PALYNOLOGICAL ANALYSIS OF THE HOLOCENE SECTION OF A NEW CORE FROM TSWAING CRATER, SOUTH AFRICA

Amr Abdel-Sabour Abdel-Hamide Metwally

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Johannesburg, January 2011

DECLARATION

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

Amr Metwally

Day of January 2011

ABSTRACT

Palynological data from a new core from Tswaing Crater Lake within the savanna biome of South Africa contributes to a better understanding of vegetation and climate dynamics during the Holocene. A 650cm sediment core section TSW1, with 65 samples and fourteen AMS ^{14}C dates, covers a time period between *ca* 10000-2000 cal yrs BP. No pollen data are available from the lower part of the profile (600-800cm) due to palynomorph destruction, but a single sample with a low number of pollen grains gives a glimpse into a presumably very dry time period at *ca*11300 cal yrs BP. A warm and dry early Holocene (*ca* 9000-7500 cal yrs BP) is evidenced by high pollen percentages of Asteraceae, *Tarchonanthus* and *Dichrostachys*. The mid Holocene phase from *ca* 7500-4000 cal yrs BP is characterised by an increase of *Burkea*, Combretaceae and *Podocarpus* as well as aquatics and swamp plant pollen. This suggests warm sub-humid conditions and local moisture during this time interval. A short-term dry period occurred *ca* 4000 -3600 cal yrs BP characterized by a significant decline of most tree pollen including *Podocarpus*, whereas Poaceae pollen increased slightly. From *ca* 3600 - 2000 cal yrs BP tree pollen percentages gradually increased and the presence of *Spirostachys* pollen suggests a return to warm sub-humid conditions. The upper part of the profile above a depth of 150cm shows disturbances due to salt mining and was therefore not sampled. The palaeoclimatic interpretation of the pollen fluctuations was supported by PCA (Principal Components Analysis). From around *ca* 1800 cal yrs BP additional samples were studied in this project in comparison to the previous study of Scott to improve the resolution. The climatic investigation from the Tswaing pollen record of the current study supports the

climatic interpretations which were inferred from the biomarker analysis by Kristen et al., 2009. A regional comparison between the current Tswaing pollen profile and pollen records from Wonderkrater and Lake Eteza was done in the frame of the current study. The general palaeoclimatic changes recorded from Tswaing pollen sequence are consistent with the pollen evidence inferred from Wonderkrater which can attributed to regional changes in eastern South Africa. These trends differ from those in lake Eteza, especially during the early Holocene, which might be explained as a consequence of the generally more humid climate in the coastal plain of KwaZulu-Natal.

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CHAPTER ONE - INTRODUCTION

1.1- General introduction

Palynology or paleopalynology is not only the study of spores and pollens but includes the study of other organic microfossils which are found in sedimentary rocks. This includes acritarchs, chitinozons, scolecodonts, and dinoflagellates. The organic microfossils are called palynomorphs and consist of the resistant organic molecules sporopollenin or chitin (Traverse. 2008). The size range of palynomorphs is 5-500µm. Palynodebris is the term given to the broken up organic matter that is sometimes found in palynological preparations Palynodebris does not consist of sporopollenin or chitin but rather of plant materials such as charcoal or cellulosic tissue fragments (Traverse. 2008). Palynodebris is important in terms of palynofacies and environment relationship.

Study of the pollen grains (recent or ancient) is useful in several scientific studies e.g., taxonomy, melissopalynology, forensic science, study of past climatic changes and study of the past human impact on the vegetation (Moore et al., 1991). Palynology is also useful in the biostratigraphic correlation especially in an area where the faulting hampers the lithostratigraphic correlation (Falcon, 1975b). Palynomorphs are generally absent in well sorted and coarse grained sandstone. Sporopollenin is affected by oxidation and alkalinity and therefore the palynomorphs are not preserved in oxidized environments e.g. red beds. Palynomorphs are usually not studied in metamorphosed rocks due to the high temperature and pressure that destroys the organic matter by carbonization (Traverse. 2008). In modern plants pollen and spores can be identified to the level of family of the parent plant and sometimes to genus. In limited cases the pollen species of the same genus can be identified (Traverse. 2008).

1.2- Objectives

1- To study the palynology of the Holocene section of a new core of Tswaing crater in high resolution in order to narrow the gaps observed by Scott (1999a) in the pollen record, and to identify and discuss short termed vegetation changes, for example, during the Holocene Altithermal (*ca* 8000-6000 yrs BP, Partridge et al., 1999).

2- To improve the Holocene chronology of the Tswaing crater core which is currently based on 4 radiocarbon dates which were predominantly measured only on bulk sediment samples (see Kristen et al., 2007; 2009) by looking for seeds, charcoal and wood in the samples which are used for AMS radiocarbon dating. Charcoal and seeds provided more accurate ages because the probability of the contaminations is lower than for the bulk samples.

3- To reconstruct the palaeoenvironment and climatic changes. There are two related ways to reconstruct the past climate:

1- Qualitatively by looking at the plant taxa. Palynology is useful for the reconstruction of palaeoenvironments because it provides detailed data of the vegetation and therefore the environmental conditions.

2- Quantitatively by selecting some sensitive taxa and using Principle Component Analysis (PCA).

4- To study the modern pollen by collecting surface samples to interpret what kind of vegetation is growing in the region and to compare them with the fossil pollen from the Holocene section.

5- To compare my results with the biomarker studies of Kristen et al., 2009 and compare my data with her findings and climatic interpretations.

6- To compare my results with the most complete published Holocene sections of South Africa which are located in different biomes but in the summer rainfall region, such as Wonderkrater (Savanna biome, Scott, 1982a) and the section from lake Eteza, KwaZulu-Natal (Indian ocean coastal belt biome Neumann et al., 2010) and Braamhoek, eastern Free State (Grassland biome, Norström et al., 2009).

1.3- Previous work

The sediments of Tswaing Crater lake (formerly: Pretoria Saltpan) provide one of the longest palaeoclimatic records from the interior of South Africa which represents two glacial-interglacial cycles from the last *ca* 200,000 years (Partridge et al., 1993). Partridge (1999) gave an overview of the geology, sedimentology and limnology of the Tswaing crater Lake. The main result of this study is the change in mineralogical composition and grain size distribution controlled by a change in global precession (changes in the configuration of the earth orbital) cycle of 19,000-23,000 years (Imbrie and Imbrie, 1979) during the last 200,000 years, which became weak during the last glacial period (Partridge, 1999). Several studies on diatoms, pollen and phytoliths from a core drilled in 1989 in the eastern side of the crater floor in order to reconstruct the palaeoenvironment and vegetation history of the crater are available (see below). The age of this core is based on seven radiocarbon dates. Certain sections of the profile records are incomplete due to the destruction of organic matter by oxidation during dry periods, for example at the Last Glacial Maximum (LGM 21,000-18,000 yrs BP. Scott, 1999), (Mclean and Scott, 1999).

Scott (1999a) studied the palynology of Tswaing crater which covered the Pleistocene and Holocene periods from the last 200,000 years. The productive sections in Tswaing sequence were recorded at the upper 34m and the lower 20m of the lake deposits while the barren intervals belong to parts of the LGM and the last interglacial. Although the Tswaing pollen profile is not continuous it provides important details on the environmental changes during the productive parts of the middle and late Pleistocene (Scott, 1999a). The resolution for the Holocene period in Scott's profile is comparably low and only a few radiocarbon dates are available (14 pollen samples, one sample represents *ca* 750 years, 4 radiocarbon dates). Scott (1999a) referred to some of the main pollen groups. The pollen groups include: grasses (Poaceae), local aquatic and semi-aquatic elements e.g. *Cyperaceae* and *Typha* and arboreal pollen. Savanna trees are represented by a number of genera, e.g. Combretaceae, *Burkea* sp, *Spirostachys africana*, *Sclerocarya* sp. Temperate upland Fynbos elements e.g. *Ericaceae*, *Passerina* and *Stoebe*-type are distinct at specific layers. Pollen of halophytic Chenopodiaceae/Amaranthaceae as well as Aizoaceae appears in small quantities. Scott (1999a) divided the Tswaing sequence into 15 pollen zones according to palaeoclimatic interpretations. Each of the pollen zones represented climatic conditions which were then compared to the environment of the region using modern surface pollen samples (Scott, 1982a and b; 1989). At the base of the Holocene period at *ca* 8000 yrs BP the climate was drier with *Tarchonanthus* pollen, grasses and Combretaceae pollen and at the top at *ca* 6000 yrs BP the climate was becoming more humid with more *Burkea* and *Acacia* trees. Three periods of warm climate were recorded at ca 38,000-44,000, 60,000-62,000 and 75,000-79,000 yrs BP resulting in more woody savanna vegetation in the surroundings of the lake. During the middle Pleistocene a detailed chronology was provided between ca 160,000 and 20,000 yrs BP. This is suggested two cool periods with grassland vegetation, fynbos and *Podocarpus* alternating with two relatively warm periods with dry open grassland savanna vegetation (Scott, 1999a).

Mclean and Scott (1999) studied the phytoliths of the Tswaing crater core in order to reconstruct the palaeoenvironment of the crater. They concluded that the presence of phytoliths of Festucoideae, a grass family, in high concentrations in parts of Middle and late Pleistocene might reflect a cool environment. Festucoid grasses are prominent between *ca* 40,000 to 10,000 yrs BP in the Tswaing core. In conclusion the Pleistocene Holocene transition was characterized by rather low temperatures. This result is supported by the presence of upland Fynbos during this interval in the pollen record (Mclean and Scott, 1999).

Metcalfe (1999) studied the diatom record from Tswaing crater in order to reconstruct the evolution of the lake and the palaeoenvironmental change. She detected three major gaps in the diatom record. This study has shown that there are periods of higher alkalinity and salinity of the lake *ca* 56,600 to 7,300 yrs BP. During the last glacial period wetter conditions can be detected while very dry conditions can be detected by the diatom record at the last glacial maximum *ca* 18,000 yrs BP. Climatic variation which covered the Holocene were not recorded due to the gaps in diatom record.

A new core at Tswaing crater was drilled in 2001/2002 by Prof Timothy Partridge and the GeoForschungsZentrum (GFZ) Potsdam and used for hydrological and sedimentological studies using XRF-Scanning, geochemistry to determine total organic carbon, total inorganic carbon and total nitrogen, organic petrology and pyrolysis (Kristen et al., 2007). As a result of this study intervals with a decrease in carbonate precipitation and salinity and an increase of autochthonous (algal and bacteria) organic matter indicated periods of higher rainfall. The chronology is currently based on 9 radiocarbon dates between 48,440 and 1,810 cal yrs BP (Kristen et al., 2007). The same core was used for analyses of biomarkers and stable carbon isotopes of sedimentary organic matter to understand the changes in the lacustrine environment (Kristen et al., 2009).The core material is stored at GFZ Potsdam, Germany. Prof. Hedi Oberhaensli sent 65 samples to BPI for the current palynological study.

In terms of history, the palynological studies in South Africa have a disadvantage in that the polliniferous deposits are very few. This can attributed to the lack of pollen preservation within the regions where there are Quaternary deposits (Scott, 1984). A part of the problem is that the long palynological records covered the late glacial and Holocene have a discontinuous nature and are based on different proxies which make it difficult to compare (Scott et al., 2008). However, the next section discusses palynological studies that have been done to reconstruct the vegetation and climate changes during late Quaternary in the summer rainfall region in South Africa (Fig.1). Despite the fact that the pollen records are temporally discontinuous they have provided useful information about climatic and vegetation changes during the late Quaternary. These records are discussed briefly below, beginning with the longer records.

The longest pollen record in the Savanna biome, Tswaing, was already discussed above. Wonderkrater is the second longest pollen record from the Savanna biome and is located about 150km north of Tswaing crater, providing a pollen record for the last 45,000 yrs BP. A warm cycle at the base of the sequence was observed, temperatures decreased between 24,000 and 22,000 yrs BP. At about 15,000 yrs

BP the temperature increased, but declined again at 14,000 yrs BP. Between *ca* 8,000 and 6,500 yrs BP the temperatures reached a maximum and decreased during the Holocene between 4,000 and 2,000 yrs BP. (Scott, 1999b).

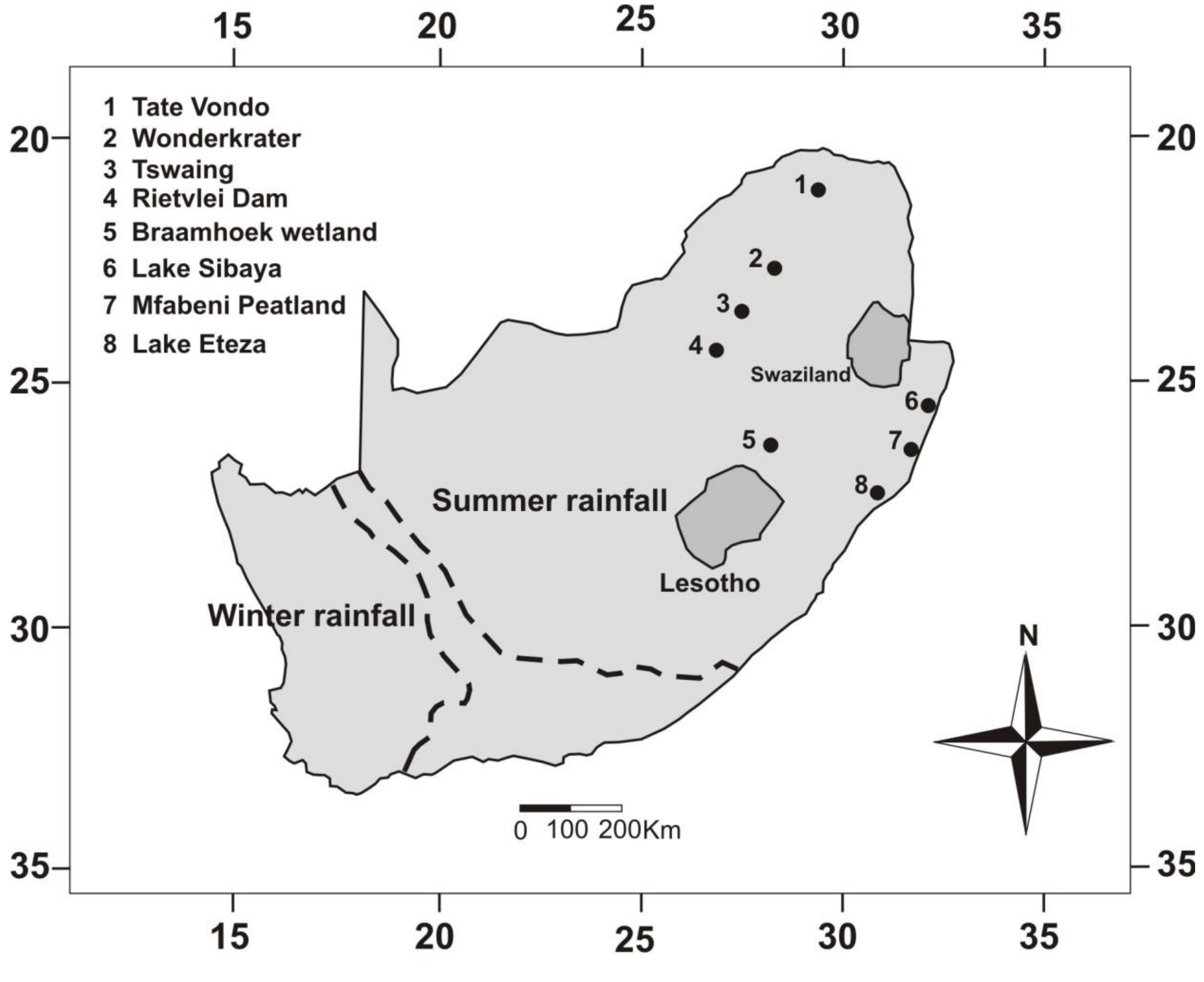


Fig.1. Map of South Africa showing the locality of some palynological sites within the summer rainfall region covering the late Quaternary (after Scott, 1989).

A continuous pollen record which covered ~44,000 yrs BP was obtained from core sediment from Mfabeni Peatland in the Maputaland coastal plain (Grundling et al., 2000). Moist, cool climate conditions were postulated before 33,000 cal yrs BP, evidenced by the abundance of *Podocarpus* pollen. Thereafter local warm, wet climate conditions were suggested from the reduction of the forest (forest retreat). Colder and drier conditions than the present were observed during the last glacial maximum (~21,000 cal yrs BP). During the Holocene Altithermal (~8,000-6,000 cal yrs BP) warm, comparatively moist conditions were observed by forest growth and expansion (Finch and Hill, 2008).

Braamhoek wetland is located in the eastern Free State within the grassland biome. The pollen record covers the last 16,000 cal yrs BP. Based on pollen, phytolith and diatom investigations dry conditions between *ca* 16,000 and 13,700, 12,800 and 10,500 and 9,500 and 8,200 cal yrs BP were recognized. More humid conditions were observed between 13,700-12,800 and between 10,500-9,500 cal yrs BP. Due to the low sedimentation rate and low sample resolution, as well as chronology, the mid and late Holocene interpretation was limited (Norström et al., 2009). Analysis of the available data suggested warm dry conditions *ca* 7,500-2,500 cal yrs BP followed by humid conditions between 2,500 and 500 cal yrs BP (Norström et al., 2009). Braamhoek wetland sequence provided a continuous phytolith record covering the late Pleistocene and Holocene (Finné et al., 2010). Their results support the climate interpretation of Norström et al., 2009. A period of increasing humidity was observed at *ca* 13,600 cal yrs BP. This phase of humidity was also recognized from the diatom record at *ca.*11,300 and 10,400-1000 cal yrs BP. This period was evidenced by a change in the diatom composition from benthic and aerophilic species toward planktonic species. At *ca* 8000 cal yrs BP the phytoliths showed contradictory results to the other record from the wetland core. The grass phytolith C_3/C_4 ratio showed a relative increase in C_3 – dominance and the phytolith aridity index I_{ph} declined indicating moist conditions. According to phytolith and other proxies in the Braamhoek wetland dry conditions were indicated during the middle Holocene. The dry period was following by a wetter period after *ca* 1500 cal yrs BP inferred from most proxy data (Finné et al., 2010).

Another record from peat deposits is located in a mountainous area close to Tate Vondo in Venda along the Transvaal-Swaziland escarpment (Scott, 1987). Cool, sub-humid conditions were observed between 12,000-10,000 yrs BP followed by an increase in the temperature and relatively arid conditions between 10,000-6,500 yrs BP. Temperature optimum signified the last *ca* 6,500 yrs BP as evidenced by the reduction of warm savanna and Fynbos pollen associated with moist conditions. The moist conditions were evidenced by swamp and mesic woodland elements. A strong decrease in the tree pollen was observed in the last *ca* 1500 yrs BP due to the burning of the forest by Iron Age people (Scott, 1987).

Another long pollen record from lake Eteza on the coast of KwaZulu-Natal within the Indian Ocean Coast Belt biome covered the last 10,250 yrs BP (Neumann et al., 2010). A dry period during the early Holocene was followed by a wet period 6,800–3,600 cal yrs BP which was characterized by forest expansion. Drier environmental conditions were observed after 3,600 cal yrs BP based on the decline in *Podocarpus* pollen which was associated with the retreat of the forest elements as well as swamp elements, whereas human disturbances were obvious from about 700 cal yrs.

A further pollen record has been obtained from peat sediments from Rietvlei Dam which is located in the Highveld grassland plateau south of the Bushveld region (Scott et al., 1995). The pollen record sheds light on the climatic changes during the end of the Pleistocene and the Holocene period (Scott and Vogel, 1983). Mesic conditions were observed at the end of the Pleistocene followed by dry conditions in the early Holocene at *ca* 8000 yrs BP. Short wetter conditions were observed after maximum temperatures at 6500 yrs BP (Scott, 1989).

Two well dated pollen records from lakes Nhaucati and Xiroche in Chibuene in the coastal lowland of southern Mozambique represent evidence of change in the vegetation, climate and human activity over the last 1600 yrs (Ekblom, 2008). Study of the vegetation change in the Chibuene area suggests that the forests were prominent on this part of the coast in the past. The vegetation of the current landscape has been dominated by savanna due to dry periods from AD 1400 to 1600. As a result of those periods the forest taxa such as *Trema*, *Celtis* and Moraceae no longer exist due to the drought which affected the vegetation.

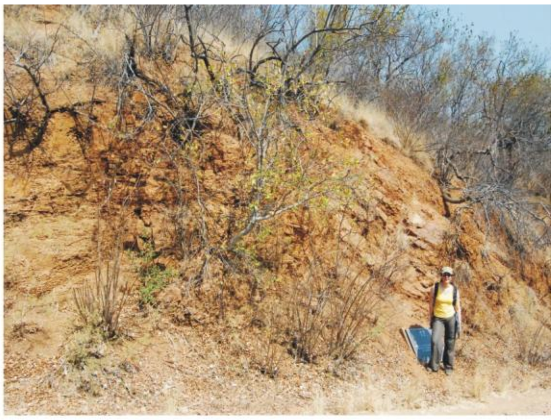
A discontinuous pollen record exists from lake Sibaya which is located in northeastern KwaZulu-Natal within the Indian Ocean Coast Belt biome (Neumann et al., 2008). The record covers the late Holocene and a short time period during the middle Holocene. Relatively humid and warm climatic conditions were observed during the middle Holocene followed by moist conditions during the late Holocene 1500-1300 cal yr BP. Cooled climate conditions were observed during the Little Ice Age 150-650 cal yrs BP which can be correlated with the information observed from stalagmites from Makapansgat Valley (Holmgren et al., 2003; Neumann et al., 2008).

1.4- Study Site

1.4.1- Geology, geomorphology

The meteorite crater of Tswaing (Pretoria Saltpan) is located 40 km northwest of Pretoria at an altitude of 1045m above sea level. It has a width of 1.13km. Tswaing crater is one of the best preserved impact craters in the world (Reimold et al., 1999). The present crater floor is below the level of the local water table, which fluctuates seasonally and annually. The lake has a depth of 3m (Partridge et al., 1993).

(A)



(B)

Fig.2. **A:** Tswaing crater Lake; **B:** Folded fragmented granite of the rim of Tswaing crater.

The lake water (Fig.2A) is saturated with dissolved carbonates and bicarbonates, especially sodium, which made it a useful source of soda from 1912 to 1956 (Levin, 1991). It is also saturated with halite in the upper sediments (Ashton and Schoeman, 1983). The lake is a closed basin without surface outflow and is nourished by groundwater, rainfall and runoff (Partridge et al., 1993, Kristen et al., 2009).

Wagner (1922) suggested a volcanic origin of the crater but Rohleder (1933) assumed a meteorite origin. According to new research the crater was formed by a meteoritic impact in granitic bedrock (Nebo granite is the main granitic type of the Bushveld complex anddated to ~2 Ma yrs BP (Brandt and Reimold, 1999). The impact is dated to 220 000±52 000 yrs using the fission-track method (Reimold et al., 1992). After its formation the crater was filled by eroded material from the crater walls; 90m of lacustrine sediments accumulated (Partridge et al., 1993). The present elevation of the crater wall is about 119m above the crater floor and 60m above the surrounding area. A geological cross-section through Tswaing crater is given in Fig. 3.

The rim of the crater is well preserved and covered by breccia which consists of angular granitic fragments (Fig. 2B). Reasonable preservation of the crater rim indicated a relatively young age of the crater (Reimold et al., 1999). Large parts of the region are covered by sands and grits which were derived from weathering process of the Nebo granite. The other areas are underlain by sandstone, shale and grit which belong to the Karoo Supergroup (Reimold et al., 1999). Weathering of the crater rim is caused by surface water penetrating joints and fractures of the granite. The weathering products of granite are large rounded boulders or smaller and angular fragments of quartz and feldspar. The mud on the crater bottom is also a product of the granite breakdown and the weathering process of the feldspar minerals (Reimold et al., 1999). The soils on the inner slope of the crater consist of coarse sandy loams and dark organic clay in the surrounding lake margin (Ashton and Schoeman, 1983).

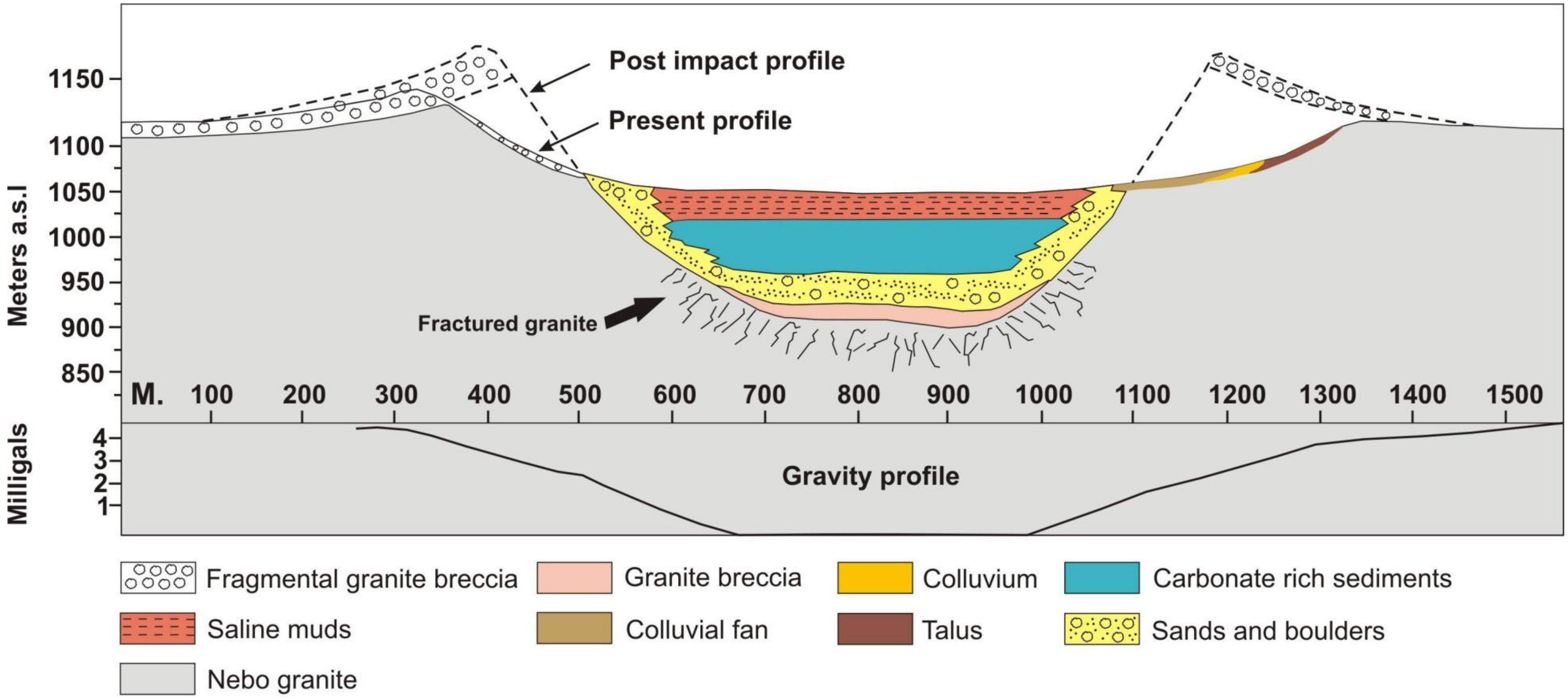


Fig. 3. Geological cross-section through Tswaing crater (after Patridge, 1993) and gravity profile measured by Fudali et al. (1973)

The sediments of the Tswaing crater core (Fig. 4) consist of granitic sand at the bottom, followed by the laminated lake sediments, which are composed of carbonate rich marls to a depth of 35m. The upper 35m of the sequence consists of organic rich mud with halite, and fluorite (Bühmann and Elsenbroek, 1999; Kristen et al., 2007). More than 1.5m of mass flow sediments (sand and gravels from the crater rim) are intercalated with lacustrine sediments at 35, 50, 70 and 77m depth (Kristen et al., 2007).

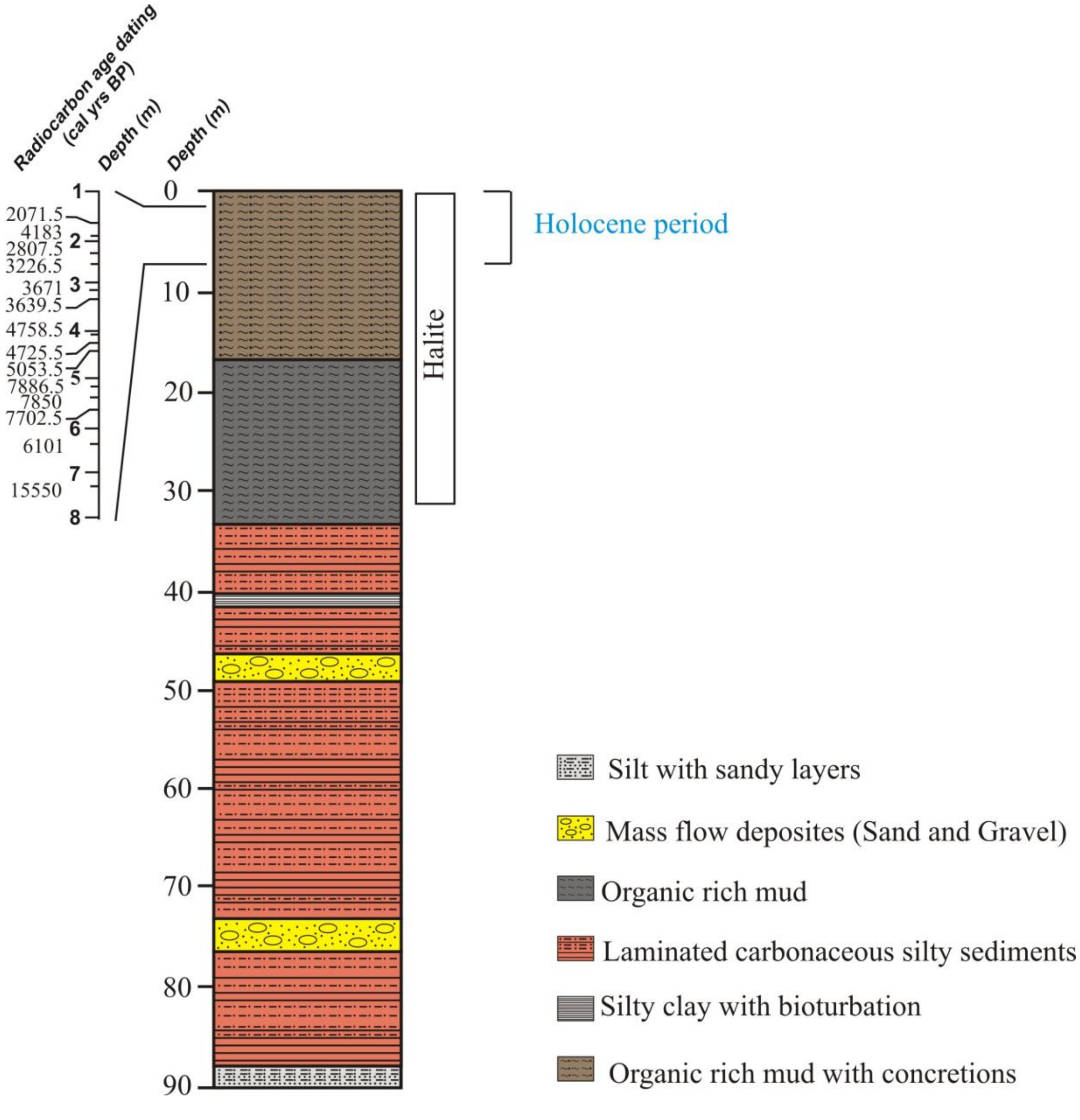


Fig. 4. Lithostratigraphy of Tswaing crater core sediments and the available radiocarbon age dating of the Holocene period(after Kristen et al. 2007)

1.4.2- Climate

South Africa's climate is affected by the position of the subcontinents in relation to the system of wind and pressure of the southern hemisphere (Tyson, 1969). A wide range of the atmospheric and oceanic circulation systems affects South Africa. The north and eastern part of the subcontinent is influenced by the seasonal interaction between the subtropical high pressure cells and the movement of the easterly flows together with the Inter Tropical Convergence Zone (ITCZ) results in rain in the tropical region (Chase and Meadows, 2007). South Africa’s rainfall is directly linked to the position of the Inter Tropical Convergence Zone (ITCZ) which plays an important role in the precipitation gradient from the west to the east coast of South Africa (Nicholson, 1996). During the summer the eastern part of South Africa is affected by warm and moist air masses from the warm Agulhas current from the Indian Ocean associated with the ITCZ movement toward the south on the eastern side of South Africa causing a higher rainfall amount during the summer (Tyson and Preston-Whyte, 2000). In the summer rainfall region more than 66% of the mean annual precipitation is received between October and March (Chase and Meadows, 2007). The ITCZ arrives at its southernmost position of 23°S during the austral summer, while in the eastern Atlantic Ocean the ITCZ rarely moves below 5°S (Schneider, 1996). Consequently the Tswaing crater region has summer rainfall (Fig.5), while the Cape region has winter rainfall (Hastenrath, 1991). Another important factor in precipitation in South Africa is the southward movement of the anticyclones (high pressure cells) of the southern Indian and Atlantic Oceans (Rutherford et al., 2006).

