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Preliminary Palynology of the Karoo Equivalent Tanga Beds, Coastal Tanzania: Insights on Preservation, Age and Depositional Environments

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Abstract

The major challenge to the current understanding of the stratigraphy of the Tanga Basin is scarcity of biostratigraphy age-control data. A number of palynomorphs retrieved from core samples of the Tanga Beds and analysed for palynology are here presented. These include bisaccate pollen grains belonging to the *Alisporites-Falcisporites* complex, making about 55% average of the total assemblage. The rest of the assemblage comprises other palynomorphs (pollen and spores) and phytoclasts. The miospores documented from the studied samples have poor to fairly good preservation; the organic residues (non-pollen palynomorphs) are excellently preserved. Based on palynologic evidences, and the presence of fossil *Glossopteris* plant leaves, late Permian to Early Triassic age is assigned to the samples collected from the Tanga Beds.

Keywords: Karoo, Bio-stratigraphy, Palynology, Age-control, Tanga Beds.

Introduction

Improvements in data acquisition techniques have led to major developments in the stratigraphy of the coastal basin of Tanzania. Outcrop studies (Smelror et al. 2018), analysis of core samples from stratigraphic drilling projects (Fossum et al. 2019), wire-line logs (Godfray and Seetharamaiah 2019), seismic stratigraphy (Seni et al. 2018) and biostratigraphic studies (Kapilima 2003, Emanuel et al. 2017) have contributed to the current understanding of stratigraphy of the Tanzania coastal basin, each method complementing the other. Despite their relevance, these studies focused mostly on the onshore and offshore parts of central and southern coastal Tanzania. Palynology being among the important stratigraphic techniques has been used to supplement other tools in a few stratigraphic studies in the Rufiji Basin (Balduzzi et al. 1992, Msaky 1995) and Mandawa basin, southern coastal Tanzania (Samuel 2011, Hudson and Nicholas 2014, Smelror et al. 2018). It has proven to be relevant in determination of prehistoric life that prevailed at the time the host lithology was deposited, and so the age of the specific strata (Deaf 2009). Moreover, palynological utility extends to stratigraphic correlation, evaluation of potential source rocks as well as forensic studies.

Evolution of the Tanzania Coastal Basin (Figure 1), Tanga Basin being a subset involved multiple tectonic rifting and continental drifting linked to the subsequent basin-fill processes (Thompson et al. 2019). The earlier rifting phase occurred during the Permo-Carboniferous to Triassic and resulted in development of complex horsts, graben and deposition of continental Karoo-equivalent rocks (Kent et al. 1971, Thompson et al. 2019). Many researchers termed this rifting event as a “failed rift” (Mpanda 1997). Another rifting event, commonly regarded as “reactivation of the earlier rift”, occurred in Middle Jurassic to Early Cretaceous (Kapilima 2003). This rifting episode is regarded as a successful one, as it led to the continental breakup of the Gondwana Supercontinent into present-day continents of Southern Hemisphere, including the separation of Madagascar away from Africa (Kent et al. 1971, Mpanda 1997, Kapilima 2003). The main drifting phase was dominated by massive subsidence and sedimentation (Bally 1981, Salman and Abdula 1995, Nicholas et al. 2007), leading to deposition of alternating marine and transitional marine deposits. This phase was followed by a period of tectonic quiescence and development of passive continental margin across the eastern African coast, until the Paleogene when tectonic reactivation occurred. The latter episode is associated with the late Cenozoic development of the East African Rift System (Mbede 1991, Mbede and Dualeh 1997, Nicholas et al. 2007). A few recent studies suggest that, parts of the Tanzania coastal basin may have started undergoing compression tectonics (Nicholas et al. 2007, Sii et al. 2015). This is contrary to the most accepted tectonic model that suggested extensional tectonics over a long period of time (Mbede and Dualeh 1997, Kapilima 2003).

