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Microfossil Constraints on the Age, Paleoenvironments and Source Rock Potential of the Eyasi-Wembere Basin, Tanzania

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Abstract

The timing and processes governing organic matter accumulation in East African Rift basins remain poorly constrained due to limited subsurface data. We present the first integrated microfossil-based study for the Eyasi Wembere Basin (EWB). Core samples from three stratigraphic boreholes drilled in the basin have been utilized in this study. Palynological, palynofacies, ostracods and sedimentological analyses were used to determine age, paleoenvironment and source-rock potential of the basin fill.

Based on the palynomorph species *Laevigatosporites ovatus* and *Triorites minor*, and the ostracod species *Cytherissa lacustris* and *Ilyocypris bradyi*, the age of the studied material ranges from the Pliocene to the Holocene. From sedimentological and micropaleontological evidence, the studied sediments were deposited within a shallow lacustrine system marked by spatial variations in water depth and hydrological conditions, with periodic fluvial input into the basin. Palynofacies analysis shows organic matter dominated by amorphous organic matter and freshwater algae (*Botryococcus*), indicating oil-prone kerogen types I and II. Spore-color observations from the studied material indicate a marginally mature source rock. Therefore, the basin represents a potentially promising but underexplored segment of the East African Rift System, where deeper drilling and additional subsurface investigations are required to fully evaluate its petroleum system potential

1. Introduction

Lacustrine rift basins within the East African Rift System preserve important records of tectonic activity, climate variability and organic matter accumulation. Several rift basins in East Africa, such as the Albertine Graben and the Turkana Basin, contain organic-rich lacustrine sediments that serve as effective petroleum source rocks (Lirong et al., 2004; Talbot, 1988). Understanding the depositional evolution and organic matter accumulation in these basins is therefore essential for reconstructing basin history and evaluating their resource potential.

The Eyasi-Wembere Basin (EWB, Fig. 1) is one of many rift basins that have formed along the eastern arm of the East African Rift System (EARS). The rift extends from the triple junction and branches further south into three rift arms: the Ethiopian, Eastern and Western East African rift arms in Tanzania (Ebinger et al., 1997). These arms originated during the Proterozoic Mobile Belts and the Archaean (Ebinger et al., 1997). The eastern rift arm runs south from southwestern Ethiopia into Tanzania, then divided into three segments of block faulting after entering the Tanzanian Rigid Craton (Ebinger et al., 1997). These segments are the Eyasi-Wembere rift, the Natron-Manyara-Balangida rift and the Pangani rift (Ebinger et al., 1997; see Fig. 1). The three rifts are known as the Northern Tanzania Divergence (Ebinger et al.,1997). Volcanism and sedimentation in the Eyasi, Natron, Manyara and Balangida basins began in the Pliocene (~5Ma), followed by a later phase of fault development (Ebinger et al., 1997).

As part of ongoing efforts to identify new frontier basins within the EARS, the Eyasi-Wembere Basin of Tanzania has been identified as a potential candidate for hydrocarbon exploration (Maduhu et al., 2017; Gama et al., 2025). This mainly results from the presence of organic-rich lacustrine sediments, which offer favorable conditions for the development of effective petroleum source rocks (Gama et al., 2025). However, little is known about basin's source-rock potential due to limited sedimentological studies and poor age control, despite the presence of tuff layers within the stratigraphy that remain undated. Published data focus on vertebrate paleontology and paleoanthropology (Harrison & Mbago, 1997); hydrocarbon prospects and structural geology (Maduhu et al., 2017), petroleum exploration (Mvile et al., 2023), stratigraphy (Mvile et al., 2023), and sedimentary environments (Kiswaka et al., 2024; Gama & Kiswaka, 2025; Gama et al., 2025). Nonetheless, detailed biostratigraphic and paleoenvironmental data from subsurface borehole samples remain scarce.

Microfossil assemblages preserved in sedimentary rocks provide valuable tools for reconstructing depositional environments and determining the relative ages of sedimentary successions (Tyson, 1995; Traverse, 2007; Magohe et al., 2023). Palynological analyses are especially useful in sedimentary basins because sporomorphs are widely distributed and sensitive to environmental and climatic changes (Batten, 1996; Magohe, 2019; Mercader et al., 2025). Similarly, ostracods serve as reliable indicators of lacustrine depositional conditions, as their assemblages respond to shifts in water depth, salinity, and hydrological factors. Furthermore, palynofacies analysis offers insights into the origin, type, and preservation of organic matter, which are essential for assessing kerogen type and the potential for sedimentary successions to serve as petroleum source rocks (Tyson, 1995).

This study presents the first integrated subsurface investigation of the Eyasi-Wembere Basin based on microfossil and sedimentological data from three shallow stratigraphic boreholes. Palynological and ostracod assemblages are used to constrain the age and depositional environments of the sedimentary succession, while palynofacies analysis provides insights into the origin, type, and preservation of organic matter. By integrating these datasets, this study reconstructs the basin's paleoenvironmental evolution and contributes to the evaluation of the source-rock potential for hydrocarbon accumulation in this underexplored part of the East African Rift System.

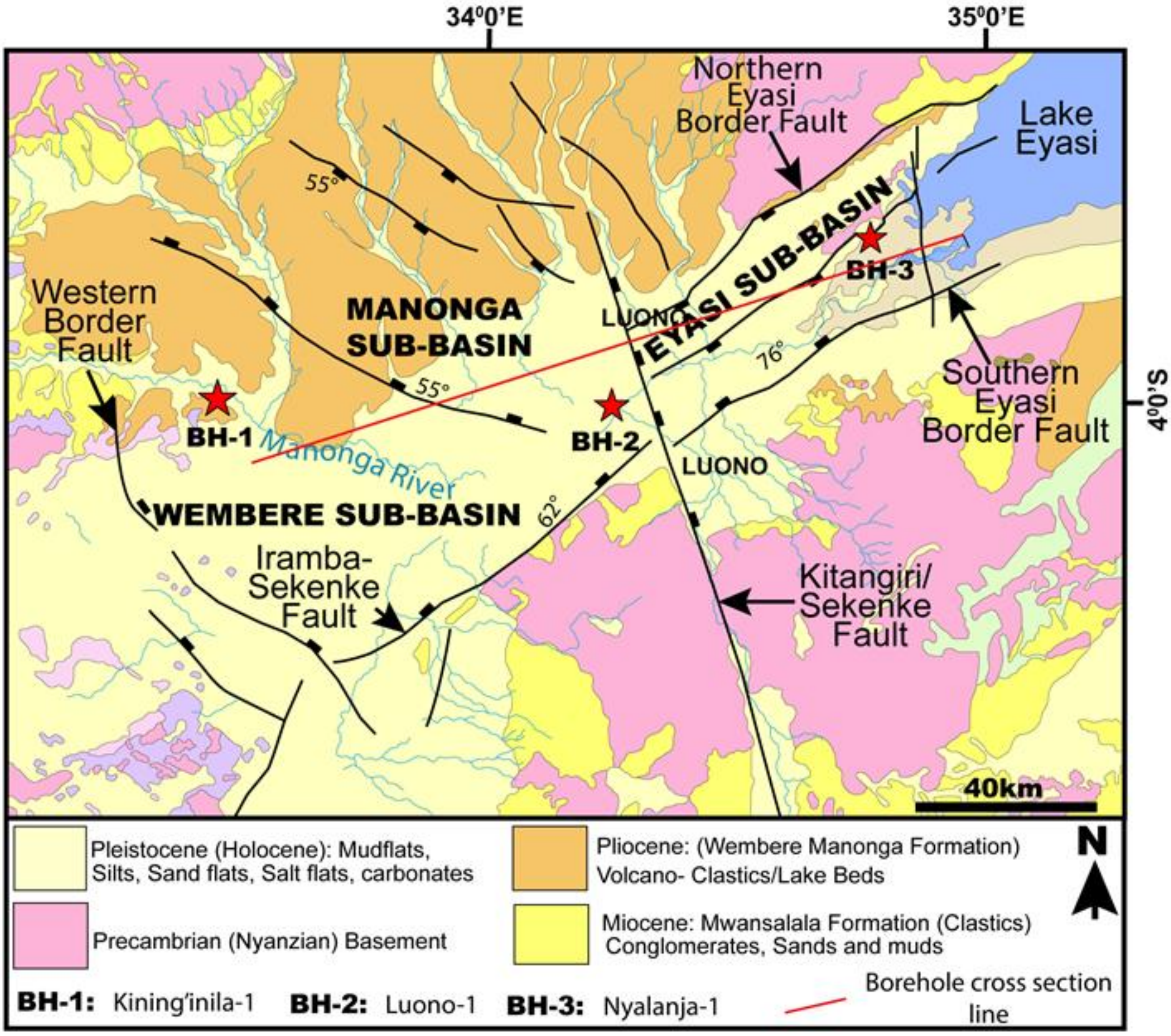

Figure 1: Geological and structural map of the Eyasi–Wembere Basin showing the major rift faults, sub-basin configuration, and the locations of the studied boreholes (Modified from Ebinger et al., 1997).

2. Materials and Methods

2.1 Materials

Forty-three (43) core samples from Kining'inila-1 borehole (170 m), Nyalanja-1 (BH Total Depth 302m), and Luono-1 (BH Total Depth 232m) were used for palynological analyses. Forty-seven (47) core samples were selected for ostracod analysis. Samples were selected based on lithology which is suitable for palynological and ostracod analysis. Rock samples, residues, slides, and digital images are curated at the TPDC headquarters in Dar es Salaam.

2.2 Methods

2.1.1 Sedimentological core-logging

Core samples from the Kining'inila-1, Nyalanja-1 and Luono-1 boreholes were logged at the drill site during drilling operations. Lithological descriptions were based on grain size, sediment colour, sedimentary structures, mineral composition, and the presence of fossil or organic material. These observations were used to construct lithological columns for each borehole. The lithological columns were later digitized and refined using Adobe Illustrator software for graphical presentation.

2.1.2 Palynology and Palynofacies Analysis

Twenty grams of washed core samples were treated with hydrochloric and hydrofluoric acids. The organic residues were then processed through heavy liquid separation using zinc chloride and sieved through a 20 µm mesh. Sample residues were permanently mounted on a glass slide with a coverslip using petropoxy 154 (10 parts resin to 1 part hardener). Two slides were prepared from each sample. All the slides were examined at TPDC with a light-transmitted microscope (OLYMPUS-BH2). Photomicrographs were captured using a camera mounted on a MEIJI light-transmitted microscope. The age of the cores was determined by comparing the recovered index pollen and spore species with published references of equivalent age elsewhere in the region.

Qualitative palynofacies analysis of the organic debris involved identifying different organic macerals (phytoclasts, opaque, and amorphous organic matter) and assessing their preservation state. The kerogen classification systems proposed by Van Bergen et al. (1990) and Tyson (1995) were adopted. A basic palynofacies analysis was conducted using 200 counts of kerogen particles. Palynomorphs and other organic materials were counted on each slide for paleoenvironmental interpretation. Counts were categorized into three main groups: (1) identifiable palynomorphs (such as pollen grains and spores); (2) structured organic remains that could be identified (such as wood and cuticle); (3) organic remains of uncertain biological affinity that lacked clear structure (such as amorphous organic matter). Well-preserved specimens were selected for coloured microphotographs (see Plates 1-6). Palynofacies data were plotted using StrataBugs and ternary diagram software licensed to TPDC.

2.1.3 Spore-colour index

Estimation of organic maturation used spore colour scales to quantify the degree of sediment maturation and its potential to generate hydrocarbons (Stach et al., 1982; Also see Fig. 2). This approach provides general measures of how sediments are subjected to heat as burial depth changes and whether the sediments have undergone metamorphism to produce gas (wet gas, dry gas) or wet oil (Stach et al., 1982). This technique involved observing and assessing the progressive changes in color of spores in kerogen as subjected to a thermal gradient. The thermal alteration of spores as a function of burial depth, affects the maturity of organic matter (Stach et al., 1982). The changes in colour of spores were correlated with the thermal alteration index, whereby the score for each colour was selected to identify the organic thermal maturity of the organic matter, indicating whether it was immature, mature, or over-matured to produce a specific hydrocarbon, as shown in Figure 2. The colour of spores was determined by paleo-geothermal state; the greater the paleo-geothermal temperature, the darker the colour of the palynomorphs became (Chuanben, 1984).

