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The building stones of ancient Egypt – a gift of its geology

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Abstract

Building stones and clay-rich Nile mud were ancient Egypt's main raw construction materials. While the mud was easily accessible along the Nile river valley, the immense quantities of the different stone materials used for construction of the famous pyramids, precious temples and tombs needed a systematic quarrying organization, well arranged transport logistics over extreme distances and a high standard of stone masonry. The petrography, occurrence, and main applications of the 11 most popular stone types used in ancient Egypt are described in this contribution. Rough estimates of the scale of this mining activity, based on the volume of many different ancient quarry sites, all over Egypt, reveal that the monuments known today represent only a small fraction of the amount of building stones mined during the long, ancient Egyptian history. © 2002 Published by Elsevier Science Ltd.

Keywords: Building stones; Nile mud; Monuments and temples; Petrography; Mining logistics

1. Introduction

Ancient Egypt was regarded by Evers (1929) as the "state out of stone" because stone was the most important raw material used during the different periods of Pharaonic Egypt until Graeco-Roman and Arab times. A very schematic geological map of Egypt (Fig. 1) presents the general geological units of this country, all of which supplied ancient dynasties with varying quantities of building stones, mainly for funereal and sacral purposes such as pyramids, temples and various tomb constructions. Apart from the temples and sacral monuments, the more mundane architecture, including dwellings of the nobility and royal palaces was almost exclusively built of sun-dried Nile mud bricks. Nile mud, formed annually along the river valley during floods which averaged three months in duration, was thus the most important raw material in ancient Egypt, as it still is today. The mud derives predominantly from the source regions of the Blue Nile, the Abyssinian Mountains, and is laid down annually as a layer of a few millimetres thickness of highly fertile clay, providing an excellent and everlasting basis for agriculture. This annual blessing together with the constant water supply by the river guaranteed Egypt its legendary reputation as the "land of milk and honey". Nile mud bricks alone do not resist weathering forces for very long and thus, most of the villages, private and noble buildings of ancient Egypt have been lost, with only scarce exceptions waiting to be uncovered by the spate of archaeologists active in the country.

Unlike the habitations of the various levels of Egyptian society, the temples, famous pyramids and tombs were built for eternity and consequently were constructed and decorated from primary stone materials much more resistant to the ravages of weathering and time. The deposits of these stone materials utilised for such gigantic projects as the pyramids were mainly pragmatically selected near the construction sites themselves, but, if the proper material for decoration or casing was not available locally, the ancient architects, supported by the royal administration, did not hesitate to mine the required stone material even at the most remote sites and to transport it over thousands of kilometres to the construction sites.

2. The main deposits of building stones and their uses in ancient Egypt

The river Nile and its man-made channels served in most cases as ideal shipping routes for long distance transport of heavy stone loads, but in quite a few cases

