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AGE REVISION OF THE MARIAKANI FORMATION OF THE UPPER DURUMA GROUP IN SOUTH LAMU BASIN OF KENYA BASED ON PRELIMINARY CALCAREOUS NANNOFOSSILS BIOSTRATIGRAPHY

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ABSTRACT

New biostratigraphic data provides evidence of the onlapping of the Jurassic and Cretaceous strata above older formations of the Duruma Series in the southern Lamu Basin. A calcareous nannofossils biostratigraphy study was undertaken on three samples consisting of sandstone and shale units outcropping in an area initially mapped belonging to the non-marine Mariakani Formation of the Karoo-Duruma Group in the southeast coastal Kenya. A total of nineteen moderately-to-well-preserved taxa characterizing the Pseudoconus enigma (NJ11) Zone of the Boreal or Watznaueria barnasae (NJT11) Zone of the Tethyan zonations were identified in sample №61 of the lower part of the section. The assemblage is dominated by such species as *Watznaueria barnesiae, W. britannica, Schizosphaerella punctulata, Lotharingius* cf. *L. contractus, Lotharingius sigillatus,* ?*Discorhabdus striatus and Watznaueria manivitiae.* Both nannofossil zonations correlate this layer with the lowermost Bathonian Zigzag Ammonite Zone. Sample №61 is stratigraphically younger than the upper shaly units of the Lower Member of the Kambe Formation from the Mwache River sections located some 25 km to the NE. This biostratigraphical evidence is the first recognition proving the presence of Early Bathonian strata in the Indo-Malgach Province since only Late Bajocian and Middle Bathonian ammonites have been described from this area. The Mid-Jurassic nannofossil assemblage share most of the zonal species determined in the corresponding stratotypes confirming marine connections with the Tethyan and Boreal realms. The correlations with the Bathonian and Albian stages stratotype sections and Ammonite zonations are also provided.

The overlying light grey-blue shale unit – samples №60 and 66 have an (?) Lower Cretaceous (Albian) age based on the presence of two zonal species – ?*Axopodorhabdus albianus* and *Eiffelithus turriseiffelii* that characterize the lower Eiffelithus turriseiffelii (BC27/NC10/CC9) Zone which makes them a correlative analogue of the fossiliferous Walu shales widely developed in the northern sector of the Post-Karoo Lamu Basin and the basal part of the Lindi Formation of Southern Tanzania.

This research was done in an attempt to upgrade and construct a detailed Meso-Cenozoic chrono – and biostratigraphic framework that is essential for regional and global correlations, paleogeographic reconstructions and exploration for hydrocarbon, water and other mineral resources. The results reveal a complex geological nature of the area with evidence of multiple transgressional – regressional episodes during the Jurassic and Cretaceous time, and show the need for a complete revision of the age for all mapped rock formations developed in the Karoo-Duruma and Post-Karoo Lamu basins. The Late Mid-Jurassic and Mid-Cretaceous marine transgressions progressed much farther to the west than originally mapped. This dataset renews and continues the discussion of how far west did the Jurassic marine sequences overlap the Karoo-Duruma Group deposits that was first suggested by some researchers in the early 20th century.

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1. INTRODUCTION

During the Mid-Jurassic, the Karoo-Duruma sedimentary basin in the southeast coastal Kenya was part of Western Gondwana that experienced drastic tectonic and paleogeomorphologic reorganizations related to the breakup of the Supercontinent. This was characterized by the shift from the previously prevailing Karoo continental depositional environments (Duruma Group) to the initial marine incursions represented by the limestones of the transgressive Kambe Formation. The age of the marine transgression remains debatable: according to the ammonite biostratigraphy (Galasz, 2017; Westermann *in* Galasz, 2017) this event took place during the Bajocian (170.3 Ma*), while evidence from calcareous nannofossils (Chiocchini et al., 2005) suggests an Aalenian (174.1 Ma*) or possibly even earlier stage. An earlier marine incursion occurred during the Toarcian time in the Lugh-Mandera Basin of North-Eastern Kenya resulting in the deposition of the lower portion of the Daua Group represented by the Didimtu Formation limestones (Schlüter, 1997).

Both the Mariakani of the Middle to Upper Triassic age and Mazeras Formations from the Upper Triassic-Lower Jurassic are composed mainly of fluvial sandstones packages that accumulated under continental conditions (Caswell, 1953; 1956; Rais-Assa, 1988; Karanja et al., 1993). The lithological resemblance of these and earlier formations to those of the Late Jurassic including the Miritini shales led to an early suspicion among the first researchers that they may have an identical age (E. Fraas *in* Caswell, 1956, pp. 2, 20, 52).

The identification of moderately preserved calcareous nannofossil species from a sandstone sample lying beneath the Mariakani shales mapped by Caswell (1956) proved that they belong to the Mid-Late Jurassic, while the abovementioned shales have a mid-Cretaceous age. The biostratigraphy results provide solid evidence that the two examined lithologies accumulated in nearshore (deltaic?) to marine conditions of the Mesozoic. These strata accumulated during the Mid-Jurassic East vs West Gondwana split and represent the transgressional sections, the extent of which is more westerly than originally suggested (Waga et al., 2019).

2. PLATE TECTONICS AND PALEOGEOGRAPHY

The tectonic setting and structural development of the Karoo-Duruma basin and the Post-Karoo Lamu basin and neighboring basins is a direct result of both plate tectonics including the mantle plume processes. During the pre – mid Jurassic time (201.3-152.1 Ma*), the Karoo-Duruma and post-Karoo Lamu basins were part of the Gondwana supercontinent. All tight and loose reassembly models of this supercontinent (Bosellini, 1986; Reeves et al., 1987; Karanja et al., 1993; Reeves et al., 2002; Reeves, 2014) place Madagascar, India and Sri Lanka continents right opposite the east African coastline of Kenya, Somalia and Tanzania, at a triple junction (Figure 1). This central part of this supercontinent remained relatively stable from the Early Cambrian times (600 Ma) for the next 250 Ma until the Late Carboniferous, when the Karoo rifting processes were initiated in the southern, eastern Africa, western Madagascar, India and Antarctica enabling sediment accumulation (Reeves, 2014). In the Early Jurassic, this Karoo rift experienced some reactivation resulting in the creation of the Tethys Ocean embayment along the Somalia coast from which the marine conditions advanced further to the south. This was accompanied by limited deposition of evaporates at about 200 Ma that is well seen on seismic reflection data (Reeves et al., 1987). A sinistral (147-110 Ma) strike-slip movement that followed generated the Rovuma Basin in Tanzania and Mozambique, and also the Morondava basin in Madagascar. It was along this structure – the proto-Davie Fault Zone that the Gondwana supercontinent separated into its West (Africa) and East (Madagascar, India, Sri Lanka) segments. Magnetic data suggests that this began slightly before the Late Oxfordian (ca. 150 Ma; Bosellini, 1986). Later, Madagascar ceased drifting southwards and has been relatively stationary at this position since the Aptian (120 Ma; Reeves, 2014) or Early Hauterivian (~130 Ma; Bosellini, 1986). At the same time, towards the north, the passive margin basins of Majunga in Madagascar and Lamu embayment of Kenya & Somalia were developed (Reeves, 2014). Figure 1 illustrates the adopted paleogeography reconstruction maps from various sources for four time slices starting from the Early Jurassic (Hettangian, 200 Ma), and extending through the Middle Jurassic (Bathonian, 167.2 Ma) and Late Jurassic (Tithonian, 150 Ma), through to the Late Jurassic-Early Cretaceous (Tithonian/Berriasian, 145 Ma).

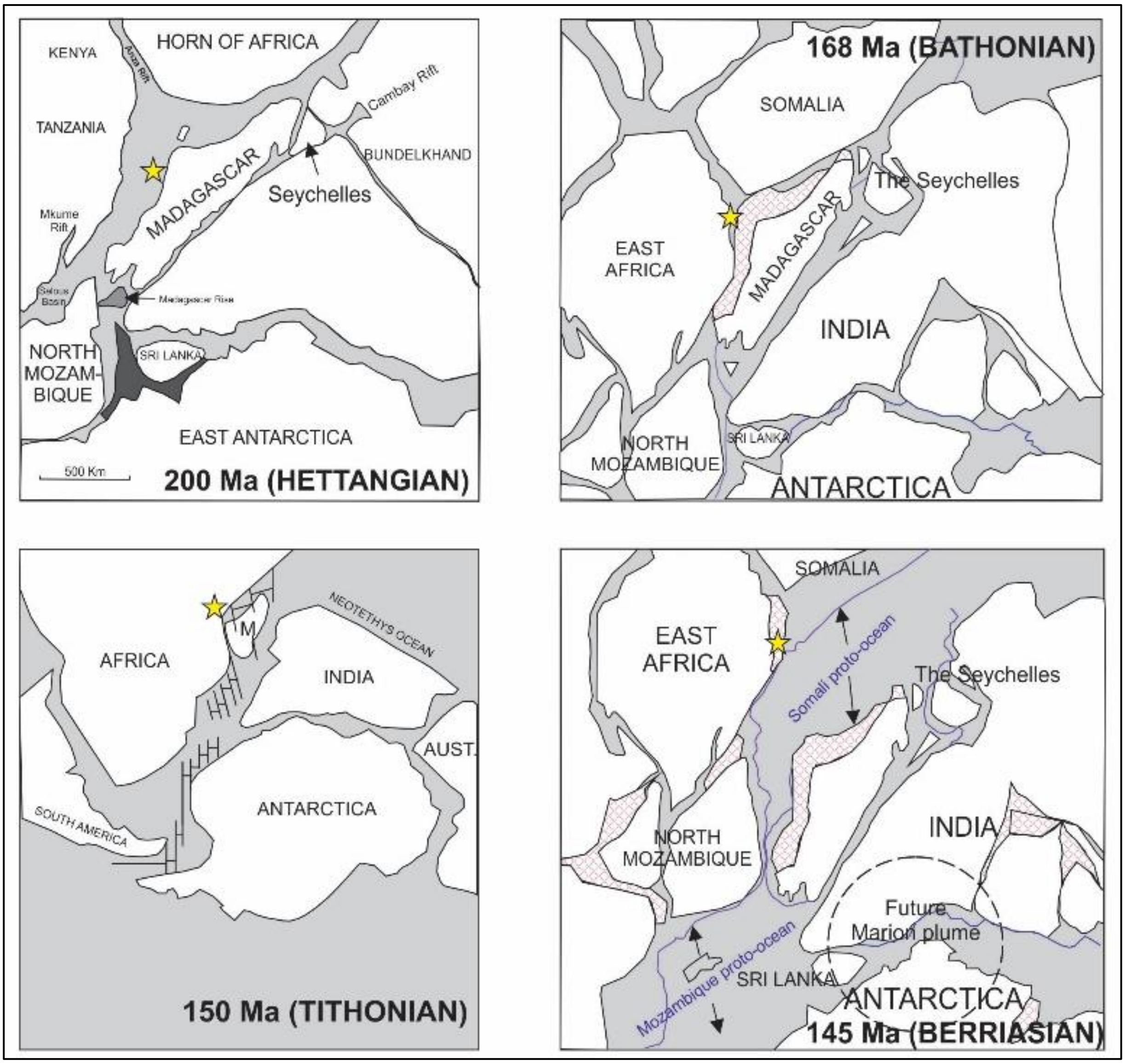

Figure 1. Modified Paleogeography maps of the Early (200 Ma), Middle (168 Ma) and Late Jurassic (150 Ma & 145 Ma) from Reeves et al. (2002), Karanja et al. (1993) and Reeves (2014). Yellow star represents the study location.