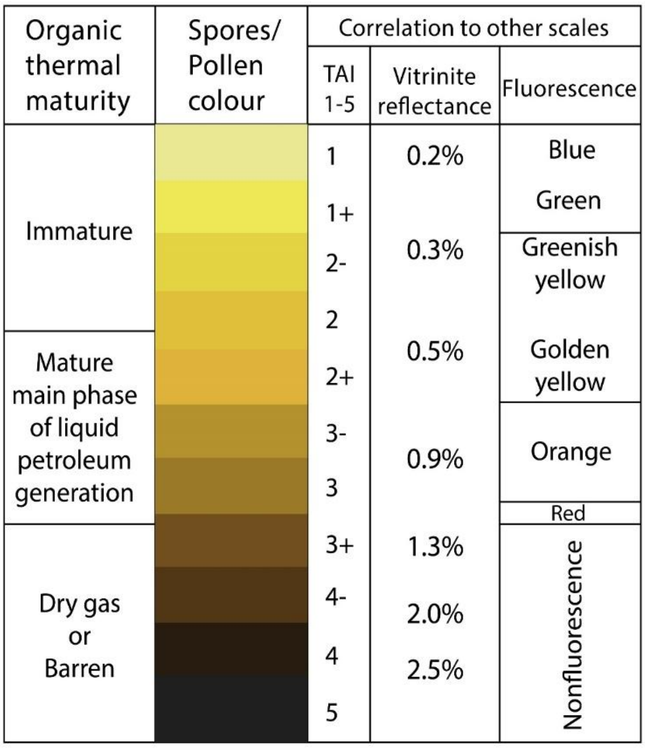

Figure 2: Correlation chart between the spores colour, thermal maturation index (TAI) and fluorescence used in assessing organic maturation (Stach et al., 1982).

2.1.4 Ostracod Analysis

Forty-seven (47) samples were selected for washing, sieving, screening, and picking of ostracods. Ostracods are sensitive to changes in environmental parameters such as salinity, pH, temperature, and depth, and are good indicators of changing environments that could be linked to geology, depositional history, and paleoclimate. Ostracods were also used to demarcate the ages of the deposited strata within the basin. Interpretation of ostracod species was carried out by using standard procedures such as those stipulated by Griffiths & Holmes (2000).

3. Results and Discussion

3.1 Borehole Lithostratigraphy

3.1.1 Kining'inila-1 Borehole

Kining'inila-1 Borehole intersects the Wembere-Manonga Formation (Fm.), Mwansalala Fm., and the basement at a shallower depth (Fig. 3). The Wembere-Manonga volcaniclastics lake beds, characterized by cyclic deposition of fossiliferous, calcareous clays interbedded with fine- to medium-grained sands and limestone layers, were encountered between 0 and 47.6 m. The late syn-rift Mwansalala Fm. occurs between 47.6 m and 161.59 m showing repeated cycles of a fining-up succession typical of a fluvial meandering channel. The succession comprises basal angular to sub-angular, light to reddish-brown, matrix-supported coarse conglomerate that grades into fine-medium, feldspathic quartz-rich sandstones, topped by floodplain muds (Miall, 2006; Fig. 3). The coarse sands in the Mwansalala Fm. indicate moderate reservoir-quality potential in a probable incised-valley setting (e.g., Abdel-Fattah & Sarhan, 2023).

The Nyanzian metamorphic basement is encountered between 161.89 m and 170.5 m, where it is heavily sheared and fractured. Several of these fractures contain oxidized clay infill. The extensive fracturing suggests that the basement could have moderate reservoir potential, especially if an effective source rock is nearby to charge these fractures. No direct hydrocarbon indicators, such as hydrocarbon odour or bituminous sands, were observed during drilling. The overlying Lake Beds in the upper part of the Kining'inila-1 borehole could represent a potential seal units.

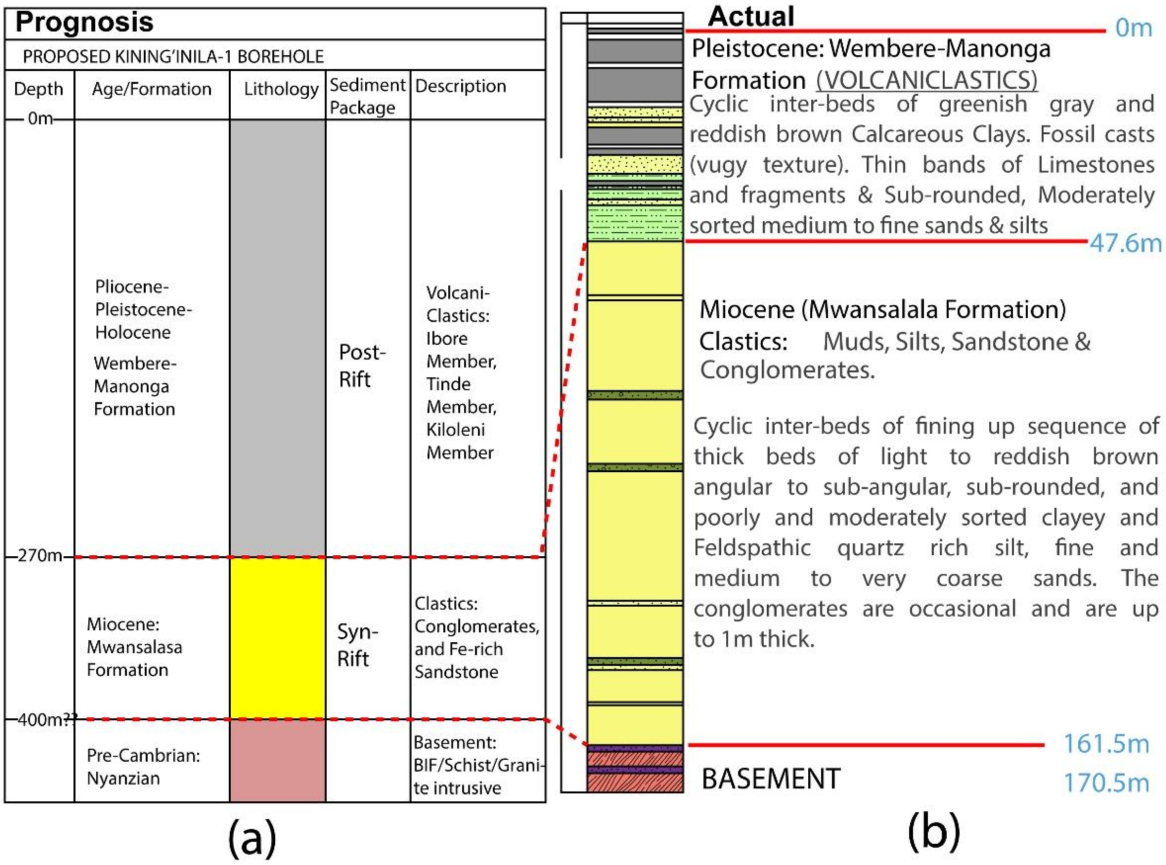

Figure 3: Kining'inila-1 (a) borehole-prognosis (b) actual stratigraphy

3.1.2 Nyalanja-1 Borehole

The Nyalanja-1 borehole intersects the Eyasi Formation from 0 to 302.6 m, revealing a thick, cyclic succession dominated by stacked fining-upward depositional packages (Fig. 4). Most cycles typically begin with coarse to medium-grained sands or occasional locally gravelly to conglomeratic bases that mark the onset of higher-energy sediment influx into the basin. These basal coarse units grade upward into progressively finer sands, silt, and ultimately clay- and mud-rich intervals, reflecting a systematic decline in flow energy and a transition into quieter lacustrine-to-floodplain conditions (Fig 4). Thin, rhythmically alternating silt–clay couplets within these transitions indicate frequent short-term fluctuations between suspension settling and low-energy traction processes, consistent with repeated inundation events or seasonal hydrological variability.

The overall vertical stacking of these cycles in Nyalanja-1 BH indicates repeated progradation and retreat of fluvial distributary systems entering a subsiding lacustrine basin (e.g., Gierlowski-Kordesch & Kelts, 2000; Cohen, 2003). The dominance of clastic sediments, fine sands, muds, silts, and occasional conglomeratic lags indicate sustained clastic supply throughout deposition of the intersected formations. The occurrence of gravelly and conglomeratic bases at multiple levels further supports episodic high-discharge events, likely related to periodic increases in stream power or incision of upstream catchments feeding the basin (Crosby et al., 2007). The Nyalanja-1 profile records a dynamic interplay between fluvial input and lacustrine accommodation, characteristic of a post-rift depositional setting overprinted by localized pulses of higher-energy inflow (e.g., Ebinger et al., 1997).

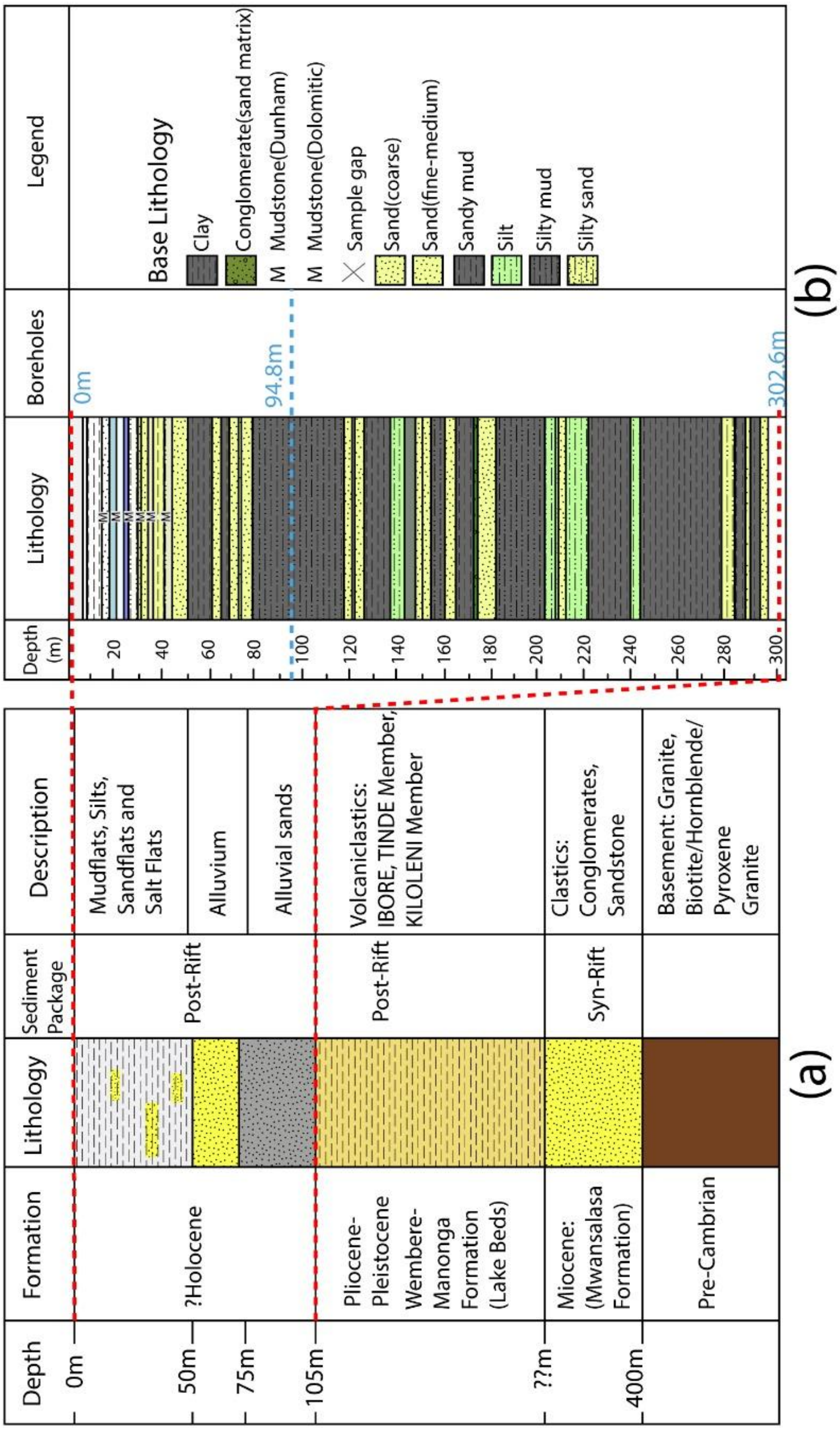

Figure 4: Nyalanja-1 Borehole (a) prognosis (b) actual stratigraphy

3.1.3 Luono-1 Borehole

The Luono-1 borehole mainly penetrates Holocene sediments within the Wembere Sub-Basin, with Plio-Pleistocene sediments found at greater depths (Fig. 5). The uppermost section, from 0 to 3.52 m, consists of Mbuga soils, representing recent surface deposits. This section is underlain by Holocene deposits- extend to about 117.21 m and exhibit cyclic changes between calcareous and micaceous sands, silt, clays, and occasional conglomeratic layers composed of granules and pebbles (Fig. 5). These layers suggest deposition under fluvial to lacustrine environments.

