woodlands were re-established as was the occupation of the valley after the YTT ashfall (Haslam et al., 2010). Haslam *et al.* (2010) argue that this supports the idea that there were no enduring catastrophic environmental conditions caused by the Toba super-eruption. Jones (2012) agrees that, even at such close range to the source of the eruption, the effects of the YTT fall may have been highly variable in the Indian subcontinent based on palaeoclimatological and volcanological evidence.

Climatic conditions in the Arabian Sea were interpreted from an ocean sediment core with a YTT layer located between two warm climatic events near the boundary of MIS 5 and 4 (Schulz et al., 2002). This observation is consistent with the geochemistry of an ice core from Greenland, from which high concentrations of sulphate aerosol in an ice layer that is dated to c. 71 ka were detected, signifying that this acidic atmosphere coincided with a cold Greenland Stadial phase (GS 20), however conditions became warmer thereafter during Interstadial- GI19 (Williams et al., 2009; Zielinsnki et al., 1996). In the Antarctic pole, it was similarly noted that climatic conditions became warmer after the deposition of an acidic ice layer that is suspected to originate from Toba (Svensson et al., 2013). This suggests that, although it is possible that the Toba super-eruption had a worldwide climatic impact, it did not accelerate global climate into the glacial MIS 4 period (Costa et al., 2014; Robock et al., 2009; Thevenon et al., 2010; Williams, 2012a; Zielinsnki et al., 1996).

There are many factors that determined the extent to which the YTT ash was dispersed, and global climate affected. For example, the wind patterns at the time may have played a major role in distributing ash to limited parts of the globe, while it seems that its' sulphate aerosols precipitated in both north and south polar regions (Svensson et al., 2013; Zielinsnki et al., 1996). However, human ancestors, including those in Eurasia who did not contribute significantly to the present genetic pool, survived this incident. The devastating effects of Toba on human populations outside Africa, as hypothesised by the TCT, have even been challenged by different researchers with evidence and reasonable perspectives (Clarkson et al., 2020b; Gathorne-Hardy & Harcourt-Smith, 2003; Ge & Gao, 2020; Haslam et al., 2010; Timmreck et al., 2012).

So far, there are two sites that allow an assessment of the human-Toba encounter more directly in Africa, i.e., that preserves the YTT as well as archaeological data, and an ongoing search to locate more to gain a better understanding of the possible impact it had on life. However, there is much archaeological data from some important sites that have been studied extensively, especially in southern Africa, that spans the estimated time of the eruption. They, along with palaeoenvironmental proxies, prove that a complex ecological aftermath ensued when Toba reached southern Africa.

7.3 The implication of Toba for southern African climate and human history

The scale of the Toba super eruption means that it is likely that this event had a distinct impact on the biota of southern Africa, including humans. Isolating this impact, however, is difficult especially without a clearly established YTT chronology in the archaeological sequences of many various sites. Since it has been established that southern Africa is situated within the ash dispersal radius of the Toba super-eruption, there has not yet been a clear indication if the landing of the YTT and the stratospheric aerosol injection contributed to an environmental stress that might be visible in the palaeoenvironmental record.

The impact of the Toba super eruption may also be difficult to determine from the archaeological record of southern Africa because there is much evidence that human behaviour was highly adaptable during the MIS 5. Evidence for differential adaptation strategies, and occupational hiatuses in some sites, during the Middle Stone Age (MSA), suggest that resources during the MSA were widely distributed, most notably inland versus

coastal areas, and that people (groups of foragers) constantly modified their resource exploitation strategies and moved frequently, perhaps, to manage the cost and returns of foraging under various ecological niches. People's adaptive strategies, thus according to the Theory of Behavioural Ecology, were suited to varied socioenvironmental contexts (Winterhalder & Smith, 2000). This is more consistent with the idea that human behaviour during the MSA was more 'flexible' than rigidly wired to transform unidirectionally.

'Behavioural flexibility' is shaped by individual and group's interactions with stimuli and the material world which, over long periods of time, can be characterised by major human behavioural trends (Roberts, 2015). These trends were selected from a variety through different cultural expressions (Henshilwood & Lombard, 2013; Lombard, 2012; Wadley, 2001). The role of environmental factors in facilitating and selecting these expressions during the late Pleistocene is not yet fully known (Braun et al., 2021; Kandel et al., 2015). Here, the Toba super eruption, as an environmental disaster that affected people, is analysed with this potential impact on life during the late Pleistocene.

7.3.1 The environmental backdrop of the Youngest Toba Tuff (YTT) deposition in southern Africa

At the end of MIS 5, i.e. approximately 75 ka, the general regional climate in southern Africa was considerably warm- characteristic of a warm interglacial period- and accompanied by a high stand in sea levels (Cawthra and Uken 2012; Roberts, Cawthra, and Musekiwa 2013; Caley et al. 2011; Butzer, Beaumont, and Vogel 1978). Climate variability during this time was driven by several factors which have been discussed by several studies based on empirical palaeoenvironmental data and climate simulations (Blome et al., 2012; Carr et al., 2016; Chase, 2010; Partridge, 1993; Partridge et al., 1997; Weldon & Reason, 2014). These observations about the general palaeoclimate behaviour of the subcontinent, have often led to an impression that the global cold and dry glacial vs warm and wet interglacial cycles – especially as interpreted from the expansion/contraction of the northern hemisphere ice sheets- do not coincide perfectly with major climatic changes observed in southern Africa, instead climate is controlled more by the interaction of local tropical and temperate circulation systems (Chase, 2010; Blome et al., 2012).

Evidence for the direct influence that these systems exerted on the environment is scarce; however, it is understood that they affected the availability and accessibility of resources on which people depended (Compton, 2011; Dupont et al., 2011). This has been suggested previously based on environmental data and the archaeological site formation and occupation patterns over southern Africa. Many researchers argue that the movement of Pleistocene populations to coastal lowlands was due to the constant occurrence of intensified arid conditions in the interior of the subcontinent, commonly expected during- but not restricted to- glacial periods (Carr et al., 2016; Chase, 2010; Partridge et al., 1997; Stager et al., 2011).

It is possible, therefore, that the effect of the eruption of Toba at the transition between MIS 5/4 coincided with many such recurring climatic deteriorations. On the east parts of southern Africa, a warm and humid climate prevailed such that there are no obvious signs of the deterioration of forests (Fisher et al., 2020; Zwane & Bamford, 2021b, 2021a). Palaeoenvironmental data from Mpondoland to Maputo Bay (or Delagoa Bay) along the east coast of the subcontinent generally shows that mesic conditions have sustained a forested south-east coast during both glacial and interglacial periods of the Pleistocene epoch (Caley et al., 2011; Dupont et al., 2011; Fisher et al., 2013; Kristen et al., 2007). These conditions are maintained by the sea surface temperatures of the Agulhas Current originating from the nearby Indian Ocean.

Some evidence indicates that at the end of MIS 5, the influence of the Agulhas Current was disturbed by the intensified counteraction of the subtropical system by the polar frontal systems; this resulted in some eastern parts of the subcontinent receiving winter rainfall and dune-building wind regimes along the east coast changing from a south-westerly direction to a more south easterly one at the onset of MIS 4 (Bruch et al., 2012; Cawthra & Uken, 2012; Chase, 2010; Chase & Meadows, 2007; Esteban, Fitchett, et al., 2020; D. Roberts et al., 2013). This movement, however, may have had a limited influence on the east coast terrestrial ecosystems because, even when the trajectory of the warm Agulhas Current is slightly displaced by the temperate system, its effects do not drift too far from east African coast (Beal et al., 2011; Caley et al., 2011; Roberts et al., 2013).

Fisher *et al.* (2013) argues that the influence of the Agulhas Current that maintains the land-sea thermal gradient and promotes precipitation has fluctuated through many other cooling

phases in the past and that these fluctuations did not decimate the forests in the south-east coastal regions. The palaeoenvironmental record for the MIS 5 to 4 transition in the southern Cape region, like the southwestern parts, suggests that the stronger influence of the circumpolar westerly frontal system may have resulted in cool, yet humid conditions which prevailed during much of the glacial MIS 4 period (Bar-Matthews et al., 2010; Sealy et al., 2016; Reynard and Henshilwood, 2019; Lukich *et al.* 2020).

It seems, therefore, that even if the super-eruption of Toba 74 ka years ago lowered global temperatures (including sea surface temperatures) by many degrees, the effects of this change on the terrestrial ecosystem might not be significant in the palaeoenvironmental record. Global climate simulations also detect a minimal to absent response of southern and east African climate, and other equatorial regions, to the Toba eruption, however this minimal response may have been variable in southern Africa (Black et al., 2021). The severity of the effects of a 'volcanic winter' typically manifested by cold and arid conditions may have been intercepted, deflected or even diminished by the stronger influence of the regional circulation systems. Furthermore, this deflected impact may have been experienced differently across the varied landscapes of the region.

7.3.2 The archaeological context of the Youngest Toba Tuff (YTT) deposition in southern Africa

Pinnacle Point Cave 5-6, in the southern Cape region, is the only site in South Africa where the Youngest Toba Tuff (YTT) has been identified (Smith et al., 2018) (Fig 7.2). It has also been implied that the continuous occupation of this site as well as occupational intensity following the deposition of the YTT proves that the cave was a refugium for people against the Toba super-eruption. Smith *et al.* (2018) argue that the occupants of this site developed or even flourished after Toba based on evidence that the occupation of the cave intensified after the YTT event, as did burning activity, and that the occupants of the cave innovated a new lithic technology (Brown et al., 2012). This impression echoes that from the Lake Malawi region, East Africa, where the YTT has also been identified. It was suggested, following this discovery, that life was minimally affected within a 50 km radius of the present lake margin after the super-eruption; this was indicated by slight reduction of precipitation (Jackson et al., 2015; Lane et al., 2013; Woltering et al., 2011; Yost et al., 2018).

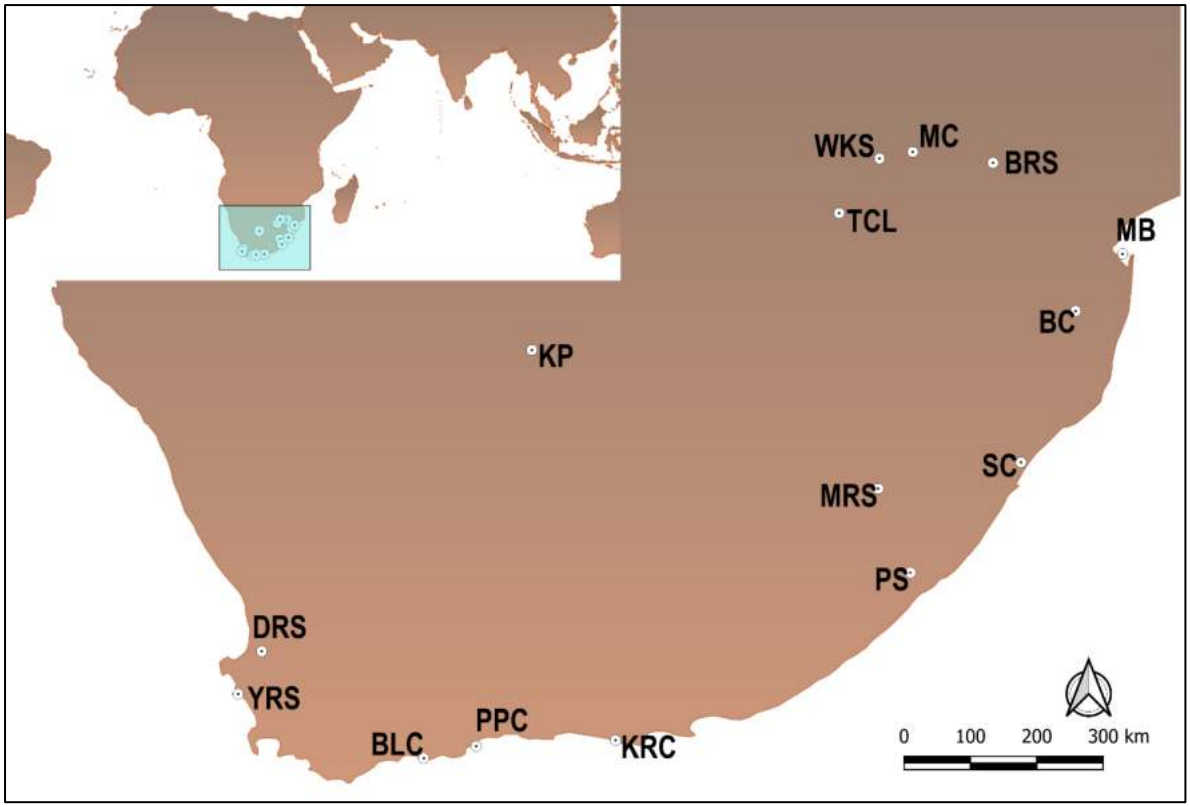


Fig.7.2 The location of all the sites discussed or referred to in this article. In alphabetical order, the abbreviations stand for: **BC**= Border Cave, **BLC**= Blombos Cave, **BRS**=Bushman Rock Shelter, **DRC**= Diepkloof Rock Shelter, **KP**= Kathu Pan, **KRC**= Klasies River Caves, **LM**= Lake Malawi, **MB**= Maputo Bay, **MC**= Mwulu Cave, **MRS**= Melikane Rock Shelter, **PPC**= Pinnacle Point Caves, **PS**= Pondoland Sites, **SC**= Sibudu Cave, **TCL**= Tswaing Crater Lake, **WKS**= Wonderkrater Rock Shelter and **YRS**= Ysterfontein Rock Shelter.

A closer look at archaeological evidence at this time shows that perhaps people's activity, particularly in the southern Cape coast, was affected by the aftermath of Toba. Considering the human response that can be drawn directly from the timing of the YTT deposition at Pinnacle Point 5-6 and the intensity of the site's occupation thereafter, it can be inferred that the aftermath of Toba, though not as severe as hypothesised by the TCT, possibly affected the ecological niches on which people could depend, leading to the sudden intensified human activity at a few localities. In this case, Pinnacle Point site 5-6 landscape, rightfully as a possible refugium, represents some of the habitats that were better resourced at the aftermath of Toba and on which people foraged more frequently in the southern Cape coast. At best, the eruption can be credited for accelerating the innovative capacities, i.e. in lithic technology, by facilitating the frequent interaction of people (and

hence the spread of ideas), when their movement in the region was constrained by the reduced range of resource bases.

The southern Cape coast, including the extinct Palaeo Agulhas Plain, is a resource-rich region that sustained many and varied stone age economies. During MIS 5e-b, this landscape experienced a general and gradual human population increase at many sites including Klasies River, Pinnacle Point 13B, Pinnacle Point 9, Pinnacle Point 5-6, Blombos Caves, Diepkloof Rock Shelter and Ysterfontein (Marean et al., 2014) perhaps due to favourable conditions (Cawthra et al., 2018; Esteban, Marean, et al., 2020; Marean et al., 2014; Nel et al., 2018; Reynard & Henshilwood, 2019). It is under these conditions that thriving MSA societies improved lithic tool making (Brenner & Wurz, 2019; Haaland, 2012; Henshilwood, 2008; Mackay, 2016; Marean, 2010; Wurz, 2012), first showed signs of symbolic behaviour (Henshilwood et al., 2004, 2009) and intentionally manipulated fire as an engineering tool (Bentsen & Wurz, 2019; Brown et al., 2009; Schmidt & Mackay, 2016), leading to the production of lithic tools from heat-treated raw materials c. 71 ka (Brown et al., 2012).

Therefore, at the time of Toba and the subsequent MIS 4 when conditions deteriorated, having predecessors who survived the harsher conditions of the preceding and even colder glacial cycle (MIS 6) (Marean *et al.* 2014), the survivors of Toba were equipped materially and culturally to withstand any potential environmental stress caused by this event, no matter how intense it may have been. The behavioural (cultural) changes seen after this event, however, are simply a product pre- existing adaptation strategies that were retained and then advanced during MIS5/4 transition.

The deposition of the YTT in the east parts of southern Africa has not been identified to date, however, it has been noted that people's migrations between different sites were, occasionally, in response to environmental conditions. This is supported, partly, by occupational pauses/intensities at different archaeological sites. For example, at Melikane Rock Shelter, Wonderkrater, Bushman Rock Shelter and possibly many other MSA sites in the interior, the pauses are often credited to periods of resource scarcity due to subcontinental inland aridity (Backwell et al., 2014; Kristen et al., 2007; Lukich et al., 2020; Porraz et al., 2018; Stewart et al., 2012).

At Melikane Rock Shelter, located on the east interior highlands, occupational pulses and hiatuses have been correlated with the occupation patterns of Sibudu Cave, located on the lowlands with a different ecological setting. During the MIS5 to 4 transition, when Sibudu was continuously occupied, i.e. 77-71 ka, Melikane Rock Shelter underwent a 20 kyr long occupational of between 80 and 60 ka, the longest hiatus identified at the site (Stewart et al., 2012). Previously, Jacobs *et al.* (2008) had argued that the movement of people across different sites in the eastern parts of the subcontinent, i.e. between 60 and 30 ka, was due to a hostile climate in some parts of the landscape, leading to both Sibudu and Border Caves to be occupied episodically. It is likely, therefore, that the occupation of these sites >70 ka coincided with occupation discontinuities/unfavourable conditions elsewhere within the region. Inferring these today, however, is not simple as some archaeological sites with crucial linking clues could even be submerged below the sea today (Jacobs et al., 2008).

Nevertheless, the behavioural complexity that is demonstrated by people who occupied Sibudu Cave, Umhlatuzana Rock Shelter and Border Cave at the MIS 5/4 transition is like that seen in the southern Cape and suggest that these contemporaneous societies shared many cultural traits, including the landscape and its resources. For example, between ~ 73 and 72 ka, Sibudu Cave occupants produced the pre-Still Bay lithic industry, used ochre and marine shells for symbolic expressions and skilfully burned rotten wood to manage fire temperatures (D'Errico et al., 2008; Hodgskiss, 2020; Lennox & Wadley, 2019; Lombard et al., 2019; Lombard & Wadley, 2007; Wadley, 2007, 2012; Wadley et al., 2009; Wojcieszak & Wadley, 2019; Zwane & Bamford, 2021a). At Border Cave, when the Howiesons Poort Industry was made ~74ka, the cave's occupants also showed signs of symbolic behaviour, ingenuity and craftmanship which demonstrated their awareness of their landscape and the variety of resources that were at their disposal (Backwell et al., 2018; D'Errico & Backwell, 2016; Rightmire et al., 1979; Wadley, Backwell, et al., 2020; Wadley, Esteban, et al., 2020; Zwane & Bamford, 2021b).

Investigating the effects of the Toba super eruption on late Pleistocene people in southern Africa, therefore, should carefully consider this behavioural versatility and other social mechanisms that accompanied people's foraging capacities in this region, such that late Pleistocene populations can be afforded an assertive encounter with the Toba that is consistent with archaeological evidence. It cannot be determined, however, at this point

whether the perceived reduction of ecological niches (signified by sporadic occupational fluctuations of archaeological sites) was accompanied by human population reduction. Until such demographic information can be confirmed in southern Africa, the argument about the human genetic bottleneck cannot be engaged here.

7.4 Conclusion

The Toba super-eruption is, unquestionably, very crucial in understanding prehistoric life, and the debate of whether it affected the late Pleistocene ecosystem and people will benefit from considering different perspectives from which to study this event. Palaeoenvironmental evidence that is dated to the time of this event suggests that the TCT overestimated its' impact on global climate. In southern Africa, climatic and environmental data does not support the assumptions of the TCT, although more work needs to be done to locate the YTT and clarify the climatic and ecological backdrop against which it was deposited in various parts of the subcontinent. It is likely that the geographical location and the more influential behaviour of the tropical and temperate climate systems in southern Africa determined the degree to which Toba affected late Pleistocene ecosystem, although this effect may have been variable.

I suggest that the effects of the aftermath of Toba, though not as severe as hypothesised by the TCT, can be inferred from people's movements across the landscape, however this can be confirmed with the identification of the YTT at various more archaeological sites. It is possible that Sibudu and Border caves, like Pinnacle Point cave 5-6, may have been refugia during MIS 5/4, perhaps due to their resource rich landscapes. These would have attracted people from various parts of the subcontinent to suddenly occupy them during times of scarcity, as seen at Pinnacle Point Cave 5-6. Such movements were part of cultural resilience that was shared by MSA populations, based on other movements that can be inferred through site occupational pauses, and were inherited from surviving previous challenging environmental conditions. This ability, along with an innate capacity to develop it, is seen in other activities, including the shared knowledge to produce the Still Bay lithic industry and the use of material objects to convey social values/meanings.

CHAPTER EIGHT- GENERAL CONCLUSIONS

The following points highlight the accomplishments of this study and include the contribution of the research that I conducted to the advancement of knowledge in archaeobotanical, palaeoenvironmental and archaeological investigations in southern Africa, as well as the knowledge about the impact of the Toba super eruption in the subcontinent.

8.1 The use of anthracological methods in addressing wood use and climate related questions in this study

Wood charcoal was analysed for long-term and short-term climatic settings because of the evolutionary history of different woody plants and their ability to store information about the conditions of their growth sites. Two aspects of plant growth were, therefore, used to derive interpretation about the past, (1) evolutionary adaptations (taxonomic classification) and (2) wood structural modification. The results that were derived from these aspects were interpreted for evidence of both environmental setting (climate effects) and wood use (human behaviour).

- The taxonomic identification of woody vegetation in this study proved useful in reconstructing the environmental conditions and evidence of wood use that is dated to the late Pleistocene period. This was done with few problems associated with taphonomy and post depositional processes.
- The taxonomic results of charcoal remains from Sibudu and Border Caves revealed that their immediate landscapes supported different patches of forests between 74 and 72 ka, despite the caves being located only 300 km apart.
- Environmental data interpreted from charcoal/woody species at both sites suggests that: 1) the Sibudu landscape was densely forested - with Afrotemperate, Mistbelt, Scarp forests with some Savanna - and was also warm and humid based on 42 charcoal types that were identified taxonomically. This observation is supported by other environmental proxies from the site. The Border Cave landscape was warm and, comparatively, drier based on abundant Savanna, Grassland and Montane Forest woods

that were identified from 37 taxa; these conditions are also supported by other environmental evidence.

- The quality assessment of archaeological charcoal remains indicated that wood structural deformation, along with fruiting bodies, was due to fungal activity in the Sibudu dataset and that this is comparable to the cell destroying pattern of resupinate fungi (Dr Jacobs-Venter, personal communication). These fungi confirm the presence of warm, shady and humid/moist environmental conditions in the vicinity of Sibudu Cave which persisted consistently between 73 and 72 ka (Talbot, 1958).

- One of the anthracology methods that were recently developed to reconstruct wood log diameters was successfully applied on southern African archaeological charcoal, however, in the future this should be done systematically as part of the main anthracological analysis. This means that this method should be prioritised along with the basic taxonomic identification of different species and done before charcoal samples are fractured to small pieces for a better chance of obtaining reliable results

- At Border Cave, a pronounced seasonal dormancy/activity of unknown fungi (represented by brown threads of hyphae) indicates that some conditions that are conducive for this microbiota to thrive fluctuated between the annual growth seasons of the woody vegetation that was studied; these represent fluctuating conditions during the years, possibly decades prior to 74 ka ± 4 ka.

- The chemical micro analysis of the charcoal fragments that were especially stained (in a blue to yellow, colour) showed that some woody specimens were partially silicified at Border Cave; this process is associated with very warm conditions.

- Based on archaeological woody vegetation that was preserved at Sibudu and Border Caves, the occupants of the two sites consistently collected a limited range of species. The wood gathering behaviours of Border versus Sibudu Cave occupants, for example, reflect a slight contrast in people's needs and adaptation. It seems that people at Sibudu used rotten wood skilfully to manage fire temperatures while at Border Cave there may have been a need to use *Tarchonanthus* species more than others. Furthermore, the wood logs of *Tarchonanthus* species were burned while green, for unknown reasons, based on the consistent presence of radial cracks in the fragments of this taxon.

- The selection of species that are known to have fuel and medicinal advantages against other woods of other calibre and qualities demonstrates skilful behaviour that is reflected in other activities which include the advanced lithic making skills and symbolic behaviour at both caves.

Recommendations

It is recommended that future anthracological assessments continue to study the ring morphology of the species that form distinct growth rings. Changes or variations in wood growth rings can be used to reconstruct wood log diameters. In cases where species of archaeological charcoal samples are known to reliably respond to known climate controls through their ring and vessel morphology, a reconstruction of concerned climate variables should be attempted using such species alone. This will be advantageous to studying climatic events such as the Toba super eruption, which require an understanding of woody vegetation growth at annual resolution.

The use of other ecological markers, represented by the presence of various microorganisms is also recommended. This method must first be developed to understand the wood deformation patterns of many different types of wood infesting microorganisms. This will also require experimentation. For example, this study was limited by the unknown range of wood dwelling insects that could fit the description of the insect damage that was noted at in the charcoal samples from Sibudu Cave.

8.2 The Toba super-eruption and human behavioural evolution in southern Africa

- Sibudu (29°31'21.50"S 31° 5'9.20"E) and Border (27° 1'29.65"S 31°59'20.52"E) Caves are located on the south-east of Africa and approximately 1000 and 1200 km away from Pinnacle Point Caves, respectively, the closest site from which the YTT has been discovered to date. Both caves preserve long archaeological sequences that include evidence for the occupation of the caves between 74 and 72 ka.
- Environmental data and evidence of wood use that was derived from archaeological charcoal do not support the assumptions of the Toba Catastrophe Theory in the localities of the two caves. This is supported by some palaeoenvironmental data and

climate simulation studies, which suggest that the subcontinent was partially insulated from the full impact of this eruption. The results from this research, along with other data complement the idea of a minimal impact from this event.

- It is important to state that, at this stage, it could not be determined if the forests in south-east Africa were affected by some unfavourable growth conditions at the MIS5/4 transition. However, this can be addressed in the future with more evidence.
- Evidence for the mobility of people across the southern African landscape, on the other hand, suggests that some movements at this time may have been due to environmental stress. It is inferred that the intensity of occupation of Pinnacle Point Cave 5-6 following the deposition of the Youngest Toba Tuff, suggests a sudden increase of human populations in parts of the southern Cape coast, perhaps due to unfavourable climate in other parts of the subcontinent. This suggests a sharing of the landscape by late Pleistocene people, a behavioural/cultural trait that is demonstrated through other shared traditions such as lithic tool making and symbolic behaviour.
- To improve the understanding about the possible impact of the 74 ka Toba super eruption in southern Africa, future studies must investigate this event outside the scope of the Toba Catastrophe Theory.

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Appendix A

An appendix of wood features used to identify archaeological charcoal types taxonomically and reference descriptions of contemporary wood descriptions used to identify species from Sibudu Cave. Underlined "Species" have corresponding micrographs in Appendix C.