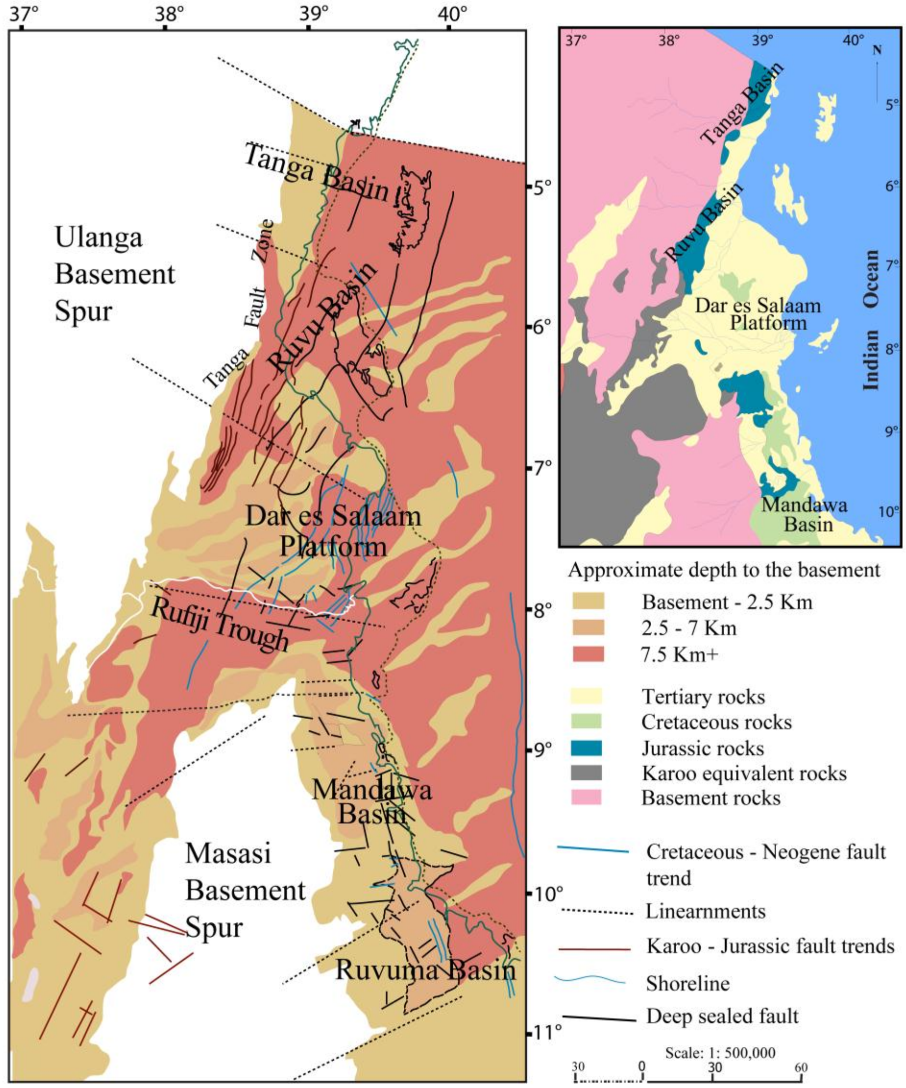

Figure 1: The map of coastal Tanzania showing geological, structural features, depth to the basement and lithological distribution (modified after TPDC 1992 and Kent et al. 1971).

The Tanga Basin (Figure 2) has a very good record of important tectono-sedimentary processes that are thought to have affected the entire Tanzanian coastal area (Kapilima 2003). The pre-Jurassic (Paleozoic to Early Mesozoic) sedimentary units are exposed in the Tanga Basin (Kent et al. 1971). In the current study, such units will be referred to as the "Karoo Equivalent Tanga Beds" because no formal stratigraphy is established in the basin. The Karoo Equivalent Tanga Beds include the ?Permo- Triassic to ?Early Jurassic rocks that crop out in the Tanga Basin, overlain by Middle Jurassic to Neogene marine strata (Kent et al. 1971). Examples of these include the Pangarawe shales, Kakindu shales and Kilulu sandstones, a unit that occurs north of the Tanga Bay (Kent et al. 1971, Cooke 1974).