From 117.21 m to 230.1 m, the borehole intersects Plio-Pleistocene volcaniclastic and lacustrine sediments, consisting mainly of sands (fine to coarse), sandy mud, silt, clay, and localized conglomeratic intervals. These sediments contain volcaniclastic material and occasional plant debris, suggesting deposition in a volcanically influenced lake basin.

The comparison between the prognosed stratigraphy and the actual borehole log reveals that the encountered lithologies broadly correspond to the predicted post-rift sedimentary sequence, dominated by volcaniclastic lake beds of the Wembere-Manonga Fm., although some variations in lithologic thickness and sediment distribution occur (Fig. 5).

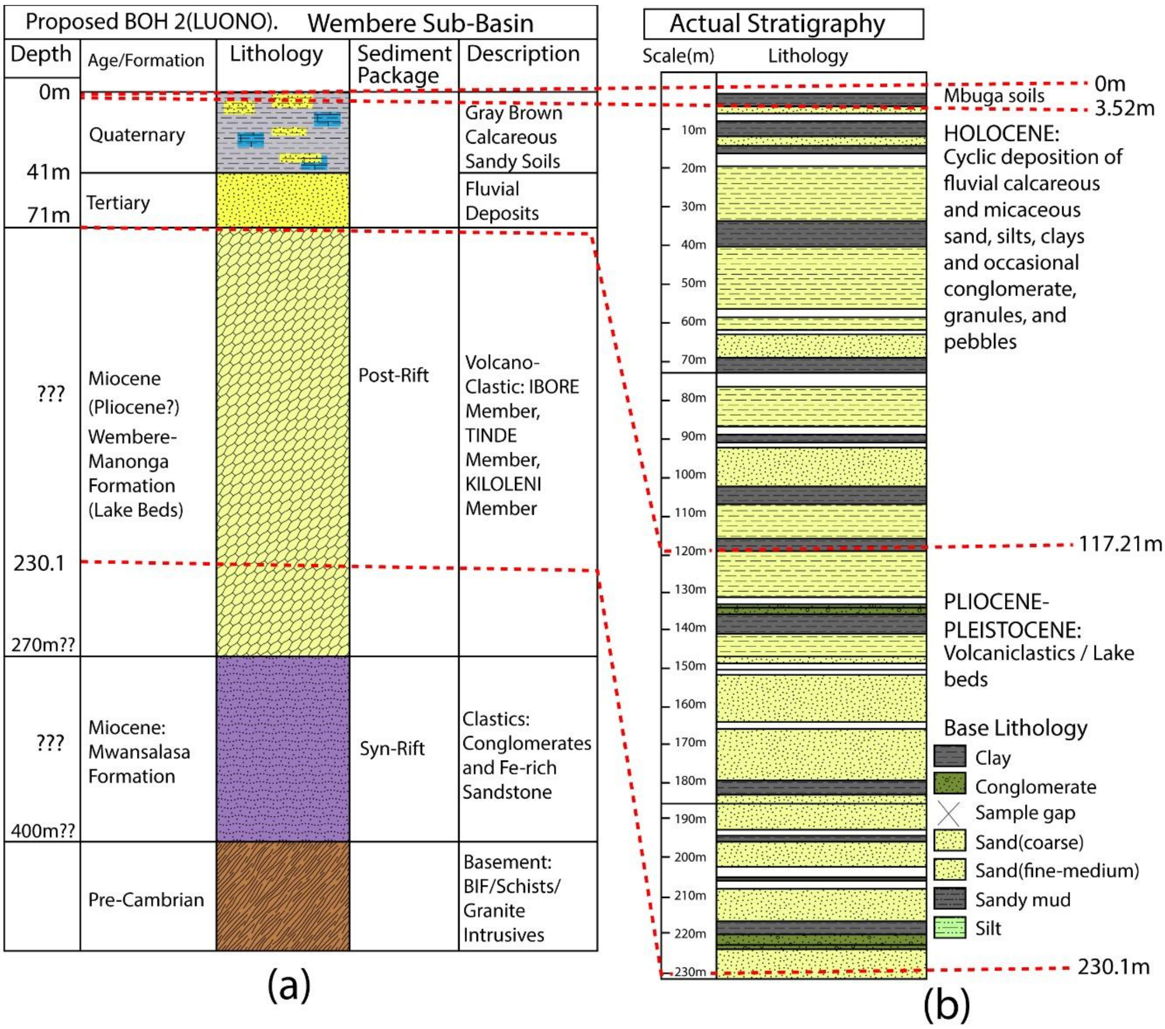

Figure 5: Luono-1 Borehole (a) prognosis (b) actual stratigraphy

3.2 Palynology

Palynological analysis of samples from the Kining'inila-1, Nyalanja-1, and Luono-1 boreholes shows varying preservation and abundance of palynomorphs and organic matter. The assemblages mainly consist of terrestrial pollen and spores, fungal remains, freshwater algae, phytoclasts, and amorphous organic matter (AOM). Key taxa identified include *Podocarpus, Juniperus, Triorites minor, Equisetosporites strigatus* and *Laevigatosporites ovatus*. The identified palynomorphs and other organic components are illustrated on Plates 1-6. Palynological details of the boreholes are presented below:

3.2.1 Kining'inila-1 Borehole

The Kining'inila-1 borehole yielded a few poorly preserved palynomorphs (Fig. 6). Limited occurrences of palynomorphs were identified within the intervals 9.85-09.98 m, 10.43-10.45 m, 22.14-22.18 m, 28.77-28.87 m, 29.93-30.63 m, 32.16-32.20 m, and 82.66-83.74 m. Although most intervals are barren of palynomorphs, a high diversity and abundance of fungal spores and hyphae are observed. Fungi are known to respond rapidly to environmental stress and disturbance (Pugh & Boddy, 1988). Fossil records indicating excessive fungal activity could present, evidence of past ecosystem destabilization (Visscher et al., 1996). Also, a rich diversity of fungal remains could be interpreted as an indicator of a humid climate in the area of deposition (Singh & Chauhan, 2008). Palynological assemblage documented here is dominated by terrestrial taxa such as *Triorites minor* and *Equisetosporites strigatus, Ascospores conidia* (fungal), *Sordnrin1es* (Fungal), (40%) amorphous organic matter (AOM), (50%) fungal spores and (10%) other microfossils and plant debris (Fig. 6). A detailed discussion of the assemblages is provided below:

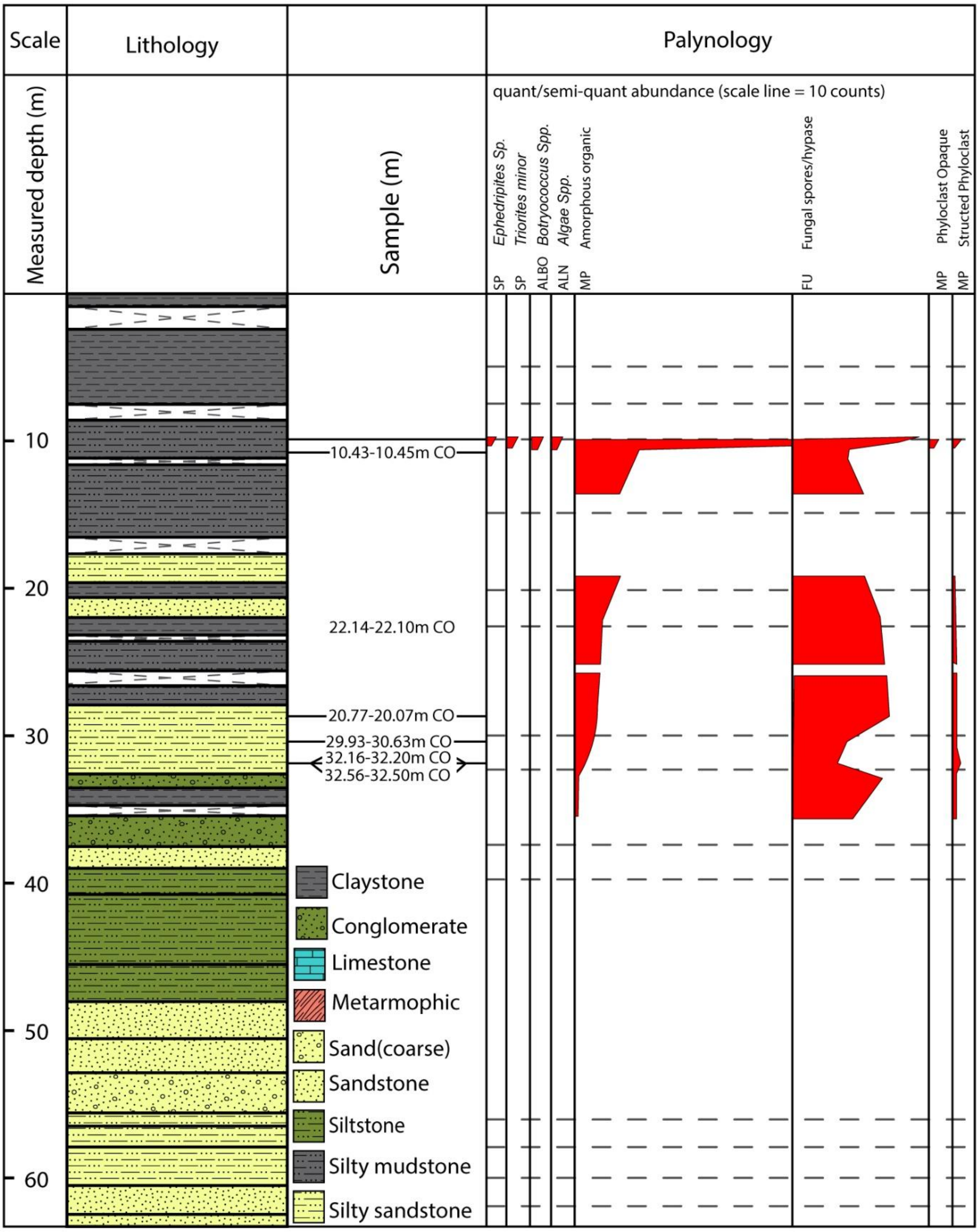

Figure 6: Palynomorphs, and Palynofacies abundance from Kining'inila-1 borehole.

Palynological interval 1 (*Equisetosporites strigatus - Triorites minor* interval) Depths: 9.85-9.98m

This interval is dominated by gymnosperm pollen genera, including *Ephedripites* and *Triorite*, which are represented by *Triorites minor* and *Equisetosporites strigatus*. *E. strigatus* (Bajocian-Pliocene) has been documented in Egypt and China (Yu et al. 1983). *Triorites minor* stratigraphic age range from Oligocene to Miocene (Couper, 1953). Accordingly, this interval is tentatively assigned an Oligocene-Miocene age based on the occurrence of *T. minor*. Fungal spores represent 40% of all specimens counted (Fig. 6). This assemblage suggests a hot, humid, wet climate that prevailed during deposition (Emberlin et al., 2000). This interval is dominated by amorphous organic matter (75%), with phytoclasts (20%), opaque (2%), and algae (3%) of all specimens observed.

