Journal of Geological Resource and Engineering 11 (2023) 1-9
doi:10.17265/2328-2193/2023.01.001

The Great Step Pyramid of Djoser: History, Geology and Nanoplankton Content from its Rock Casing

Jhonny E. Casas[1], Mayra Cañizares[2] and Ivan Baritto[2]

1. Departamento de Petróleo, Universidad Central de Venezuela, Caracas 1050, Venezuela

2. Gerencia de Exploración, INTEVEP, Los Teques 1201, Venezuela

Abstract: The Great Step Pyramid of Djoser is an archaeological site in the Saqqara necropolis. This six-tiered, four-sided structure is the oldest stone colossal building in Egypt, built in the 27th century B.C., to bury Pharaoh Djoser. On the plateaus and escarpments of the Nile Valley flanks, limestones were mined to be used as core material for many pyramids and temples during the Old Kingdom. The step pyramid, when completed, had a thin limestone casing on top. The Saqqara plateau is made up mostly of rocks from the middle-upper Eocene, with the Mokkatam Formation as the most important, relative to the main materials used in the construction of the necropolises. A limestone sample, most likely used in the casing of Djoser's pyramid, was analyzed from its nannofossil content. The nannofossil association, defined a middle Eocene age (upper Lutetian to Bartonian) corresponding to zones NP16 and NP17 (42.4 to 36.8 Ma), based on the first occurrence of *Reticulofenestra umbilica* and the last occurrence of *Chiasmolithus grandis*. This dating suggests that this pyramid casing material, corresponded to the Giushi Member of the Mokattam Formation.

Key words: Egypt, Djoser, pyramid, Eocene, nannofossils.

1. Introduction

The Saqqara (Sakkara) Plateau is located about 40 km southeast of Cairo, Egypt, on the left bank of the Nile River (Fig. 1), rising 17-25 m above the modern flood terrace of the river. Since Early Dynastic times, this plateau has been used as a necropolis for over 3,000 years. For the ruling pharaohs, tombs were built as mastabas-like structures and later pyramids. Among the most famous and monumental Egyptian pyramids are those of Khufu (Cheops or Keops), Kafre (Kefrén) and Menkaure (Micerinos); as well as the oldest of all, the Step Pyramid of Djoser (Zoser or Djeser). A limestone sample, most likely used in the casing of Djoser's pyramid, was paleontologically analyzed in order to determine nanoplankton content. The sample comes from the lower southeast corner of the pyramid itself, a place where remains of the possible covering of the structure were still preserved.

2. From Mastaba to Pyramid

The Step Pyramid of Djoser, is an archaeological site in the Saqqara necropolis, northwest of Memphis, seat of power of the Old Kingdom. This six-tiered, four-sided structure is the oldest stone colossal building in Egypt. It was built in the 27th century B.C. (between 2630 and 2611 B.C.), during the Third Dynasty, to bury Pharaoh Djoser. Initially, the structure had the shape of a small mastaba, contours of which are currently visible from the south side, and enlarged on the fly in a second phase [1]. The second mastaba was wider than the first, and in its center the burial chamber was dug. The next stage consisted of continuing the construction of the pyramid with the shape we see today (Fig. 2), most probably in order to raise its height, until it became a step pyramid. The structure is the centerpiece of a vast mortuary complex, surrounded by ceremonial structures. Some archaeologists [1], believe that its chief architect was probably Imhotep, chancellor to the pharaoh, and high priest of the god Ra.

The transformation of the mastaba into a pyramid led

Corresponding author: Jhonny E. Casas, MSc, professor, research fields: stratigraphy, sedimentology, petroleum geology.

to a change in the design, where the builders used, in addition to the traditional clay or mud blocks, larger and better-quality limestone blocks. But instead of horizontal beds, they built successive inclined layers of 2 to 3 m thick, which supported each other from opposite ends, providing greater stability and preventing possible collapse. Then, the whole structure was covered with fine white limestone. This phase of the pyramid had four steps that rose to a height of approximately 42 m. Imhotep, then probably convinced the pharaoh to extend the pyramid to the north and west from four to six steps, completed with a final layer of limestone casing that gave the pyramid its final shape. When finished, the step pyramid had a rectangular base (121 m by 109 m), rising to a height of about 63 m, occupying a calculated volume of 330,400 m^3 [3]. From 2006 to 2019, the pyramid engaged a large-scale restoration project.