The dispersing of the supercontinent land masses was a result of consequent breakouts of mantle plumes (Karoo/Bouvet at 182 Ma, Marion at ~88 Ma, Reunion & Deccan Traps at ~66 Ma and recent activities near Comores Islands *in* Reeves, 2014), rifting and drifting phases. These processes led to a) the formation of grabens and half-grabens and accumulation of syn-rift Permo-Triassic –Early Jurassic successions; b) Mid-Jurassic to Paleogene drift and c) Late Paleogene-Present day passive margin sedimentation (USGS, 2012). Reeves et al. (1987, p. 308) provide a two stage evolution for the eastern Kenya region basins: a) active rifting from the Carboniferous – Permian until the Mid-Jurassic for the Karoo-Duruma basin; and, b) passive margin basin stage from Mid-Jurassic – Present for the Post-Karoo Lamu basin.

3. STRATIGRAPHIC FRAMEWORK AND PREVIOUS NANNOFOSSIL BIOSTRATIGRAPHY STUDIES

Most of the broad stratigraphic subdivisions of the Mombasa region were developed during the late 19th to early 20th centuries, and related to the contributions of Gregory (1921), McKinnon-Woods (1930), Spath (1920, 1930) and others. More detailed bio – and litho – stratigraphic analyses of the Meso – Cenozoic sediments of the Karoo-Duruma and Post Karoo Lamu basins were proposed much later in the 1950 – 1980s when significant progress in the understanding of the region's stratigraphy was made following the medium-scale geological mapping of this area (Miller, 1952; Caswell, 1953; 1956; Thompson, 1956). Since then, the proposed stratigraphic units with minor changes have been included into the modern stratigraphic schemes of the Meso-Cenozoic of southeastern Kenya (Walters et Linton, 1973 in Karanja et al., 1993; Rais-Assa, 1988; Karanja et al., 1993; Nyagah, 1995). Lately, there have been sporadic attempts to update these stratigraphic subdivisions through detail biostratigraphy provided by various index fossil groups, such as, spores and pollen (Hankel, 1991,1992), calcareous nannofossils (Chiocchini et al., 2005; Waga et al., 2019), ammonites (Verma & Westermann, 1984; Galasz, 2017).

The Karoo-Duruma Group deposits of the Late Paleozoic-Mid Mesozoic or Late Carbonifereous – Lower Jurassic are considered within the following Formations: Taru, Maji -ya -Chumvi, Mariakani, and Mazeras which represent alluvial-fan, braided fluvial plain, fluvial-fan-delta and lacustrine depositional systems complexes (Rais-Assa, 1988; Karanja et al., 1993). These are succeeded by the Kambe and Mtomkuu Formations which include the Upper Jurassic Kibiongoni beds, Miritini, Rabai and Changamwe shales (Caswell, 1953; 1956; Rais-Assa, 1988; Karanja et al., 1993) all of which characterize the marine transgression phase related to the further disintegration of the East Gondwana. All previous mapping exercises performed within this region (Caswell, 1953; Rais-Assa, 1988; Karanja et al., 1993) have reported that the marine Jurassic Kambe Formation deposits transgressively overlie the fluvial – aeolian deposits of the Mazeras Formation (Upper Triassic-Lower Jurassic) with a sharp contact characterized by either a major unconformity, or a normal fault with a basinward hade to the south-east.

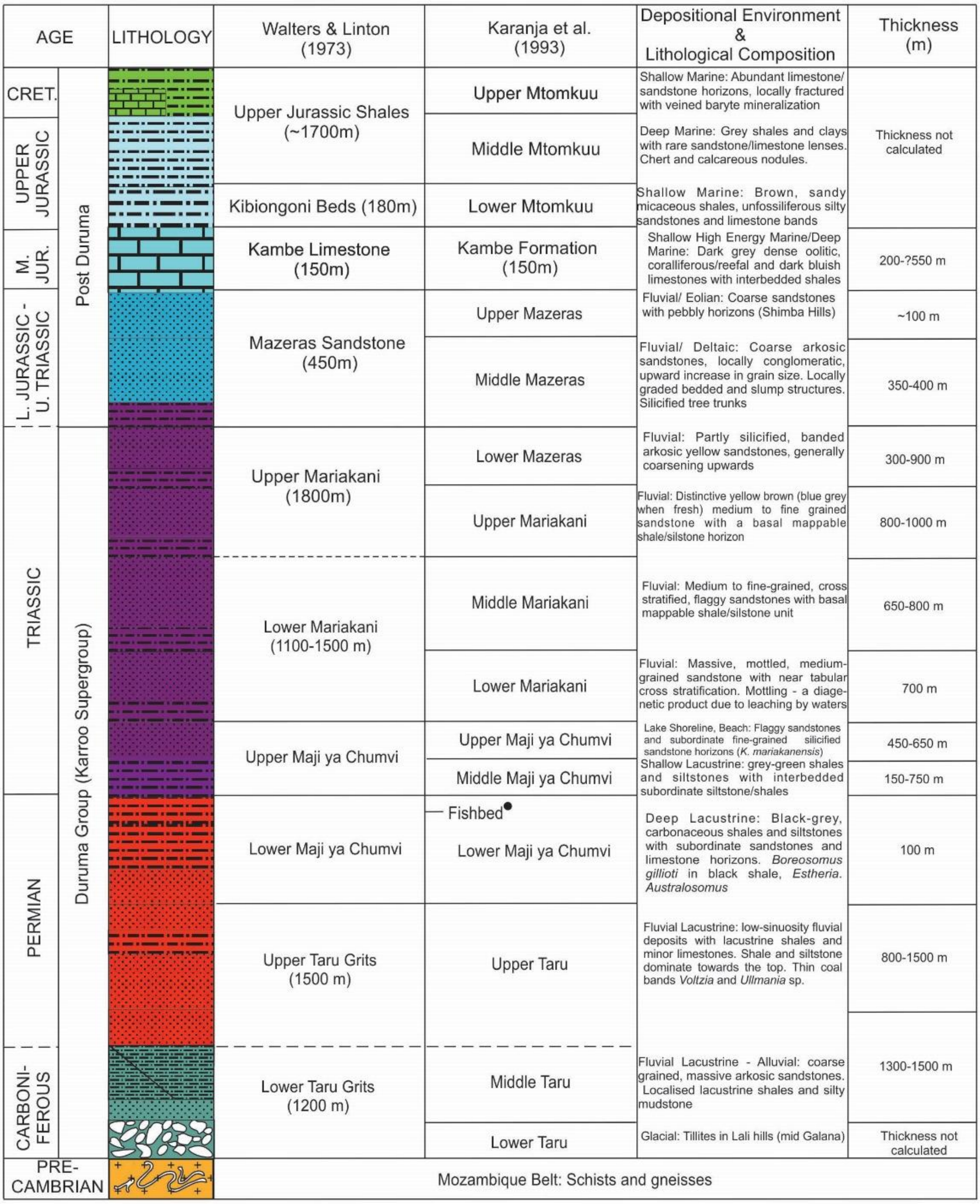

Figure 2. Stratigraphy of the Late Paleozoic and Mesozoic sediments outcrops of Coastal Kenya (Modified after Cannon et al., 1981 and Karanja et al., 1993)

According to the geological map of the Kilifi-Mazeras area (Caswell, 1956), the studied outcrop locations and collected samples in Waypoints 060 and H1 (Figure 3) all belong to the Mariakani Formation of the Karoo-Duruma Group. This area is located in the vicinity of the Mazeras-Kinango road junction (Figure 3).

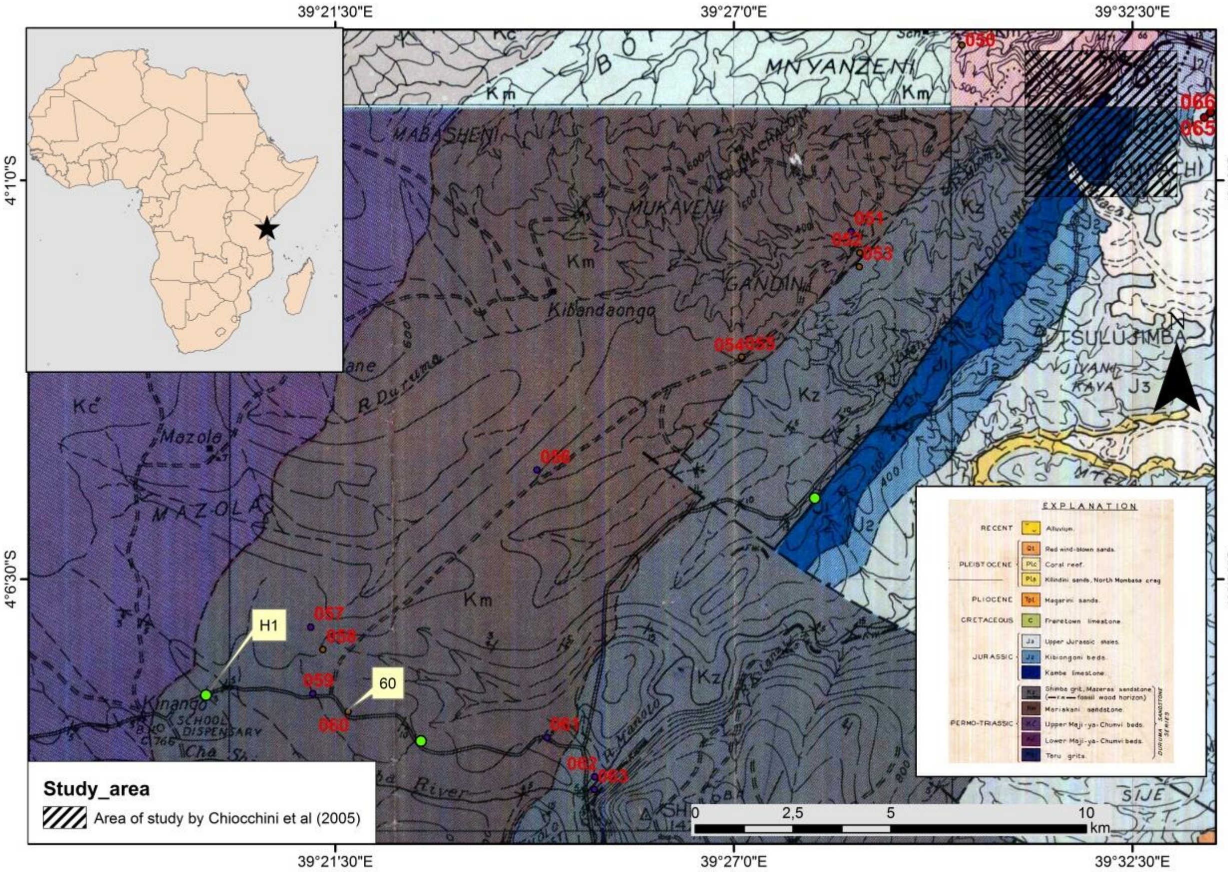

Figure 3. Geological maps of Miller (1952) and Caswell (1953; 1956) with waypoints readings and samples collected from the current research location and that of Chiocchini et al. (2005).

