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# The pyramid builders' waterways: Reconstructing the ancient topography of Khufu's Pharaonic Harbour at Giza, Egypt

Gamal Younes [a,b,*], Nick Marriner [c,*], David Kaniewski [d,e], Hader Sheisha [a,f], Zhongyuan Chen [g], Asem Salama [h], Gad El-Qady [h], Christophe Morhange [a,i]

[a] Aix-Marseille Université, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France
[b] Department of Geography and GIS, Faculty of Arts, Ain Shams University, Cairo, Egypt
[c] CNRS, ThéMA, Université de Franche-Comté, UMR 6049, MSHE Ledoux, 32 rue Mégevand, 25030 Besançon Cedex, France
[d] TRACES, UMR 5608 CNRS, Université Toulouse Jean Jaurès, Maison de la Recherche, 5 allées A. Machado 31058 Toulouse Cedex 9, France
[e] Département de Biologie et Géosciences, Université Paul Sabatier - Toulouse 3, Toulouse cedex 9, France
[f] Europôle méditerranéen de l'Arbois, Institut Méditerranéen de Biodiversité et d'Ecologie - IMBE (Aix Marseille Univ, Avignon Université, CNRS, IRD), Aix-en-Provence, France
[g] SKLEC-State Key Laboratory of Estuarine and Coastal Research, East China Normal University ECNU, Zhongshan N. Road 3663, Shanghai 200062, China
[h] National Research Institute of Astronomy and Geophysics, 1 Mirsad Street, 11421 Helwan, Egypt
[i] EPHE-Section des Sciences Historiques et Philologiques, AOROC, UMR 8546 - Archéologie et Philologie d'Orient et d'Occident, CNRS/PSL, École normale supérieure, 45 rue d'Ulm, 75230 Paris Cedex 5, France

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A B S T R A C T

This article describes the location and sedimentary environments of the Khufu harbour in Giza, Egypt, with the aim of reconstructing its palaeoenvironmental evolution during the Old Kingdom (2686–2160 BCE). We use chronostratigraphy and sedimentology to elucidate the site's Holocene sedimentary units and compare and contrast the results with previous studies. Our research provides new insights into the palaeogeography of the Giza floodplain during the 4th Dynasty (2613–2494 BCE), including its impacts on the settlement patterns and cultural practices of the ancient Egyptians and their interactions with the natural environment. The findings provide valuable information for understanding the history and archaeology of the Giza area and contribute to ongoing efforts to preserve and interpret the cultural heritage of ancient Egypt.

## 1. Introduction

During the Old Kingdom (2686–2160 BCE), the ancient Egyptians built monumental constructions on the Giza plateau, including the pyramids, Sphinx, the residence of the king and his royal court, a city for workers, and many other service facilities. Khufu harbour was built during the reign of the Pharaoh Khufu, who ruled Egypt during the Fourth Dynasty (2613–2494 BCE) (Butzer et al., 2013; Malek, 2003). This fluvial port was located on the western bank of the Nile and accommodated in a now defunct fluvial channel called the "Khufu branch," to the east of the Giza Plateau (Fig. 1). The ancient Egyptians used this fluvial harbour to transport the large stones and masonary materials used in building the pyramids, tombs, and temples, be it limestone from Tura, east of Giza, or granite stones from Aswan, southern Egypt (Bell, 1970; Bunbury & Lutley, 2008; Butzer et al., 2013; Hassan, 1981; Lehner, 2014, 2020; Sheisha et al., 2022, 2023; Tallet & Lehner, 2022).

This study is the third publication of our ongoing palaeoenvironmental research efforts at Giza. Our previous work, centered on the reconstruction of its vegetation landscapes (Sheisha et al., 2023) and Holocene water levels of the Nile (Sheisha et al., 2022), using cores Giza-1 and Giza-4. In contrast, the present study focuses on the chronostratigraphy of the unpublished core Giza-3. A key distinction between this research and our previous endeavors is that cores Giza-1 and Giza-4 were extracted from the sediments of the now-extinct Nile Khufu branch, while core Giza-3 originates from within Khufu's ancient fluvial harbour.

The construction of Khufu harbour in Giza was part of a larger project to build a canal linking the Nile River to the Red Sea, which would provide Egypt with direct access to the lucrative trade routes of the Indian Ocean (Bard, 2015). Khufu harbour in Giza was functional at the same time as the harbour of Wadi Al-Jarf on the Red Sea, which was

* Corresponding authors.
*E-mail addresses:* younes@cerege.fr (G. Younes), nick.marriner@univ-fcomte.fr (N. Marriner).

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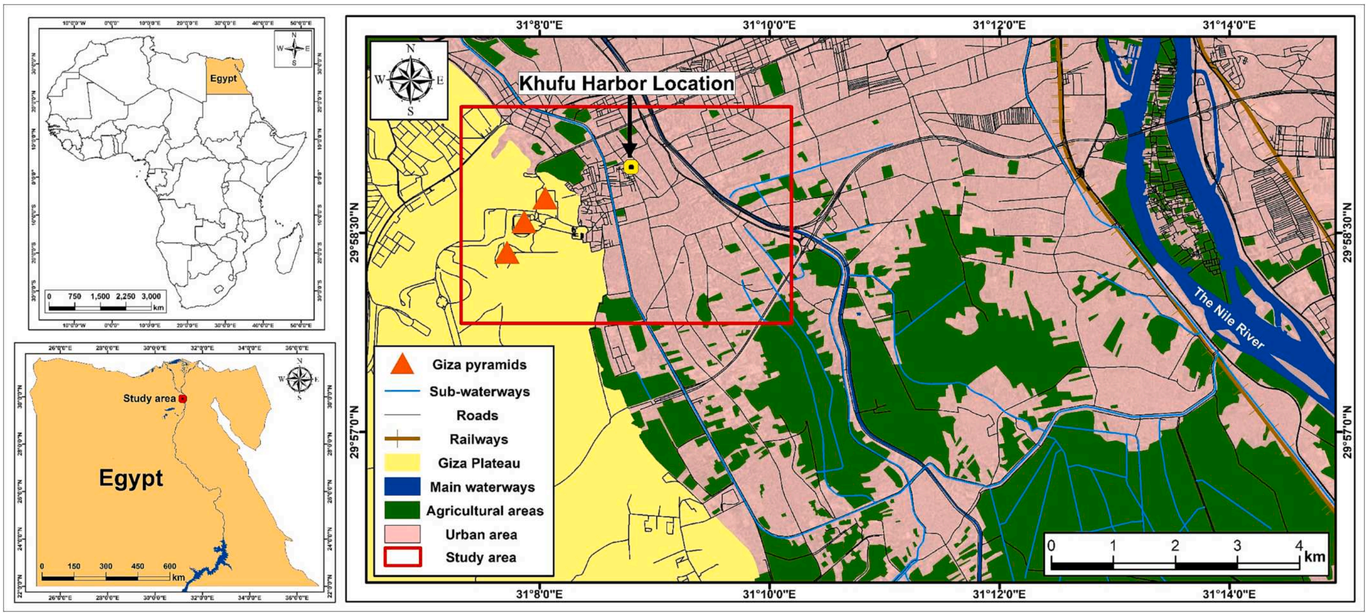


**Fig. 1.** The general location of the study area and the site of Khufu harbour in Giza.

discovered in 2011 by a team from the University of Paris-Sorbonne and the IFAO. Wadi Al-Jarf was exclusively occupied during the early 4th Dynasty until the final closure of this installation at the end of the reign of Khufu (Tallet & Lehner, 2022; Tallet & Marouard, 2014). Archaeological evidence suggests that Khufu harbour in Giza was a bustling center during the Old Kingdom. Excavations at the site have uncovered numerous artifacts, including pottery, tools and even a wooden boat dating back to the Fourth Dynasty. The remains of a stone ramp and a series of quays have also been discovered (Hawass, 1997), providing further evidence of the harbour's importance as a transport hub. It was likely used as a loading and unloading point for ships transporting goods between the Nile and the Red Sea. The Nile River is currently located about 8 km from the Giza plateau, and the floodplain is heavily urbanized (See Fig. 1).