3. Geological Setting

From the Late Cretaceous to the Eocene, most of Egypt was under a shallow sea, accumulating carbonate sediments, which today are represented by outcropping Eocene limestones (Fig. 1).

From the Oligocene to the Quaternary, most of Egypt continued to be above sea level, receiving predominantly siliciclastic sediments [4]. The Saqqara plateau is made up mostly of rocks from the middle-upper Eocene, with the Mokattam Formation being the most important from the perspective of the main materials used in the construction of the necropolises. This formation is composed of stratified limestone rocks, formed in shallow marine sedimentary conditions. The thickness of each sedimentary cycle is not constant and variations are observed from decimeters to a few meters. The repeated alternation of fifth-order cycles between transgressive and regressive facies implies a eustatic control with relative sea level rises and falls [5, 6].

The middle-upper Eocene stratigraphy throughout this region of Egypt has been very complex and has changed nomenclature constantly in recent decades [5, 6]. More recent authors such as Ref. [7], studied the middle Eocene succession at Gebel Mokattam, sotheast of Cairo (Fig. 1), and defined the Mokattam Formation as consisting of two members, the so-called Building Stone Member (once divided into lower and upper,

Fig. 1 Schematic map of Egypt with location of some archeological sites and ancient quarries.
In yellow: the extension of the Eocene outcrops.
Modified from Ref. [2].

with a thin intermediate level known as the *Nummulites gizehensis* level) and the Giushi Member above. The Building Stone Member consists of thick-bedded, moderately hard, creamy-white bioclastic limestones with very thin muddy beds. At the top is characteristic a dolomitic shell bed. This member is nummulitic at several horizons with poorly preserved mollusks, bryozoans and echinoderms [7]. The Giushi Member consists of well-developed strata of nummulitic limestones interbedded with yellowish grey marls. The top bed of this unit is very hard, dolomitic, and rich in pelecypod shells belonging to *Macrosolen* sp. [7]. At the Cairo-Giza area, Ref. [8] mentioned an average thickness of 75 m for Lower Building Stone and Gizehensis, 65 m for Upper Building Stone and 60 m for the Giushi unit. The Building Stone Member at Gebel Mokattam area (east of Cairo), in the section studied by Ref. [7], contained six species of Nummulites belonging to the upper Lutetian. These species were: *Nummulites farisi*, *N*. cf. *praegizehensis*, *N*. cf. *gizehensis*, *N*. *discorbinus*, *N*. *crassichordatus*, and *Arxina schwageri*. The Giushi Member contained only three species, indicating a probable Bartonian age. These species, which continued from their FO (first occurrence) in the Upper Building Stone Member, were: *Nummulites discorbinus*, *N. crassichordatus*, and *A. schwageri* [6]. The carbonate sediments of the Upper Building Stone and Giushi members were interpreted as deposited on a shallow marine platform with high carbonate productivity, where the deposition occurred under warm semi-arid climate and normal seawater oxygenation and salinity [5].

4. Origin of the Rocks Used in the Construction of Temples, Mastabas and Pyramids

Limestone and sandstone were the main building stones of ancient Egypt. Since dynastic times, limestone was the preferred material in the region for pyramids, tombs, mastabas and temples. Additionally, structures built of limestone and sandstone often included ornamental stones, notably Aswan granite and granodiorite, but also basalt and travertine were widely used in the Ancient Period [9].

Ref. [10] described in detail the location and characteristics of building rocks in ancient Egypt. In particular, the Eocene rocks were described by these authors from the area south of Luxor, to the Cairo area, where the Nile River is flanked by limestone escarpments from this geological period. In these rocks of varied characteristics, Ref. [10] stated that the limestone facies ranged from marly and dense rocks, with numerous flint nodules (cryptocrystalline form of quartz), towards the surroundings of Luxor (where it is called Thebes Formation). Further north to the Helwan locality, only a few quarries of restricted local importance were used during antiquity, but from there to the Mokattam Hills south of Cairo, an impressive number of galleries were carved deeply into the rock, or in open pit quarries. These limestone facies belonging to the Mokkatam Formation, were exploited during all the historical periods of Egypt, even in the Roman periods [10].