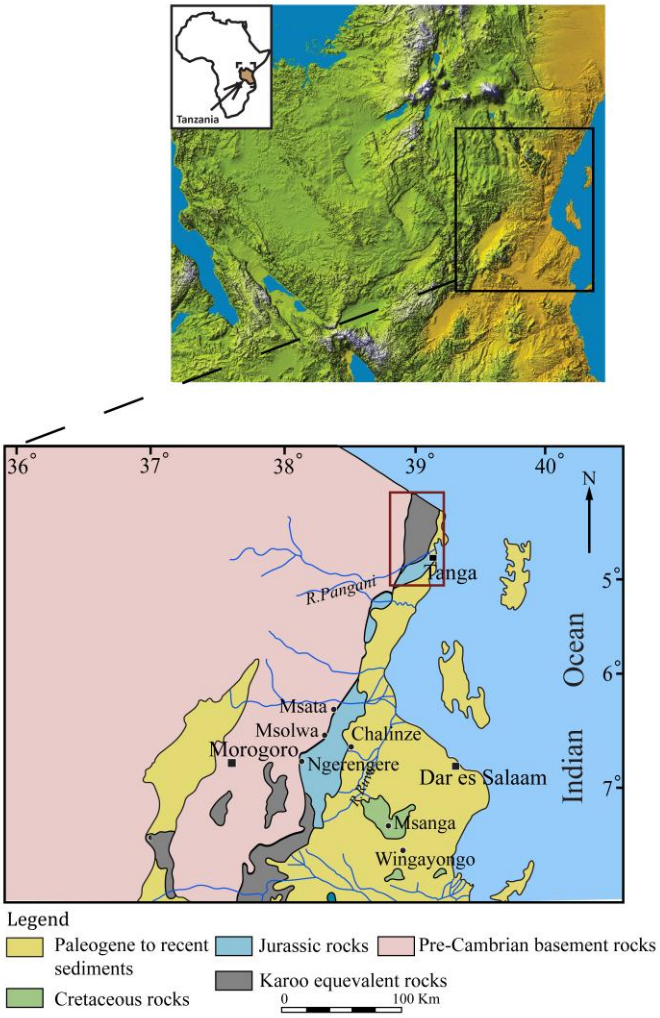

Figure 2: A close up map and satellite image of central – northern coastal Tanzania showing study area location and lithological distribution (Modified after Kent et al. 1971).

Regardless of this general knowledge, major challenge to the current understanding of stratigraphy of this basin is scarcity of biostratigraphic age-control data. Detailed published palynological studies do not exist (Msaky 2007). A few related exceptions include two paleobotanical studies conducted in the Tanga Basin (Seward 1922, Seward 1934). These studies have published interesting findings on paleobotanical analyses of the Tanga Beds samples. However, challenges to these studies were poor recovery of fossil plants from these samples. This resulted into conclusions made based on negative evidences influenced by significant absence of fossil *Glossopteris* plant (Seward 1922, Seward 1934). Apart from these studies, no thorough palynological data is available especially from the pre- Jurassic succession in the Tanga Basin. Hence, the age of the Tanga Beds remains inconclusive and a consistent stratigraphic framework remains a subject of ongoing debate (Wopfner 2002). This study, therefore presents the first attempt to conduct a palynological investigation of the subsurface (well core samples) from the Tanga Basin. The biostratigraphic data from this study is expected to provide a new lead in palynology researches in northern coastal Tanzania.

Stratigraphy

The Tanga Beds (Figure 3) are informally sub-divided into Lower, Middle and Upper divisions (Seward 1922). The Lower division consists of the non - fossiliferous rocks which overlie the basement rocks (Seward 1922). The lithology of these rocks consists of conglomerates, arkose and feldspathic sandstones interbedded by dark, carbonate rich shales (Figure 3), which contains significant plant remains (Seward 1922). The lower subdivision is conformably overlain by the Middle division which is characterized by thick strata of carbonate rich shales. These strata host abundant plant remains which are poorly preserved but reliable for a scientific study (Seward 1922). The Middle division is overlain conformably by the Upper-division which is dominated by alternating sandstones and sandy shales. This unit extends further to the north of the Tanga bay (Kent et al. 1971, Cooke 1974).

Materials and Methods

Materials

The following materials and data from Tanga Basin were absolutely necessary for this study: Geological maps, lithological well logs for the selected well and stratigraphic data gathered from 15 core samples from various depths of well X (Figure 4), and transmitted light microscope for sedimentary organic matter identification (Model: Microscope Primotech D/A cod, stage ESD, integrated IP Camera), software such as (C2 data analysis 1.7.2, Arc map version 10.1 and Adobe Illustrator Creativity Suite 6). Materials used for sieving the samples included sieves of different sizes. 120-micron sieves were used for the first run and 10-micron sieves for the second run and even the third run. Others were running water (i.e., tap water), three ultrasonic baths filled with water to the limit level, small plastic containers for storing final sieved material after the process completion (i.e., Vial Sample Eppis), a small water splash bottle, and a plastic jar/beaker (0.5-1 L). Portable mini centrifuge (table top centrifuge) and the vortex mixer shaker were also required.

Methods

Palynology sampling

The stratigraphic positions of the samples are the Middle and Upper portions of the informal Karoo stratigraphy in the Tanga Basin. Sampled cores are owned by the Tanzania Petroleum Development Corporation (TPDC) and are stored at the TPDC’s- Mikocheni core storage. All the fifteen (15) samples consisted of dark grey mudstone to occasionally silty-mud. The mudstone was dominated by fossilized plant remains and bituminous coal fragments (Figure 4). Very few samples were also collected from the siltstone intervals. In the course of sampling, upper most intervals were avoided to reduce the chances of oxidized materials that could hinder pollen and spore yields. The well was carefully logged to obtain as much details as possible (Figure 4).