Geoarchaeological research on fluvial environments has attempted to address various archaeological questions and problems (Brown, 1997; Ferring, 2001; Haynes & Huckell, 1986; Stanley et al., 2004; van Dinter et al., 2017; Waters, 2000). Rivers offer fresh water, expansive landscapes, and transportation channels for human societies and have been inhabited throughout history (Hill, 2014). Within these riverscapes, alluvial sediments provide a foundation for geoarchaeological interpretations, and they carry crucial information about environmental and climatic changes during the late Quaternary (Waters, 2000). Holocene sediments from the Nile floodplain have also been the focus of much geological and archaeological research. These studies have mainly focused on estimating the magnitude of Nile floods, as well as palaeoenvironmental and palaeoclimate changes. The effects of flood fluctuations on the development and demise of Egyptian civilization has been a key focus of research (Butzer, 1976; Hamdan et al., 2019; Wendorf & Schild, 1976).

Over the past few decades, several studies (Bell, 1975; Butzer, 1976; Hassan et al., 2003; Hassan, 2006) have attempted to explain the palaeogeography of the Giza plateau and its surrounding environment during the Old Kingdom, to determine the location of ancient Nile channels and their changes through time. Several other studies have focused on Khufu harbour and its use during the same period (Butzer et al., 2013; Hawass, 1997; Lehner, 2014).

Hawass (1997) described the possible borders of the Khufu harbour and its commercial importance during the Old Kingdom. His work focused on excavations carried out at the site and the analysis of the findings, including large stone blocks probably used in the construction of the harbour, as well as pieces of rope, wood, and pottery.

Lehner (2014) built upon the earlier work of Hawass and focused on the geomorphological and topographical contexts of the harbour within the Giza landscape. Using a combination of archaeological evidence and satellite imagery, Lehner argued that the harbour was part of a larger complex of structures and facilities built to support the construction of the pyramid of Khufu. These included quarries, storage facilities and workshops for tool and material production. Lehner also suggested that the harbour was connected to a network of waterways and canals used for transportation and irrigation. This would have allowed for the efficient movement of goods and materials to and from the harbour, supporting the agricultural and economic needs of the pyramid builders. Overall, Lehner's study provided a more detailed and nuanced picture of Khufu harbour and its place within the wider context of the Giza plateau. Importantly, Lehner developed a detailed model and high-resolution contour maps of Khufu harbour, showing its topography during the Old Kingdom, and its relationship to Giza's other Nile waterways.

Butzer et al. (2013) focused on the environmental context of Khufu harbour and its surrounding landscape. Specifically, the study examined the impact of the construction and use of the harbour on the local hydrology. The authors emphasized the importance of taking a holistic and interdisciplinary approach to the study of the Khufu harbour and its surrounding landscape.

Here, we examine the Holocene sedimentary environments at the proposed location of Khufu harbour. In particular, we use chronostratigraphy and sedimentology, to reconstruct the Holocene paleoenvironmental conditions of the Giza floodplain, with a particular focus on the Old Kingdom. We compare and contrast our findings with the topographical results of previous studies.

## 2. Historical context of Giza

The Old Kingdom lasted for over five centuries (2686–2160 BCE) and included the Third to Eighth Dynasties. This era was characterized by economic prosperity and political stability in most of Egypt, and it is also known as the pyramid builders' period. The most famous and significant pyramids were built on the Giza plateau during the Fourth Dynasty (2613–2494 BCE). King Sneferu (2613–2589 BCE) changed the external shape of the royal cemetery during his reign to a real pyramid, which reached its climax during the reign of his son and successor, Khufu (2589–2566 BCE), who built the Great Pyramid on the Giza plateau,

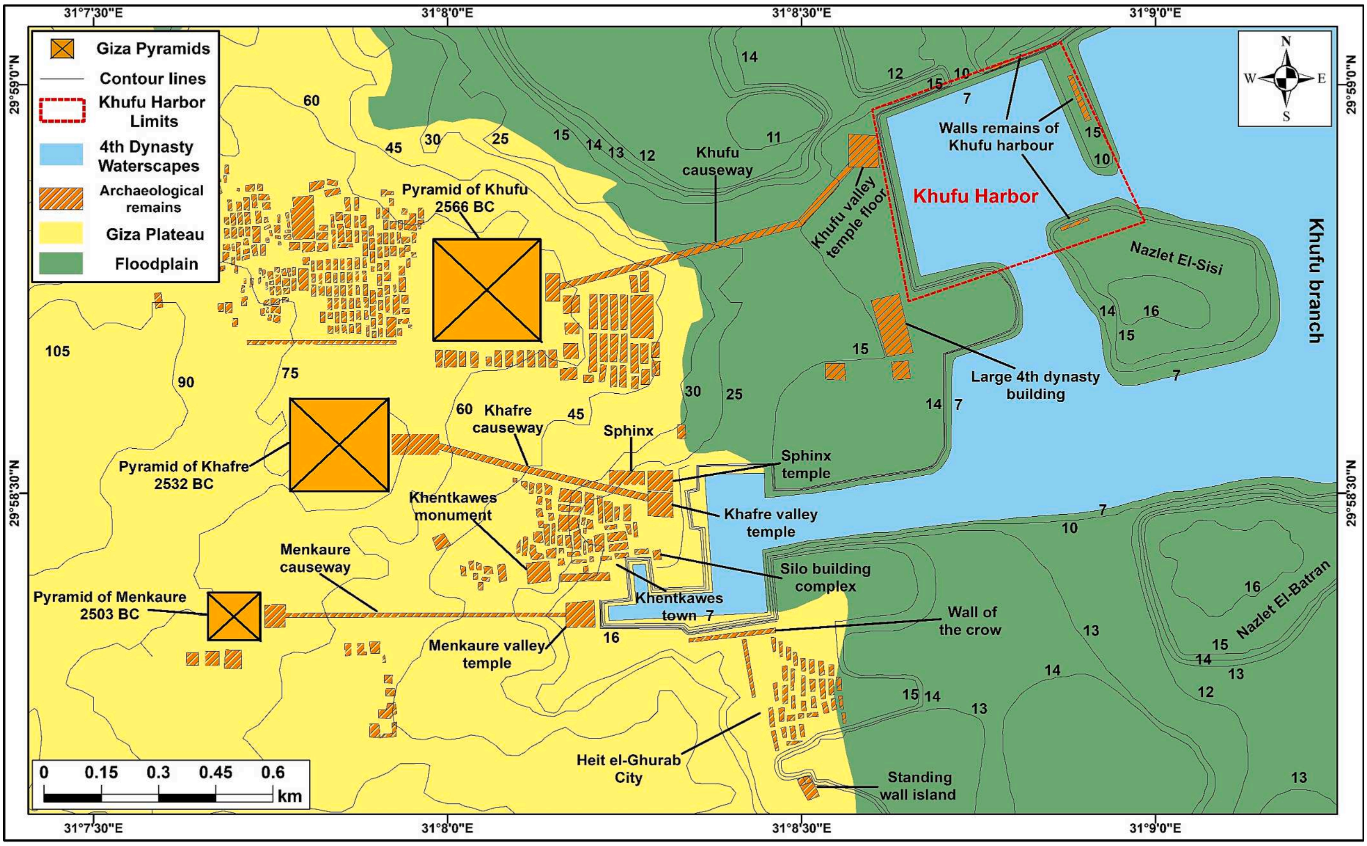


**Fig. 2.** Archaeological and topographical map of Giza landscapes during the 4th Dynasty (2613–2494 BCE), modified and adapted from Lehner, 2014

which is the largest pyramid in Egypt. Khufu was followed by his son Djedefra (2566–2558 BCE), who built a pyramid bearing his name northwest of Giza. King Khafre (2558–2532 BCE), another son of Khufu, erected his pyramid on the Giza plateau next to the Great Pyramid. Khafre's pyramid complex includes the Great Sphinx, a human-headed lion. Menkaure's pyramid complex was finished by his son and successor, Shepseskaf (2503–2498 BCE), who was the first Old Kingdom pharaoh to forego the pyramidal design. Khentkawes, a likely queen of Menkaure, had a tomb at Giza and a minor pyramid complex built for her at Abusir (Malek, 2003).