Palynological interval 2 (Fungal spore interval)
Depths: 10.43-83.74m
This interval is dominated by fungal spores (80%), which implies a humid climate in the area of deposition (Singh & Chauhan, 2008). A decrease of amorphous organic matter downhole is noted. Also, the section has a few structured terrestrial materials (wood/cuticle), barren in palynomorphs and scarce in algae. Fungi are known to respond rapidly to environmental stress and disturbance (Pugh & Boddy, 1988). Excessive fungal activity is evidence of past ecosystem destabilization (Visscher et al., 1996). Besides, abundant fossilized fungi have been interpreted as evidence of continental drift with tectonic activity (Nease & Wolf, 1975; El Atfy et al., 2013).

3.2.2 Nyalanja-1 borehole

Nyalanja-1 cores yielded well-preserved organic matter and palynomorphs; but some samples contain poorly preserved organic matter. The age of the studied sediments ranges from the Miocene to the Holocene, based on occurrence of spore species *Laevigatosporites ovatus* (Fig. 7). Details of the palynological intervals in the Nyalanja-1 borehole are provided below.

Palynological interval 1 (*Podocarpus* sp. interval)
Depth 24.85-24.90 m
Interval 1 is defined by the first downhole occurrences of *Podocarpus* sp. and *Juniperus* sp., with *Podocarpus* sp. forming up to 39% of the assemblage. Based on the reported Late Miocene-Holocene range of *Podocarpus* sp. (Shaw et al., 2008), this interval is tentatively assigned a Late Miocene-Holocene age. However, because *Podocarpus* has a long stratigraphic range, this age assignment should be regarded as broad and tentative.

Palynological interval 2 (Amorphous Organic Matter-dominated interval).
Depth 29.98-75.9m
The interval 2 is poor in organic matter between depths of 29.98 –30.5m. At 60.24-60.31m, proliferation of AOM and phytoclasts is noted. At 75.84-75.9m, AOM dominates, but phytoclasts are scarce. Due to the absence of age diagnostic taxa, the age of this interval is indeterminate.

Palynological interval 3 (*Podocarpus* sp.–-*Laevigatosporites ovatus* interval)
Depth 117.01-130m
Interval-3 is dominated by AOM, phytoclasts and diverse palynomorphs. Various species of palynomorphs are documented: bisaccate pollen grains belonging to *Podocarpus* sp., freshwater algae *Botryococcus*, aquatic to semi-aquatic fern spore *Laevigatosporites ovatus* and (?)Fungal spores. Stratigraphic range of *Podocarpus* sp. is Late Miocene to Holocene (Shaw et al., 2008), *Laevigatosporites ovatus* is reported from Pleistocene intervals in Egypt (Mahmoud, 1998). Based on the combined palynological assemblage, this interval is tentatively assigned a Late Miocene-Holocene age. The presence of freshwater algae *Botryococcus* and the spore *Laevigatosporites ovatus* in the assemblage indicates lakeside marsh vegetation and wet, low-energy, freshwater depositional settings. *Podocarpus* sp. and *Laevigatosporites ovatus* also occur at intervals 128.42-129.12 m. The presence of fungal spores in this interval further supports the existence of lakeside marsh vegetation and wet climatic conditions.

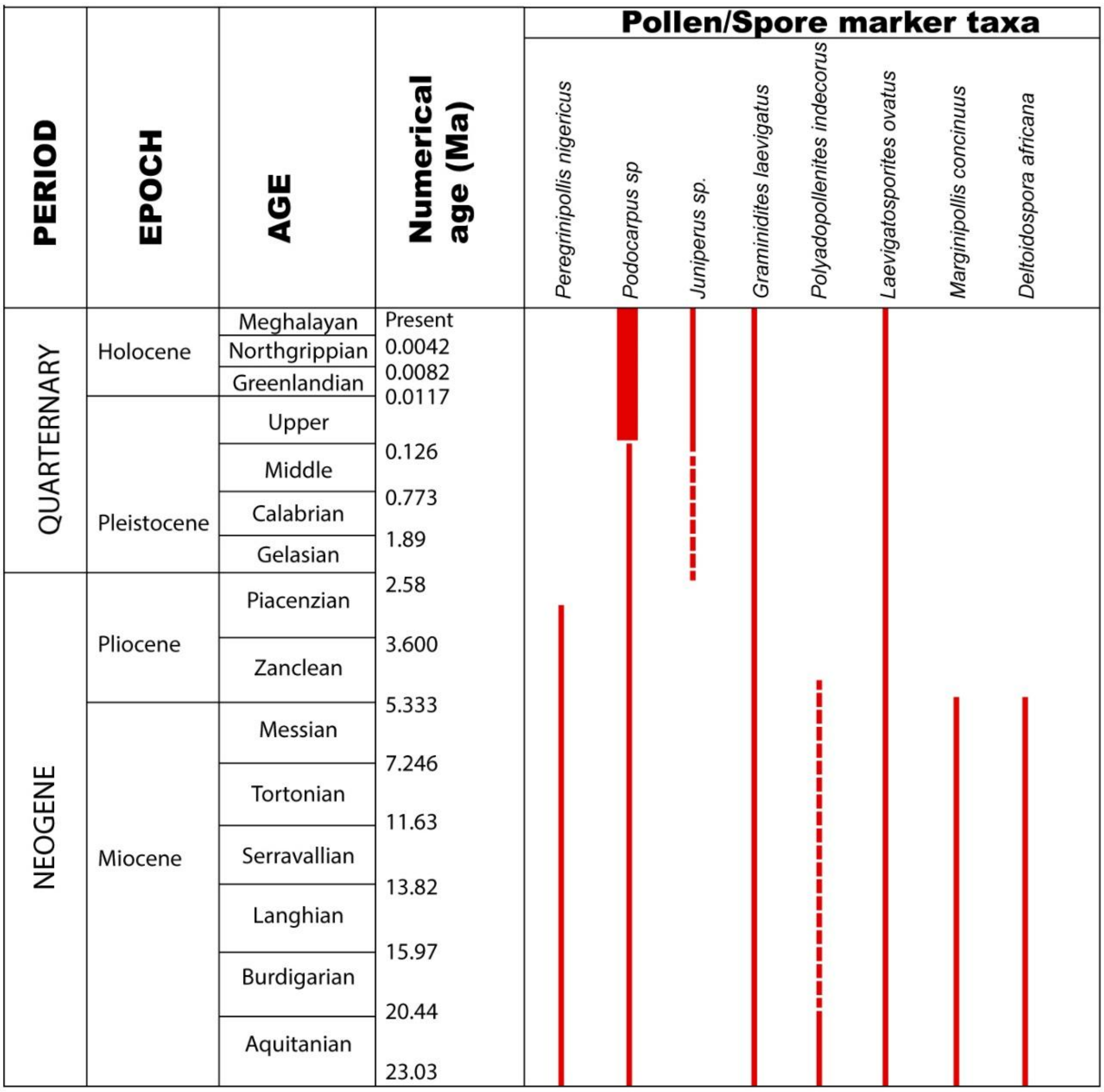

Figure 7. Distribution of palynomorph taxa of Nyalanja-1 Borehole core samples.

3.2.3 Luono-1 borehole

Palynological interval 1 (*Acacia* sp. interval)

Depth 8.05-8.15m

Age diagnostic taxa are absent in Interval-1. However, rare occurrence of *Acacia* sp. at this interval indicates a humid climate at the time of deposition (Shaw et al., 2008; Fig. 8). Depth 15.51 – 69.04m is poor in organic matter but highly pyritized. The pyrite occurrence signifies low-oxygen depositional environments.

Palynological interval 2 (*Cyperaceae* sp. interval)

Depth 92.10-104.76m

This interval is characterized by moderate organic matter content and generally low to absent palynomorph abundance throughout most of the section. However, a distinct increase in palynomorph abundance occurs between 104.71 and 104.76 m, where *Cyperaceae* pollen is recorded. The occurrence of *Cyperaceae* indicates lakeside marsh vegetation and wet climatic conditions (Shaw et al., 2008).

Palynological interval 3 (*Podocarpus* sp.– *Juniperus* sp. interval)

Depth 106.47-106.53 m,

Podocarpus sp. is a dominant species in this interval, but it is a long-ranging species, *Juniperus* pollen species -Late Neogene to Pleistocene (Bonnefille, 1976, 1979, 1995). dominates this interval; Such species is used to assign the Late Neogene to Pleistocene age to the interval.*Juniperus* sp. has previously been reported in the Late Neogene to Pleistocene of Kenya and Ethiopia (Bonnefille, 1976, 1979, 1995). Both *Podocarpus* sp. and *Juniperus* sp. indicate an arid, cooler climate (Shaw et al., 2008).

Palynological interval 4 (Barren)

Depth: 137.82-223.02m

Intervals 137.82-137.88 m, 138.18–138.26 m, 139.33-139.38 m, 161.02–161.10 m, and 196.78–196.86 m are characterized by low organic matter content and are barren or nearly barren of palynomorphs. *Podocarpus* sp. reappears only higher in the succession at 223.01–223.02 m

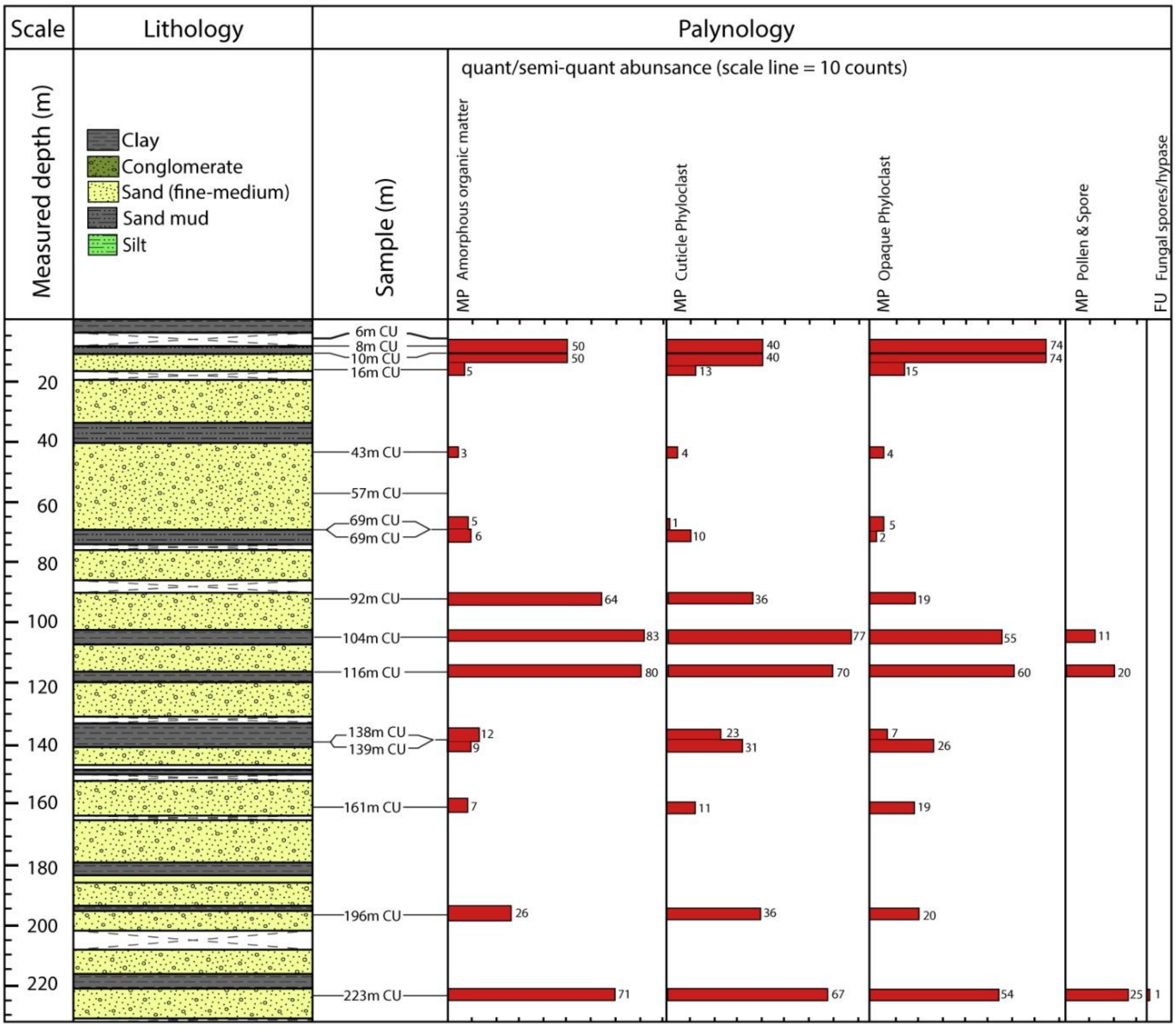

Figure 8: Percentage distribution of palynofacies in the Luono-1 borehole.