In the Mombasa-Kwale area, the Mariakani Formation consists of a series of fine-grained, flaggy sandstones packages and silty shales that conformably lay above the Maji-ya-Chumvi Formation beds (Caswell, 1953). Macroscopically, these are grey, greenish-grey or yellowish to brownish upon weathering. They are well-jointed, ripple-marked and current-bedded and show evidence of slumping. To the north, in the Kilifi-Mazeras area, Caswell (1953) subdivides the Mariakani Formation into two Members based on the color variations with the Lower Member of the Formation represented by light greenish grey and blotched or mottled sandstones, while the Upper Member has darker greenish-brown or yellowish-brown colors.

Towards the Mariakani – Kizurini area, Karanja et al. (1993) and later Schlüter (1997) subdivided the Mariakani Formation into three Members – Lower, Middle and Upper comprising fluvial sandstone packages separated by the Middle mappable shale/siltstone horizons. From bottom to top these are: a) Lower Member comprised of massive, mottled, medium-grained sandstones, locally showing faintly preserved near tabular cross stratification. The mottling is a result of diagenetic processes, and indicates removal of former carbonate cement by surface or near surface leaching by acidic pore waters; b) Middle member comprised of medium- to fine-grained, cross-stratified, flaggy sandstones with basal mappable shale/siltstone units and c) Upper Member comprised of distinctive yellow brown (blue grey when fresh) medium – to fine-grained sandstones which also have a basal mappable shale/siltstone horizon. Locally the sandstones are silicified, cross-stratified, massive and thinly bedded. The Mariakani Formation attains thicknesses varying in the range of 1800-2400 m (Schlüter, 1997, p.179).

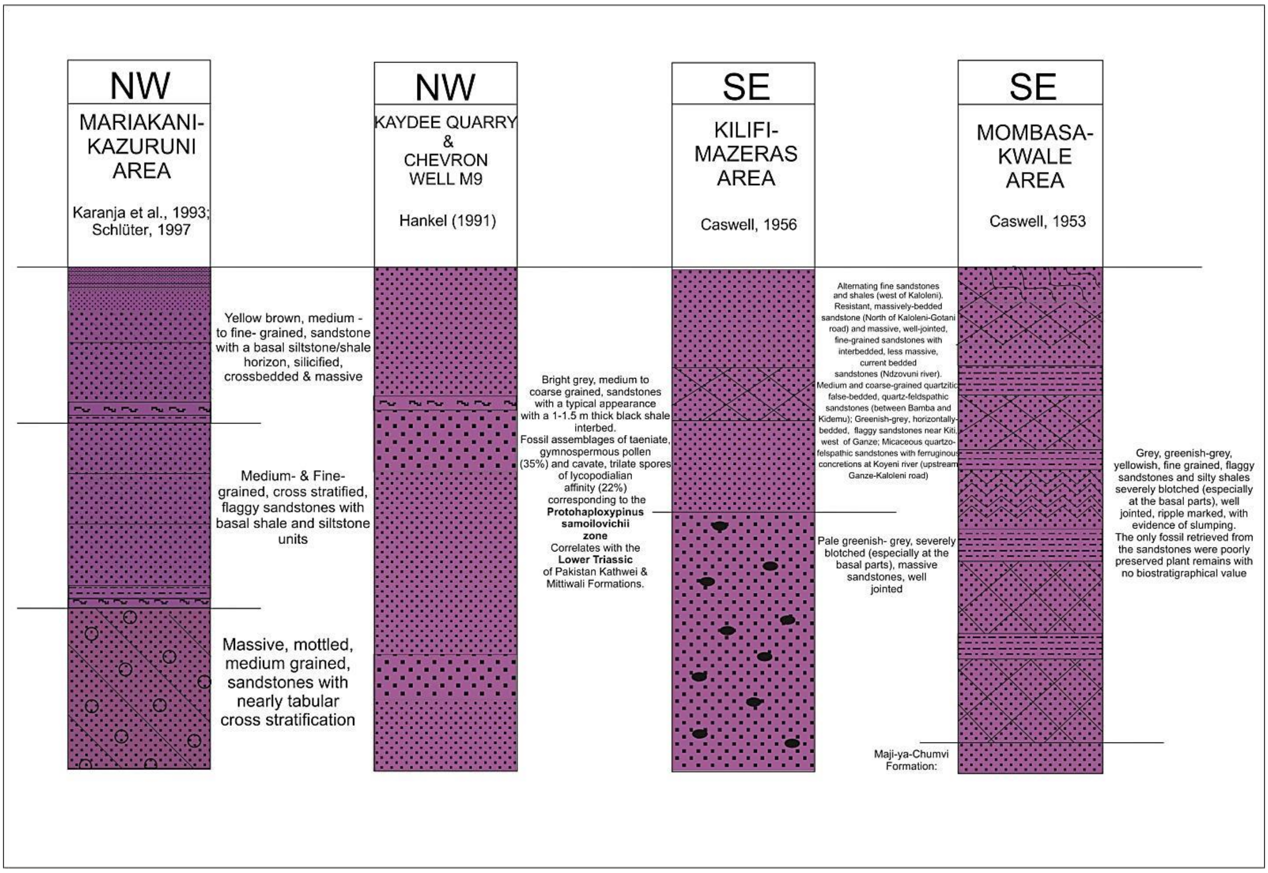

Figure 4. The litho – and biostratigraphy of the Mariakani Formation in Karoo-Duruma basin based on Caswell (1953; 1956), Hankel (1991), Karanja et al. (1993) and Schlüter (1997) interpretations.

Spores and pollen microfossil remains were first reported by Hankel (1991) from the Lower and Middle Members of the Mariakani Formation who analyzed 20 samples collected from the Kaydee Quarry and Chevron borehole M-9 located some 35.89 km and 33.26 km to the North-East and North-West, respectively, of the current study area. At these sites, the Mariakani Formation section is represented by a 20 m exposure composed of bright grey, medium to coarse grained sandstones with a typical mottled appearance and a 1.0 – 1.5 m thick black shale interbed. The samples contained a relatively rich palynomorph content of good to moderate preservation. The assemblage is dominated by taeniate, gymnospermous pollen (35.7%) and cavate, trilete spores of lycopodialian affinity (22.9%). Both of these groups dominate in the assemblage. The identified microflora and lithology from the Kaydee Quarry resembles that from the Chevron borehole M-9 (some 1.6 km SW of Kaydee Quarry). Therefore, it was suggested that these two sections are contemporaneous and belong to the *Protohaploxypinus samoilovichii zone* correlating it with Lower Triassic assemblages of Pakistan (Kathwai and Mittiwali Formation), India (Purnea Basin), Western Australia (*Kraeuselisporites saeptatus zone;* Kockatea shale), upper part of Tuggerah Formation and Patonga claystone of New South Wales, Queensland and Zone IIA uppermost Middle Sakamena Formation of Madagascar (Hankel, 1991).

The depositional environment of the Mariakani Formation sediments remains debatable with even some bizarre suggestions made. The blotched or mottled spheres of the sandstone seem to be diagenetic. They occurred during or shortly after the deposition. They are compressed on the upper and lower surfaces (Caswell, 1953; 1956). Gregory *in* Caswell, 1953 considered them to be aggregates of finer particles of quartz, feldspar, and epidote. Microscope sections examined by Caswell (1956) have rejected this opinion. Another theory that has also been abandoned is that of Thompson (1956) stating that a slight chemical change in the sand occurred as a result of bioturbation of the strata by worms, and that the mottled sandstones represent remains of digestive tracts. Earlier Caswell (1953) suggested that the blotching was caused by the initiation of local centers of leaching that left spheres deficient in certain constituents. Karanja et al. (1993) and Schlüter (1997) emphasized that the lithology of the Mariakani Member indicated reworking of the basement possibly due to renewed uplifting of the basin shoulders, while the sedimentary features suggest mainly fluvial low sinuosity/braided channel environment of deposition. Hankel (1991) concluded that the shale horizon of the Mariakani Formation was deposited in a lacustrine and/or deltaic environment. The investigated shale horizon might have accumulated in a particular sub-environment of a deltaic complex.

Chiocchini et al. (2005) proposed the first nannofossil biozonation of the undisputed Mid-Jurassic aged Lower Kambe Formation exposed near Mombasa town (Mwache River area). Here four lithological units are developed and their sedimentological features indicate transitional shoreline, mid to outer ramp depositional environments. The nannofossil content enabled to conclude that the age of the formation is Aalenian-Bajocian p.p, contrary to the ammonite biostratigraphy which dated the same formation units as Bajocian. This age discrepancy was attributed to the complex tectonic history of the area (Chiocchini et al., 2005).

4. MATERIALS AND METHODS

In January 2018, a reconnaissance mapping exercise was undertaken in the southern sector of the Karoo-Duruma and onshore Lamu basins during which more than 30 samples representing the top Karoo –Duruma Group and Kambe Formation – Upper Jurassic shales were collected with their GPS locations recorded. They were analyzed for their microfossil content, namely for calcareous nannofossils. This group of microfossils is widely used for biostratigraphic and regional correlation purposes of Mesozoic-Cenozoic marine sediments. Among the collected samples, three (3) were of particular interest since they reacted on cold diluted HCl acid confirming high carbonate content. Their lithological composition, stratigraphic affiliation and GPS locations are provided in Table 1.

Table 1. List of samples collected for the calcareous nannofossil biostratigraphy study

	Sample ID	Formation (Caswell maps)	Lithology	GPS location
1	66	Mariakani (Km)	Light grey, shales	39°19'43"E, 4°8'6"S
2	60	Mariakani (Km)	Jointed, Limy sandstone	39°21'40.721"E, 3°52'45.142"S
3	61	Mariakani (Km)	Light grey, shales	39°21'40.721"E, 4°8'19.637"S

The locations where the samples were collected from are presented by small exposures up to a meter in height; Figure 5) consisting of a succession of light grey, weathered soft shales (samples № 60 & H1) overlying layers of heavily jointed (Sample №61) light-greyish, fine-grained, carbonate sandstones.