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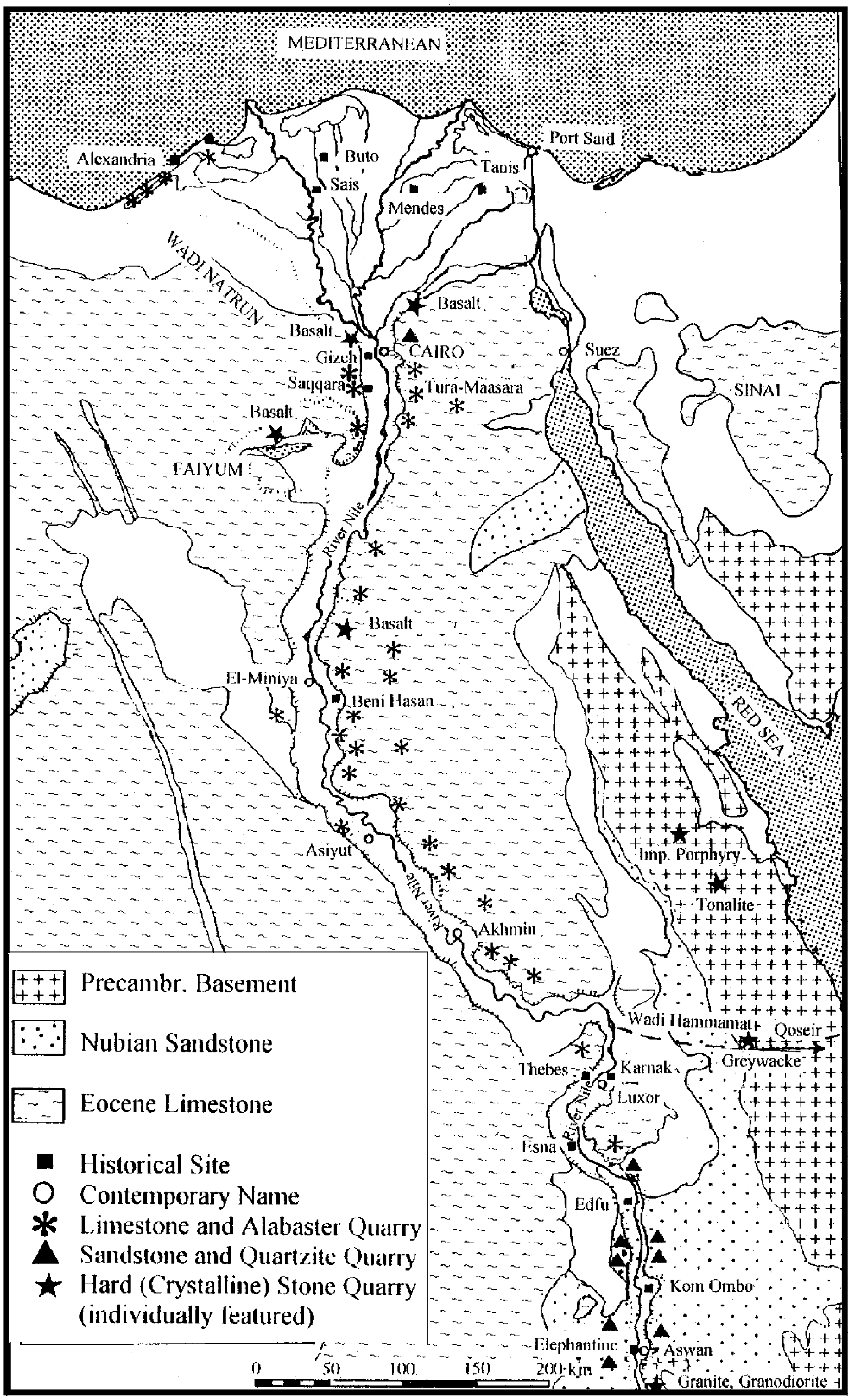

Fig. 1. Schematic geological map of Egypt with location of the main ancient quarry sites.

the stone material was also transported with utmost difficulty, and up to a 100 km or more, along desert tracks. During a systematic survey of quarries mined in ancient Egypt we have visited approximately 80 quarry districts, almost always subdivisible into local sites each exploited during the different historical periods. In this way, about 200 quarry sites have been listed. Most of the results are reported in detail in Klemm and Klemm (1993), but in this contribution we shall briefly discuss the various quarry districts, starting with the geologically oldest sites and ending with the youngest. The most recent deposits, the Nile mud quarries located everywhere along the river valley, have already been discussed above.

2.1. Deposits of anorthosite-gneiss in the Western Desert

These deposits belong to the "African basement" and occur in a series of amphibolites, gabbro- and diorite-gneisses with minor intercalations of calcsilicate-hornfelses (Huth and Franz, 1988), which form a dome at the Gebel el-Asr, some 30 km west of the Lake Nasser, at Toshka. The deposits most probably represent a highly metamorphosed part of a layered intrusion of anorthosites, gabbros and diorites into calcareous sediments of mid-Precambrian age. The main mineral constituents of this anorthosite gneiss are bytownite and a dark green to greenish-black, common hornblende (Harrell and Brown, 1994). The area is cut by various mafic dikes of unknown age.