3.2.4. Palynofacies Analysis

Palynofacies samples from the Kining'inila-1 borehole, plotted on the APP ternary diagram, show clusters in palynofacies regions VI and IX, indicating proximal-to-distal suboxic-to-anoxic depositional environments (Batten, 1983; Atta-Peters et al., 2015: Fig. 9). The predominance of amorphous organic matter (AOM) and low recovery of palynomorphs in the Kining’inila-1 assemblages suggest deposition under reducing bottom-water conditions and relatively stable water columns that favoured the preservation of organic matter. These conditions are typical of low-energy lacustrine environments where restricted circulation promotes dysoxic to anoxic conditions and supports organic matter accumulation.

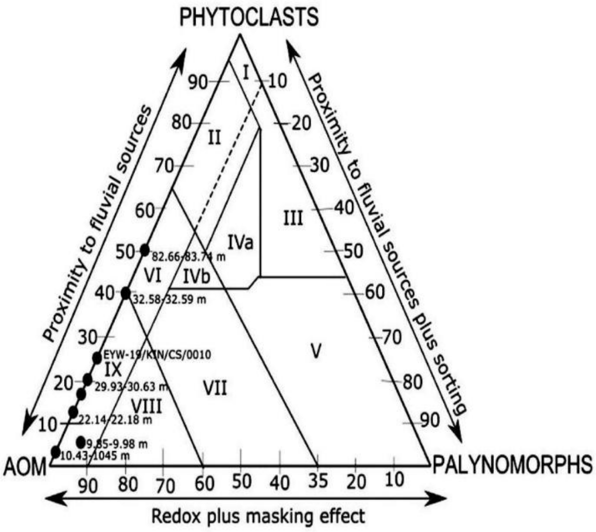

Figure 9: A ternary diagram for palynofacies classification of Kining’inila -1 borehole

3.3 Borehole Ostracod Assemblages

The ostracod assemblages and sedimentological features from the Kining’inila-1, Nyalanja-1, and Luono-1 boreholes suggest deposition within a lacustrine basin characterized by shallow marginal environments and variable hydrological conditions (Fig. 10). In all three boreholes, ostracods are generally sparse and mainly consist of *Limnocythere* spp. (*Limnocythere cusminskyae*, *L.* cf. *borisi*, and *L. inopinata*), with occasional presence of *Eucypris*, *Cyclocypris*, *Candona*, *Ilyocypris*, and *Cytherissa lacustris* (Fig. 9). The presence of *Limnocythere* spp. in sections such as 10.43-26.60 m in Kining’inila-1, 8.9-39.07 m in Nyalanja-1 and 64.09-64.16 m and 137.82-137.88 m in Luono-1 indicates that these sediments are no older than the Pleistocene (e.g., Ramon-Mercau et al., 2014). These taxa inhabit shallow lake systems and thus imply deposition in littoral zones near the lake edges, where carbonate precipitation frequently occurs (Platt & Wright, 1991; De Deckker, 1981, 1983; Also see Figs. 10 & 11).

Several intervals across the boreholes lack ostracods, especially at 28.77-32.59 m in Kining’inila-1, 68.96-92.16 m and 138.18-223 m in Luono-1, and parts of the deeper section of Nyalanja-1. Absence of ostracods in these intervals could indicate harsh environmental conditions, including intense evaporation, fluctuating salinity and lower oxygen levels at the lake bottom (McCormack et al., 2019). In Kining’inila-1, the presence of microbial filaments and ooids, particularly at 22.14-22.18 m and 29.93-32.59 m, suggests microbial activity played a significant role in carbonate precipitation when benthic faunal communities were limited (Riaz et al., 2024; Dupraz et al., 2009). Ooid formation within these shallow lacustrine environments probably occurred under agitated bottom-water conditions (Bádenas & Aurell, 2010).

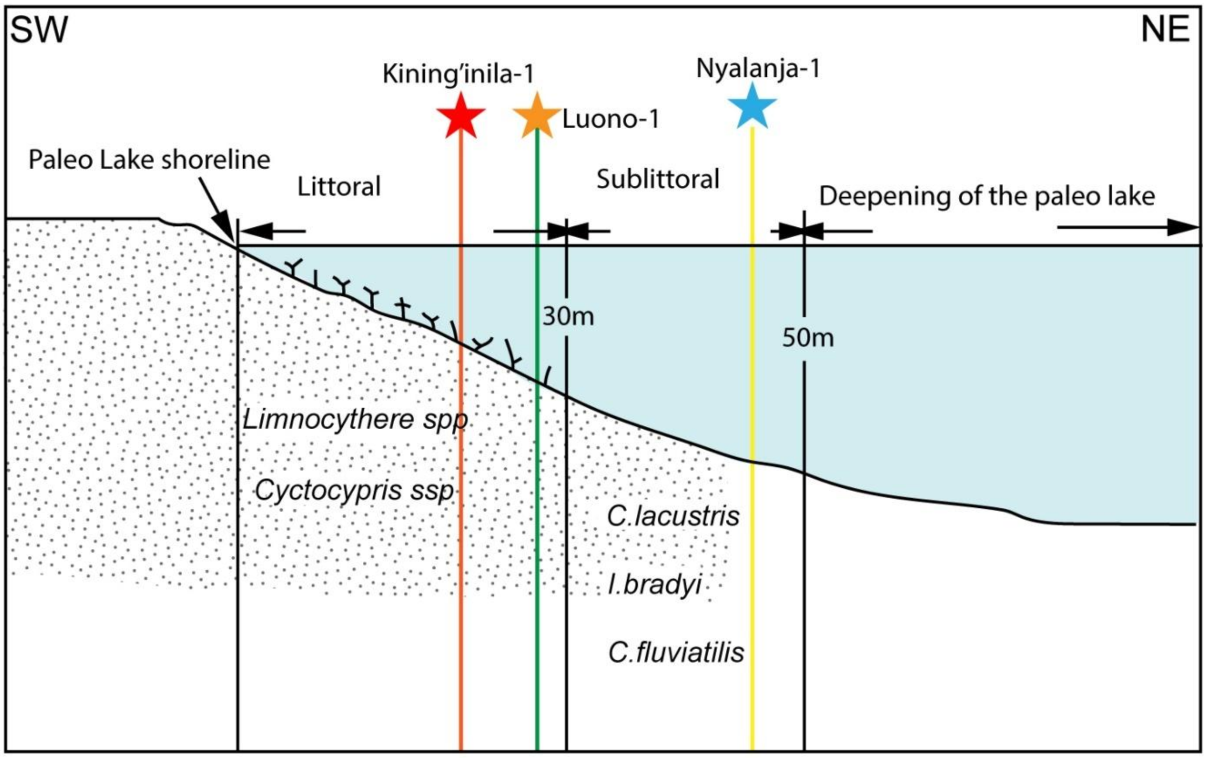

Figure 10: Schematic SW-NE cross-section showing the inferred positions of the Kining'inila-1, Luono-1, and Nyalanya-1 boreholes relative to the reconstructed paleolake shoreline, illustrating a transition from littoral to sublittoral environments and increasing water depth based on ostracod assemblages.

Lithological evidence from the boreholes also indicates variable sediment input into the basin. Quartz-rich sandstones observed in 82.66-83.70 m and 109.21-109.29 m of Kining'inila-1, also sandy intervals in Luono-1, contain angular to sub-angular grains, suggesting short transport distances and episodic siliciclastic input from nearby sources, likely through fluvial inflow into the lake basin. In contrast, the clay-rich sediments of Nyalanja-1, between 117.01-148.77 m and 158.91-233.82 m, contain plant fragments, calcite nodules, and ostracods species such as *Candona*, *Ilyocypris*, and *Cytherissa lacustris*, indicating periods of increased freshwater input and relatively deeper lacustrine conditions (Meisch, 2000; Geiger, 1993: Also see Fig. 12).

Biological indicators further confirm variability in lake conditions. The presence of *Cladoceran* zooplankton (*Daphnia*) in the interval 104.71-104.76 m of the Luono-1 borehole indicates shallow open-lake conditions where filter-feeding zooplankton thrived in nutrient-rich waters. In the deeper parts of the Nyalanja-1 borehole, the presence of pyrite and the reduced abundance of ostracods suggest dysoxic to anoxic bottom-water conditions, reflecting deeper and more stagnant areas of the basin (Froelich et al., 1979).

Overall, the sedimentological and ostracod evidence from the three boreholes indicates that the basin underwent repeated fluctuations in lake level, salinity, oxygenation, and sediment input, reflecting changes in hydrology and climate conditions during the Pleistocene to recent times.

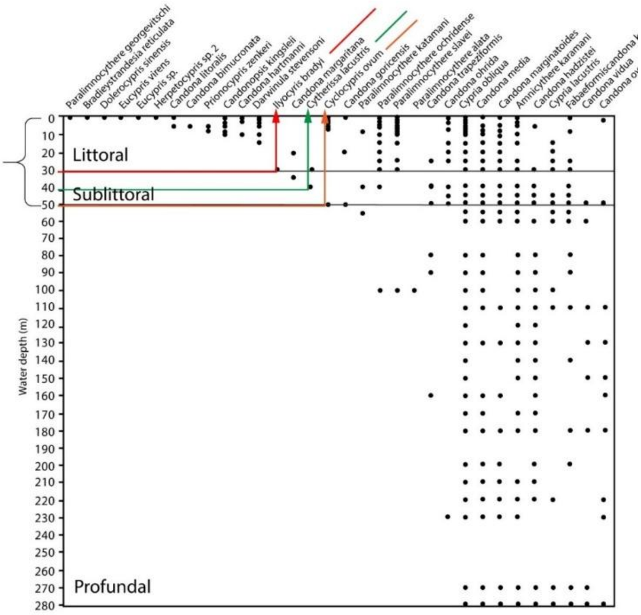

Figure 11: Summary of depth range (paleo bathymetry) of some ostracod species found in the Nyalanja-1 borehole.

4.0 Paleoenvironmental Interpretation

The combined lithological, palynological, palynofacies, and ostracod evidence from the Kining'inila-1, Nyalanja-1, and Luono-1 boreholes indicates that the Eyasi-Wembere evolved as a dynamic lacustrine basin with fluctuating hydrological conditions and variable sediment input from surrounding catchments (Fig. 12). The sedimentary successions recorded in the boreholes show repeated fining-upward cycles of sands, silts, and clays, reflecting alternating phases of fluvial influx and quieter lacustrine sedimentation. Such cyclic sedimentation suggests that the basin functioned as a lake system periodically supplied by distributary fluvial channels that transported siliciclastic material from nearby uplands into the basin interior (Gierlowski-Kordesch & Kelts, 2000; Cohen, 2003).

Palynological assemblages provide insights into the surrounding vegetation and climate at the time of sediment deposition (Traverse, 2007). The dominance of terrestrial pollen and spores such as *Podocarpus*, *Juniperus*, *Laevigatosporites ovatus* and *Equisetosporites strigatus* indicates that the basin was bordered by vegetated landscapes supplying organic material to the lake (Shaw et al., 2008). Freshwater algae (*Botryococcus*) and wetland indicators such as *Cyperaceae* suggest the presence of lakeside marsh vegetation and shallow marginal environments along the lake margins (Shaw et al., 2008). Abundant fungal spores in some borehole intervals indicate humid climatic phases and environmental disturbances affecting surrounding ecosystems (Shaw et al., 2008; Singh & Chauhan, 2008).

Palynofacies composition further supports deposition in a low-energy lacustrine setting. The dominance of amorphous organic matter with subordinate phytoclasts suggests that much of the preserved organic material originated from aquatic productivity within the lake, with terrigenous plant debris transported from surrounding terrestrial environments. Such assemblages are typical of quiet depositional environments where reducing bottom-water conditions favor the preservation of organic matter (Batten, 1983; Atta-Peters et al., 2015; Tyson, 1987; 1993).