The semi-arid Tswaing crater region is affected by the wind system of eastern equatorial Africa (Kristen et al., 2009). The annual precipitation is 400 - 750mm per year with a maximum during October to April whereas the winter is dry or very dry (Kristen et al., 2007). The mean annual temperature in the region is 14.2° C to 15.6° C (Ashton, 1999).

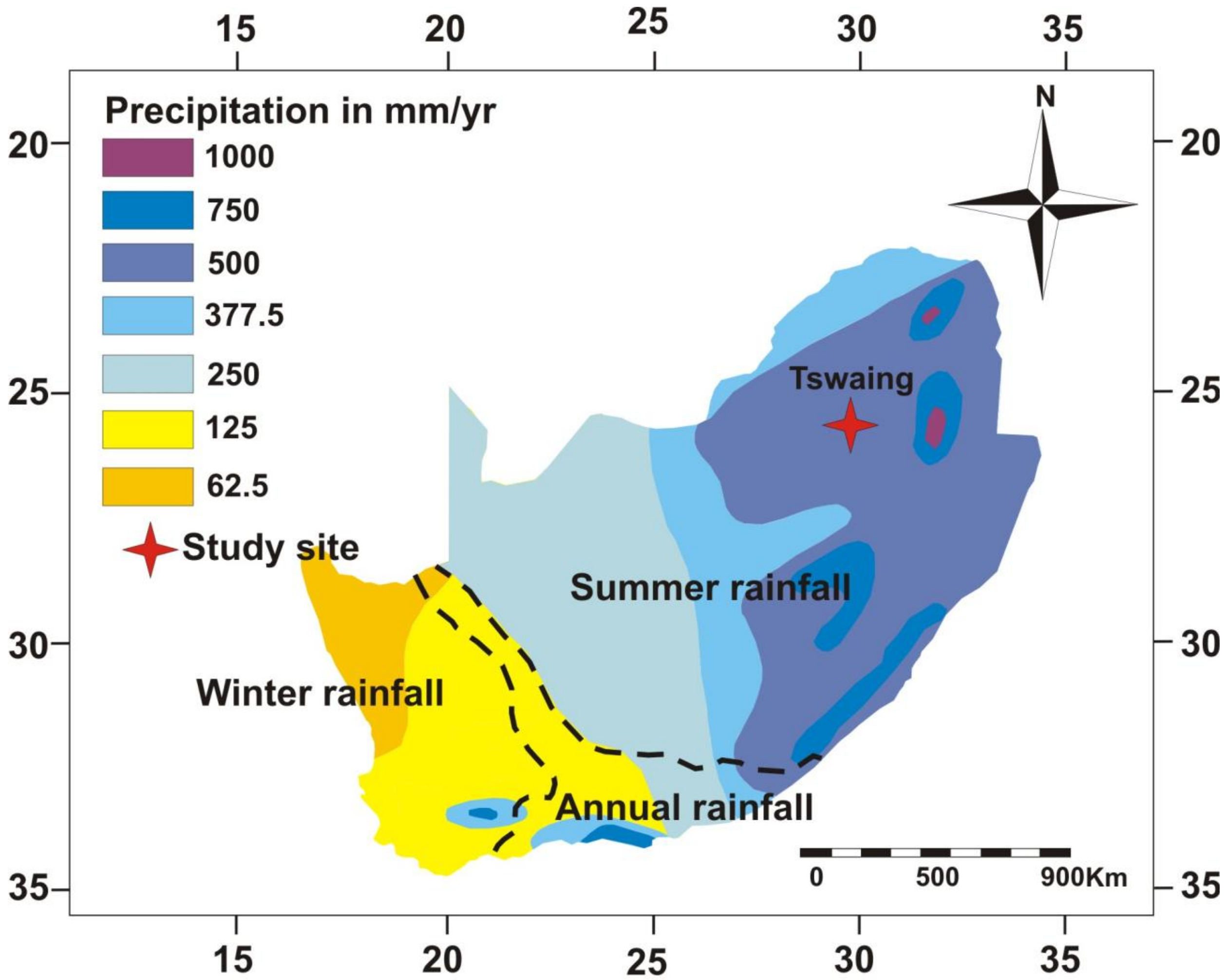


Fig. 5. Map of South Africa showing the distributions of the summer rainfall and the annual precipitation in mm/year (redrawn from Philip and London, 1969)

1.4.3- Vegetation of Tswaing crater.

Savanna is one of the major terrestrial biomes in the world consisting of trees (C_3 type) and grasses (C_4 photosynthetic pathway) which means that savanna consists of varying proportions of open woodland and grassland (Beerling and Colin, 2006; Sankaran et al., 2005). South African savanna extends from 34°S in the Eastern Cape to the north along the eastern side of South Africa and at 26°S. The savanna extends towards the west covering the northern Highveld plateau at Pretoria and crossing the Kalahari to Namibia and continues towards the north to Central Africa (Scholes, 2003).–Savanna occupies 35% of the South African surface area. The essential vegetation elements of the savanna are trees and grasses (Scholes and Walker, 1993).

The composition of savanna woodlands varies depending on the differences in soils and drainage which is in fact related to the geomorphology (Cole, 1963). Her study demonstrated the relation between the distribution of savanna and geomorphology in northern Rhodesia (now Zambia). These geomorphological features are characterized by drainage superimposition from a Karoo underlain by ancient rocks and by pediplantation since Jurassic times (Cole, 1963). The study also showed that the savanna woodlands and grassland are associated with the old pediplains which are characterized by sandy to sandy-clay soils and nodular laterite beds below the surface. The soils are acidic and characterized by poor exchangeable bases and organic matter. The ability of trees such as *Brachystegia* and *Isoberlinia* to grow in the laterite soil was probably because their long root systems which can go deeper and their large lignotubers (Cole, 1963). In contrast the evergreen forests, *Marquesia* woodlands and *chipyas* cannot grow in the laterite soil but rather favour areas with good drainage and soils that are continuously renewed (Cole, 1963).

The soils under savanna vary depending on the interaction between the source rocks and the weathering system. Dry savanna soils are rich in bases, which is attributed to the basic igneous source rock (basalt or fine grained sediments such as shale or mudstone); where the source rock is basalt or basic lava smectite dominated clayey soils which are rich in organic matter are produced; where the source rock is granite in dry savanna the result is a sandy landscape, infertile uplands and more fertile bottomlands. Soils under wet savanna are acidic and very deep; kaolinites, iron oxides and aluminum are dominant (Scholes and Walker, 1993). The soils of the savanna in Tswaing region are characterized by red-yellow apedal, black and vertic clay. Soils with fluctuating water tables point to swelling and shrinking during wet and dry seasons. Soil cracks are common in the dry seasons, with loose soil surface and high calcium carbonate content (Rutherford et al., 2006)

Several studies and field observations of soil-vegetation relationships in savanna have been made to try to understand the ecological significance of the soils under savanna vegetation (MacVicar, 1962; Van Rooyen, 1971; Verster, 1974; Venter, 1990). A well-defined relationship between the soils and vegetation was found in the Kalahari in the deep red sandy soils (base-saturated). *Acacia erioloba* and *Acacia haematoxylon* are indicators of these soils, while the vegetation on the yellow-coloured, sandy-calcareous soils is dominated by Poaceae (Van Rooyen, 1971).

South African savanna ecosystems are highly affected by water availability and fire intensity (Duffin, 2008). Fire intensity is defined as the rate of energy emission along the fire front (Byram, 1959). It is important to determine the fuel load and the vegetation response to fire in savanna (e.g. Trollope, 1978, 1984; Higgins et al., 2000; Van Langevelde et al., 2003; Van Wilgen et al., 2003). Fire intensity depends on the amount of rainfall, humidity and wind speed (Higgins et al., 2000). In African savannas the fires generally are surface fires which burn the layers of herbaceous vegetation and grasses below the tree canopy (Frost and Robertson, 1987; Govender et al., 2006).

Fire is an important source for producing trace gases and aerosols from the savanna (Korontzi et al., 2003). Scholes and Andrea (2000) reported that there is a direct relationship between the enhancement of the seasonal tropospheric ozone and the burnt biomass. The probability of fire is closely connected to the grass biomass (Van Wilgen et al., 2003). Dry grasses are the main source of fuel in South Africa which burn producing low methane, carbon monoxide and aerosol emissions (Scholes et al., 1996). The effect of fire on savanna vegetation is variable; a recent study by Jacobs and Biggs (2001) on populations of *Sclerocarya birrea* in the Lowveld showed that the fire adversely affects lower individuals (less than 2m tall). In the Central Bushveld savanna, dominated by *Dichrostachys cinerea* and *Acacia gerrardii*, the trees less than 3m tall were damaged by fire while the trees more than 3m tall were unaffected (Jordaan, 1995).

The vegetation of the Tswaing crater rim varies from broad leaved woodland with *Combretum* on the upper part of the slope to *Acacia* woodland on the lower part (Reimold et al., 1999). According to Rutherford et al., (2006) the savanna vegetation in the region can be classified into six vegetation units (Fig. 6) as the following:

Marikana Thornveld: This vegetation unit is characterized by open *Acacia karroo* woodland vegetation in the valleys, on the lowland hills and shrubs along the drainage lines. Tall trees are e.g. *Acacia burkei* and small trees include *Acacia caffra, Combretum molle, Rhus lancea, Dombeya rotundifolia* and *Peltophorum africanum* are predominant. Tall shrubs are *Euclea crispa* subsp and *Olea europaea* subsp. *africana.* Herbs, eg. *Hermannia depressa,* and *Barleria macrostegia*, is abundant.

Norite Koppies Bushveld: This vegetation unit is characterized by semi-open to closed woodland vegetation. Important trees are *Sclerocarya birrea* subsp. *caffra*, *Combretum molle*, *Croton gratissimus* and *Combretum apiculatum.* Tall shrubs, eg. *Grewia flavescens, Canthium gilfillanii* and *Euclea natalensis,* are common.

Central Sandy Bushveld: Tall deciduous trees, e.g *Terminalia sericea* and *Burkea africana,* dominate the woodland. *Acacia burkei* and *Sclerocarya birrea* subsp. *caffra* as well as *Burkea africana, Grewia bicolor, Combretum apiculatum,* and *Peltophorum africanum* are abundant.

Loskop Mountain Bushveld: The vegetation is dominated by *Burkea africana* and broadleaved savanna trees, e.g. *Diplorhynchus condylocarpon, Combretum* *apiculatum* and *Acacia caffra*. Small trees e.g. *Croton gratissimus* and *Combretum apiculatum* are abundant.

Western Sandy Bushveld: *Acacia* species, *Combretum apiculatum* and *Terminalia sericea* are prominent. Characteristic tall shrubs are *Combretum hereroense, Euclea undulata, Dichrostachys cinerea* and *Grewia bicolor*. Low shrubs, e.g. *Clerodendrum ternatum* and *Indigofera filipes,* and herbs, e.g. *Blepharis integrifolia* and *Monsonia angustifolia,* are abundant.

Springbokvlakte Thornveld: The Tswaing crater is located within this vegetation unit. The vegetation unit is characterized by *Acacia* species and shrubby grassland is prominent. Characteristic small trees are *Acacia karroo, Acacia luederitzii* and *Ziziphus mucronata.* Tall shrubs, e.g. *Euclea undulata, Rhus engleri, Dichrostachys cinerea, Tarchonanthus camphoratus* and *Grewia flava* are widespread.

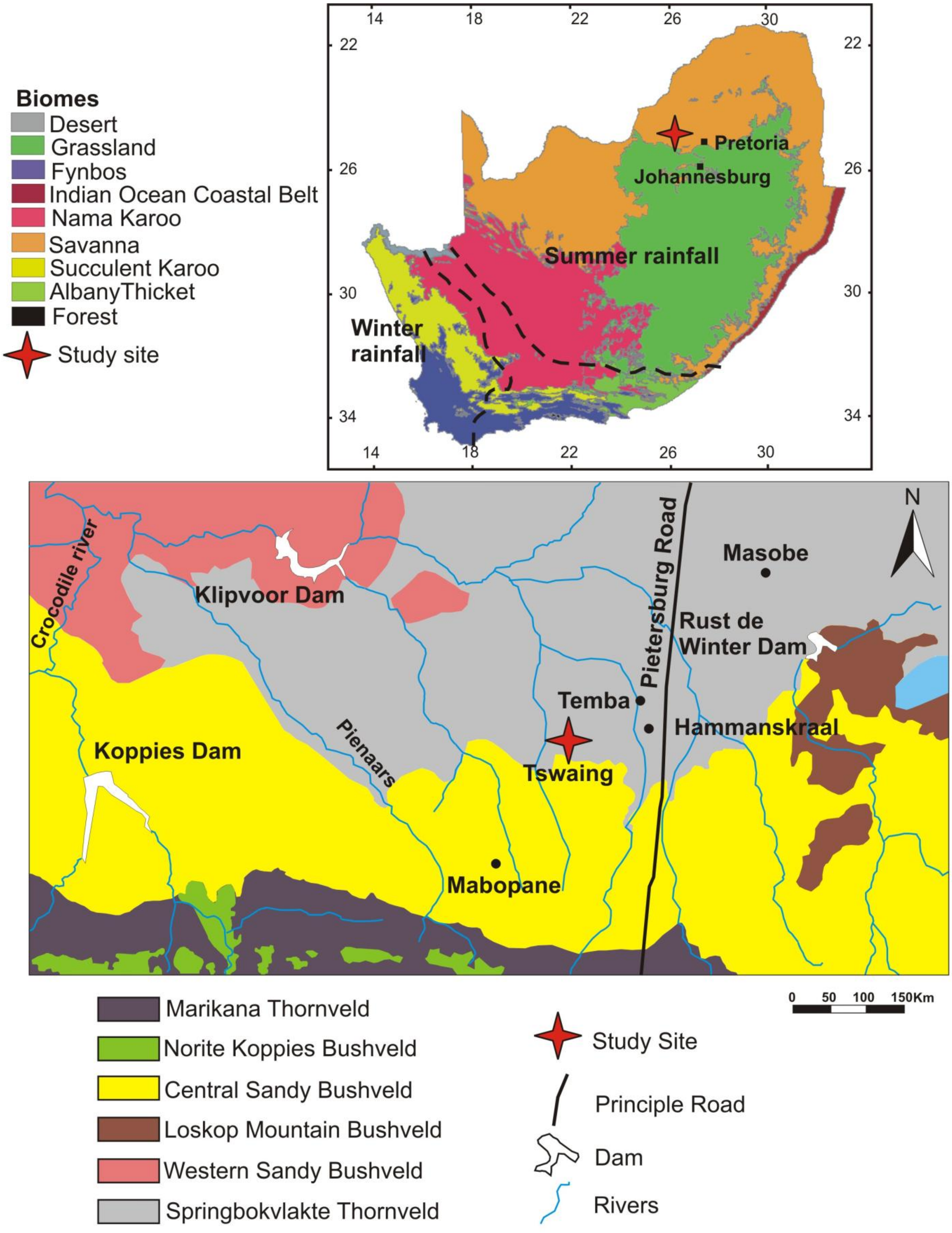


Fig. 6. Location map; upper diagram: vegetation map of South Africa with boundaries of summer and winter rainfall areas, bottom diagram: detailed vegetation map around Tswaing (after Mucina and Rutherford, 2006)

CHAPTER TWO – MATERIAL AND METHODS

2.1- Core sampling

The new core was drilled between November 2001 and February 2002 by Soiltech (Franki Africa Ltd.). The drilling was done using a solid promontory (a tube built for salt-production during the earlier time, Kristen 2009). This study is on the first core section, TSW-1, for which a Shelby tube drilling was used (Fig.7) and secured a good quality core (Kristen, 2009). In order to study the palynology of the Holocene of Tswaing crater 65 samples were taken in short intervals (ranging from 0.5cm to 15cm) to obtain a higher resolution than had been obtained by Scott (1999a). The samples covered the whole Holocene period and were represented by 8m of sediments.

(A) (B) (C)

Fig.7. A: Soiltech driller, B: Shelby tube drilling and C: TSW-1 core sediments (Kristen, 2009)

2.2- Pollen studies on modern surface samples

Nine surface samples were collected by the author from sites along a transect between the lake and the crater rim from nine locations. The samples were taken based on the vegetation change along the transect. The modern vegetation along the transect was also described and identified to the species level. The samples were collected using a trowel. Between each sample the trowel was cleaned using a clean cloth to avoid contamination. Around 50g of surface sediment were taken for each sample and packed into plastic bags, labeled and numbered. Co-ordinates were established using a GPS instrument (GPS, Garmin-calibration WS1983) and the vegetation around each sample was described.

2.3- Sample Preparation

2.3.1- Acid preparation

65 samples from the Holocene section of the Tswaing core as well as the surface samples were processed to extract the palynomorphs using standard palynological methods. To extract the palynomorphs from the sediments acid preparation is recommended. The outer layer of the pollen grain, which is called the exine, consists of sporopollenin. It is acid resistant while the majority of the minerals which comprise the sediments are not. So the acid preparation is helpful to extract the pollen without damage (Traverse, 2008). Each sample was treated as follows:

1- The sample was weighed and two *Lycopodium* tablets were added as exotics to calculate the pollen concentration. HCL 10% was added in order to dissolve the carbonate. The sample was stirred and centrifuged for three minutes. Then HCL 10% solution was decanted, the tube was rinsed with distilled water and again centrifuged (followed by washing twice).

2- HF 40% was added to dissolve the clay minerals and silicates, the samples were left in the acid for 24 hours. The next day the samples were stirred and centrifuged. Then samples were washed with distilled water and centrifuged.

3- Hot KOH 10% was added to remove the organics. After boiling the samples were washed with distilled water and centrifuged until clear.

4- Mineral separation was applied to the samples ($ZnCl_2$ solution, specific gravity 2) to separate the undissolved minerals from the organic fraction and to maximise the pollen concentration. The samples were centrifuged at 4000 r.p.m for 5 minutes.

5- Acetolysis treatment was required (standard method after Faegri and Iversen, 1989) in order to remove the plant remains :

   a- Glacial acetic acid was added and then samples were stirred, centrifuged and decanted.

   b- A mixture of acetic anhydride and sulphuric acid (ratio 9:1) was added. The samples were heated up (80° C) and stayed in the water bath for 3 minutes.

c- In the next step the samples were put in cold water to stop the acetolysis reaction and then the samples were centrifuged and decanted.

d- Glacial Acetic Acid was added again. The tubes were centrifuged and decanted.

e- The residues were washed with distilled water (3 times) and were then ready for slide preparation.

2.3.2- Slide preparation

Glycerine-jelly is one of the most favourable mounting media (e.g. Praglowski, 1970; Chapman, 1985; Collinson, 1987). Glycerine-jelly has major advantages because of its excellent optical properties (Batten and Morrison, 1983). A major disadvantage of using glycerine jelly is the possibility of absorption of moisture from the atmosphere which results in the swelling of the pollen grains (Faegri and Deuse, 1960). Additionally mounting in a solid medium does not allow the palynomorphs to move. Slides also can be stored for a long time and the pollen grains can be identified even long after the preparation of the slides. Pollen grains are easy to photograph under light microscope. Residues were mounted in glass slides with glycerine-jelly and sealed with glass cover slips and dried on a warming plate.

2.3.3- Light microscopic analysis

A petrographic light microscope (Zeiss microscope, Axioskop2) was used for pollen analysis and photographs were taken by using the 1000 x oil immersion objective and digital camera at BPI Paleontology. Measurements were made using the image analysis program AnalySIS 5.1. Pollen grains were identified by using modern reference material and photographs in the Department of Plant Sciences, University of Free Sate, Bloemfontein and at BPI Paleontology, as well as literature (Van Zinderen Bakker, 1953-1970; Bonnefille and Riollet, 1980; Scott, 1982b, Moore et al., 1991; Jürgen, 2004). At least 500 terrestrial pollen grains were counted in each sample to reach a reasonable pollen sum. Other remains like algae, fungal spores and microscopic charcoal were recorded in the process. Charcoal fragments (size categories >50-99µm and > 10µm) were counted in each slide in order to reconstruct the fire history. Tilia 2.0 (Grimm, 1992) was used for the percentage calculation of the diagram. The calculation of pollen concentration (formula is given below) is based on the ratio of fossil to known numbers of exotic *Lycopodium* spores which were added to each sample.

(P/m)* e)/w = pc

p: pollen grains counted

m: marker grains (*Lycopodium*) counted

e: number of exotic marker pollen grains added

w: weight or volume of sediment

pc: pollen concentration

2.4- Radiocarbon chronology

Each sample was treated with 50% KOH and 50% distilled water before the palynology extraction processing started. Charcoal particles and seeds were collected using tweezers under binocular microscope (Zeiss, StemiSV6) using

400x magnification. Charcoal fragments were weighed and wrapped in tin foil for AMS radiocarbon dating. Accelerator mass spectrometry (AMS) is known as the technique for which specific element atoms can be detected according to their atomic weight (Bowman, 1990).

In the AMS technique, a system of a tandem accelerator in a high energy mass spectrometer is used to measure the radiocarbon age (Gillespie, 1986). Ion counting is applied directly to measure the amount of radioactive ^{14}C isotopes directly instead of waiting for the decay event as in conventional radiocarbon dating. Generally 0.5 to 2 milligrams of carbon in the form of synthesized graphite are used in the AMS system (Gillespie, 1986). The major advantage of AMS radiocarbon dating is that small samples with low carbon content can be measured (Bowman, 1990). The concentration of ^{14}C in plant (e.g. charcoal) or animal tissue (e.g. bones) can be affected by several factors such as hardwater effect (Bowman, 1990). Those factors can affect the age which make it older than the real age.

The calibration of ^{14}C age dating to calibrated years is very important to enhance the validity of time estimates (Stuiver et al., 1998). Dendrochronolgy or tree-ring dating method is very useful to calibrate the radiocarbon results (Bowman, 1990). In a seasonal, temperate climate zone, trees make one growth ring each year. Each ring varies in the width depending on the climate factors such as temperature and rainfall. Trees in the same region will have the same patterns of ring width for a certain period. On the basis of this a tree ring sequence of unknown age with one of known age can be built up. This technique is called cross-dating and allows long chronologies or master curves to be build up (Bowman, 1990). The accuracy of the dendrochronology is recognized through standard dentrochronologica checks for double or missing tree rings (Stuiver et al., 1998). The Irish tree oak (Pilcher et al., 1984), German oak and pine chronologies (Spurk et al., 1998) are important in the dendrochronolgy. The German oak has given absolute counts of dendroyears back to *ca* 10300 cal yrs BP. Matching of ^{14}C of the latest part of German pine chronology to the first German oak dating has expanded the previous chronology to 11,857 cal BP (Stuiver et al., 1998).

Corals also can be used for calibration. Corals are perfect closed systems for ^{14}C, ^{234}U, ^{234}Th exchange (Stuiver et al., 1998). The ages dating of corals using Uranium-thorium dating method have expanded the range of the calibrated age (Bard et al., 1998; Burr et al., 1998; Edwards et al., 1993). When the tree ring ^{14}C is balanced with the carbon dioxide of the atmosphere, corals are in balance with the mixed layer ocean bicarbonate. The relatively lower activity of ^{14}C of the mixed layer in compared to the ^{14}C in the atmosphere thus causing an offset between the atmosphere and the ocean. The ^{14}C reservoir age correction (offset) was corrected by comparing the early Holocene tree ring and coral ^{14}C activities of samples which are from the same time period. On the basis of this the coral age dating has expanded the calibration curve to 24,000 cal BP (Stuiver et al., 1998).

2.5- Principal Component Analysis (PCA)

In order to identify certain trends in the pollen spectra which than can be interpreted in terms of climate or ecological change, pollen indicators were identified. Those indicators have to show major fluctuations throughout the diagram and might signal certain climatic conditions. Those indicators were subjected to principal component analysis (PCA) using JMP8 program. The main idea of the principle component analysis is to reduce large numbers of interrelated variables. This can be obtained by converting to a new set of variables which are called Principal Components (PCs). Principal components are uncorrelated and ordered. On the basis of this the first few components are reserve the majority of the variation represented in all of the original value (Jolliffe, 2002). The next chapter deals with the results that were obtained from the above mentioned methods.

CHAPTER THREE – RESULTS

3.1- Chronology and sedimentation rate

The chronology of the Holocene period in the Tswaing core sediments is based on fourteen radiocarbon dates (Table 1). Nine AMS dates are new in addition to five dates that were published by Kristen *et al*. (2009). The ages of the samples were determined at the Poznan Radiocarbon Laboratory, Poland. These dates were measured at depths between 160 and 737cm. Nine of the ages were measured on small charcoal fragments and five on bulk sediments. In order to estimate an age correction, reservoir correction of 1,150 years (the mean age offset of recent lake sediments, Partridge et al., 1997) was applied to the two youngest samples at a depth of 160 and 222.5cm, respectively, where the autochthonous materials (algal and bacteria) are dominant (Kristen et al., 2009). The ages showed a normal increase with the depth with the exception of two samples (Fig. 8). The first sample (190.5cm depth, 4183 cal yrs BP) showed an older age than the general trend. This is probably because the amount of carbon in the charcoal fragments was too small which can result in an age error. The other sample (621cm depth) showed a younger age than the general trend, 6101 cal yrs BP. The age of this sample was determined on the bulk sediment which might have been contaminated with younger material which can affect the age (Christen, 1994). Root contamination can result in age dating error. Living tree roots can bring modern carbon into an older material which makes it apparently younger than the real age (Scott et al, 2003). Because of this the latter two samples were treated as outliers and excluded from the further analysis.

Table 1: Radiocarbon ages and calibration ages for the samples of Lake Tswaing

Depth (cm)	Lab no.	^{14}C age (uncal.)	SD ±	% area enclosed 68.3 (1σ)	95.4 (2σ)	Average cal yrs BP	Material
160	Poz-15663	3095	35	3210-3275 3280-3334	3081-3091 3114-3122 3141-3362	2071.5**	bulk sample
190.5	Poz-37251	3840	40	4090-4133 4137-4236	3986-4050 4063-4297 4330-4351 4373-4380	4183*[a]	charcoal
222.5	Poz-15669	3675	35	3872-3980	3833-4006 4031-4082	2807.5**	bulk sample
276.75	Poz-37252	3100	50	3168-3179 3208-3344	3078-3095 3101-3375	3226.5*	charcoal
302.5	Poz-37255	3470	90	3564-3733 3742-3766 3789-3827	3448-3894	3671*	charcoal
304.75	Poz-37256	3430	70	3484-3531 3554-3696	3451-3778 3787-3828	3639.5*	charcoal
403	Poz-12211	4305	30	4728-4750 4820-4858	4645-4675 4693-4761 4802-4872	4758.5*	charcoal
410.5	Poz-37258	4280	40	4653-4669 4705-4757 4809-4850	4588-4595 4614-4766 4784-4863	4725.5*	charcoal
422.5	Poz-37259	4430	50	4861-4978 5011-5034	4839-5066 5110-5121 5184-5216 5221-5271	5053.5*	charcoal
521.5	Poz-37261	7130	40	7855-7904 7918-7955	7794-7814 7817-7979	7886.5*	charcoal
523.5	Poz-15664	7090	50	7799-7805 7827-7937	7735-7965	7850*	bulk sample
561.5	Poz-37262	6910	50	7620-7734	7589-7795 7813-7819	7702.5*	charcoal
621	Poz-37264	5360	50	6000-6033 6037-6120 6147-6178	5942-5973 5985-6208 6254-6260	6101*[a]	bulk sample
737	Poz-15665	13130	70	Invalid calibration curve calibration data from Kristen et al.,2009		15550*[b]	bulk sample

*Calib 6 after McCormac *et al* (2004) and Reimer *et al*. (2004)
*[b]Calib 5.0.2 after McCormac *et al* (2004) and Reimer *et al*. (2004)
Gray shadow in the table showing data from Kristen et al., 2009.
**1150 years reservoir correction subtracted (mean age offset of recent lake sediments; Partridge et al., 1997)
*[a] eliminated samples

The other samples showed a regular chronology for the sequence with the exception of samples 410.5cm, 523.5cm and 561.5cm which seem to be slightly younger than the general trend (Table 1). The ages were calibrated using Calib 6 after McCormac et al., (2004) and Reimer et al., (2004) except the sample at 737cm depth (Kristen et al., 2009) which was calibrated using Calib 5.0.2 after McCormac *et al*., (2004) and Reimer et al., (2004). The latter sample was calibrated using Calib 5.0.2 because it seems to be an error or invalid calibration when using Calib 6. The sedimentation rate of Tswaing sequence was calculated on the basis of the calibrated ages and the depth (Fig. 8). The sedimentation rate was not calculated between depths 302.5 and 304.75cm, 403 and 410.5cm, 521.5 and 561.5cm because they are reversed in ages (Table1). This might be due to small massflow events which resulted in high sedimentation rate in a short time. The sedimentation rate of the Tswaing sequence seems to be stable through the Holocene period. Otherwise the sedimentation rate was relatively high (0.062cm/yr) between 2071.5 and 7886.5 cal yrs BP (160-521.5cm depth). Low sedimentation rate (0.022cm/yr) occurred between 7819 and 15550 cal yrs BP (561.5-737cm depth).