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
1	*Mystroxylon aethiopicum*	Vessel diameter is 30 µm; Vessel frequency is 150/ mm^2; Solitary vessel arrangement; Perforation plates are simple; Intervessel pits are opposite; Apotracheal parenchyma: banded parenchyma with 3-4 bands/linear mm & 5- 8 cells/band. Rays are Heterocellular, body cells are procumbent with a row of upright cells, rays are 1-3 cells wide and 20 cells high, ray length is <0.5mm; has prismatic crystals in ray cells. Shares many characteristics with other Celastraceae species such as *Maytenus* spp., however prismatic crystals seem consistent in *M. aethiopicum* (Allott 2005: BPI/20/565).
4	*Diospyros austro-africana*	Vessel dimeter is 50 µm; Vessel frequency is 80/mm^2; Solitary and clustered vessels; Perforation plates are simple, Intervessel pits are alternating; Axial parenchyma is rare or absent; Rays are homocellular procumbent; Rays are uniseriate and < 0.5 mm long; has very thin fibre; Prismatic crystals present (Allott 2005: BPI/20/574).
9	*Podocarpus* sp. (new name: *Afrocarpus* sp.)	Wood vesselless; Tracheids present; Rays are homocellular with only procumbent cells; Rays are uniseriate and <0.5mm long Could not be identified to species level however, compared well to *P. latifolius* and *P. falcatus* (Allott 2005: BPI/20/527; Kromhout 1975).
10	*Schotia brachypetala*	Vessel diameter is 55µm; Vessel frequency is 45/mm^2; Vessel are arranged in short-radial multiples; Intervessel pits are bordered and alternating; Axial is paratracheal- vasicentric; Rays are heterocellular: Body ray cells procumbent with 1-2 lines of upright cells, rays are 1-3(-4) cells wide, and <0.5mm high, Ray frequency is 8 rays /lin. mm (Allott 2005: BPI/20/713)
11	*Englerophytum magalismontanum*	Vessel diameter is 30µm; Vessel frequency is 100/mm^2; Vessels are arranged in diagonal and short-radial multiples; Rays are homocellular? All cells upright; Rays are uniseriate to biseriate 1(-2) c and <0,5mm high; Fibres are thin (Allott 2005: BPI/20/678)
12	*Olea capensis*	Vessel diameter is 65 µm; Vessel frequency is 70/mm^2; Perforation plates are simple; Vessels are clustered and in short radial multiples, Intervessel pits alternate; Vessel length is <350, Axial parenchyma is paratracheal- vasicentric; Rays are heterocellular: body rays cells are procumbent with 2-4 rows of square marginal cells, Rays are 1-4 cells wide, and

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
		~0,3mm high, Ray frequency is 8/lin. mm, Fibres are thin-thick walled. Compared closely to (Apiaceae) *Heteromorpha arborescens*, however O. capensis was a better fit (https://insidewood.lib.ncsu.edu/)
13	*Trema orientalis*	Vessel diameter is 60 µm; Vessel frequency is 20/mm^2; Perforation plates are simple; Solitary and clustered vessels; Axial parenchyma is paratracheal- vasicentric; Rays are Heterocellular: square and upright cells noted; Rays are uniseriate to biseriate 1(-2)? Cells; Fibres are very thin walled. Very good match for this species despite a minor mismatch of vessel diameter (Allott 2005: BPI/20/698)
16	*Vepris lanceolata*	Vessel diameter is 40 µm; Vessel frequency 170/mm^2; Perforated plates are simple; Vessels are in short radial multiples, Axial Parenchyma is paratracheal: scanty to vasicentric; Rays are Heterocellular: body cells are procumbent with a row of square marginal cells; Rays are uniseriate with some rays are 1-2 cells wide and <0,5mm high, Fibres are thin-thick walled (Allott 2005: 672)
18	*Dodonea viscosa*	Vessel diameter is 80 µm; Vessel frequency 65/mm^2; Perforation plates are simple; Vessels are arranged in long radial multiples and clusters; Intervessel pits are opposite and elongated; Axial parenchyma is paratracheal: scanty, Rays are Heterocellular: square and upright cells mixed in a ray; Rays are uniseriate (strictly 1 cell wide) and <0,5mm high; Ray frequency is 8-12/lin. mm; Fibres are thin to thick walled; gums inside vessels (https://insidewood.lib.ncsu.edu/)
19	*Strychnos* sp.	Vessel diameter is 46 µm; Vessel frequency is 136/mm^2; Perforation plates are simple; Solitary vessels; Rays are heterocellular body ray cells procumbent with unknown rows of square marginal cells, and are ~ 0,25mm high; Ray frequency is 4 rays /lin. mm, Fibres are thin walled; included phloem is diffuse. Has many features that are common to many *Strychnos* species, i.e. *S. pungens*, *S. gerrardii* (Allott 2005: BPI/20/609-613; https://insidewood.lib.ncsu.edu/)
20	cf. *Bolusanthus speciosus*	Vessel diameter is 35 µm; Vessel frequency is 182/mm^2; Perforation plates are simple, Vessels are arranged in diagonal and short radial multiples; growth ring boundaries are distinct; wood is ring porous; Intervessel pits are opposite and bordered; Axial parenchyma is paratracheal- scanty; Rays are Heterocellular: square and upright cells look mixed in a ray; Rays are uniseriate (1 cell wide); and <0,5mm high; Fibres are thin walled (https://insidewood.lib.ncsu.edu/; Kromhout 1975)
21	*Harpephyllum caffrum*	Vessel diameter 58 µm; Vessel frequency is 170/mm^2; Vessels are arranged in short radial multiple -long radial multiples; Rays are homocellular: all ray cells are procumbent cells; Rays are triseriate (1-3 cells wide); and <0,5mm high; Ray frequency is 12/lin. mm; Fibres are thin-thick walled (Allott 2005: BPI/20/528)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
22	*Ficus burkei*	Vessel diameter is 50 µm; Vessel frequency is 113/mm^2; Perforation plates are simple; Solitary vessels; Axial parenchyma is apotracheal- banded (4 bands/lin. mm and 5-7 cells per band); Rays are Heterocellular: body cells procumbent with ?rows of upright marginal cells; Rays are 1-6 cells wide and >0,5mm high, Ray frequency is 8/lin. mm, Fibres are thin-thick walled (Allott 2005: BPI/20/620)
23	*Cryptocarya woodii*	Vessel diameter is 50 µm; Vessel frequency is 112/mm^2; Simple perforation plates; Vessels are arranged in short radial multiples and and also solitary; growth ring boundaries somewhat distinct; wood is semi-ring porous; Intervessel pits alternate, Helical thickening present; Vessel length is 145-200 µm; Axial parenchyma is diffuse or scanty??; Rays are heterocellular: square and upright cells noted; Rays are 1-4 cells wide and <0,5 high; Ray frequency is 12/lin. mm; Fibres are thin-thick walled; Prismatic crystals in ray cells (Allott 2005: BPI/20/607)
24	*Buxus macowanii*	Vessel diameter 30 µm; Vessel frequency 200+/mm^2; Perforation plates are simple and scalariform perforation plates with 10-20 bars; Solitary vessel; growth ring boundaries are distinct; wood semi-ring porous; axial parenchyma is paratracheal- scanty, Rays are Heterocellular: body ray cells are procumbent with square marginal cells; Rays are biseriate (strictly 1-2 cells wide); and <0,5mm high; Ray frequency is 8-12/lin. mm; Fibres are thin-thick walled (https://insidewood.lib.ncsu.edu/)
27	*Eugenia zeyheri*	Vessel diameter is 35 µm; Vessel frequency is 120/mm^2 ; Perforated plates are simple; Vessels are in short radial multiples and clusters; Intervessel pits alternate; Vessel length is 590 µm; axial parenchyma is apotracheal- diffuse; Rays are heterocellular: body cells are procumbent with upright marginal cells; Rays are biseriate (strictly 1-2 cells wide) and <0,5mm high; Ray frequency is 6-8/lin. mm; Fibres are thin walled; Prismatic crystals are present in ray cells (Kromhout 1975; Oskolski and van Wyk, 2008)
28	cf. *Olax dissitiflora*	Vessel diameter is 50 µm; Vessel frequency is 40/mm^2; Solitary vessels, Rays are homocellular; all cells look procumbent?; Rays are 1-3 cells wide; and <0,5mm high, silica bodies present in ray cells (https://insidewood.lib.ncsu.edu/)
30	*Dombeya tiliaceae*	Vessel diameter is 75 µm; Vessel frequency is 24/mm^2; Vessels are solitary or in short radial multiples; Intervessel pits alternate; Axial parenchyma is paratracheal- scanty; Rays are Heterocellular- body ray cells are procumbent with one row of upright cells; Rays are biseriate (mostly 1-2 cells wide) and <0,5mm high; Ray frequency is 6-8/lin. mm; Fibres are thin walled; prismatic crystals present in ray cells; sheath cells or idioblasts present; oil or mucilage associated with rays (Allott 2005: BPI/20/689)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
31	cf. *Passerina* sp.	Vessel diameter is 45 µm; Vessel frequency 64/mm^2; Vessels arranged in long tangential multiples; Rays look Homocellular-all cells procumbent?; Rays are uniseriate (strictly 1 cell wide) and <0,5mm high; Fibres are thick (Zwane 2018: BPI/20/744)
33	cf. *Androstachys johnsonii*	Vessel diameter is 40 µm; Vessel frequency is 200/mm^2; Perforation plates are simple; Vessels are exclusively solitary; Axial parenchyma is paratracheal- scanty; Rays are Heterocellular- a mixture of upright and square cells; Rays are uniseriate (strictly 1 cell wide) and <0,5mm high; Ray frequency is 8-12/linear mm; Fibres are thick; Fibres are pitted and septate fibres present; Prismatic crystals are present in ray cells (Kromhout 1975; https://insidewood.lib.ncsu.edu/)
35	*Mimusops obovata*	Vessel diameter is 60 µm; Vessel frequency is 115/mm^2; Perforation plates are simple; Vessels are arranged in short and long radial multiples; Growth Ring Boundaries are distinct and wood is semi-ring porous; Intervessel pits alternate; Axial parenchyma is paratracheal- scanty; Rays are Heterocellular- procumbent body cells with more than two rows of upright cells; Rays are uniseriate with some rays have paired cells; rays are <0,5mm high; Ray frequency is 8-12/lin. mm; Fibres are thin walled (Allott 2005: 680)
37	*Buddleja pulchella*	Vessel diameter is 88 µm; Vessel frequency is 35/mm^2; Perforation plates are simple; Vessels are solitary; Axial parenchyma is paratracheal- scanty; Rays are Heterocellular- body cells are procumbent with square marginal cells; Rays are 1-4 cells wide and ~ 0,5mm high; Ray frequency is 8-12/lin. mm; Fibres are thin-thick walled (https://insidewood.lib.ncsu.edu/)
38	*Canthium* sp.	Vessel diameter is 30 µm; Vessel frequency is 170/mm^2 ; Perforation plates are simple; Vessels are solitary; Growth Ring Boundaries are distinct – wood is semi-ring porous; axial parenchyma is paratracheal- scanty?, Raya are Heterocellular- body cells procumbent with rows upright and square marginal cells; Rays are up to 3 cells wide (includes 1, 2, -3) cells and <0,5mm high; Rays frequency is 12-16/lin. mm; Fibres are thin to thick-walled; prismatic crystals present? (Kromhout 1975; https://insidewood.lib.ncsu.edu/)
39	*Chaetachme aristata*	Vessel diameter is 85 µm; Vessel frequency is 30/mm^2; Perforation plates are simple; Vessels are solitary and also in short radial multiples; Intervessel pits alternate and are 4-12 µm wide; Vessel length is approximately 200 µm; Axial parenchyma is apotracheal- banded (6 bands per lin. mm)(3-6 cells per band); Rays are Heterocellular- upright and square cells mixed through the ray; Rays are 1-3 cells wide and ~0,5mm high; Ray frequency is 6/lin. mm; Fibres are thin-walled (https://insidewood.lib.ncsu.edu/)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
41	*Cordia caffra*	Vessel diameter is 120 µm; Vessel frequency is 15/mm^2; Perforation plates are simple; Vessels are solitary; Growth ring boundaries are indistinct; Axial parenchyma is paratracheal- confluent; Rays are Heterocellular- body cells procumbent with square marginal cells; Rays are 1-5 cells wide and <0,5mm high; Ray frequency is 4-8/lin. mm; gums and tyloses inside vessels (Allott 2005: BPI/20/557)
42	cf. *Baphia racemosa*	Vessel diameter is 15 µm; Vessel frequency is 50/mm^2; Vessels are solitary; Axial parenchyma is apotracheal- irregularly banded; Rays are homocellular square ray cells?; Rays are uniseriate (strictly 1 cell wide); Fibres are very thick walled (Allott 2005: BPI/20/ 728)
43	*Allophylus* sp.	Vessel diameter is 35 µm; Vessel frequency is 200/mm^2; Perforation plates are simple; Vessels are solitary; Intervessel pits alternate; Axial parenchyma is paratracheal- scanty; Rays are Homocellular- all cells procumbent; Rays are 1 cell wide; and <0,25mm high; Ray frequency is 8-12/lin. mm; Fibres are thin to thick-walled (https://insidewood.lib.ncsu.edu/)
51	*Vitex rhemannii*	Vessel diameter is 35 µm; Vessel frequency is 130/mm^2; Perforation plates are simple; Vessels are solitary; Growth Ring Boundaries are distinct- wood ring porous; Intervessel pits alternate; Rays are Homocellular- procumbent? cells?; Rays are biseriate 1-2 cells and <0,5mm high; Ray frequency is 6-8/lin. mm; Fibres are thin to thick-walled (Allott 2005: BPI/20/702)
55	cf. *Rauvolfia caffra*	Vessel diameter is 60 µm; Vessel frequency is 100/mm^2; Perforation plates are simple; Vessels are clustered/ in short radial multiples; Axial parenchyma is paratracheal- scanty?; Rays are heterocellular procumbent and upright marginal cells?; Rays are 1-6 cells wide and <0,5mm; Ray frequency 6-8/lin. mm; Fibres are thin-walled (https://insidewood.lib.ncsu.edu/)
56	*Commiphora* cf. *marlothii*	Vessel diameter is 45 µm; Vessel frequency is 90/mm^2; Perforation plates are simple; Vessels are in short radial multiple/ sometimes solitary; Growth ring boundaries are distinct- wood is semi-ring porous; Axial parenchyma is paratracheal- scanty/rare; Rays are Heterocellular- body cells procumbent with upright and square marginal cells; Rays are 1-2-3 cells wide and <0,5mm; Ray frequency is 8-12/lin. mm; Fibres are thin to thick-walled; Prismatic crystals in ray cells (Allott 2005: BPI/20/559)
57	*Vachellia* (*Acacia*) *erioloba*	Vessel diameter is 60 µm; Vessel frequency 90/mm^2; Perforation plates are simple; Vessels are in short radial multiples, Growth ring boundaries are indistinct; Axial parenchyma is paratracheal- vasicentric to aliform; Rays are Heterocellular-

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
		body cells procumbent with square marginal cells; Rays are 1-3 cells wide and <0,5mm high; Ray frequency is 10-12/lin. mm; Fibres are thin to thick-walled. Also compares well to *A. nilotica, A. robusta, A. sieberiana* (Allott 2005: BPI/20/717)
59	cf. *Deinbollia* sp.	Vessel diameter is 65 µm; Vessel frequency is 35/mm^2; Vessel are solitary/clustered; Growth ring boundaries are indistinct; Intervessel pits: shape of alternate pits polygonal; Axial parenchyma is paratracheal-scanty; Rays are Heterocellular- body cells procumbent with square marginal cells; Rays are uniseriate 1 cell wide and sometimes 1(-2) cells wide and <0,25mm high; Ray frequency 8-12/lin. mm; Fibres are thin-walled; gums & tyloses in vessels (Allott 2005: BPI/20/674)
60	*Strychnos decussata*	Vessel diameter is 35 µm; Vessel frequency is 56/mm^2; Perforation plates are simple; Vessels are solitary; Growth ring boundaries are distinct – porosity: wood diffuse porous; Intervessel pits are opposite and bordered; Vessel length is approximately 296 µm; Axial parenchyma paratracheal- scanty; Parenchyma strands: >4 cells per strands; Rays are Heterocellular- body cells are procumbent with1-2 rows of square and upright cells; Rays are 1-5 cells wide and 0,5-1mm high; Ray frequency is 4-6/lin. mm; Fibres are thin and pitted; Prismatic crystals present in ray cells; Included phloem concentric (https://insidewood.lib.ncsu.edu/)
62	*Dombeya burgessiae*	Vessel diameter is 65 µm; Vessel frequency is 32/mm^2; Perforation plates are simple; Vessels are clustered, Growth ring boundaries are indistinct; Vessel length is approximately 156 µm; Axial parenchyma is paratracheal- vasicentric to confluent, Rays are Heterocellular- body cells are procumbent one row of square marginal cells; Rays are 1-2(-3) cells wide and <0,25mm high; Ray frequency is 8-12/lin. mm; Fibres are thin-walled; septate fibres noted; tyloses sclerotic in vessels and storied fibres present (https://insidewood.lib.ncsu.edu/)
63	*Burkea africana*	Vessel diameter is 120 µm; Vessel frequency is 15/mm^2; Perforation plates are simple; Vessels are in short radial multiples; Intervessel pits alternate and are polygonal-shaped?; Axial parenchyma is paratracheal- vasicentric to confluent; Rays are Homocellular- all cells procumbent?; Rays are 1-2-3 cells wide and <0,5mm high; Ray frequency is 4-8/lin. mm; Fibres are thin to thick-walled; tyloses and gums inside vessels (Allott 2005: BPI/20/711)
64	*Spirostachys africana*	Vessel diameter is 55 µm; Vessel frequency is 82/mm^2; Perforation plates are simple; Vessels are clustered and in short radial multiples; Axial parenchyma paratracheal-vasicentric; Rays are Heterocellular- body cells procumbent with some rows of upright and square marginal cells; Rays are uniseriate (strictly 1 cell wide) and <0,5mm; Ray frequency is 4-8/lin. mm; Fibres are thin-walled (Allott 2005: BPI/20/ 597; https://insidewood.lib.ncsu.edu/)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
65	*Apodytes dimidiata*	Vessel diameter is 75 µm; Vessel frequency is 230/mm^2; Perforation plates are scalariform with <10 bars; Vessels are solitary/clustered; Growth Ring Boundaries are distinct - wood diffuse porous; Intervessel pits are round- opposite and bordered; Vessel length is 300 µm; Axial parenchyma is rare; Rays are Heterocellular- body cells are procumbent and upright marginal cells; Rays are 1-2 cells wide and <0,5mm high; Ray frequency is 6-8/lin. mm; Fibres are thin walled and pitted (Allott 2005: BPI/20/603)
66	*Ptaeroxylon obliquum*	Vessel diameter is 55 µm; Vessel frequency is 100/mm^2; Perforation plates are simple; Vessels are in long and short radial multiples; Intervessel pits alternate; Axial parenchyma is rare, Rays are Homocellular- all cells procumbent; Rays are uniseriate strictly 1 cell wide and <0,5mm; Ray frequency is 8-12/lin. mm; Fibres are thin walled; gums and other deposits inside vessels (Allott 2005: BPI/20/644; https://insidewood.lib.ncsu.edu/)
67	*Catha edulis*	Vessel diameter is 35 µm; Vessel frequency is 220/mm^2; Perforation plates are simple; Vessel are solitary; Axial parenchyma is rare; Rays are 1-2-3 cells wide, more than 50 cells high and >1mm high; Ray frequency is 8-12/lin. mm; Fibres are thin walled (Kromhout 1975; https://insidewood.lib.ncsu.edu/)
69	*Searsia chirindensis*	Vessel diameter is 60 µm; Vessel frequency is 50/mm^2; Perforation plates are simple; Vessel are arranged in short radial multiples; Vessel length is 265 µm; Axial parenchyma is paratracheal- scanty to vasicentric; Rays are Homocellular- square? ray cells; Rays are biseriate and <0,5mm, Ray frequency is 16-20/lin. mm; Fibres are thin walled (Allott 2005: BPI/20/533)
70	*Dombeya kirkii*	Vessel diameter is 25 µm; Vessel frequency is 68/mm^2; Vessels are solitary; Axial parenchyma is rare; Rays are Heterocellular- body cells are procumbent with square marginal cells; rays are 1-2-3-4 cells wide and <0,5mm; Ray frequency is 12-16/lin. mm; Fibres are thin walled; has prismatic crystals in ray, storied fibres and parenchyma cells (Kromhout 1975; https://insidewood.lib.ncsu.edu/)
71	*Cryptocarya myrtifolia*	Vessel diameter is 45 µm; Vessel frequency is 53/mm^2; Perforation plates are simple; Vessels are arranged in short radial multiples but also has solitary vessels; Intervessel pits alternate; Vessel length is approximately 265 µm; Axial parenchyma is paratracheal- vasicentric; helical thickening present; Rays are Heterocellular- body cells are procumbent and has upright marginal cells; Rays are 1-6 cells wide and <1mm high; Ray frequency is 10-12/lin. mm, Fthks: thin-thick; Secretory elements noted- oil and /or mucilage cells associated with ray parenchyma; gums & other deposits inside vessels. Also compares closely to *C. liebertiana* (Allott 2005: BPI/20/605)

Appendix B

An appendix of wood features used to identify archaeological charcoal types taxonomically and reference descriptions of contemporary wood descriptions used to identify species from Border Cave. Underlined 'Species' names have corresponding micrographs in Appendix D

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
1	*Vachellia sieberiana*	Vessels are solitary and clustered; Vessel frequency is 5-20/mm^2; Vessel diameter is 100-200 µm; Intervessel pits alternate; Axial parenchyma lozenge-aliform; Rays are commonly 4-10 seriate; Homocellular rays: all ray cells procumbent; Prismatic crystals present (ESI herbarium samples: BPI/20/ 74, BPI/20/ 75 and BPI/20/721)
2	cf. *Heywoodia lucens*	Wood diffuse-porous; Vessels in radial multiples of 4 or more common; Scalariform perforation plates with <= 10 bars; Vessel diameter: <=50 µm; Vessel frequency: 100-200/mm^2; Axial parenchyma diffuse; Ray width 1 to 3 cells; Heterocellular rays- procumbent cells with more than one row of marginal upright/square cells; Ray frequency: >=12. This identification is not certain because the archaeological sample also shares many features with two Rutaceae species, *Vepris reflexa* and *V. lanceolata*. (Kromhout 1975 & ESI sample: BPI/20/293)
3	*Senegalia* sp.	Vessels are solitary and clustered; Vessel frequency is 5-20/mm^2; Vessel diameter is 100-200 µm; Intervessel pits alternate; Axial parenchyma confluent; Ray width 1 to 3 cells; Larger rays commonly 4 - to 10 seriate; All ray cells procumbent; Prismatic crystals in chambered axial parenchyma cells. The difference between *Vachellia* and *Senegalia* species based on wood anatomy is not obvious. There are many overlaps in the occurrence and variation of diagnostic features such as the vessel arrangement, parenchyma, ray size. However, based on the authors' ongoing detailed study of *Vachellia* and *Senegalia* species, there is one difference noted about the rays of the two genera. The genus *Senegalia* has species that commonly have mixed ray width classes of both 1-3 cells wide and 4-10 cells wide. On the other hand, *Vachellia* species seem to have rays that are consistently 4-10 seriate. Archaeological fragments of this type have ray width range that is more similar to the genus *Senegalia* than to *Vachellia*. (InsideWood and 30 samples from ESI herbarium)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
4	cf. *Chionanthus foveolatus*	Distinct growth ring boundaries; Wood semi-ring porous; Vessels are in radial multiples; Intervessel pits are minute; Vessel diameter: <=50 µm; Vessel frequency: 200-300/mm^2; Fibre pits are common on radial and tangential walls; Fibres are thin-walled; Axial parenchyma absent or extremely rare; Homocellular rays- all cells procumbent, Ray frequency: 4-12, rays are storied. The description also compares with that of some species within the Burseraceae family, i.e. the genus *Commiphora* (Allott 2005: LFA107)
5	cf. *Rauvolfia caffra*	Vessels exclusively solitary (90% or more) with some paired vessels; Intervessel pits small to minute: 4 - 7 µm; Vessel diameter: <=50 µm; Vessel frequency: 40-100; Tracheids present; non-septate fibres; Axial parenchyma diffuse; Rays are 1-4 cells wide and some 4-10 cells wide; Heterocellular rays- mixed procumbent, square and upright cells in the ray; Prismatic crystals in ray cells. Archaeological description compares, to some degree, with the wood anatomy of *Rapanea melanophloes* (InsideWood & Kromhout 1975)
9	*Diospyros dichrophylla*	Wood diffuse porous; Vessels in radial multiples; Vessel diameter: <=50 µm; Vessel frequency: 100-200/mm^2; Axial parenchyma diffuse; Heterocellular rays, body cells procumbent with 2 lines of upright/square cells (Zwane 2018: BZ012, BZ014 & Lennox: SJL152)
12	*Vachellia* sp. 1	Wood diffuse porous; Vessels are solitary and in short radial multiples; Vessel diameter: 100-200 µm; Vessel frequency: 5-20/mm^2; Axial parenchyma confluent; Larger rays commonly 4 - to 10 seriate; Homocellular rays- all cells procumbent; Prismatic crystals in chambered parenchyma cells. Archaeological fragments share more ray features with species that belong to genus *Vachellia* than *Senegalia,* i.e rays that are consistently 4-10 seriate. (InsideWood and 30 samples from ESI herbarium)
14	*Mystroxylon aethiopicum*	Wood diffuse porous; Vessels are solitary; Vessel diameter <=50 µm; Vessel frequency: 40-100/mm^2; Thick fibres; Banded parenchyma in bands that are >3 cells wide; Rays are 1-2(-3) cells wide; Heterocellular rays- body ray cells procumbent with more than 4 rows of upright/square marginal cells, Crystals present in ray cells. Shares many features

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
		with other Celastraceae species. However, this identification is certain because of the ray cell arrangement on the radial longitudinal section as well as the presence of crystals. The number of parenchyma cells per band on the transverse was also used to distinguish between the Celastraceae species, however there are overlaps in this feature especially between *M. aethiopicum* and *Pterocelastrus tricuspidatus* (Allott 2005: LFA39)
18	*Tarchonanthus* sp.	Wood semi-ring porous; Vessels in radial multiples; Vessel diameter: <=50; Vessel frequency: 50-100/mm^2; Axial parenchyma diffuse; Rays are biseriate; Heterocellular rays- body ray cells procumbent with 2-4 rows of upright/square marginal cells, it is very difficult to distinguish from other *Tarchonanthus* species, such as *T. trilobus*, *T. littoralis* and *T. galpinii* (Lennox 2016: SJL96, 107, 108, 161, InsideWood)
19	*Chionanthus battiscombei*	Wood diffuse porous; Vessels are solitary and clustered; Vessel diameter: <=50 µm; Vessel frequency: 40-100/mm^2; 5-8 cells per parenchyma strand; Rays are1-3 cells wide; Heterocellular rays- body ray cells procumbent with one row of upright/square cells (Allott 2005: LFA106)
20	*Podocarpus/ Afrocarpus* sp.	Growth ring boundaries are distinct; Wood is vesselless; Rays uniseriate; Separate pits on tracheids; Uniseriate rays; Rays Homocellular rays- all cells procumbent (Kromhout 1975)
22	*Protea* sp. 1	Wood diffuse porous; Vessels are solitary; Intervessel pits are bordered; Vessel diameter: <=50 µm; Vessel frequency: 100-200/mm^2; Fibres are thin-walled; Axial parenchyma absent or extremely rare; Ray height > 1 mm; Heterocellular rays- body cells procumbent with more than 4 rows of upright/square cells (Allott 2005: LFA115, 116, 117, Lennox: SJL18, 46)
23	*Vachellia* sp. 2	Wood diffuse porous; Vessels are solitary and short radial multiple; Vessel diameter: 100-200 µm; Vessel frequency: 5-20/mm^2; Axial parenchyma confluent; Parenchyma strands >8 cells long; Rays commonly 4-10 cells wide; Ray height > 1 mm; Homocellular rays- all cells procumbent; Prismatic crystals present. Archaeological fragments share more ray features with species that belong to genus *Vachellia* than to *Senegalia* i.e rays that are consistently 4-10 seriate. (InsideWood and 30 samples from ESI herbarium)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
24	*Sterculia rogersii*	Vessels are solitary; Intervessel pits are alternate; Vessel diameter: 100-200 µm; Vessel frequency: 5-20/mm^2; Axial parenchyma is diffuse in aggregates and vasicentric; 8 cells per parenchyma strand; Ray height > 1 mm; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray. Compares better to *S. rogersii* than to *S. murex* because of the ray cell arrangement on the RLS (Lennox: SJL19)
25	*Senegalia ataxacantha*	Wood diffuse porous; Vessels are solitary and short radial multiple; Vessel diameter: 50-100 µm; Vessel frequency: 20-40/mm^2; Axial parenchyma aliform; Ray width 1 to 3 cells; Larger rays commonly 4 - to 10 seriate; Homocellular rays- all cells procumbent; Prismatic crystals in chambered axial parenchyma cells (Kromhout 1975, Chikumbirike 2014: Z12 & Allott 2005: LFA189)
26	*Apodytes dimidiata*	Wood semi ring porous; Vessels are solitary; Scalariform perforation plates with 10-20 bars, Vessel diameters: 50-100 µm; Vessel frequency: >=100/mm^2; Axial parenchyma scanty paratracheal; Ray width 1 to 3 cells; Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (InsideWood, Kromhout 1975 & Allott 2005: LFA77)
31	*Vachellia tortilis*	Wood diffuse porous; Vessels are solitary; Vessel diameter: 50-100 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma confluent with wide bands that are >3cells wide; Larger rays commonly 4 - to 10 seriate; Homocellular rays- all cells procumbent; Prismatic crystals in parenchyma cells (Allott 2005: LFA196 & Kromhout 1975)
32	*Sclerocarya birrea*	Wood diffuse porous, Vessels are solitary; Vessel diameter: 50-100 µm; Vessel frequency: 20-40/mm^2; Gums and tyloses present; Fibres are thin-walled; Septate fibres present; Axial parenchyma vasicentric; Ray width 1 to 3 cells; Heterocellular rays-body ray cells procumbent with more than 4 rows of upright/square marginal cells; Radial canals; Prismatic crystals present. Compares well with many samples of this species, however there might be a variation in the width of the rays, i.e., not consistently 1-3 cells wide (BPI/20/ 30, Allott 2005: LFA15 & Chikumbirike 2014: Z111)