In this area, the exploitation concentrated on the famous Gebel Tura-Maasara quarry, and Mokattam limestone, a very dense and resistant rock, located on the eastern flank of the Nile valley (Fig. 1), relatively close to the Giza plateau [10]. In contrast, on the escarpments and plateaus on the western flank of the Nile Valley, the generally less resistant limestones were heavily mined to yield huge volumes of stone for the core material of many of the mortuary pyramids and temples of the Nile during the Old Kingdom [10], such as the Step Pyramid of Djoser (Fig. 2). At the beginning, the best quality limestone was extracted from the Giza Plateau where the Great Pyramids and the Sphinx stand today, this last monument was carved entirely in the Mokattam Formation by ancient Egyptian stonemasons, but from the time of Pharaoh Snofru (Senefru), founder of the fourth dynasty, and father of the famous pharaoh Khufu (Keops), the revetment of the pyramids required enormous tonnages of strong limestone blocks, which were quarried exclusively from the quarries on the eastern flank of the Nile, mainly from Tura-Maasara, some 30 km southeast of Giza [10].

Djoser's mortuary complex has been looted and rebuilt several times since ancient times. It is therefore difficult to identify the times of each restoration [2]. In the search for cheap construction materials during the last 2,000 years, the elements used in the construction of the pyramid, as well as the temples and auxiliary buildings of the complex itself, have been partially or totally looted and left in ruins. The very existence of the casing limestone of the step pyramid is a discovery made only in the last decades [3]. This original casing, denotes the high level of skill of the ancient masons in producing comparatively thin and homogeneous stone slabs, transporting them from their place of origin, or even across the Nile, and applying them over the vast surface of the pyramid facades [3].

Many scholars [3, 10, 11], claimed that the step pyramid, when completed, had a thin limestone casing. Today, the aforementioned casing is still visible on some corners of the base of the pyramid. Unfortunately, many of these items may have been replaced over thousands of years and therefore, it is impossible to verify their authenticity, as none of the previous reconstruction work has been documented [11]. A certain enigma still persists today as to the origin of the highly resistant calcareous casing material used for the pyramids and temples of Djoser (2690-2640 B.C.) and his successors. Ref. [11] stated that some tooled fine grained limestone blocks are from Tura quarry (eastern flank of the Nile), but Ref. [10] studied from a geochemical perspective, the casing limestones from Djoser's pyramid, determining that they are very similar to the limestone and calcareous materials of the Mokkatam Formation in the Saqqara area, where these pyramids were built. Unfortunately, extensive fieldwork done [10], did not reveal any fully identified quarries, but only many loose blocks, found along the Saqqara plateau. Thus, if this calcareous material were almost entirely extracted for hundreds of years, only loose blocks remain that testify to its ancient existence in this area [10].

Fig. 2 South face of the Great Step Pyramid of Djoser.

5. Previous Studies of Calcareous Nannofossils in the Mokattam Formation

Ref. [12], in a published study of Eocene planktonic foraminifera and nannofossils in the Gebel Mokattam region (Fig. 1), found that the upper part of the Building Stone Member is dominated by a Fossil Group called the *Discoaster barbadiensis/saipanensis* association. The faunal group was described by Ref. [12], as composed of: *Discoaster aster*, *D. barbadiensis*, *D. niloticum*, *D. saipanensis*, *D. quinarius*, *Braarudosphaera discula* and *B. bigelowi*, all of them indicating an upper Lutetian age. Ref. [13], studied also the Gebel Mokattam area, including the Cairo citadel. In this area, they defined two nanoplankton zones for the upper members of the Mokattam Formation (Building Stone and Giushi). For the Building Stone Member and the lower part of the Giushi Member, the *Reticulofenestra umbilica* zone is defined, corresponding to the middle-upper Lutetian. In this area, the following were identified: *Reticulofenestra umbilica*, *Coccolithus eopelagicus*, *C. pelagicus*, *Cyclococcolithus formosus*, *Cyclicargolithus ftoridanus*, *Neococcolithes dubius*, *Sphenolithus moriformis*, *Braarudosphaera bigelowi* and *Pemma basquensis*. For the upper part of the Giushi Member, Ref. [13], identified the *Discoaster saiponensis* zone corresponding to the transition between the upper part of the Lutetian and the lower part of the Bartonian, mentioning the following species: *Coccolithus eopelagicus*, *C. pelagicus*, *Cyclicargolithus ftoridanus*, *C. reticulatus*, *Cyclococcolithus formosus*, *Reticulofenestra bisecta*, *R. reticulata*, *R. umbilica*, *Pontosphaera multipora*, *Rhabdosphaera spinulosa*, *Braarudosphaera bigelowi*, *Micrantholithus inaequales*, *M. vesper*, *Pemma basquensis* and *Discoaster woodringi*.