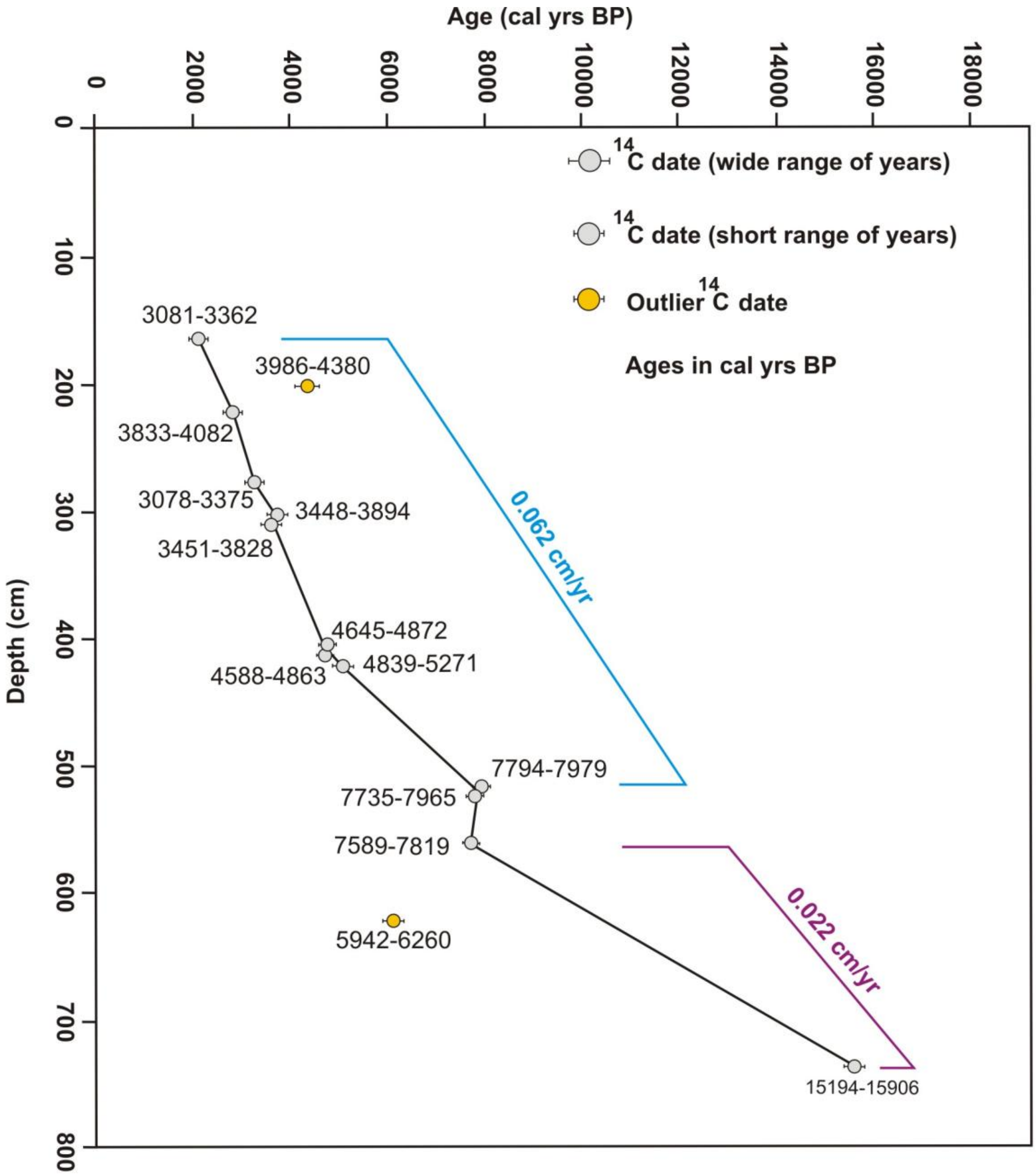


Fig. 8. Age determination at lake Tswaing, showing the calibration age with 95% error plotted by depth

3.2- Palynology of the fossil samples

The pollen concentrations through the productive part of the sequence (150cm-600cm) were reasonable ranging between 20,000 and 70,000 pollens/g (Fig.9 and appendix D). 500 pollen grains were counted in each slide. At the bottom of the sequence (600cm-800cm), eleven samples were barren with the exception of one sample at a depth of 621cm which had a very low pollen concentration. The total fossil pollen in the latter sample was 49 pollen grains and they were well preserved. The sample contained high numbers of Asteraceae pollen (19 grains) as well as grasses (Poaceae>25µm, 19 grains). Tree pollen was weakly represented such as *Grewia* (1), *Spirostachys* (1), *Anthospermum* (1), *Rhynchosia* (2), *Tarchonanthus* (3), *Burkea* (2), Combretaceae (1). Due to the low pollen sum this sample was excluded from the pollen diagram and marked in Fig. 9 by a dashed line. Pollen grains were normally identified to the genus or family level. Identifications to the species level were rather exceptional because of the species within the same family are quite similar to each other which make their identification problematic. The Tswaing pollen sequence is divided into three zones on the basis of pollen composition, pollen fluctuations and the relative abundance of the pollen species (Fig. 9). The diversity of the vegetation of the Tswaing pollen sequence was relatively high, 74 pollen taxa were identified. The average time resolution per pollen sample is *ca* 138 yrs BP between 150cm and 600cm depth.

3.2.1- Zone 1 (600-510cm depth)

Zone 1 is characterized by relatively high percentages of herb pollen like Asteraceae (30%) as well as halophytic Chenopodiaceae/Amaranthaceae (Cheno/Ams.). Pollen of other herbs (Liliaceae, *Stoebe*-type and *Artemisia*) is present but occur in low percentages. Pollen of savanna trees and shrubs such as *Tarchonanthus* and *Dichrostachys, Protea* and *Grewia,* are highly represented in Zone 1 (Fig. 9). Other savanna tree and shrub pollen, such as *Spirostachys*, Combretaceae, *Burkea* and *Acacia*, are present but appear in low percentages. Forest elements such as *Podocarpus* and *Acalypha* are represented in low percentages. Grass pollen (Poaceae >25μm) are extremely abundant (86%). Aquatics, swamp plants and algae (Cyperaceae, *Typha* and *Botryococcus*) are rare.

3.2.2- Zone 2 (510-300cm depth)

Zone 2 is marked by increasing tree pollen percentages, e.g. *Burkea* and Combretaceae (Fig. 9). Forest elements such as *Podocarpus* and *Acalypha* are increasing. *Celtis* pollen is presented in relatively high percentages while it was absent in Zone 3 (Fig. 9). Asteraceae and Poaceae >25μm values are decreasing. Aquatics, swamp plants and algae (Cyperaceae, *Typha* and *Botryococcus*) are becoming more abundant. Cyperaceae pollen percentages are reaching 50% and *Botryococcus* 52%.

3.2.3- Zone 3 (300-150cm depth)

The transition to Zone 3 (330-300cm) is characterized by a decline of tree pollen percentages and an increase in Poaceae >25μm (Fig. 9). The percentage of *Spirostachys* pollen is rising (Fig.9) and characterizes Zone 3. Cyperaceae pollen decreases slightly. Asteraceae and Cheno/Am pollen remain low. *Botryococcus* has two peaks in Zone 3, 110% in 260cm depth and 50% in 200cm depth (Fig. 9). Summaries of the pollen assemblage Zones are given in Table 2.

Microscopic charcoal percentage (size categories: >50 and >100 μm) do not show major fluctuations through the productive part of Tswaing sequence except for the relatively high percentages in the middle of Zone 2 between 460-350cm depth and at the bottom of Zone 3 between 300-260cm depth (Fig. 9).

Table 2: Summary of the pollen Zones with the depth from Tswaing crater core sediments.

Pollen Zones	**Depth (cm)**	**Pollen taxa**
Zone 3	300-150	*Spirostachys* increases, Combretaceae, *Burkea*, *Acacia* and other trees are well represented. Poaceae is highly abundant. *Typha* and Cyperaceae are still increasing as well as *Botryococcus*.
Zone 2	510-300	Increase of tree pollen. Slight increase of *Podocarpus*. *Burkea* is dominant; Combretaceae and *Acacia* are well represented. Asteraceae, Cheonpodiaceae/Amaranthaceae are decreasing. *Typha* and Cyperaceae are increasing as well as *Botryococcus*. Poaceae pollen is very abundant.
Zone 1	600-510	Decrease of the tree pollen. Increase of shrub pollen like *Tarchonanthus and Dichrostachys.* Herb pollen like Asteraceae and halophytic Chenopodiaceae/Amaranthaceae pollen are increasing. Poaceae pollen increase. Low values of aquatics, algae and swamp plants (e.g. *Botryococcus*, *Typha* and Cyperaceae).

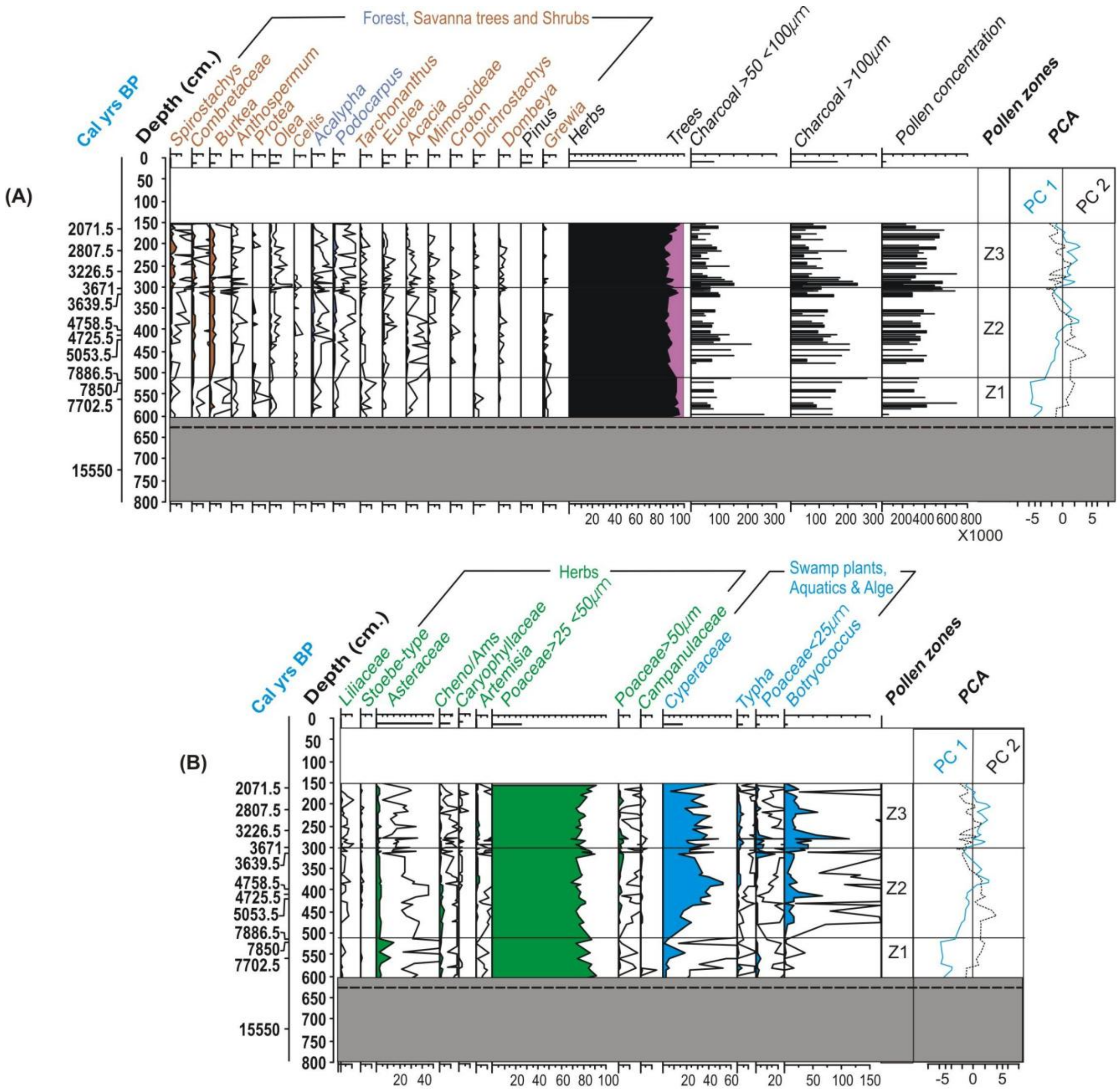


Fig. 9. Short pollen diagram showing selected taxa representing Tswaing core sediments vegetation with PCA. The black dashed line is representing the sample in a depth of 621cm which contain very low pollen concentration. The hollow curves are showing an exaggeration x 10. Diagram A: trees (pink) and shrubs, diagram B: herbs (black), aquatics and swamp plants.

3.2.4- Pollen concentration

The pollen concentrations were relatively high in the productive part of Tswaing sequence and ranged between 20,000 and 70,000 pollens/g (Fig. 9). The pollen concentration was highest (69045 pollens/g) at sample depth 570.5cm in Zone 1. At depth 598.5cm at the bottom of Zone 1 the pollen concentration was low (5530 pollen/g). At the transition between Zone 2 and Zone 3 the pollen concentration was high (56423 pollens /g). At depth 290.5cm as well as at Zone 3 at depth 271cm it was 70424 pollens/g. The uppermost sample from lake Tswaing at a depth of 0.5cm also has low pollen concentration (2558 pollens/g). There are no pollen grains in the upper 150cm due to the sediments disturbance

3.3- Vegetation survey

On the basis of a qualitative botanical survey in the Tswaing Nature Reserve (on 28 September 2010) the vegetation along a transect between the crater rim and the lake was described by Prof. Marion Bamford and the vegetation around each surface sample was also reported (Table 3). The locations of the surface samples are given in Fig. 10.

The vegetation of Tswaing crater comprises broadleaved trees which cover the upper slope and thorny trees covering the lower slope of the inner crater rim (Reimold *et al*, 1999). The crater rim is covered by typical savanna woodland species. Trees and shrubs such as *Peltophorum africanum, Euclea crispa, Rhus lancea, Boscia albitrunca, Acacia tortilis, Ochna pulchra, Kirkia wilmsii* and *Grewia flavescens, Acacia tortilis* subsp. *raddiana*, *Dombeya rotondifalia, Combretum zeyheri, Maytenus heterophylla, Dichrostachys cinerea,* and

Sclerocarya birrea are common. Prominent small trees are *Combretum collnium* and *Aloe davyana* (succulent). Grasses are represented by *Trachypogon*, *Pogonarthria squarros*a, *Setaria pumila* and *Melinis repens*. Along the lake shore sedges are common like *Cyperus* sp.and *Eleocharis sp*.

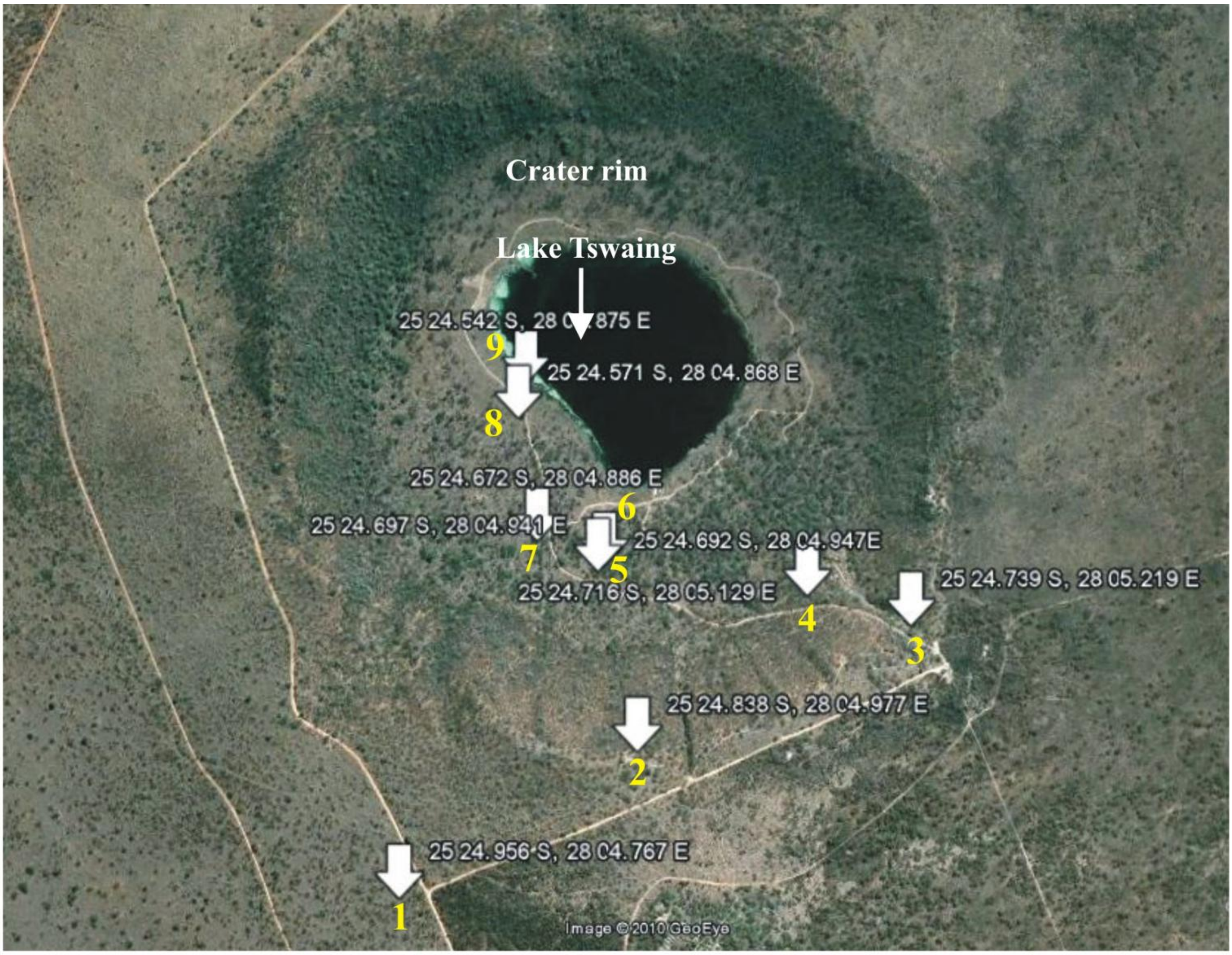


Fig. 10. Satellite image (Google earth) showing the location of the surface samples between Tswaing crater rim and the lake

Table 3: Vegetation description for the surface samples along a transect between the Tswaing crater rim and the lake.

Sample No.	Location	Coordinates	Vegetation Description
1	Along the transect	S 25° 24.956′ E 28° 04.767′	**Trees:** *Combretum collinum, Dichrostachys cinerea, Aloe davyana, Peltophorum africanum, Acacia nilotica, Ziziphus mucronata.* **Herbs:** *Lippia javanica, Tagetes minuta*
2	Along the transect	S 25° 24.838′ E 28° 04.977′	**Trees:** *Sclerocarya birrea, Combretum collinum, Dichrostachys cinerea, Ziziphus mucronata.* **Shrubs:** *Pappea capensis, Gymnosporium arenicola* **Herbs:** *Tagetes minuta, Bidens formosa.* **Grasses:** *Panicum maximum, Setaria pumila* and *Eragrostis* sp.
3	Along the transect	S 25° 24.739′ E 28° 05.219′	**Trees:** *Acacia tortilis, Combretum collinum* and *Rhus lancea.* **Shrubs:** *Pappea capensis, Gymnosporium arenicola* **Herbs:** *Bidens formosa, Clematis* sp. **Grasses:** *Panicum maximum.*
4	Along the transect	S 25° 24.716′ E 28° 05.129′	**Trees:** *Combretum collinum.* **Shrubs:** *Tephrosia* sp., *Combretum molle.* **Grasses:** *Panicum maximum, Pennisetum* sp. and *Eragrostis* sp.

5	Crater rim, 5m to the path	S 25° 24.692′ E 28° 04.947′	**Trees:** *Acacia tortilis, Dichrostachys cinerea* and *Combretum collinum.* **Shrubs:** *Abutilon* sp., *Tephrosia* sp. **Herb:** *Solanum nigrum* **Grasses:** *Panicum maximum, Eragrostis* sp.
6	Slope on the crater rim, 5m to the path	S 25° 24.697′ E 28° 05.941′	**Trees:** *Peltophorum africanum, Acacia tortilis* and *Dichrostachys cinerea.*
7	Slope on the crater rim, 3m to the path	S 25° 24.672′ E 28° 04.886′	**Trees:** *Acacia tortilis Combretum collinum, Ziziphus mucronata.* **Shrub:** *Grewia* sp.
8	Near the water lake	S 25° 24.571′ E 28° 04.868′	Open, no trees except *Dichrostachys cinerea.* Leaf litter and small broadleaved shrub.
9	Water lake edge	S 25° 24.542′ E 28° 04.875′	Smectitic clay. **Shrub:** *Vernonia* sp. **Sedges:** *Eleocharis* sp. **Grasses:** *Brachiaria* sp.

3.4- Palynology of the surface samples

The results from the pollen analysis of the surface samples showed low pollen concentrations. The tree pollen occurred in relatively low percentages with the exception of Combretaceae (25%) and *Dichrostachys* (8%) (Fig. 11). Pollen of other savanna elements such as *Burkea, Spirostachys, Acacia, Euclea, Grewia, Dombeya, Rhus and Sclerocarya* appeared in low percentages. Pollen from the afromontane forest tree *Podocarpus* occurred in very low percentages in all surface samples (Fig. 11). *Pinus* pollen occurred in relatively high percentages in the surface samples and reached its highest percentage of 40% of the pollen sum in sample no. 4 (Fig. 11). Pollen from other trees like *Olea* and *Celtis* occurred in low percentages. Asteraceae pollen is represented in high percentages throughout the samples and reached its highest percentage, 55% of the pollen sum, in sample no. 8 (Fig. 11). Chenopodiaceae (Cheno/Ams) occurred in low percentages; Liliaceae, *Stoebe*-type, *Selago*-type and *Vernonia* are rare or absent. Poaceae, aquatics and swamp plants e.g. Cyperaceae and *Typha* occurred in low percentages. Microscopic charcoal (>50µm and >100µm) does not show fluctuations along the transect (Fig. 11). The upper most sample from Tswaing lake sediments has low tree pollen percentages in comparison to the fossil samples of Holocene Tswaing sequence (Fig. 9). The uppermost sample of Tswaing lake sediments is characterized by relatively high percentage of *Pinus* pollen (9% of the pollen sum) as well as higher percentage of Asteraceae (49% of the pollen sum). Aquatics and swamp plants e.g., Cyperaceae and *Typha* occurred in low percentages (Fig. 9). Details of the pollen taxa of the surface samples are given in Table 4.

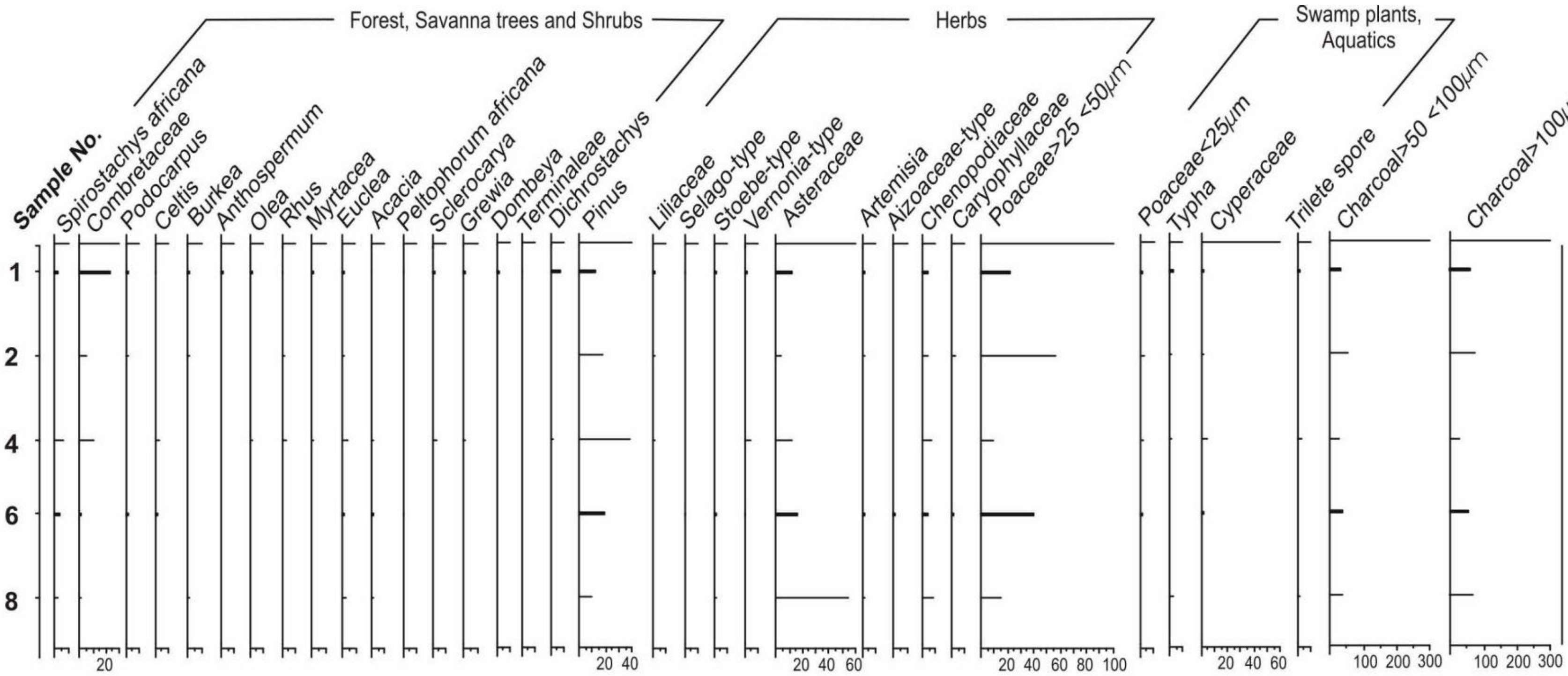


Fig.11. Pollen diagram showing the percentges of the pollen taxa in Tswaing surface samples. Coordinates of the samples are given in Table 3

Table 4: Pollen taxa distribution through the surface samples. The coordinates for the samples are given in Table 3

Sample No.	Pollen taxa
Sample 1	High percentages of Combretaceae and *Dichrostachys*. Other savanna trees appear in low percentages. *Podocarpus* occurs in low percentage. *Pinus* pollen strongly presented. Poaceae pollen abundant. Asteraceae pollen is well represented. Other herbs are occurring in low percentages. Aquatics and swamp plants are rare.
Sample 2	Tree pollen in general rare or absent. *Pinus* abundant. Herb pollen in low percentages or absent. Poaceae pollen appears in high numbers. Aquatics and swamp plants occur in low percentages.
Sample 4	High values of *Spirostachys africana* and Combretaceae pollen. *Pinus* pollen very abundant. Asteraceae pollen relatively rare. Poaceae pollen, aquatics and swamp plants in low percentages.
Sample 6	Tree pollen occurs in low percentages. *Pinus* pollen is abundant. Asteraceae pollen is very abundant. Other herbs are low or absent. Poaceae occur in high percentage.
Sample 8	Low tree pollen percentages. *Pinus* pollen abundant. High percentage of Asteraceae. Poaceae pollen is represented in low percentages. Aquatics and swamp plants are nearly absent.

3.5- Principle component analysis (PCA)

Forty-three pollen indicators based on the percentage of the pollen sum were selected from 74 pollen taxa (total of the pollen taxa were identified) and subjected to PCA. 75% of the variations were explained by 14 principle components. The curves of the first two factors showed clear trends and a good separation between the different variances. The first component (13.92%) separated samples between a depth of 550 and 350cm from the samples of the upper section of the core between depth 350 and 150cm (Fig. 12A). The first component (PC1, the blue line in Fig. 12B) shows positive loadings of P*odocarpus*, *Burkea*, Cyperaceae, *Typha*, *Dombeya*, *Artemisia*, *Rhus* and *Spirostachys* and negative loadings of *Tarchonanthus*, *Dichrostachys*, Asteraceae, Chenopodiaceae and *Caryophyllaceae* (Fig. 13). In the second component (11.11%), samples between a depth of 550 and 350cm are separated from the samples of the upper section of the core between depths 350 and 150cm (Fig. 12A). The second component (PC2, the black line in fig. 12B) showed negative loadings of Poaceae, *Tarchonanthus, Dichrostachys* and *Grewia* and positive loadings of *Burkea, Rhus, Asteraceae,* Combretaceae, Cyperaceae, *Typha*, *Podocarpus* and *Spirostachys*. The two PCA curves showed fluctuations through the productive part of Tswaing sequence. The first component (PC1) showed strong fluctuations on the negative value at Zone 1 between depths 600 and 500cm (Fig. 12B). The PC1 curve is characterized by two lows during this interval, one peak at a depth of 570cm and the other at a depth of 510cm while the PC2 curve did not show higher fluctuation during this interval (Fig. 12B). The two PCA curves showed higher fluctuation on the positive value between depth 460 and 360cm at Zone 2.

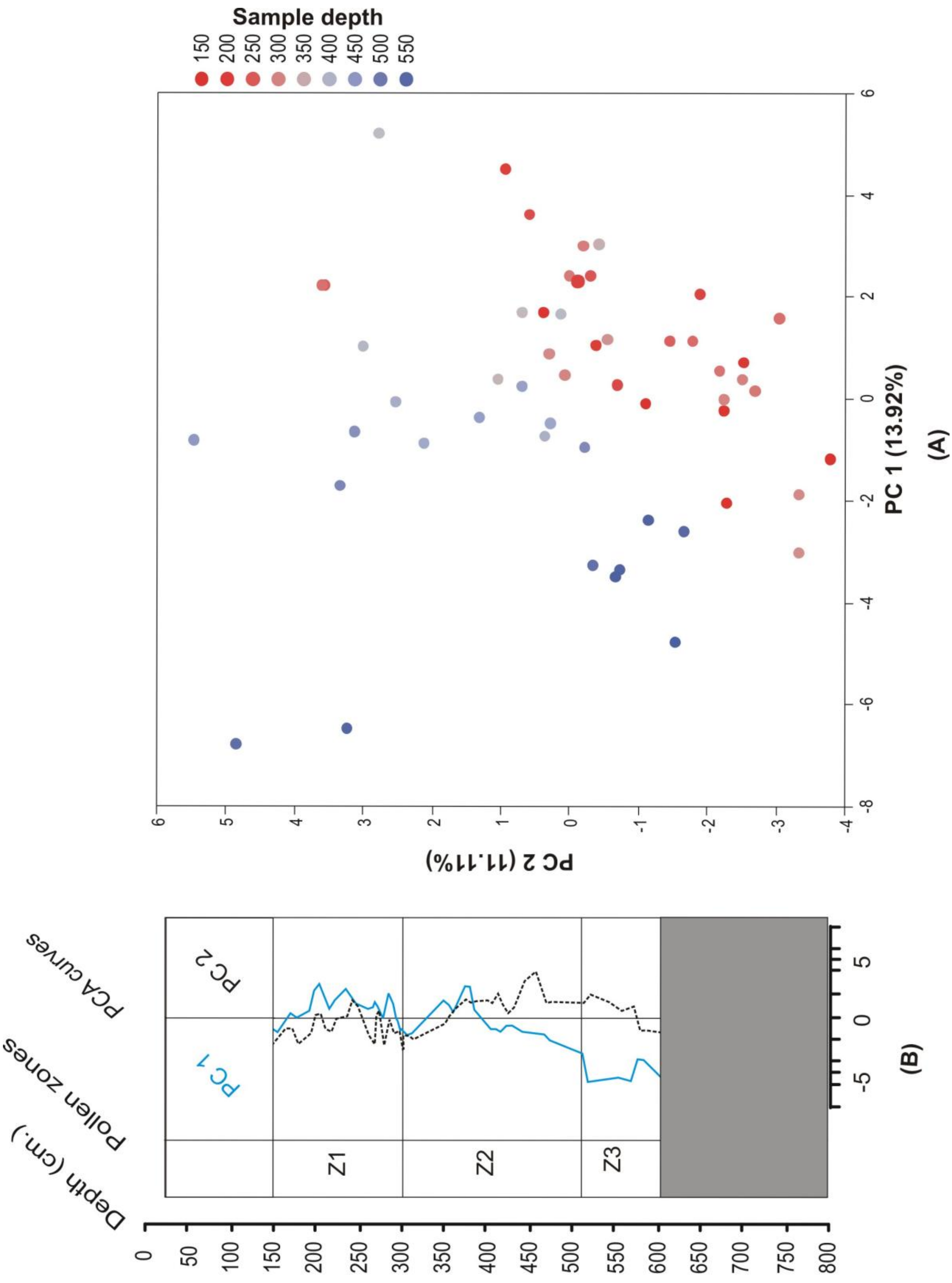


Fig. 12. A: Distributions of the variables throughout the Tswaing sequence according to depth, B: fluctuation of the PCA curves.