Ostracod assemblages provide additional constraints on the spatial organization of the paleolake. The predominance of *Limnocythere* species in several intervals indicates shallow littoral conditions near the margins of the lake, whereas the occurrence of *Candona*, *Cytherissa lacustris*, and *Ilyocypris bradyi* in deeper intervals, particularly in the Nyalanja-1 borehole, reflects relatively deeper sublittoral environments with increased freshwater influence. Intervals lacking ostracods likely represent phases when environmental conditions became unfavorable for benthic fauna, possibly due to increased evaporation, fluctuating salinity, or reduced oxygen availability at the lake floor (De Deckker, 1981; 1983; Meisch, 2000; Geiger, 1993; McCormack et al., 2019). Therefore, the borehole records indicate that the Eyasi-Wembere acted as a shallow lacustrine basin with repeated shifts in lake level, water chemistry, and sediment supply (Fig. 12). Periods of increased fluvial inflow brought coarser clastic sediments and fresh water into the basin, while calmer phases allowed for the build-up of fine-grained lacustrine sediments and organic material. At times, lake expansion created deeper sublittoral environments, especially seen in the Nyalanja-1 succession, whereas other periods show shallow marginal conditions and environmental stress within the lake (Fig.12). These fluctuations reflect changes in basin hydrology and climate conditions during the Pliocene to Holocene, which influenced the development of the lacustrine system within the Eyasi-Wembere Basin as it was for many other sub basins in the EARS (e.g., Maslin & Trauth, 2009).

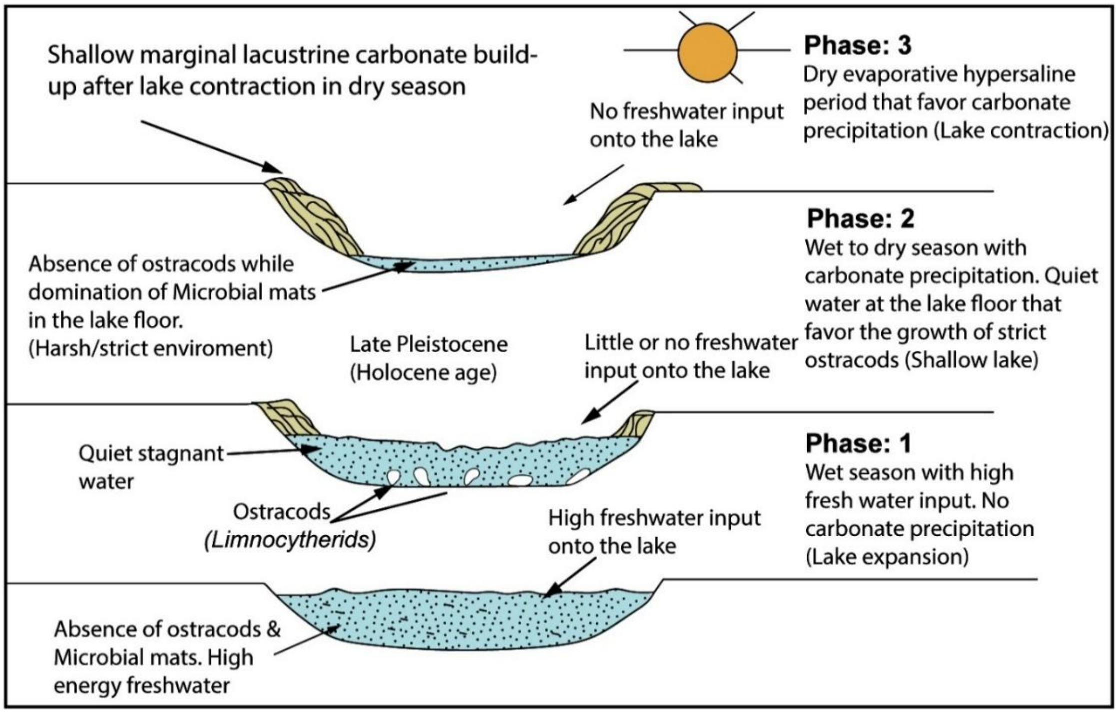

Figure 12: Depositional model describing the climatic changes associated with deposition of the analyzed section deduced from ostracod assemblages and sedimentology.

5.0 Correlation

The Kining'inila-1, Luono-1 and Nyalanja-1 boreholes are aligned along a southwest-northeast transect across the Eyasi-Wembere, separated by about 120 km (Fig. 13). Correlation of lithology and ostracod distribution shows clear lateral variation in depositional conditions across the basin. The Kining'inila-1 borehole, located in the southwestern part of the transect, mainly consists of fluvial sandstone deposits and intersects the basement at approximately 170 m depth, indicating proximity to a basin margin or structural high (Fig. 13). In contrast, Nyalanja-1, situated in the northeastern part of the basin, revealed a thick sequence of lacustrine sediments rich in ostracods. The first appearance of *Candona* spp. at Ca 117 m, along with a notable *Candona* peak near 253 m, suggests relatively deeper lacustrine conditions in the basin.t. Luono-1, located between these two boreholes, comprises lacustrine sediments with scattered occurrences of *Limnocythere*. Therefore, the distribution of lithologies and ostracod assemblages across the three boreholes reveals a basin-wide gradient from marginal fluvial environments in the southwest to deeper lacustrine conditions in the northeast (Fig. 13).

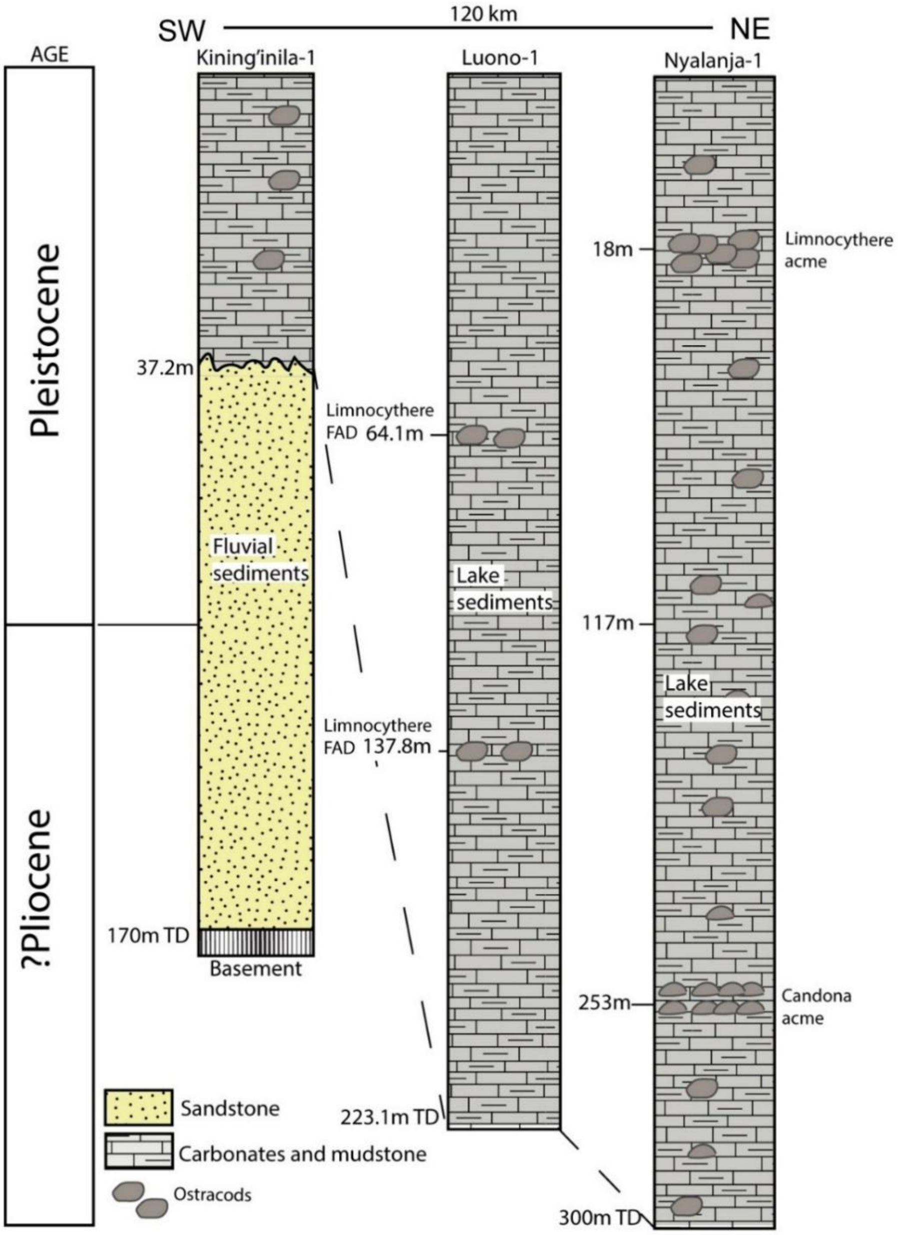

Figure 13: Correlation among Kining'inila-1, Nyalanja-1 and Luono-1 boreholes based on ostracod assemblages.

6.0 Source Potential for Hydrocarbons

Organic matter from the Eyasi-Wembere Basin mainly consists of amorphous organic matter (AOM) and aquatic algae (*Botryococcus* sp.), with minor woody plant remains. This indicates the presence of Type I and Type II kerogen, which are typically associated with oil potential (Tyson, 1987, 1993). Spore colour ranges from light brownish yellow to yellow, indicating marginally mature organic matter, with limited hydrocarbon generation at the current burial depth (Stach et al., 1982). With respect to ostracod assemblages that contain species which characterize sublittoral lake environments, occur at ~30 m water depth and extends into deeper settings. Unequivocally, suggests limited light penetration to the benthic zone, therefore, absence of macrophytes. Primary productivity is dominated by benthic algae and cyanobacteria (Cohen, 2003).

These macroorganisms are associated with the formation of kerogen types I and II, consistent with palynological evidence (see above).

The presence of oil-prone organic matter indicates favourable source rock quality within the basin. However, the studied boreholes are shallow. Thus, thermal maturity and hydrocarbon generation potential of deeper parts of the EWB remain uncertain. Geochemical investigations of Cenozoic sediments from the Eyasi-Wembere Basin have shown that organic matter content and kerogen types vary significantly across the basin, with source rock quality ranging from poor to good and maturity levels ranging from immature to the onset of the oil window (Gama et al., 2025). These findings suggest that favourable source rock intervals may occur in the deeper parts of the basin where burial conditions are sufficient for hydrocarbon generation. Hence, further exploration, including drilling of deep exploration wells and geophysical investigations, is required to reveal suitable petroleum system with the onset of the oil window elsewhere in the basin (Maduhu et al., 2017, Gama et al,, 2025). Comparable lacustrine petroleum systems are well documented in coeval basins in the East African Rift, e.g., the Albertine Graben in Uganda and the Lokichar Basin in northern Kenya. In these basins; hydrocarbons are sourced from organic-rich lacustrine sediments dominated by algal and amorphous organic matter that generates oil-prone kerogen types I and II (Katz et al., 1990; Morley, 1995; Tiercelin & Lezzar, 2002).

7.0 Conclusions

This study presents the first integrated microfossil-based investigation of the Eyasi-Wembere Basin (EWB). Using core samples from three stratigraphic boreholes and integrating sedimentological, palynological, and ostracod data, the following conclusions are drawn regarding the basi''s depositional history, age, and petroleum potential.