6. Sample Location and Description

The studied sample comes from the base of Djoser's pyramid in its southeast corner, where it was possible to appreciate the remains of the probable casing that covered the pyramid in its original state. The small limestone sample was macroscopically described as a creamy-white bioclastic packstone (Fig. 3A), slightly marly, where planktonic foraminifera, ostracods, bryozoan and mollusk fragments, and large foraminifera, including *Nummulites* sp. (Figs. 3B and 3C), can be observed with a microscope. The limestone is medium-coarse grained, and is cemented by sparite-type calcite crystals. It is possible to identify scattered quartz grains in the rock and the presence of stylolites (Fig. 3D).

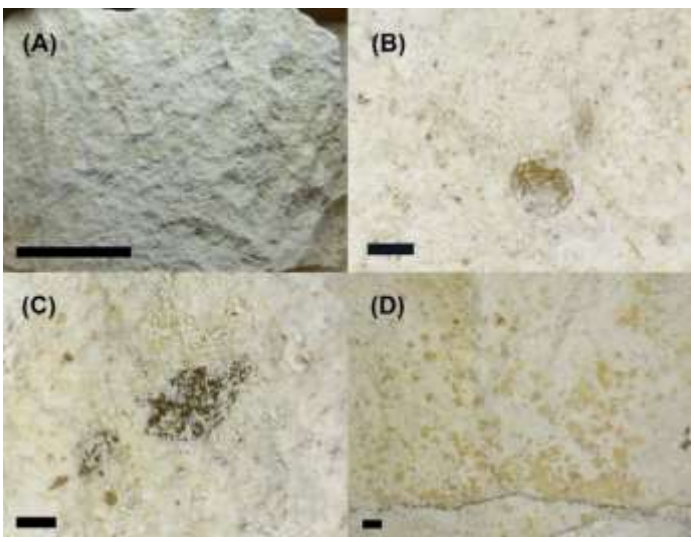

Fig. 3 (A) Creamy-white bioclastic packstone, corresponding to the probable casing of the Djoser pyramid. Detailed images (B and C), where some large foraminifera can be observed, identified as *Nummulites* sp. (D) Same sample with ostracods and some stylolites towards the bottom of the photograph. Scale at (A) = 2 cm. Scales in (B, C and D) = 1 mm.

7. Sample Preparation Method

High-quality slides were prepared to visualize and photograph the nannofossils present on each sample. The samples were processed by preparing slides from whole rock samples, following the procedure described by Ref. [14]. A small portion of each sample was placed in a 25 mL beaker and allowed to soak in distilled water for about 12 h. After complete disaggregation of the sediment, the permanent glassy slide was prepared by adding a few drops of slightly turbid suspension to each sample, using a pipette. Drops of suspension were spread on the slide and then allowed to dry using a warm hot plate.

After the suspension was dry, the mounting medium (Canada balsam) was placed on the glassy slide. The slide was subsequently cooked on the hot plate at about 120 °C for 1-2 min and then a rectangular glassy cover was mounted on top of the Canada balsam to make the slide more durable and easier to store for future studies. The examination of calcareous nanoplankton was carried out in the present study by using the polarized light microscope (Zeiss AxioImagen 2.0) with 1,000× magnification. Samples were counted along a random visual walk over the slide.

The zonation's used in the age interpretation from nannofossils are those from Ref. [15], modified for the Paleogene [14], and with the latest revision by Ref. [16]. A nanofacies classification [17], was also applied on the estimation of the paleoenvironmental trend referred to the distance from the coastline. Those three levels are:

Nanofacies Type I = farthest from the coastline/deep.

Nanofacies Type II = internal neritic level.

Nanofacies Type III = closest to the coastline.

The relative abundance of calcareous nannofossils was classified as follows:

A (Abundant) ≥ 10 specimen/Field of view.