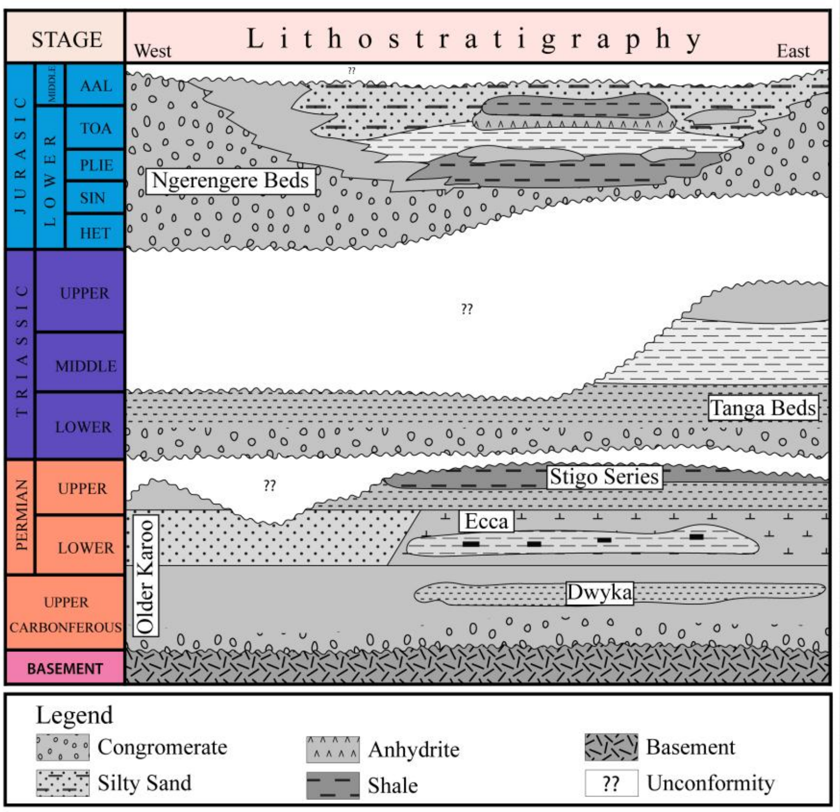

Figure 3: Stratigraphic column showing the lithostratigraphy of Tanga Beds (Modified after TPDC 1992). AAL = Aalenian, TOA = Toarcian, PLEI = Pliensbachian, SIN = Sinemurian, HET = Hettangian.

Laboratory sample processing

Palynomorphs in sedimentary rocks are brought through transportation by different dispersal agents before they are deposited and trapped in sediments. Therefore, in laboratory processing, maceration is used to free these miospores from their host rocks. Different maceration techniques are described by Wood et al. (1996) and Vega (1992). In this study, palynological processing involved the following:

i. Cleaning of the samples (i.e., physically removing visible impurities and eventually washing).
ii. Grinding into approximately 2 mm^2 (or smaller) parts to simplify the chemical processing by increasing the surface area for a chemical reaction to take place.
iii. Depending on the lithology, clay- and silty-rich samples less material (about 5-8 g) sand was required and with calcareous samples, more material was generally needed (approx. 10-15 g), while in organic-rich lithologies, like coal or black shales, 1-3 g were already sufficient.
iv. Placing the material in an acid-resistant plastic container (HDPE; preferable volume 180 ml or more) and labelling appropriately. Moving the samples to the laboratory for chemical processing and later in a fume-hood (protected environment).

v. Adding hydrofluoric acid (38-40%) to the sample (a very strong reaction that can be diminished by adding more hydrofluoric acid). When the reaction stopped, water was added to fill-up the sample container and left to settle over-night. After approximately twelve hours, decantation was performed without disturbing the settled sediments. Water was filled-up again and centrifugation was conducted.

vi. Placing the beakers with HF onto an orbital shaker for about 2 hours. After two hours of shaking, the samples were returned to a fume chamber. Eventually, the samples were washed to remove the organic matter rim formed at the side of the beaker and water was added to the samples. The samples were put away to rest for the night with closed lids.

vii. Decanting the samples on the next day, adding water, centrifuging and decanting again.