Khufu harbour was built during King Khufu's reign (2589–2566 BCE) and was used to transport materials for his pyramid's construction, as well as for trade and the transportation of food and goods (Sheisha et al., 2022, 2023; Tallet & Lehner, 2022). The harbour is located to the east of the Khufu valley temple floor in front of the Khufu pyramid. In 1994, the remains of ancient walls were uncovered in Zaghloul Street, mainly comprising limestone and basalt. The basalt and limestone match the materials used in Khufu's upper pyramid, valley temple, and causeway, indicating that the walls were a part of the Khufu complex and likely represented the borders of the harbour (Fig. 2) (Hawass, 1997; Lehner, 2014).

The contour lines in Fig. 2 show the ancient topography of the area during the 4th Dynasty (2613–2494 BCE) and the construction of the Giza pyramids, according to Lehner's model. Heit el Ghurab city, also known as the "lost city," was located to the southeast of the Giza pyramids and was used for logistic purposes, such as transferring food and masonry material for the construction of the pyramids. The Khufu causeway, composed of fine Tura limestone, runs to the east of the Khufu pyramid until it reaches the upper temple of Khufu valley (Fig. 2). Its length has been estimated to be around 825 m (Hawass, 1995).

Another important wall constructed during the Old Kingdom was the Wall of the Crow, which was built at 16 m above sea level and measured 10 m in height and 200 m in length. It was considered a part of the Heit el-Ghurab old city located a few hundred yards from the Sphinx (Fig. 2). Butzer et al. (2013) suggest that the wall of the crow acted as a barrier against Nile floods.

The study by Lehner (2014) provides compelling archaeological evidence supporting the presence of a river branch adjacent to the Giza plateau during the 4th Dynasty (2613–2494 BCE) (Malek, 2003), which included harbours used for transporting large stones and construction materials for the pyramids. Lehner (2014) employed three methods to reach these conclusions: 1) Analysis of ancient vestiges in the present-day topography to identify an ancient Nile channel used during the Old Kingdom. 2) Study of ancient features uncovered through excavation, with structures from the Fourth Dynasty serving as benchmarks for canals and harbours, as well as the floodplain and riverbank levels. 3) Analysis of sediment cores extracted from the floodplain, showing the fluvial facies of abandoned watercourses, as well as riverbank sand and gravel where 4th Dynasty people established settlements.

Based on this evidence, Lehner (2014) developed a model for the canals and harbours of Giza during the 4th Dynasty (Fig. 2), partly using on the ancient topography of the floodplain. The contour lines range from 7 to 16 m above sea level, with Nazlat El-Sissi and Nazlat El-Batran islands ranging from 14 to 16 m above sea level. According to Lehner's model, the water level during the low season reached approximately 7 m ($\pm$0.5 m) above sea level with a fairway depth of about 4 m. During the flood season, after rainfall over the Ethiopian highlands, the water level rose about 7 m ($\pm$0.5 m) for a period of six to eight weeks. During the height of the flood, the water level in the river channels and harbours attained around 14 m ($\pm$0.5 m) above sea level and a fairway depth of 10 m ($\pm$0.5 m), allowing for the passage of cargo boats.

The importance of Lehner's (2014) study lies in the detailed maps created for Khufu harbour, as seen in Fig. 3, which illustrates the harbour's geography during the pyramid-building era and the contour lines

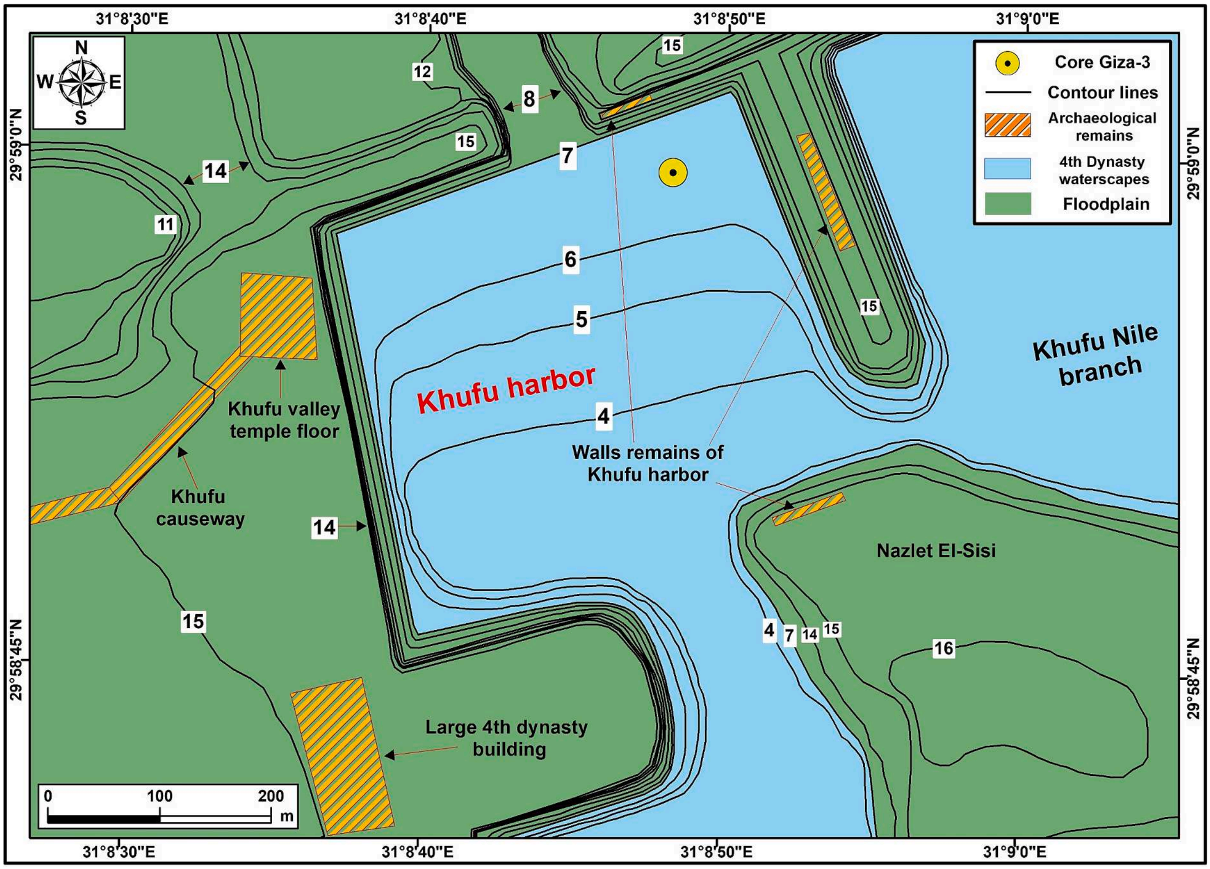


**Fig. 3.** Detailed map of the archaeological and topographical contexts of Khufu harbor during the 4th Dynasty (2613–2494 BCE) modified and adapted from Lehner, 2014

coinciding with this period. The figure demonstrates that the harbour's contour lines ranged between 3.5 and 4 m at the bottom, reaching a level of 7 m at the water surface during the low season. The water column was only 3 to 3.5 m, which is insufficient to permit the passage of ships loaded with stones and construction materials required for the pyramid of Khufu. However, according to Lehner's model, during the flood season, the water inside the harbour rose to 7 m (±0.5 m), resulting in a total water depth of 10 m (±0.5 m), which ancient Egyptian engineers utilized to transport ships loaded with heavy materials essential for pyramid construction. In this study, we will verify these levels using sedimentary unit analysis.