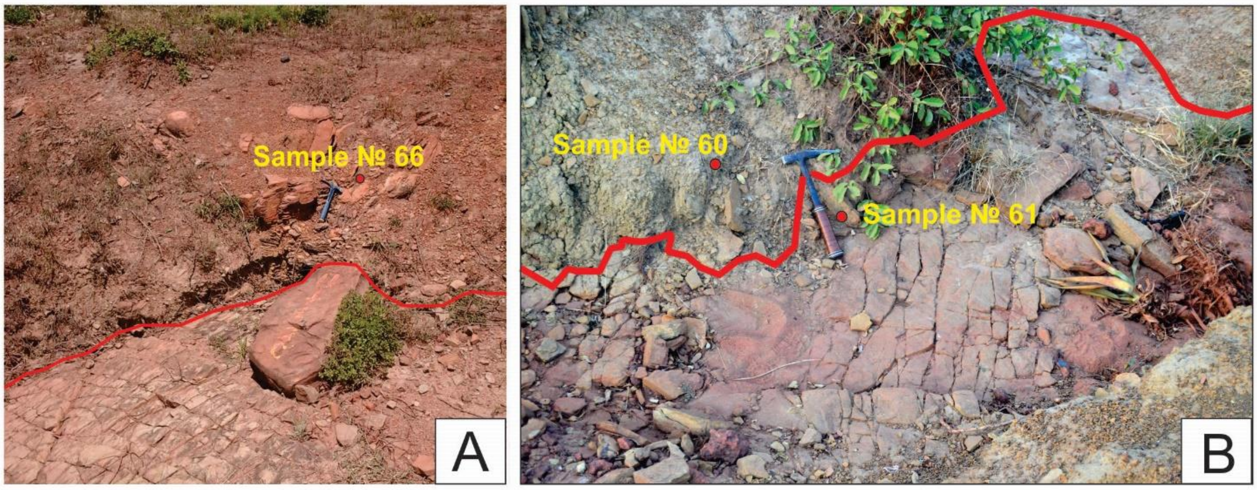

Figure 5. Photos of studied outcrops at waypoints (A) H1 and (B) 060 composed of heavily jointed, light grey-pinkish sandstones (sample №61) and light-grey shales (sample № 60)

The carbonate sandstone possesses a minor cross bedding (sample №61; Waypoint 060) with the following bedding measurements: 284NW/008SW. The overlying shales have evidence of slumping. The samples from both layers contained calcareous nannofossils of moderate to poor preservation.

The standard techniques described in Bown et Young (1998) were used to prepare the smear slides. The rock samples and prepared smear slides are stored at the Department of Earth and Climate Sciences, University of Nairobi. The slides were examined using the MI-6 microscope under 1000-1200 magnification with an average of 60 fields viewed for each smear slide. The standard Jurassic nannofossil biozonation of Bown et Cooper (1998) which provides correlation with the ammonite biostratigraphy was used in this study. Previous results of nannofossil and ammonite biozonations (Chiocchini et al., 2005; Galasz, 2017) of Jurassic sediments from neighboring sections and exposures were incorporated for correlation purposes.

5. RESULTS AND DISCUSSION

5.1. Section at Waypoint H1

Sample №66 from Section H1 consists of a thin bed (approximately 1 m) light grey, highly fissile, carbonate shale overlaying fractured, light brown carbonate sandstones (Figure 5A). A moderately diverse and preserved nannofossil assemblage consisting of some twelve (12) species was identified within the shale unit. These were *Watznaueria barnasae*, ?*Axopodorhabdus* spp., *Thoracosphaera* spp., ?*Eiffelithus turriseifelli, Prediscosphaera* sp., *Watznaueria* sp., *Watznaueria* cf. *W. barnasae*, *Watznaueria* cf. *W. biporta*, *W. britannica* C, *W. britannica* A and *W. cf. W. britannica. Lothatingius* sp. is probably reworked specie from the underlying Jurassic sandstone formation.

This assemblage characterizes the Eiffellithus turriseifellii Zone (BC27) of the Bown et al. (1998) Zonation or the synonymous NC 10 Zone of the Bralower et al. (1993) zonation. This Zone (Figure 6) is the correlative analogue of the Eiffelithus turriseiffelii (CC9) Zone of Sissingh (1977) Zonation. All these zonations suggest a mid-Cretaceous age (Albian-Cenomanian transition) for these overlying shaly units. In the Post-Karoo Lamu basin stratigraphy, the mid-Cretaceous is considered within the thick Walu shales commonly reported from the northern sector of the Lamu Basin. They comprise both deep and shallow-water marine facies that accumulated during the mid-Cretaceous transgressive phase (Nyagah, 1995). Walu shales contain a diverse microfossil assemblage characterizing shallow water to bathyal conditions. The only planktonic foraminifera associated with these shales is *Hedbergella* cf. *sigali* (Nyagah, 1995). As per the latest taxonomic database (www.microtax.org) the Last Occurrence (LO) of this specie occurs in the latest Aptian stage, within the T. bejaouaensis Zone; 113.26-118.02Ma).

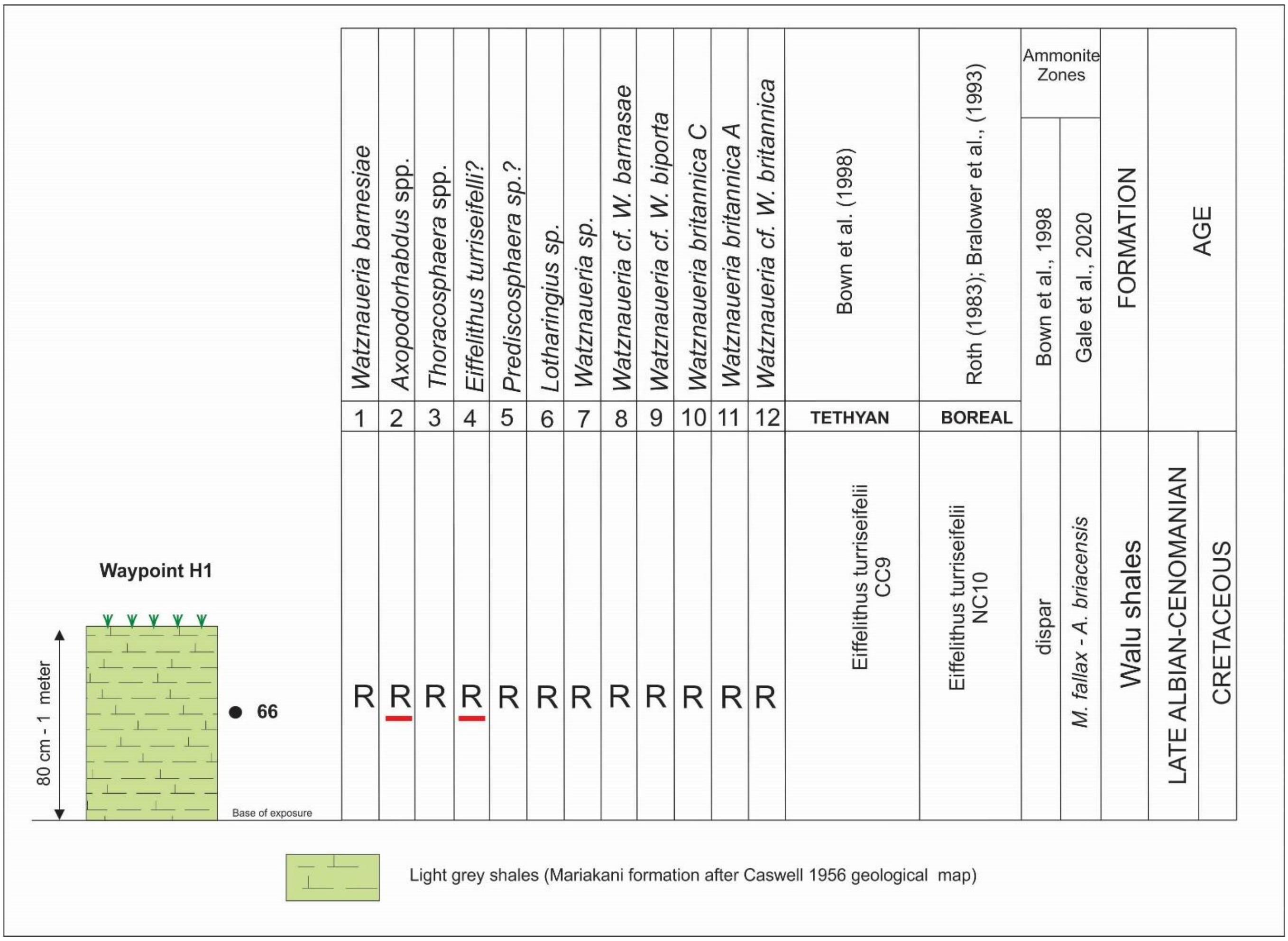

Figure 6. The distribution of calcareous nannofossils of the examined exposure at sample 66 in waypoint H1

5.2. Section at Waypoint 60

The section at Waypoint 60 occurs some 3.7 km to the east from Waypoint H1 (Figure 3). The examined samples include the lower sample № 61 which is composed of jointed sandstones (Figure 7) and contains a diverse, moderately to well preserved nannofossil assemblage consisting of nineteen (19) nannofossil species. Among them the most common were: *Watznaueria barnasae*, ?*Watznaueria britannica*, complete and fragmented coccolithospheres of *Schizosphaerella cf. S. punctulata-Thoracosphaera spp.* group (Plate I, Fig. 25)*, Lotharingius cf. L. contractus, Discorhabdus striatus, Lotharingius spp.*, *Watznaueria spp* , *Watznaueria manivitiae* (Plate II, Fig 7-8, 23), *Lotharingius sigillatus?* (Plate III, Fig. 29; Plate IV, Fig. 7), *Lotharingius velatus* and *Lotharingius cf. L. hauffii* (Plate IV, Figs. 21, 22), *Biscutum dubium*, *Discorhabdus striatus*, *Lotharingius cf. L. velatus,* ?*Acadialithus denne*i, *Lotharingius hauffii*, (?) *Lotharingius umbriensis*, *Watznaueria fossacincta, Pseudoconus enigma* (Plate I, Fig. 26).

Based on the FAD *Watznaueria barnasae*, the nannofossil assemblage is assigned to the lower part of Watznaueria barnasae (NJT11) Zone of the Tethyan zonation (Mattioli et Erba, 1999; Ferreira et al., 2019) and defined as the interval between the FO *Watznaueria barnasae* to the FO *Cyclagelosphaera wiedmannii.* All associated species mentioned for the NJT11 Zone (Mattioli et Erba, 1999), except for *Cyclogelosphaera margerelii*, are present in the studied nannofossil assemblage. Sample № 61 also corresponds to the boreal Pseudoconus enigma (NJ11) Zone of the Lower Bathonian (Bown et Cooper, 1998) that is identified as the interval between the FO *Pseudoconus enigma* to FO *Ansulasphaera helvetica* (Bown et Cooper, 1998; p. 39). NJ11 Zone correlates with the Zigzag Ammonite Zone (Bown et Cooper, 1998) and the Convergens Subzone (Fernandez-Lopez et al., 2009; Fernandez-Lopez, 2009).