1. From sedimentological and micropaleontological evidence, deposition in the EWB occurred within a lacustrine system characterized by spatial variations in water depth and depositional energy. Nyalanja-1 and Luono-1 reveal low-energy lacustrine environments with diverse ostracod assemblages, and Kining'inila-1 represents a more proximal setting influenced by fluvial processes.
2. Based on biostratigraphic evidence, the age of the currently studied material ranges from Pliocene to Holocene. This finding is supported by the occurrence of age-diagnostic palynomorph species: *Podocarpus* sp. *Laevigatosporites ovatus*, *Juniperus sp* and *Triorites minor*; and age-diagnostic ostracod taxa: *Limnocythere*, *Candona*, *Cytherissa lacustris*, and *Ilyocypris bradyi* in the studied material.
3. Palynofacies analysis revealed organic matter assemblages that are dominated by amorphous organic matter and aquatic algae (*Botryococcus*), indicating oil-prone kerogen types I and II.
4. Spore colour observations indicate marginally, thermally mature source rock.
5. Occurrence of organic-rich lacustrine sediments in the EWB is proof of the presence of a productive petroleum system such as those of Albertine Graben (Uganda) and Lokichar Basin (Kenya), where HCs have been discovered from algal-rich lacustrine deposits.
6. The current study covers the upper part of the sedimentary succession of the EWB; the depositional architecture, geochronology and petroleum system potential in the deeper parts of the basin is poorly understood. Further investigations, including detailed sedimentological studies, geochronology (e.g., $^{40}Ar/^{39}Ar$ dating of the interbedded tuffs), geophysical surveys and deeper exploratory drilling are required to better understand the basin fill and evaluate its hydrocarbon potential.

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Plates

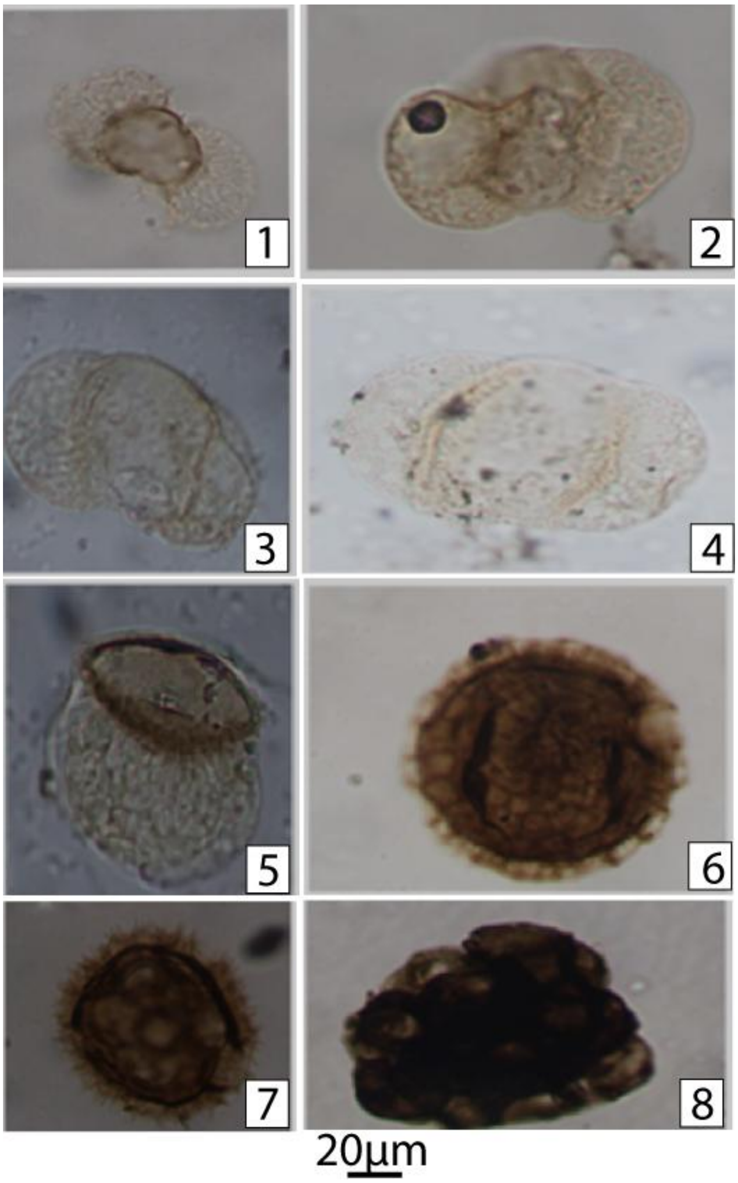

Plate 1. Photomicrographs of selected palynomorphs.Scale bar = 20µm. Each taxa is identified by slide number, depth and England finder coordinates.

(1-4). *Podocarpus capensis;* Slide number; EYW-19/CS-003, Depth =24.85-24.90 m P42-3 **(5).** *Podocarpus* sp**.;** Slide number; EYW-19/CS-003 Depth = 24.85-24.90 m, N46-4 (**6). ***Polygonum* sp.*;* Slide number; EYW-19/CS-007, Depth = 60.24-60.31 m, P37 (**7**). *Bothriodine amplifolia.* Slide number; EYW-19/CS-008, Depth = 75.84-75.9 m, H50-2 (**8**)**.** *Acacia* sp**.;** Slide number; EYW-19/CS-011, Depth =148.70-148.77 m, M45-1.

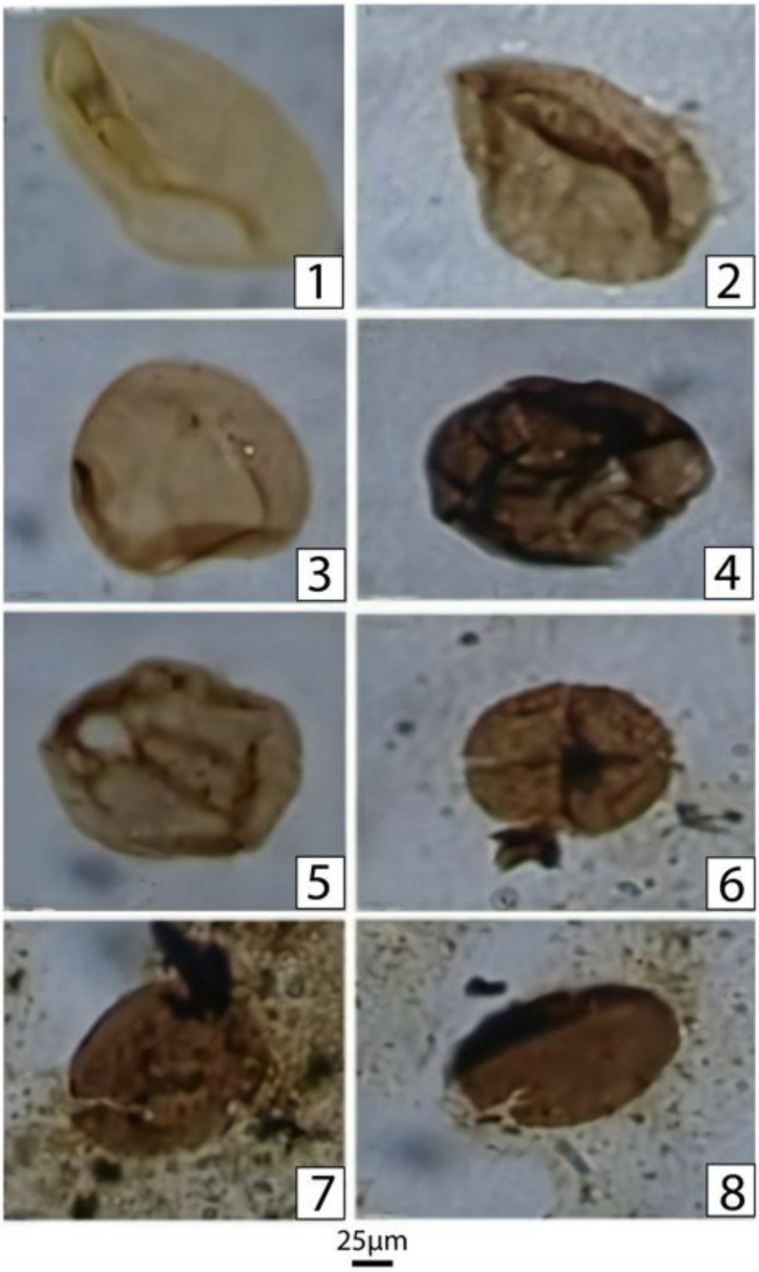

Plate 2. Photomicrographs of selected palynomorphs . Scale bar = 25 μm.Each taxa is presented by slide number, depth and England finder coordinates . (1). *Monocolpites* sp., Slide number; EYW-19/CS-012, Depth =148.70-148.77 m, L41 (2). *Cycadopites* sp., Slide number; EYW-19/CS-013, Depth =158.91-158.98 m N32 (4). Indeterminate taxa (5). *Cyclopsiella elliptica,* Slide number, EYW-19/CS-013, Depth = 158.91-158.98 m, S36-3 (6). *Euphorbia* sp., Slide number; EYW-19/CS-014, Depth = 70.01-170.17 m, Q33 (7-8). *Taxodiaceapollenites* sp., Slide number; EYW-19/CS-012, Depth = 148.70-148.77 m, W46-4.

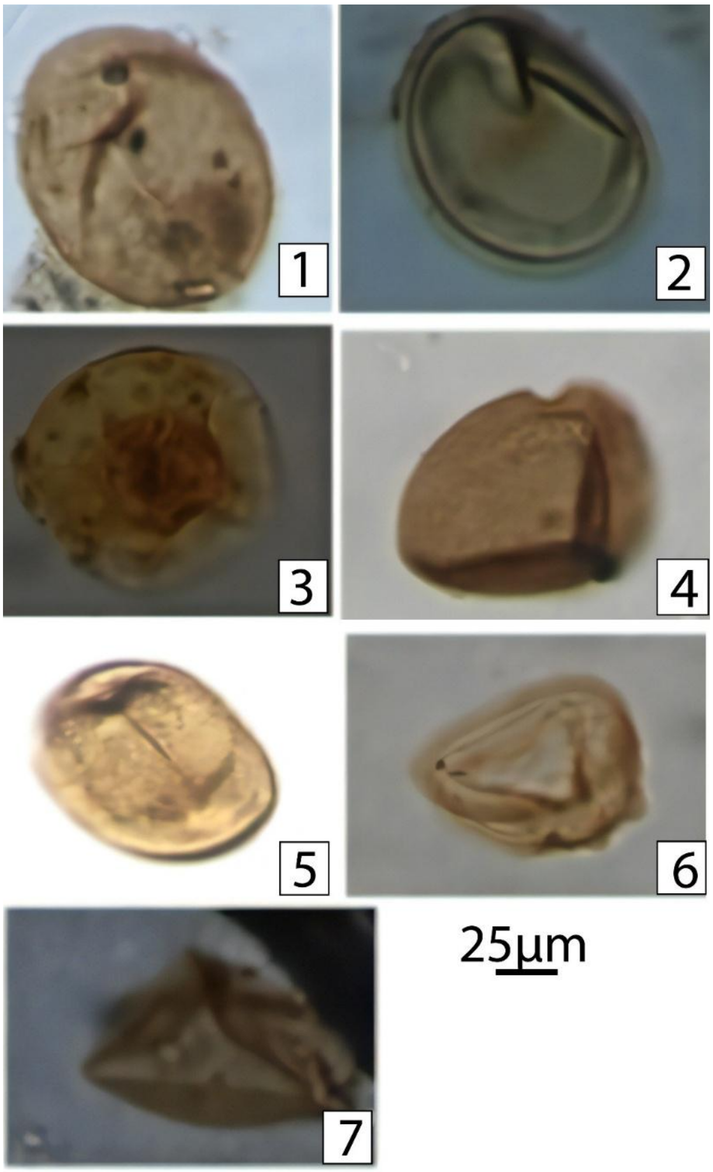

Plate 3. Photomicrographs of selected palynomorphs.Scale bar = 25 µm. Each taxa is presented with slide number, depth and England finder coordinates. (**1).** *Laevigatosporites ovatus,*Slide number; EYW-19/CS-010, Depth = 28.42-128.49 m, E40-1 (**2).** *Exesipollenites tumulus*, Slide number; EYW-19/CS-006, Depth =24.85-24.90 m, R37-2 (**3).** *Spheripollenites* sp., Slide number; EYW-19/CS-006, Depth =24.85-24.90 m, T21-2 (**4).** *Monosporites* sp., Slide number; EYW-19/CS-011, Depth = 137.82-137.88 m, K39-4 (**5).** *Spheripollenites* sp., Slide number EYW-19/CS-013, Depth: 158.91-158.98 m, V43-1 (**6-7)** *Deltoidosporites africana*, Slide number; EYW-19/CS-012, Depth = 48.70-148.77 m, G26-3.