C (Common) = 1-10 specimen/Field of view.

F (Few) = 1 specimen/10-20 Field of view.

R (Rare) = 1 specimen/20-50 Field of view.

VR (Very rare) = 1 specimen//>50 Field of view.

8. Nanoplankton Content

A calcareous nanoplankton analysis on the sample from the casing of Djoser Step Pyramid allowed the identification of: *Reticulofenestra bisecta*, *Cyclicargolithus floridanus*, *Reticulofenestra minuta*, *Ericsonia formosus*, *Clausicoccus subdistichus*, *Reticulofenestra dictyoda*, *R. umbilica*, *R. daviesii*, *Coccolithus eopelagicus*, *Chiasmolithus grandis*, *Sphenolithus* cf. *moriformis* (Fig. 4), *Coccolithus pelagicus*, *Reticulofenestra* cf. *reticulata*, *Reticulofenestra hampdenensis*, *Helicosphaera* sp., and *Discoaster* sp., defining a middle Eocene age (upper Lutetian to Bartonian) corresponding to zones NP16 and NP17, between 42.4 and 36.8 Ma, even reaching the very beginning of the late Eocene (Priabonian). The age range of the studied sample was given by the FO (first occurrence) of *Reticulofenestra umbilica* (NP16-NP22) and the LO (last occurrence) of *Chiasmolithus grandis* (NP11-NP17) as is shown in Fig. 5. In the study of the sample, an association of very abundant and highly diverse nanoflora was also observed, which is probably associated with an interpreted MFS (maximum flooding surface), equivalent to paleobathymetries ranging from 30-60 m deep (a middle neritic environment). The presence of specimens such as *Helicosphaeras*, *Sphenolithus*, and *Discoasters* suggested this paleoenvironmental interpretation. In the same way, frequent glauconite and organic matter content was observed in the sample. In the analysis, it was possible to identify the Type I nanofacies, according to Duran's methodology [17], characterized by a great abundance of nanoflora and counts of other marine material, indicating a far distance from the coastline. The sample showed a great abundance and diversity of calcareous nanoplankton, exceeding up to 300 specimens per field of view. Although there is diversity in the specimens, the most dominant species were *Reticulofenestra bisecta* and *Ciclycargolithus floridanus*.

Although only one sample from the Djoser Step Pyramid casing was analyzed, when placed in a stratigraphic context, it can be postulated that the origin