Ancient quarrying was restricted to a small area of mainly anorthosite- and diorite-gneisses. The exact identification of the different quarry sites is somewhat difficult, due to heavy cover of windblown desert sand. Nevertheless, many loose blocks of various local stones show intensive ancient working traces. Engelbach (1933, 1938), who rediscovered this district, found a series of stelae (incribed stone columns), particularly from the Old Kingdom (OK, about 2700–2160 BC) and the Middle Kingdom (MK, 2119–1794 BC) as well as a copper chisel with a cartouche (an oval framed rendering of the king's name) of Pharaoh Cheops (about 2550 BC), now displayed in the Egyptian Museum in Cairo.

According to the working marks and these stelae traces it appears very probable that this site was indeed mainly worked during OK–MK periods, and that objects made of this stone material in later periods represent only reworked parts of broken material collected from earlier periods. Recycling of natural resources was thus already invented in ancient Egypt. Many stone vessels, objects mainly from Predynastic times to MK periods were made of this material, from which the "Falcon-Chephren" statue in the Cairo museum might be the best known. Total rock material mined in this quarry district was in the order of some 100 tons, which had to be transported along an approximately 30 km long desert track to the river and from there, passing the first cataract, some 1500 km by water towards the north, to Gizeh (Cairo), close to the ancient capital of Memphis at that time.

2.2. Deposits of "Bekhen-stone" (greywacke-siltstone) at Wadi Hammamat

Large parts of the Eastern Desert of Egypt, between the river Nile and the Red Sea consist mainly of nappes of intensely folded Pan African series, predominately comprising ophiolitic and other volcano-sedimentary rocks. These thrust sheets are exposed in the Eastern Desert of Egypt with a few exceptions of old African basement.

A zoisite-chlorite facies metamorphosed molasse-type sedimentary rock, resulting from these thrust systems and some syn-kinematic granitoid intrusives, consists mainly of green siltstones, dark green greywackes and conglomerates, which are best exposed in the Wadi Hammamat (Fig. 2) along the Quft-Quseir road from the Nile valley to the Red Sea. At this type locality these meta-sediments are also of favourable cleavage development, whereas at the many other occurrences of the Eastern Desert, the Hammamat series are mainly characterized by intense schistosity and are highly brittle. Thus, larger blocks of suitable construction stones could only be obtained from the Hammamat region itself, where along a gorge type-section of about 2 km, an impressive quarrying activity is documented by almost 600 rock inscriptions over a time interval from Predynastic until the late Roman period (about 4000 BC until 300 AD). These many inscriptions concentrated along a relative short distance in the wadi obviously indicate the uniqueness of this site and its extraordinary importance to ancient Egyptian culture. Consequently the rock type extracted here received a special name: "Bekhen-stone", as reported in many ancient Egyptian documents.

The oldest topographical sketch map hitherto documented, known as the "Turin mining papyrus", was ascribed to the Wadi Hammamat locality by Klemm and Klemm (1989). Apart from some gold and silver mines and a mining settlement displayed on this papyrus, it also shows the location of the Bekhen-stone quarry site, coloured in dark blackish green. Other

Fig. 2. Unfinished sarcophagus in Wadi Hammamat greywacke and siltstone quarries. The blocks for suitable work pieces could easily be broken off using the almost horizontal and vertical joint patterns. Eastern Desert of Egypt.

differently coloured parts of this papyrus obviously represent different rock types of the portrayed region and seduced some geologists to postulate this sketch map to be the oldest geological map (Harrell and Brown, 1992), which claim cannot be substantiated realistically at all.