A specimen resembling *Micula staurophora* was identified in this sample (Plate IV, Figure 30). Species of this genus are known commonly to occur in the Late Cretaceous (Coniacian-Maastrichtian interval; http://www.mikrotax.org/; Perch-Nielsen, 1985, p.388,). Recent studies from Kachchh (also spelled as Cutch mainland) in western India have provided evidence of the presence of *M. staurophora* in the late Early Aalenian (Mid Jurassic) Dingi Hill member of the Kaladongar formation (Rai et Jain, 2013, pp. 108, 110). However, we suggest that the appearance of this specimen in the nannofossil assemblage might as well be a result of contamination. In the southern sector of the Lamu Basin, the species of *Rucinolithus* genera (? *R. aff. irregularis*, ?*Assipetra cf. A. terebrodentarius youngii*) occur within the late Mid-Jurassic (Bathonian) sediments. This biostratigraphy results support the suggestion of the Jurassic origin of this genera (Tiraboschi et Erba, 2010).

Thus, the jointed carbonate sandstone layer (Figure 7) is a correlative analogue of the mid-Jurassic Kambe formation (Caswell, 1953, 1956; Rais-Assa, 1988) which is composed predominantly of limestones with interbedded shales (Karanja et al., 1993).

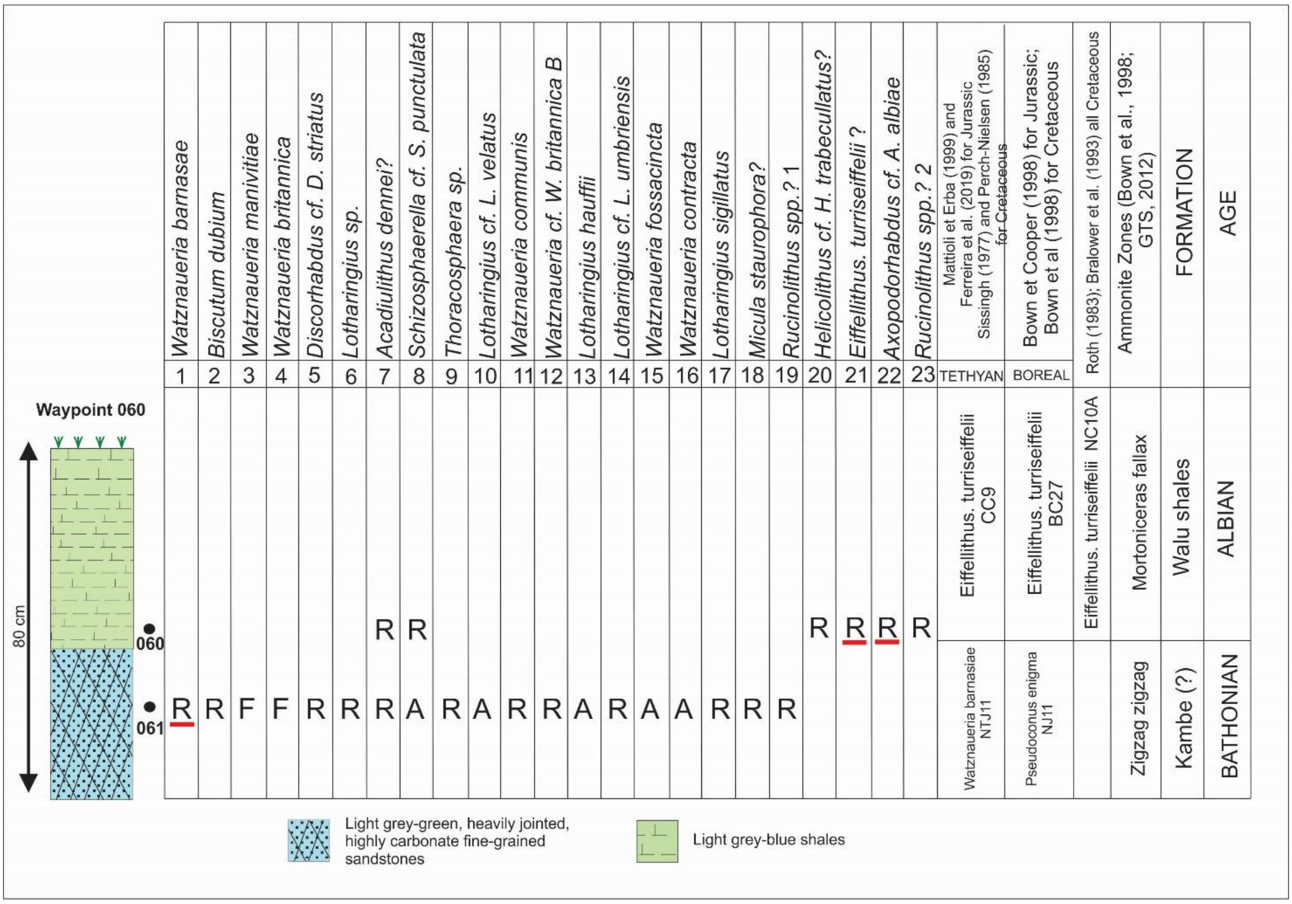

Figure 7. Stratigraphy and the distribution of calcareous nannofossils in samples №61 and 60 of the examined exposure at waypoint № 060

The overlying shale unit (sample № 60) contained remains of poorly to moderately preserved nannofossil assemblage of six species including singular forms and fragments of *? Schizaphaerella cf. S. punctulata,* and heavily overgrown specimens of *?Ethmorhabdus gallicus or Retacapsa cf. R. incompta?/ Helicolithus cf. trabecullatus* (Plate V; Figures. 7-12). Additionally, the sample contained nannoliths belonging to *Rucinolithus spp* (Plate V; Figure 6) and biozonal species – (?) *Axopodorhabdus cf. A. albianus* and *Eiffelithus turriseifelii*? (Plate V; Figures 9, 13-14) whose presence correlates sample № 60 with the Late Albian Eiffelithus turriseiffelii (CC9) Zone of Sissingh (1977) and Axopodorhabdus albianus NC9 – Eiffelithus turriseiffelii NC10 Zones of Roth (1978, 1984) and Bralower et al. (1993) or the Axopodorhabdus albianus (BC25) – Eiffelithus turriseifelii (BC27) Zones of Bown et al. (1998). The sample also contains large and massive silica grains with thin carbonate coats. Similar to the section at waypoint H1, the identified nannofossils from this shale unit characterizes the mid-Cretaceous Walu Shales (Figure 7).

The low species diversity and poor nannofossil preservation in the Early Cretaceous shales is likely related to the increased detrital input from the uplifted highlands that induced eutrophic conditions that stressed the development of both nannoconids and coccoliths. The shallow marine conditions and cooling trend of surface waters that dominated in the Early Cretaceous (Albian) in the South Lamu basin is supported by the complete absence of *Nannoconus* species that are warm water taxa and common in low latitudinal settings (Wagreich, 1992; Mutterlose et al., 2005). The genus has also been reported to prefer to grow in deeper (80-200 m) waters of the lower photic zone (Erba, 1994; Mutterlose et al., 2005).

5.3. Correlation between ammonite and other nannofossil biostratigraphy results

Jurassic nannofossils have been reported from other neighboring localities of the Post-Karoo Lamu Basin. The first nannofossil biozonation was performed by Chiocchini et al. (2005) who examined the content of the Mid-Jurassic (Lower Kambe Formation) from the Mwache river tributary sections that are located approximately 22.3 km to the north-east of our study area (Figure 3).

Our biostratigraphy interpretations indicate that the studied strata are stratigraphically younger than those examined by Chiocchini et al. (2005) and Galasz (2017) whose Upper Shale members belong either to the uppermost Aalenian or to the base of Bajocian (sample 95K 25; Chiocchini et al., 2005; p. 452) based on the occurrence of *Watznaueria britannica* and absence of *W. manivitiae* or the Garantiana ammonite Zone (Galasz, 2017) that characterizes the Upper Bajocian (Bown et Cooper, 1998; Gradstein et al., 2012). The Upper Shaly Member also contained rare presence of *Lotharingius sigillatus*, *Watznaueria contracta* and *Watznaueria fossacincta* (Chiocchini et al., 2005; p. 450).

The presence of *W. barnasiae* in Sample №61 correlates the heavily-jointed, carbonate sandstone layer with the lower part of Pseudoconus enigma (NJ11) of the Boreal (Bown et Cooper, 1998) or Watznaueria barnasae (NJT11) Zones of the Tethyan Zonations (Mattioli et Erba, 1999; Ferreira et al., 2019). Both of these zones characterize the base of the Lower Bathonian stage corresponding to the Zigzag Boreal and Tethyan ammonite zone (Bown et Cooper, 1998, Gradstein et al., 2012) with the corresponding Convergens**,** Parvum and Dimorphitiformis Subzones (Fernandez-Lopez et al., 2009). More than 50% of the determined species in South Lamu are common to those listed from the Rabin du Bes Global Stratotype Section Point or GSSP (Tiraboschi et Erba, 2010) and 45% from the Cabo Mondego Auxiliary Section and Point or ASSP (Lopez-Otalvaro et al., 2018), thus, demonstrating marine connections with the Sub-Mediterranean Province of the Tethys and probably Boreal realm. Additionally, high diversity and good preservation of delicate coccospheres is an indication of open ocean depositional environments. The dominating species belong to the Lotharingius-Watznaueria genus group. The absence of Stephanolithion specimens in sample №61 is probably a result of their delicate structure (Roth et al., 1983) or some paleogeographical control. In the Ravin du Bes GSSP section, the FO *Stephanolithion speciosum octum* occurs at the uppermost part of the Bajocian preceding the FO *W. barnasae* event (Fernandez-Lopez et al., 2009), but even here it is reported to have a very rare occurrence. In the Boreal realm sections its FO is simultaneous with those of *C. margerelii*, *T. shawensis* and *H. cuvillieri* (Bown et Cooper, 1998). The distribution of these species is different to the west of the Tethys realm, in the Cabo Mondego ASSP (Portugal) where the FO *Stephanolithion speciosum octum* occurs simultaneously with the FO *W. barnasae* at the top of the Bajocian Parkinsoni AZ (Lopez-Otalvaro et Henriques, 2018).

The Post-Karoo Lamu Basin probably experienced several transgression-regression episodes since the Early Jurassic times (Turk-Martin et al., 2018). The nannofossil biozonation provides the first paleontological evidence of the presence of Early Bathonian strata in the western part of the “Indo-

Malgach Province" which includes the East African margin, Madagascar and Western India (Fernando-Lopez et al., 2009). Earlier biostratigraphy research based on ammonites recorded only the Late Bajocian and Middle Bathonian assemblages from this area (Kapilima, 2003; Fernando-Lopez et al., 2009). *Rucinolithus spp*. from Table V, 1 resembles *R. aff. irregularis* of Bralower et al., 1989, Plate VII, Fig. 8, 4, 5. The FO of *Hayesites* (*Rucinolithus*) *irregularis* is used for determining the base of NC6 – Chiastozygus litterarius Zone of the Aptian stage (Bralower et al., 1993; Frau et al., 2018). Probably the presence of one of these species is an indicator of contamination or reworking.