In the upper part of Tswaing sequence between depths 300 and 150cm at Zone 3 the PC1 curve showed slightly higher fluctuations on the positive part of the profile while the PC2 curve does not show major fluctuation (Fig. 12B). The ecological indicator values of the fossil pollen taxa are given in Table 5. The next chapter discusses the results in more detail.

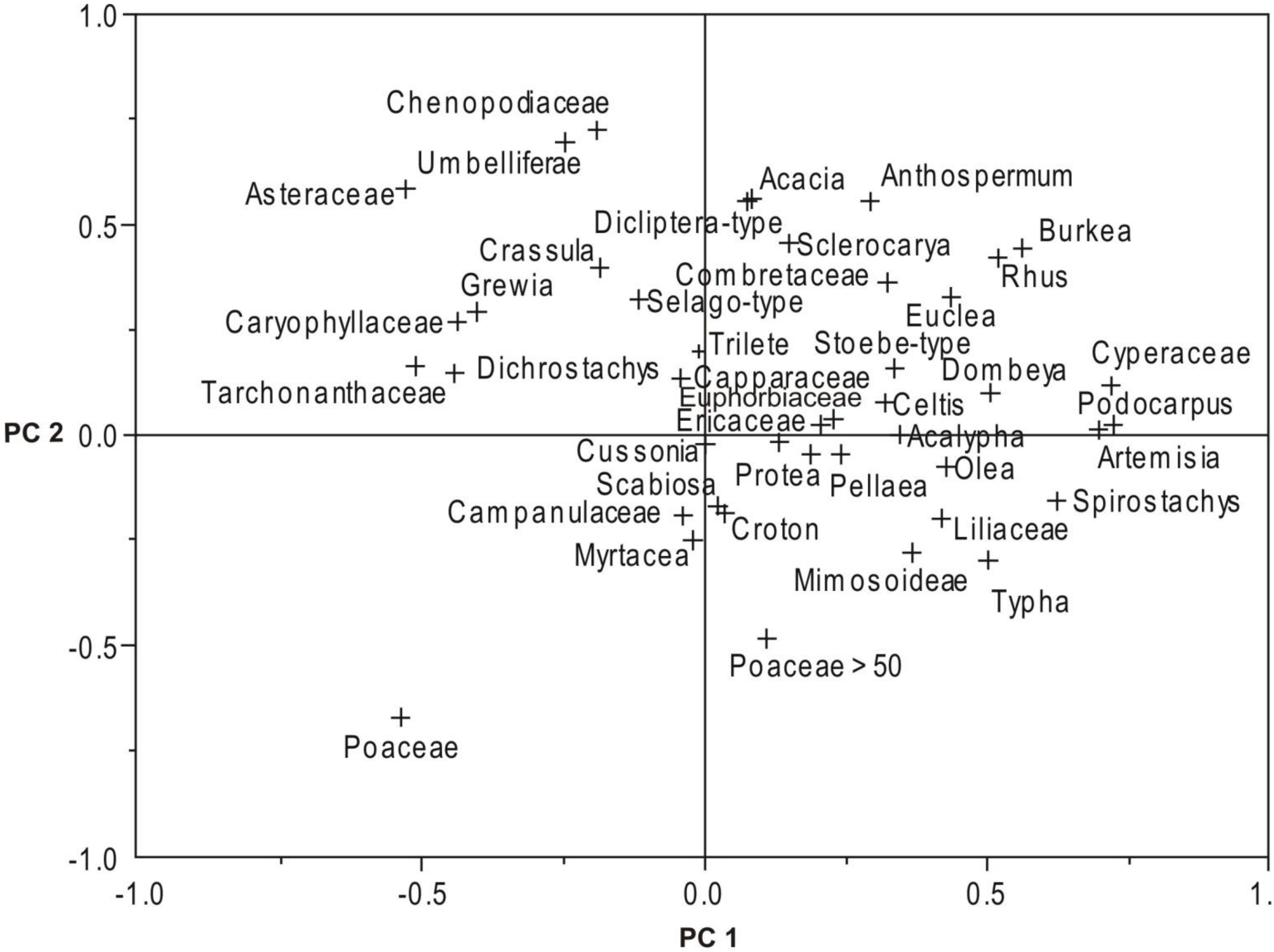


Fig. 13. PCA loadings of the first two factors of selected pollen indicators from the Lake Tswaing core sediments.

Table 5: Environmental indicator value of pollen taxa recorded from Tswaing core sediment derived from Scott, 1999a.

Pollen taxa	Vegetation	Environment
Podocarpus	Forest	Relatively moist conditions
Proteaceae *Olea* *Burkea*	Upland or mesic savanna	Wide range of temperatures, sub-humid conditions
Combretaceae *Spirostachys* *Sclerocarya* *Peltophorum* *Acacia* *Dichrostachys*	Microphyllous or plains savanna	Relatively warm conditions, wide range of moisture conditions. Acacia associated with the relatively deep local soils
Tarchonanthus	Kalahari thronveld savanna	Relatively dry conditions
Asteraceae *Artemisia*	Shrubland	Relatively even seasonal moisture distribution
Cheno/Ams	Halophytes	Local? Evaporation
Typha	Aquatics	Shallow fresh-water conditions
Cyperaceae	Semi-aquatics	Local swamp, shallow water or damp soli
Poaceae	Grassland or savanna	Generally indicative of summer rain

3.6. Palynomorph images

Images of the most important pollen indicators are given in plate 1-6. Black bar in each image indicates scale (10μm).

PLATE 1 (trees)

a, b. *Spirostachys* (TSW-1, fossil pollen sample 2.90-2.91m.).

c. *Acalypha* (TSW-1, fossil pollen sample 1.90-1.91m.).

d, e. Combretaceae (TSW-1, fossil pollen sample 4.04-4.05m, 1.90-1.91m.).

f. *Terminalia-type* (TSW-1, fossil pollen sample 3.205-3.22m.).

g. *Podocarpus* (TSW-1, fossil pollen sample 2.985-3.0m.).

h. *Celtis* (TSW-1, fossil pollen sample 2.90-2.91m.).

PLATE 2 (trees and shrub)

a. *Acacia* (TSW-1, fossil pollen sample 3.68-3.69m.).

b. Mimosoideae (TSW-1, fossil pollen sample 2.57-2.58m.).

c, d. *Burkea* (TSW-1, fossil pollen sample 2.90-2.91m.).

e, f. *Olea* (TSW-1, fossil pollen sample 2.76-2.775m.).

g, h. *Tarchonanthus* (TSW-1, fossil pollen sample 5.84-5.85m.).

PLATE 3 (trees and shrubs)

a, b. *Sclerocarya* (TSW-1, fossil pollen sample 1.76-1.77m.).

c, d. *Croton* (TSW-1, fossil pollen sample 2.90-2.91m.).

e. *Dichrostachys* (TSW-1, fossil pollen sample 2.04-2.05m.).

f. *Euclea* (TSW-1, fossil pollen sample 2.93-2.94m.).

g, h. *Peltophorum afrianum* (TSW-1, fossil pollen sample 4.04-4.05m.).

PLATE 4 (trees and shrubs)

a, b. Caryophyllaceae (TSW-1, fossil pollen sample 3.56-3.57m.).

c, d. *Grewia* (TSW-1, fossil pollen sample 3.68-3.69m.).

e. *Dombeya* (TSW-1, fossil pollen sample 2.21-2.22m.).

f. *Protea* (TSW-1, fossil pollen sample 2.875-2.89m.).

g, h. *Anthospermum* (TSW-1, fossil pollen sample 1.76-1.77m.).

PLATE 5 (herbs)

a. Asteraceae (TSW-1, fossil pollen sample 1.68-1.70m.).

b. *Artemisia* (TSW-1, fossil pollen sample 3.15-3.165m.).

c, d. Cheno/Ams (TSW-1, fossil pollen sample 1.90-1.91m.).

e, f. *Pentzia*- type (TSW-1, fossil pollen sample 3.56-3.57m.).

g. *Liliaceae* (*Aloe* type, TSW-1, fossil pollen sample 2.57-2.58m.).

h. *Stoebe*- type (TSW-1, fossil pollen sample 1.68-1.70m.).

PLATE 6 (herbs and aquatics)

a, b. *Vernonieae*- type (TSW-1, fossil pollen sample 3.62-3.63m.).

c, d. Campanulaceae (TSW-1, fossil pollen sample 2.76-2.775m.).

e. Ericacea*e* (TSW-1, fossil pollen sample 2.04-2.05m.).

d. *Pellaea* (TSW-1, fossil pollen sample 2.93-2.94mm.).

g, h. *Typha* (TSW-1, fossil pollen sample 2.76-2.775m.).

PLATE 1

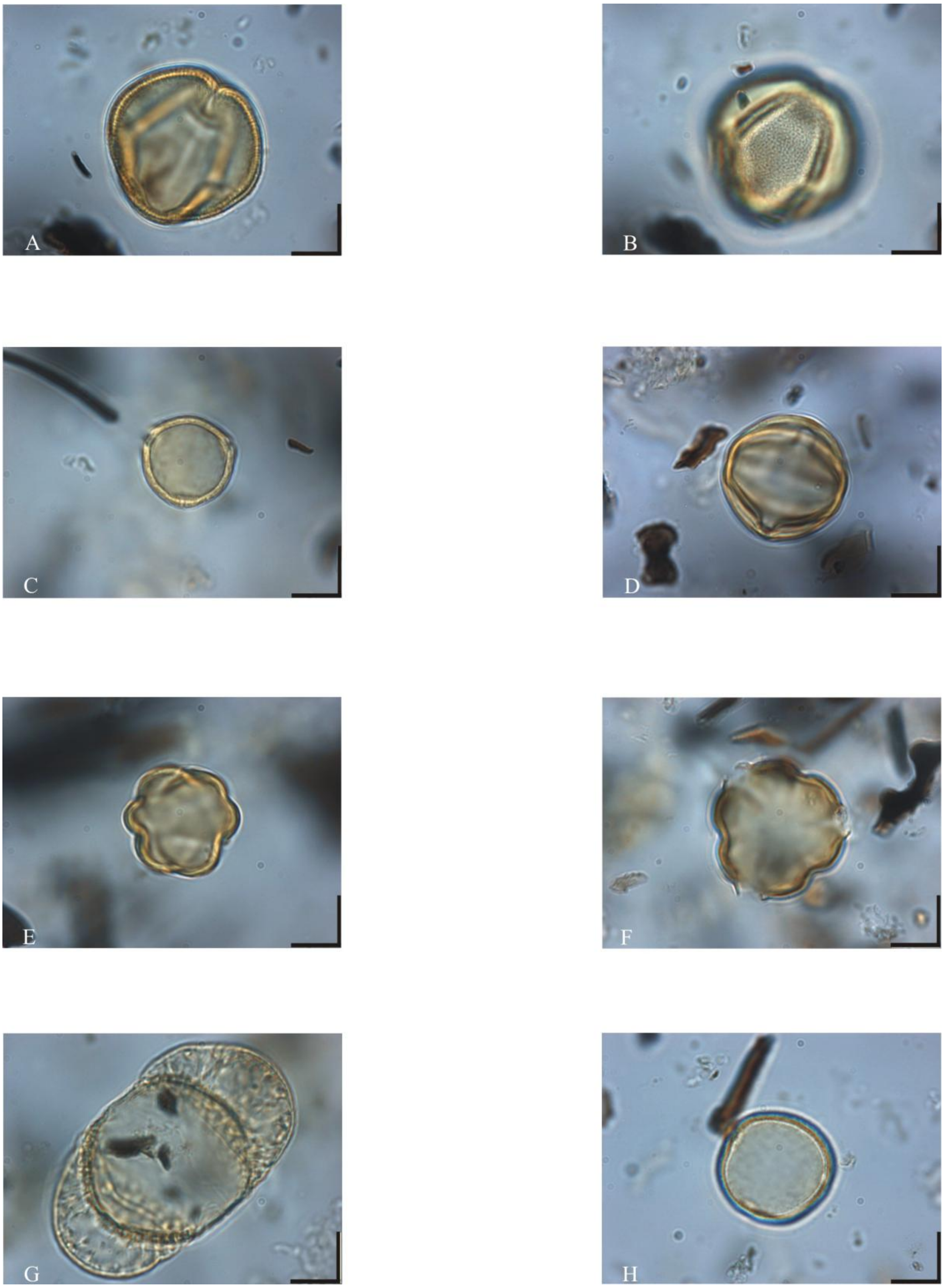


PLATE 2

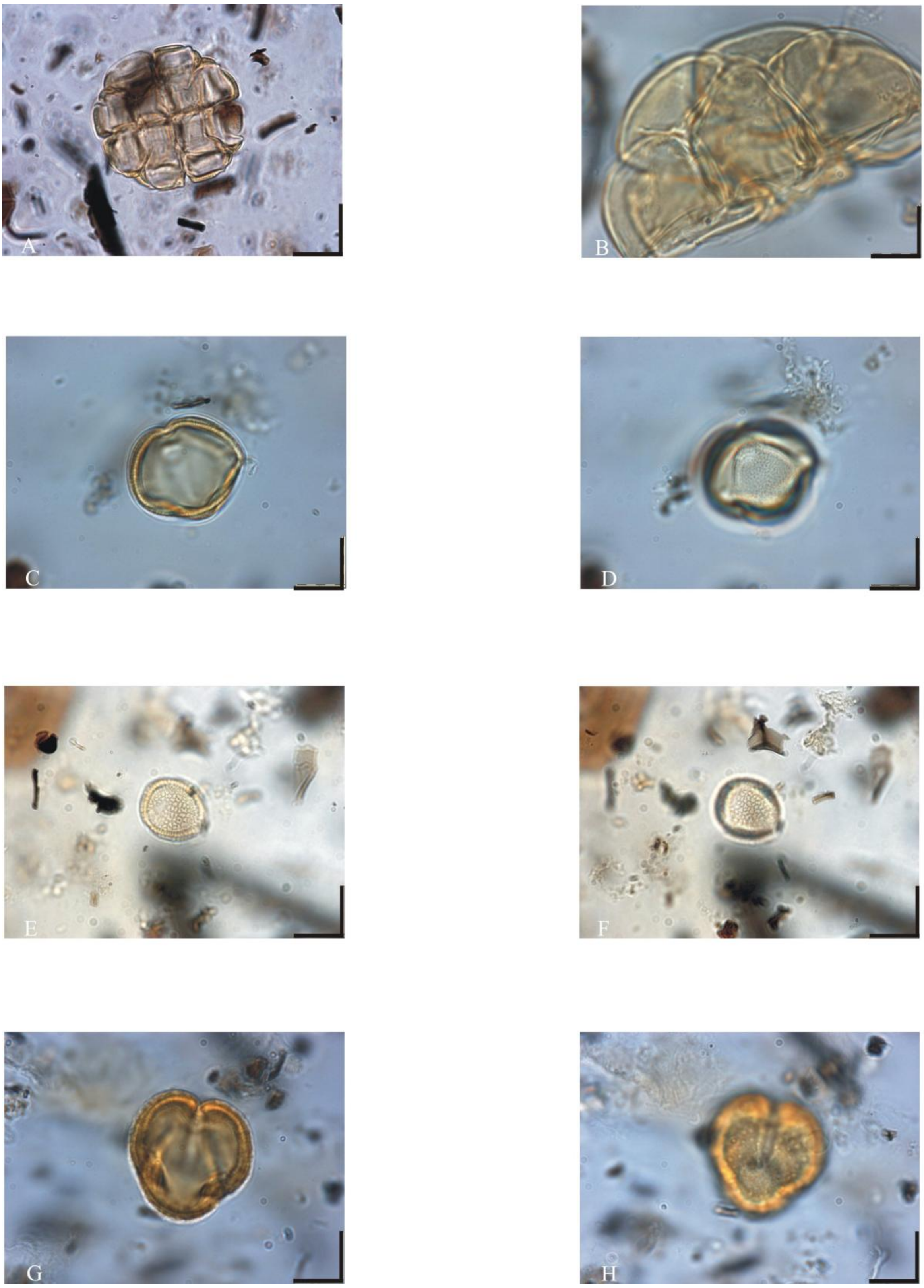


PLATE 3

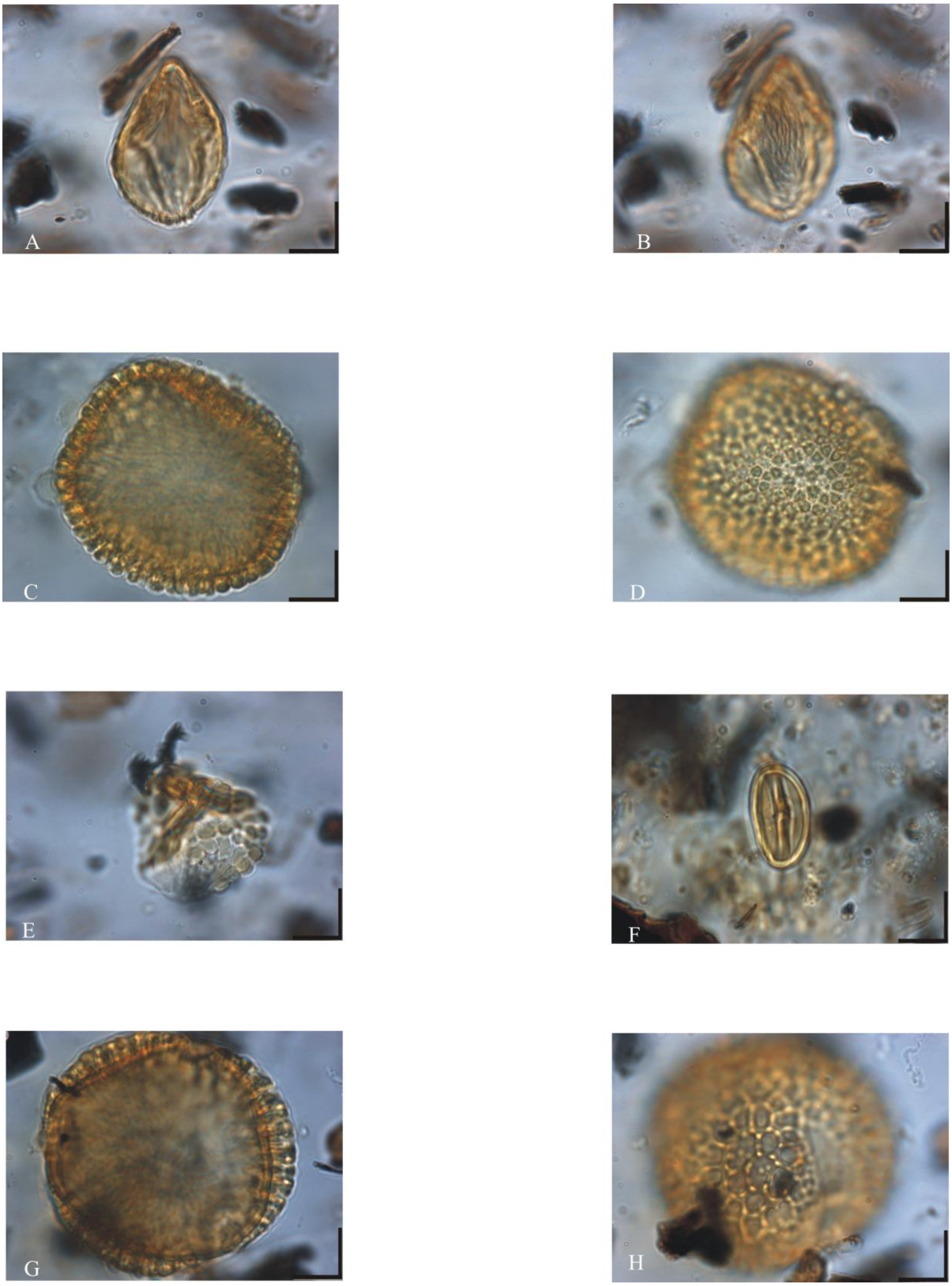


PLATE 4

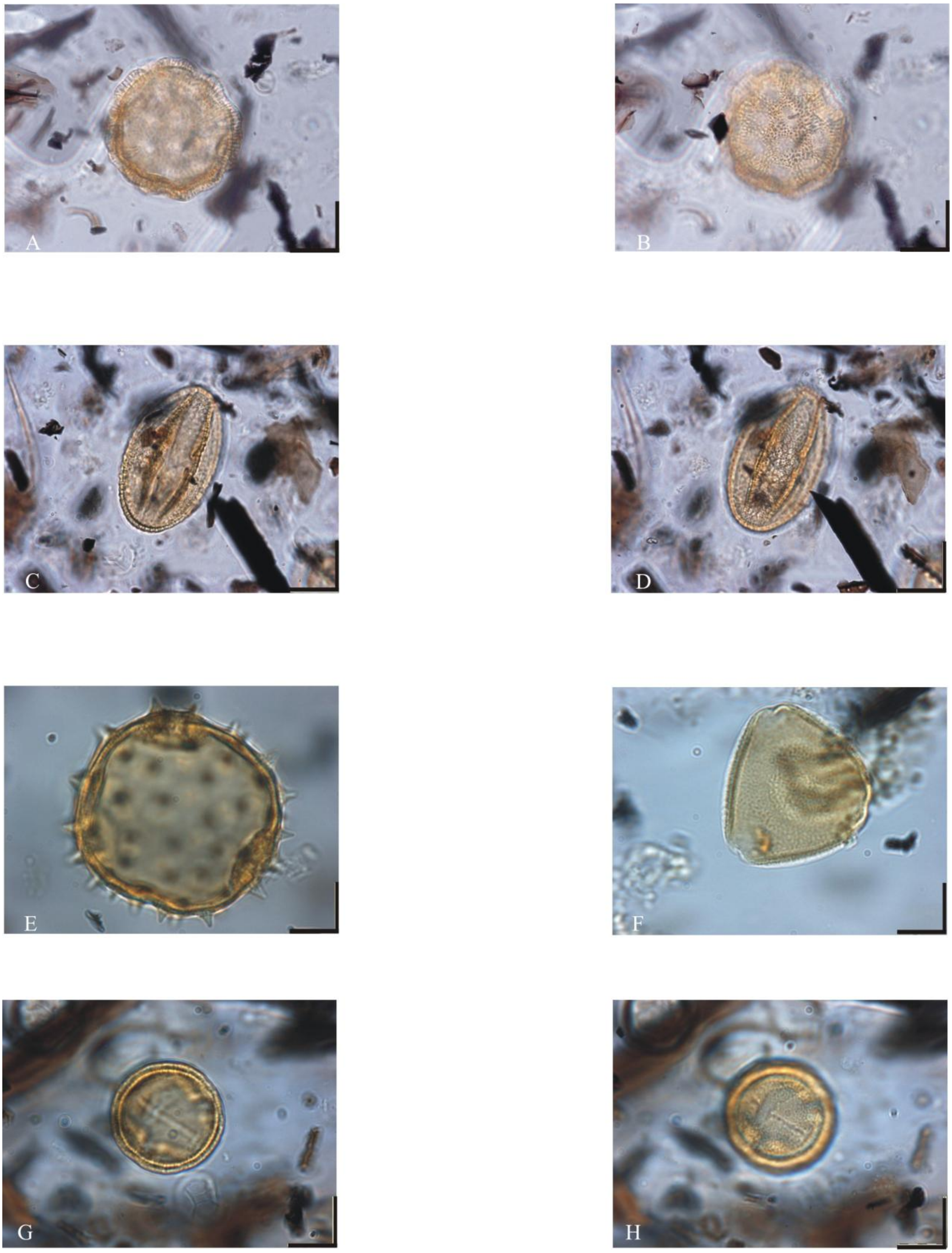
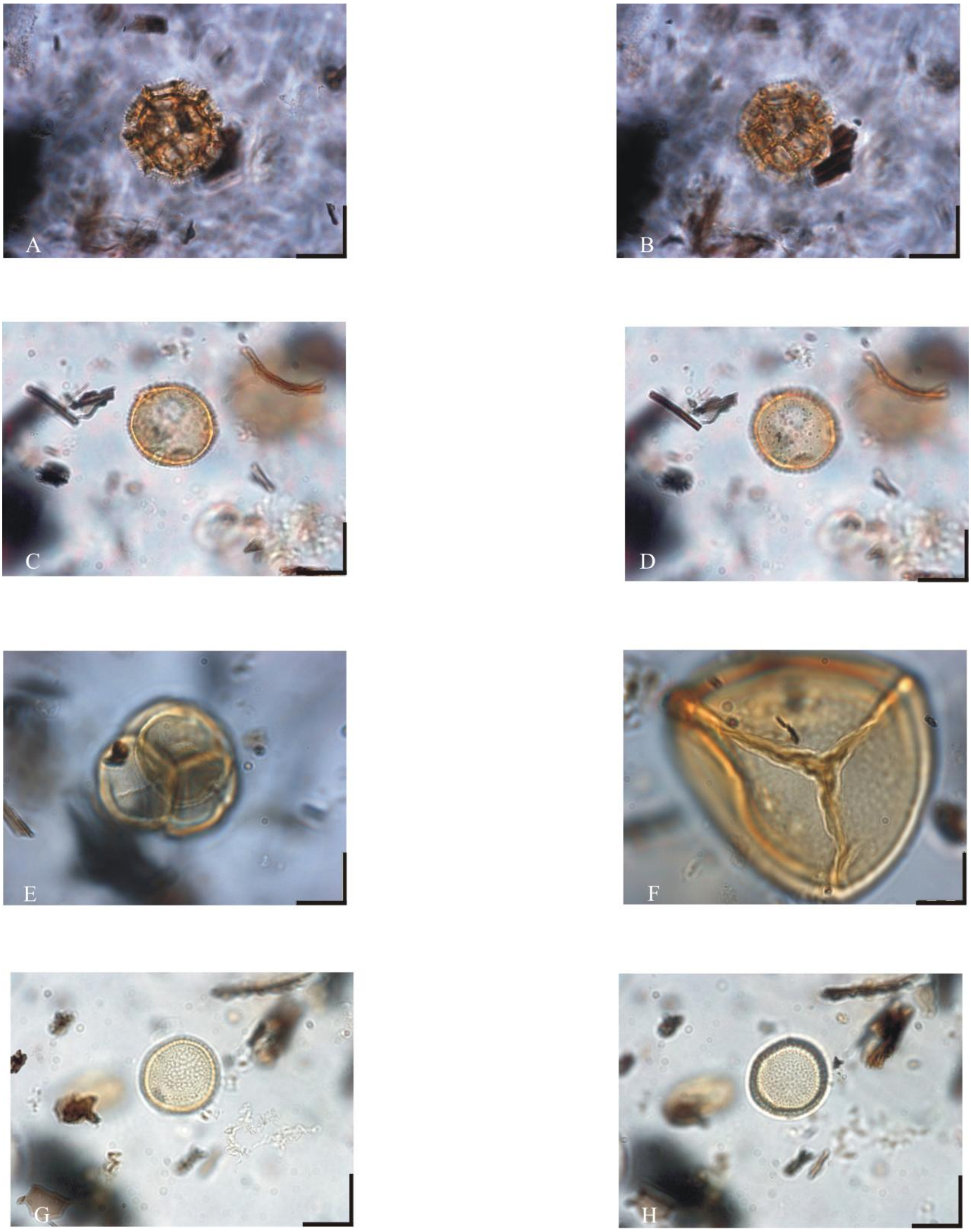


PLATE 5

PLATE 6



CHAPTER FOUR – DISCUSSION

The pollen diagram of Tswaing crater (Fig. 9) is dominated by grass (Poaceae) pollen (62%-85%) which suggests a grass dominated savanna. *Podocarpus* pollen appears regularly in low percentages. Aquatics and swamp plants are common in the Tswaing sequence with the exception of the lower part of the sequence (depth: 600-800cm). The Holocene sequence of the Tswaing profile is divided into three pollen Zones according to visual observation of the pollen assemblages (Z1-Z3).

The non-productive part of Holocene Tswaing sequence, 600-800cm depth (Fig. 9), was barren except one sample which has very low pollen concentration at *ca* 11300 cal yrs BP (621cm depth). The sample contained a high number of Asteraceae pollen which suggests a dry condition during this time or the lake had dried up entirely during this interval. The scarcity or absence of palynomorphs during this interval is probably due to the oxidation which can affect the sporopollenin and resulted in destruction of the palynomorphs (Traverse, 2008).

4.1- Vegetation history of Tswaing crater

4.1.1. Zone 1 (600-510cm) ca 10000-7500 cal years BP

Tree pollen is low (*ca* 10%) as well as aquatics and swamp plants e.g. Cyperaceae and *Typha*. Asteraceae pollen reaches the highest percentages in the pollen record (*ca* 11%). Cheno/Ams pollen is well represented.

Warm and relatively dry climate conditions are evidenced by the higher percentages of Asteraceae and Cheno/Ams. Seasons with low rainfall or drier and cooler summers are favorable conditions for Asteraceae vegetation (Coetzee, 1967; Cooremans, 1989; O'Connor and Bredenkamp, 1997). The higher percentage of Chenopodiaceae might indicate saline environmental conditions such as salt pans (Dyer, 1975; Pooley, 2005). Cheno/Ams also show local evaporation conditions (Scott, 1999a). The relatively high percentages of *Tarchonanthus* and *Dichrostachys* also point to dry environmental conditions. *Dichrostachys* is drought resistant and favours open or lightly wooded grassland environment (Onderstall, 1984; Boon, 2010). The presence of *Tarchonanthus*, which is a member of the Kalahari thornveld savanna vegetation, points to warm and dry open savanna conditions. High percentages of Poaceae, Asteraceae and Chenopodiaceae support the suggestion of an open, rather dry and grass dominated environment. The low percentages of trees like *Burkea* and Combretaceae also indicate less humid conditions (compare Scott, 1982b). *Protea* and *Grewia* pollen are abundant during this interval. There is no certain reason explaining why both genera are so common during Zone 1 because they can live in a wide range of habitats (Coates-Palgrave, 2002).