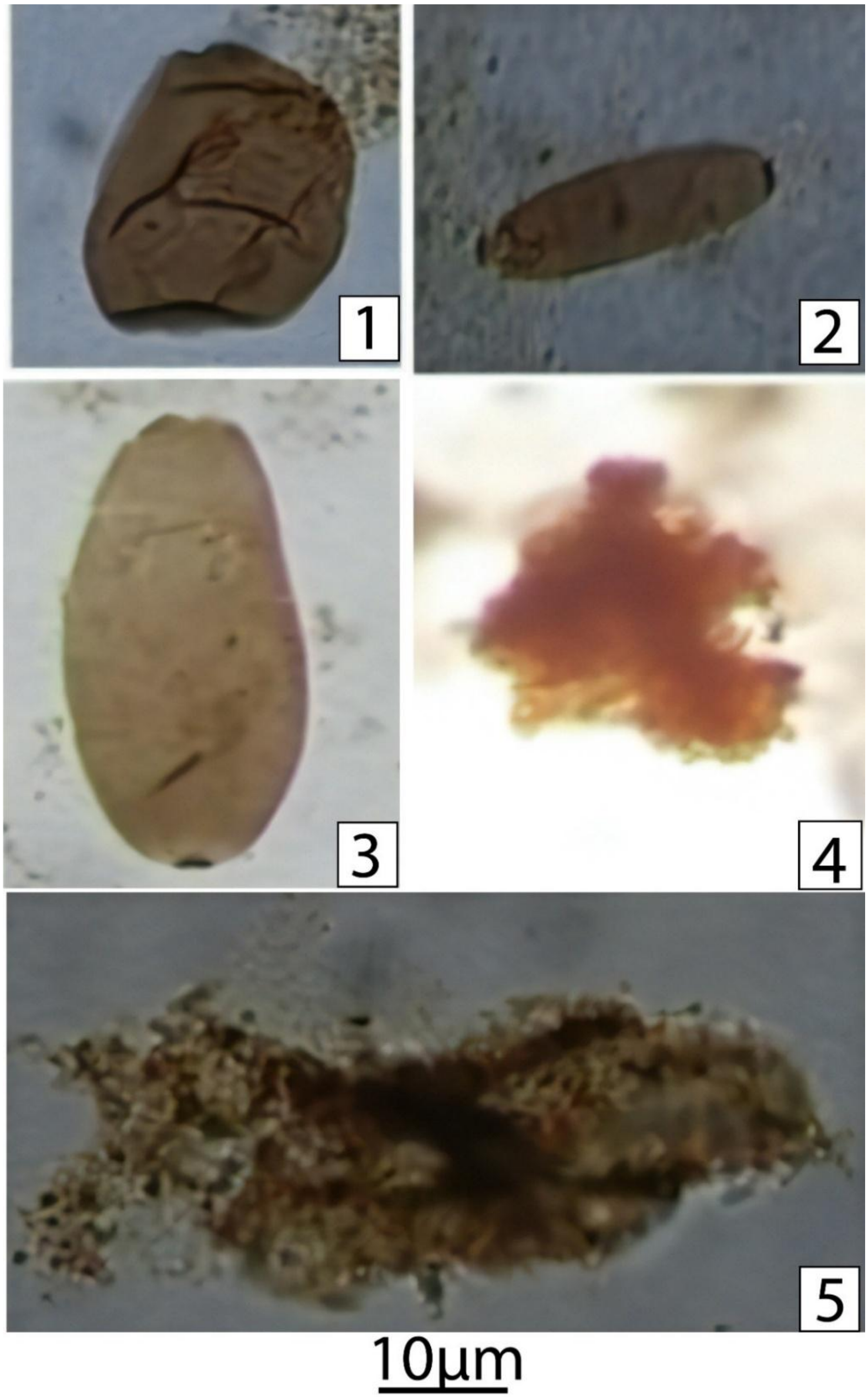

Plate 4. Photomicrographs of selected fungal spores and phytoclasts. Scale bar = 10 µm. **(1-3).** Fungal spore. **(4).** *Botryococcus* sp. **(5).** Amorphous Organic Matter.

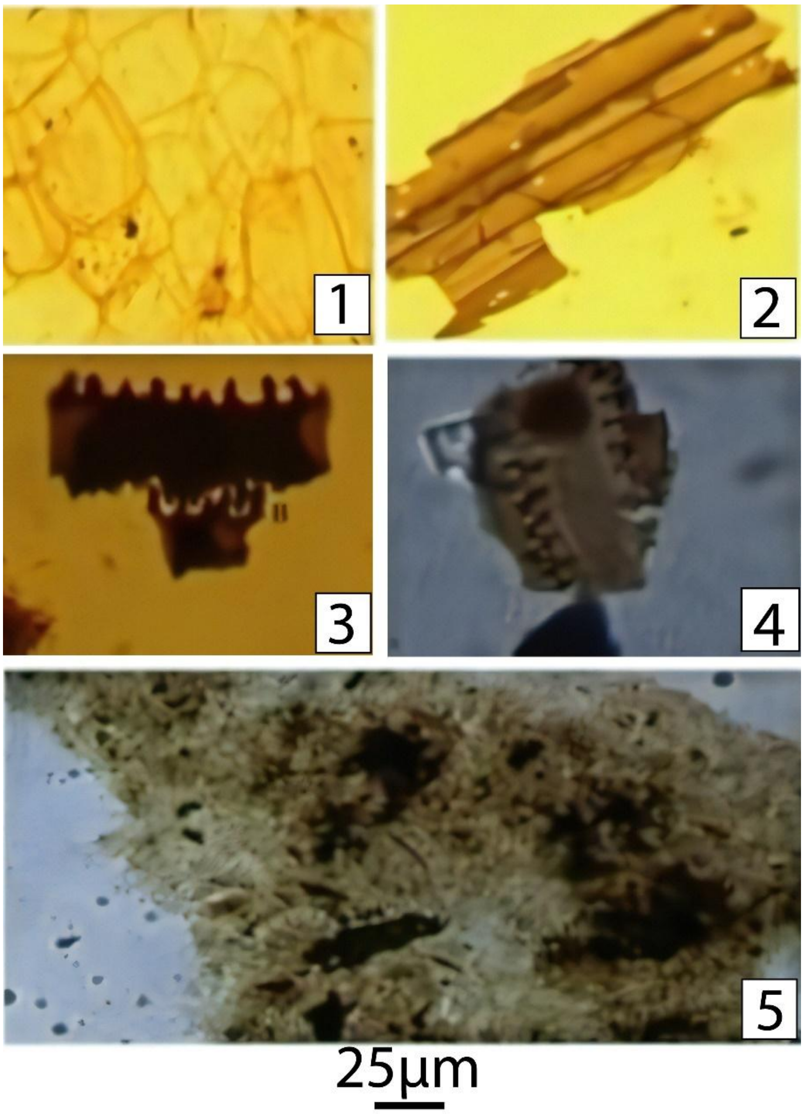

Plate 5: Photomicrographs of selected phytoclasts. Scale bar = 25 µm. finder coordinates. **(1).** Plant cell. **(2).** Brown wood **(3).** Wood Cuticles **(4).** Wood debris **(5).** Amorphous Organic Matter.

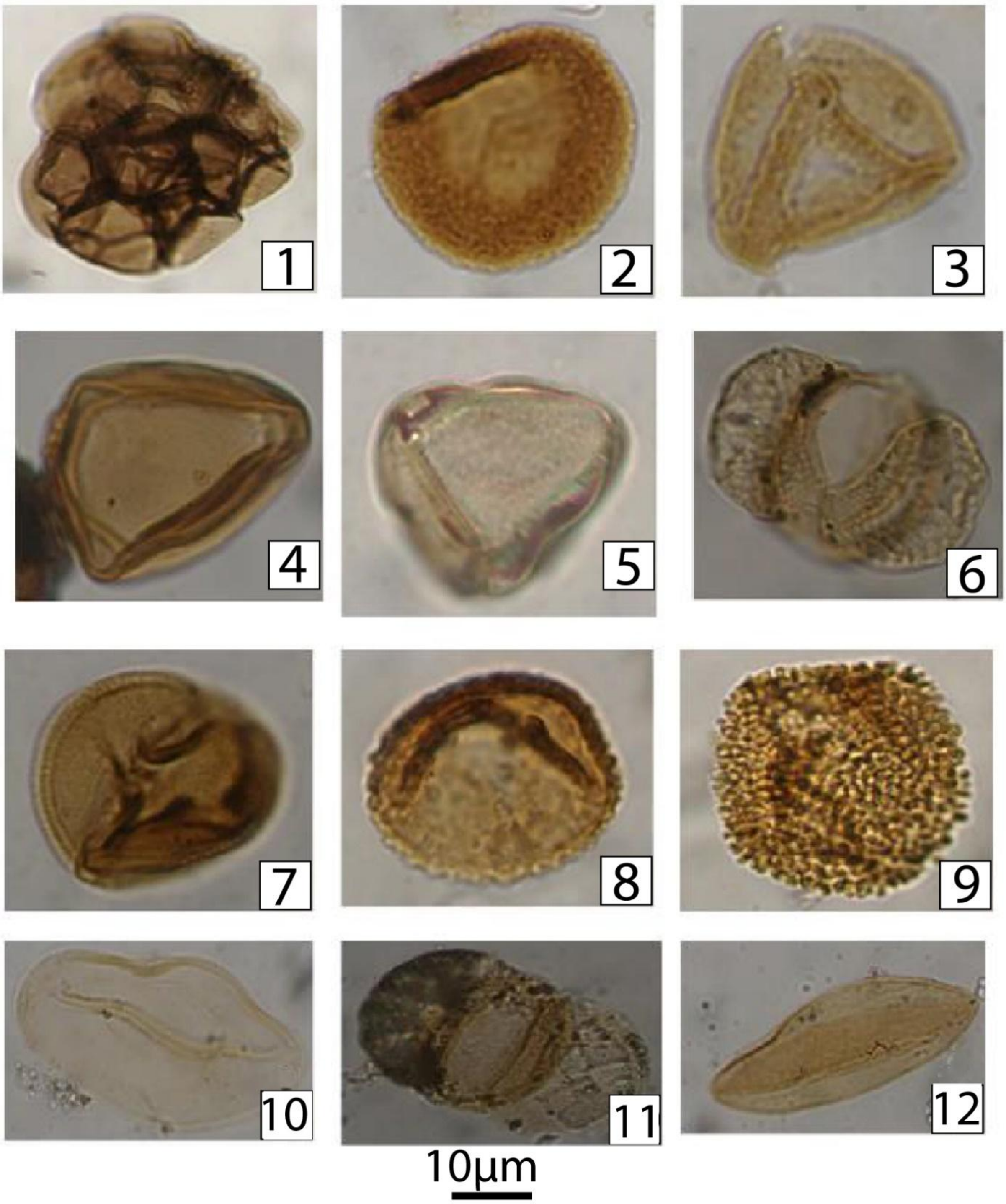

Plate 6: Photomicrographs of selected palynomorphs. Scale bar = 10 µm. Each taxa is presented with slide number, depth and England finder coordinates. **(1).** *Acacia* sp., Slide number; EYW-19/CS-001, Depth = 8.05-8.15, U54 **(2).** *Verrucatosporites usmensis*, Slide number; EYW-19/CS-011, Depth =137.82-137.88 m, K39-4 **(3-5).** *Cyperaceae* sp., Slide number; EYW-19/CS-013, Depth = 139.33-139.38 m, P42-2 **(6).** Bisaccate pollen **(7).** *Podocarpus* sp., Slide number; EYW-19/CS-009, Depth =117.24-117.3 m, U31-3 **(8).** *Perfotricolpites digitatus*, Slide number; EYW-19/CS-010, Depth = 106.47-106.53 m, M33-1 **(9).** *Junisperus* sp., Slide number; EYW-19/CS-

010, Depth = 117.24-117.31 m, K35-1 **(10).** *Ilex* sp. Slide number; EYW-19/CS-015, Depth = 196.76-196.86 m, H49-1 **(11).** *Monocolpites* sp. Slide number; EYW-19/CS-015, Depth = 196, 76-196.86 m, H49-1, **(12).** *Crudia* sp. Slide number; EYW-19/CS-010, Depth = 117.24-117.31 m, K35-1.