The mid-Cretaceous Eiffelithus turriseifelii (BC27) Zone corresponds to the dispar Boreal Ammonite Zone (Bown et al., 1998). In the Geological Time Scale (Gradstein et al., 2012, p. 811-812) this zone correlates with the Mortoniceras fallax –Arrhaphoceras briacensis Ammonite Zones. In this same Time Scale, the CC9 nannozone which is determined by the FAD *E. turriseiffelii* and dated at 103.13 Ma (Gradstein et al., 2012, p. 831) corresponds to the lower part of BC27 and coincides with the base of Mortoniceras fallax Ammonite Zone of the Upper Albian. As Bown *in* Gale et al., (2011, p. 109) mentions the FO *E. turriseiffelii* is the principal nannofossil event for this time interval. Unfortunately, the preservation of the encountered specimen does not allow us to evaluate the exact orientation of the central bar structure and further classify its morphotype. However, the size of the species outer rim classifies it to the original *E. turriseiffelii* (Watkins et Bergen, 2003; *Bown in* Gale et al., 2011).

The Bathonian carbonate sandstone (sample № 61) is a correlative analogue of the Kambe limestones developed 20 km to the north-east, and also the Amboni limestone developed in the Tanga area of Northern Tanzania (Kapilima, 2003). The Amboni limestones of the Tanga were considered equivalents of the Kambe coral limestones of Kenya. These are commonly exposures of massive, oolitic, pisolitic and porcellanoeus limestones of 70-90 m of thickness (Schlüter, 1997). The dominance of *Watznaueria britannica* and to a much less extent *Lotharingius lauffii* in the assemblage of sample № 61 could possibly indicate mesotrophic conditions (Giraud et al., 2006).

The overlying Late Albian shales (samples №66 and 60) of the NC10 Zone correlate with the basal part of the Lindi Formation, a 335 m thick succession composed of dark gray claystones and intercalating siltstones developed between Kilwa and Lindi in Southern Tanzania (Jimènez Berrocoso et al., 2015). In the Lamu Basin, the Early Cretaceous strata are considered within the lower portion of the Megasequence II that includes the Ewaso sands, Walu shales and Freretown limestones (Nyagah, 1995, pp. 49, 51-52). These shales are represented by bluish-grey to dark-grey shale successions reaching large thicknesses in the well sections of the North Lamu Basin sector (*ca*. 2105 m in Walu-2 well; Nyagah, 1995). They unconformably lie above the Mtomkuu shales from which they differ by the absence of concretions and septarian nodules (Nyagah, 1995, p. 51). Walu shales have also been reported to contain a mixture of agglutinated (*Haplophragmoides, Ammodiscus, Bathysiphon*) and shallow water (*Epistomina* sp*., Lenticulina* cf. *indentosuturalis, Planularia* sp. among others) foraminifera. Among planktonic forms, only *Hedbergella* cf. *sigila* was determined. As per the latest biostratigraphy data, this specie has an Early Cretaceous Late Valanginian – Late Aptian fossil range (http://www.mikrotax.org/pforams/index.php?id=110263). The species of Hedbergella genera are marine cosmopolitan taxa occupying inner-middle shelfal zones and greater depths (Kennedy et al., 2017, p.179).

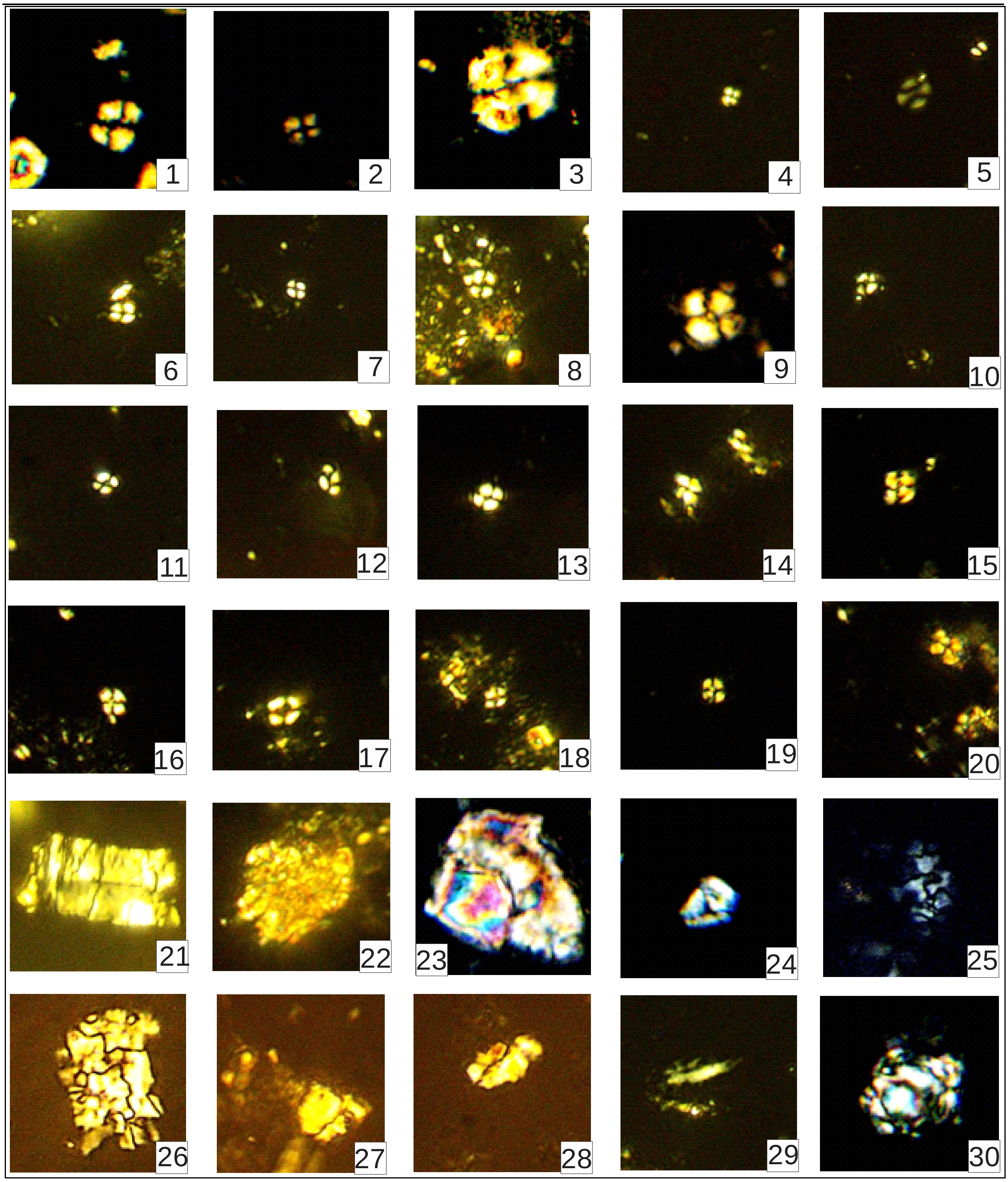

Plate I. Calcareous nannofossils from Sample № 61 from Southern Lamu Basin (SE Kenya). All specimens at 1080 magnification. 1. *Watznaueria barnasae*. 2. *Biscutum dubium*. 3. *Watznaueria manivitiae*. 4. *Biscutum dubium*. 5. *Watznaueria sp*.? 6-8. *Biscutum dubium*. 9. *Watznaueria britannica*. 10-14. *Biscutum dubium*. 15. *Watznaueira barnasae*? 16. *Watznaueria sp*. 17. ?*Lotharingius sp*. 18-19. *Discorhabdus cf. D. striatus*. 20. *Watznaueria sp*. 21. *Acadialithus dennei?* 22. *Schizosphaerella cf. S. punctulata* (fragment). 23-24. Incertae sedis. 25. *Thoracosphaera spp*.? 26. *Pseudoconus aff. P. enigma?* (Tiraboschi et Erba, 2010, p.64, Fig. 5.13). 27-30. Incertae sedis.