This study aims to investigate the sediments of the purported Khufu harbour, using the harbour's chronostratigraphy to reconstruct the ancient topography of Giza during the Pharaonic era. We also compare and contrast the results with previous studies.

## 3. Materials and methods

A sediment core was drilled at the proposed site of Khufu harbour (see Fig. 3) during a field study in May 2019 using a percussion vibrocorer. The core, named "Giza-3″, has a total length of 980 cm and is located at 29°58′59.50″N, 31°8′48.40″E, with the surface being 16 m above sea level.

In the field, 183 samples were collected from the core, with the upper 130 cm of the core being sampled at intervals of 15 cm and the remainder at intervals of 5 cm. Information related to the sediment's texture, colour and constituent layers was recorded during the sampling process. The samples were stored in a refrigerator at low temperature to preserve their organic components.

Radiocarbon dating was conducted on seven samples from the core, all of which were from organic clay. Three samples were dated at the Poznań Radiocarbon Laboratory in Poland, while the other four samples were dated at the Beta Analytic Radiocarbon Dating laboratory in Miami, Florida, USA. The radiocarbon results were calibrated using the

**Table 1**
Results of radiocarbon dating of core Giza-3.

| Giza-3 | | | | | | |
|---|---|---|---|---|---|---|
| lab no. | Sample material | Sample depth cm | Age $^{14}$C | (1 sigma) 68.3 % | (2 sigma) 95.4 % | Best estimation |
| Poz-130340 | Organic mud | 205 | 2725 ± 35 BP | Cal. BC 900–829 | Cal. BC 931–807 | Cal. BC 868 |
| Beta-539936 | Organic mud | 345 | 3230 ± 30 BP | Cal. BCE 1529–1450 | Cal. BCE 1596–1425 | Cal. BCE 1485 |
| Poz-150711 | Organic mud | 435 | 3265 ± 30 BP | Cal. BCE 1608–1499 | Cal. BCE 1614–1494 | Cal. BCE 1528 |
| Beta-539937 | Organic mud | 650 | 4080 ± 30 BP | Cal. BC 2637–2572 | Cal. BCE 2700–2564 | Cal. BCE 2623 |
| Beta-539938 | Organic mud | 802 | 4590 ± 30 BP | Cal. BCE 3374–3343 | Cal. BCE 3379–3329 | Cal. BCE 3365 |
| Poz-150712 | Organic mud | 880 | 6750 ± 130 BP | Cal. BCE 5755–5529 | Cal. BCE 5914–5473 | Cal. BCE 5663 |
| Beta-539939 | Organic mud | 975 | 7600 ± 30 BP | Cal. BCE 6462–6432 | Cal. BCE 6481–6411 | Cal. BCE 6448 |

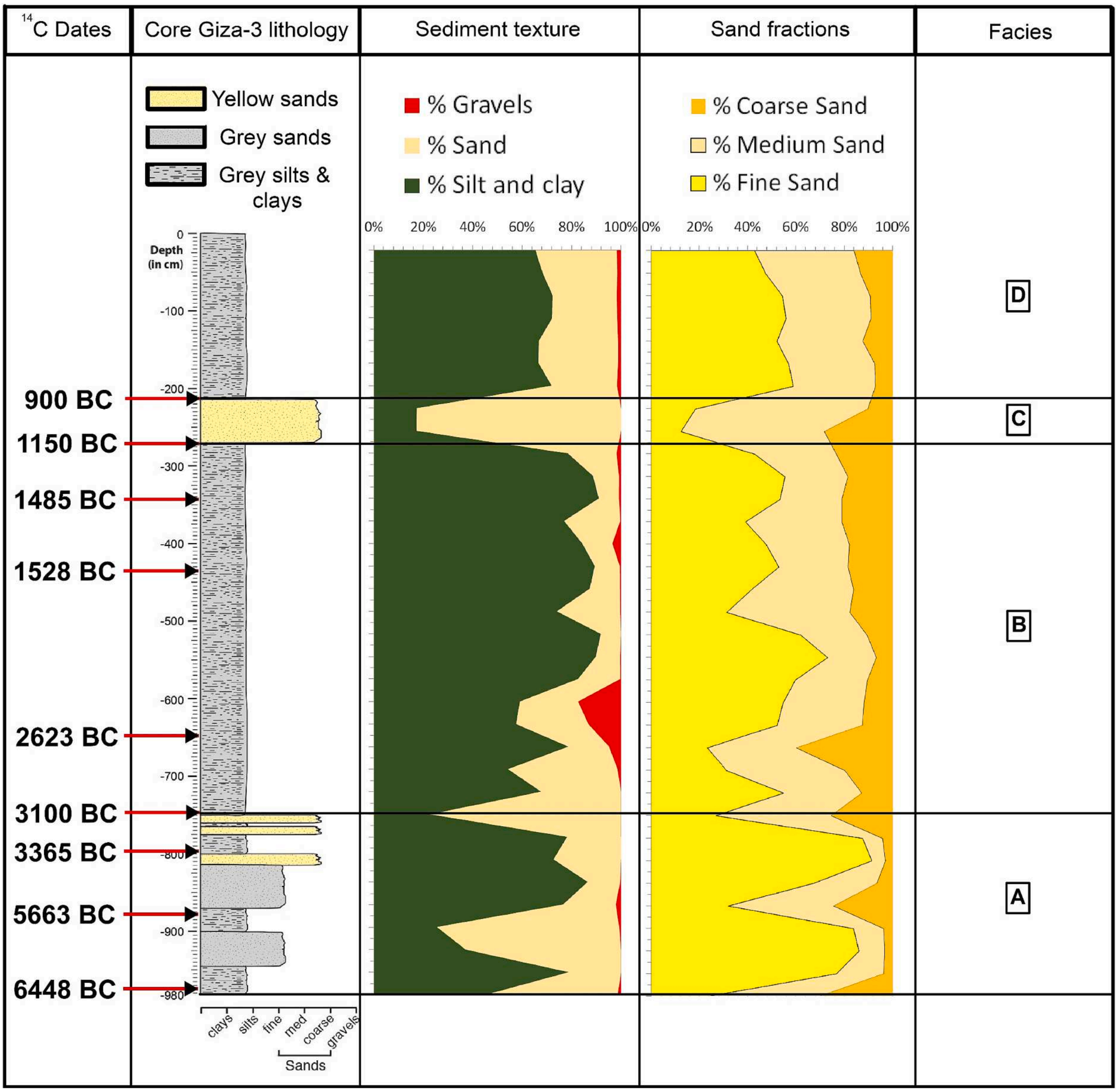


**Fig. 4.** Stratigraphic log of the sediment core Giza-3 from the Khufu harbour in Giza. Unit A: Palaeo-channel sediments, Unit B: Khufu harbour sediments, Unit C: Wadi outwash deposits, Unit D: Nile floodplain sediments.

calibration curve Intcal20 (Reimer et al., 2020) (Table. 1).

34 sedimentary samples were selected along the Giza-3 core for grain-size analyses. These samples were dried at 50 °C, weighed, and then prepared for grain size analysis. After determining the weight of each sample, wet sieving was performed to separate the silt and clay (<63 µm), sand (0.63–2 mm) and gravel (>2 mm). Dry sieving was then performed to separate sand sizes into three categories: fine sand (63–200 µm), medium sand (200–500 µm) and coarse sand (500 µm – 2000 mm). The weight of each sediment fraction was recorded to characterize the sedimentary environment and to divide the core into sedimentary units.

The grain-size data were analyzed using the GRADISTATv9.1 program, which is a Grain Size Distribution and Statistics Package for the Analysis of Unconsolidated Sediments by Sieving or Laser Granulometer. This program provides graphs of the grain-size distribution and cumulative distribution of the data, both in metric and phi units (Blott & Pye, 2001). The samples were also examined under the microscope to check for microfaunal remains.