Botryococcus is strongly fluctuating through the sequence and becomes predominant in some layers. The presence of *Botryococcus* (fresh water algae) is triggered by water depth and salinity (Scott, 1999a). In this Zone percentages of *Botryococcus were* extremely low, suggesting decline in the water level as well as increasing salinity due to the evaporation as a result of a probably drier climate. Furthermore the low representation of aquatics and swamp plants e.g. Cyperaceae and *Typha* supports the assumption of rather arid environmental conditions.

The PCA result (Fig. 13) shows high negative loadings of the first component (PC1) of vegetation elements favouring drier conditions like Asteraceae, Chenopodiaceae *Tarcheonanthus* and *Dichrostachys*. The first dip of the negative loadings of PC1 is correlated with the first peak of the increase in Asteraceae and *Dichrostachys* (Fig. 9) while the second peak of the negative loadings of PC1 is correlated with the second peak of Asteraceae and *Tarchonanthus* percentages. Charcoal during Zone 1 showed lower percentages than Zone 2 and Zone 3. This might indicate low fire intensity between *ca* 10000 and *ca* 7500 cal yrs BP where the tree percentage was the lowest in the Tswaing sequence (Fig. 9). The charcoal percentages gradually increased toward the bottom of Zone 2 *ca* 3600 where the climate became more humid and with more rainfall than Zone 1.

4.1.2. Zone 2 (510-300cm) ca 7500-3600 cal years BP

This Zone is characterized by an increase of the tree pollen percentages as well as aquatics and swamp plants e.g. Cyperaceae and *Typha*. Percentages of Asteraceae pollen are rapidly decreasing and stay comparably low until about 150cm.

The vegetation suggests warm and sub-humid climate conditions evidenced by the higher percentages of *Burkea* and Combretaceae pollen since *ca* 7300 cal yrs BP. *Burkea* is highly sensitive and responds faster to an increase of rainfall. This can be explained by the rather shallow root depths of *Burkea*, which is between 15 and 60cm (Rutherford, 1983). As a result *Burkea* trees have some difficulty in accessing ground water when compared to other trees with deeper roots. As a result of this *Burkea* favours seasons of increasing humidity and rainfall (Fichtler et al., 2004). Combretaceae are an indicator of warm bushveld (Boon, 2010) and also indicative of sub-humid conditions (Scott, 1999a). Increasing humidity is also inferred from the decline of Asteraceae percentages since *ca* 7500 cal yrs BP at the transition between Zone 1 and Zone 2. The relatively high pollen percentages of *Burkea*, Combretaceae and *Acacia* suggest open savanna vegetation and well-developed broadleaved woodland (Scott, 1999a), which is still dominant in the surroundings today as evidenced by above mentioned botanical survey. Pollen from *Croton,* which was totally absent in the lower Zone, becomes more common in top of Zone 1 and Zone 2 after *ca* 7380 cal yrs BP. The relatively high percentages of *Olea* pollen also evidences sub-humid conditions, and together with *Burkea,* an upland or mesic savanna vegetation is indicated (Scott, 1999a). The slight increase of *Podocarpus* since *ca* 4500 cal yrs BP (360cm depth) also suggests rather humid conditions in the region and long distance transport of pollen. Today *Podocarpus* does not grow in the Tswaing region but grows in Waterberg and in the Magaliesburg, but it is more abundant in Mistbelt and Afromontane forest (Pooley, 1993; Coates-Palgrave, 2002). *Acalypha* shows a minor increase *ca* 4700 cal yrs BP (430cm depth) which also indicates humid conditions. *Acalypha* in general favours moist conditions and mostly grows in an afromontane forest environment (Hilliard, 1985; Van Wyk and Van Wyk, 1997; Thomas and Grant, 2002). Pollen grains of *Croton* were absent at the lower Zone (Z1) but becomes more abundant at Zone 2 at *ca* 7300 cal yrs BP. This also indicates increasing humidity (Scott, 1982b). Cyperaceae pollen increase strongly in the middle of this Zone and reach a strong peak (50%) at depth 360cm when also the percentages of *Podocarpus* are increasing (*ca* 4500 cal yrs BP). The increase of Cyperaceae and *Typha* and other swamp plants points to local swampy conditions (e.g. Genever et al., 2003; Gaballero et al., 2005; Dupont et al., 2007). Cyperaceae are often used as moisture indicators in palaeoecological studies (e.g. Giresse et al., 2005; Gil-Romera et al., 2006; Mighall et al., 2006). Charcoal percentages show a slight increase between 460 and 350cm depth (*ca* 7300-4200 cal yrs BP). The increase of fire intensity during that time is probably due to the vegetation change from dry open savanna (Zone 1) to woody savanna (Zone 2), which made more fuel available. Increase of humidity and the amount of rainfall can also be a reason for increasing fire intensity during this time (Duffin, 2008). The increase of the rainfall at Zone 2 can be recognized from the strong increase in Cyperaceae as well as *Burkea* pollen percentages (Fichtler et al., 2004). A short period at the transition between Zone 2 and Zone 3 (330-300cm depth) at *ca* 4000-3600 cal yrs BP is characterized by increasing Poaceae percentages whereas tree pollen percentages are declining. Cyperaceae and *Typha* pollen percentages as well as *Botryococcus* and charcoal values also decrease (Fig. 9). The vegetation change during this short interval points to short-term aridity. Gradually at the bottom part of Zone 3 at *ca* 3600 cal yrs BP tree pollen percentages are increasing again as well as Cyperaceae, *Typha* and *Botryococcus* and continued until *ca* 2000 cal yrs BP. The reconstructed vegetation suggests sub-humid condition. Charcoal percentages are also increasing suggesting increase in the fire intensity due to increasing humidity and rainfall as well as more fuel.

The two PCA curves show positive loadings of pollen indicators of plants, mostly trees, which favour comparably humid conditions like *Podocarpus, Burkea, Olea, Acalypha* and *Croton*. There is a peak characterizing the first component (PC1) on the positive value of the profile coinciding with the increasing of the *Podocarpus* *ca* 4500 cal yrs BP suggesting an increase in humidity (Fig. 9). The second component (PC2) also shows a peak on the positive value of the profile *ca* 7300 cal yrs BP coinciding with the beginning of the increase of Combretaceae and *Burkea* pollen. The PC2 curve indicates change from dry open savanna vegetation to more woody savanna with *Burkea* and Combretaceae (Fig. 9). Also the pollen indicators show short dry conditions at *ca* 4000-3600 cal yrs BP (330-300cm depth). The PCA curves do not show a significant fluctuation during this period (Fig. 9).

4.1.3. Zone 3 (300-150cm) ca 3600-2000 cal years BP

From *ca* 3600 cal yrs BP onward *Spirostachys* pollen percentages, and to a lesser degree *Olea* pollen values, are increasing while other trees, e.g. Combretaceae, *Burkea, Podocarpus* and *Acacia,* are still well represented. Asteraceae percentage is gradually decreased in Zone 3. The relatively high percentages of *Spirostachys*, Combretaceae and *Burkea*, as well as *Podocarpus*, suggest warm sub-humid conditions. Cyperaceae and *Typha* indicate local moisture. *Botryococcus* shows a strong peak at *ca* 3400 cal yrs BP (270cm depth) and another peak at *ca* 2800 cal yrs BP (220cm depth) suggesting local moisture condition. The percentage of Poaceae <25μm is slightly increased at Zone 3 which might be produced by *Phragmites* (Bonnefille and Riollet, 1980). The PCA result shows high positive loadings of the first component (PC1) on *Podocarpus, Burkea*, Cyperaceae, *Typha* and *Spirotachys* suggesting also warm sub-humid conditions during this time. There are two peaks of the first component (PC1) on the positive value of the profile. The peaks coincide with the increase of *Spirostachys* pollen percentage suggesting warmer conditions than the previous Zone (Fig.9).

4.1.4. The surface level

The analysis of the upper most sample of Tswaing lake sediments (S 25° 24.542'E 28° 04.875′) shows a low pollen concentration in comparison to sediment samples of the core. This is probably because of the sediments are unconsolidated and water-saturated. The sample is characterized by low tree pollen percentages with the exception of the relatively high percentages of *Pinus*, Asteraceae (49%) and Chenopodiaceae. Pollen of Poaceae, aquatics and swamp plants, e.g. Cyperaceae and *Typha,* are present but show low percentages. The pollen spectrum indicates dry climatic conditions due to the higher percentage of Asteraceae and Cheno/Ams pollen. Unfortunately, the Tswaing pollen sequence does not cover the interval to recent times (above 150cm depth) as a result of mining activity as a source of soda from 1912 to 1956 (Levin, 1991). The climate reconstruction during this interval cannot be confirmed from single sample (the upper most sample). The relatively high percentage of *Pinus* (exotic forest tree) indicates long distance transport. Pine pollen has the ability to travel more than several thousand kilometers (Scamoni, 1949; Faegri and Iversen, 1989; Rousseau et al., 2006). Pine plantations do not occur in the Tswaing region, but pine pollen might have been transported from Gauteng where the *Pinus* spp. plants are abundant (Rouget et al., 2002).Several species of *Pinus* have been introduced into the Southern Hemisphere because of its economic value (Richardson et al., 1994b). *Pinus* is planted in South Africa due to their economics value as a source of soft wood, e.g.

in the Western Cape, Eastern Cape and Kwazulu Natal (Coates-Palgraves, 2002). Pine trees (*Pinus pinaster*) were first planted in the Cape region at the end of the 17th century and the other species were planted from the 1850's AD (Poynton, 1977; Richardson and Higgins, 1998). The disadvantage of the introduced pine trees are their relatively large size and ability to form a dense cover which can affect the ecosystem processes (e.g. Versveld and Van Wilgan, 1986; Richardson et al., 1994a).

4.2. Modern surface samples

The pollen analysis of the surface samples (No. 1, 2, 4, 6, 8, see fig. 11, Table 3) show low pollen concentrations and the pollen grains are badly preserved in comparison with the fossil pollen of the Holocene sequence. This is probably because the sediments are not compacted or due to the oxygen which can attack the sporopollenin and destroy the pollen grains. Palynomorphs are always scarce or absent in well sorted and coarse grained sand (Traverse, 2008). The pollen grains also can be destroyed by some fungi (fungal activity) which can digest the sporopollenin and attack the pollen (Elsik, 1966; Srivastava, 1976a). Most of the vegetation around the surface samples collection sites was described in table 3. Combretaceae and *Dichrostachys* pollen are predominant in sample no. 1 (25%, 9% respectively). The high representations of those taxa are probably because they grow abundantly in the Tswaing region (Pers. Comm. Marion Bamford), or due to the pollination dispersal mechanism of those trees. They are characterized by insect pollination but can also be wind pollinated (Whitehead, 1968). The wind can carry the pollen grains for a short distance and deposit not far from the parent tree. Samples no.1 and 2 represent open vegetation according to what I observed in the field and to the Google satellite image (Fig. 10). Sample no. 4 shows the lowest pollen concentration of the surface samples.

The tree canopy is dense with tall trees such as *Sclerocarya* around surface sample no. 6. The high abundance of the tree is not reflected in the pollen spectrum of sample no. 6 (Fig.11). In contrast the Poaceae pollen percentages are quite high. Sample no. 8 is different from the other samples as it is very close to the lake and issimilar with the high Asteraceae percentage to the uppermost sample from the lake. The Asteraceae pollen attains its highest percentage in sample no. 8 (55%). Asteraceae probably grew near to the lake but was not observed in the botanical survey. Although there is a high abundance of grasses in the Tswaing region this is not reflected in the pollen spectrum of sample no. 8. The reasons for that are unknown. Although sample no. 8 is only 5m from the lake shore pollen from Cyperaceae, *Typha* and Poaceae < 25μm occur in low percentages (Fig. 11).

Microscopic charcoal (size categorize >50 and >100μm) in all samples are low in comparison to the Tswaing pollen diagram and do not show significant difference between the surface samples (Fig. 11). *Pinus* pollen is well represented in the all surface samples. This indicates long distance transport. Pollen of other trees such as *Spirostachys, Burkea, Rhus, Olea* and *Acacia* are also present but appear in low percentages. For the better understanding of the connection between current vegetation and pollen in the uppermost soil horizon more surface samples are necessary.

4.3. Comparison with the previous study of Scott, 1999a

In order to narrow the gaps that were observed previously (Scott, 1999a) in Tswaing pollen sequence the Holocene section was analyzed here. The correlation between the two pollen records is based on the fluctuation of certain pollen indicators and the available radiocarbon dates (Fig. 14). The fluctuations of the pollen indicators were quite similar with the exception of the higher resolution in the current study. *Burkea* and Combretaceae pollen increased at *ca* 7300 cal yrs BP in the current study. In the previous study (Scott, 1999a) the increase in *Burkea* and Combretaceae pollen occurred later, at *ca* 7200 cal yrs BP (Fig. 14). *Spirostachys africana* pollen increase was not contemporaneous: at *ca* 3600 cal yrs BP in the current study and at *ca* 3500 cal yrs BP in Scott's profile. The decrease in Asteraceae and *Tarchonanthus* pollen was observed at *ca* 7500 cal yrs BP in the current pollen record while it was recorded earlier *ca* 6500 cal yrs BP in Scott's profile. This difference in age is probably due to uncertainties of the chronology or the difference in the material which used for radiocarbon dating (charcoal or bulk sediments). A strong peak in Cyperaceae pollen was observed in the two pollen records (Fig. 14): at *ca* 4500 cal yrs BP in the current pollen record and at nearly the same time of *ca* 4400 cal yrs BP in the previous pollen record (Scott, 1999a). One of the most peculiar dissimilarities between the two records is that of *Pellaea* (fern spore). In Scott's profile *Pellaea* was well represented in the intervals where the pollen concentrations are low or absent which suggests that *Pellaea* spores are more resistant to the dry climate conditions (Scott, 1999a; Partridge et al., 1993). *Pellaea* is an indicator of dry climate conditions (Tryon, 1957) and supports Scott's interpretation of dry conditions between *ca* 8200 and

6400 cal yrs BP (Scott, 1999a). In the current study the presence of *Pellaea* was extremely low (Fig. 13). The reasons for the low percentages of *Pellaea* in the current profile are unknown but it seems to be local vegetation change. This is probably because *Pellaea* was grown near the position of Scott's core where it is not in the new core. There is no certain reason to explain the scarcity or the absence of *Pellaea* spores in the current study. As a result of the high sample number and chronology resolution in the current study a short dry period was observed between *ca* 4000 and 3601 cal yrs BP. This period is characterized by declining of most trees percentages including *Podocarpus*, aquatics, swamp plants and algae (e.g. Cyperaceae, *Typha* and *Botryoccocus*) and increase of Poaceae pollen percentages. In the previous pollen record the short dry period was not discovered. The comparison of the uppermost sample in the both records shows a similarity in the trees, herbs and aquatics with the exception of the higher Asteraceae value in the current study (Fig. 14). The latter indicates that the lake was drier than during the time when the uppermost sample of the previous study was collected (Scott, 1999a). This is probably due to changes in the rainfall variability over Gauteng province. Dyson (2009) showed that years with higher summer rainfall are occurred over Gauteng province in 1995/1996 (968mm) and 1999/2000 (793mm). Years with very dry summers (341mm) were reported for 1978/1979 and in 2006/2007 (364mm). The wettest late summer (568mm of rain) was in 2000 as a result of the tropical cyclone Eline which affected Southern Africa in February 2000 and resulted in a strong rainfall season over the whole subcontinent as well as Gauteng (Dyson and Van Heerden, 2001). The other wet late summer seasons (over 400mm of rain) were in 1978, 1991, 1996, 1997, 2006/2007 and 2008 (Dyson, 2009). The high Asteraceae percentages might also be a local signal rather than climatic signal. This is because the high representation of Asteraceae pollen in surface sample no. 8, taken only 6m away from the lake margin, where it was probably growing. The major finding of the comparison between both studies on the basis of radiocarbon age dating is an additional 1800 cal yrs BP that was covered in the Holocene period at the bottom of Tswaing sequence (at the base of Zone 1).

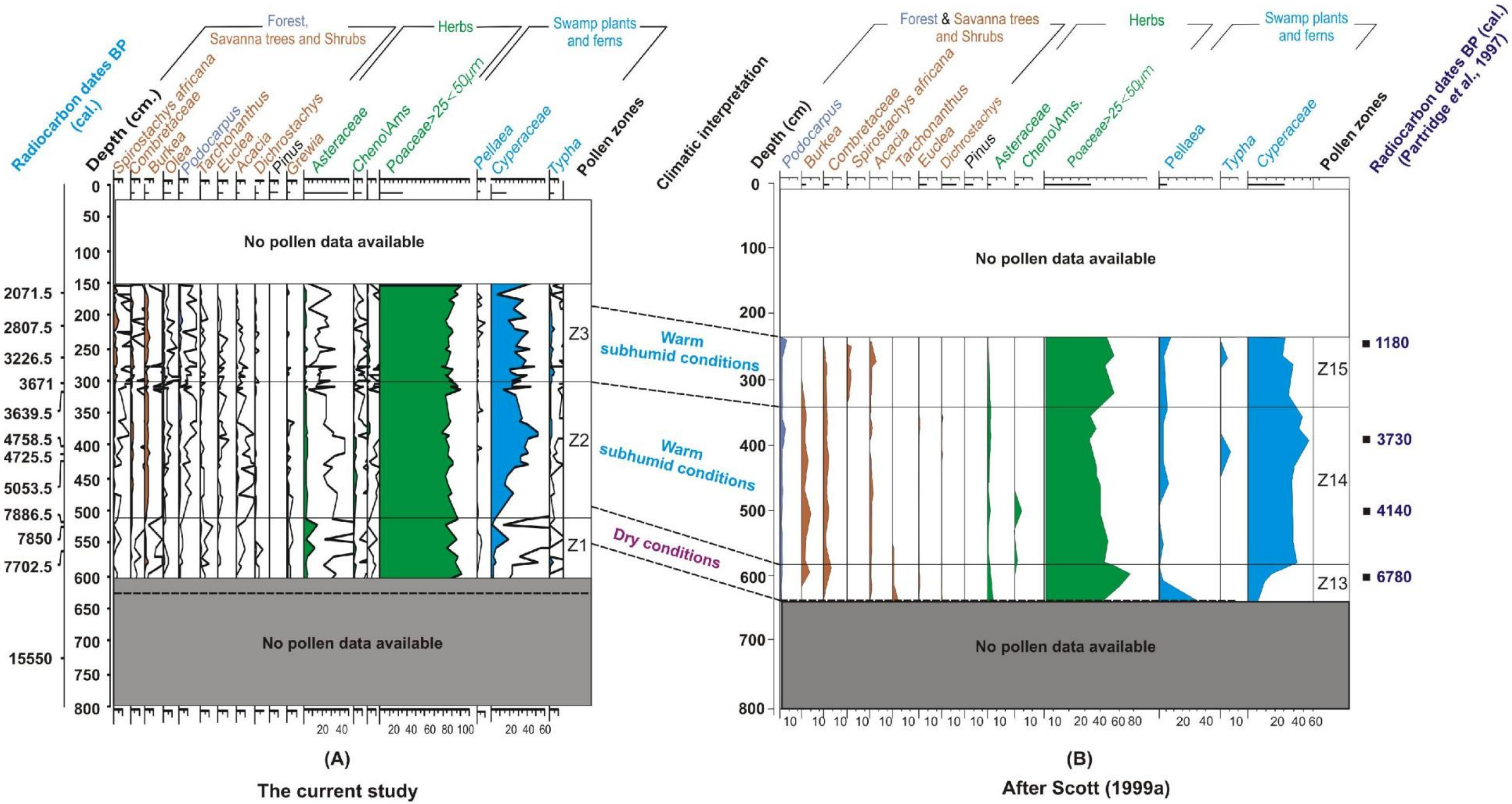


Fig. 14. Comparison of the short pollen diagram of the current study (A) and of the pollen record of an old core of previous study (Scott, 1999) (B) based on pollen fluctuation and radiocarbon dates

4.4. Comparison with biomarker study of Kristen et al., 2009

The same core of Tswaing crater which I used for pollen and charcoal analysis was used to understand the palaeoecological changes in the lacustrine environments (see Kristen et al., 2009). The biomarker study of Kristen et al., 2009 showed the significance of the biogeochemical methods to reconstruct the climate and environmental change over the time. As a result of this study a period of decreasing concentrations of *n*-C17 (alkanones), Moretene and Tetrahmanal was recorded between 10,000 and 7,500 years BP. This period indicated a reduction in the surface lake productivity of nutrients (Kristen et al., 2009). During this interval the chlorine increased and the potassium decreased indicating arid conditions (Kristen et al., 2007). The period of a severe decrease in the surface water lake productivity of nutrients coincides with the more arid period which was recorded at *ca* 10000-7500 cal yrs BP in the current pollen study (Fig. 16). This drier period is characterized by a decrease in tree pollen percentages and aquatics, swamp plant and algae e.g. Cyperaceae, *Typha* and *Botryococcus* which reach their lowest percentages during this interval as discussed above in greater detail. The PC1 curve is supporting the dry climatic interpretation during this time. The PC1 curve is showing a decrease of the humidity (Fig.15 B) by means negative loadings on vegetation favoring dry condition such as Asteraceae, *Tarchonanthus* and *Dichrostachys.*

From *ca* 7500-5500 years BP there was a period of increase in autochthonous material (algal and bacterial). This period coincided with the higher $\delta^{13}C$ values of *n*-C_{17}, *n*-C_{29} and total organic carbon (Fig.16 A, Kristen et al., 2009). Those changes indicated an increase of the surface water lake productivity probably due to the increase of the nutrient supply and the grasses or macrophytes near the lake. Those changes suggested humid conditions during this interval (Kristen et al., 2009). This period corresponded with the humid period which was observed in the current study at *ca* 7500-4000 cal years BP (Fig. 16). This period is characterized by an increase in the trees percentages which represent humid climate e.g. *Burkea* and *Podocarpus* and high percentages of aquatics, swamp plant and algae e.g. Cyperaceae, *Typha* and *Botryococcus*. The PC1 curve is suggesting increase of the moisture during this time by showing positive loadings on vegetation favoring moist condition such as *Podocarpus* (Fig. 15B). The PC2 curve is showing change in the vegetation from dry open grassy savanna to woody savanna vegetation with more trees such as *Burkea* and Combretaceae. The sub-humid climate at the current site is continuing until *ca* 2000 cal yrs BP whereas no climatic interpretation is available after *ca* 5500 cal yrs BP in Kristen et al., 2009 (Fig. 15 A). Finally and most importantly the climatic investigation from the Tswaing pollen record of the current study supports the climatic interpretations which were previously inferred from the biomarker analysis (Kristen et al., 2009) but can, as a result of a much higher resolution, provide further details of the climate history of the region.

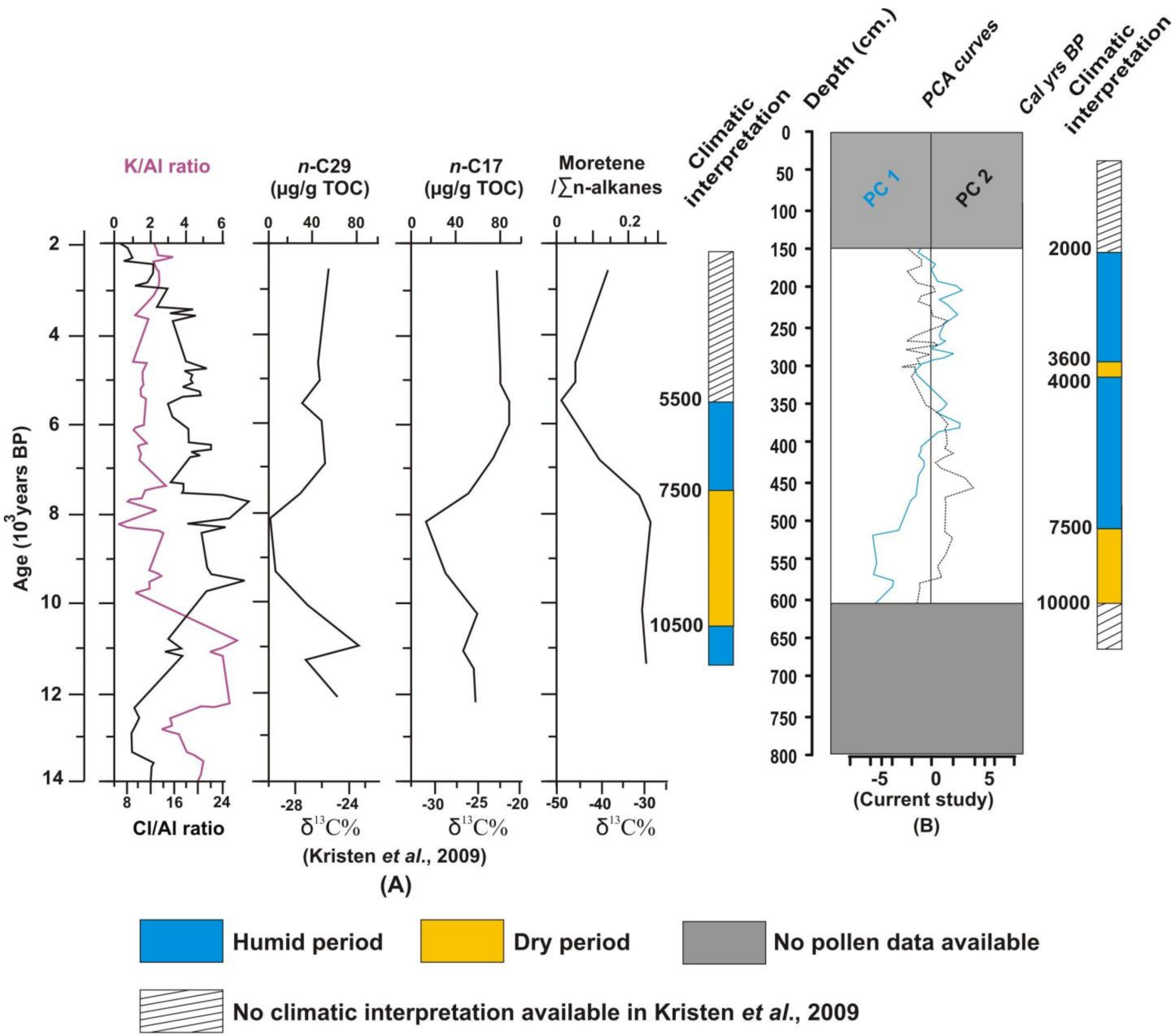


Fig. 15. Comparison of the biochemical proxies of Kristen et al., 2009 (A) and palynological data of the Holocene Tswaing sequence from the current study (B)

4.5. Regional comparison

In order to obtain a regional overview of vegetation- and climate dynamics in eastern South Africa a correlation between Tswaing crater (within the savanna biome, 400-750mm precipitation), Wonderkrater (within the savanna biome, 400-600mm precipitation, Scott, 1982a), the Braamhoek wetland (grassland biome, 1400mm precipitation, Norström et al., 2009) and lake Eteza (Indian Ocean Costal Belt biome, 760-1250mm precipitation, Neumann et al., 2010) can be attempted. The locations of the sites are shown in Fig. 1. However, the pollen record from Braamhoek wetland (Norström et al, 2009) was excluded from the correlation due to the low sample resolution between *ca* 7500 cal yrs BP to present, as well as low chronological resolution. Currently a detailed pollen analysis of the Holocene sequence of this profile is in progress (Neumann et al., unpublished data) and the comparison to this record is planned for the near future. Accurate correlation between the other sites seems to be critical and problematic due to the differences in the radiocarbon dating. Keeping those problems in mind a preliminary correlation between Tswaing, Wonderkrater and lake Eteza can be attempted.

4.5.1- From *ca* 11000 to 7500 cal yrs BP

From *ca* 11000 to 7500 cal yrs BP there are indicators for dry climate conditions at Tswaing (*ca* 10000-7500 cal yrs BP) and Wonderkrater (*ca* 11000-6000 yrs BP, Scott, 1982a; Scott et al., 2003) while lake Eteza was under relatively sub-humid conditions from *ca* 10200-8000 cal yrs BP (Fig. 17) and became relatively dry from *ca* 8000-6800 cal yrs BP (Neumann et al., 2010). There is no pollen data available from Tswaing profile before *ca* 10000 cal yrs BP due to the above mentioned destruction of the palynomorphs. Pollen data from lake Eteza before 10200 cal yrs BP is not available because the base of the section (2072-1929cm) consists of sand (Neumann et al., 2010). The pollen record of Wonderkrater starts with sub-humid indications and shows a drying trend but comparably cooler conditions between *ca* 11000-9500 yrs BP (Fig. 17) as suggested by increasing numbers of Capparaceae and *Tarchonanthus* (Scott, 1982a). After 9500 yrs BP it was continuously dry until 6000 yrs BP but changed from cooler to warmer temperatures. The temperature change is inferred from the increase of the tree percentages (Fig. 16), especially of elements of the Kalahari thornveld such as *Tarchonanthus,* Combretaceae and Capparaceae (Scott, 1982a). Pollen records from Wonderkrater and from the Makapansgat speleothem isotopes suggested that the early warm Holocene period might have continued until *ca* 6000 yrs BP (Scott et al., 2003; Holmgren et al., 2003). The Makapansgat Valley record (Holmgren et al., 2003) is showing higher values of $\delta^{13}C$ at the early Holocene at *ca* 8000 yrs BP suggesting dry Kalahari thronveld vegetation (Acocks, 1953) with open C_4 grassland vegetation (Scott et al., 2008). The Makapansgat Valley $\delta^{18}O$ stalagmite record and the Wonderkrater temperature index suggest warm climate conditions between 10000 and 6000 yrs BP (Holmgren et al., 2003). The warm conditions between 10000 and 6000 yrs BP coincide with the early Holocene warming episode which are observed in Antarctic ice cores in the South Atlantic (Masson et al., 2000; Hodell et al., 2001) and in the Kilimanjaro ice core (Thompson et al., 2002). A study of the linear dune construction in Zambia is showing aridity between 10000 and 8000 yrs BP (O'Connor and Thomas, 1999). These dry conditions are matching with the low sunspot activity period (Stuiver et al., 1998) which recorded from the North Atlantic (e.g. Alley et al., 1997; deMenocal et al., 2000; Peterson et al., 2000). These conditions are also coinciding with the precessional minimum of the solar radiation over South Africa (Holmgren et al., 2003). Dry climate conditions in Wonderwerk cave in the Northern Cape Province of South Africa were also observed between *ca* 13,300 and 4000 cal yrs BP. This is suggested by a hiatus in the deposition as well as pollen evidence from animal dung deposits (Brook et al., 2010). Comparing the Tswaing results with more distant sites, an arid condition was observed during the early Holocene between *ca* 11600 and 7700 cal ka at lake Malawi which is located between Malawi, Mozambique and Tanzania (Castañeda et al., 2009). This dry early Holocene is abnormal in comparison to the other lakes in the East African Rift Valley which were attributed to lake level highstands or overflowing conditions during this time (Gasse, 2000). The low precessional cycle which took place at the start of the Holocene is obviously reflected in the antiphase response of African lakes south of the equator on the both sides of the latidunal line 10-15°. South of 10-15° dry climate conditions associated with the Early Holocene decline in the incoming solar radiation reflected in the low lake levels, while in the north and around the equator the lakes are characterized by high levels in conformity with the northward shift in the ITCZ position (Partridge and Scott, 2000; Tyson and Partridge, 2000; Holmgren et al., 2003). However, in lake Eteza the climate was relatively different from the Wonderkrater pollen record which is also a consequence of the generally more humid climate in the coastal plain of KwaZulu-Natal. From *ca* 10200-8000 cal yrs BP the climate was relatively sub-humid which is evidenced by the high percentage of *Phoenix* and forest tree pollen such as *Olea* and *Manilkara* (Neumann et al., 2010). Similarly, an increase of the humidity in the coastal plain of KwaZulu-Natal during the early Holocene was also recorded from Mfabeni Peatland in Maputaland coastal plain at *ca* 11000 and 5000 cal yrs BP (Finch and Hill, 2008). The humidity increase in Mfabeni Peatland was evidenced by the rapid increase in *Podocarpus* percentages and the presence of arboreal taxa such as Anacardiaceae, Celastraceae and Rubiaceae (Finch and Hill, 2008). The sea surface temperature (SST) from the Mozambique Channel increased up to *ca* 7000 cal yrs BP which has been interpreted as a continuation of the deglaciation after the Last Glacial Maximum (Bard et al., 1997; Mayewski et al., 2004). In the lake Eteza pollen record there is a gradual increase of Poaceae, Cheno/Ams., Crassulaceae and Asteraceae since *ca* 8000-6800 cal yrs BP indicating relatively dry environmental conditions (Neumann et al., 2010). In comparison to Tswaing a relatively dry and warm period at *ca* 10000-7500 cal yrs BP is evidenced by the relatively high pollen percentages of *Tarchonanthus* and Asteraceae (Fig.16).