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
33	*Gymnosporia nemorosa*	Wood diffuse porous; Vessel are mostly solitary; Vessel diameter: <=50 µm; Vessel frequency: 100-200/mm^2; Axial parenchyma in bands that are >3 cells wide; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray (Zwane 2018: BZ060)
34	*Brachylaena* cf. *discolor*	Wood diffuse porous; Vessels are solitary and in short radial multiples, also vessel clusters are common; Vessel diameter: <=50 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma scanty paratracheal; Rays are uniseriate; Heterocellular rays - procumbent, square and upright cells mixed throughout the ray; Fibres are storied (InsideWood & Lennox 2016: SJL56)
36	*Maytenus* sp.	Wood diffuse porous; Vessels in radial multiples; Intervessel pits are alternating; Vessel diameter: 50-100 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma vasicentric; Rays are biseriate; Heterocellular rays- body cells procumbent with 2 rows of upright/square cells. Could be *M. acuminata*, however compares better with a *Maytenus* species in Allots' collection that was not originally identified to species level (Allott 2005: LFA36 & InsideWood)
37	*Euphorbia* sp.1	Wood diffuse porous; Vessels in short radial multiple; Intervessel pits are alternate; Vessel diameter: <=50 µm; Vessel frequency: 20-40/mm^2; Septate fibres present; Fibres are thin-walled; Axial parenchyma is scanty; Rays are uniseriate; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray; Laticifers present. Three different species Euphorbia were studied for a positive identification; namely: *E. ingens*, *E. confinalis* and *E. tirucalli,* however the anatomy of these species is slightly different from this description (Lennox: SJL171, InsideWood & Mennega 2005)
38	*Lannea discolor*	Wood diffuse porous; Vessels are in short radial multiples; Vessel diameter: 50-100 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma scanty paratracheal; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray, Radial canals present and crystals also present. The sample was also compared to *L. schweinfurthii* however it compares better to *L. discolor* (InsideWood)
39	*Allophylus* sp.	Wood diffuse porous; Vessels are solitary and in short radial multiples; Vessel diameter: <=50 µm; Vessel frequency: 40-100/mm^2; Gums and other posits inside vessels; Fibre pits are common on the longitudinal walls; Axial parenchyma

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
		absent or extremely rare; Rays are uniseriate; Homocellular rays- all rays procumbent, very few crystal-like features are visible in this sample (InsideWood)
40	*Vachellia robusta*	Wood diffuse porous; Vessels are solitary and some in short radial multiples; Vessel diameter: 50-100 µm; Vessel frequency: 20-40/mm^2; Axial parenchyma confluent; Rays are commonly more than 4 cells wide; Homocellular rays- all cells procumbent; Few crystals visible inside parenchyma cells (ESI samples: BPI/20/228, BPI/20/249, BPI/20/432, BPI/20/720)
41	*Protea* cf. *roupelliae*	Wood diffuse porous; Vessels are solitary and a few in short radial multiples; Vessel diameter: 50-100 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma vasicentric; Rays >10 cells wide; Ray height > 1 mm; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray; Ray frequency: <=4 (Lennox, Allott 2005: LFA116)
42	*Senegalia caffra*	Wood diffuse porous; Vessels are solitary and in short radial multiple; Intervessel pits are alternating; Vessel diameter: 100-200 µm; Vessel frequency: 5-20/mm^2; Fibres are thin walled; Axial parenchyma aliform; Rays 1-3 cells wide; Homocellular rays-all rays procumbent (Lennox: SJL120, InsideWood, DeChamps 1993)
43	*Dichrostachys cinerea*	Wood diffuse porous; Vessels are solitary and short radial multiple; Intervessel pits are alternating; Vessel diameter: 50-100 µm, Vessel frequency: 40-100/mm^2; Tyloses are present inside vessels; Axial parenchyma scanty paratracheal to vasicentric; Rays are 1-3 cells wide; Homocellular rays- All ray cells procumbent, but look Heterocellular on first glance, some ray cells on the radial walls oddly shaped (Chikumbirike 2014: Z6, ESI sample: BPI/20/7, Allott 2005: LFA200 & InsideWood)
44	*Ozoroa* cf. *paniculosa*	Wood diffuse porous; Vessels are solitary; Vdiam: 50-100 µm; Vessel frequency: 40-100/mm^2; Intervessel pits alternate; Fibres are thin-walled; Septate fibres present; Axial parenchyma scanty paratracheal; Rays 1-3 cells wide Heterocellular rays- body cells procumbent with more than 4 rows of upright/ square cells (ESI sample: BPI/20/15, Allott 2005: LFA4 & InsideWood)

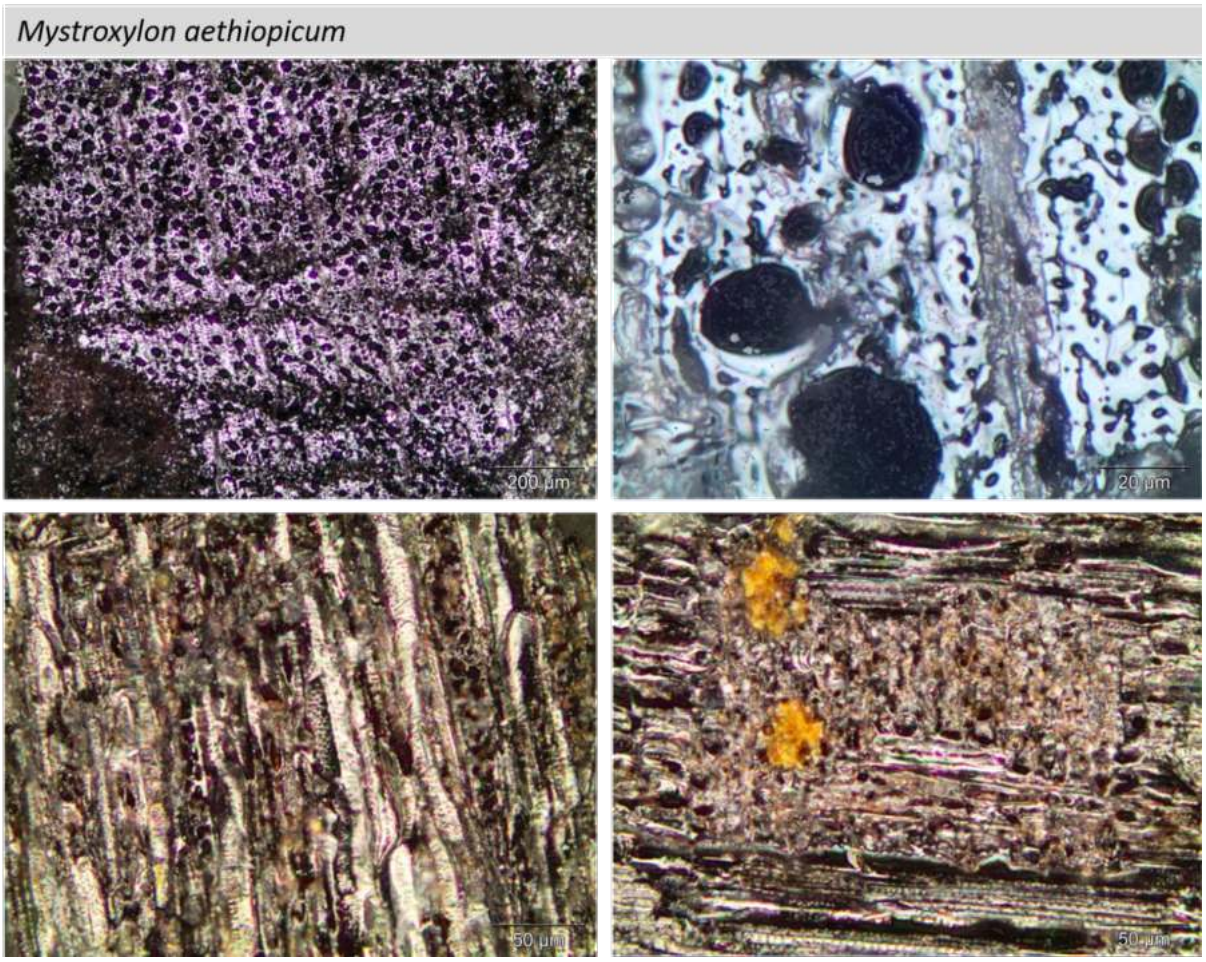
Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
46	*Diospyros natalensis*	Wood diffuse porous; Vessels in short radial multiples; Vessel diameter: <=50 µm, Vessel frequency: 40-100/mm^2; Vlngth: <350, Fibres are thin walled; Axial parenchyma scanty paratracheal; Rays are uniseriate; Homocellular rays- upright cells. Was compared also to *D. lycoides*, however the rays of this species are too many (Allott 2005: LFA50)
47	*Searsia lancea*	Wood diffuse porous; Vessels are solitary and in short radial multiple; Intervessel pits are alternating; Vessel diameter: 50-100 µm; Vessel frequency: 40-100/mm^2; Axial parenchyma diffuse; Rays 1-2(-3) cells wide; Heterocellular rays- procumbent, square and upright cells mixed throughout the ray; Radial canals present (ESI sample: BPI/20/42, Allott 2005: LFA12 & Kromhout 1975)
48	*Euphorbia* sp.2	Wood diffuse porous; Vessels mostly in short radial multiples; Intervessel pits are scalariform; Vessel diameter: 100-200 µm; Vessel frequency: 5-20/mm^2; Vessel element length: 350-800 µm; Axial parenchyma scanty paratracheal; Rays mostly uniseriate and short; Homocellular rays- all rays upright. The sample compares very well with the description of *E. candelabrum*, however, the archaeological sample crumbled into powdery pieces before laticifers could be noted as required for this species (InsideWood & Mennega 2005)
49	*cf. Protea* sp. 2	Wood diffuse porous; Vessels are solitary; Vessel diameter: <=50 µm; Vessel frequency: >=100/mm^2; Axial parenchyma scanty paratracheal; Rays more than 3 cells wide; some rays up to 1 mm long; Heterocellular rays- procumbent, square and upright cells mixed throughout the rays. This type generally shares many features with species belonging to genus *Protea* however could not be identified to species level due to a lack of distinctive features (Allott 2005: LFA117 & ESI sample: BPI/20/226)
50	*Brachylaena huillensis*	Wood diffuse porous; Vessels in radial multiples of 4 or more common; Vessel diameter: <=50 µm; Vessel frequency: 40-100/mm^2; Fibres very thick-walled; Axial parenchyma scanty paratracheal; Ray width 1 to 3 cells wide; Rays Homocellular- all rays procumbent; Storied structure present, all ray cells storied (InsideWood)
55	*Searsia chirindensis*	Wood diffuse porous; Vessel are solitary with a few short radial multiples; Vessel diameter: 50-100 µm; Vessel frequency: 20-40/mm^2; Axial parenchyma vasicentric; Rays 1-3 cells wide; Heterocellular rays- procumbent, square and

Type no.	Species	Important diagnostic wood features noted in the archaeological fragments (reference for contemporary species description)
		upright cells mixed throughout the ray; Prismatic crystals in ray cells (Chikumbirike 2014: Z37, Allott 2005: LFA7 & Kromhout 1975)
56	*Combretum krausii*	Wood diffuse porous; Vessels are solitary; Vessel diameter: 50-100 µm; Vessel frequency: 20-40/mm^2; Axial parenchyma aliform; Rays are uniseriate; Heterocellular rays- procumbent, square and upright cells mixed in a ray; Ray frequency: >=12, Included phloem diffuse (Lennox: SJL76, Kromhout 1975, Allott2005: LFA43 & InsideWood)
57	*Colophospermum mopane*	Wood diffuse porous; Vessels in short radial multiple; Intervessel pits are small; Vessel diameter: 50-100 µm; Vessel frequency: 5-20/mm^2; Gums and other deposits; Axial parenchyma is vasicentric; Biseriate and short rays; Homocellular rays- all cells procumbent; Prismatic crystals present in chambered axial parenchyma cells (InsideWood, Kromhout 1975 & Lennox: SJL6)

Appendix C - Micrographs of some archaeological samples from Sibudu Cave that were identified with certainty. Species are in order of type numbers.

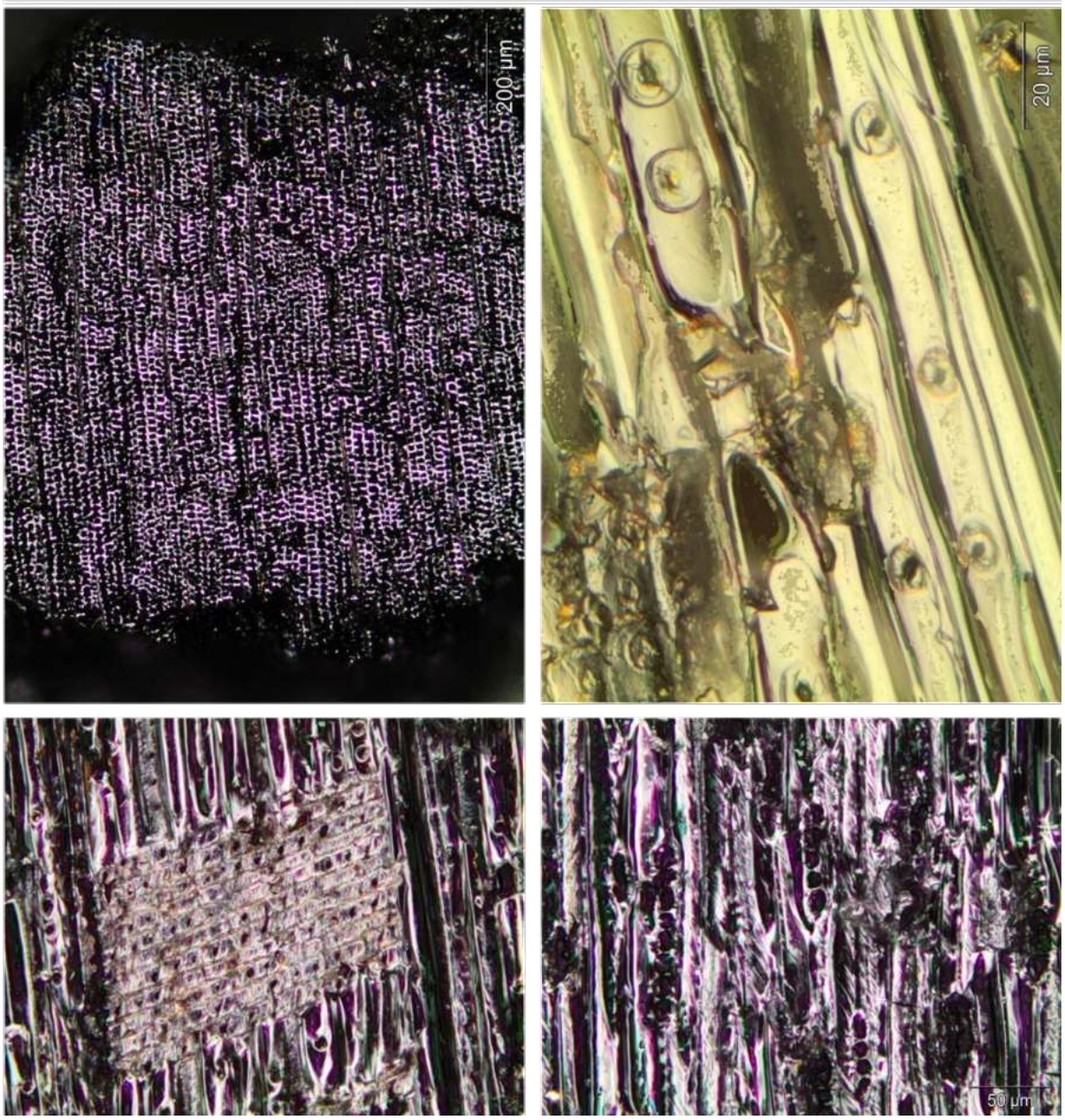
Type #	Species name
1	*Mystroxylon aethiopicum*
9	*Podocarpus/Afrocarpus* sp.
11	*Englerophytum magalismontanum*
13	*Trema orientalis*
18	*Dodonea viscosa*
19	*Strychnos* sp.
21	*Harpephylum caffrum*
23	*Cryptocarya woodii*
27	*Eugenia zeyheri*
30	*Dombeya tiliaceae*
35	*Mimusops bovata*
41	*Cordia caffra*
43	*Allophylus* sp.
56	*Commiphora marlothii*
57	*Vachellia erioloba*
60	*Strychnos decussata*
62	*Dombeya burgessiae*
65	*Apodytes dimidiata*
66	*Ptaeroxylon obliquum*
69	*Searsia chirindensis*
70	*Dombeya kirkii*
71	*Cryptocarya myrtifolia*

Type 1



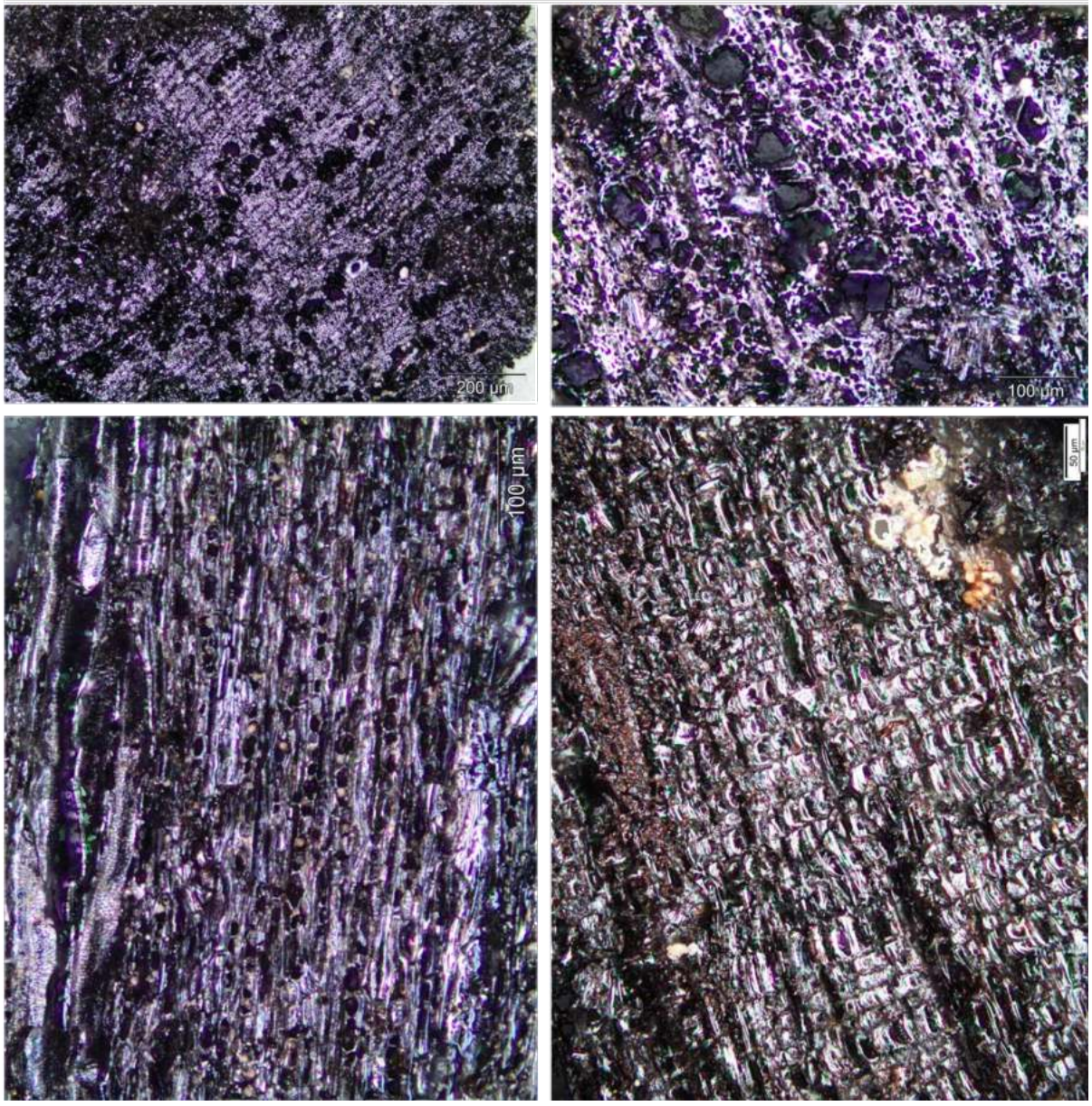
Type 9

Podocarpus /Afrocarpus sp.