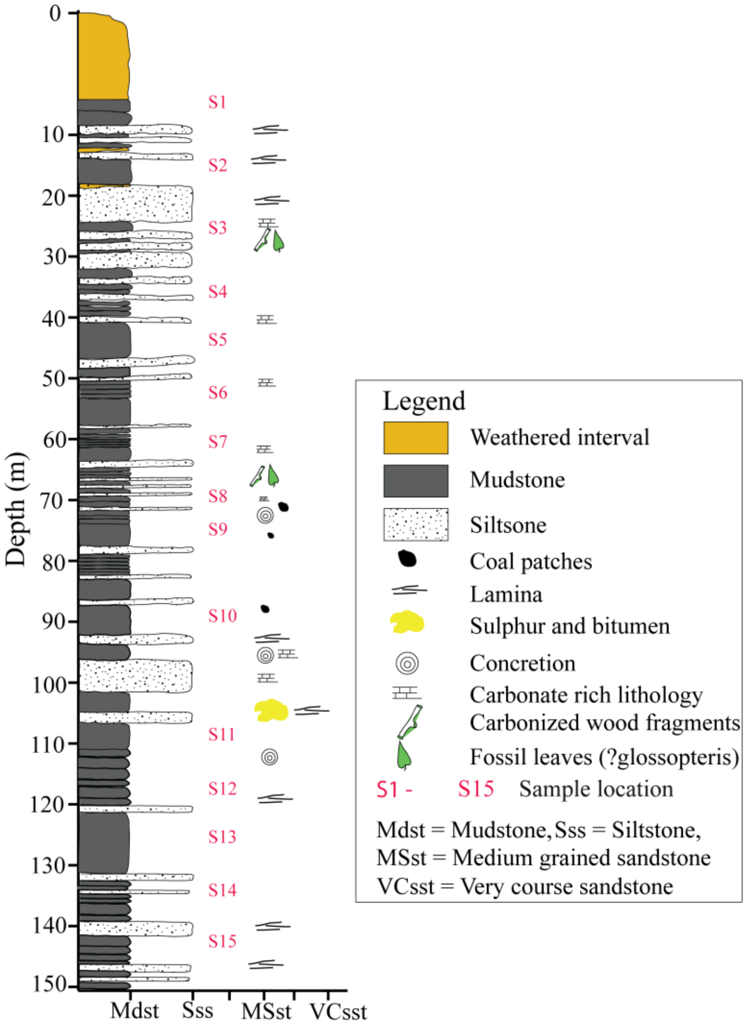

Figure 4: Well X (Lithological descriptions and sample location).

After the chemical procedure was done, the samples were ready to sieve. The residue containing palynomorphs were mounted to the slides ready for microscope work. The details of mounting and slide procedures are described by Vernal et al. (2010). After mounting, a transmitted-light microscope was used for examination of the palynomorphs including photographing. Objective magnifications of x16, x40, x60 and rarely x100 are used in examination. Photomicrography was done with a digital camera, which stores images in JPEG file format. These were later transferred to a computer for further analysis. The study of palynomorphs at generic and specific levels within each sample is conducted to establish the stratigraphic range of each taxon recovered. For pollen grains and spores, nomenclature used is according to Jansonius and Hills (1976). The nomenclature for non-pollen palynomorphs follows the descriptions by Tyson (1995).

Results and Discussion

Palynology

The palynomorphs analysed in this study are shown and illustrated in Plates 1-2. Generally, the main bisaccate pollen zone is recognized amongst well preserved non-pollen palynomorphs. Regardless of the quality of the specimens recovered, it is agreed (on the basis of the outline/shape, size, ornamentation and presence/absence of apertures) that the observed bisaccate pollen grains represent part of the *Alisporites-Falcisporites* complex. The dominant taxa include *Alisporites australis, Falcisporites zapfei, and Falcisporites stabilis*, with a few *Pteruchipollenites gracilis* pollen grains as sub dominant taxa in the assemblage. These assemblages are described below.

Falcisporites zapfei (Plate 1; Figure B and Plate 2; Figure A and B)
Bisaccate pollen; brown in color, amb oval, latitudinal elongated in all specimen; non-taeniae, haploxylonoid (Plate 1; Figure B and Plate 2; Figure B) to weakly diploxylonoid (Plate 2; Figure B), corpus weakly distinct (Plate 2; Figures A and B) to indistinct/ indistinguishable from sacci (Plate 1; Figure B), corpus outline latitudinal oval (Plate 2; Figure B) to ?rectangular (Plate 2; Figure A), capulla distinct, approximately 70%-80% width of the corpus (Plate 2; Figure A and B), sacci semi-circular and probably smaller than corpus (Plate 2; Figure A and B).