4.5.2- From *ca* 7500 to 3600 cal yrs BP

A humid trend in all three sites seems to have occurred after *ca* 7500 cal yrs BP. The mid Holocene phase at Braamhoek showed a contradictory climatic trend in comparison to the other sites. The interpretation of the Braamhoek pollen sequence is somewhat difficult since a higher resolution is needed in order to reliably compare it with the Tswaing pollen record. Warm and relatively dry conditions were observed between *ca* 7500 and 2500 cal yrs BP at Braamhoek (Norström et al, 2009). The dry condition was inferred from the high percentage of Asteraceae pollen and the decrease in the forest and Fynbos pollen as well as Poaceae pollen (Norström et al, 2009). In Tswaing crater the relatively sub-humid period was observed at *ca* 7500 cal yrs BP and continued until *ca* 4000 cal yrs BP (Fig. 18). This is evidenced by the high percentages of *Podocarpus*, *Burkea*, Combretaceae and *Acacia* pollen grain (Fig. 16). Humid climate conditions were characteristic of the mid Holocene phase in Lake Malawi between *ca* 7700 and 2000 cal ka as evidenced by the high inputs of C_3 vegetation (Castañeda et al., 2009). Forest expansion was recorded in several records in East Africa (Bonnefille et al., 1995; Ssemmanda and Vincens, 2002; Beuning et al., 1997) which might explain as a strengthening of the African monsoon (DeMenocal et al., 2000). However, shortly after *ca* 4000 cal yrs BP the climate at Tswaing changed from sub-humid to drier until *ca* 3600 cal yrs BP (Fig. 17). The short dry period was evidenced by a decrease of the tree pollen percentages and increase of Poaceae pollen. There is no obvious change during *ca* 4000- 3600 cal yrs BP in Wonderkrater and lake Eteza due to the low sample resolution at the later two records during this time. The sub-humid period in Wonderkrater (Fig. 17) became well established *ca* 6000 cal yrs BP although the trend started earlier *ca* 7000 cal yrs BP, which seems to be slightly earlier at Tswaing. It was warmer since *ca* 6000-4000 yrs BP which is indicated by the high presence of Combretaceae, *Tarchonanthus* and Capparaceae (Scott, 1982a). Gradually the temperature changed from warmer to cooler sub-humid condition from *ca* 4000-2000 yrs BP. This is inferred from the decline in the arboreal pollen percentages. In comparison to lake Eteza there is a humid period which started *ca* 6800-3600 cal yrs BP, nearly at the same time as the sub-humid period in Tswaing. The humid period at lake Eteza was inferred from the increase of forest trees, especially *Podocarpus*, which reached its highest percentage at 3700 cal yrs BP, as well as aquatics and swamp elements (Neumann et al., 2010). The increase of *Podocarpus* pollen percentage coincided with the proposed increase in precipitation of 5 to 10% in Maputaland (Partridge, 1997). The increase of the *Podocarpus* percentages in the middle Holocene was also recorded from Tswaing at *ca* 4800 cal yrs BP and in Wonderkrater at *ca* 4300 yrs BP (Scott, 1982a). This is an indication of increasing humidity in eastern South Africa. The humid phase of the middle Holocene is distinguished by a uniform increase of the Southern Africa sea level curve to reach a maximum high stand of +3.5m higher than the modern sea level at 4653 cal yrs BP (Ramsay, 1995).

4.5.3- From *ca* 3600 cal yrs BP to present

From *ca* 2000 to the present it was warm sub-humid at Wonderkrater evidenced by the increase in the arboreal pollen percentages such as *Burkea africana*, Combretaceae and *Rhus* (Scott, 1982a). In the Tswaing pollen record it was continuously warm sub-humid until *ca* 2000 cal yrs BP. At lake Eteza after *ca* 3600 cal yrs BP the climate was relatively dry. This is evidenced by the decrease of trees percentages including *Podocarpus* and the increase of Poaceae and Asteraceae *ca* 3500-2000 cal yrs BP (Neumann et al., 2010). In Tswaing and Wonderkrater the climate was relatively sub-humid. Several forest elements increased and Poaceae and Asteraceae decreased in Eteza after *ca* 2000 cal yrs BP indicating a relatively sub-humid condition until *ca* 700 cal yrs BP (Neumann et al., 2010). This period in Eteza coincides with the warm sub-humid period in

Wonderkrater. It started at the same time *ca* 2000 cal yrs BP but it ended at ca700 cal yrs BP in Eteza and continued until recent times in Wonderkrater (Fig. 17). Unfortunately there is no pollen data in the Tswaing core after *ca* 2071.5 cal yrs BP to compare them with the other two sites (see above). The climate became drier in lake Eteza after *ca* 700 cal yrs BP inferred from the strong decrease in *Podocarpus* and other trees (Neumann et al., 2010). The decrease in the tree pollen percentages and the increase in Poaceae and neophytes were also indicative of human activity by the first Iron Age settlers in KwaZulu-Natal. This period represented the start of the cold and dry Little Ice Age (650-150 cal yrs BP) in eastern South Africa (Holmgren et al., 2003; Neumann et al., 2010).

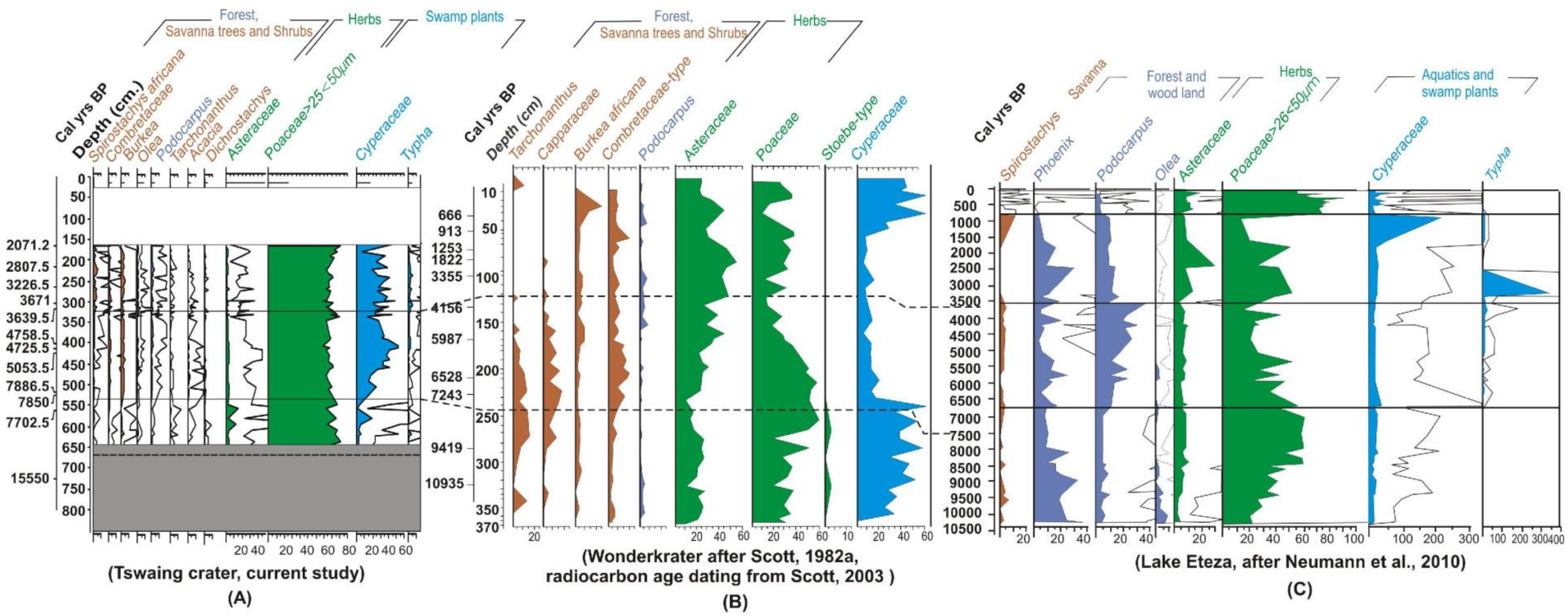


Fig. 16. Comparison of a shortened version of the pollen diagram of the Tswaing current study (A), Wonderkrater, Scott, 1982a (B) and Lake Eteza, Neumann et al, 2010 (C). The dashed lines in the figure are representing the lines of correlation shown in figure 17

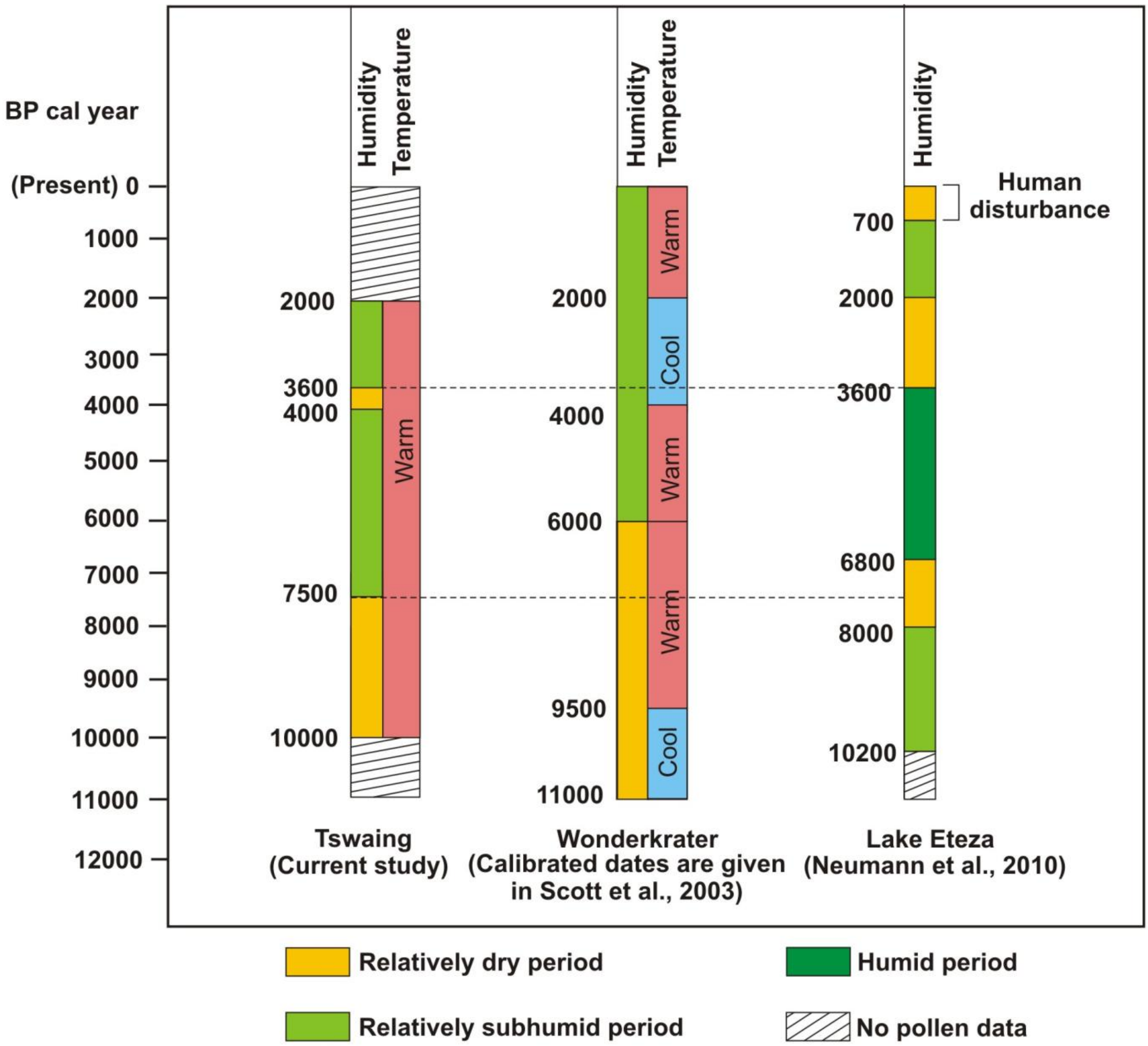


Fig. 17. Regional comparison showing the climate change with the radiocarbon ages of Tswaing crater, Wonderkrater and Lake eteza

5- CONCLUSION

- A new pollen record from Tswaing crater sheds light on the relation between the climate and vegetation change in the summer rainfall region in South Africa from *ca* 10000-2000 cal yrs BP. The current study achieved the aim of providing a higher sample resolution (65 samples) and an improved chronology (12 AMS dates) of the Holocene period in comparison to previous studies on Tswaing crater. Time resolution is *ca* 138 cal yrs/sample. An additional 1800 cal yrs BP cover the Holocene period at the bottom of Tswaing sequence in comparison with the previous pollen record of Scott (1999a). Additionally the study shows the benefit of an analysis of surface samples for the interpretation of core sediment samples.

- The non productive part of the Holocene Tswaing sequence between 600 and 800cm depth contains a single sample at *ca* 11300 cal yrs BP which contains high Asteraceae which gives evidence of a presumably extremely dry period during the early Holocene although Asteraceae could have been merely a local phenomenon near the lake shore. Dry and warm climate conditions seem to prevail between *ca* 10000 and 7500 cal yrs BP. Warm sub-humid climate conditions characterize the mid Holocene phase between *ca* 7500 and 4000 cal yrs BP. Short-term dry environmental conditions are signaled between *ca* 4000 and 3600 cal yrs BP. The short dry period in the current study was not observed in the previous (Scott, 1999a) which in turn shows that the current study achieved its objective to narrow the gap observed previously and demonstrate the short climate and vegetation change periods. A return to warm sub-humid conditions after *ca*

3600 cal yrs BP until *ca* 2000 cal yrs BP is suggested by the pollen indicators. The increasing *Spirostachys* pollen percentages from *ca* 3600 cal yrs BP probably suggest warmer conditions. A dry early Holocene and wetter mid and late Holocene was also suggested by Partridge et al., 1997 and Scott et al., 2008

- The current palynological study of the Tswaing pollen profile supports and complements the climatic interpretation of the biochemical proxy data of Kristen et al., 2009. A dry period between *ca* 10000 and 7500 cal yrs BP which is observed from the biomarker analysis coincides with the dry period *ca* 10000-7500 cal yrs BP in the current palynological study. The PC1 curve supports the interpretation of a dry climate. The biomarker data suggested humid condition between *ca* 7500 and 5500 cal yrs BP. This period matches the sub-humid period that is observed in the current profile *ca* 7500-4000 cal yrs BP. The PCA results suggested an increase of the moisture during this time.

- A correlation between the current Tswaing pollen profile and pollen records from Wonderkrater (Scott, 1982a) and lake Eteza (Neumann et al., 2010) was done in the frame of the current study. The correlation shows similar climate conditions between Tswaing and Wonderkrater. Dry conditions occurred at Tswaing *ca* 11300-7500 cal yrs BP; this period corresponds to the dry period at Wonderkrater *ca* 11000-6000 yrs BP. Wonderkrater also shows similar climatic and environmental changes to those which were observed in Tate Vondo and Rietvlei dam (Scott, 1987). At Wonderkrater and Rielvlei there was a dry early Holocene with increasing temperatures followed by temperature optimum with humid conditions shortly after *ca* 7000 yr BP (Scott, 1987). Despite the uncertainties of the dating, the changes occur nearly at the same time which might attributed to regional changes in the general atmospheric circulation pattern overt the Transvaal province (Scott, 1987). Lake Eteza show a different climatic trend than Tswaing and Wonderkrater, sub-humid conditions in occurred at *ca* 10200-8000 cal yrs BP and drier conditions at *ca* 8000-6800 cal yrs BP. This difference was probably because of the general more humid climate in the coastal plain of KwaZulu-Natal. This is also confirmed from Mfabeni Peatland pollen record in Maputaland coastal plain where the humid conditions recorded at *ca* 11000 and 5000 cal yrs BP (Finch and Hill, 2008) . An increase in moisture characterized the period between *ca* 7500 and 4000 cal yrs BP in all three sites. The Tswaing record indicates a dry event *ca* 4000 until 3600 cal yrs BP whereas evidence of dry conditions during this time is missing in the other two pollen records. Sub-humid conditions prevailed until *ca* 2000 cal yrs BP at Tswaing and to the present at Wonderkrater (since *ca* 6000 yrs BP to the present). In lake Eteza there are two periods of dry conditions, *ca* 3600-2000 cal yrs BP and *c*a 700 cal yrs BP to the present, intercalated by sub-humid condition *ca* 2000-700 cal yrs BP.

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Appendix A: List of the species name with authority

Acacia nilotica (L.) Willd. Ex Delile subsp. kraussiana (Benth.) Brenan (Germishuizen et al., 2006).

Acacia caffra (Thunb.) Willd (Germishuizen et al., 2006).

Acacia tortilis (Forssk.) Hayne subsp. heteracantha (Burch.) Brenan (Germishuizen et al., 2006).

Aloe davyana Schönland = A. greatheadii var. davyana (Germishuizen et al., 2006).

Burkea africana Hook (Germishuizen et al., 2006).

Boscia albitrunca (Burch.) Gilg and Gilg-Ben. (Germishuizen et al., 2006).

Bidens formosa (Bonato) Sch.Bip = Cosmos bipinnatus (Germishuizen et al., 2006).

Combretum apiculatum (Sond) subsp. apiculatum (Germishuizen et al., 2006).

Combretum collinum Fresen. subsp. gazense (Swynn. and Baker f.) Okafor (Germishuizen et al., 2006).

Combretum molle R. Br. Ex G. Don (Germishuizen et al., 2006).

Combretum zeyheri Sond (Germishuizen et al., 2006).

Dichrostachys cinerea (L.) Wight and Arn. subsp. africana Brenan and Brummitt var. africana (Germishuizen et al., 2006).

Dombeya rotundifolia (Hochst.) Planch. var. rotundifolia (Germishuizen et al., 2006).

Euclea crispa (Thumb.) Gürke subsp. crispa (Germishuizen et al., 2006).

Grewia flavescens Juss. var olukondae (Schinz) Wild = G. olukondae (Germishuizen et al., 2006).

Gymnosporia arenicola Jordaan (Germishuizen et al., 2006).

Kirkia wilmsii Engl. (Germishuizen et al., 2006).

Lippia javanica (Burm.f.) Spreng. (Germishuizen et al., 2006).

Maytenus heterophylla in sense of (Eckl. and Zeyh.) N. Robson in part = ***Gymnosporia heterophylla*** (Germishuizen et al., 2006).

Ochna pulchra Hook. f. (Germishuizen et al., 2006).

Panicum maximum Jacq (Germishuizen et al., 2006).

Pappea capensis Eckl. and zeyh (Germishuizen et al., 2006).

Peltophorum africanum Sond. (Germishuizen et al., 2006).

Pogonarthria squarrosa (Roem. and Schult.) Pilg. (Germishuizen et al., 2006).

Rhus lancea L.f. (Germishuizen et al., 2006).

Sclerocarya birrea (A.Rich.) Hochst. supsp. Caffra (Sond.) Kokwaro (Germishuizen et al., 2006).

Setaria pumila (Pior.) Roem. and Schult. (Germishuizen et al., 2006).

Solanum nigrum Lester (Germishuizen et al., 2006).

Spirostachys africana Sond. (Germishuizen et al., 2006).

Tagetes minuta L. (Germishuizen et al., 2006).

Ziziphus mucronata Lam. (Germishuizen et al., 2006).

Appendix B: The raw data of the Tswaing pollen taxa

Sample	*Spirostachys*	*Acalypha*	Combretaceae	*Podocarpus*	*Celtis*	*Trema*
0.5	2.0	0.0	4.0	5.0	0.0	0.0
154.5	4.0	2.0	0.0	8.0	0.0	0.0
161.5	22.0	3.0	2.0	6.0	0.0	0.0
169.0	2.0	2.0	4.0	5.0	0.0	0.0
176.5	11.0	5.0	12.0	10.0	0.0	0.0
183.5	4.0	4.0	13.0	4.0	0.0	0.0
190.5	7.0	7.0	7.0	8.0	0.0	0.0
204.5	19.0	1.0	12.0	11.0	0.0	0.0
209.5	26.0	3.0	0.0	22.0	1.0	0.0
215.5	19.0	4.0	10.0	10.0	1.0	1.0
221.5	16.0	5.0	7.0	13.0	0.0	1.0
227.5	2.0	5.0	10.0	2.0	1.0	0.0
233.5	14.0	5.0	0.0	11.0	3.0	0.0
245.5	5.0	8.0	8.0	10.0	0.0	3.0
251.5	18.0	5.0	17.0	10.0	0.0	0.0
257.5	10.0	12.0	10.0	3.0	1.0	0.0
271.0	20.0	0.0	17.0	6.0	0.0	0.0
276.8	16.0	5.0	17.0	15.0	0.0	0.0
278.5	7.0	3.0	21.0	6.0	0.0	0.0
282.3	4.0	2.0	10.0	4.0	0.0	0.0
288.0	10.0	1.0	10.0	7.0	0.0	0.0
290.5	14.0	9.0	11.0	7.0	2.0	2.0
293.5	25.0	1.0	25.0	5.0	0.0	0.0
299.3	7.0	4.0	4.0	5.0	0.0	0.0
302.5	13.0	0.0	9.0	4.0	0.0	0.0
304.8	7.0	6.0	10.0	5.0	0.0	0.0
308.5	7.0	3.0	9.0	1.0	0.0	0.0
308.5	7.0	8.0	11.0	7.0	0.0	0.0
315.8	3.0	1.0	4.0	3.0	0.0	0.0
321.3	4.0	2.0	8.0	8.0	0.0	0.0
356.5	7.0	8.0	9.0	15.0	4.0	0.0
362.5	3.0	5.0	8.0	9.0	0.0	0.0
368.5	5.0	4.0	14.0	7.0	0.0	0.0
380.5	9.0	3.0	14.0	12.0	0.0	0.0
385.5	8.0	4.0	16.0	8.0	0.0	0.0
391.5	2.0	2.0	14.0	6.0	0.0	0.0
404.5	5.0	8.0	6.0	3.0	0.0	0.0
410.5	3.0	0.0	16.0	5.0	1.0	0.0
416.5	1.0	4.0	16.0	4.0	1.0	0.0
422.5	4.0	10.0	11.0	6.0	0.0	0.0
428.5	4.0	6.0	7.0	2.0	0.0	0.0
434.5	0.0	4.0	8.0	4.0	1.0	0.0
446.5	0.0	4.0	9.0	6.0	0.0	0.0
459.5	1.0	4.0	18.0	4.0	1.0	0.0
471.5	0.0	4.0	11.0	7.0	0.0	0.0
477.5	4.0	4.0	13.0	6.0	0.0	0.0
514.5	2.0	1.0	9.0	2.0	0.0	0.0
521.5	0.0	1.0	11.0	1.0	0.0	0.0
542.5	4.0	4.0	3.0	2.0	0.0	0.0
556.5	1.0	2.0	2.0	2.0	0.0	0.0
570.5	0.0	0.0	6.0	1.0	0.0	0.0
577.5	0.0	4.0	2.0	2.0	1.0	0.0
584.5	0.0	1.0	2.0	1.0	0.0	0.0
598.5	2.0	0.0	4.0	1.0	0.0	0.0

Sample	*Apodytes*	*Allophyllos*	*Burkea*	Euphorbia	Euphorbiaceae	*Anthospermum*
0.5	0.0	0.0	2.0	0.0	0.0	0.0
154.5	0.0	0.0	3.0	0.0	0.0	1.0
161.5	0.0	0.0	10.0	0.0	0.0	3.0
169.0	0.0	0.0	14.0	0.0	0.0	2.0
176.5	0.0	0.0	19.0	0.0	1.0	3.0
183.5	0.0	0.0	24.0	0.0	0.0	0.0
190.5	0.0	0.0	15.0	0.0	0.0	1.0
204.5	0.0	0.0	23.0	0.0	1.0	0.0
209.5	0.0	0.0	17.0	0.0	0.0	6.0
215.5	0.0	0.0	15.0	0.0	1.0	4.0
221.5	0.0	0.0	19.0	0.0	0.0	0.0
227.5	0.0	0.0	19.0	0.0	1.0	0.0
233.5	0.0	0.0	31.0	0.0	1.0	2.0
245.5	0.0	0.0	14.0	0.0	0.0	1.0
251.5	0.0	0.0	19.0	0.0	0.0	3.0
257.5	0.0	0.0	20.0	0.0	0.0	1.0
271.0	1.0	0.0	13.0	0.0	0.0	0.0
276.8	4.0	0.0	4.0	0.0	0.0	0.0
278.5	0.0	0.0	29.0	0.0	0.0	6.0
282.3	0.0	0.0	16.0	0.0	0.0	1.0
288.0	1.0	0.0	10.0	0.0	0.0	0.0
290.5	0.0	0.0	18.0	0.0	0.0	7.0
293.5	2.0	0.0	20.0	0.0	0.0	1.0
299.3	0.0	0.0	13.0	0.0	0.0	0.0
302.5	0.0	0.0	24.0	0.0	0.0	4.0
304.8	0.0	0.0	13.0	0.0	0.0	0.0
308.5	0.0	0.0	6.0	0.0	0.0	1.0
308.5	0.0	0.0	26.0	0.0	0.0	3.0
315.8	0.0	1.0	5.0	0.0	0.0	0.0
321.3	0.0	0.0	25.0	0.0	0.0	3.0
356.5	0.0	0.0	20.0	0.0	0.0	1.0
362.5	0.0	0.0	25.0	0.0	0.0	3.0
368.5	0.0	0.0	18.0	0.0	0.0	4.0
380.5	0.0	0.0	26.0	0.0	1.0	8.0
385.5	0.0	0.0	22.0	0.0	1.0	2.0
391.5	0.0	0.0	24.0	1.0	0.0	3.0
404.5	0.0	0.0	14.0	0.0	0.0	1.0
410.5	0.0	0.0	27.0	0.0	0.0	2.0
416.5	0.0	0.0	20.0	0.0	0.0	3.0
422.5	0.0	0.0	18.0	0.0	0.0	2.0
428.5	0.0	0.0	15.0	0.0	0.0	1.0
434.5	0.0	0.0	23.0	0.0	0.0	6.0
446.5	0.0	0.0	24.0	0.0	0.0	5.0
459.5	0.0	0.0	22.0	0.0	0.0	4.0
471.5	0.0	0.0	23.0	0.0	0.0	3.0
477.5	0.0	0.0	24.0	0.0	0.0	1.0
514.5	0.0	0.0	8.0	0.0	0.0	1.0
521.5	0.0	0.0	2.0	0.0	0.0	2.0
542.5	0.0	0.0	10.0	1.0	0.0	2.0
556.5	0.0	0.0	6.0	0.0	0.0	1.0
570.5	0.0	0.0	6.0	1.0	0.0	3.0
577.5	0.0	0.0	22.0	0.0	0.0	2.0
584.5	0.0	0.0	10.0	0.0	0.0	3.0
598.5	0.0	0.0	2.0	0.0	1.0	1.0

Sample	*Olea*	*Mimusops*	*Rhus*	*Heteromorpha*	Celastraceae	Myrtaceae
0.5	4.0	0.0	2.0	0.0	0.0	0.0
154.5	4.0	0.0	2.0	0.0	0.0	0.0
161.5	3.0	0.0	0.0	0.0	0.0	0.0
169.0	3.0	0.0	1.0	0.0	0.0	0.0
176.5	3.0	0.0	1.0	0.0	0.0	0.0
183.5	1.0	0.0	1.0	0.0	0.0	0.0
190.5	1.0	0.0	0.0	1.0	0.0	0.0
204.5	3.0	0.0	0.0	0.0	0.0	0.0
209.5	2.0	0.0	1.0	0.0	0.0	0.0
215.5	6.0	0.0	8.0	0.0	0.0	0.0
221.5	3.0	0.0	1.0	0.0	0.0	1.0
227.5	2.0	0.0	2.0	0.0	0.0	0.0
233.5	5.0	0.0	3.0	0.0	0.0	0.0
245.5	4.0	0.0	1.0	0.0	0.0	0.0
251.5	8.0	0.0	3.0	0.0	0.0	0.0
257.5	2.0	0.0	5.0	0.0	0.0	0.0
271.0	6.0	0.0	1.0	0.0	0.0	0.0
276.8	3.0	0.0	0.0	0.0	0.0	0.0
278.5	2.0	0.0	3.0	0.0	1.0	1.0
282.3	3.0	0.0	4.0	0.0	0.0	0.0
288.0	3.0	0.0	2.0	0.0	0.0	0.0
290.5	3.0	0.0	0.0	0.0	0.0	0.0
293.5	5.0	0.0	5.0	0.0	0.0	0.0
299.3	22.0	0.0	3.0	0.0	0.0	0.0
302.5	2.0	0.0	0.0	0.0	0.0	1.0
304.8	5.0	0.0	2.0	1.0	0.0	0.0
308.5	1.0	0.0	2.0	0.0	0.0	0.0
308.5	0.0	1.0	0.0	0.0	0.0	0.0
315.8	3.0	0.0	0.0	0.0	0.0	0.0
321.3	2.0	0.0	0.0	0.0	0.0	0.0
356.5	2.0	0.0	2.0	0.0	0.0	0.0
362.5	2.0	0.0	6.0	0.0	0.0	0.0
368.5	3.0	0.0	3.0	0.0	0.0	0.0
380.5	5.0	0.0	4.0	0.0	0.0	0.0
385.5	2.0	0.0	4.0	0.0	0.0	0.0
391.5	4.0	0.0	4.0	0.0	0.0	0.0
404.5	3.0	0.0	1.0	0.0	0.0	0.0
410.5	2.0	0.0	2.0	0.0	0.0	0.0
416.5	4.0	0.0	3.0	0.0	0.0	0.0
422.5	3.0	0.0	2.0	0.0	0.0	0.0
428.5	3.0	0.0	1.0	0.0	0.0	0.0
434.5	0.0	0.0	4.0	0.0	0.0	0.0
446.5	3.0	0.0	0.0	0.0	0.0	0.0
459.5	0.0	0.0	4.0	0.0	0.0	0.0
471.5	0.0	0.0	4.0	0.0	0.0	0.0
477.5	2.0	0.0	1.0	0.0	0.0	0.0
514.5	1.0	0.0	2.0	0.0	0.0	0.0
521.5	1.0	0.0	0.0	0.0	0.0	0.0
542.5	0.0	0.0	1.0	0.0	0.0	0.0
556.5	0.0	1.0	1.0	0.0	0.0	1.0
570.5	1.0	0.0	0.0	0.0	0.0	0.0
577.5	3.0	0.0	2.0	0.0	0.0	0.0
584.5	3.0	0.0	0.0	0.0	0.0	1.0
598.5	2.0	0.0	2.0	0.0	0.0	0.0