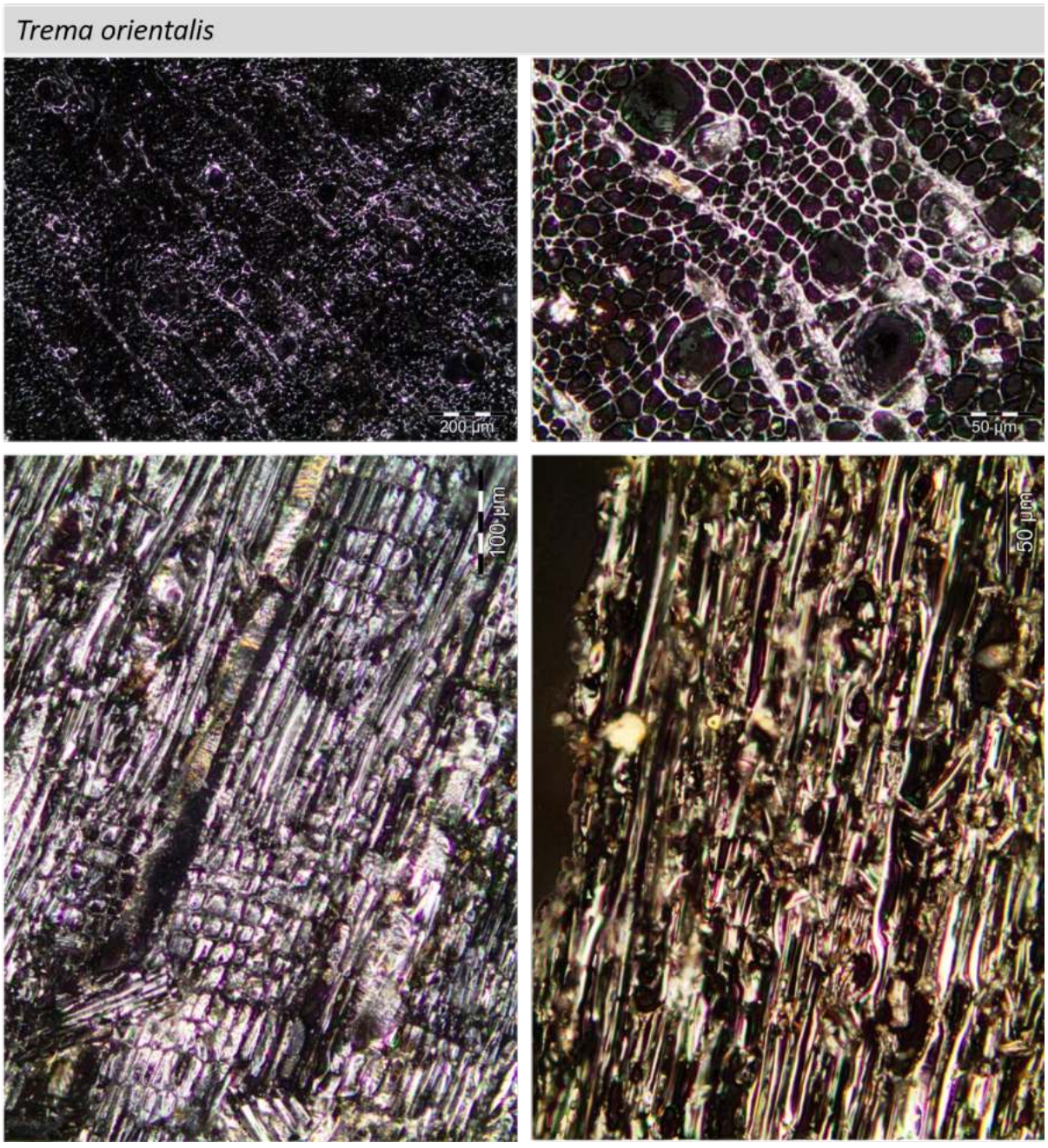


Type 11

Englerophytum magalismontanum

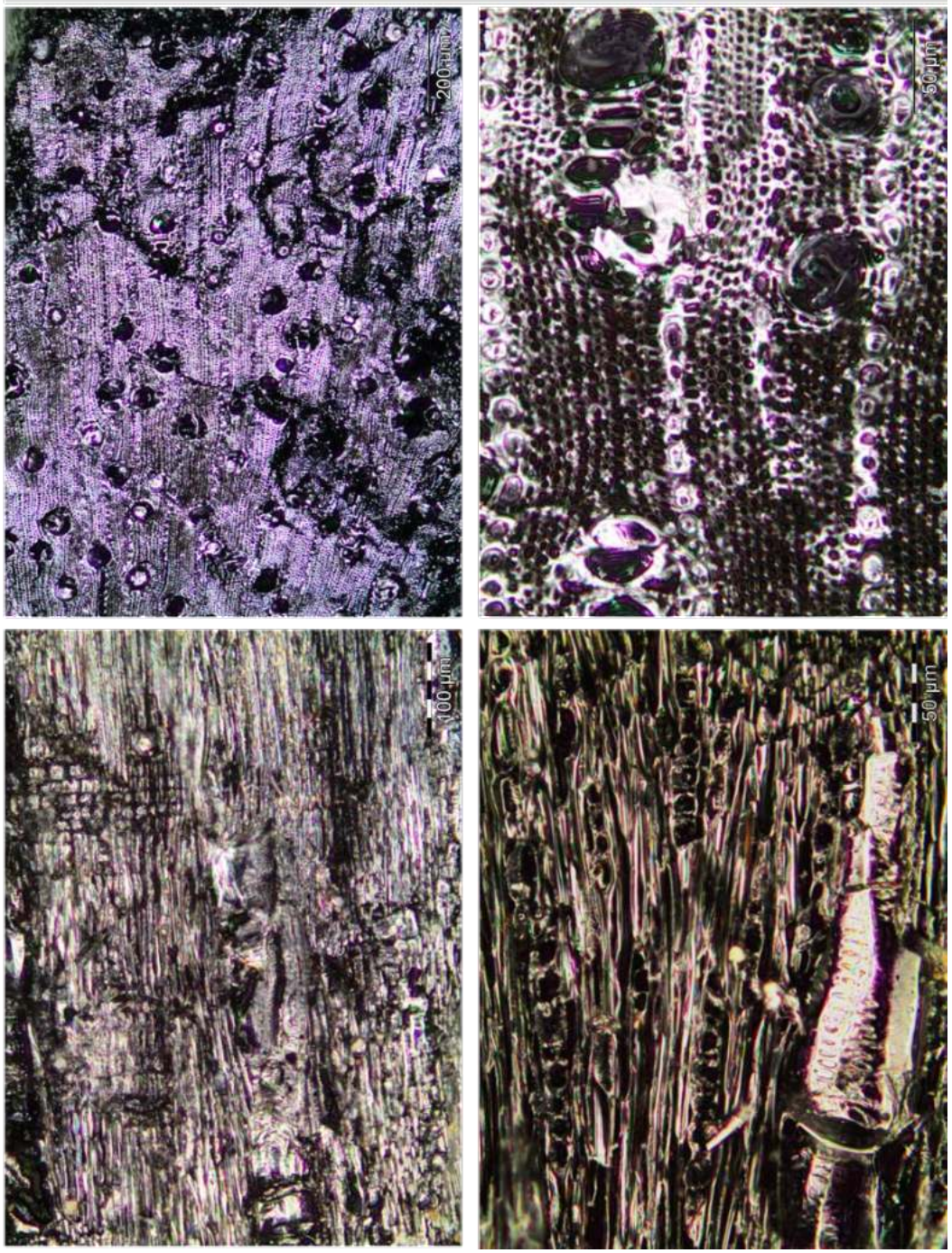


Type 13



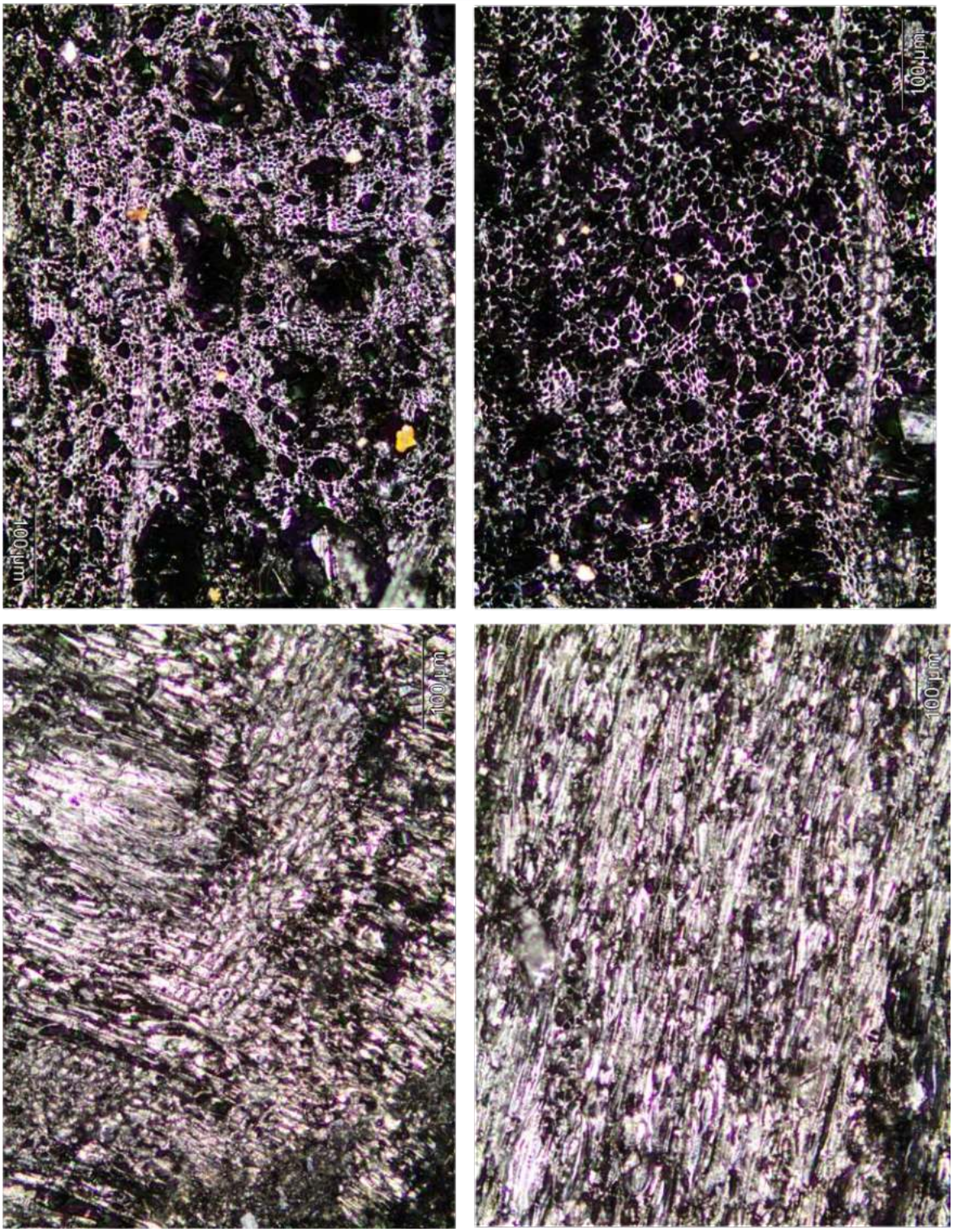
Type 18

Dodonea viscosa



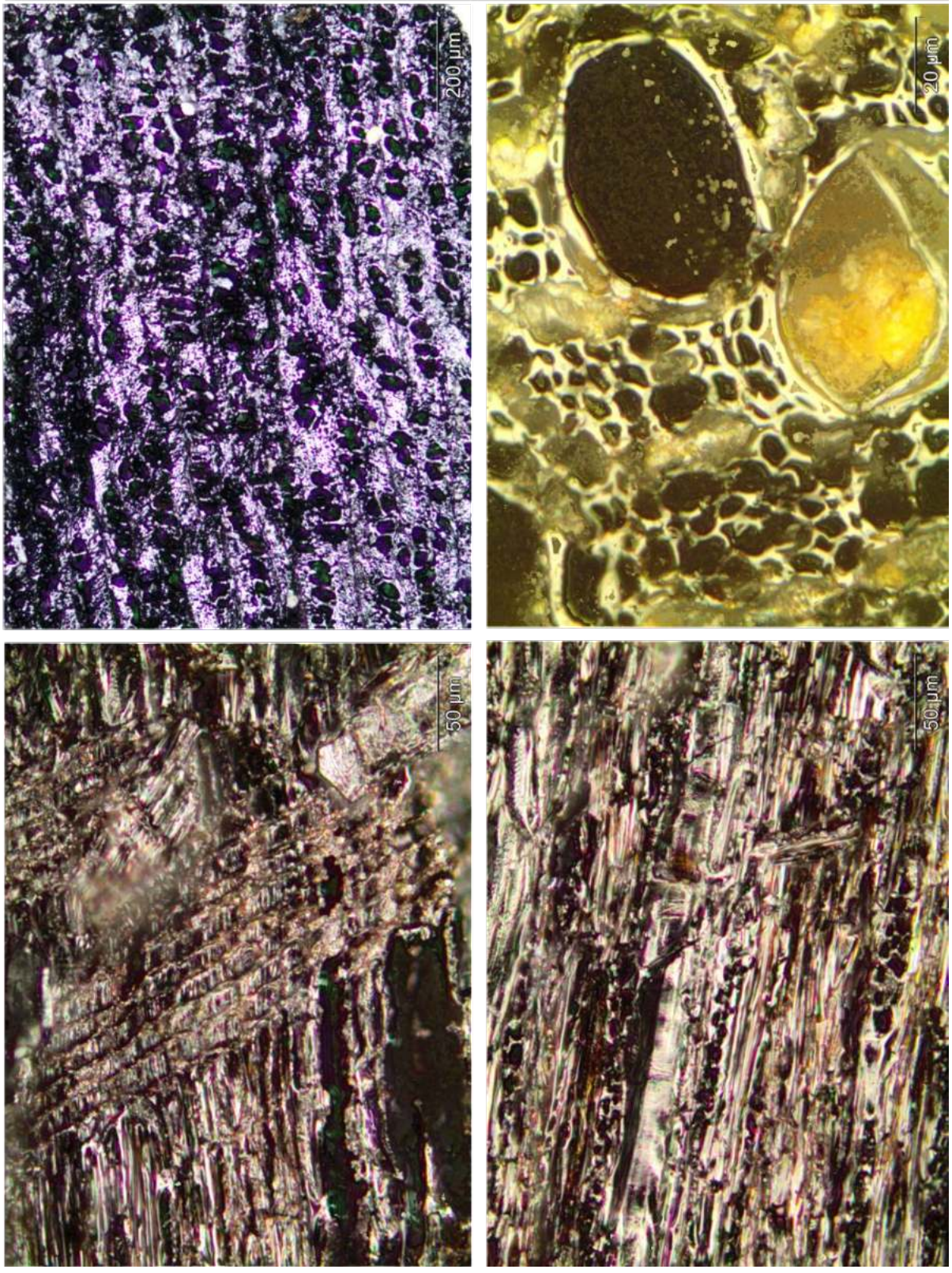
Type 19

Strychnos sp.

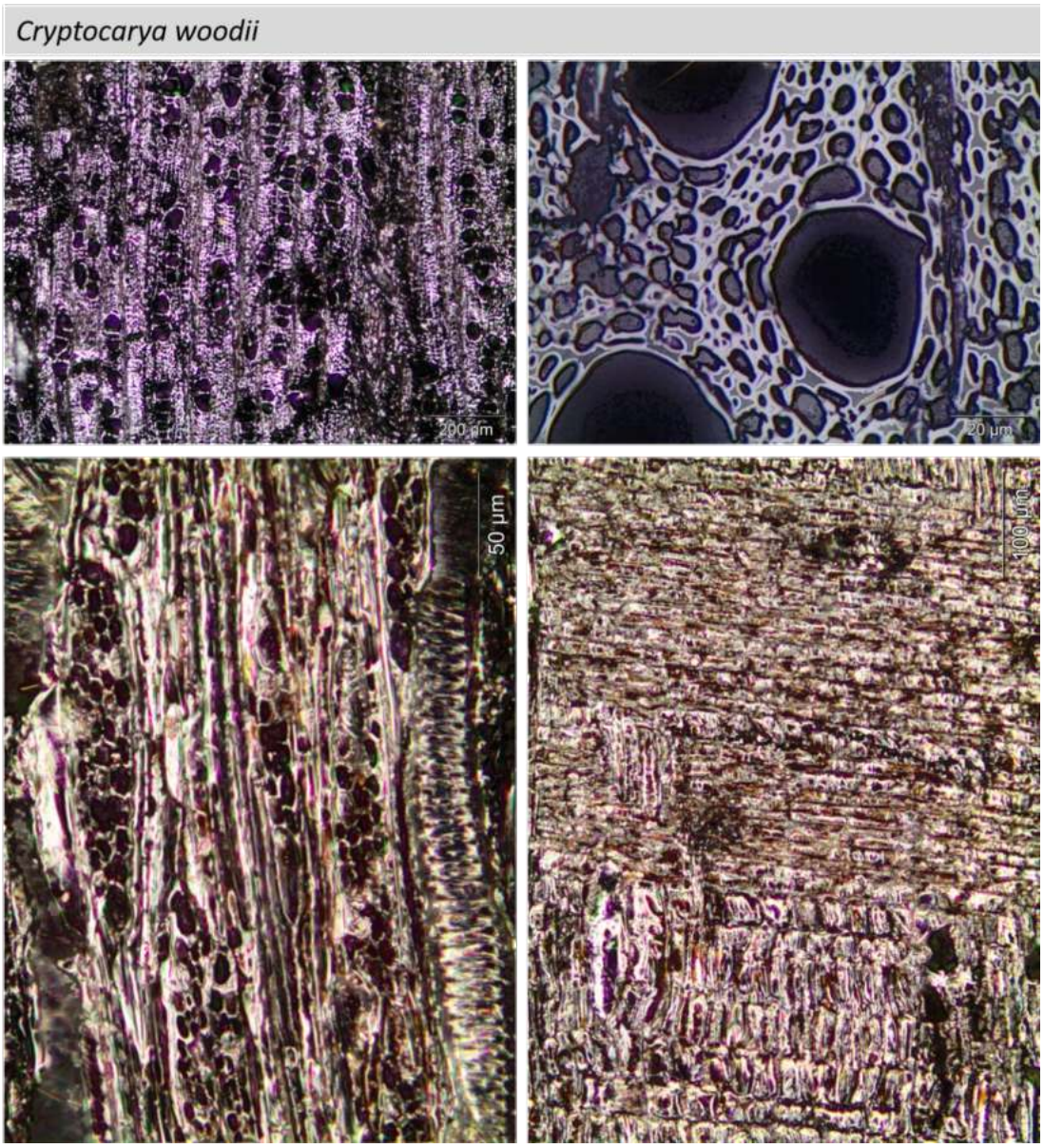


Type 21

Harpephyllum caffrum

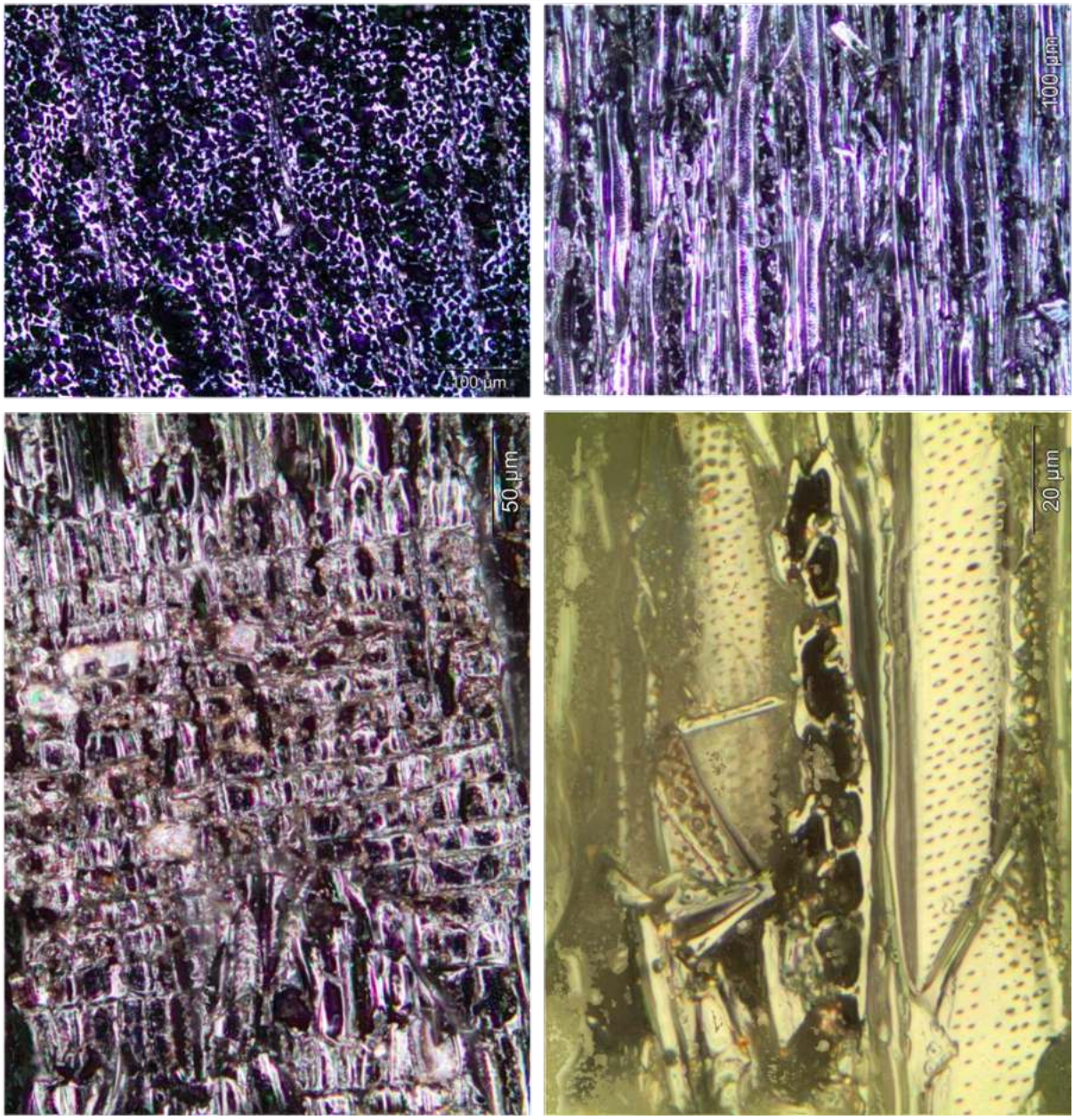


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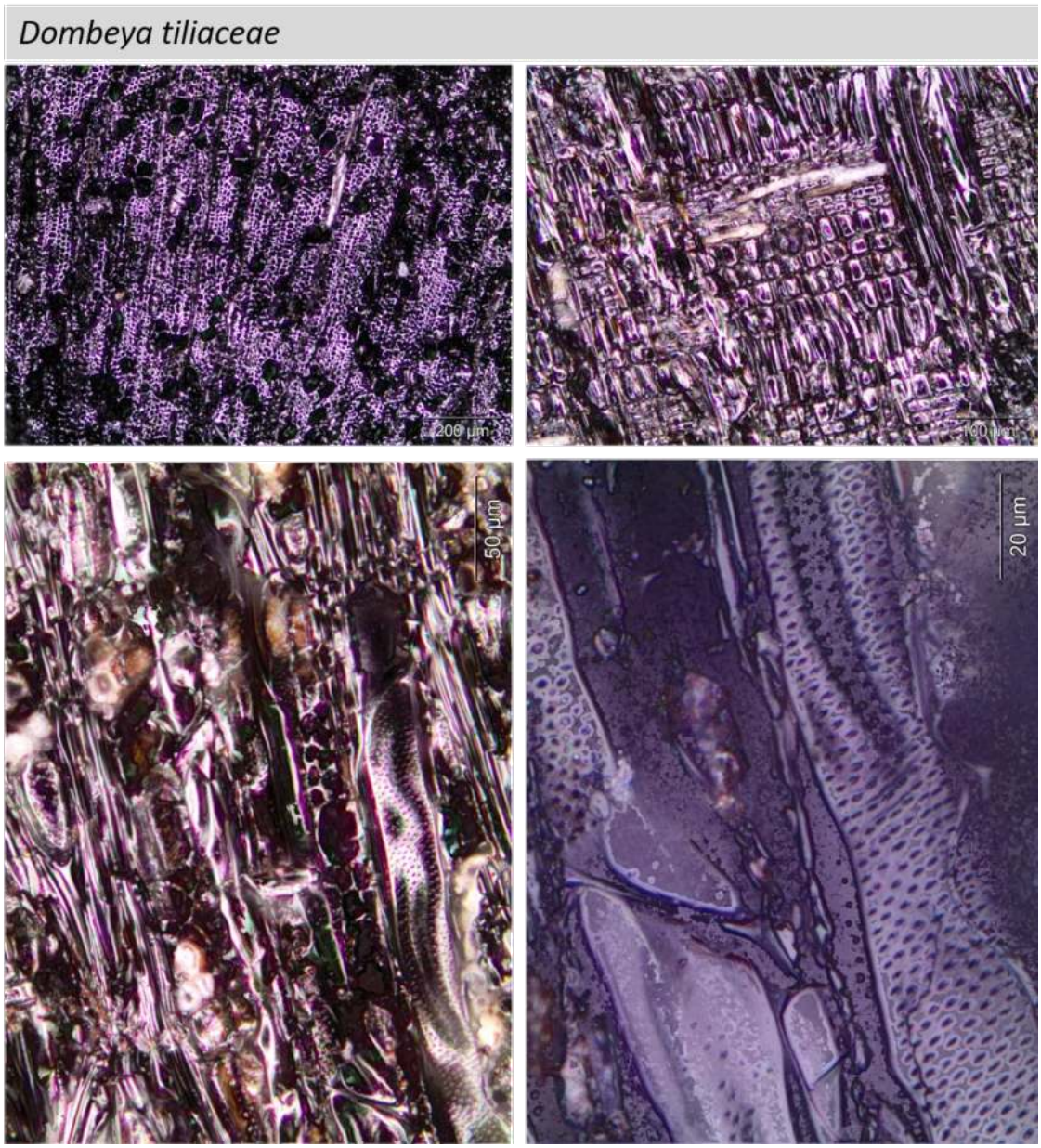


Type 27

Eugenia zeyheri

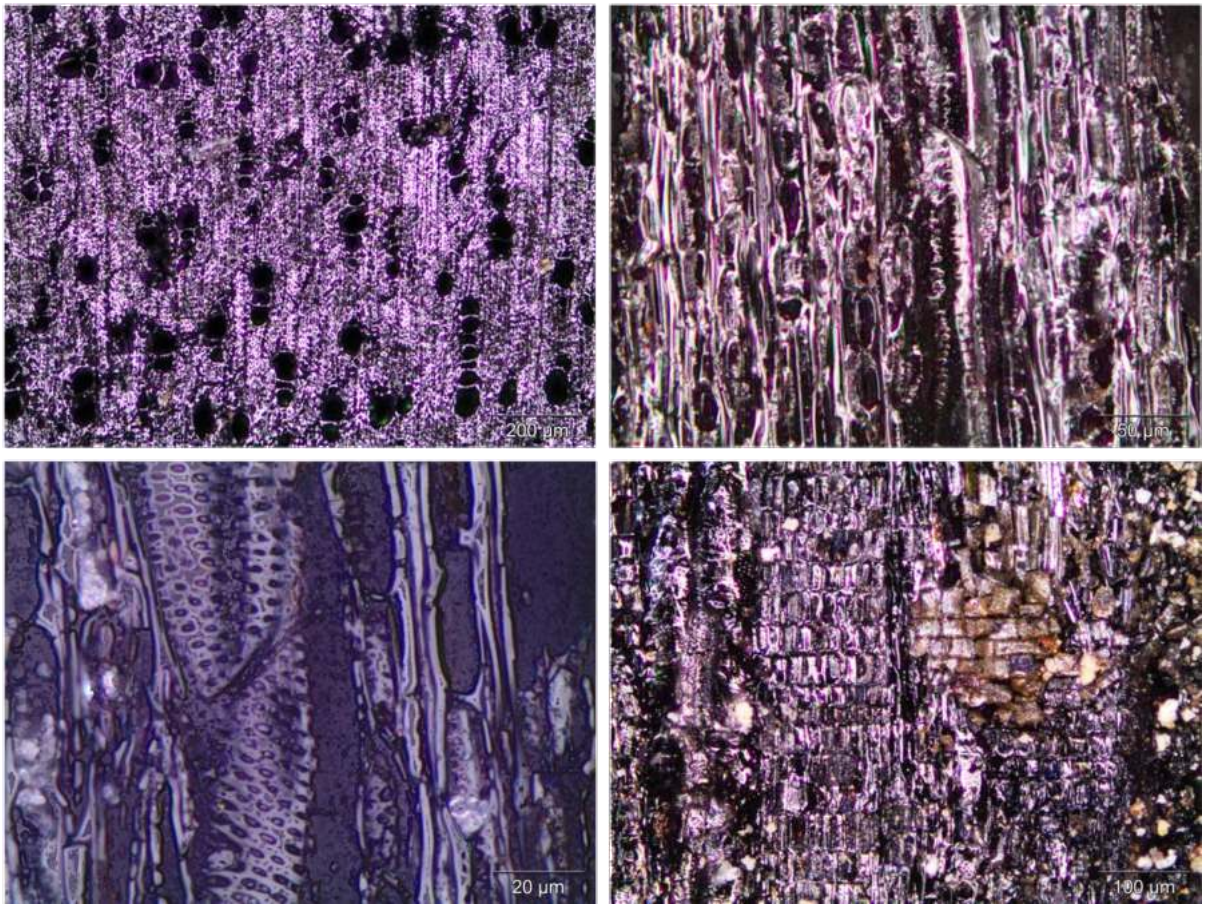


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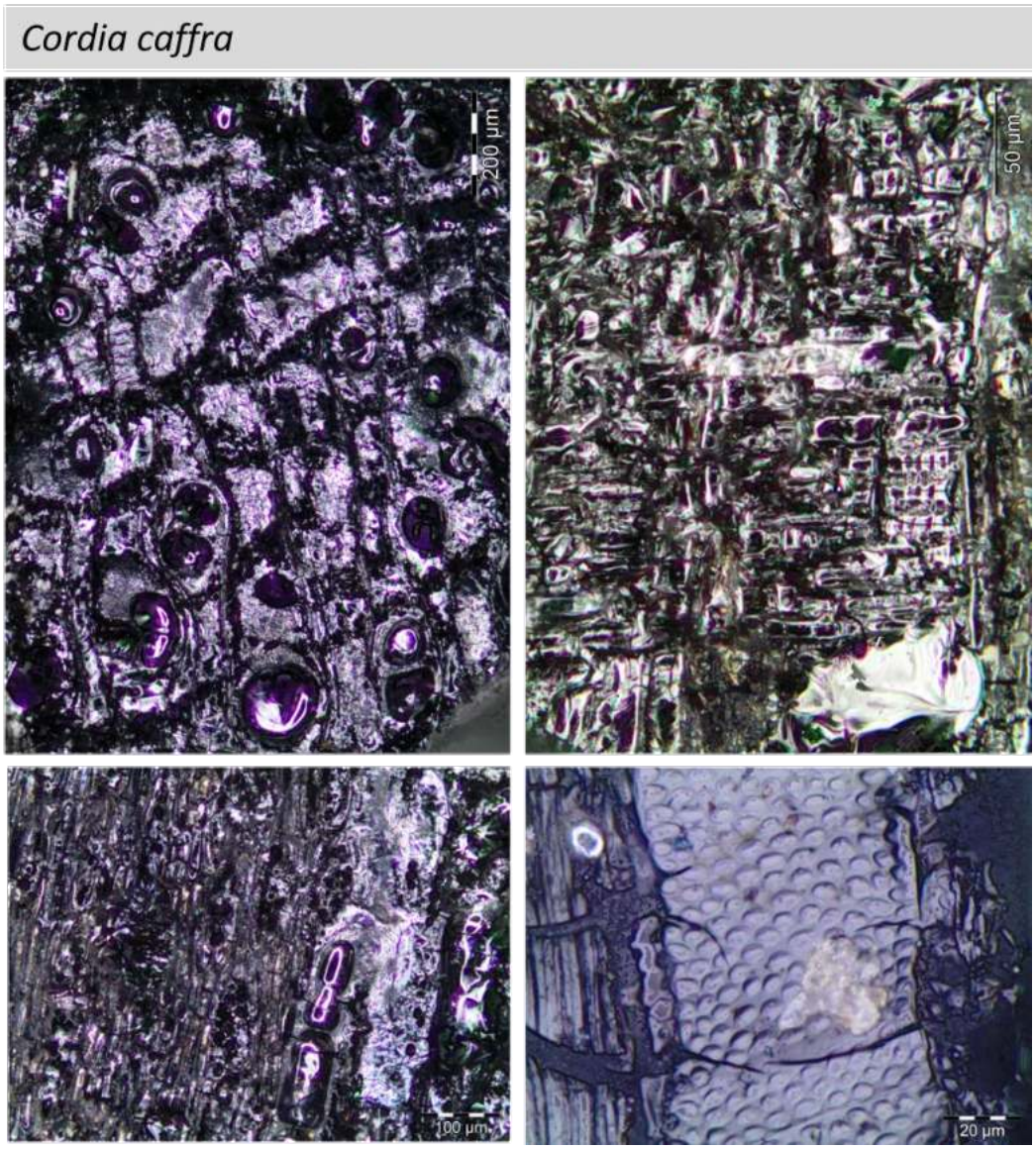