## 4. Results

Four sedimentary units were identified (Fig. 4). The data required to replicate all analyses in the paper are available in the JAS Dataest Repository Excel file (Tables 1 to 4). The age model (Fig. 5) shows the chronological sequence of deposition of these units.

"Giza-3″ was taken from the proposed Khufu harbour site, which was used at the time of the pyramid builders in the third millennium BC to transport large and heavy granite rocks from Aswan and limestone from Tura (Butzer et al., 2013; Lehner, 2014; Sheisha et al., 2022, 2023). We consider floodplain sedimentation in two main contexts: within and close to the Nile channel, and outside of the channel (i.e. on the floodplain). To fully understand the grain-size analysis results as evidence of the sedimentary environments in which facies were deposited, we need to combine these results with potential sediment sources, detailed geomorphological and geological maps and chronostratigraphy (Folk, 1980). Holocene Nile sediments in Egypt consist mainly of Ethiopian silt with local sand dune deposits, wadi and pond deposits (Adamson et al., 1980). It should also be emphasized that these sedimentary events are

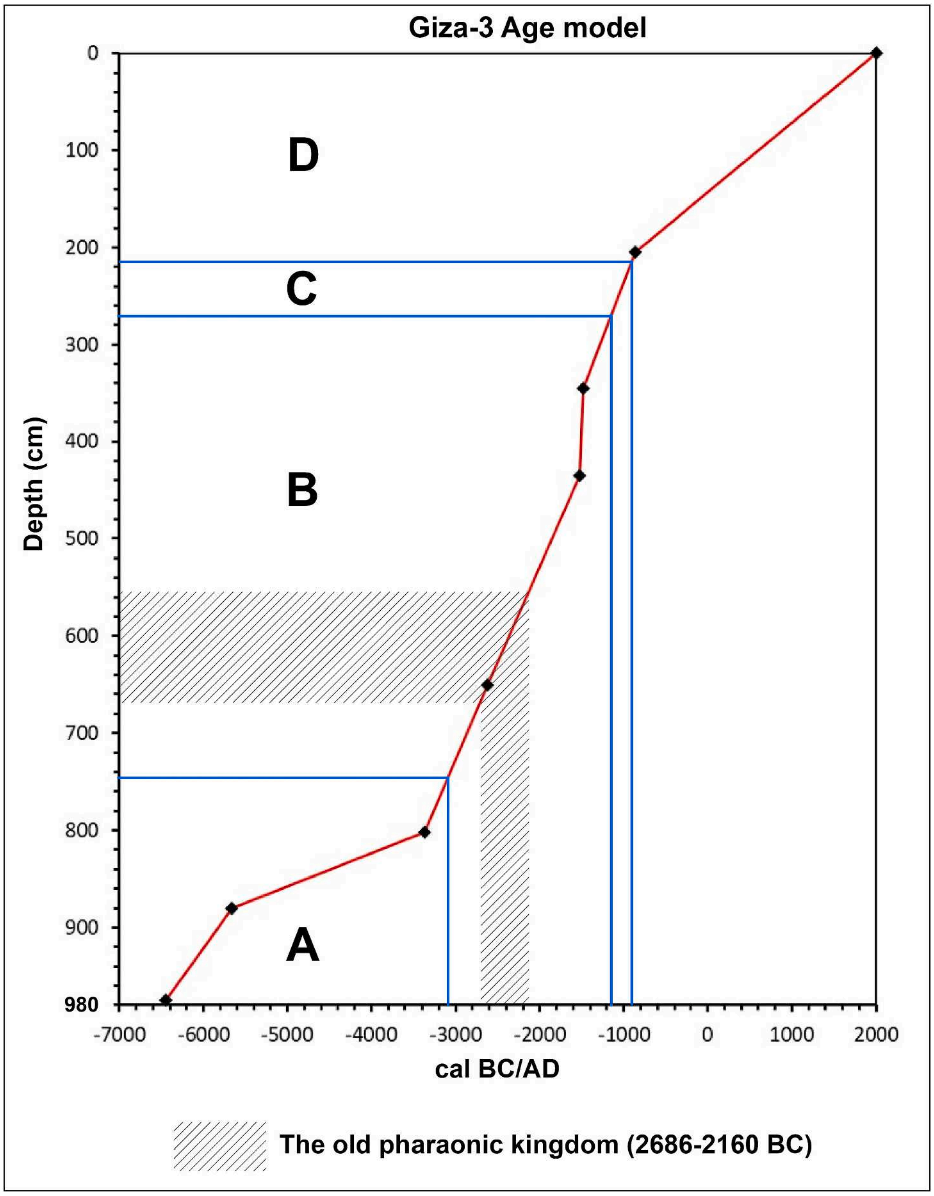


**Fig. 5.** Giza-3 age model. Unit A was deposited during the pre-dynastic period (5000–3100 BCE) at a very low sedimentation rate of about 0.06 cm/year. Unit B was deposited during the Pharaonic period (3100–1150 BCE) at a sedimentation rate of about 0.24 cm/year. Unit C was deposited between 1150 and 900 BCE at a sedimentation rate of 0.22 cm/year. Unit D, with a thickness of 215 cm, was deposited from about 900 BCE until the present time at a sedimentation rate of 0.07 cm/year.

placed in the appropriate time frame according to the age model (**see** Fig. 5).

### *4.1. Unit A: Secondary palaeo-channel of the Nile (5000–3100 BCE)*

This unit extends between 745 and 980 cm below the surface. It consists of thin layers of silt, clay, and sand. The average percentage of silt and clay in the unit is 59 % while the average percentage of sand is 40 %. The gravels constitute just 1 %. The sediment is unimodal, very poorly sorted, while the textural group is slightly gravelly sandy mud. The mean grain size of this unit is very coarse silt, and the skewness is symmetrical.

The sand fraction is dominated by fine sands (60 %) with lesser amounts of medium sands (27 %) and coarse sands (13 %). The sand is unimodal, poorly sorted, and the mean grain size is fine sand. Ostracods were found at a depth of 880–890 cm. These were identified under the microscope as being *Cyprideis torosa* (Jones, 1850). The faunal density of the ostracods was 84 per 10 g of sand, which is low (See JAS Data Repository "DR Fig. 1″).

Unit A contains alternating grains of sand and silt in a mixed texture of sandy mud and muddy sand. This sedimentary mixture is indicative of deposition in a high-energy environment, interpreted as a meandering river channel migrating laterally across the floodplain. Thin beds of sand and silt in this unit refer to natural levee deposits, a common sequence of facies associated with the river channel environment (Bridge & Leeder, 1979; Hassan et al., 2017; Miall, 2014). Additionally, wash-out sediments from wadis surrounding the Giza pyramids plateau would have contributed to sediment supply (Butzer et al., 2013).

Ostracod analysis of this unit found 84 ostracods per 10 g at a depth of 880–890 cm below the surface, identified as all belonging to the species "*Cyprideis torosa* (Jones 1850)". *Cyprideis torosa* has a wide ecological distribution in aquatic environments, including freshwater rivers and lakes, although it is most common in high saline and brackish environments (Karanovic, 2012; Klie, 1938).