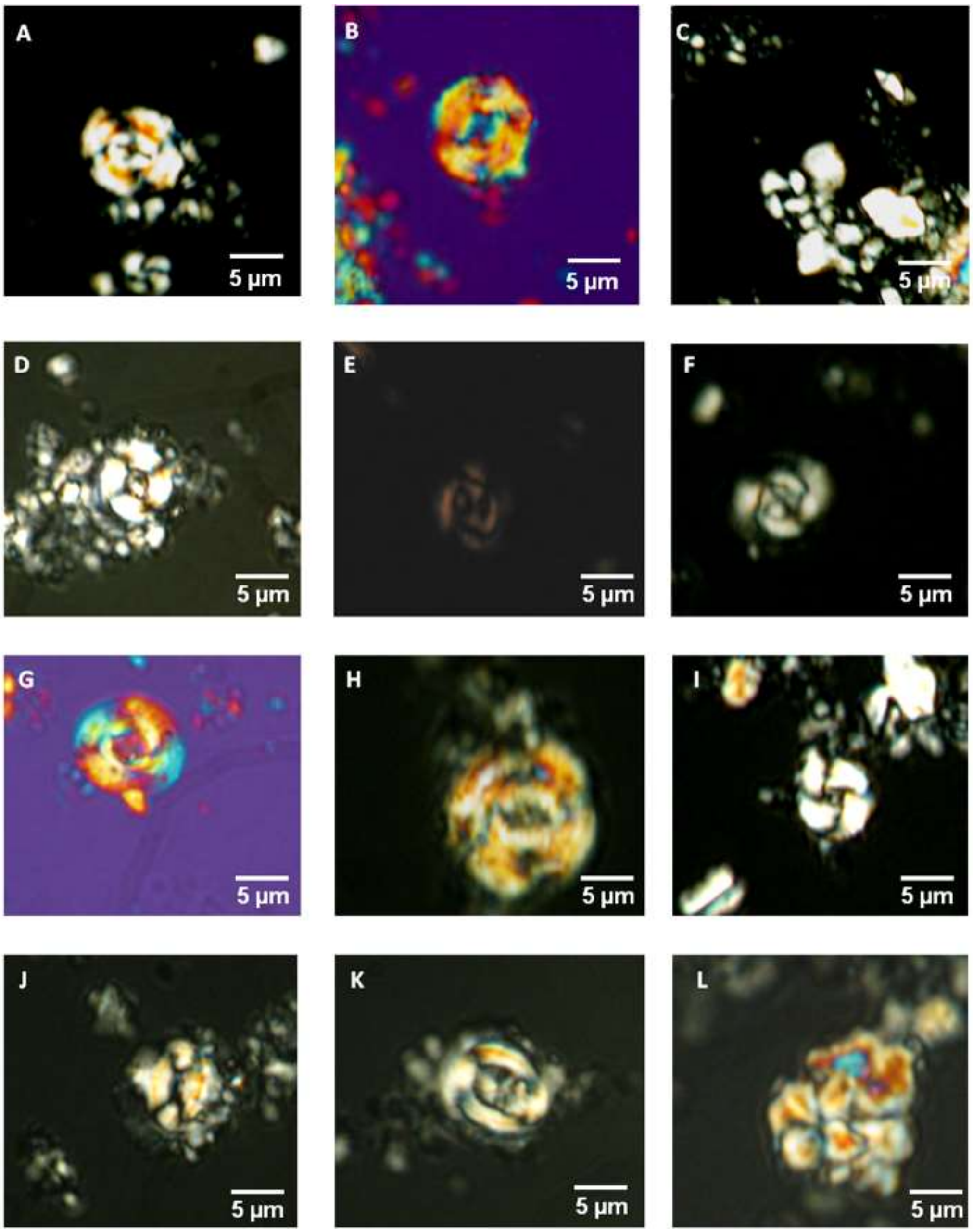

Fig. 4 Photomicrographs of the most prominent calcareous nanoplankton identified in the Djoser Step Pyramid sample. (A) *Reticulofenestra bisecta* (NP16-NN1); (B) *Cyclicargolithus floridanus* (NP15-NN6); (C) *Reticulofenestra minuta* (NP13-Pliocene); (D) *Ericsonia formosus* (NP12-NP21); (E) and (F) *Clausicocus subdistichus* (NP14-NN2); (G) *Reticulofenestra dictyoda* (NP12-NP25); (H) *Reticulofenestra umbilica* (NP16-NP22); (I) *Reticulofenestra daviesii* (NP14-NN2); (J) *Coccolithus eopelagicus* (NP14-NP23); (K) *Chiasmolithus grandis* (NP11-NP17); (L) *Sphenolithus* cf. *moriformis* (NP5-NN15).

of this casing material, according to the age range of the nanoplankton content (Fig. 5), corresponded to the Giushi Member (Mokattam Formation), a unit that has been dated, mainly as upper Lutetian to Bartonian [13], using also nannofossils. Some species in common with our study were: *Reticulofenestra bisecta*, *R. umbilica*, *R. reticulata*, *Coccolithus eopelagicu*s, *C. pelagicus*, *Cyclicargolithus floridanus*, and *Sphenolithus moriformis*. Some other authors [18, 19], stated that the Giushi Member is a stratigraphic unit from the Bartonian time, reaching the beginning of the Priabonian (the transition between upper middle Eocene and late Eocene).