Alisporites australis (Plate 1; Figure C)
Bisaccate pollen, brown in color, bilaterally symmetrical, outline latitudinally elongated, slightly diploxylonoid to haploxylonoid, corpus weakly distinct with visible longitudinal furrow at the centre, cappa and cappula well distinct, sacci semicircular in shape.

Falcisporites stabilis (Plate 1; Figure D)
Bisaccate pollen, brown in color, strongly haploxylonoid, corpus weakly distinct, cappa distinct, width approximately 70% of the corpus, sacci distally inclined and probably vary in size.

Pteruchipollenites gracilis (Plate 1; Figure A)
Bisaccate pollen, amb latitudinal elongated oval, slightly diploxylonoid to haploxylonoid, bilaterally symmetrical, ?taeniate, corpus slightly distinct, pale brown color, sacci black in color, ?smaller than the corpus, and distally inclined, cappa distinct occupying 85% of the corpus width.

Organic residues

Organic residues (Plate 2: Figures C1, C2, and C3) represent 9% percent of total organic matter retrieved from the Tanga Beds samples (Figure 5). These include: unstructured amorphous organic matter with no structural framework but pits and scars probably caused by fungal damage or bacterial attacks. Equant massive opaque phytoclasts with no internal bio-structures, bio-structured phytoclasts, black to brown tracheid fragments with circular holes, lath shaped opaque phytoclasts with an angular outline characterized by an obvious structural framework are also observed.

Organic matter residues, such as plant fragments or fungal spores are important in inferring paleoenvironment of deposition of the studied samples. Also, different colors of plant fragments at recovery imply different thermal conditions of depths where the samples were collected. However, this is beyond the scope of this study.