Type 35

Mimusops obovata

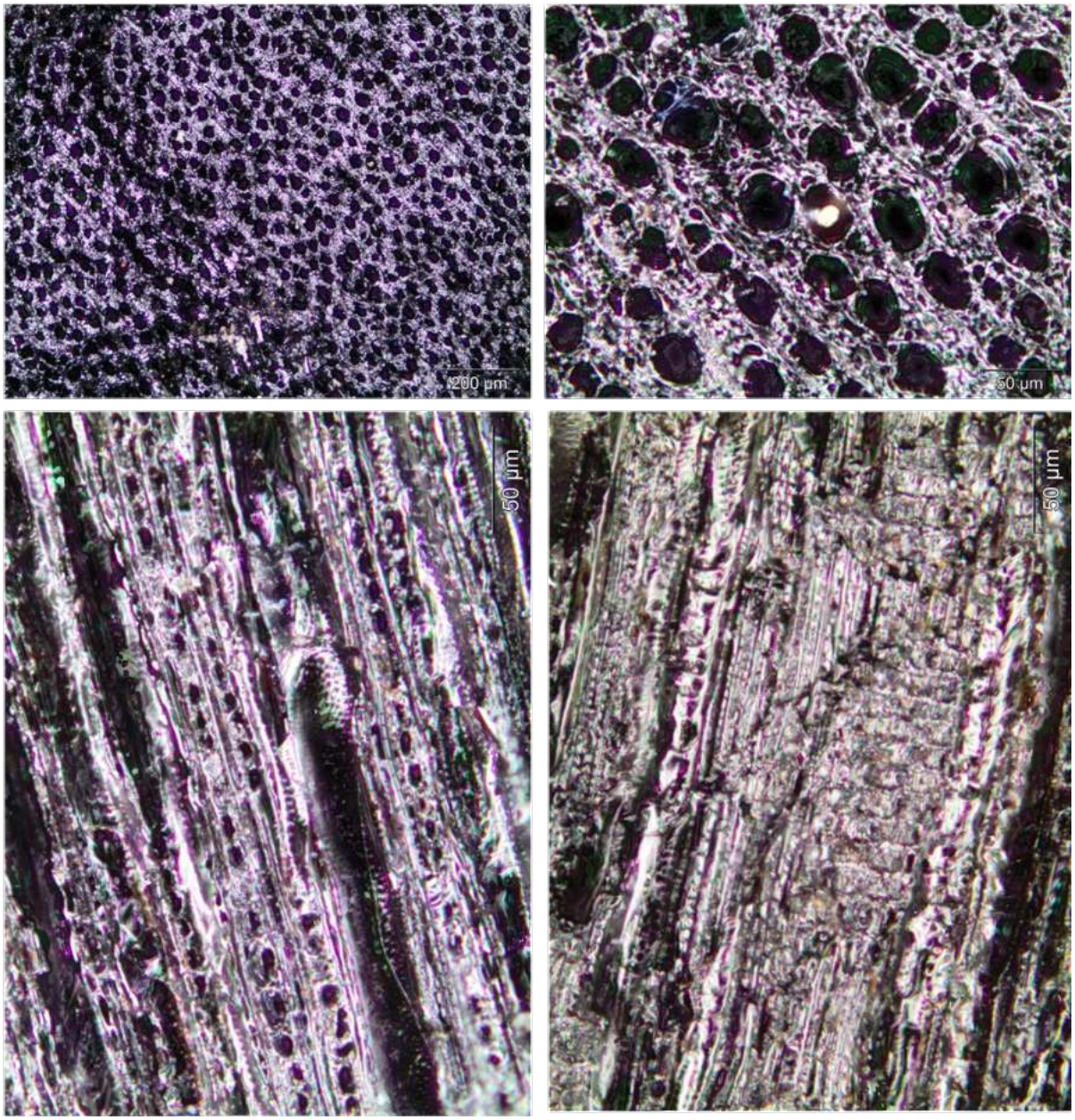


Type 41

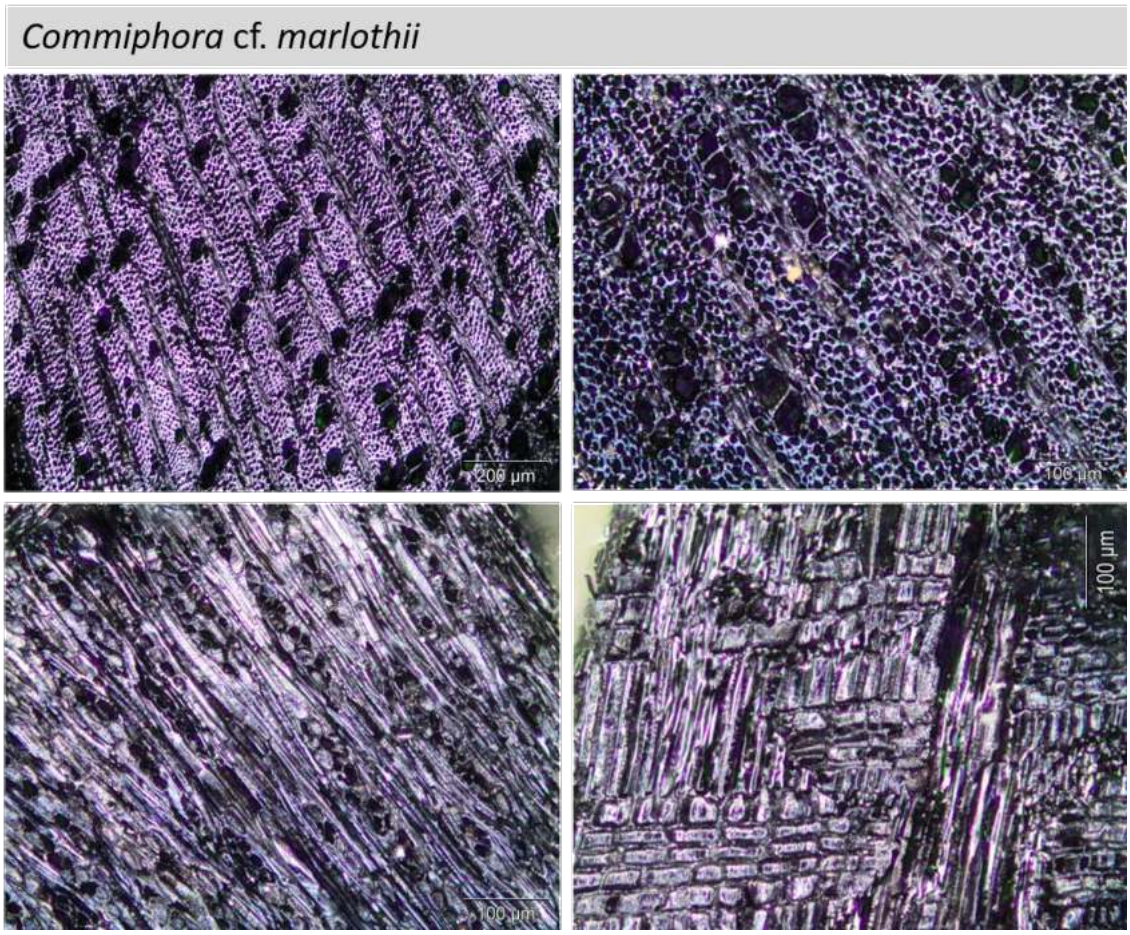


Type 43

Allophylus sp.

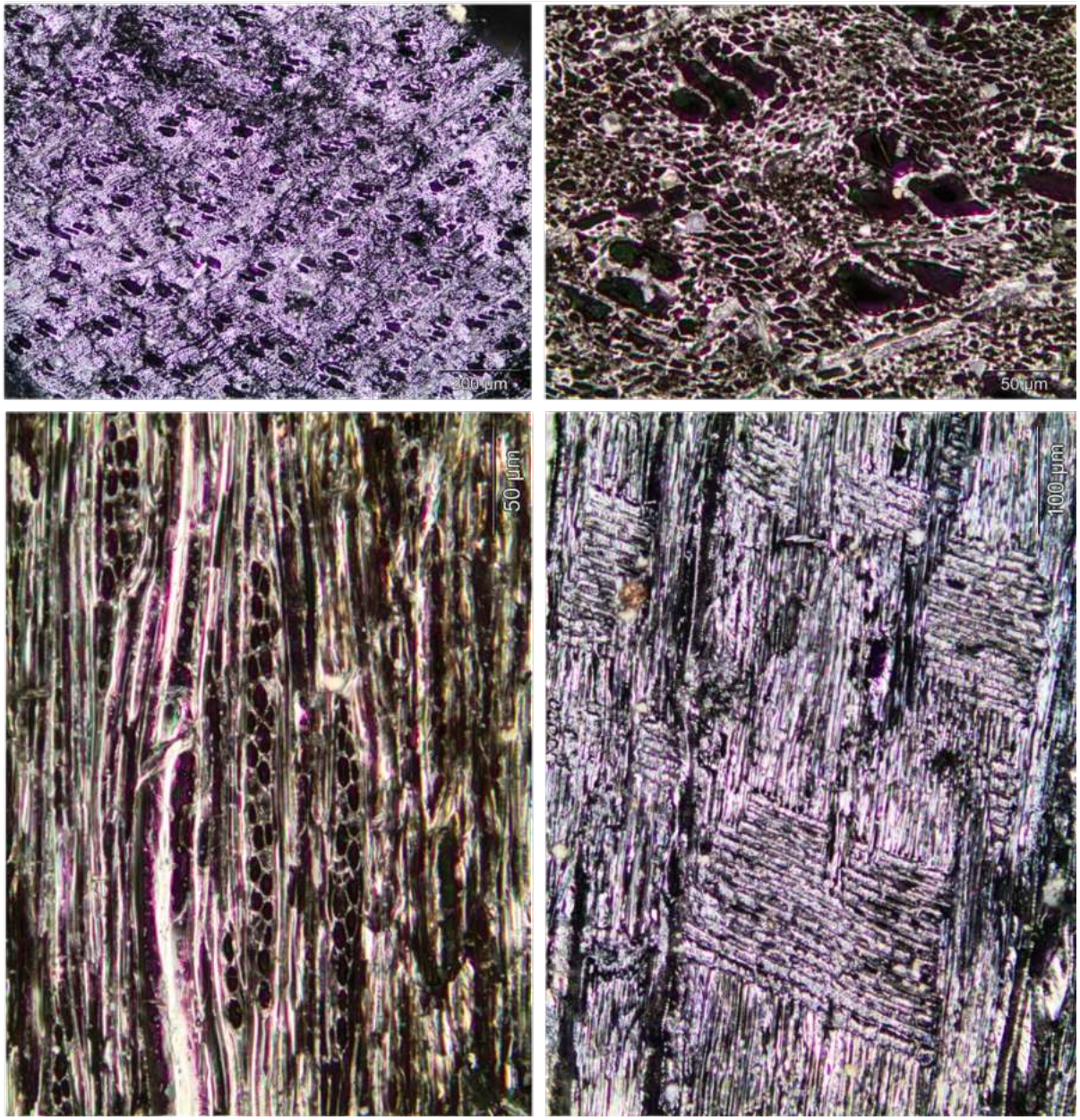


Type 56



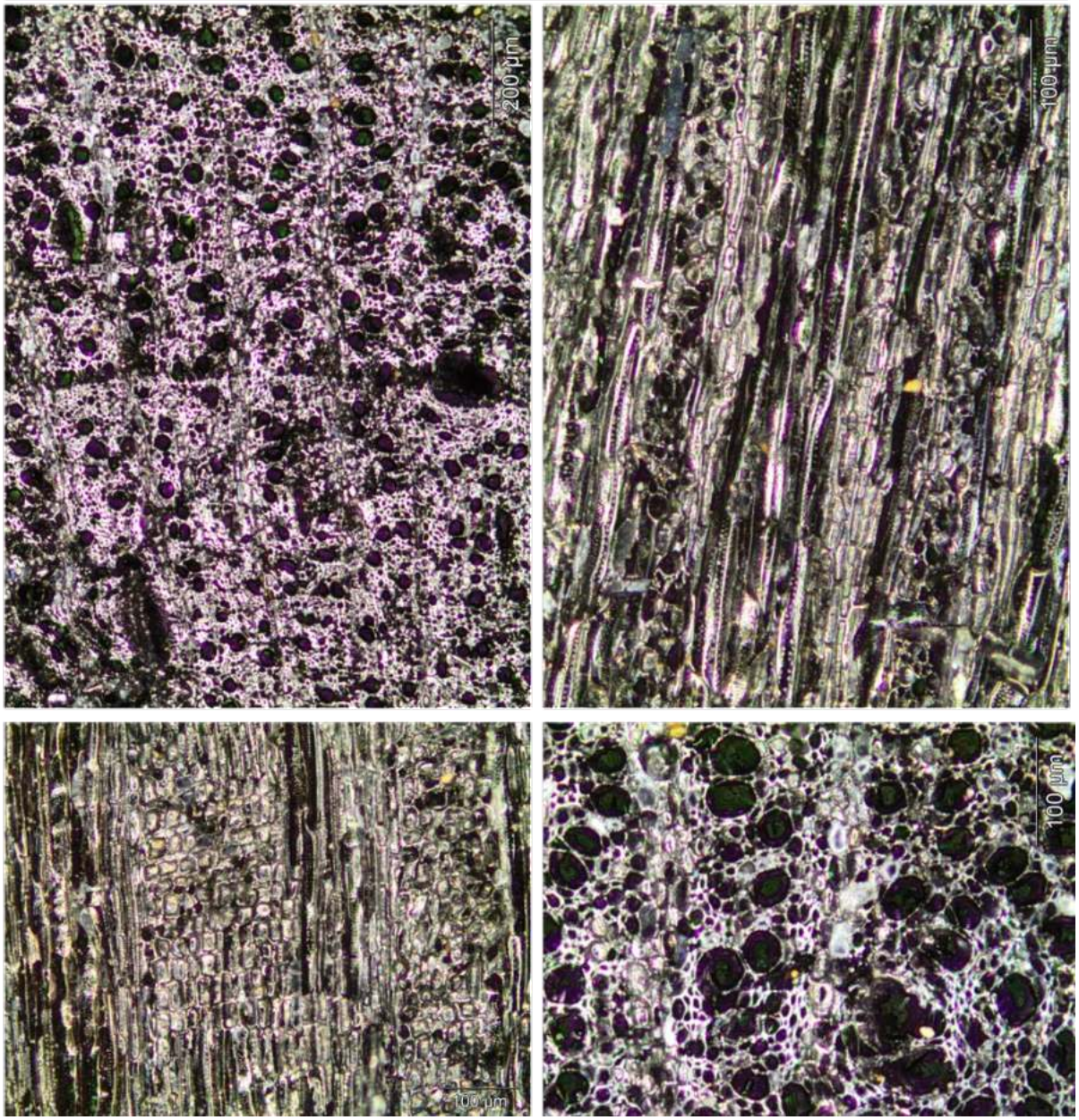
Type 57

Vachellia erioloba



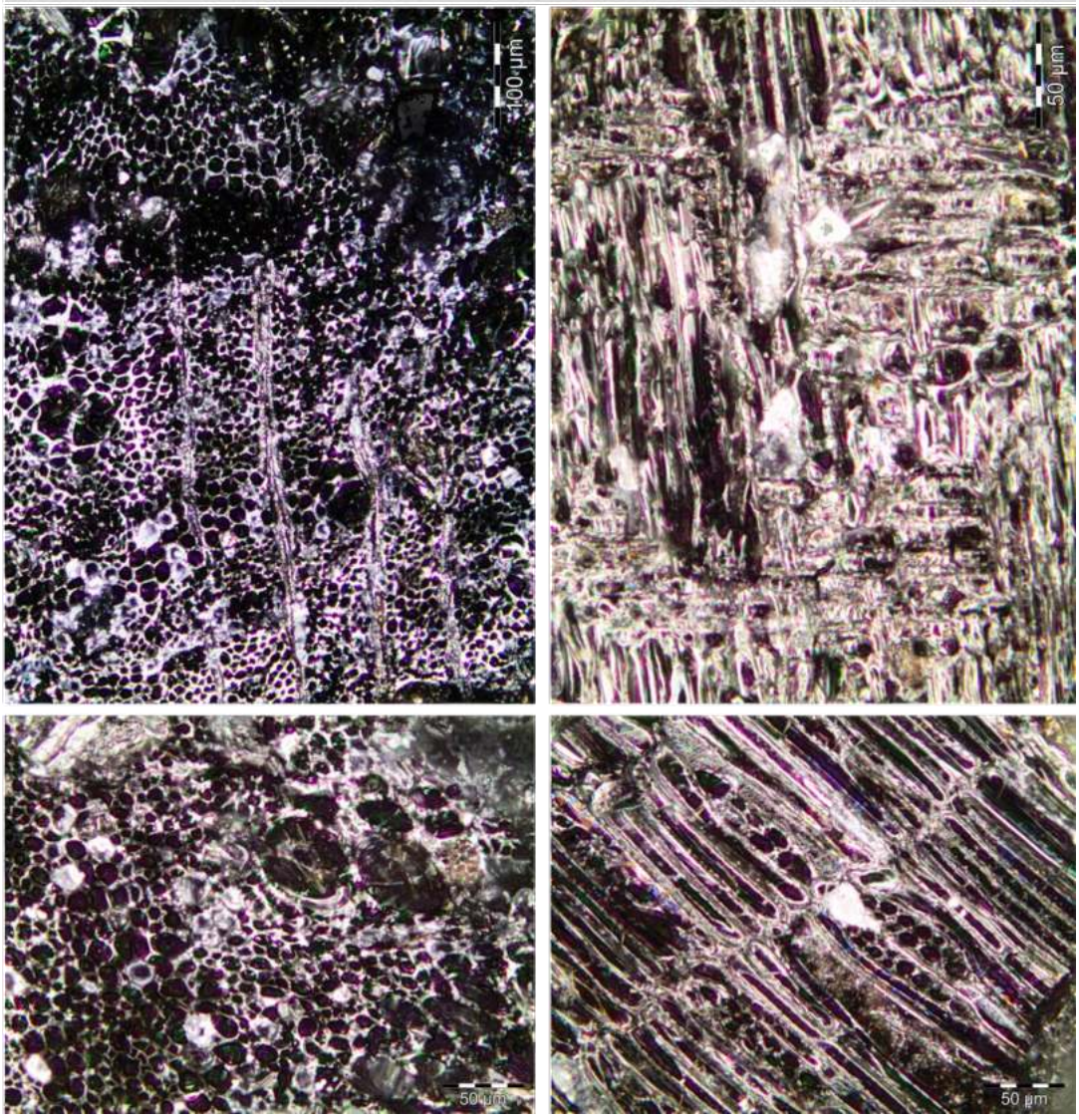
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Strychnos decussata



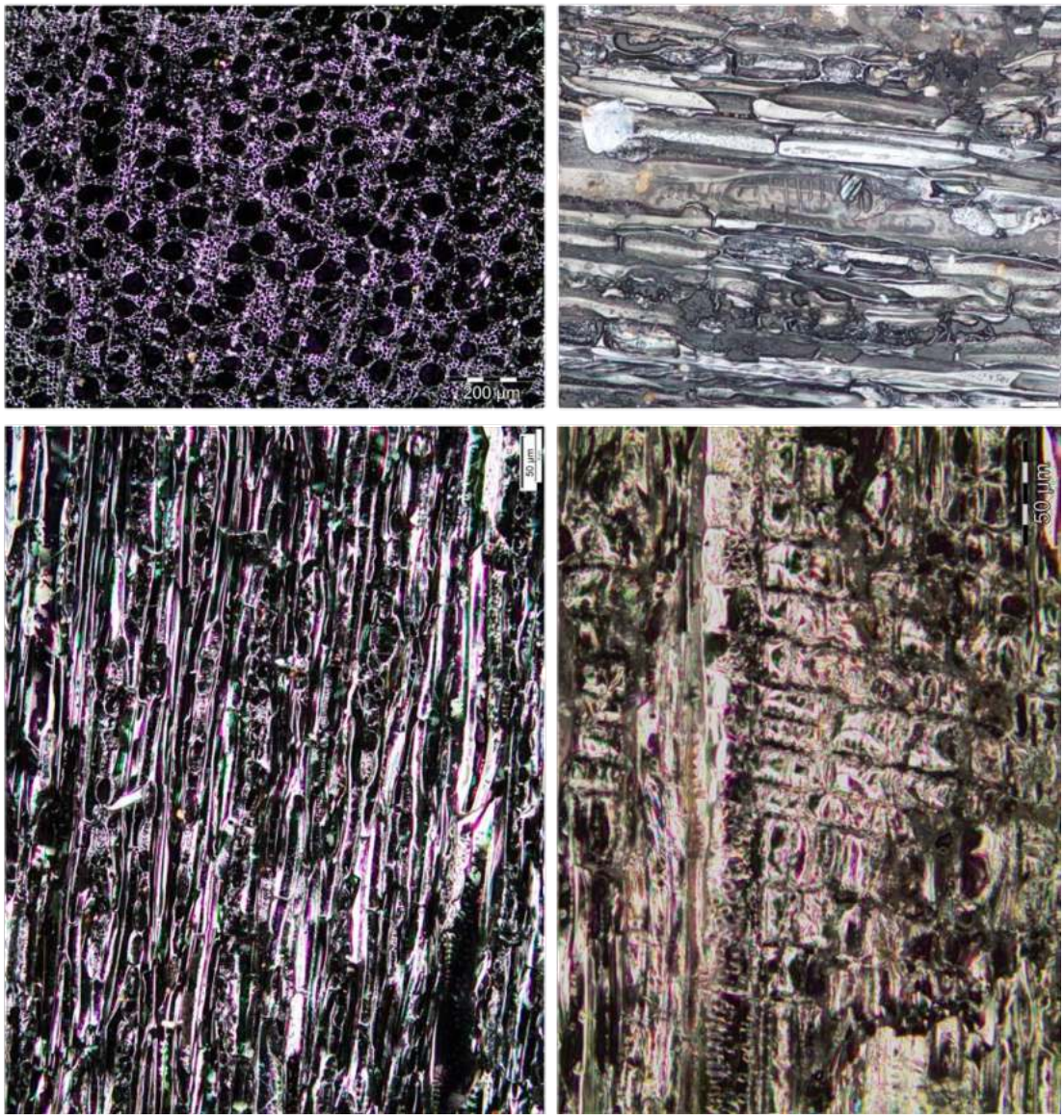
Type 62

Dombeya burgessiae



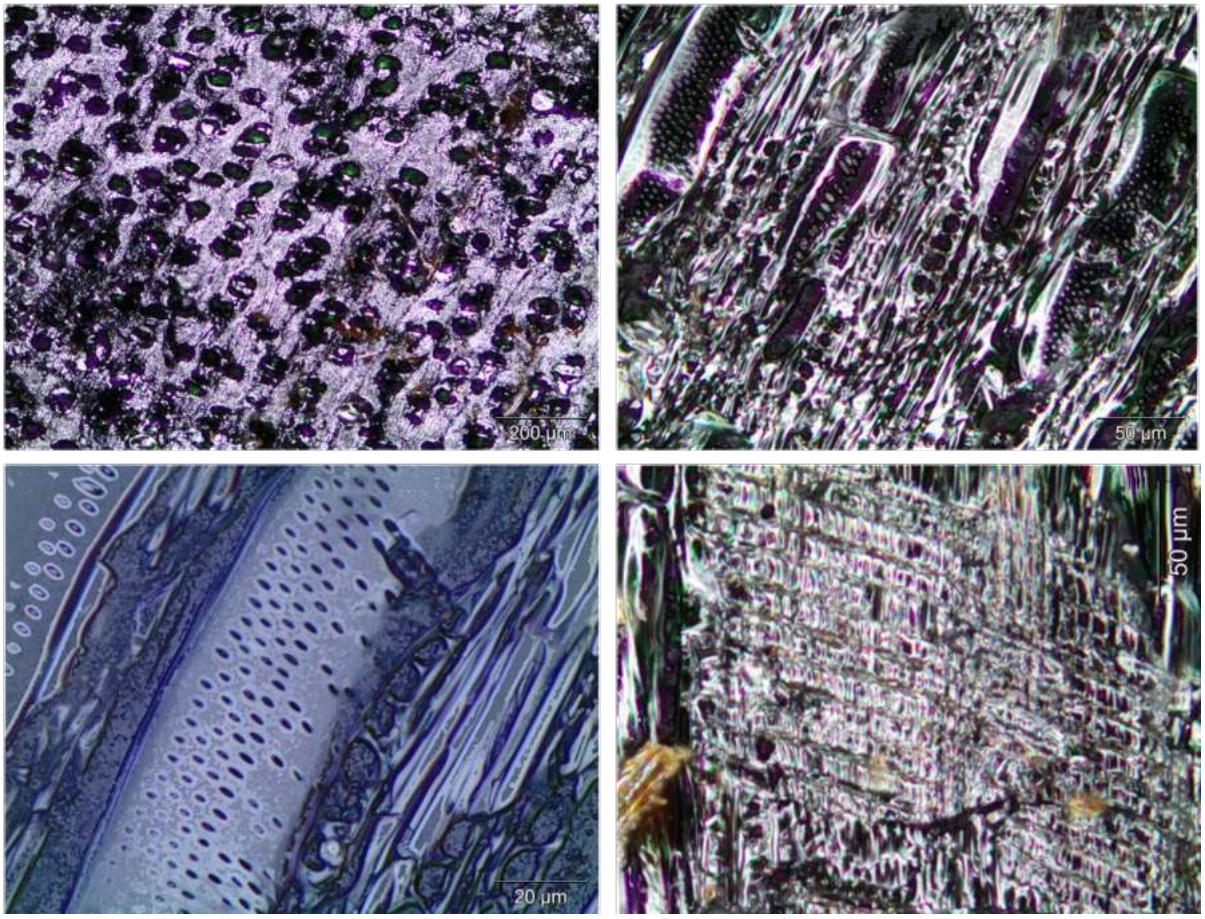
Type 65

Apodytes dimidiata



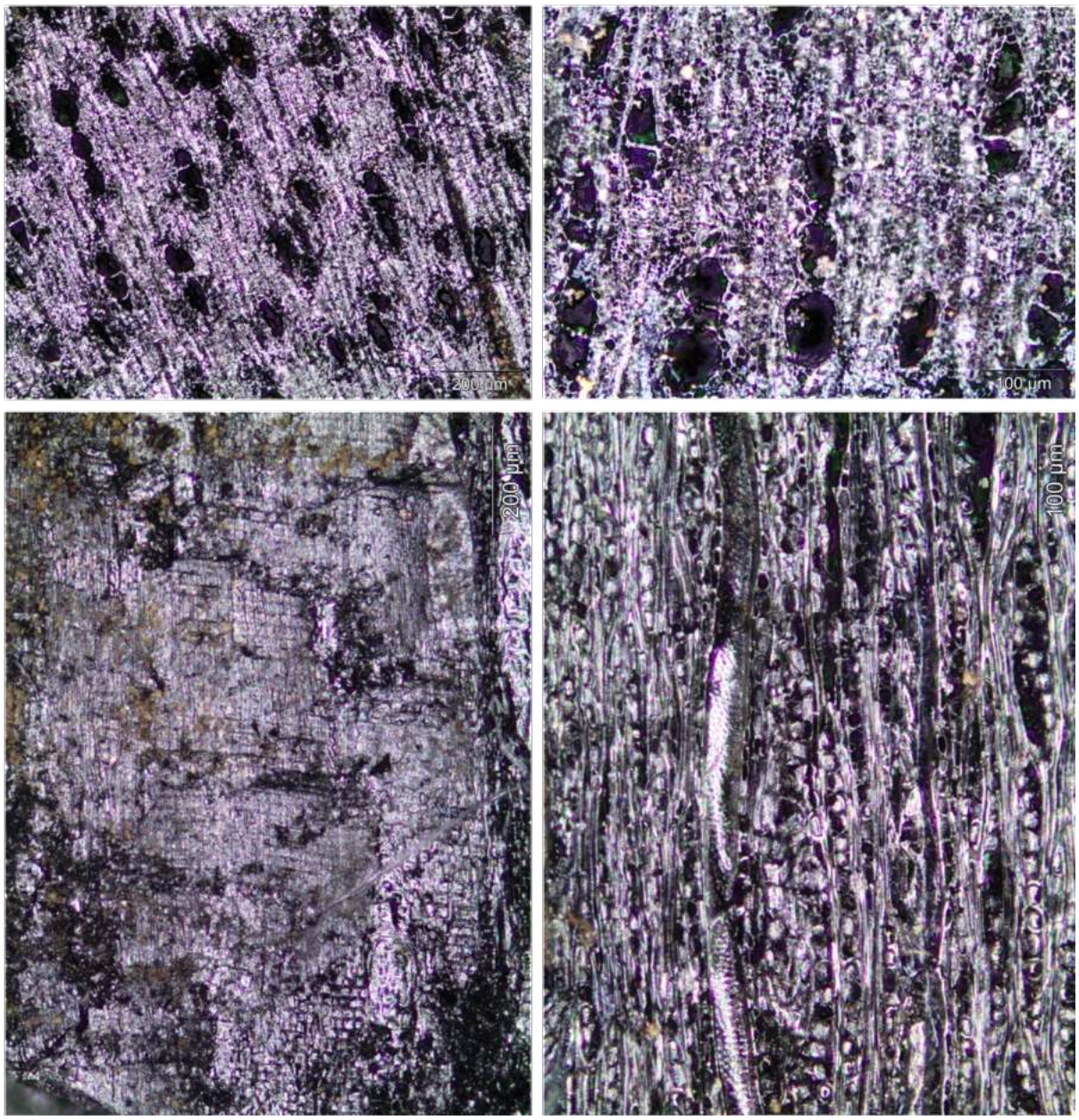
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Ptaeroxylon obliquum