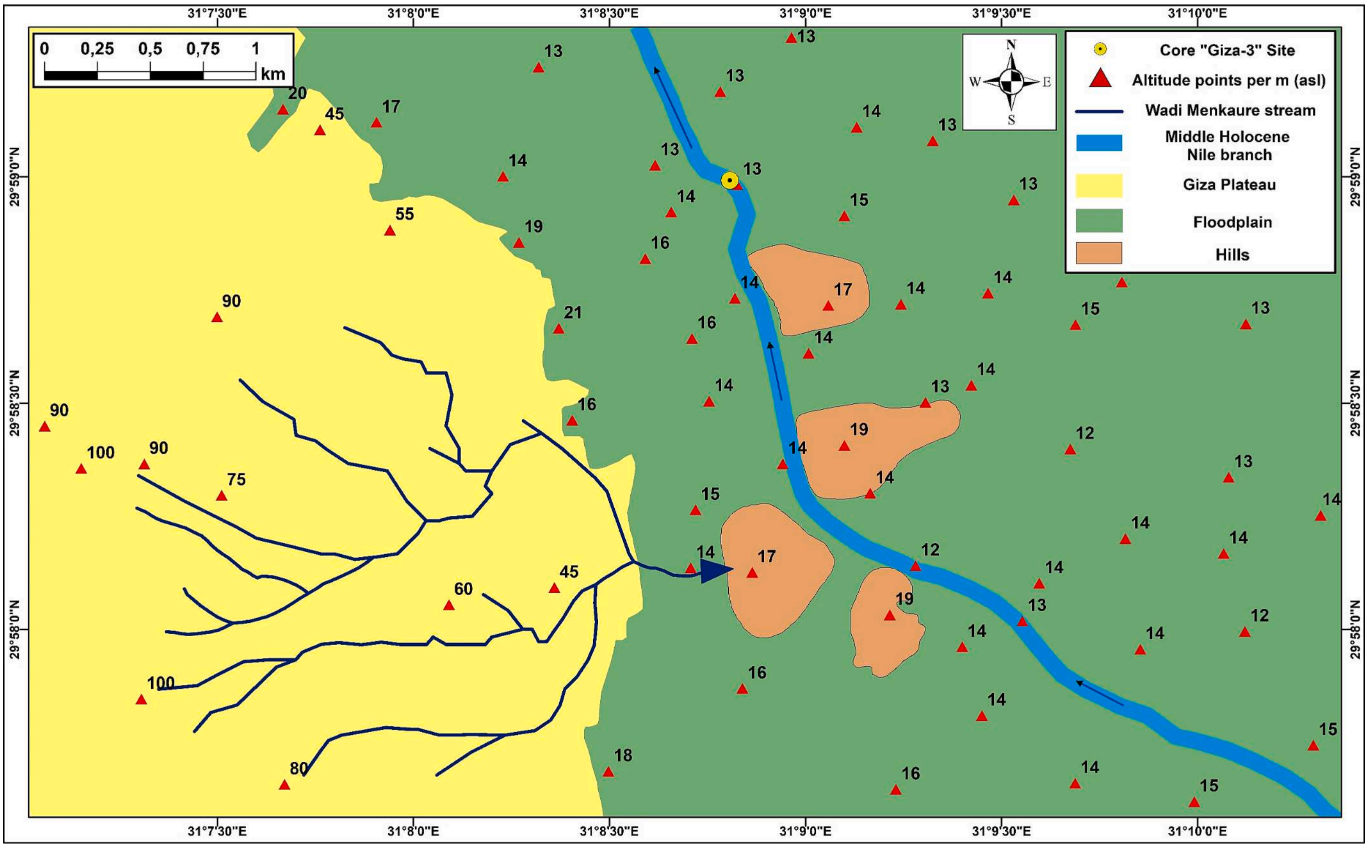


**Fig. 6.** Topographic map of the Giza area during the early and middle Holocene (before the Pharaonic era) based on our findings and those of Butzer et al., (2013) and Said (1975).

### *4.2. Unit B: Low-energy fluvial environment and Khufu harbour (3100–1150 BCE)*

Unit B has a thickness of approximately 475 cm, extending from 270 to 745 cm below the surface. Silt and clay deposits dominate this unit, comprising, on average, 81 % of the total sediment fraction. The average percentage of the sand fraction is 16 %, and the average percentage of the gravel fraction is just 3 %. The samples are bimodal and very poorly sorted, characterized as being slightly gravelly sandy mud. This unit is distinguished as being slightly medium gravelly, very fine sandy, and very coarse silt, with the mean being coarse silt and the skewness coarse skewed. Pottery shards were found between 590 and 650 cm (See JAS Data Repository “DR Fig. 2″). The sand fraction comprises fine sands (50 %), medium sands (33 %), and coarse sands (17 %). The sand samples of this unit are unimodal and poorly sorted, with the mean being fine sand.

Unit B is dominated by silt and clay (>80 %) consistent with a low-energy environment similar to a harbour sedimentary environment. Butzer et al. (2013) referred to this 500-cm thick unit as a block of uniform Nilotic silts, accumulated after a system change from high-energy bedload to low-energy suspended silts from Ethiopia that spread over the floodplain in the Giza area. This suggests that the harbour was located on the western side of a secondary branch of the Nile at the end of Khufu’s causeway and in front of the valley Temple of Khufu (**Fig. 3**) (Butzer et al., 2013; Lehner, 2014, 2020; Lehner et al., 2009; Sheisha et al., 2022; Tallet & Lehner, 2022). This harbour played an important role in transporting masonary and construction materials used in building the pyramids of Giza during the 4th Dynasty (2613—–2494 BCE).

The onset of this unit coincided with the emergence of the Pharaonic era in Egypt around 3100 BCE, and it continued to be deposited until almost the end of the Pharaonic era, around 1069 BCE (Shaw, 2003). Pottery shards were found in this layer at depths of between 590 and 650 cm, deposited around 2600–2300 BCE according to our age model. This coincides with the Old Kingdom period (2686–2160 BCE), specifically the 4th Dynasty (2613–2494 BCE), the 5th Dynasty (2494–2345 BCE) and the beginning of the 6th Dynasty (2345–2160 BCE) (Malek, 2003). These remains attest to the intensity of human activity in the vicinity of this study site during the Old Kingdom period.

### *4.3. Unit C: Wadi outwash deposits (1150–900 BCE)*

Unit C is a sandy unit that extends from 215 to 270 cm below the surface and is dominated by sand, averaging 83 %, with low percentages of silts and clays at 17 %. The grain size analysis shows that the samples of this unit are unimodal and poorly sorted, with a textural group of muddy sand where coarse silt and medium sand predominate. The mean grain size fraction of this layer is fine sand. Medium sands (66 %) dominate the sand of this unit, followed by coarse sands (19 %) and fine sands (15 %). The sand samples of this unit are also unimodal and poorly sorted, with the mean being medium sand and the skewness being coarse skewed.

This unit is characterized as the thinnest in this core, with a thickness of only about 55 cm, and about 83 % of the sediments are sand. The skewness in this unit is positive due to the predominance of sand grains, but the sorting is poor, which indicates that water was the primary factor in the transportation of the sediments, as aeolian sediments are usually well sorted (Folk, 1980). The unit is void of ostracods, shell fragments or organic materials.

Medium and coarse sands dominated more than 85 % of the total sand percentage in this unit. This could reflect torrential desert floods on the Giza plateau, causing torrents to carry local wadi sediments of all sizes towards the floodplain. Butzer et al. (2013) also described this unit