Sample	*Tarchonanthus*	*Euclea*	Acacia	Mimosoideae	*Croton*	*Peltophorum*
0.5	0.0	2.0	1.0	0.0	0.0	0.0
154.5	0.0	0.0	0.0	0.0	0.0	0.0
161.5	1.0	0.0	1.0	0.0	0.0	0.0
169.0	0.0	0.0	0.0	0.0	0.0	0.0
176.5	1.0	1.0	1.0	0.0	0.0	0.0
183.5	1.0	1.0	0.0	3.0	0.0	0.0
190.5	2.0	2.0	2.0	2.0	0.0	0.0
204.5	4.0	2.0	2.0	0.0	0.0	0.0
209.5	0.0	1.0	0.0	0.0	1.0	0.0
215.5	1.0	1.0	4.0	0.0	0.0	1.0
221.5	2.0	1.0	2.0	2.0	0.0	0.0
227.5	1.0	0.0	4.0	0.0	0.0	1.0
233.5	3.0	5.0	2.0	5.0	0.0	0.0
245.5	0.0	2.0	5.0	3.0	0.0	1.0
251.5	0.0	3.0	5.0	0.0	0.0	1.0
257.5	1.0	0.0	4.0	1.0	0.0	0.0
271.0	3.0	4.0	2.0	0.0	4.0	0.0
276.8	1.0	0.0	7.0	3.0	1.0	0.0
278.5	1.0	3.0	4.0	0.0	0.0	0.0
282.3	0.0	2.0	4.0	1.0	0.0	0.0
288.0	3.0	0.0	2.0	2.0	0.0	0.0
290.5	2.0	0.0	5.0	0.0	1.0	0.0
293.5	1.0	4.0	2.0	0.0	1.0	0.0
299.3	0.0	2.0	3.0	1.0	1.0	0.0
302.5	3.0	2.0	4.0	0.0	1.0	1.0
304.8	1.0	1.0	2.0	4.0	0.0	0.0
308.5	0.0	0.0	0.0	3.0	3.0	0.0
308.5	0.0	1.0	4.0	0.0	0.0	0.0
315.8	2.0	0.0	0.0	0.0	2.0	0.0
321.3	1.0	5.0	6.0	3.0	4.0	0.0
356.5	0.0	0.0	1.0	3.0	0.0	1.0
362.5	1.0	3.0	1.0	0.0	1.0	0.0
368.5	0.0	2.0	5.0	1.0	0.0	0.0
380.5	0.0	5.0	12.0	4.0	0.0	1.0
385.5	0.0	0.0	6.0	0.0	0.0	0.0
391.5	0.0	6.0	5.0	0.0	1.0	0.0
404.5	2.0	2.0	8.0	1.0	4.0	1.0
410.5	1.0	2.0	4.0	0.0	0.0	1.0
416.5	1.0	2.0	8.0	0.0	1.0	0.0
422.5	1.0	0.0	9.0	0.0	0.0	0.0
428.5	0.0	1.0	12.0	1.0	0.0	1.0
434.5	2.0	0.0	3.0	0.0	0.0	1.0
446.5	2.0	0.0	18.0	0.0	0.0	0.0
459.5	2.0	1.0	9.0	0.0	0.0	0.0
471.5	2.0	1.0	2.0	0.0	2.0	0.0
477.5	1.0	3.0	12.0	0.0	0.0	1.0
514.5	2.0	0.0	5.0	1.0	0.0	0.0
521.5	7.0	1.0	1.0	0.0	0.0	0.0
542.5	2.0	0.0	4.0	0.0	0.0	0.0
556.5	4.0	0.0	5.0	0.0	0.0	11.0
570.5	1.0	1.0	3.0	0.0	0.0	0.0
577.5	5.0	1.0	2.0	0.0	0.0	0.0
584.5	1.0	0.0	3.0	0.0	0.0	0.0
598.5	3.0	0.0	0.0	0.0	0.0	0.0

Sample	*Sclerocarya*	*Kirkia*	Capparaceae	*Grewia*	*Crassula*	*Commiphora*
0.5	3.0	0.0	0.0	1.0	0.0	0.0
154.5	0.0	1.0	0.0	0.0	0.0	0.0
161.5	1.0	0.0	0.0	1.0	1.0	0.0
169.0	0.0	0.0	0.0	0.0	0.0	0.0
176.5	5.0	0.0	0.0	0.0	0.0	0.0
183.5	0.0	0.0	0.0	0.0	0.0	0.0
190.5	0.0	0.0	0.0	0.0	0.0	0.0
204.5	0.0	0.0	0.0	0.0	0.0	0.0
209.5	0.0	0.0	0.0	0.0	0.0	0.0
215.5	2.0	2.0	0.0	0.0	1.0	0.0
221.5	1.0	0.0	0.0	0.0	0.0	0.0
227.5	0.0	0.0	0.0	1.0	1.0	0.0
233.5	0.0	0.0	0.0	0.0	1.0	0.0
245.5	2.0	2.0	0.0	0.0	0.0	0.0
251.5	4.0	0.0	0.0	0.0	1.0	0.0
257.5	1.0	0.0	0.0	0.0	0.0	0.0
271.0	0.0	0.0	0.0	0.0	0.0	0.0
276.8	1.0	0.0	0.0	0.0	0.0	0.0
278.5	2.0	0.0	0.0	2.0	0.0	0.0
282.3	2.0	0.0	0.0	0.0	0.0	0.0
288.0	0.0	0.0	0.0	1.0	0.0	0.0
290.5	0.0	0.0	0.0	0.0	0.0	0.0
293.5	1.0	0.0	0.0	0.0	1.0	0.0
299.3	0.0	0.0	0.0	0.0	0.0	0.0
302.5	0.0	0.0	0.0	0.0	1.0	0.0
304.8	2.0	0.0	0.0	0.0	0.0	0.0
308.5	0.0	0.0	0.0	0.0	0.0	0.0
308.5	0.0	0.0	0.0	0.0	0.0	0.0
315.8	0.0	1.0	0.0	0.0	0.0	0.0
321.3	0.0	1.0	0.0	0.0	0.0	0.0
356.5	2.0	0.0	0.0	0.0	0.0	0.0
362.5	4.0	0.0	0.0	4.0	2.0	0.0
368.5	1.0	0.0	0.0	2.0	0.0	0.0
380.5	2.0	0.0	0.0	1.0	1.0	0.0
385.5	0.0	0.0	0.0	0.0	0.0	0.0
391.5	0.0	0.0	0.0	0.0	1.0	0.0
404.5	0.0	0.0	1.0	1.0	0.0	0.0
410.5	2.0	0.0	0.0	0.0	1.0	0.0
416.5	2.0	0.0	0.0	2.0	0.0	0.0
422.5	0.0	0.0	0.0	0.0	0.0	0.0
428.5	0.0	0.0	2.0	0.0	0.0	0.0
434.5	3.0	0.0	0.0	2.0	1.0	0.0
446.5	4.0	1.0	0.0	0.0	0.0	0.0
459.5	3.0	0.0	0.0	1.0	0.0	0.0
471.5	0.0	0.0	0.0	1.0	0.0	0.0
477.5	4.0	0.0	1.0	3.0	0.0	0.0
514.5	2.0	0.0	0.0	1.0	0.0	0.0
521.5	0.0	0.0	0.0	2.0	5.0	0.0
542.5	0.0	1.0	0.0	3.0	1.0	0.0
556.5	0.0	0.0	0.0	1.0	0.0	0.0
570.5	0.0	0.0	0.0	1.0	0.0	0.0
577.5	1.0	0.0	0.0	1.0	0.0	1.0
584.5	2.0	0.0	0.0	2.0	0.0	0.0
598.5	0.0	0.0	0.0	2.0	0.0	0.0

Sample	Liliaceae	*Dicliptera*-type	Acanthaceae	*Selago*- type	Scrophulariaceae	*Stoebe*-type
0.5	0.0	0.0	0.0	0.0	0.0	0.0
154.5	4.0	0.0	0.0	0.0	0.0	0.0
161.5	0.0	0.0	0.0	0.0	1.0	0.0
169.0	0.0	0.0	0.0	0.0	0.0	1.0
176.5	2.0	0.0	0.0	1.0	0.0	0.0
183.5	3.0	0.0	0.0	0.0	0.0	0.0
190.5	6.0	1.0	0.0	0.0	0.0	0.0
204.5	2.0	0.0	0.0	1.0	0.0	0.0
209.5	1.0	0.0	0.0	0.0	0.0	2.0
215.5	1.0	0.0	0.0	0.0	0.0	0.0
221.5	2.0	1.0	0.0	0.0	0.0	1.0
227.5	1.0	0.0	0.0	0.0	0.0	0.0
233.5	3.0	2.0	0.0	2.0	0.0	0.0
245.5	3.0	0.0	0.0	1.0	0.0	1.0
251.5	1.0	3.0	0.0	1.0	0.0	1.0
257.5	4.0	0.0	0.0	0.0	0.0	0.0
271.0	3.0	0.0	0.0	0.0	0.0	0.0
276.8	1.0	0.0	0.0	0.0	0.0	0.0
278.5	0.0	3.0	0.0	0.0	0.0	0.0
282.3	3.0	0.0	0.0	0.0	0.0	1.0
288.0	2.0	0.0	0.0	0.0	0.0	0.0
290.5	4.0	1.0	0.0	1.0	0.0	0.0
293.5	7.0	1.0	3.0	1.0	0.0	1.0
299.3	4.0	0.0	0.0	0.0	0.0	1.0
302.5	0.0	1.0	0.0	0.0	0.0	0.0
304.8	2.0	0.0	0.0	0.0	0.0	0.0
308.5	3.0	0.0	0.0	1.0	0.0	0.0
308.5	0.0	1.0	0.0	2.0	0.0	1.0
315.8	0.0	1.0	0.0	0.0	0.0	0.0
321.3	2.0	0.0	0.0	1.0	0.0	0.0
356.5	2.0	0.0	0.0	0.0	0.0	1.0
362.5	0.0	0.0	0.0	0.0	0.0	0.0
368.5	2.0	2.0	0.0	0.0	0.0	0.0
380.5	5.0	0.0	0.0	0.0	0.0	2.0
385.5	0.0	0.0	0.0	0.0	0.0	0.0
391.5	2.0	2.0	0.0	0.0	0.0	1.0
404.5	2.0	1.0	0.0	0.0	0.0	1.0
410.5	0.0	1.0	0.0	0.0	0.0	0.0
416.5	0.0	0.0	0.0	1.0	0.0	0.0
422.5	0.0	0.0	0.0	2.0	0.0	1.0
428.5	3.0	2.0	0.0	0.0	0.0	0.0
434.5	3.0	2.0	0.0	0.0	0.0	1.0
446.5	3.0	2.0	0.0	1.0	0.0	0.0
459.5	4.0	2.0	0.0	1.0	3.0	0.0
471.5	1.0	0.0	0.0	1.0	0.0	0.0
477.5	0.0	0.0	0.0	0.0	2.0	0.0
514.5	0.0	1.0	0.0	0.0	0.0	0.0
521.5	0.0	1.0	0.0	3.0	2.0	0.0
542.5	2.0	0.0	0.0	0.0	0.0	0.0
556.5	0.0	1.0	0.0	0.0	0.0	1.0
570.5	0.0	0.0	0.0	0.0	0.0	0.0
577.5	1.0	1.0	0.0	1.0	0.0	0.0
584.5	0.0	0.0	0.0	1.0	0.0	0.0
598.5	1.0	0.0	0.0	0.0	0.0	0.0

Sample	*Lychnophora*-type	*Vernonia*-type	*Pacourina*-type	*Dicoma*-type	*Pentzia*-type	Asteraceae
0.5	2.0	1.0	0.0	0.0	0.0	180.0
154.5	0.0	0.0	0.0	0.0	0.0	2.0
161.5	0.0	0.0	0.0	0.0	0.0	14.0
169.0	0.0	0.0	0.0	0.0	0.0	16.0
176.5	1.0	0.0	0.0	0.0	1.0	11.0
183.5	0.0	0.0	0.0	0.0	0.0	8.0
190.5	0.0	0.0	0.0	0.0	0.0	3.0
204.5	0.0	0.0	0.0	0.0	0.0	13.0
209.5	0.0	0.0	0.0	0.0	0.0	12.0
215.5	1.0	0.0	0.0	0.0	0.0	14.0
221.5	0.0	0.0	0.0	0.0	0.0	8.0
227.5	1.0	0.0	0.0	0.0	0.0	9.0
233.5	0.0	0.0	0.0	0.0	0.0	6.0
245.5	0.0	0.0	0.0	0.0	0.0	9.0
251.5	0.0	0.0	0.0	0.0	0.0	18.0
257.5	0.0	0.0	0.0	0.0	0.0	9.0
271.0	0.0	0.0	0.0	0.0	0.0	7.0
276.8	0.0	0.0	0.0	0.0	0.0	3.0
278.5	0.0	0.0	0.0	0.0	0.0	18.0
282.3	0.0	0.0	0.0	1.0	0.0	9.0
288.0	0.0	0.0	0.0	0.0	0.0	11.0
290.5	0.0	0.0	0.0	0.0	0.0	8.0
293.5	0.0	0.0	0.0	0.0	0.0	11.0
299.3	0.0	0.0	0.0	1.0	0.0	9.0
302.5	1.0	0.0	0.0	0.0	0.0	16.0
304.8	0.0	0.0	0.0	0.0	0.0	8.0
308.5	0.0	0.0	0.0	0.0	0.0	8.0
308.5	0.0	0.0	0.0	0.0	0.0	18.0
315.8	0.0	0.0	0.0	0.0	0.0	3.0
321.3	0.0	0.0	1.0	0.0	0.0	13.0
356.5	0.0	0.0	0.0	0.0	2.0	13.0
362.5	0.0	1.0	0.0	0.0	0.0	12.0
368.5	0.0	0.0	0.0	0.0	0.0	12.0
380.5	0.0	0.0	0.0	0.0	1.0	19.0
385.5	0.0	0.0	0.0	0.0	0.0	16.0
391.5	0.0	0.0	0.0	0.0	0.0	23.0
404.5	0.0	0.0	0.0	0.0	0.0	24.0
410.5	1.0	0.0	0.0	0.0	1.0	23.0
416.5	0.0	0.0	0.0	0.0	0.0	18.0
422.5	1.0	0.0	0.0	0.0	0.0	13.0
428.5	0.0	0.0	0.0	0.0	0.0	11.0
434.5	0.0	0.0	0.0	0.0	0.0	17.0
446.5	0.0	0.0	0.0	0.0	0.0	11.0
459.5	0.0	0.0	0.0	0.0	0.0	14.0
471.5	1.0	0.0	0.0	0.0	0.0	19.0
477.5	0.0	0.0	0.0	1.0	0.0	20.0
514.5	0.0	0.0	0.0	0.0	0.0	16.0
521.5	0.0	0.0	0.0	0.0	0.0	81.0
542.5	0.0	0.0	0.0	0.0	0.0	12.0
556.5	0.0	0.0	0.0	0.0	0.0	58.0
570.5	0.0	0.0	1.0	0.0	0.0	17.0
577.5	0.0	0.0	0.0	1.0	0.0	13.0
584.5	1.0	0.0	0.0	0.0	0.0	11.0
598.5	0.0	0.0	0.0	0.0	0.0	18.0

Sample	*Artemisia*	*Ericaceae*	*Aizoaceae*-type	Chenopodiaceae	Caryophyllaceae	Poaceae
0.5	2.0	0.0	0.0	29.0	3.0	85.0
154.5	8.0	0.0	0.0	0.0	0.0	466.0
161.5	11.0	0.0	0.0	2.0	0.0	421.0
169.0	4.0	0.0	0.0	3.0	0.0	447.0
176.5	8.0	1.0	0.0	6.0	1.0	406.0
183.5	9.0	0.0	0.0	3.0	0.0	432.0
190.5	10.0	0.0	0.0	2.0	0.0	430.0
204.5	11.0	1.0	0.0	4.0	3.0	384.0
209.5	11.0	0.0	0.0	15.0	0.0	378.0
215.5	13.0	0.0	1.0	4.0	0.0	395.0
221.5	13.0	0.0	0.0	0.0	0.0	425.0
227.5	12.0	0.0	0.0	5.0	0.0	416.0
233.5	12.0	0.0	0.0	4.0	0.0	374.0
245.5	20.0	0.0	0.0	9.0	0.0	422.0
251.5	9.0	0.0	0.0	6.0	0.0	387.0
257.5	10.0	0.0	0.0	9.0	0.0	403.0
271.0	15.0	0.0	0.0	4.0	0.0	406.0
276.8	6.0	0.0	0.0	2.0	0.0	379.0
278.5	14.0	1.0	0.0	12.0	0.0	352.0
282.3	4.0	0.0	0.0	2.0	0.0	434.0
288.0	13.0	0.0	0.0	7.0	0.0	438.0
290.5	9.0	0.0	0.0	3.0	0.0	394.0
293.5	2.0	1.0	0.0	7.0	0.0	439.0
299.3	6.0	1.0	0.0	8.0	0.0	430.0
302.5	19.0	0.0	0.0	3.0	0.0	434.0
304.8	5.0	0.0	0.0	0.0	0.0	456.0
308.5	4.0	0.0	0.0	4.0	0.0	503.0
308.5	8.0	0.0	0.0	6.0	0.0	415.0
315.8	1.0	0.0	0.0	1.0	0.0	453.0
321.3	10.0	0.0	0.0	7.0	0.0	384.0
356.5	12.0	0.0	0.0	3.0	1.0	408.0
362.5	9.0	0.0	1.0	5.0	0.0	414.0
368.5	16.0	0.0	1.0	6.0	0.0	413.0
380.5	21.0	0.0	0.0	12.0	0.0	387.0
385.5	11.0	0.0	0.0	3.0	2.0	389.0
391.5	7.0	0.0	0.0	15.0	0.0	366.0
404.5	4.0	0.0	0.0	13.0	0.0	400.0
410.5	5.0	0.0	0.0	8.0	0.0	385.0
416.5	6.0	0.0	0.0	19.0	0.0	395.0
422.5	2.0	0.0	0.0	7.0	0.0	411.0
428.5	3.0	0.0	0.0	9.0	0.0	413.0
434.5	9.0	0.0	0.0	6.0	0.0	415.0
446.5	5.0	0.0	0.0	20.0	0.0	373.0
459.5	7.0	0.0	0.0	13.0	0.0	405.0
471.5	5.0	0.0	0.0	6.0	0.0	410.0
477.5	6.0	0.0	0.0	15.0	1.0	402.0
514.5	2.0	0.0	0.0	8.0	0.0	439.0
521.5	0.0	0.0	0.0	12.0	3.0	377.0
542.5	6.0	1.0	0.0	4.0	1.0	446.0
556.5	1.0	0.0	0.0	14.0	9.0	374.0
570.5	4.0	0.0	0.0	11.0	0.0	440.0
577.5	4.0	0.0	0.0	4.0	0.0	425.0
584.5	5.0	0.0	0.0	13.0	0.0	438.0
598.5	3.0	0.0	0.0	7.0	1.0	454.0

Sample	Poaceae>50	Umbelliferae	Moraceae	*Pinus*	*Typha*	*Lemna*
0.5	0.0	0.0	0.0	33.0	13.0	0.0
154.5	18.0	0.0	0.0	0.0	2.0	0.0
161.5	3.0	0.0	0.0	0.0	12.0	0.0
169.0	13.0	0.0	0.0	0.0	1.0	1.0
176.5	7.0	0.0	0.0	0.0	8.0	0.0
183.5	10.0	0.0	0.0	0.0	6.0	0.0
190.5	22.0	0.0	0.0	0.0	7.0	0.0
204.5	4.0	0.0	0.0	0.0	17.0	0.0
209.5	2.0	0.0	0.0	0.0	14.0	0.0
215.5	0.0	0.0	0.0	0.0	14.0	0.0
221.5	9.0	0.0	0.0	0.0	28.0	0.0
227.5	11.0	0.0	0.0	0.0	14.0	0.0
233.5	2.0	0.0	0.0	0.0	11.0	0.0
245.5	6.0	0.0	0.0	0.0	8.0	0.0
251.5	6.0	1.0	0.0	0.0	20.0	0.0
257.5	8.0	0.0	0.0	0.0	16.0	0.0
271.0	21.0	0.0	0.0	0.0	6.0	0.0
276.8	46.0	0.0	0.0	0.0	13.0	0.0
278.5	11.0	0.0	0.0	0.0	0.0	0.0
282.3	25.0	0.0	0.0	0.0	20.0	0.0
288.0	23.0	0.0	0.0	0.0	32.0	1.0
290.5	9.0	0.0	0.0	0.0	21.0	0.0
293.5	16.0	0.0	0.0	0.0	19.0	0.0
299.3	18.0	0.0	0.0	0.0	14.0	0.0
302.5	5.0	1.0	0.0	0.0	19.0	0.0
304.8	8.0	0.0	0.0	0.0	6.0	0.0
308.5	16.0	0.0	0.0	0.0	12.0	0.0
308.5	2.0	0.0	0.0	0.0	9.0	0.0
315.8	24.0	0.0	0.0	0.0	5.0	0.0
321.3	25.0	0.0	0.0	0.0	7.0	0.0
356.5	8.0	0.0	1.0	0.0	6.0	0.0
362.5	8.0	0.0	0.0	0.0	16.0	0.0
368.5	9.0	0.0	0.0	0.0	13.0	0.0
380.5	5.0	0.0	0.0	0.0	16.0	0.0
385.5	4.0	0.0	0.0	0.0	14.0	0.0
391.5	12.0	1.0	2.0	0.0	5.0	0.0
404.5	15.0	0.0	0.0	0.0	3.0	0.0
410.5	2.0	1.0	0.0	0.0	4.0	0.0
416.5	6.0	0.0	0.0	0.0	2.0	0.0
422.5	5.0	0.0	0.0	0.0	4.0	0.0
428.5	8.0	0.0	0.0	0.0	8.0	0.0
434.5	18.0	0.0	0.0	0.0	6.0	0.0
446.5	10.0	2.0	0.0	0.0	1.0	0.0
459.5	6.0	1.0	0.0	0.0	2.0	0.0
471.5	7.0	0.0	0.0	0.0	3.0	0.0
477.5	4.0	1.0	0.0	0.0	1.0	0.0
514.5	0.0	0.0	0.0	0.0	3.0	0.0
521.5	2.0	1.0	0.0	0.0	0.0	0.0
542.5	9.0	0.0	0.0	0.0	9.0	0.0
556.5	0.0	1.0	0.0	0.0	0.0	0.0
570.5	7.0	0.0	0.0	0.0	0.0	0.0
577.5	8.0	0.0	0.0	0.0	19.0	0.0
584.5	6.0	0.0	0.0	0.0	9.0	0.0
598.5	0.0	0.0	0.0	0.0	0.0	0.0

Sample	*Ascolepis*	Cyperaceae	Triletespore	*Riccia*	Geraniaceae	Lamiaceae
0.5	0.0	60.0	4.0	0.0	0.0	0.0
154.5	0.0	187.0	0.0	0.0	0.0	0.0
161.5	0.0	233.0	3.0	0.0	0.0	0.0
169.0	0.0	37.0	0.0	0.0	0.0	0.0
176.5	0.0	185.0	2.0	0.0	0.0	0.0
183.5	0.0	162.0	0.0	0.0	0.0	0.0
190.5	0.0	135.0	0.0	0.0	0.0	0.0
204.5	0.0	197.0	0.0	0.0	0.0	0.0
209.5	0.0	99.0	0.0	0.0	0.0	0.0
215.5	0.0	131.0	2.0	0.0	0.0	0.0
221.5	0.0	138.0	0.0	0.0	0.0	0.0
227.5	0.0	216.0	0.0	0.0	0.0	0.0
233.5	0.0	172.0	0.0	0.0	0.0	0.0
245.5	0.0	153.0	1.0	0.0	0.0	0.0
251.5	0.0	226.0	2.0	0.0	0.0	0.0
257.5	0.0	132.0	0.0	0.0	0.0	0.0
271.0	0.0	202.0	0.0	0.0	0.0	0.0
276.8	0.0	181.0	0.0	0.0	0.0	0.0
278.5	1.0	247.0	0.0	0.0	0.0	0.0
282.3	0.0	110.0	0.0	0.0	0.0	0.0
288.0	0.0	123.0	0.0	0.0	0.0	0.0
290.5	0.0	152.0	0.0	0.0	0.0	0.0
293.5	0.0	239.0	0.0	0.0	0.0	0.0
299.3	0.0	126.0	0.0	0.0	0.0	0.0
302.5	1.0	182.0	0.0	1.0	0.0	0.0
304.8	0.0	130.0	0.0	0.0	1.0	0.0
308.5	0.0	134.0	0.0	0.0	0.0	0.0
308.5	0.0	231.0	0.0	0.0	0.0	0.0
315.8	0.0	71.0	0.0	0.0	0.0	0.0
321.3	0.0	141.0	0.0	0.0	0.0	0.0
356.5	0.0	185.0	0.0	0.0	0.0	0.0
362.5	0.0	164.0	0.0	0.0	0.0	0.0
368.5	0.0	216.0	0.0	0.0	0.0	0.0
380.5	0.0	293.0	0.0	0.0	0.0	0.0
385.5	0.0	266.0	0.0	0.0	0.0	0.0
391.5	0.0	210.0	0.0	0.0	0.0	0.0
404.5	0.0	194.0	0.0	0.0	0.0	0.0
410.5	0.0	212.0	0.0	0.0	0.0	0.0
416.5	0.0	170.0	0.0	0.0	0.0	0.0
422.5	0.0	171.0	0.0	0.0	0.0	0.0
428.5	0.0	213.0	0.0	0.0	0.0	0.0
434.5	0.0	143.0	1.0	0.0	0.0	1.0
446.5	0.0	91.0	1.0	0.0	0.0	0.0
459.5	0.0	79.0	0.0	0.0	0.0	0.0
471.5	0.0	129.0	0.0	0.0	0.0	0.0
477.5	0.0	117.0	0.0	1.0	0.0	0.0
514.5	0.0	21.0	2.0	0.0	0.0	0.0
521.5	0.0	7.0	1.0	0.0	0.0	0.0
542.5	0.0	99.0	0.0	0.0	0.0	0.0
556.5	0.0	28.0	0.0	0.0	1.0	0.0
570.5	0.0	16.0	0.0	0.0	0.0	0.0
577.5	0.0	27.0	0.0	0.0	0.0	0.0
584.5	0.0	12.0	0.0	0.0	0.0	0.0
598.5	0.0	12.0	0.0	1.0	0.0	0.0

Sample	Rosaceae	*Scabiosa*	Poaceae<25	*Botryococcus*	Campanulaceae	*Dombeya*
0.5	0.0	2.0	5.0	5.0	0.0	0.0
154.5	0.0	0.0	1.0	161.0	0.0	0.0
161.5	0.0	0.0	14.0	139.0	1.0	0.0
169.0	0.0	1.0	7.0	11.0	0.0	0.0
176.5	0.0	0.0	8.0	86.0	0.0	0.0
183.5	0.0	0.0	8.0	117.0	1.0	0.0
190.5	0.0	0.0	3.0	94.0	2.0	1.0
204.5	0.0	0.0	8.0	132.0	1.0	1.0
209.5	0.0	0.0	25.0	133.0	0.0	4.0
215.5	0.0	0.0	3.0	305.0	0.0	3.0
221.5	0.0	0.0	8.0	108.0	1.0	2.0
227.5	0.0	0.0	6.0	101.0	0.0	1.0
233.5	0.0	0.0	11.0	81.0	0.0	3.0
245.5	0.0	0.0	11.0	98.0	1.0	2.0
251.5	0.0	0.0	8.0	103.0	0.0	2.0
257.5	0.0	1.0	13.0	88.0	0.0	0.0
271.0	0.0	0.0	19.0	297.0	0.0	2.0
276.8	0.0	0.0	86.0	594.0	3.0	0.0
278.5	0.0	0.0	4.0	107.0	2.0	2.0
282.3	0.0	1.0	43.0	253.0	2.0	2.0
288.0	0.0	0.0	24.0	135.0	2.0	2.0
290.5	0.0	0.0	12.0	195.0	1.0	0.0
293.5	0.0	0.0	44.0	266.0	0.0	1.0
299.3	0.0	0.0	30.0	223.0	1.0	4.0
302.5	0.0	1.0	10.0	158.0	3.0	0.0
304.8	0.0	0.0	19.0	195.0	1.0	3.0
308.5	0.0	0.0	49.0	45.0	1.0	0.0
308.5	0.0	1.0	5.0	22.0	0.0	1.0
315.8	0.0	0.0	86.0	89.0	0.0	1.0
321.3	0.0	0.0	11.0	87.0	1.0	0.0
356.5	0.0	0.0	10.0	33.0	0.0	1.0
362.5	0.0	0.0	8.0	71.0	0.0	1.0
368.5	0.0	0.0	11.0	63.0	1.0	1.0
380.5	0.0	0.0	7.0	124.0	0.0	4.0
385.5	0.0	0.0	6.0	53.0	0.0	1.0
391.5	0.0	0.0	8.0	66.0	0.0	1.0
404.5	0.0	0.0	6.0	138.0	0.0	0.0
410.5	0.0	0.0	1.0	338.0	1.0	2.0
416.5	0.0	0.0	4.0	94.0	1.0	0.0
422.5	0.0	0.0	3.0	89.0	0.0	1.0
428.5	0.0	0.0	12.0	10.0	0.0	2.0
434.5	0.0	0.0	9.0	91.0	0.0	2.0
446.5	0.0	0.0	13.0	42.0	0.0	1.0
459.5	0.0	0.0	13.0	89.0	1.0	0.0
471.5	0.0	0.0	11.0	87.0	1.0	2.0
477.5	0.0	0.0	1.0	39.0	0.0	0.0
514.5	0.0	0.0	5.0	2.0	0.0	1.0
521.5	0.0	0.0	12.0	2.0	0.0	0.0
542.5	0.0	0.0	9.0	20.0	0.0	0.0
556.5	0.0	0.0	21.0	0.0	0.0	1.0
570.5	0.0	0.0	8.0	2.0	0.0	0.0
577.5	0.0	0.0	7.0	9.0	0.0	0.0
584.5	0.0	0.0	14.0	0.0	7.0	0.0
598.5	0.0	0.0	12.0	0.0	0.0	0.0