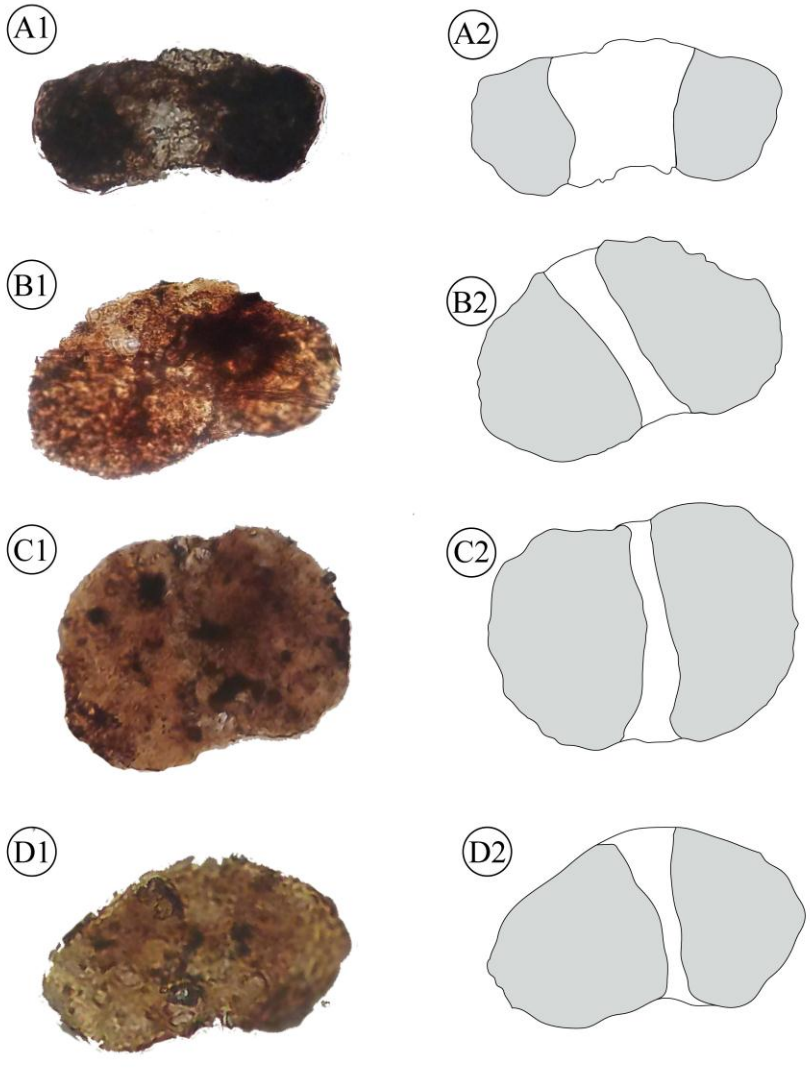

Plate 1: Representative pollen from the Tanga Beds. Sample and slide numbers are provided. **A**. **(1, 2)** *Pteruchipollenites gracilis* (Ottone and Garcia 1991), TNG-12. **B (1, 2)** *Falcisporites zapfei* (Freudenthal 1964, Jansonius and Hills 1976), TNG-S10. **C (1, 2)** *Alisporites australis* (Jansonius and Hills 1976, De Jersey and McKellar 2013), TNG-S5(03). **D (1, 2)** *Falcisporites stabilis* (Jansonius and Hills 1976), TNG-S12 (01).

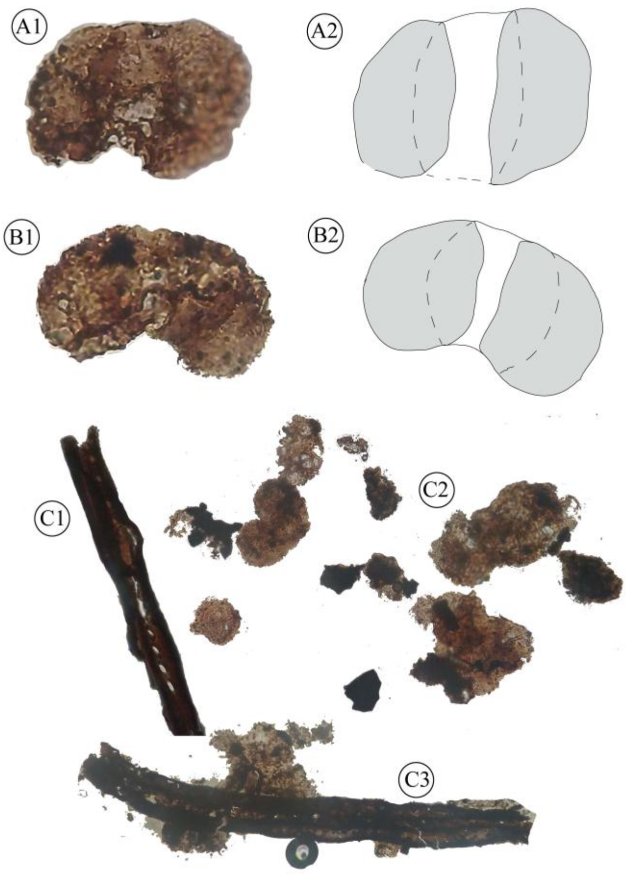

Plate 2: Representative pollen and palynodebris from the Tanga Beds. Sample and slide numbers are provided. **A (1, 2)** *Falcisporites zapfei* (Freudenthal 1964), TNG-S6 (02). **B (1, 2)** *Falcisporites zapfei* (Freudenthal 1964), TNG-S13 (1). **C (1, 3)** Bio structured phytoclasts (Batten 1982, Tyson 1995 and Batten and Stead 2005), TNG-S13 (02). **D (2)** Opaque phytoclasts (Massive), (Batten 1982, Tyson 1995 and Batten and Stead 2005), TNG-S13 (02).

Distribution and correlations

In this study, the presence of *Alisporites-Falcisporites* sp. as dominating taxon, and a noteworthy number of bissacates (Plates 1 and 2) in the assemblage suggests that the observed samples constitute palynomorphs of the Permo-Triassic period. Most palynological zonations of African Karoo, place *Alisporites australis* in the Lower Triassic or younger (Stapleton 1977) while *Falcisporites zapfei* and *Falcisporites stabilis* are placed in the Upper Permian (Schwindt et al. 2003 and Steiner et al. 2003). Fungal remains have also been reported to make part of this transition and a few were observed in this study. Nevertheless, the Late Permian signal appears to be powerful in these samples from an additional evidence of *Pteruchipollenites gracilis* and the observed *Glossopteris* (Figure 4) advocating that, the age of the observed samples to be older than Triassic (i.e., Late Permian).

As reported by other authors in Pakistan and eastern Australia (Brugman 1983), and in line of evidence from the European assemblages (Freudenthal 1964, Brugman 1983, Eshet et al. 1995), the striate bissacates (in comparison with the non-striate forms), tend to dominate in the Late Permian and Early Triassic to a large extent (Freudenthal 1964). Studies from different parts of the globe have also confirmed a similar pattern to a certain degree (Jansonius 1962). Most of these conclusions characterize the European assemblages and are still debatable. However, the reverse trend is observed in the current study where non-striate bissacates dominate the entire assemblage by 59% (Figure 5) and to the author’s opinion, there is a chance that observations were limited by preservation problems. Nevertheless, a few exceptions that are similar to the trend in this study also exist (Freudenthal 1964).