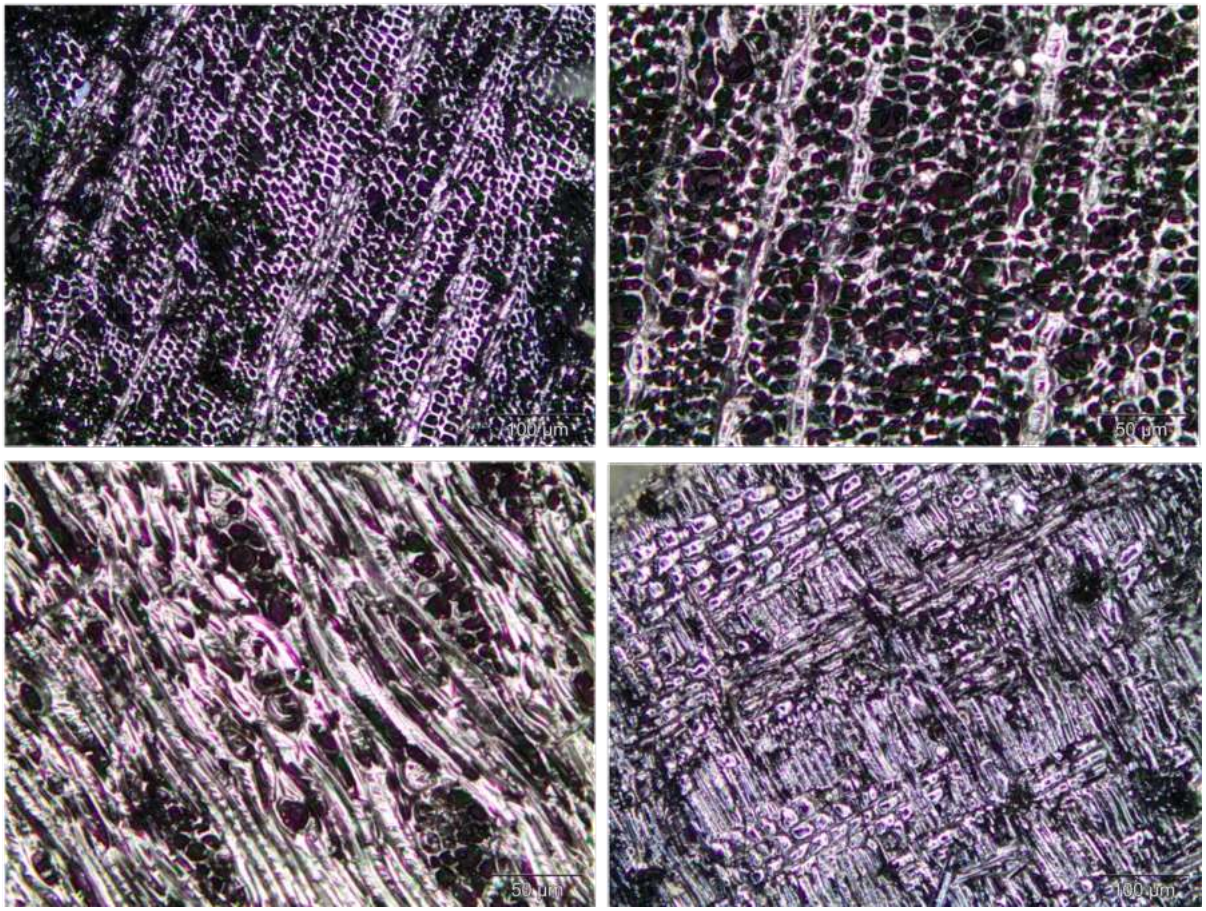
Type 69

Searsia chirindensis



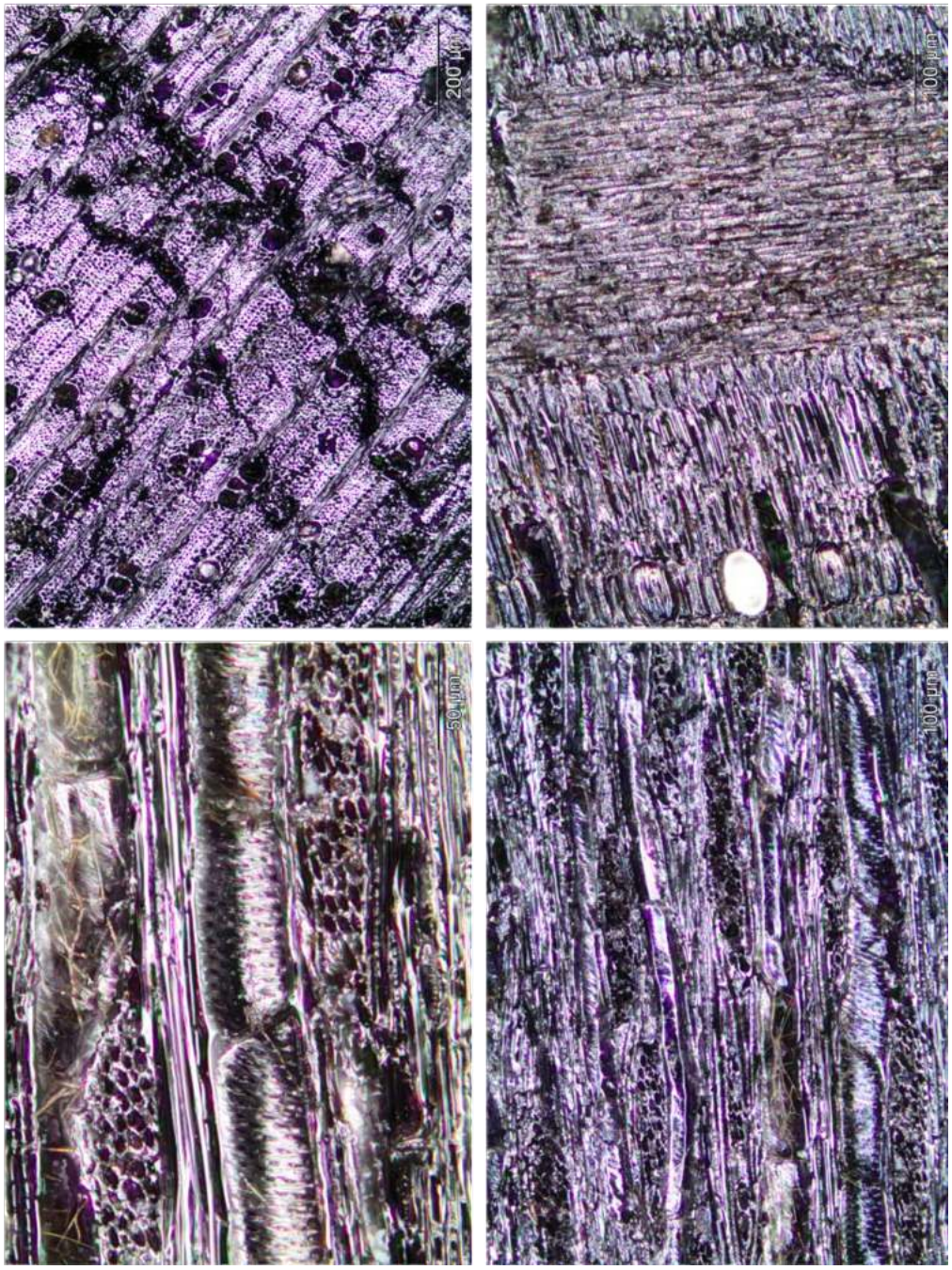
Type 70

Dombeya kirkii



Type 71

Cryptocarya myrtifolia

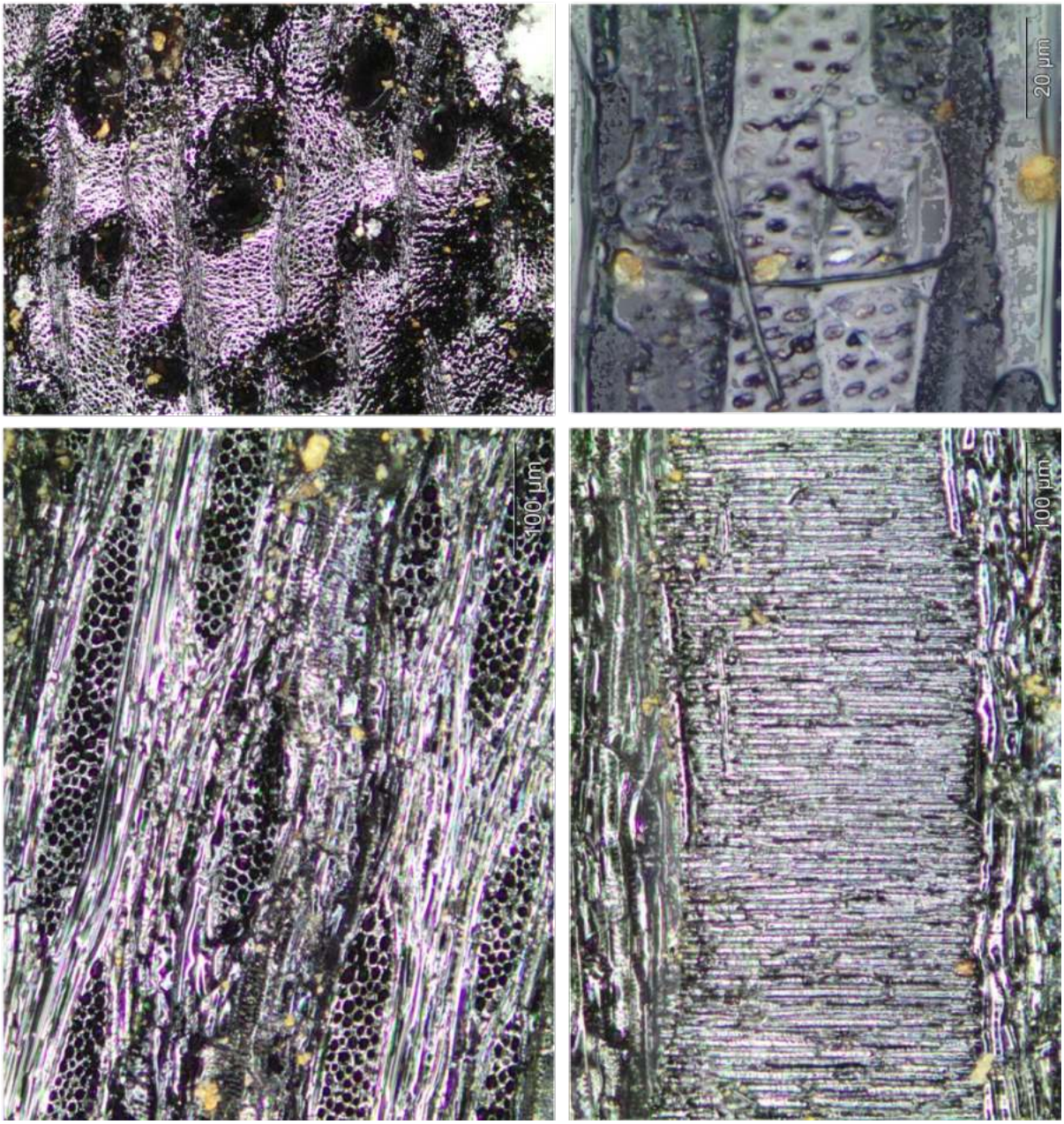


Appendix D - Micrographs of some archaeological samples from Border Cave that were identified with certainty. Species are listed in the order of their type numbers.

Type #	Species name
1	*Vachellia sieberiana*
3	*Senegalia* sp.
19	*Chionanthus battiscombei*
9	*Diospyros dichrophylla*
14	*Mystroxylon aethiopicum*
20	*Podocarpus/Afrocapus* sp.
23	*Vachellia* sp. 2
24	*Sterculia rogersii*
25	*Senegalia ataxacantha*
26	*Apodytes dimidiata*
31	*Vachellia tortilis*
32	*Sclerocarya birrea*
33	*Gymnosporia nemorosa*
34	*Brachylaena* cf. *discolor*
40	*Vachellia robusta*
42	*Senegalia cafrra*
43	*Dichrostachys cinerea*
50	*Brachylaena huillensis*
56	*Combretum krausii*
57	*Colophospermum mopane*

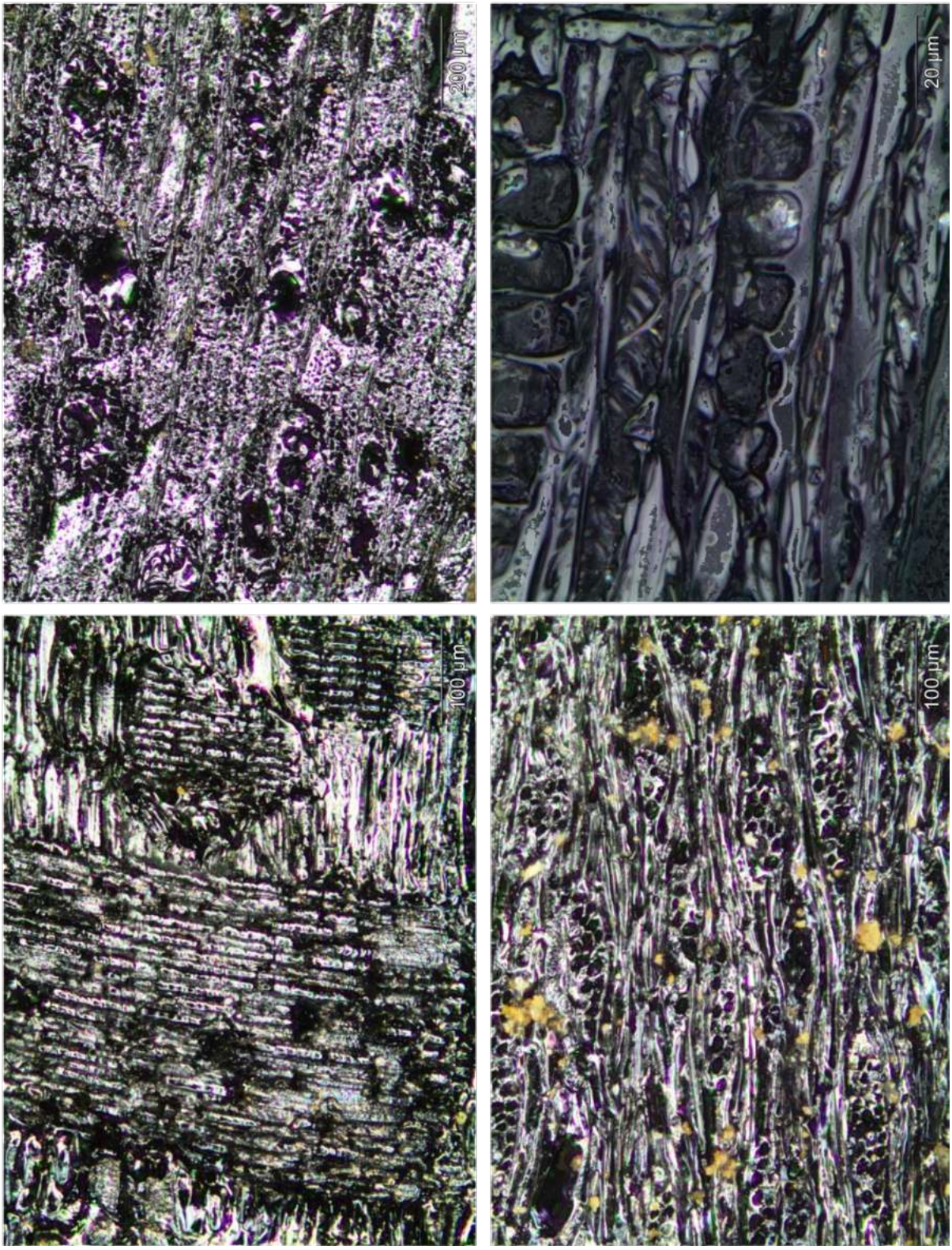
Type 1

Vachellia sieberiana



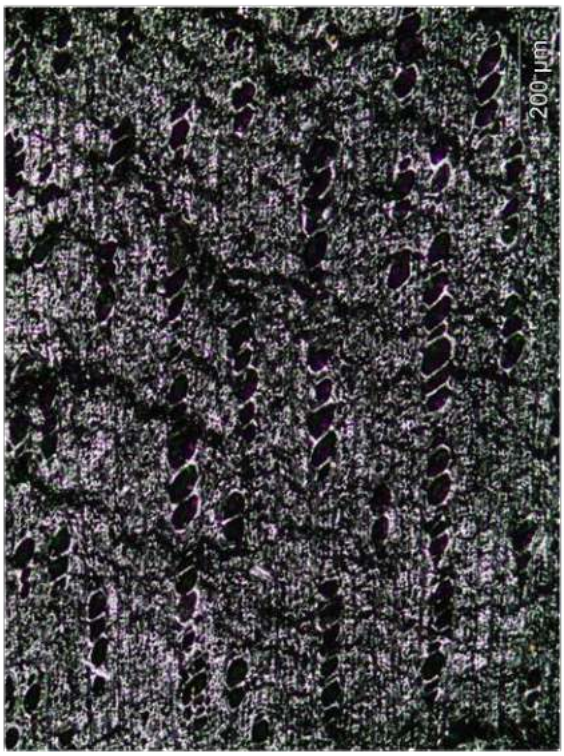
Type 3

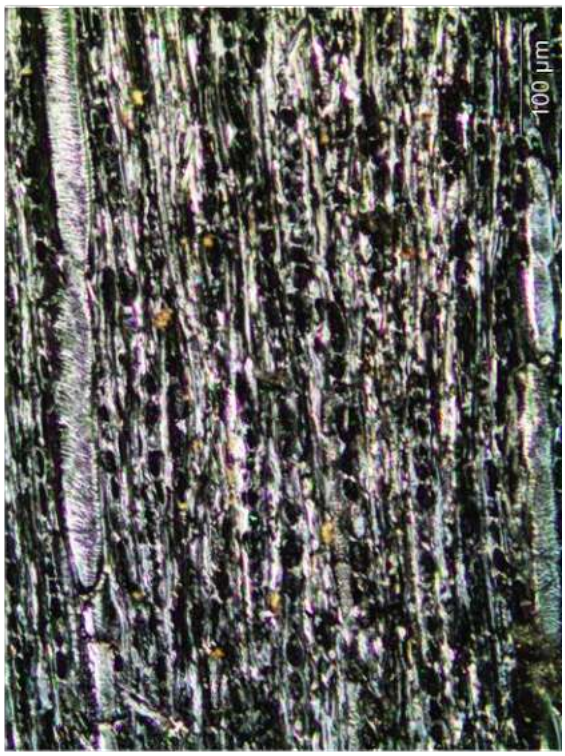
Senegalia sp.