Sample	*Protea*	*Terminaleae*	*Pellaea*	*Chironiae*	*Cussonia*	*Rhynchosiae*
0.5	1.0	0.0	0.0	0.0	0.0	0.0
154.5	0.0	0.0	0.0	0.0	0.0	0.0
161.5	0.0	0.0	3.0	0.0	0.0	0.0
169.0	0.0	0.0	0.0	0.0	0.0	0.0
176.5	4.0	1.0	3.0	0.0	0.0	2.0
183.5	0.0	0.0	0.0	0.0	0.0	0.0
190.5	1.0	0.0	0.0	0.0	0.0	0.0
204.5	1.0	0.0	1.0	0.0	0.0	0.0
209.5	0.0	0.0	5.0	0.0	0.0	0.0
215.5	4.0	0.0	1.0	0.0	0.0	1.0
221.5	0.0	0.0	0.0	0.0	0.0	0.0
227.5	0.0	0.0	4.0	0.0	0.0	0.0
233.5	0.0	2.0	1.0	0.0	0.0	0.0
245.5	0.0	0.0	2.0	0.0	0.0	0.0
251.5	0.0	0.0	0.0	0.0	0.0	0.0
257.5	1.0	0.0	0.0	1.0	0.0	0.0
271.0	0.0	0.0	0.0	0.0	0.0	0.0
276.8	0.0	0.0	1.0	0.0	1.0	0.0
278.5	0.0	1.0	1.0	0.0	0.0	0.0
282.3	0.0	0.0	1.0	0.0	0.0	0.0
288.0	2.0	0.0	0.0	0.0	0.0	0.0
290.5	0.0	1.0	0.0	0.0	0.0	1.0
293.5	0.0	0.0	1.0	0.0	0.0	0.0
299.3	0.0	0.0	0.0	0.0	0.0	1.0
302.5	1.0	0.0	1.0	0.0	1.0	0.0
304.8	0.0	0.0	0.0	0.0	0.0	0.0
308.5	0.0	0.0	0.0	0.0	0.0	0.0
308.5	1.0	0.0	1.0	0.0	0.0	0.0
315.8	0.0	0.0	0.0	0.0	0.0	0.0
321.3	1.0	1.0	0.0	0.0	0.0	0.0
356.5	1.0	0.0	2.0	0.0	0.0	0.0
362.5	0.0	0.0	4.0	0.0	0.0	0.0
368.5	1.0	0.0	0.0	0.0	0.0	0.0
380.5	1.0	1.0	1.0	0.0	0.0	0.0
385.5	0.0	0.0	0.0	0.0	0.0	0.0
391.5	1.0	0.0	0.0	0.0	0.0	0.0
404.5	0.0	0.0	0.0	0.0	0.0	0.0
410.5	0.0	0.0	0.0	0.0	1.0	0.0
416.5	0.0	0.0	0.0	0.0	0.0	0.0
422.5	0.0	0.0	0.0	0.0	0.0	0.0
428.5	0.0	0.0	3.0	0.0	0.0	0.0
434.5	0.0	1.0	0.0	0.0	0.0	0.0
446.5	0.0	0.0	1.0	0.0	0.0	0.0
459.5	0.0	1.0	0.0	0.0	0.0	0.0
471.5	0.0	0.0	0.0	0.0	2.0	0.0
477.5	0.0	1.0	0.0	0.0	0.0	0.0
514.5	0.0	0.0	0.0	0.0	0.0	0.0
521.5	0.0	0.0	0.0	0.0	0.0	0.0
542.5	0.0	0.0	1.0	0.0	0.0	0.0
556.5	0.0	0.0	0.0	0.0	0.0	0.0
570.5	1.0	0.0	0.0	0.0	0.0	0.0
577.5	1.0	0.0	1.0	0.0	0.0	0.0
584.5	0.0	0.0	2.0	0.0	0.0	0.0
598.5	0.0	0.0	3.0	0.0	0.0	0.0

Sample	*Dichrostachys*	Fabaceae	*Nuxia*	Rutaceae	Nyctaginaceae	*Pseudolachnastylis*
0.5	1.0	0.0	0.0	0.0	0.0	0.0
154.5	0.0	0.0	0.0	0.0	0.0	0.0
161.5	0.0	0.0	0.0	0.0	0.0	0.0
169.0	0.0	0.0	0.0	0.0	0.0	0.0
176.5	1.0	0.0	0.0	0.0	0.0	0.0
183.5	0.0	0.0	0.0	0.0	0.0	0.0
190.5	0.0	0.0	0.0	0.0	0.0	0.0
204.5	1.0	0.0	0.0	0.0	0.0	1.0
209.5	0.0	0.0	0.0	0.0	0.0	0.0
215.5	1.0	0.0	0.0	0.0	0.0	0.0
221.5	0.0	0.0	0.0	0.0	0.0	0.0
227.5	2.0	0.0	0.0	0.0	0.0	1.0
233.5	0.0	0.0	0.0	0.0	0.0	0.0
245.5	0.0	0.0	0.0	0.0	0.0	0.0
251.5	2.0	0.0	0.0	0.0	0.0	0.0
257.5	0.0	0.0	0.0	0.0	0.0	0.0
271.0	0.0	0.0	0.0	0.0	0.0	0.0
276.8	0.0	0.0	0.0	0.0	0.0	0.0
278.5	0.0	0.0	0.0	0.0	0.0	0.0
282.3	0.0	0.0	0.0	0.0	0.0	0.0
288.0	0.0	0.0	0.0	0.0	0.0	0.0
290.5	0.0	0.0	0.0	0.0	0.0	0.0
293.5	0.0	0.0	0.0	0.0	0.0	0.0
299.3	2.0	0.0	0.0	0.0	0.0	0.0
302.5	0.0	0.0	0.0	0.0	0.0	0.0
304.8	0.0	1.0	0.0	0.0	0.0	0.0
308.5	1.0	0.0	1.0	0.0	0.0	0.0
308.5	0.0	0.0	0.0	0.0	0.0	2.0
315.8	1.0	0.0	0.0	0.0	0.0	0.0
321.3	0.0	0.0	0.0	0.0	0.0	0.0
356.5	0.0	0.0	0.0	0.0	0.0	0.0
362.5	0.0	0.0	0.0	0.0	0.0	0.0
368.5	0.0	0.0	0.0	0.0	0.0	0.0
380.5	0.0	0.0	0.0	0.0	0.0	0.0
385.5	0.0	0.0	0.0	0.0	0.0	0.0
391.5	0.0	0.0	1.0	1.0	0.0	0.0
404.5	0.0	0.0	0.0	0.0	0.0	0.0
410.5	1.0	0.0	0.0	0.0	0.0	0.0
416.5	0.0	1.0	0.0	0.0	0.0	0.0
422.5	0.0	0.0	0.0	0.0	0.0	0.0
428.5	0.0	0.0	0.0	0.0	0.0	0.0
434.5	1.0	0.0	0.0	0.0	0.0	0.0
446.5	1.0	0.0	0.0	0.0	1.0	0.0
459.5	0.0	0.0	0.0	0.0	0.0	0.0
471.5	0.0	0.0	0.0	0.0	0.0	0.0
477.5	1.0	0.0	0.0	0.0	0.0	0.0
514.5	0.0	0.0	0.0	0.0	0.0	0.0
521.5	0.0	0.0	0.0	0.0	0.0	0.0
542.5	0.0	0.0	0.0	0.0	0.0	0.0
556.5	4.0	0.0	0.0	0.0	0.0	0.0
570.5	1.0	0.0	0.0	0.0	0.0	0.0
577.5	1.0	0.0	0.0	0.0	0.0	0.0
584.5	2.0	0.0	0.0	0.0	0.0	1.0
598.5	2.0	0.0	0.0	0.0	0.0	0.0

Appendix C: The percentages of variables used in PCA

Sample	*Spirostachys*	*Acalypha*	Combretaceae	*Podocarpus*	*Celtis*	*Burkea*	Euphorbiaceae
154.5	0.769231	0.384615	0	1.538462	0	0.576923	0
161.5	4.347826	0.197628	0.395257	1.185771	0	1.976285	0
169	0.3861	0.3861	0.772201	0.965251	0	2.702703	0
176.5	2.099237	0.954198	2.290076	1.908397	0	3.625954	0.19084
183.5	0.766284	0.766284	2.490422	0.766284	0	4.597701	0
190.5	1.310861	1.310861	1.310861	1.498127	0	2.808989	0
204.5	3.754941	0.197628	2.371542	2.173913	0	4.545455	0.197628
209.5	5.03876	0.581395	0	4.263566	0.193798	3.294574	0
215.5	3.653846	0.769231	1.923077	1.923077	0.192308	2.884615	0.192308
221.5	2.990654	0.934579	1.308411	2.429907	0	3.551402	0
227.5	0.38835	0.970874	1.941748	0.38835	0.194175	3.68932	0.194175
233.5	2.811245	1.004016	0	2.208835	0.60241	6.2249	0.200803
245.5	0.909091	1.454545	1.454545	1.818182	0	2.545455	0
251.5	3.396226	0.943396	3.207547	1.886792	0	3.584906	0
257.5	1.934236	2.321083	1.934236	0.580271	0.193424	3.868472	0
271	3.759398	0	3.195489	1.12782	0	2.443609	0
276.75	3.065134	0.957854	3.256705	2.873563	0	0.766284	0
278.5	1.372549	0.588235	4.117647	1.176471	0	5.686275	0
282.25	0.747664	0.373832	1.869159	0.747664	0	2.990654	0
288	1.801802	0.18018	1.801802	1.261261	0	1.801802	0
290.5	2.692308	1.730769	2.115385	1.346154	0.384615	3.461539	0
293.5	4.118616	0.164745	4.118616	0.823723	0	3.294893	0
299.25	1.323251	0.756144	0.756144	0.94518	0	2.457467	0
302.5	2.321429	0	1.607143	0.714286	0	4.285714	0
304.75	1.296296	1.111111	1.851852	0.925926	0	2.407408	0
308.5	1.215278	0.520833	1.5625	0.173611	0	1.041667	0
308.5	1.325758	1.515152	2.083333	1.325758	0	4.924242	0
315.75	0.589391	0.196464	0.785855	0.589391	0	0.982318	0
321.25	0.766284	0.383142	1.532567	1.532567	0	4.789272	0
356.5	1.315789	1.503759	1.691729	2.819549	0.75188	3.759398	0
362.5	0.570342	0.95057	1.520913	1.711027	0	4.752851	0
368.5	0.931099	0.744879	2.607076	1.303538	0	3.351955	0
380.5	1.598579	0.53286	2.486679	2.131439	0	4.618117	0.17762
385.5	1.596806	0.798403	3.193613	1.596806	0	4.391218	0.199601
391.5	0.39604	0.39604	2.772277	1.188119	0	4.752475	0
404.5	0.957854	1.532567	1.149425	0.574713	0	2.681992	0
410.5	0.595238	0	3.174603	0.992063	0.198413	5.357143	0
416.5	0.193424	0.773694	3.094778	0.773694	0.193424	3.868472	0
422.5	0.787402	1.968504	2.165354	1.181102	0	3.543307	0
428.5	0.788955	1.183432	1.380671	0.394477	0	2.95858	0
434.5	0	0.746269	1.492537	0.746269	0.186567	4.291045	0
446.5	0	0.788955	1.775148	1.183432	0	4.733728	0
459.5	0.18797	0.75188	3.383459	0.75188	0.18797	4.135338	0
471.5	0	0.77821	2.140078	1.361868	0	4.474708	0
477.5	0.749064	0.749064	2.434457	1.123595	0	4.494382	0
514.5	0.397614	0.198807	1.789264	0.397614	0	1.590457	0
521.5	0	0.193798	2.131783	0.193798	0	0.387597	0
542.5	0.767754	0.767754	0.575816	0.383877	0	1.919386	0
556.5	0.199601	0.399202	0.399202	0.399202	0	1.197605	0
570.5	0	0	1.176471	0.196078	0	1.176471	0
577.5	0	0.787402	0.393701	0.393701	0.19685	4.330709	0
584.5	0	0.194553	0.389105	0.194553	0	1.945525	0
598.5	0.398406	0	0.796813	0.199203	0	0.398406	0.199203

Sample	*Anthosparmum*	*Olea*	*Rhus*	Myrtacea	*Tarchonanthus*	*Euclea*	Acacia
154.5	0.192308	0.576923	0	0	0	0	0
161.5	0.592885	0.592885	0.197628	0	0.197628	0	0.197628
169	0.3861	0.579151	0.19305	0	0	0	0
176.5	0.572519	0.19084	0.19084	0	0.19084	0.19084	0.19084
183.5	0	0.191571	0	0	0.191571	0.191571	0
190.5	0.187266	0.561798	0	0	0.374532	0.374532	0.374532
204.5	0	0.395257	0.197628	0	0.790514	0.395257	0.395257
209.5	1.162791	1.162791	1.550388	0	0	0.193798	0
215.5	0.769231	0.576923	0.192308	0.192308	0.192308	0.192308	0.769231
221.5	0	0.373832	0.373832	0	0.373832	0.186916	0.373832
227.5	0	0.970874	0.582524	0	0.194175	0	0.776699
233.5	0.401606	0.803213	0.200803	0	0.60241	1.004016	0.401606
245.5	0.181818	1.454545	0.545455	0	0	0.363636	0.909091
251.5	0.566038	0.377358	0.943396	0	0	0.566038	0.943396
257.5	0.193424	1.160542	0.193424	0	0.193424	0	0.773694
271	0	0.56391	0	0	0.56391	0.75188	0.37594
276.75	0	0.383142	0.574713	0.191571	0.191571	0	1.340996
278.5	1.176471	0.588235	0.784314	0	0.196078	0.588235	0.784314
282.25	0.186916	0.560748	0.373832	0	0	0.373832	0.747664
288	0	0.540541	0	0	0.540541	0	0.36036
290.5	1.346154	0.961538	0.961538	0	0.384615	0	0.961538
293.5	0.164745	3.624382	0.494234	0	0.164745	0.658979	0.329489
299.25	0	0.378072	0	0.189036	0	0.378072	0.567108
302.5	0.714286	0.892857	0.357143	0	0.535714	0.357143	0.714286
304.75	0	0.185185	0.37037	0	0.185185	0.185185	0.37037
308.5	0.173611	0	0	0	0	0	0
308.5	0.568182	0.568182	0	0	0	0.189394	0.757576
315.75	0	0.392927	0	0	0.392927	0	0
321.25	0.574713	0.383142	0.383142	0	0.191571	0.957854	1.149425
356.5	0.18797	0.37594	1.12782	0	0	0	0.18797
362.5	0.570342	0.570342	0.570342	0	0.190114	0.570342	0.190114
368.5	0.744879	0.931099	0.744879	0	0	0.372439	0.931099
380.5	1.420959	0.35524	0.71048	0	0	0.888099	2.131439
385.5	0.399202	0.798403	0.798403	0	0	0	1.197605
391.5	0.594059	0.594059	0.19802	0	0	1.188119	0.990099
404.5	0.191571	0.383142	0.383142	0	0.383142	0.383142	1.532567
410.5	0.396825	0.793651	0.595238	0	0.198413	0.396825	0.793651
416.5	0.580271	0.580271	0.386847	0	0.193424	0.386847	1.547389
422.5	0.393701	0.590551	0.19685	0	0.19685	0	1.771654
428.5	0.197239	0	0.788955	0	0	0.197239	2.366864
434.5	1.119403	0.559702	0	0	0.373134	0	0.559702
446.5	0.986193	0	0.788955	0	0.394477	0	3.550296
459.5	0.75188	0	0.75188	0	0.37594	0.18797	1.691729
471.5	0.583658	0.389105	0.194553	0	0.389105	0.194553	0.389105
477.5	0.187266	0.187266	0.374532	0	0.187266	0.561798	2.247191
514.5	0.198807	0.198807	0	0	0.397614	0	0.994036
521.5	0.387597	0	0.193798	0	1.356589	0.193798	0.193798
542.5	0.383877	0	0.191939	0.191939	0.383877	0	0.767754
556.5	0.199601	0.199601	0	0	0.798403	0	0.998004
570.5	0.588235	0.588235	0.392157	0	0.196078	0.196078	0.588235
577.5	0.393701	0.590551	0	0.19685	0.984252	0.19685	0.393701
584.5	0.583658	0.389105	0.389105	0	0.194553	0	0.583658
598.5	0.199203	0	0	0	0.59761	0	0

Sample	Mimosoideae	*Croton*	*Sclerocarya*	Capparaceae	*Grewia*	*Crassula*	Liliaceae
154.5	0	0	0	0	0	0	0.769231
161.5	0	0	0.197628	0	0.197628	0.197628	0
169	0	0	0	0	0	0	0
176.5	0	0	0.954198	0	0	0	0.381679
183.5	0.574713	0	0	0	0	0	0.574713
190.5	0.374532	0	0	0	0	0	1.123595
204.5	0	0	0	0	0	0	0.395257
209.5	0	0.193798	0	0	0	0	0.193798
215.5	0	0	0.384615	0	0	0.192308	0.192308
221.5	0.373832	0	0.186916	0	0	0	0.373832
227.5	0	0	0	0	0.194175	0.194175	0.194175
233.5	1.004016	0	0	0	0	0.200803	0.60241
245.5	0.545455	0	0.363636	0	0	0	0.545455
251.5	0	0	0.754717	0	0	0.188679	0.188679
257.5	0.193424	0	0.193424	0	0	0	0.773694
271	0	0.75188	0	0	0	0	0.56391
276.75	0.574713	0.191571	0.191571	0	0	0	0.191571
278.5	0	0	0.392157	0	0.392157	0	0
282.25	0.186916	0	0.373832	0	0	0	0.560748
288	0.36036	0	0	0	0.18018	0	0.36036
290.5	0	0.192308	0	0	0	0	0.769231
293.5	0	0.164745	0.164745	0	0	0.164745	1.153213
299.25	0.189036	0.189036	0	0	0	0	0.756144
302.5	0	0.178571	0	0	0	0.178571	0
304.75	0.740741	0	0.37037	0	0	0	0.37037
308.5	0.520833	0.520833	0	0	0	0	0.520833
308.5	0	0	0	0	0	0	0
315.75	0	0.392927	0	0	0	0	0
321.25	0.574713	0.766284	0	0	0	0	0.383142
356.5	0.56391	0	0.37594	0	0	0	0.37594
362.5	0	0.190114	0.760456	0	0.760456	0.380228	0
368.5	0.18622	0	0.18622	0	0.372439	0	0.372439
380.5	0.71048	0	0.35524	0	0.17762	0.17762	0.888099
385.5	0	0	0	0	0	0	0
391.5	0	0.19802	0	0	0	0.19802	0.39604
404.5	0.191571	0.766284	0	0.191571	0.191571	0	0.383142
410.5	0	0	0.396825	0	0	0.198413	0
416.5	0	0.193424	0.386847	0	0.386847	0	0
422.5	0	0	0	0	0	0	0
428.5	0.197239	0	0	0.394477	0	0	0.591716
434.5	0	0	0.559702	0	0.373134	0.186567	0.559702
446.5	0	0	0.788955	0	0	0	0.591716
459.5	0	0	0.56391	0	0.18797	0	0.75188
471.5	0	0.389105	0	0	0.194553	0	0.194553
477.5	0	0	0.749064	0.187266	0.561798	0	0
514.5	0.198807	0	0.397614	0	0.198807	0	0
521.5	0	0	0	0	0.387597	0.968992	0
542.5	0	0	0	0	0.575816	0.191939	0.383877
556.5	0	0	0	0	0.199601	0	0
570.5	0	0	0	0	0.196078	0	0
577.5	0	0	0.19685	0	0.19685	0	0.19685
584.5	0	0	0.389105	0	0.389105	0	0
598.5	0	0	0	0	0.398406	0	0.199203

Sample	*Dicliptera*-type	*Selago*-type	*Stoebe*-type	Asteraceae	*Artemisia*	Ericaceae	Chenopodiaceae
154.5	0	0	0	0.384615	1.538462	0	0
161.5	0	0	0	2.766798	2.173913	0	0.395257
169	0	0	0.19305	3.088803	0.772201	0	0.579151
176.5	0	0.19084	0	2.099237	1.526718	0.19084	1.145038
183.5	0	0	0	1.532567	1.724138	0	0.574713
190.5	0.187266	0	0	0.561798	1.872659	0	0.374532
204.5	0	0.197628	0	2.56917	2.173913	0.197628	0.790514
209.5	0	0	0.387597	2.325581	2.131783	0	2.906977
215.5	0	0	0	2.692308	2.5	0	0.769231
221.5	0.186916	0	0.186916	1.495327	2.429907	0	0
227.5	0	0	0	1.747573	2.330097	0	0.970874
233.5	0.401606	0.401606	0	1.204819	2.409639	0	0.803213
245.5	0	0.181818	0.181818	1.636364	3.636364	0	1.636364
251.5	0.566038	0.188679	0.188679	3.396226	1.698113	0	1.132075
257.5	0	0	0	1.740812	1.934236	0	1.740812
271	0	0	0	1.315789	2.819549	0	0.75188
276.75	0	0	0	0.574713	1.149425	0	0.383142
278.5	0.588235	0	0	3.529412	2.745098	0.196078	2.352941
282.25	0	0	0.186916	1.682243	0.747664	0	0.373832
288	0	0	0	1.981982	2.342342	0	1.261261
290.5	0.192308	0.192308	0	1.538462	1.730769	0	0.576923
293.5	0.164745	0.164745	0.164745	1.812191	0.329489	0.164745	1.153213
299.25	0	0	0.189036	1.701323	1.134215	0.189036	1.512287
302.5	0.178571	0	0	2.857143	3.392857	0	0.535714
304.75	0	0	0	1.481481	0.925926	0	0
308.5	0	0.173611	0	1.388889	0.694444	0	0.694444
308.5	0.189394	0.378788	0.189394	3.409091	1.515152	0	1.136364
315.75	0.196464	0	0	0.589391	0.196464	0	0.196464
321.25	0	0.191571	0	2.490422	1.915709	0	1.340996
356.5	0	0	0.18797	2.443609	2.255639	0	0.56391
362.5	0	0	0	2.281369	1.711027	0	0.95057
368.5	0.372439	0	0	2.234637	2.979516	0	1.117318
380.5	0	0	0.35524	3.374778	3.730018	0	2.131439
385.5	0	0	0	3.193613	2.195609	0	0.598802
391.5	0.39604	0	0.19802	4.554455	1.386139	0	2.970297
404.5	0.191571	0	0.191571	4.597701	0.766284	0	2.490422
410.5	0.198413	0	0	4.563492	0.992063	0	1.587302
416.5	0	0.193424	0	3.481625	1.160542	0	3.675048
422.5	0	0.393701	0.19685	2.559055	0.393701	0	1.377953
428.5	0.394477	0	0	2.169625	0.591716	0	1.775148
434.5	0.373134	0	0.186567	3.171642	1.679104	0	1.119403
446.5	0.394477	0.197239	0	2.169625	0.986193	0	3.944773
459.5	0.37594	0.18797	0	2.631579	1.315789	0	2.443609
471.5	0	0.194553	0	3.696498	0.972763	0	1.167315
477.5	0	0	0	3.745318	1.123595	0	2.808989
514.5	0.198807	0	0	3.180914	0.397614	0	1.590457
521.5	0.193798	0.581395	0	15.69767	0	0	2.325581
542.5	0	0	0	2.303263	1.151631	0.191939	0.767754
556.5	0.199601	0	0.199601	11.57685	0.199601	0	2.794411
570.5	0	0	0	3.333333	0.784314	0	2.156863
577.5	0.19685	0.19685	0	2.559055	0.787402	0	0.787402
584.5	0	0.194553	0	2.140078	0.972763	0	2.529183
598.5	0	0	0	3.585657	0.59761	0	1.394422

Sample	Caryophyllaceae	Poaceae>25	Poaceae>50	Umbelliferae	*Typha*	Cyperaceae
154.5	0	89.61539	3.461539	0	0.384615	35.96154
161.5	0	83.20158	0.592885	0	2.371542	46.04743
169	0	86.29343	2.509653	0	0.19305	7.142857
176.5	0.19084	77.48092	1.335878	0	1.526718	35.30534
183.5	0	82.75862	1.915709	0	1.149425	31.03448
190.5	0	80.52435	4.11985	0	1.310861	25.2809
204.5	0.592885	75.88933	0.790514	0	3.359684	38.93281
209.5	0	73.25581	0.387597	0	2.713178	19.18605
215.5	0	75.96154	0	0	2.692308	25.19231
221.5	0	79.43925	1.682243	0	5.233645	25.79439
227.5	0	80.7767	2.135922	0	2.718446	41.94175
233.5	0	75.1004	0.401606	0	2.208835	34.53815
245.5	0	76.72727	1.090909	0	1.454545	27.81818
251.5	0	73.01887	1.132075	0.188679	3.773585	42.64151
257.5	0	77.94971	1.547389	0	3.094778	25.53192
271	0	76.31579	3.947368	0	1.12782	37.96992
276.75	0	72.60536	8.812261	0	2.490422	34.67433
278.5	0	69.01961	2.156863	0	0	48.43137
282.25	0	81.1215	4.672897	0	3.738318	20.56075
288	0	78.91892	4.144144	0	5.765766	22.16216
290.5	0	75.76923	1.730769	0	4.038462	29.23077
293.5	0	72.3229	2.635914	0	3.130148	39.37397
299.25	0	81.28545	3.402647	0	2.646503	23.81853
302.5	0	77.5	0.892857	0.178571	3.392857	32.5
304.75	0	84.44444	1.481481	0	1.111111	24.07407
308.5	0	87.32639	2.777778	0	2.083333	23.26389
308.5	0	78.59849	0.378788	0	1.704545	43.75
315.75	0	88.99803	4.715127	0	0.982318	13.94892
321.25	0	73.56322	4.789272	0	1.340996	27.01149
356.5	0.18797	76.69173	1.503759	0	1.12782	34.77444
362.5	0	78.70722	1.520913	0	3.041825	31.17871
368.5	0	76.90875	1.675978	0	2.420857	40.22346
380.5	0	68.7389	0.888099	0	2.841918	52.04263
385.5	0.399202	77.64471	0.798403	0	2.794411	53.09381
391.5	0	72.47525	2.376238	0.19802	0.990099	41.58416
404.5	0	76.62835	2.873563	0	0.574713	37.16475
410.5	0	76.38889	0.396825	0.198413	0.793651	42.06349
416.5	0	76.40232	1.160542	0	0.386847	32.88201
422.5	0	80.90551	0.984252	0	0.787402	33.66142
428.5	0	81.45956	1.577909	0	1.577909	42.01183
434.5	0	77.42538	3.358209	0	1.119403	26.6791
446.5	0	73.57002	1.972387	0.394477	0.197239	17.94872
459.5	0	76.12782	1.12782	0.18797	0.37594	14.84962
471.5	0	79.76654	1.361868	0	0.583658	25.09728
477.5	0.187266	75.2809	0.749064	0.187266	0.187266	21.91011
514.5	0	87.27634	0	0	0.596421	4.17495
521.5	0.581395	73.06201	0.387597	0.193798	0	1.356589
542.5	0.191939	85.60461	1.727447	0	1.727447	19.00192
556.5	1.796407	74.6507	0	0.199601	0	5.588822
570.5	0	86.27451	1.372549	0	0	3.137255
577.5	0	83.66142	1.574803	0	3.740157	5.31496
584.5	0	85.214	1.167315	0	1.750973	2.33463
598.5	0.199203	90.43825	0	0	0	2.390438

Sample	Triletespore	*Scabiosa*	Campanulaceae	*Dombeya*	*Protea*	*Pellaea*
154.5	0	0	0	0	0	0
161.5	0.592885	0	0.197628	0	0	0.592885
169	0	0.19305	0	0	0	0
176.5	0.381679	0	0	0	0.763359	0.572519
183.5	0	0	0.191571	0	0	0
190.5	0	0	0.374532	0.187266	0.187266	0
204.5	0	0	0.197628	0.197628	0.197628	0.197628
209.5	0	0	0	0.775194	0	0.968992
215.5	0.384615	0	0	0.576923	0.769231	0.192308
221.5	0	0	0.186916	0.373832	0	0
227.5	0	0	0	0.194175	0	0.776699
233.5	0	0	0	0.60241	0	0.200803
245.5	0.181818	0	0.181818	0.363636	0	0.363636
251.5	0.377358	0	0	0.377358	0	0
257.5	0	0.193424	0	0	0.193424	0
271	0	0	0	0.37594	0	0
276.75	0	0	0.574713	0	0	0.191571
278.5	0	0	0.392157	0.392157	0	0.196078
282.25	0	0.186916	0.373832	0.373832	0	0.186916
288	0	0	0.36036	0.36036	0.36036	0
290.5	0	0	0.192308	0	0	0
293.5	0	0	0	0.164745	0	0.164745
299.25	0	0	0.189036	0.756144	0	0
302.5	0	0.178571	0.535714	0	0.178571	0.178571
304.75	0	0	0.185185	0.555556	0	0
308.5	0	0	0.173611	0	0	0
308.5	0	0.189394	0	0.189394	0.189394	0.189394
315.75	0	0	0	0.196464	0	0
321.25	0	0	0.191571	0	0.191571	0
356.5	0	0	0	0.18797	0.18797	0.37594
362.5	0	0	0	0.190114	0	0.760456
368.5	0	0	0.18622	0.18622	0.18622	0
380.5	0	0	0	0.71048	0.17762	0.17762
385.5	0	0	0	0.199601	0	0
391.5	0	0	0	0.19802	0.19802	0
404.5	0	0	0	0	0	0
410.5	0	0	0.198413	0.396825	0	0
416.5	0	0	0.193424	0	0	0
422.5	0	0	0	0.19685	0	0
428.5	0	0	0	0.394477	0	0.591716
434.5	0.186567	0	0	0.373134	0	0
446.5	0.197239	0	0	0.197239	0	0.197239
459.5	0	0	0.18797	0	0	0
471.5	0	0	0.194553	0.389105	0	0
477.5	0	0	0	0	0	0
514.5	0.397614	0	0	0.198807	0	0
521.5	0.193798	0	0	0	0	0
542.5	0	0	0	0	0	0.191939
556.5	0	0	0	0.199601	0	0
570.5	0	0	0	0	0.196078	0
577.5	0	0	0	0	0.19685	0.19685
584.5	0	0	1.361868	0	0	0.389105

Appendix D: The long version of Tswaing pollen diagram representing the pollen taxa recorded in the current study**.** The hollow curves showing an exaggerations x10