The *Alisporites-Falcisporites* complex has never been documented in a few existing miospore zonations of the Tanzanian Karoo including that of Hart (1965). Furthermore, comparison shows that, the pollen grains recovered in this study are different from those documented by Balduzzi et al. (1992) in their earlier work on sporomorph stratigraphy in the Karoo equivalent rocks (i.e., the ?Ngerengere beds) of the adjacent Ruvu Basin. Balduzzi et al. (1992) recorded a few non-striate bisaccate pollen grains from Kizimbani well samples of the Mandawa basin, ?correlatable to the Ngerengere Beds of the Ruvu Basin. The conclusions made by Balduzzi et al. (1992) regarding palynology of the Ruvu basin, relied on lithostratigraphic correlations since there is no any dating that has been done using samples from the actual locality (i.e., ?Ngerengere Beds). In the Mandawa Basin, southern coastal Tanzania, bisaccate pollen grains of Mesozoic (Cretaceous) and Cenozoic were also documented by Shrank (1999) and Mkuu (2018), respectively.

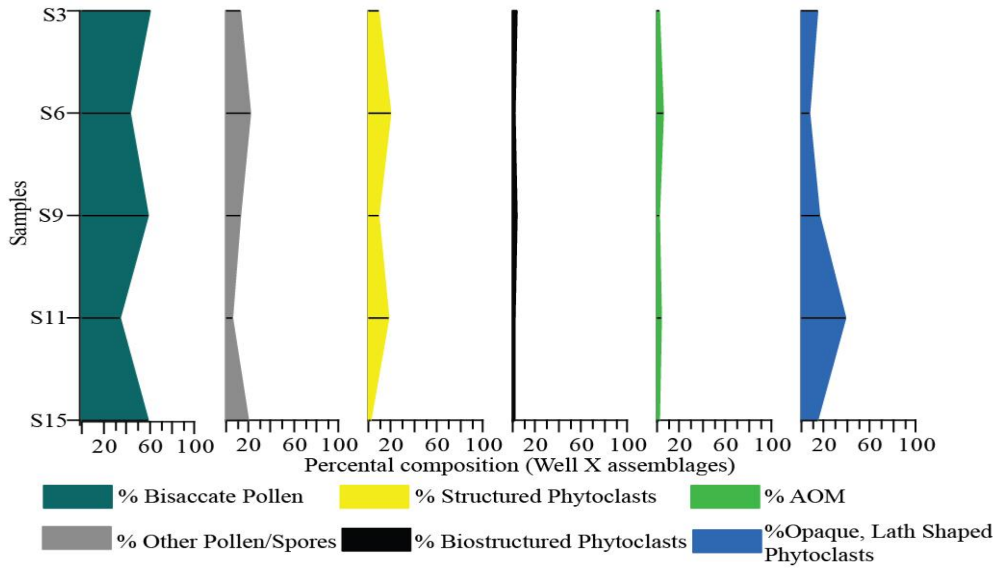

Figure 5: Percental composition of Well X assemblages.

Conclusions

The current study focused on palynology of the Karoo-equivalent Tanga Beds in the Tanga Basin, Tanzania. Based on sporomorph assemblages recovered from the Tanga Beds core samples, following-up on previous biostratigraphic works in the Tanga Basin. This study puts forward the following preliminary conclusions:

1. The recovered palynomorphs are poor to fairly well preserved, but their current state of preservation is still important for

a palynological study. The probable circumstances of pollen destruction in the Tanga Beds may relate to general questions regarding pollen preservation in the Permian–Triassic terrestrial Gondwana sequences. The observed fungal remains offer preliminary evidence of environmental disruptions.

2. The sporomorph assemblages presented herein from the Tanga Beds are interpreted to be typically of Late Permian to Early Triassic.
3. Relatively high abundance of well-preserved organic residues (non-pollen palynomorphs) such as fungal spores, hyphae, and micro plant fragments support a good palynofacies study to ascertain depositional environment, but more data will be required. As no dinoflagellates are observed so far, the assemblage reported in this study suggest terrestrial; depositional environments.

The sole use of palynology to determine with confidence the biostratigraphic age of Tanga Beds is limited by preservation and scarce data obtained at this stage. Therefore, future work will constitute more sampling from the Tanga beds and further analysis of the recovered palynomorphs.

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