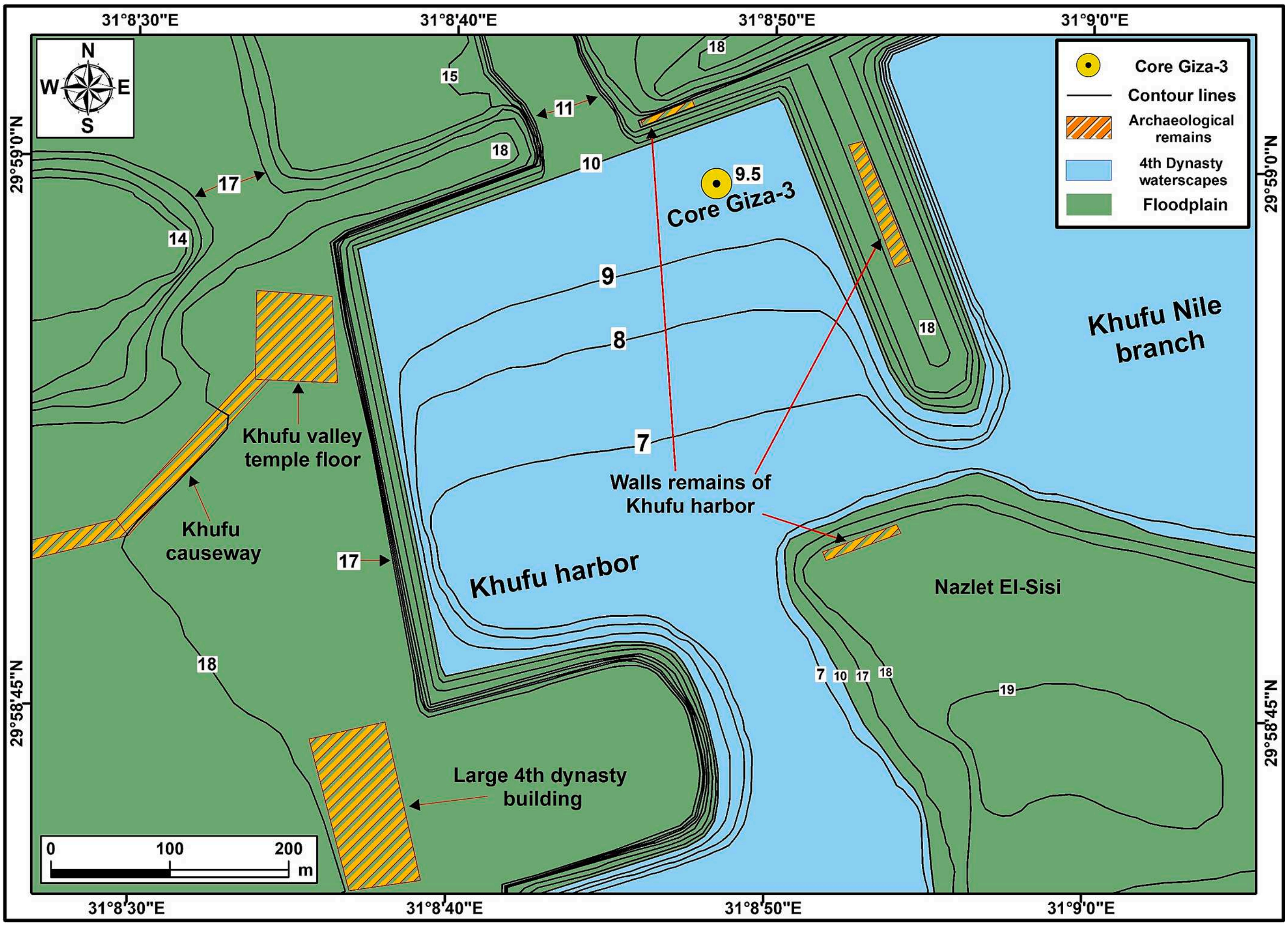


**Fig. 7.** Reconstruction of the palaeotopography of Khufu harbor during the 4th Dynasty (2613–2494 BCE) based on (Lehner, 2014).

in Giza's Holocene floodplain stratigraphy. He attributed the facies to exceptional climatic anomalies that caused devastating floods, especially at the feet of the Giza plateau, leading to the progradation of alluvial fans onto the Nile floodplain, covering older branch channels. During the period 1150–900 BCE, the impact of desert hazards, torrential rains, and local runoff on the floodplain was greater than Nile floods. Lots of independent archives within the Nile watershed show evidence for failing Nile floods around 3200 years ago. These extend for over 6500 km from the Nile source areas at Lake Victoria and in Ethiopia, through the Nile valley, including the Faiyum basin, right down to the Nile Delta (Butzer, 1976; Kaniewski et al., 2015).

### *4.4. Unit D: Nile floodplain sedimentation (900 BCE to present)*

Unit D extends from the surface down to 215 cm. This unit is also dominated by silt and clay sediments (69 %), with 30 % sand and 1 % gravel. The grain size distribution is unimodal, very poorly sorted, and its texture is sandy mud, with a coarse-skewed mean that is fine sand. The sand fraction is mostly fine sand (53 %), followed by medium sand (37 %) and coarse sand (10 %).

This unit occupies the first 215 cm of core "Giza-3" and is very similar to the deposits of Unit B. It consists of silt and clay, which make up around 70 % of the sediment, while about 29 % of it is sand, falling into the sandy mud texture group. All samples of this unit are very poorly sorted, and the skewness has negative values, indicating the domination of silt and clay. The mean size is coarse silt, while the fine sand represents about 53 % of the total sand grains. These characteristics indicate a low-energy sedimentary environment that led to the deposition of silts, clays, and fine sands on the Nile floodplain environment (Ferring, 2017; Folk, 1980; Holliday, 2004; Miall, 1992). The age model indicates that this unit began to be deposited around 900 BCE and continues up to the present day.

Between about 939–645 BCE, the Giza floodplain experienced a period of high Nile floods that reached its peak around 710 BCE (Butzer et al., 2013). These high floods led to the deposition of a mud layer ranging from a few centimeters to more than 1 m in some places at the base of the Giza plateau. These events largely coincide with the onset of Unit D deposition in this study.

## 5. Discussion and paleoenvironmental reconstruction

The study focuses on reconstructing the paleoenvironments of the Khufu harbour, which the ancient Egyptians used to transport building materials and supplies for the pyramids of Giza and to facilitate trade between the Nile and the Red Sea. Our study has shown that Unit A is consistent with a secondary palaeo-channel of the Nile River. This secondary channel functioned from the early Middle Holocene until about 3100 BCE. This finding is consistent with earlier studies (Butzer et al., 2013; Said, 1975) suggesting that the main channel of the Nile was near its current course in Cairo, while the secondary channel passed near the Giza plateau during the early and middle Holocene (refer to Fig. 1).

Based on historical data, sedimentary analyses and dating, Figs. 6 to 8 depict the palaeogeography of the study area. Fig. 6 illustrates the Giza region during the middle Holocene period, before the pyramids were constructed. It shows Wadi Menkaure, which transfers flashflood waters resulting from short and intense rainfall events from the plateau to the