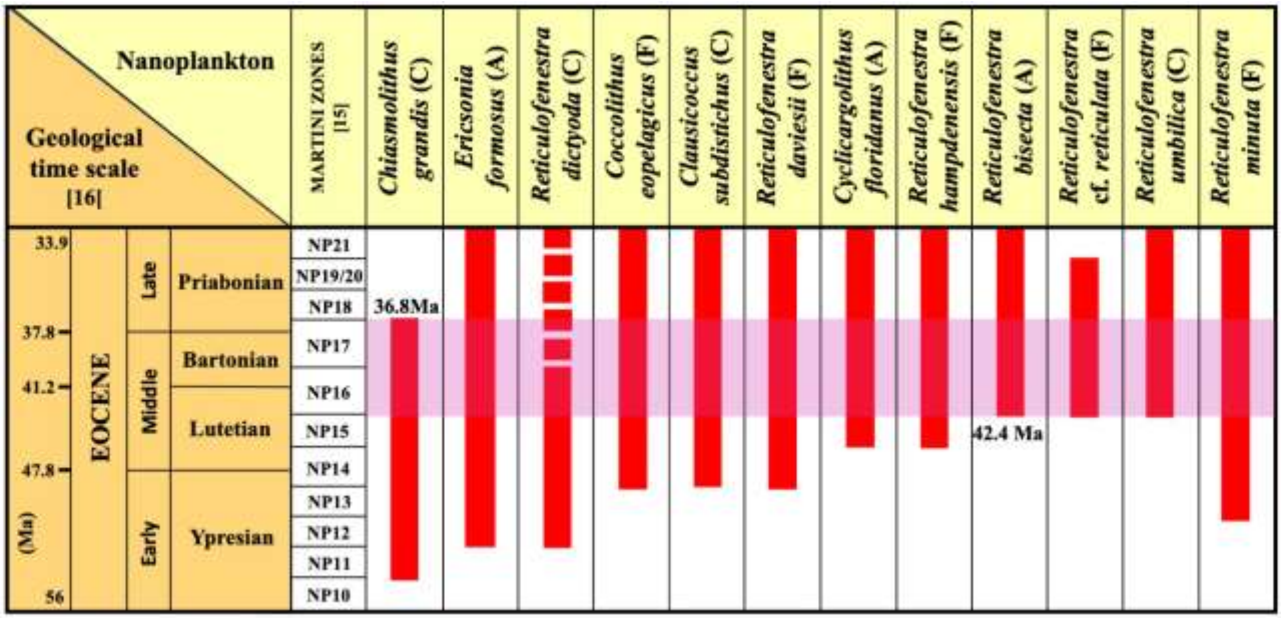

Fig. 5 Chronostratigraphic table with the age ranges of the most outstanding calcareous nannofossils from the sample of Djoser Step Pyramid casing, corresponding to zones NP16-NP17 (purple stripe) of the middle-late Eocene (upper Lutetian-Bartonian-lower Priabonian), between the 42.4 and 36.8 Ma. Nanoplankton relative abundance: Abundant (A), Common (C), Few (F), Rare (R), Very rare (VR).

As derived from the study carried out on our sample, the age span encompasses from the upper Lutetian to the beginning of Priabonian (Fig. 5).

9. Conclusions

A casing sample from the base of Djoser's pyramid in its southeast corner, was described as a bioclastic packstone, containing a high abundance and variety of calcareous nannofossils such as: *Reticulofenestra bisecta*, *R. dictyoda*, *R. daviesii*, *R. umbilica*, *Cyclicargolithus floridanus*, *Ericsonia formosus*, *Coccolithus eopelagicus*, *Sphenolithus moriformis*. The most dominant species in the sample were *Reticulofenestra bisecta* and *Ciclycargolithus floridanus*.

The associations of these nannofossils defined a middle Eocene age (upper Lutetian to Bartonian), corresponding to zones NP16 and NP17 (between 42.4 and 36.8 Ma), even reaching the very beginning of the late Eocene (Priabonian). The origin of this casing rock sample, according to the age range from the calcareous nanoplankton analysis, corresponded to the Giushi Member of the Mokattam Formation.

The biostratigraphic analysis carried out through the identification of calcareous nanoplankton in the sample from Djoser's pyramid casing, provides chronostratigraphic information that contributes to elucidating from the geoarchaeological point of view, the possible origin of some carbonatic material used by the stonemasons in the construction or reconstruction of this important architectural monument of the ancient Egypt.

Acknowledgments

The authors thank Paul Davis (MSc in Geology & History) for the revision of the manuscript. Also, we would like to thank INTEVEP for storing the nannofossil samples at the Micropaleontology Center Dr. Pedro Joaquin Bermúdez (Venezuela), for future study and reference.

References

[1] Hawass, Z. 2021. "The Discovery of the Sarcophagus of Djoser and the Restoration of the Step Pyramid." *Journal of the General Union of Arab Archaeologists* 6 (3): 83-107.