Particularly the very dense, medium-grained dark green greywacke was used during the entire Pharaonic era and on until the Ptolemaic (Greek) period (from 332–30 BC), mainly for sarcophagi, archetraphes and for the finest carved sculptures of Egyptian antiquity. Scattered unfinished or broken sarcophagi indicate that at least the raw form of these vessels were worked out at the quarry site, which is understandable as they had to be transported over 90 km through the desert, until shipped on the river Nile to their final destination.

Most of the royal sarcophagi of the OK and about 100 sarcophagi for private individuals of the Late Period (since 600 BC) and of Ptolemaic and Roman times were made of this rock variety. Mainly in Roman times, additionally, the use of a conglomeratic variety of rock, the so-called "breccia verde" became fashionable. The most exciting examples of Hammamat greywacke statues are the Mycerinos (259–2511 BC) triades in the Cairo and Boston museums, and a great number of extremely fine carved statues was produced throughout the ancient times, with a definite maximum during the Late Period.

The stone material worked in the Wadi Hammamat quarry district exceed some 10,000 t, of which about a third was transported to the river Nile valley. According to the rock inscriptions, up to 4000 men were involved in the different quarrying expeditions into the Eastern desert, were well treated with food and "at least five litres of beer every day" and "no man got lost" (Couyat and Montet, 1912). Strange as it may seem, this strongly indicates that the work forces were not made up of slaves and were well taken care of.

2.3. Deposits of tonalite and the Roman search for grey granitoids in the Eastern Desert

For the construction of the imperial Pantheon temple in Rome, due to unknown reasons, a mixture of reddish and grey, 21 m long monolithic columns was required. Nowhere in the Roman empire were such long-jointed granitoid rocks known, except in the pink-granite district of Aswan; however, the grey granodiorites of that area have a much closer joint system, preventing the manufacture of such monolithic work pieces. Therefore, a systematic prospection for long-jointed, grey granitoids was started in the Eastern Desert. At least two localities were evaluated, at Semna and Barud, but in dioritic-gabbroic lithological terrains of the eastern desert (Klemm and Klemm, 1993). Finally, in the area of Mons Claudianus, in a gneissic tonalitic massif, the required long-jointed rock variety was located. Nevertheless, even here, the desired joint spacing could not be found, forcing the Roman architects to reduce the envisaged height of the entrance-porticus (Nanz, 1987) by about 3 m, still recognisable today by the double tympanum frames.

The tonalites occurring in the Mons Claudianus quarrying district are actually leuco-tonalites, with a relatively low quartz content (see Fig. 5), and only with an average of 7 vol% hornblende and 4 vol% biotite, which distinguishes them clearly from the much darker granodiorites and tonalites of the Aswan area, also used during Roman times for building stones and as smaller work pieces. Apart from the columns in front of the Pantheon temple, an uncountable number of large columns were manufactured from Mons Claudianus material and delivered to almost all parts of the Roman Empire, certainly with a maximum in Rome itself, with its Fori, especially the Forum Romanum but also, for example, in Villa Hadriana, Tivoli, the thermes of Caracalla and Diocletian (Fig. 3). This Egyptian quarry district, with more than 150 different working sites was exploited from the time of emperor Claudius (41–54 AD) until the fourth century. Because of its excellent conservation state quite a voluminous archaeological literature exists, from its rediscovery by Wilkinson (1832) until recent works, of which only a small representative selection need be referred to here (Meredith, 1954; Kraus and Röder, 1962; Klein, 1988; Peacock and Maxfield, 1997).

The amount of leuco-tonalite mined at Mons Claudianus was in the order of some hundreds of thousands of tons. The very heavy work pieces had to be transported 150 km through a dry desert, always in fear of Blemmyes raids, along fortified roads with strongly armed forts and water wells, about 40–50 km apart, until the river Nile was reached at Qena. From there the rock was shipped to Alexandria and from thence to different overseas destinations.

Fig. 3. Roman column at Mons Claudianus tonalite quarry sites. It still rests on an ancient loading ramp waiting for transportation. Eastern Desert of Egypt.