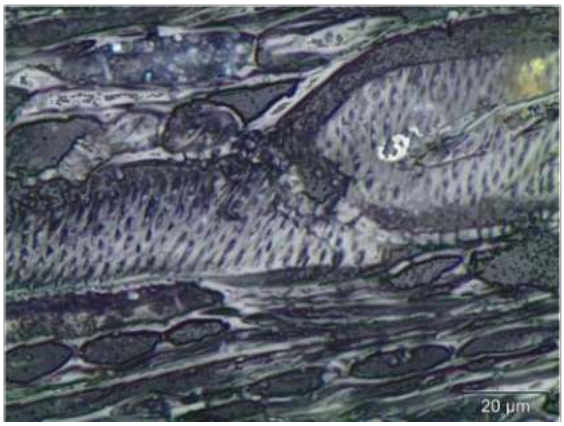


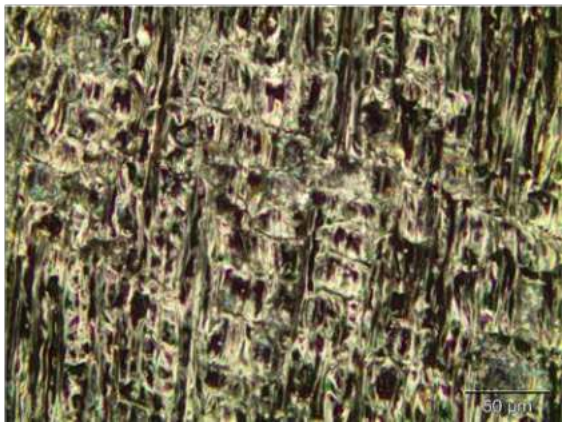
Type 9

Diospyros dichrophylla



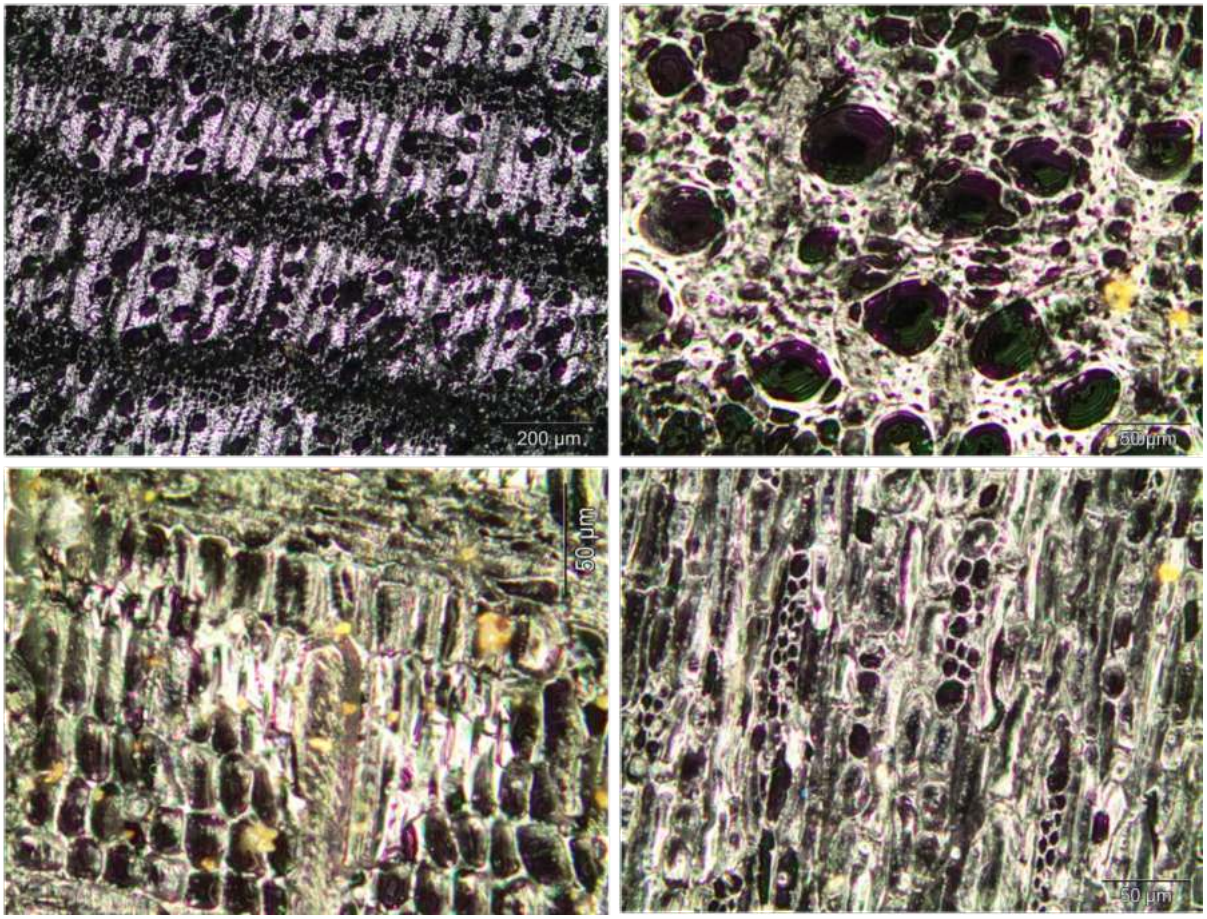






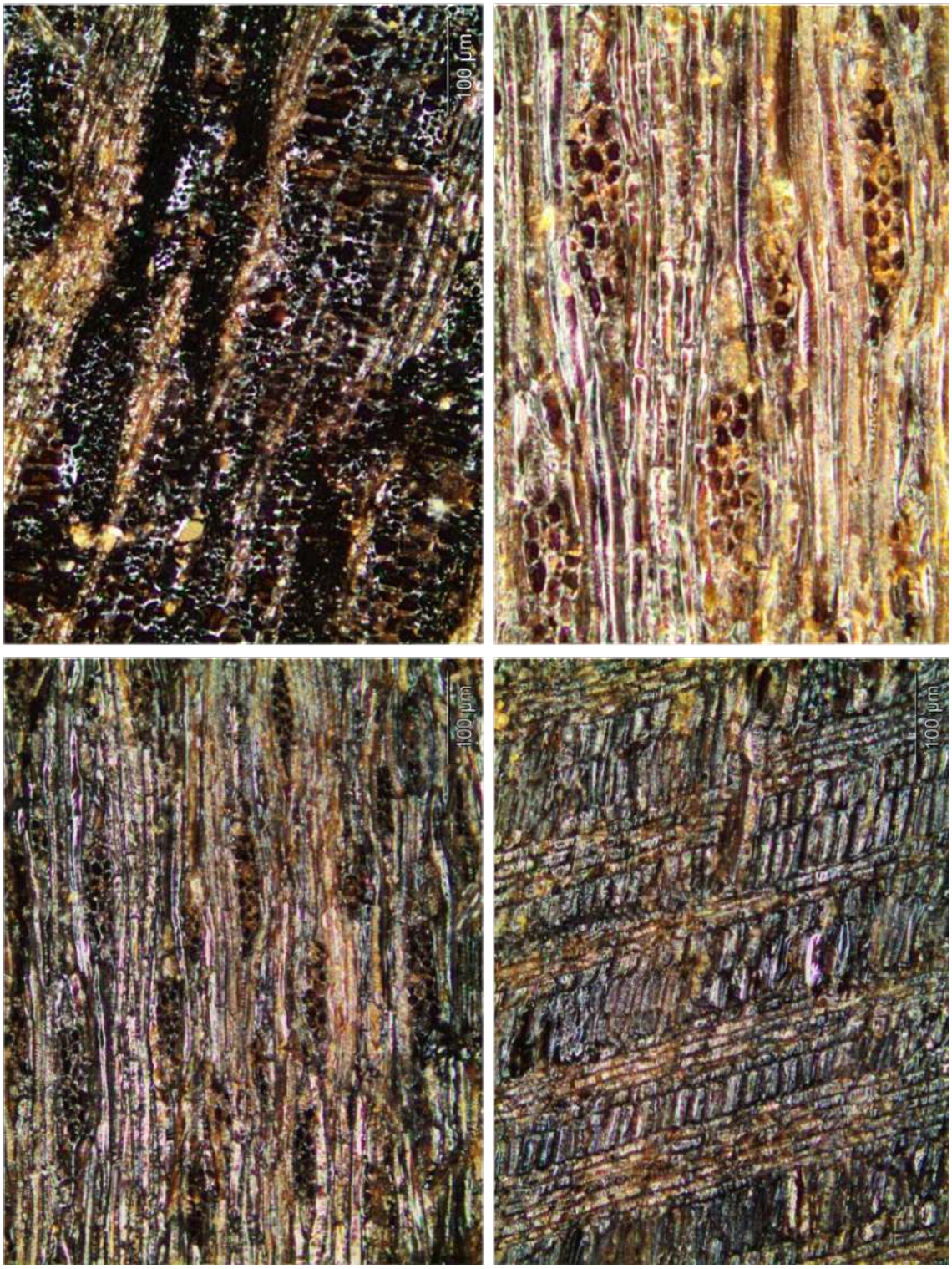
Type 14

Mystroxylon aethiopicum



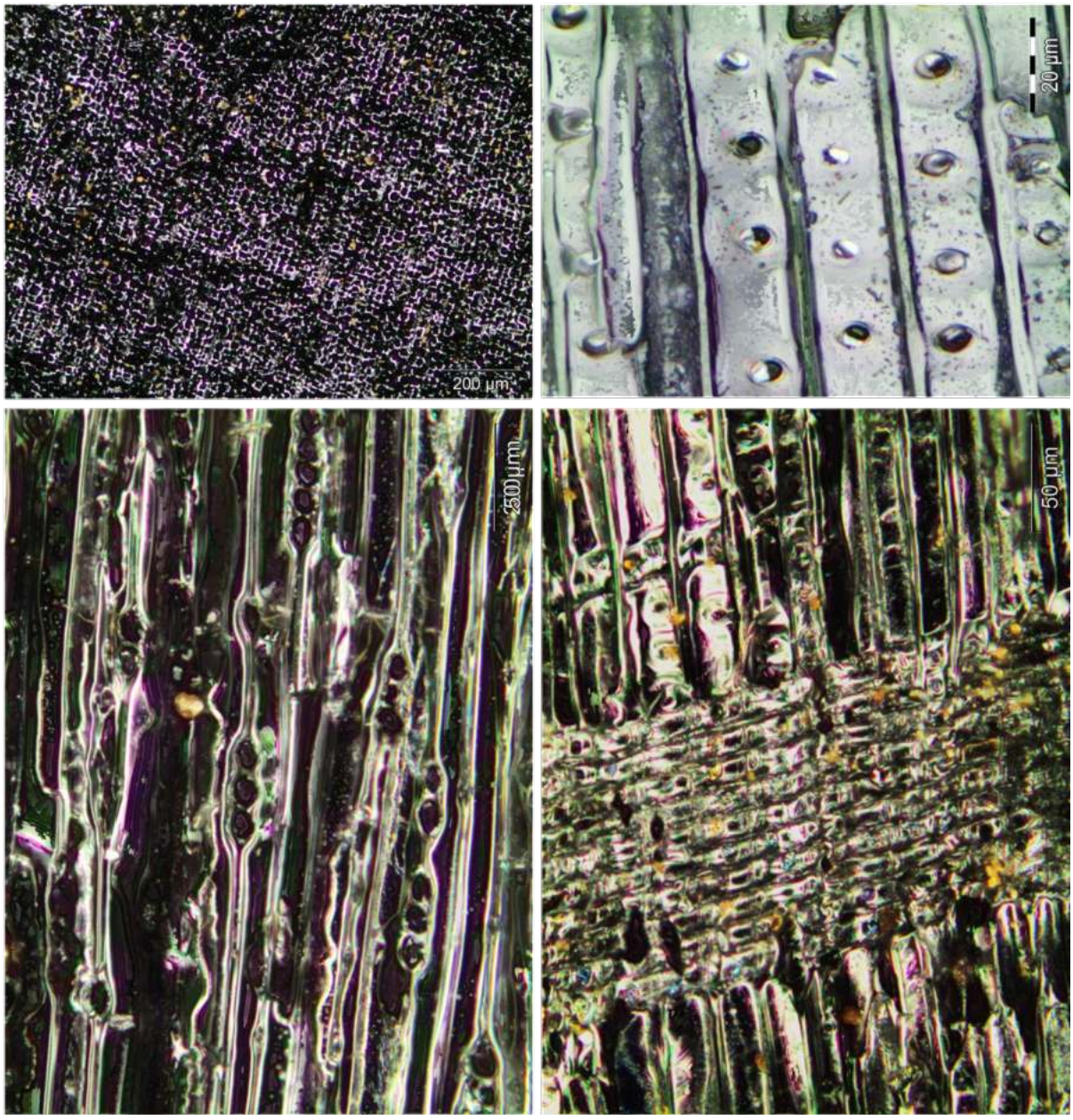
Type 19

Chionanthus battiscombei



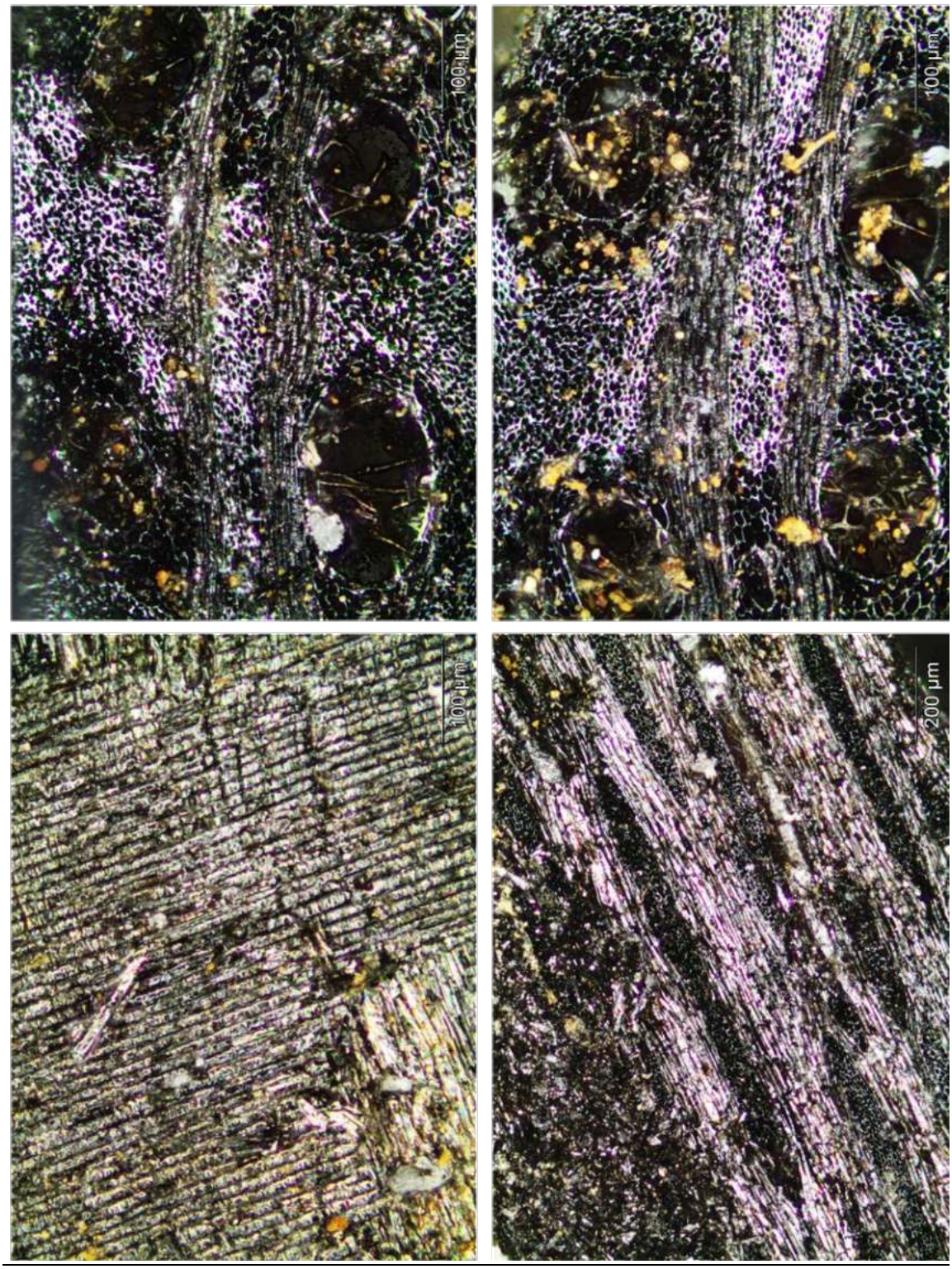
Type 20

Podocarpus/ Afrocarpus sp.



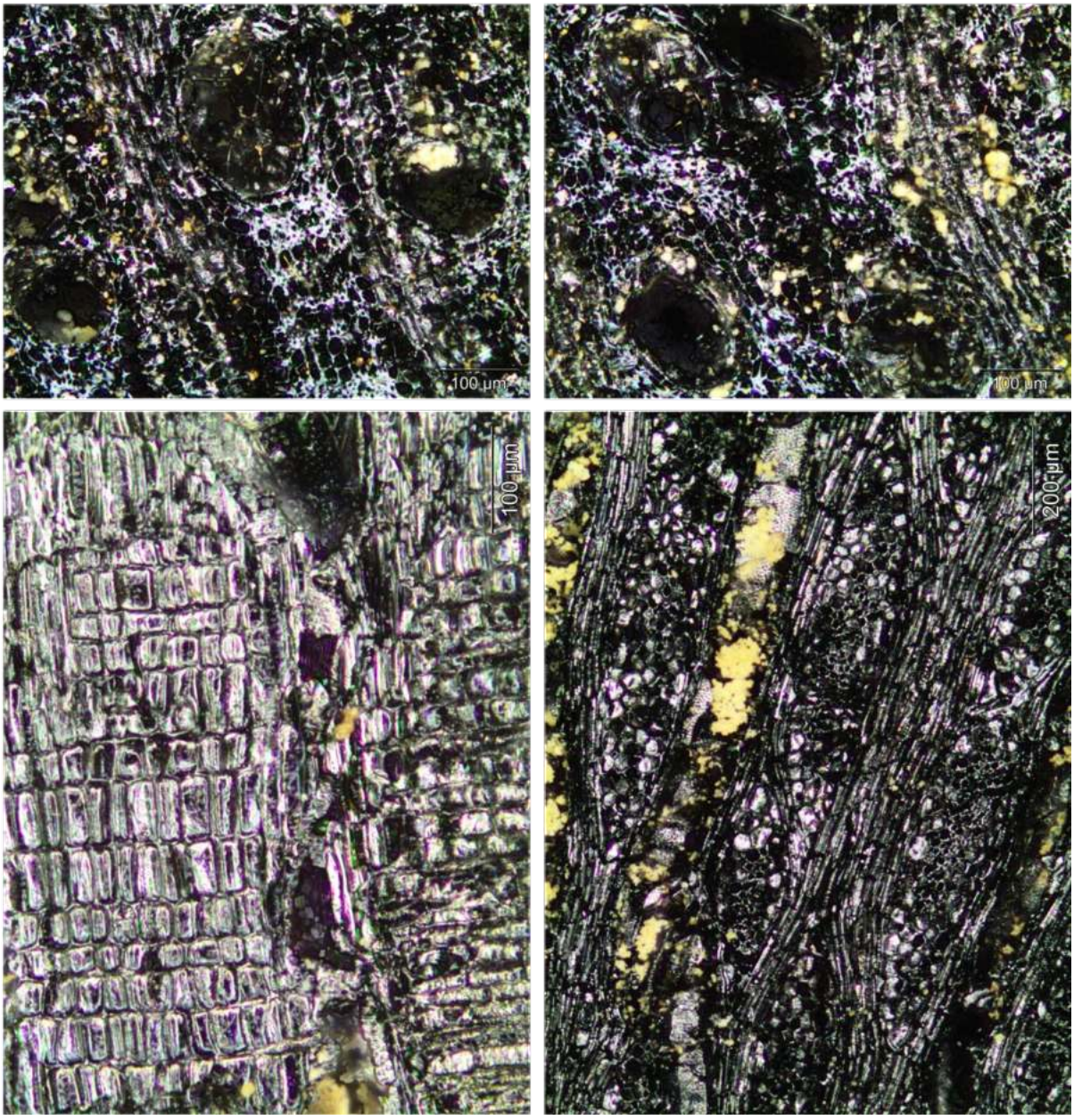
Type 23

Vachellia sp. 2



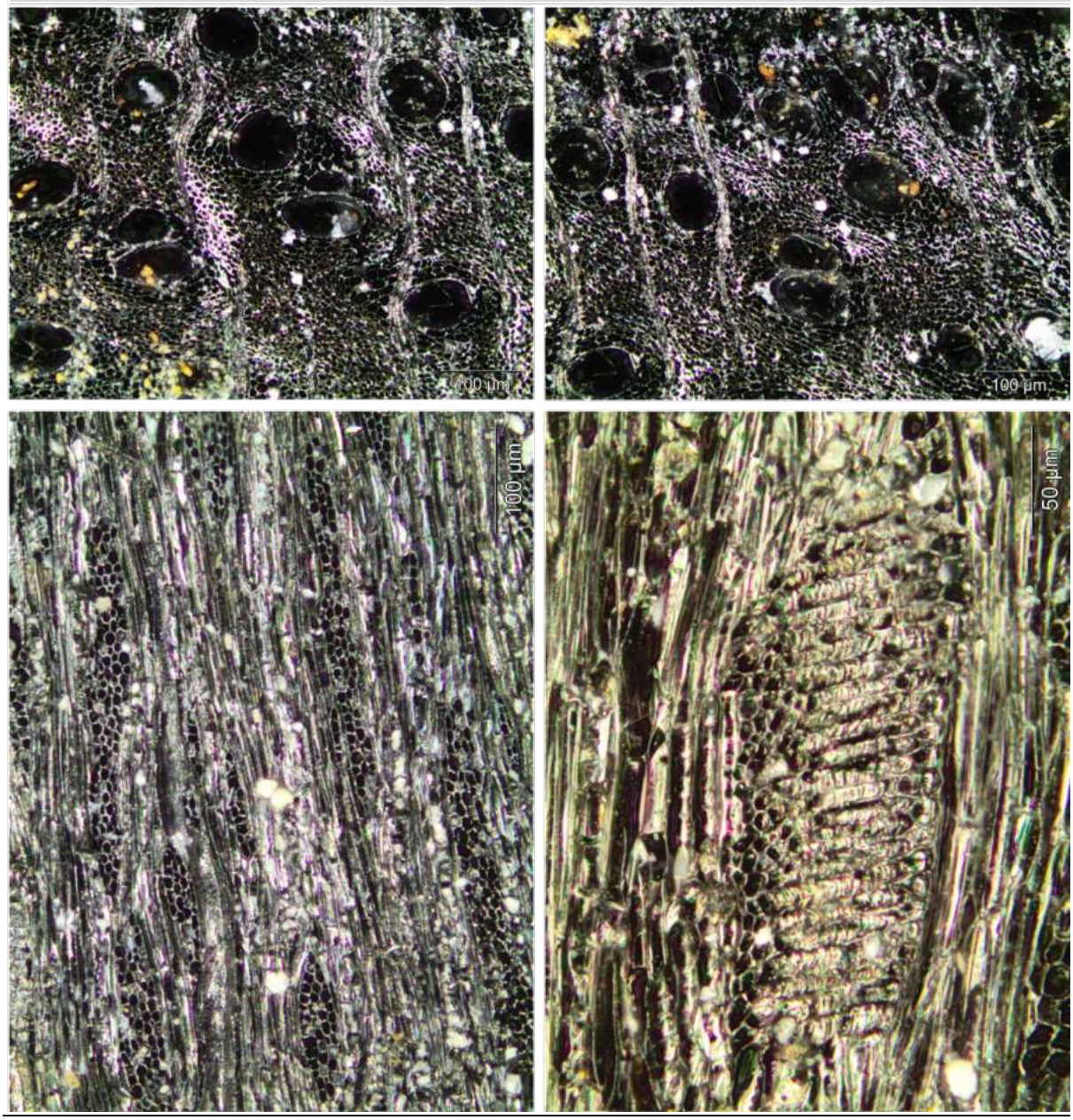
Type 24

Sterculia rogersii



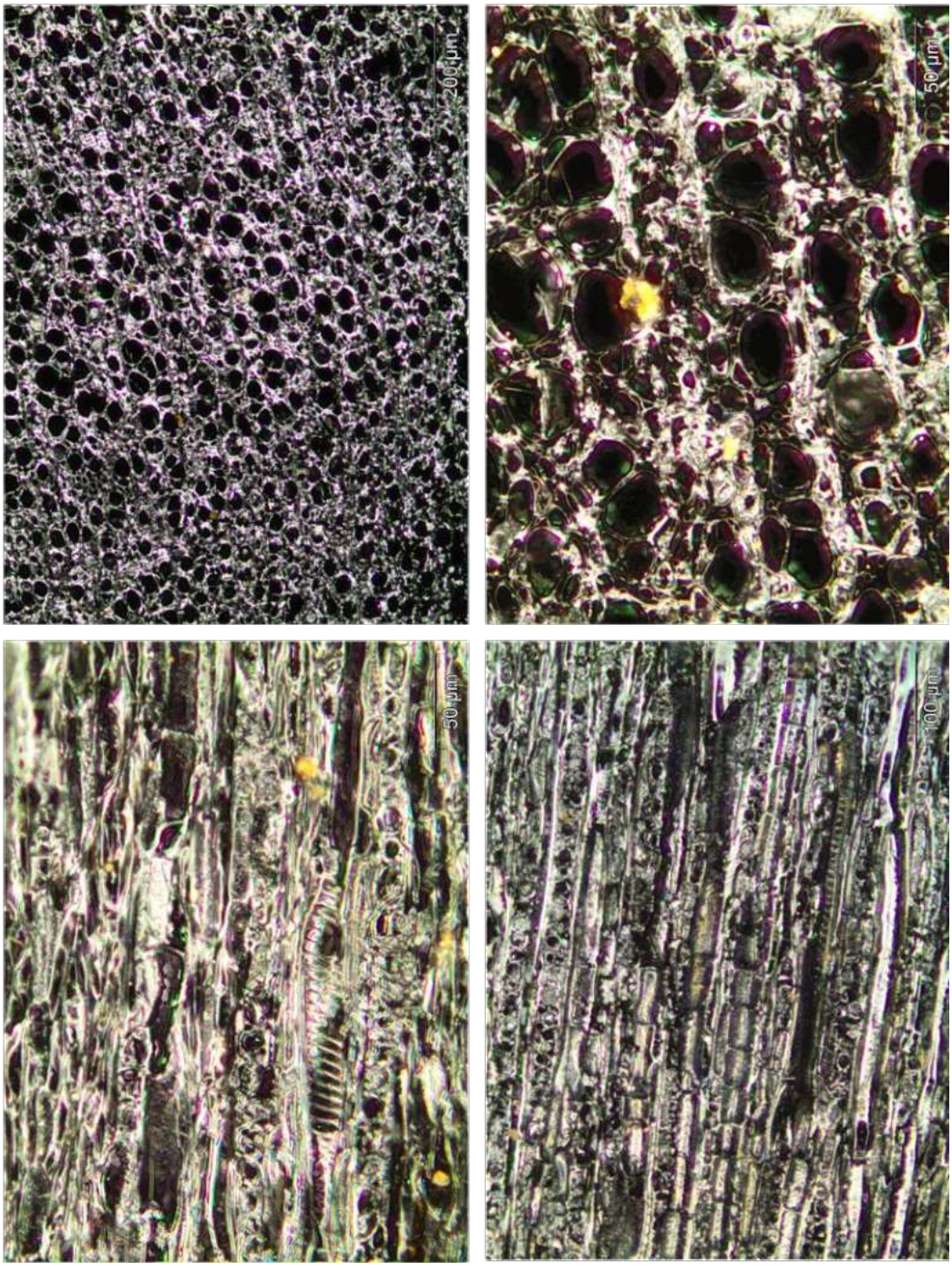
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Senegalia ataxacantha



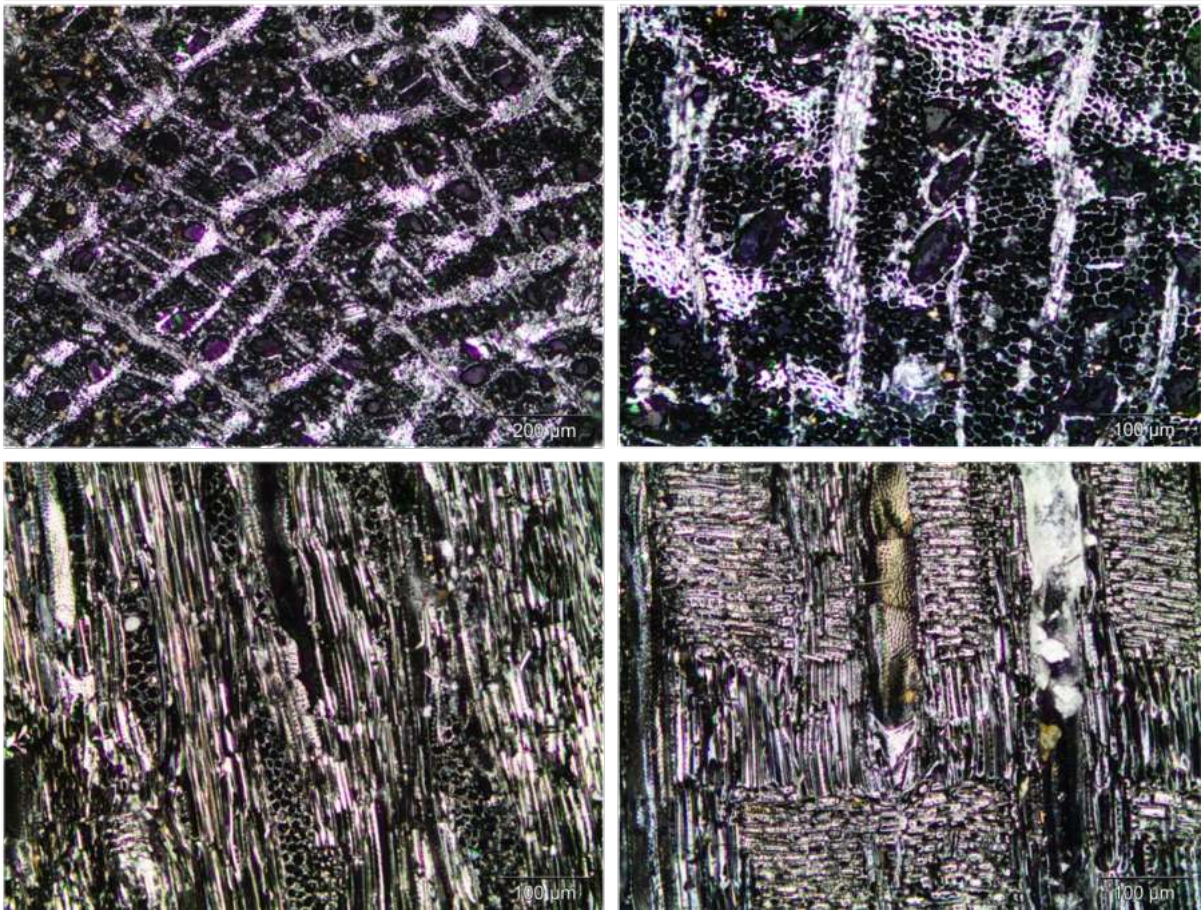
Type 26

Apodytes dimidiata



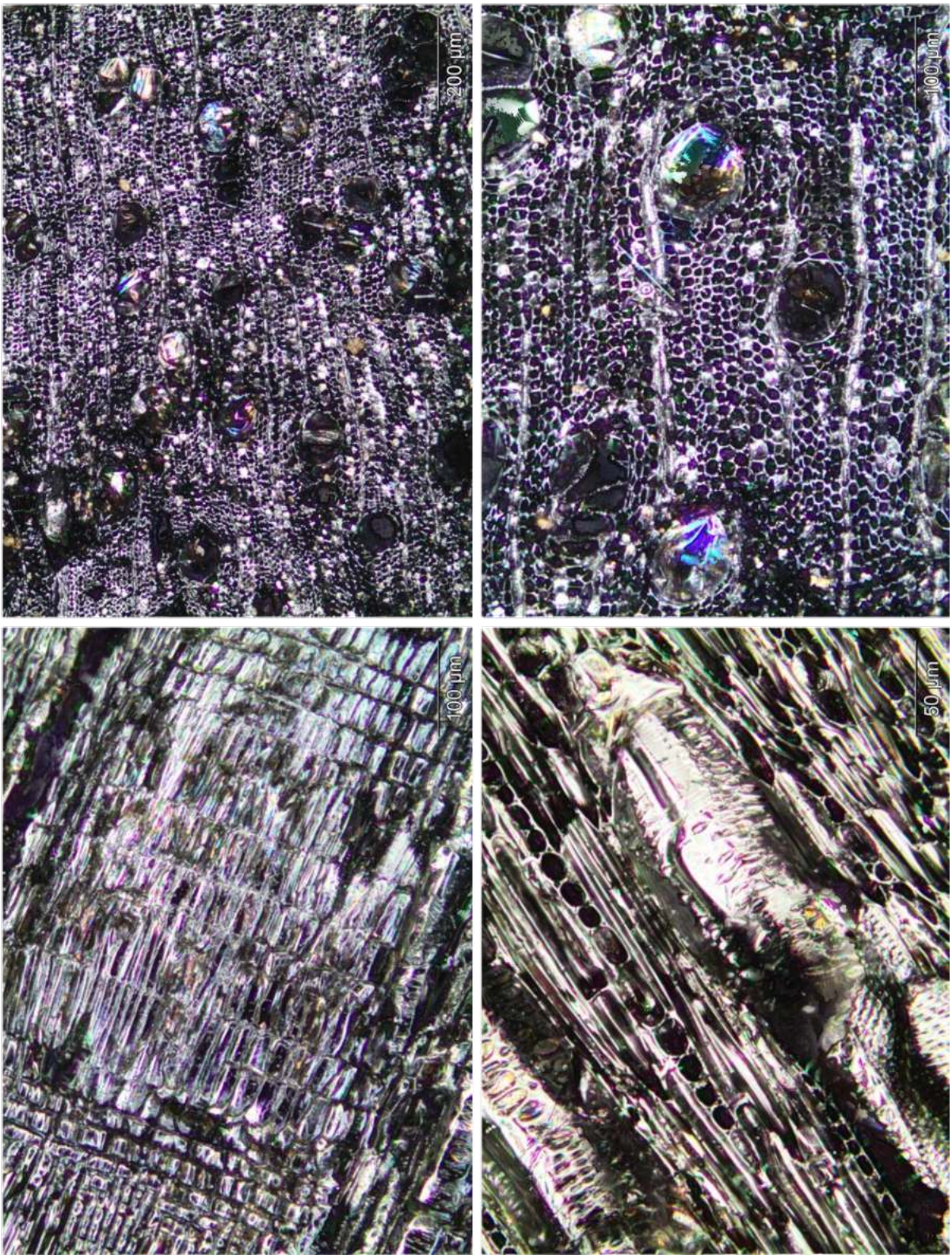
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Vachellia tortilis