[2] Hassan, H., and Korin, A. 2019. "Contribution to the Biostratigraphy of the Middle-Upper Eocene Rock Units at North Eastern Desert: An Integrated

Micropaleontological Approach." *Heliyon* 5: 1-15.

[3] Kukela, A. 2012. "The Development of Geological Knowledge in the Old Kingdom of Ancient Egypt." Ph.D. thesis, University of Riga.

[4] Harrell, J. A., and Storemyr, P. 2009. "Ancient Egyptian Quarries—An Illustrated Overview." In *QuarryScapes: Ancient Stone Quarry Landscapes in the Eastern Mediterranean*, edited by Abu-Jaber, N., Bloxam, E. G., Degryse, P., and Heldal. T. Geological Survey of Norway Special Publication, 12: 7-50.

[5] El-Azabi, M. H. 2006. "Sedimentological Characteristics, Palaeoenvironments and Cyclostratigraphy of the Middle Eocene Sequences in Gabal El-Ramliya, Maadi-Sukhna Stretch, North Eastern Desert, Egypt." In *Intern. Conf. Geol. Arab World* (GAW8), Cairo Univ., Giza, Egypt, pp. 459-84.

[6] Tafwik, M., El-Sorogy, A., and Moussa, M. 2016. "Metre-Scale Cyclicity in Middle Eocene Platform Carbonates in Northern Egypt: Implications for Facies Development and Sequence Stratigraphy." *Journal of African Earth Sciences* 119: 238-55.

[7] Al Safia, M., Radwan, A., and Marwa, A. 2019. "A New Hiatus within the Lutetian of the El Basatin Section, Gebel Mokattam, Egypt: Field and Sedimentological Observations, with Special Emphasis on Nummulites." *Acta Geologica Sinica* 93 (1): 12-29.

[8] Gingerich, P. D. 1995. "Marine Mammals (Cetacea and Sirenia) from the Eocene of Gebel Mokattam and Fayu, Egypt: Stratigraphy, Age and Paleoenvironments." PhD thesis, The University of Michigan.

[9] Harrell, J. A. 2009. "Building Stones." In *UCLA Encyclopedia of Egyptology*, edited by W. Wendrich, Los Angeles, pp. 1-25.

[10] Klem, D., and Klem, R. 2001. "The Building Stones of Ancient Egypt—A Gift of Its Geology." *African Earth Sciences* 33: 631-42.

[11] Kukela, A., and Senglis, V. 2012. "Application of Building Stone in the Old Kingdom of Ancient Egypt as an Indicator of Changes in Knowledge." *Material Science and Applied Chemistry* 25: 31-36.

[12] Sadek, A. 1971. "Nannofossils from the Middle-Upper Eocene Strata of Egypt." *Jahrbuch der Geologischen Bundesanstalt Sonderbände* 19: 107-130.

[13] Allam, A., Bassiouni, A., and Zalat, A. 1988. "Calcareous Nannoplankton from Middle and Upper Eocene Rocks at Gebel Mokattam, East-Cairo, Egypt." *Journal of African Earth Sciences* 7 (1): 201-11.

[14] Perch-Nielsen, K. 1985. "Cenozoic Calcareous Nannofossils." In *Plankton Stratigraphy*, edited by Bolli, H. M., Sanders, J. B., and Perch-Nielsen, K. Cambridge: Cambridge University Press, pp. 427-554.

[15] Martini, E. 1971. "Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation." In *Nannofossil Biostratigraphy*, edited by B. U. Haq. Benchmark Papers in Geology, 78: 264-307.

[16] Gradstein, F., Ogg, J., Schmith, G., and Ogg, G. 2020. *The Geologic Time Scale 2020*. Amsterdam: Elsevier.

[17] Durán, I. 1995. *Nanofacies: Definición de Asociaciones. MARAVEN, S.A. Exploración y Producción. Caracas*. Informe Técnico EPC-13740. (in Spanish)

[18] Abedl-Kireem, M. R. 1985. "Planktonic Foraminifera of Mokattam Formation (Eocene) of Gebel Mokattam, Cairo, Egypt." *Revue de Micropalentologie* 28: 77-96.

[19] Strougo, A., and Boukhary, M. A. 1987. "The Middle Eocene—Upper Eocene Boundary in Egypt: Present State of the Problem." *Revue de Micropaleontologie* 30: 122-7.