2.4. Deposits of imperial porphyry around Gebel Dokhan in the Eastern Desert

During the Neoproterozoic an intensive dacitic-andesitic volcanism formed voluminous layers of ignimbritic lava-flows and tuffs, outcropping at many sites within the Eastern Desert of Egypt. These rocks are partly interbedded with, but mainly cut through the Hammamat sediments and overlie them. The volcanic beds mainly have a dark grey-green porphyric appearance. The matrix is normally fine crystalline, but in the upper portions of the flows also has a crypto-crystalline to (devitrified)-glassy character. An auto-hydrothermal alteration of these sequences is pervasive, changing the mineral composition mainly by altering the albitic plagioclase, the less abundant K-feldspar and the mostly idiomorphic augitic clinopyroxene into epidote and especially, in the purple varieties (as the result of a slight manganese-metasomatism), into piemontite (Fig. 4).

These purple varieties with their pink to porcelain-white porphyric remnants of feldspar crystals, formed predominantly in the uppermost layers of the volcanic succession and provided the source for the desired "porfido rosso antico", during Roman times exclusively reserved for imperial use ("imperial porphyry"). During Pharaonic Egyptian periods this rock type was only used for small bowls, manufactured exclusively from rounded small wadi boulders but never mined from a quarry site. Only in Ptolemaic times is there evidence for the first quarrying activity for this material, in the region of Gebel Dokhan in the Red Sea hills of the Eastern Desert. But the culmination of stone working at this, now renamed "Mons Porphyrites" area, began in the reign of Tiberius, continuing during early to middle Roman imperial time, and ending in the fifth century AD.

Most probably because of its purple colour, its high hardness, extreme difficulty to work and its singularity, the "imperial porphyry" enjoyed an exceptional status in the Roman and Byzantine Empire. It was used for statues, ceremonial bathtubs, bowls and vessels, mantle pieces, pedestals, benches and sarcophagi, always strictly reserved for imperial use. During Byzantine times the importance of this porphyry reached its apogy, when the legitimacy of imperial princes was bound to their birth in an imperial porphyry encased special room, leading to the genealogical suffix "Porphyrogenesus". Much later, Charlemagne (742–814 AD) attributed great importance to his throne, with its seat of imperial porphyry.

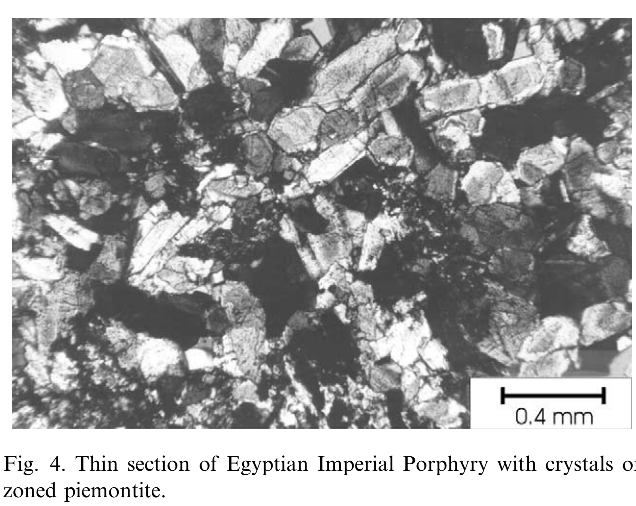

Fig. 4. Thin section of Egyptian Imperial Porphyry with crystals of zoned piemontite.

The working conditions in the porphyry quarries around Mons Porphyrites, some 150 km away from the river Nile in a desolate, dusty and dry rocky desert must have been horrible, and the work force was mainly recruited from slaves and the "damnati" (Klein, 1988), politically condemned persons without real hope of survival. The amount of imperial porphyry quarried within this region was in an order of magnitude of some 10,000 tons; nevertheless, the logistic expenditure was enormous with special road constructions through the desert, a fortified well and camp every 15–25 km and at the quarrying area itself, numerous settlements including the Isis and Serapis temples.