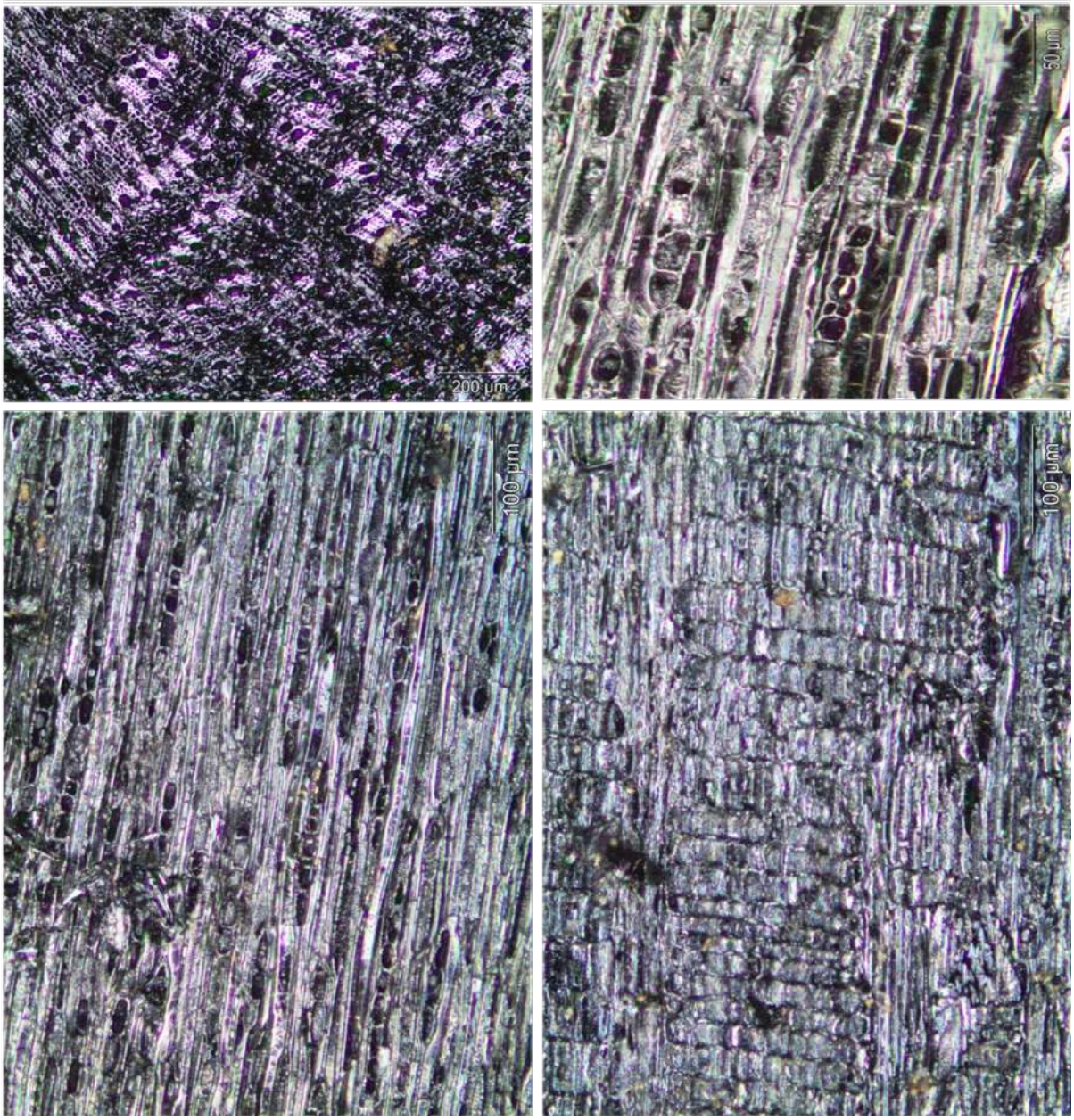
Type 32

Sclerocarya birrea

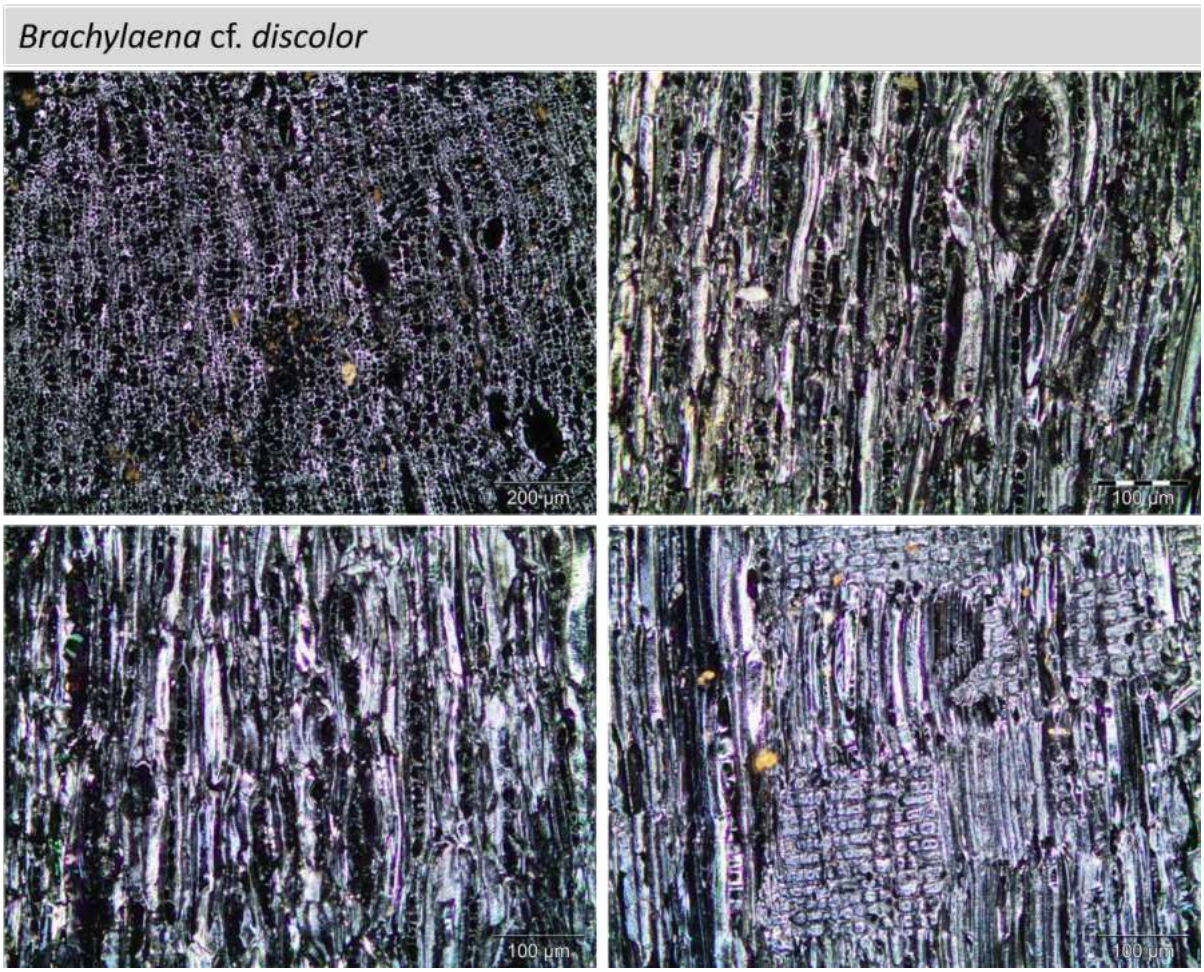


Type 33

Gymnosporia nemorosa

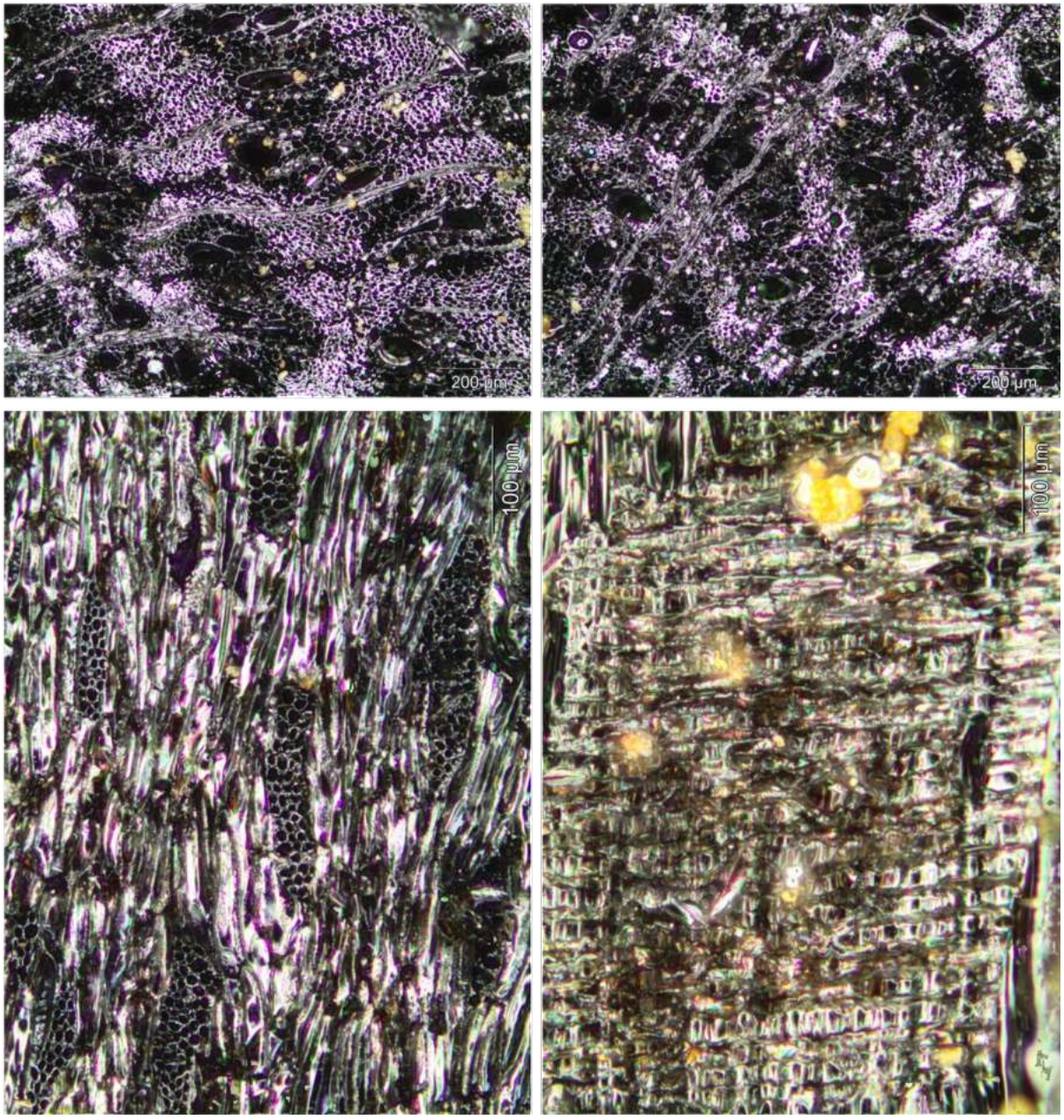


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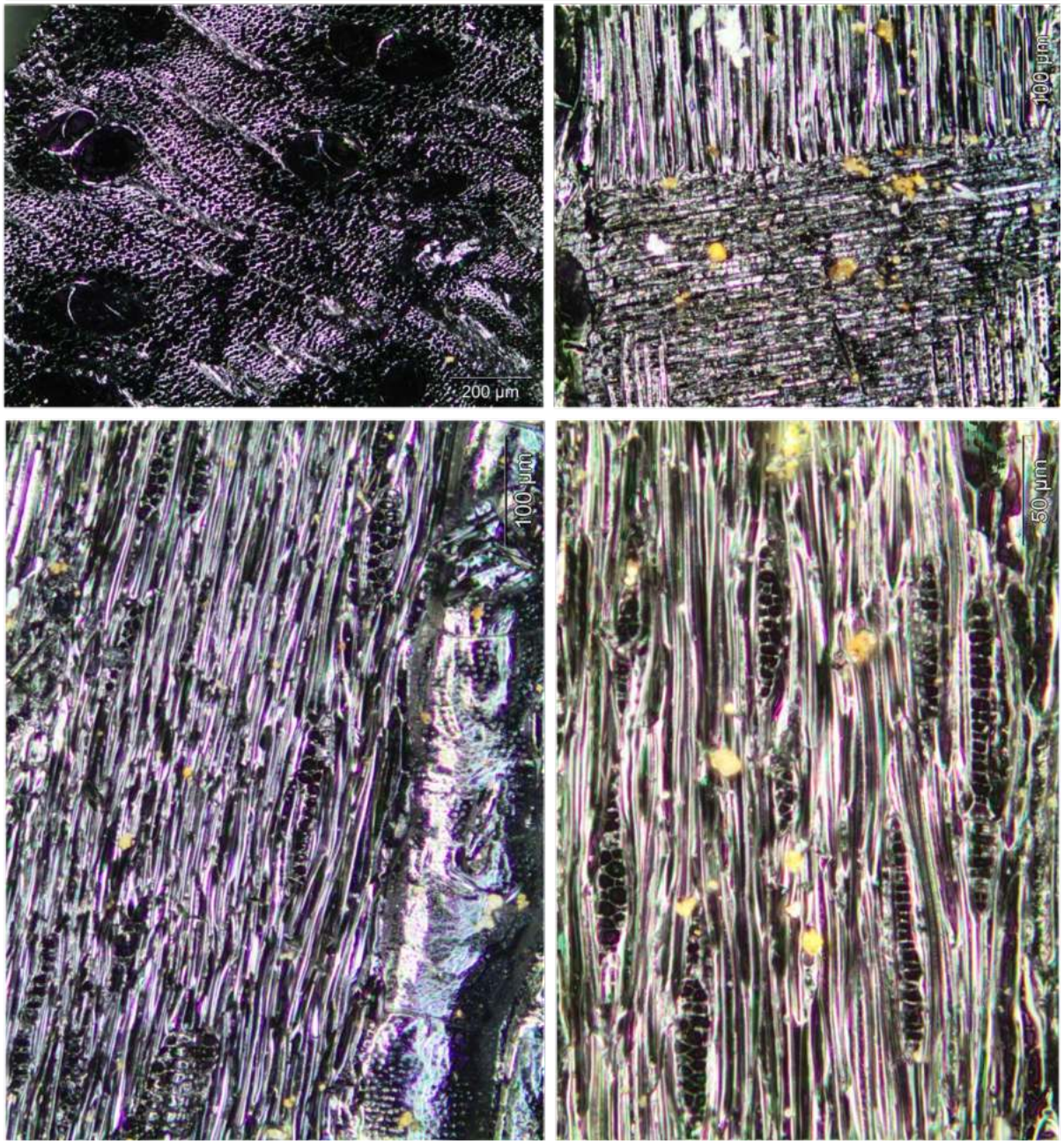
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Vachellia robusta



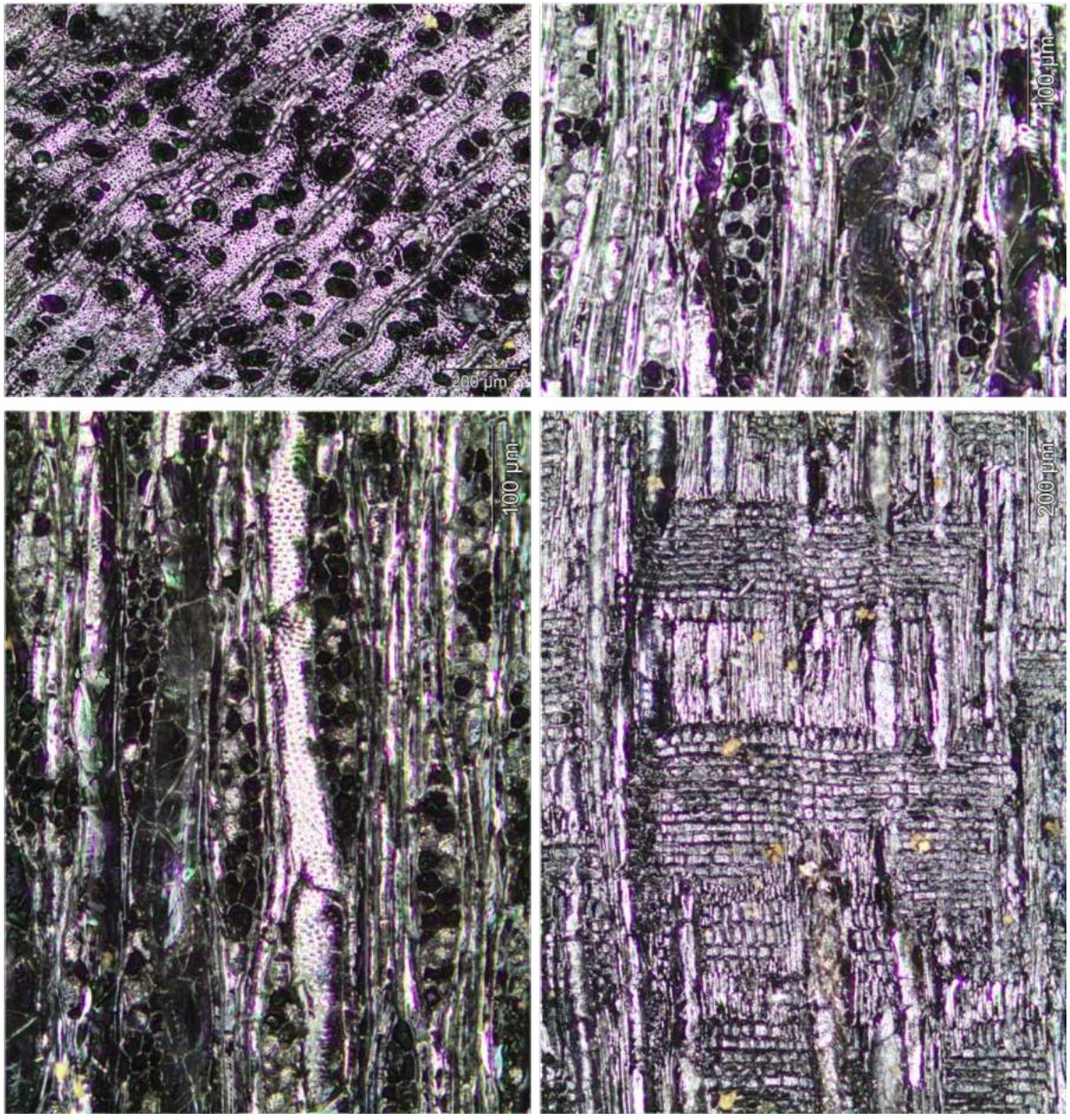
Type 42

Senegalia caffra

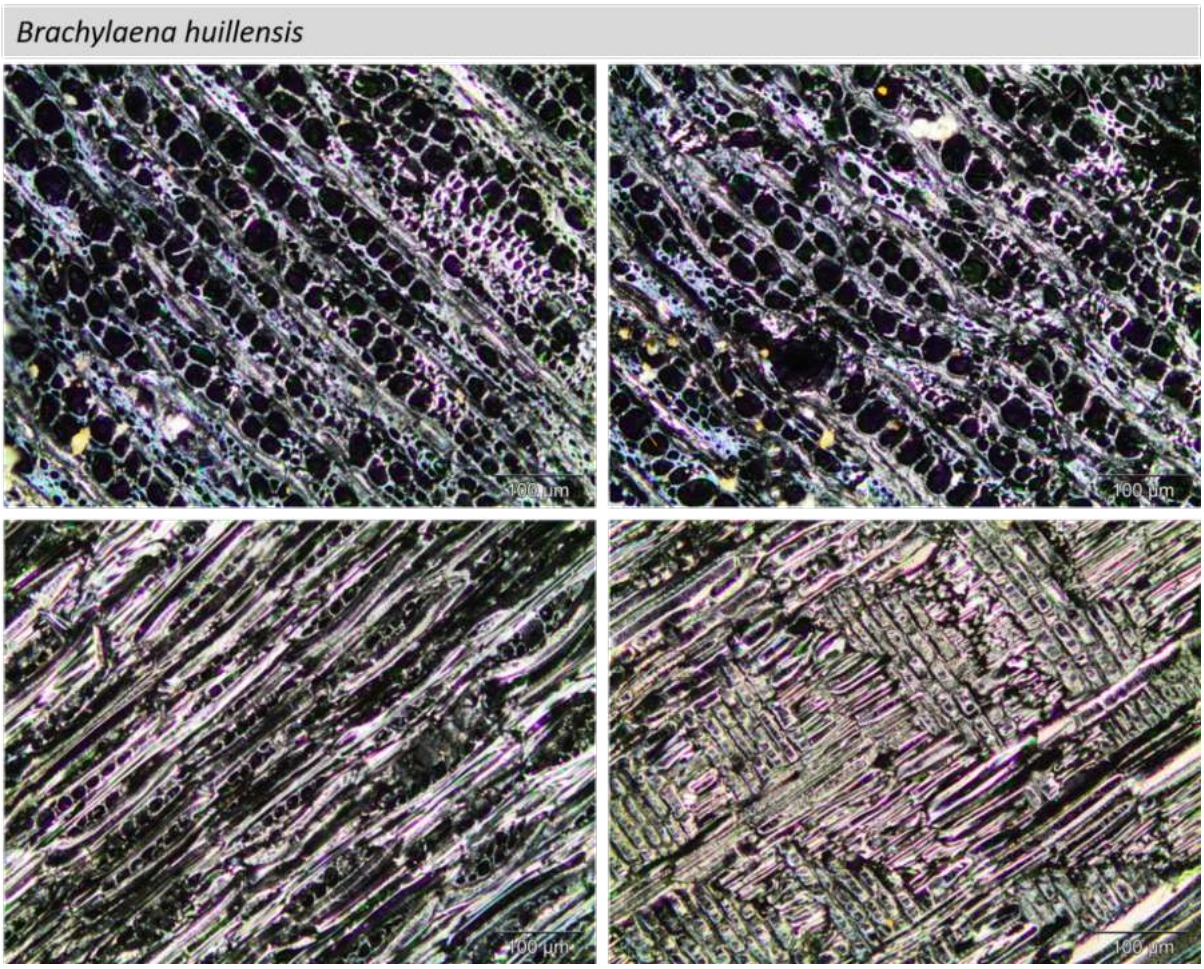


Type 43

Dichrostachys cinerea

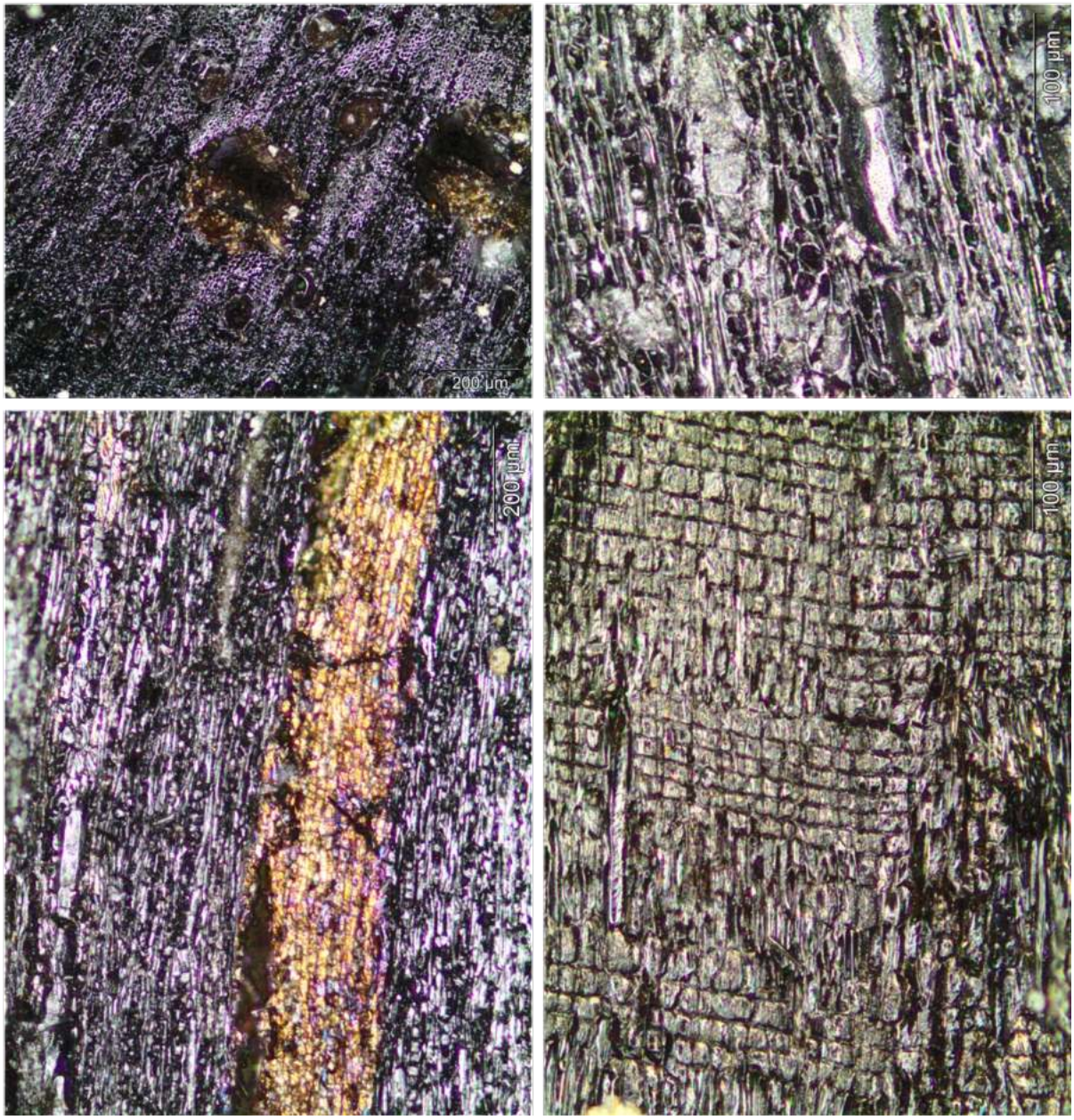


Type 50



Type 56

Combretum krausii



Type 57

Colophospermum mopane