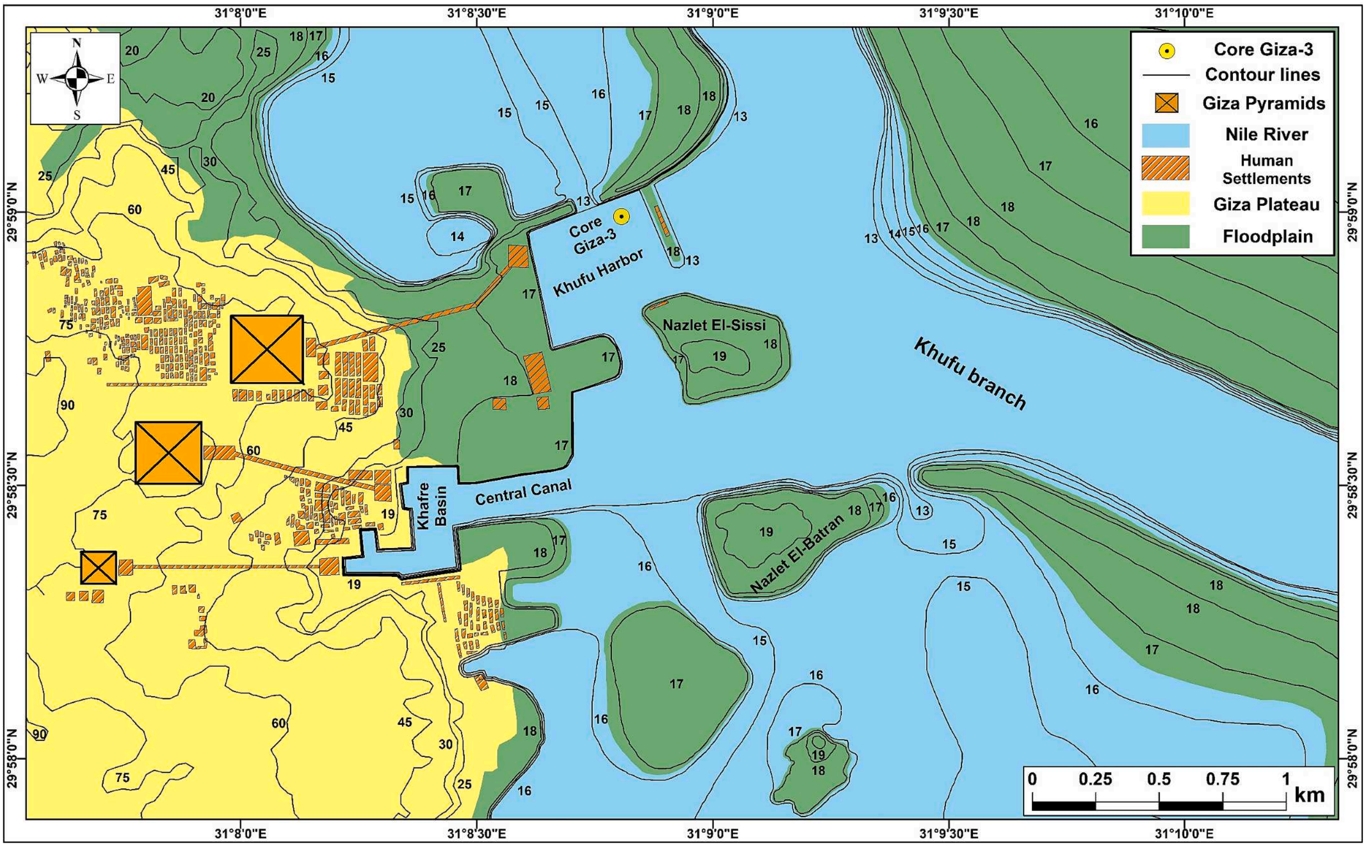


**Fig. 8.** Reconstruction of the palaeogeography of Giza during the 4th Dynasty (2613–2494 BCE) in the flood season, adapted from Lehner (2014)

floodplain.

The ostracods found in the core Giza-3 sediments date back to around 5600 BCE, consistent with the bottom of the secondary river channel. Given the surface level of core Giza-3, 16 m above sea level, and the depth of the ostracods at approximately 9 m below the surface, the bottom of this secondary channel was at a level of 7 m (±0.3 m) above sea level during that period. Earlier studies suggest that this secondary Nile branch had an average width of 20 m and a depth of 6.5 m during the middle Holocene (Brown, 1892; Butzer et al., 2013). Therefore, the surface of the floodplain at core site Giza-3 was approximately 13 m (±0.5 m) above sea level, which is about 3 m (±0.5 m) lower than the current surface level. To reconstruct the palaeogeography of the area, 3 m were subtracted from each level on the floodplain. The Giza Plateau's elevation points were left unchanged because these comprise bedrock. Finally, the secondary river channel's path was determined using the ArcMap program, following the lowest topographic points (see Fig. 6).

The secondary palaeo-channel persisted at the site of core Giza-3 until around 3100 BCE, after which time it was replaced by the sediments of the floodplain unit B. This suggests that the channel shifted eastwards, and that the core site became a swampy area affected by flood waters and sediment. The discovery of pottery remains from the 4th Dynasty in unit B supports the conclusion of scholars such as (Butzer et al., 2013; Hawass, 1997; Lehner, 2014; Sheisha et al., 2022; Tallet & Lehner, 2022) that this site was used by the builders of the Giza pyramids as a harbour known as the "Khufu harbour.".

Lehner's (2014) model indicates that water levels in Khufu harbour during the pyramid-building era ranged from contour lines of 4 to 7 m, corresponding to a depth of about 3 m (±0.5 m) (**see** Fig. 3). During the Nile flood between August and October, water levels increased to 7 m (±0.5 m), or a contour line of 14 m (±0.5 m) above sea level, with a depth of 10 m (±0.5 m). This depth was sufficient for boats carrying masonry and materials to anchor near the construction site. Lehner's model suggests that the harbour bottom at the position of core "Giza-3″ during the reign of Khufu was between the contour lines 6 and 7 m, or about 6.5 m above sea level.

Our chronostratigraphy suggests that the harbour bottom was actually about 3 m higher than in Lehner's model. The dating results of core Giza-3 indicate that a sample from a depth of 6.5 m below the surface (about 9.5 m above sea level) was deposited around 2600 BCE, during the period of harbour use and pyramid construction (Fig. 7 **&** Table 1).

After analyzing the study area, this study reveals that during the pyramid building period, the water level in Khufu harbour was around 10 m above sea level, with a depth of approximately 3 m (±0.5 m). However, during the flood season, the water level would increase to 17 m (±0.5 m) for a duration of six to eight weeks, yielding a total channel depth of around 10 m (±0.5 m), which is sufficient to accommodate cargo boats (Fig. 8).

This study confirms Mark Lehner's model, which places the Khufu harbour site to the east of Khufu Valley temple. This conclusion is based on an analysis of the sediments of Unit B, which were deposited during the Pharaonic period (3100—–1150 BCE) and indicate that the contour lines were about 3 m higher than what Lehner (2014) proposed. In the research conducted by Sheisha et al. (2022), dating analysis of core Giza-1 revealed that during the Fourth Dynasty (2613—–2494 BCE), the bottom of the Khufu branch was situated at an elevation of 11.5 ± 0.5 m above sea level. In contrast, core Giza-4 indicated a slightly higher position for the base of the Khufu branch at 12.5 ± 0.5 m) above sea level. Consequently, the findings from this study, which places the bottom of the Khufu harbour during the Fourth Dynasty at core Giza-3 at an elevation of 9.5 ± 0.5 m above sea level (as depicted in Fig. 7) is a coherent result.

At some point during the Pharaonic era, Khufu harbour was abandoned. Unit C represents the alluvial fan deposits resulting from flashfloods over the Giza plateau. These floods deposited coarse outwash deposits over the margins of the Nile floodplains, including the former Khufu harbour and the ancient Khufu branch. During this period, the impact of desert flashfloods and local runoff on the Nile floodplain was greater than that of Nile floods.

According to our data, significant Nile flooding returned around 900 BCE and attained a peak around 710 BCE, covering most of the study area up to the feet of the Giza plateau. This contributed to the sedimentation of the floodplain deposits represented by Unit D.

## 6. Conclusion

This study provides valuable insights into the sedimentary environments of Giza's Khufu harbour. Our new data help to characterize the ancient harbour unit and reconstruct the palaeoenvironmental conditions, shedding light on the climatic and environmental changes that affected the area during the mid- to late Holocene. By comparing the findings with previous studies, the research reconstructs the ancient topography of Khufu harbour at the time of the pyramid builders. Our results are important for the ongoing efforts to preserve and interpret the cultural heritage of ancient Egypt and provide a deeper understanding of the region's history and archaeology. This study also contributes to providing a better understanding of the relationship between human societies in the Egyptian Nile valley and their natural surroundings.

## CRediT authorship contribution statement

**Gamal Younes:** Writing – review & editing, Writing – original draft, Supervision, Visualization, Investigation, Methodology, Conceptualization. **Nick Marriner:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Visualization, Investigation, Methodology, Conceptualization. **David Kaniewski:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Visualization, Investigation, Methodology, Conceptualization. **Hader Sheisha:** Writing – review & editing, Investigation, Methodology. **Zhongyuan Chen:** Writing – review & editing, Funding acquisition, Investigation. **Asem Salama:** Writing – review & editing, Investigation. **Gad El-Qady:** Writing – review & editing, Investigation. **Christophe Morhange:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Visualization, Investigation, Methodology, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Two files have already been sent with the manuscript (a Word file and an Excel file) under the category of "Supplementary Material" in order to verify the data that was used in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104303.

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