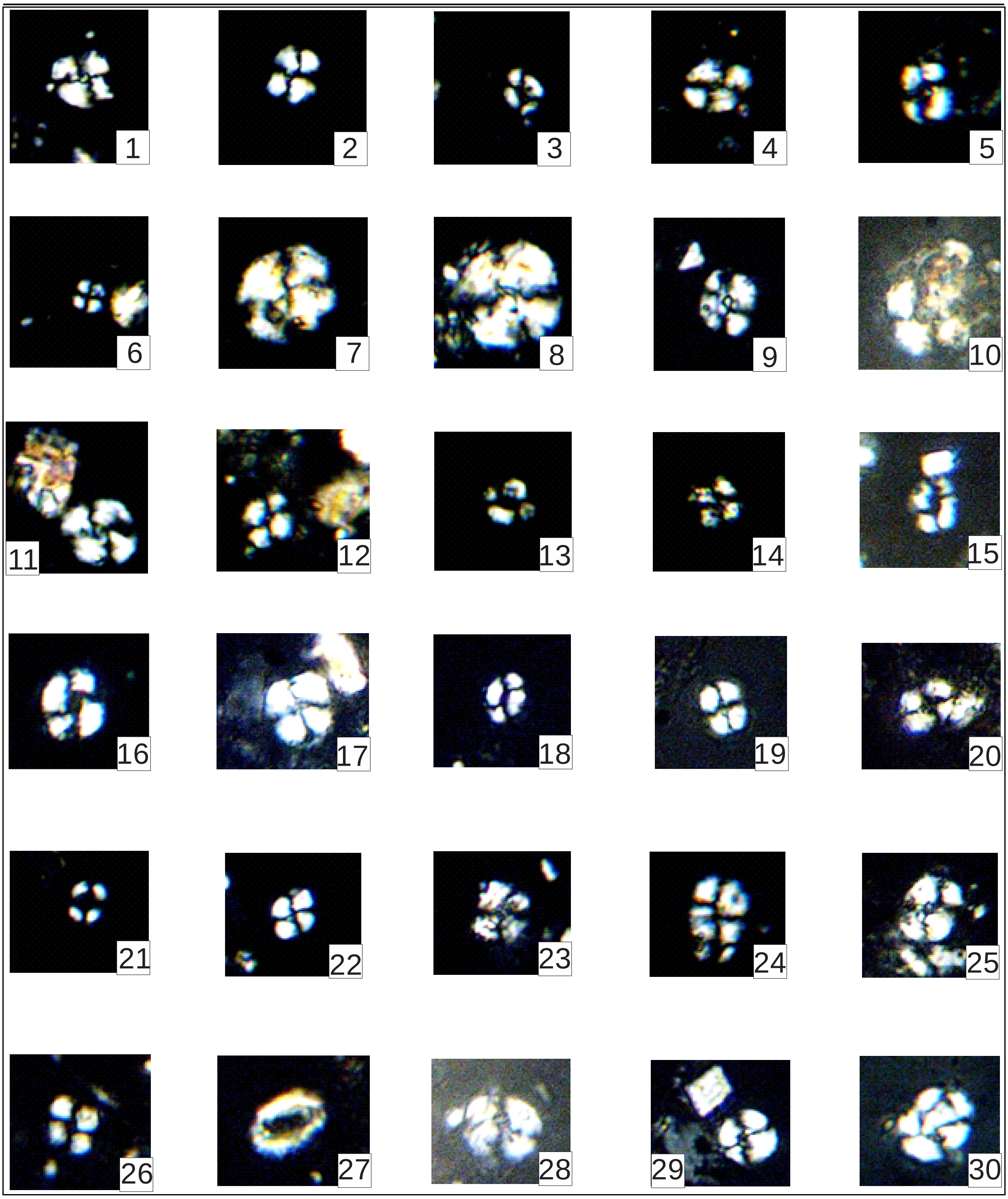

Plate II. Calcareous nannofossils from Sample № 61 from Southern Lamu Basin (SE Kenya). All specimens at 1080 magnification. 1. *Watznaueria britannica*. 2. *Watznaueira barnasae*? 3. *Watznaueria barnasae*. 4. *Watznaueria barnasae*. 5. *Lotharingius cf. L. velatus.* 6. *Biscutum dubium*. 7-8. *Watznaueria manivitiae*. 9. *Watznaueria cf. W. communis – W. cf. britannica* B. (Ferreira et al., 2019). 10. Watznaueria contracta. 11. *Discorhabdus cf. D. striatus*. 12. *Watznaueria barnasae*. 13. Lotharingius cf. L. hauffii. 14. *Discorhabdus striatus*?. 15. *Lotharingius umbriensis.* 16. *Watznaueria aff. W. contracta*. 17. *Watznaueria spp.?* (tiny). 18. *Watznaueria colacicchii*?-19. *Lotharingius sp.* 20. *Lotharingius cf. L. hauffii*. 21. *Lotharingius umbriensis?* 22. *Watznaueria barnasae?* 23. *Watznaueria manivitiae* 24. *Watznaueria fossacincta*. 25. *Watznaueria cf. W. britannica.* 26. *Lotharingius cf. L. hauffii.* 27. *Biscutum grandis-B. intermedium?* 28. *Watznaueria aff. W. contracta*. 29. *Discorhabdus cf. D. striatus*? 30. *Lotharingius spp.*?.

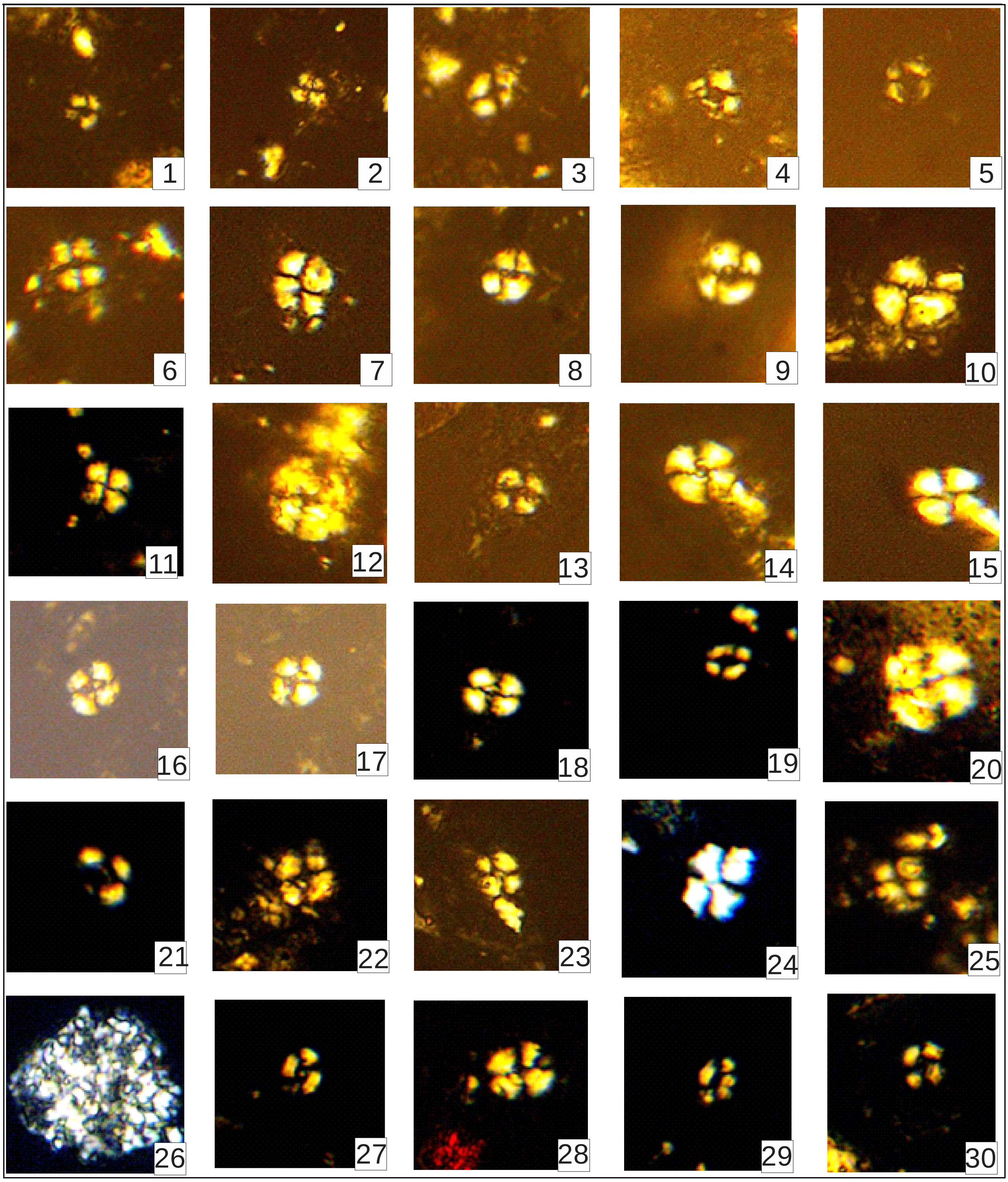

Plate III. Calcareous nannofossils from Sample № 61 from Southern Lamu Basin (SE Kenya). All specimens at 1080 magnification. 1. *Watznaueria barnasae*. 2. *Watznaueria barnasae*. 3. *Watznaueria sp*. 4. *Lotharingius cf. L. hauffii*. 5. *Lotharingius cf. L. hauffii* 6. *Watznaueria contracta*? 7. Watznaueria fossacincta. 8. *Lotharingius cf. L. hauffii*. 9. *Watznaueria contracta?* 10. Waznaueria cf. W. manivitiae. 11. *Watzanaueria fossacincta*. 12. *Waznaueria manivitiae*. 13. *Lotharingius hauffii*. 14-15. *Watznaueria britannica*. 16. *Watznaueria fossacincta*. 17-18. *Watznaueria barnasae*. 19. *Watznaueria sp.* 20. *Waznaueria manivitiae*. 21. *Lotharingius velatus?* 22. *Discorhabdus cf. D. striatus*? 23. *Lotharingius umbriensis*? 24 *Watzanaueria fossacincta*. 25 *Watznaueria contracta*? 26. *Schizosphaerella cf. S. punctulata* (coccosphere). 27. *Lotharingius sigillatus*. 28. *Watznaueria manivitiae*. 29. *Lotharingius sigillatus*. 30. *Watznaueria contracta?*

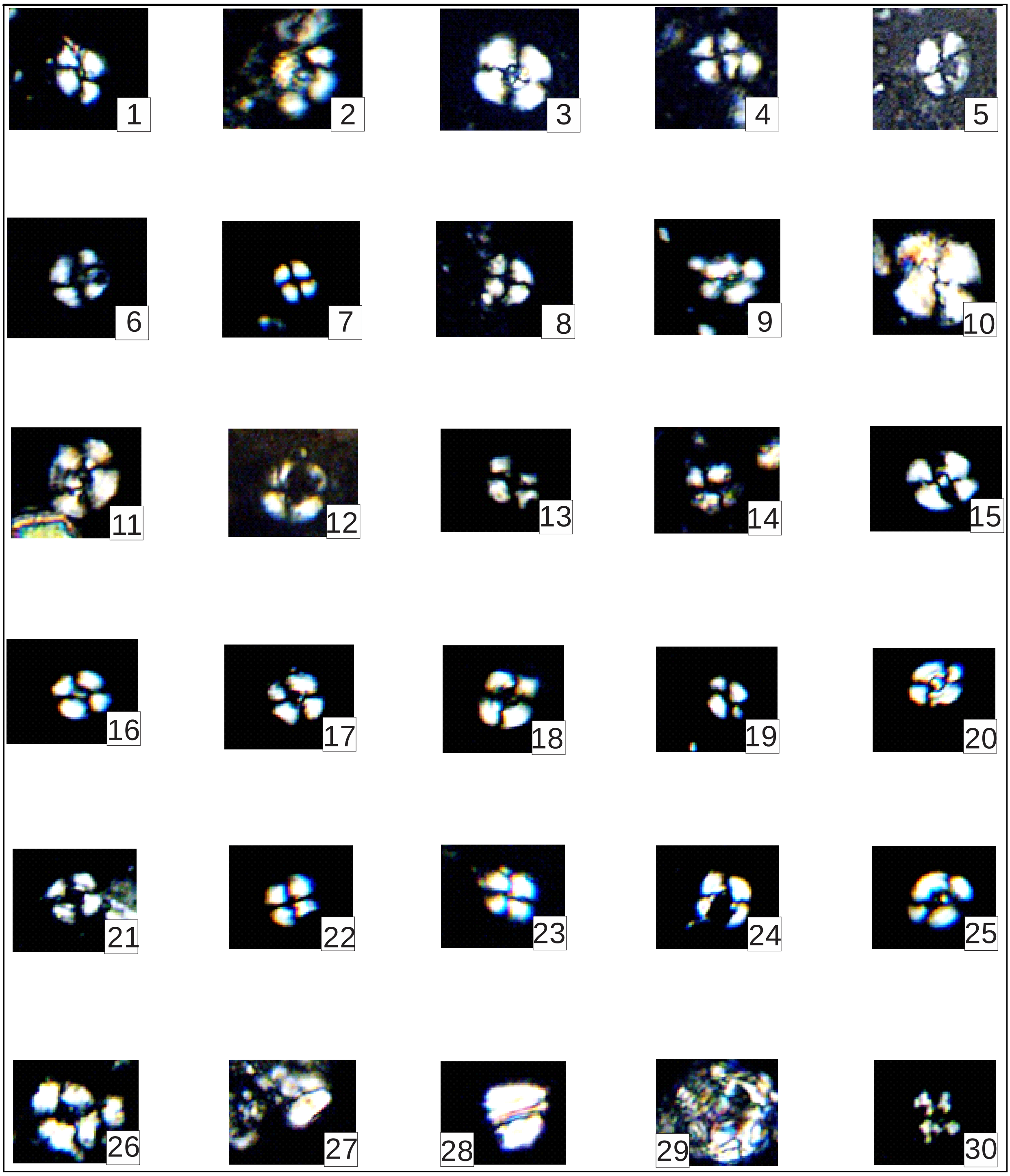

Plate IV. Calcareous nannofossils from Sample № 61 from Southern Lamu Basin (SE Kenya). All specimens at 1080 magnification. 1. *Watznaueria barnasae*. 2. *Lotharingius spp.* 3. *Watznaueria fossacincta*. 4. *Watznaueira cf. W. barnasae*. 5. *Watznaueria cf. W. fossacincta*? 6. *Lotharingius hauffii*. 7. *Lotharingius sigillatus*? 8. *Lotharingius hauffii*. 9. *Watznaueria barnasae*. 10. *Watznaueria manivitiae*. 11. *Watznaueria cf. W. fossacincta*. 12. *Lotharingius velatus?* 13-14. *Watznaueria cf. W. barnasae*. 15. *Watznaueira britannica* 16. *Watznaueira cf. W. britannica*. 17. *Watznaueira britannica* 18. *Lotharingius cf. L. velatus*. 19. *Lotharingius sigillatus*. 20. *Watznaueria britannica*. 21. *Lotharingius hauffii* 22. *Lotharingius cf. L. hauffii*. 23. *Watznaueria barnasae* 24. *Watznaueria* spp. 25. *Watznaueria britannica* 26. *Lotharingius velatus*? 27-28. *Incertae sedis*. 29. *Schizosphaerella punctulata*. 30. *Micula staurophora*?

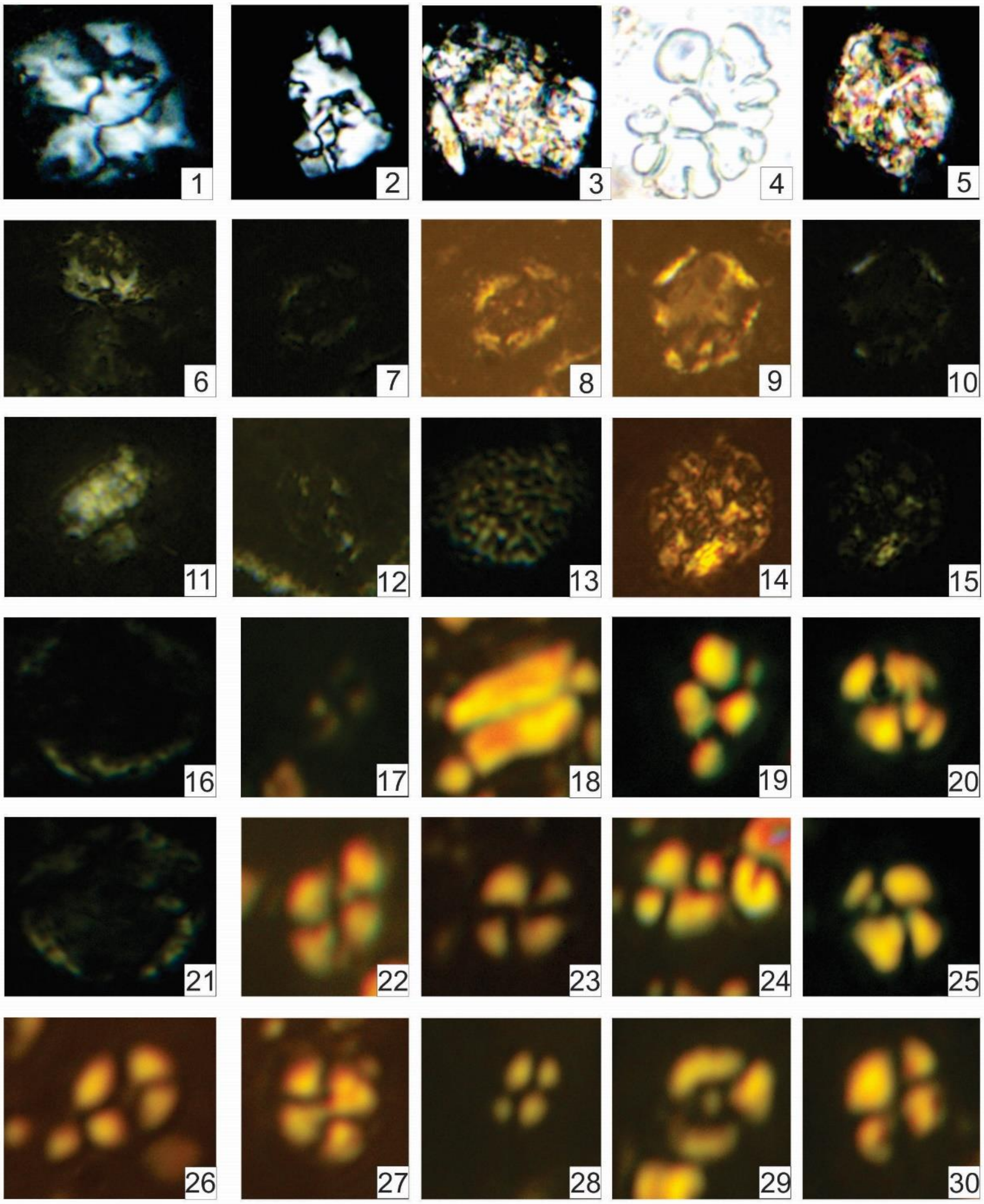

Plate V. Calcareous nannofossils from Samples № 61, 60 and 66 from Southern Lamu Basin (SE Kenya). All specimens at 1080 magnification. **Sample № 61, 1-5**: 1. *Rucinolithus spp.* (*R. aff. irregularis*? of Bralower et al., 1989, Plate VII, Fig. 8, 4, 5,) 2. *Pseudoconus aff. P. enigma?* (Tiraboschi et Erba, 2010, p.64, Fig. 5.13). 3. *Faviconus multicolumnatus*? (Bralower et al., 1989). 4. Large *"Rucinolithus"?* **/**Assipetra cf. A. terebrodentarius youngii?? (Bown, 2005; plate 12; 17-18)**.** 5. *?Rucinolithus spp.* **Sample 60, 6-12**: 6. Incertae sedis. 7-8. *Ethmorhabdhus gallicus*? (Menini et al., 2018, Plate LAL18)/*Retecapsa sp.* (Kadar et al., 2015, Plate 3, Fig.1 from Sargelu-Dhruma Transition). 9-10**.** ?*Axopodorhabdus cf. A. albianus.* 11**.** Incertae sedis. 12. ?*Eiffelithus turriseiffelii*. **Sample № 66, 13-30**: 13-15. *Thoracosphaera spp.* 16, 21. ?*Axopodorhabdus spp*. 17. *Watznaueria sp*. 18**.** Incertae sedis. 19. *Watznaueria sp*.2. 20. *Watznaueria* cf. *W. barnasae*. 22. *Watznaueria barnasae*. 23. *Watznaueria* cf. *W. barnasae*. 24. ?*Watznaueria barnasae*. 25. *Watznaueria* cf. *W. biporta*. 26. ?*Watznaueria britannica* C. 27. ?*Watznaueria biporta*. 28. *Watznaueria* sp.3. 29. ?*Watznaueria britannica* A. 30. *Watznaueria* cf. *W. britannica*.

The smear slide is dominated by large silica and mica grains with thin carbonate coats which we speculate can be an indication of an increased input of detrital material and probably a cooling trend of the surface waters at the time of deposition of the Early Cretaceous transgressional shale unit. The studied shale units in both sections are stratigraphically younger than the Freretown limestone Formation developed in a small old quarry near Freretown, Mombasa. Nyagah (1995, p. 52) refers to Linton and Maclean who identified foraminifera *Orbitolina bulgarica janesci* and *Orbitolina kurdica* indicating a Late Aptian-Early Albian and Aptian age ranges, correspondingly.

6. CONCLUSIONS

The results of this detailed nannofossil research enabled us to conclude the following:

None of the studied samples of №61, 60 and 66 belongs to the Triassic Mariakani Formation as previously and currently mapped. Rock sample №61 is represented by a carbonate sandstone layer that has a completely different composition compared to the sandstone units belonging to the Mariakani Formation. This carbonate sandstone characterizes shallow-marine deltaic settings. The presence of relatively well preserved nannofossils characterizing the Pseudoconus enigma (NJ11) Zone of the Boreal or Watznaueria barnasae (NJT11) Zone of the Tethyan zonations is a direct indication of its marine origin and it is probably related to a short transgressional event that resulted in the accumulation of thin carbonate layers above the Mariakani Formation. This also suggests that the contact between the non-marine Late Karoo and marine Mid-Jurassic formations occurs some 20 km westwards from its currently mapped location. The overlying shale formations (samples № 60 & 66) are definitely of post-Bathonian-Callovian age. The studied shale samples contained poorly preserved assemblage consisting of six to twelve species belonging to the Mid-Late Albian Eiffelithus turriseiffelii (CC9) Zone of Sissingh (1977), NC10a of Roth (1978) and Bralower et al. (1993) or BC27 of Burnett et al. (1998). These sediments are the western and southward wedging-off correlative analogues of the Mid-Cretaceous (Albian) Walu shales developed in deep well sections of the northern Post-Karoo Lamu Basin sector.

Previous studies mention that the mid Jurassic marine incursion into the Lamu Basin began in the Aalenian-Bajocian times. However, our results conclude that the carbonate sandstones in the south Lamu Basin were deposited during the Bathonian transgressional phase and that this is the first biostratigraphical evidence proving the presence of Early Bathonian strata in the Indo – Malgach Province. Previous ammonite biostratigraphy described only Late Bajocian and Middle Bathonian species. The next transgressional phase in the South Lamu Basin occurred during the Albian time.

The palaeoenvironmental conditions were probably different during the mid-Jurassic and Late Early Cretaceous times. This is attested by the diversity and level of preservation ranging from moderate-to-good for the Bathonian and poor for the Albian. This suggests better marine circulations in the study area with the Boreal and Tethyan realms during the mid-Jurassic. The increased amount of *Watznaueria britannica* and carbonate content suggests dominating warm palaeoenvironmental conditions in the mid-Jurassic in the Lamu Basin.

This refinement of the stratigraphy will have further implications on the hydrocarbon exploration, since it increases the extent of the Jurassic marine incursion into the interior of the Karoo-Duruma and Post-Karoo Lamu Basins. The Mid-Jurassic sandstone unit could have some hydrocarbon or water reservoir potential, while the overlying shales may act as hydrocarbon seals.

Further detailed study of the area would be necessary to understand the extent of the Jurassic-Cretaceous marine transgressions into the southern part of the Lamu Basin. The biozonation resolution will be enhanced if the studies would integrate other marine micro- and macrofossil groups (planktonic/ benthic foraminifera, ammonites, etc.) not only within the Lamu Basin, but from other areas of Kenya where thick sedimentary successions have been reported (Lugh-Mandera and Anza Basins). This would enable to construct a more reliable Meso-Cenozoic chrono- and biostratigraphic framework that is essential for regional and global correlations, paleogeographic reconstructions and exploration of various mineral resources developed within these sedimentary basins.

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