2.5. Deposits of "Rose-Granite" and of other granitoids south of Aswan

Perhaps the best known quarries of ancient Egypt occur south of Aswan. They cover an area of about 4×5 km. Here, almost all varieties of granitoids used during the Pharaonic and also Roman periods in Egypt were quarried.

The most prominent group is a variety of rich pink to reddish-pink, coarse- grained, porphyric granite, well known as "rose-granite" and of an unmistakable appearance worldwide. In spite of its different local varieties, it is hard to confuse this granite type with fresh types occurring elsewhere. A striking feature of this granite is the dominant texture of intensely etched, 2–5 cm long, pink to reddish, porphyric K-feldspar grains, set in a medium-grained granitic matrix. Under the polarizing microscope the intensive microclinal texture of the K-feldspars and the ubiquitous presence of allanite are characteristic. The fabric of the "rose"-granites varies from amorphous to almost gneissic, but always preserving its porphyric character and the phenocrysts themselves comprise 40–60 vol% of the rock.

The amount of rose-granite mined in this region is hard to estimate but is likely to be in the range of some million tons. The best known examples for the use of this rock are the many obelisks and the uncountable columns distributed all over the Roman Empire, with a maximum in Italy. There are also numerous applications of this granite in many Egyptian temples, pyramids, and in early Christian churches. Furthermore, sarcophagi of kings, nobles and sacrificed animals, colossi and more cosmopolitan statues of kings, gods, sphinxes and private persons were made from this material.

Also in the granitoid district south of Aswan, grey coloured granodiorites and tonalites to quartz diorites are interfingered with the rose-granite. The exact distribution of these granitoid varieties is not yet satisfactorily mapped and, according to our own field work, this seems rather difficult as variations of granodiorite to tonalite may occur gradually within a few hundred meters of outcrop, thus being difficult to map in detail. They appear to be medium-to coarse-grained with biotite and common green hornblende comprising 20–40 vol% of the rock (biotite always about a third of hornblende). Porphyric plagioclase up to 3 cm long is common in the matrix but never exceeds 15 vol%. In some tonalitic varieties this porphyric plagioclase has a greenish tint due to a slight sericitic alteration. In general, a change from the central granodiorites around Gebel Ibrahim Pasha to more tonalites towards the river Nile is recognizable (see spread of compositions in Fig. 5). With this gradation, there is also a remarkable increase of apatite in the rocks' matrix, and this can be used for more detailed provenance determinations.

The Aswan granodiorite-tonalites are not by any means as unique as the rose-granite and are therefore difficult to recognize, according to their outer appearance, among other equivalent rock types worldwide. The Aswan granodiorites-tonalites were used in ancient Egypt as widely as the rose granite, but never for large obelisks or columns, due to their smaller joint distances. Prominent examples are the many bull sarcophagi in the Serpaeum in Sakkara, the lion-headed Sahmet-statues of Amenhotep III and also the Rosetta-stone, which gave the key to Champollion's (1822) deciphering of the hieroglyphic symbols. The tonnage of these granodioritic-tonalitic rocks mined during ancient Egyptian history through to Roman times probably did not exceed about a third of the quantity of pink granite quarried.

The mining methods applied to these very hard granitoid rocks, but also to the greywackes and siltstones of Wadi Hammamat and to the anorthosite-gneiss already mentioned as well as to similarly hard rock types like basalt and quartzites, were rather ingenious and simple. In Pharaonic times, from the OK to the New Kingdom (NK; 1550–1070 BC), the mining was done exclusively with stone hammers made of 20–30 cm sized dolerite and andesite cubes. Our field work indicated at least two stages in stone working. At the beginning of intensive quarry working during the OK–MK, the weathering crust of the large boulders covering the entire area south of Aswan was first cut off with the sharp edges of hand hammers, in order to uncover the fresh cores. The fresh boulder cores were then treated in the same way until the requested size or raw form of a statue or stela were reached. The manifold, differently sized boulders in this district allowed, during the early

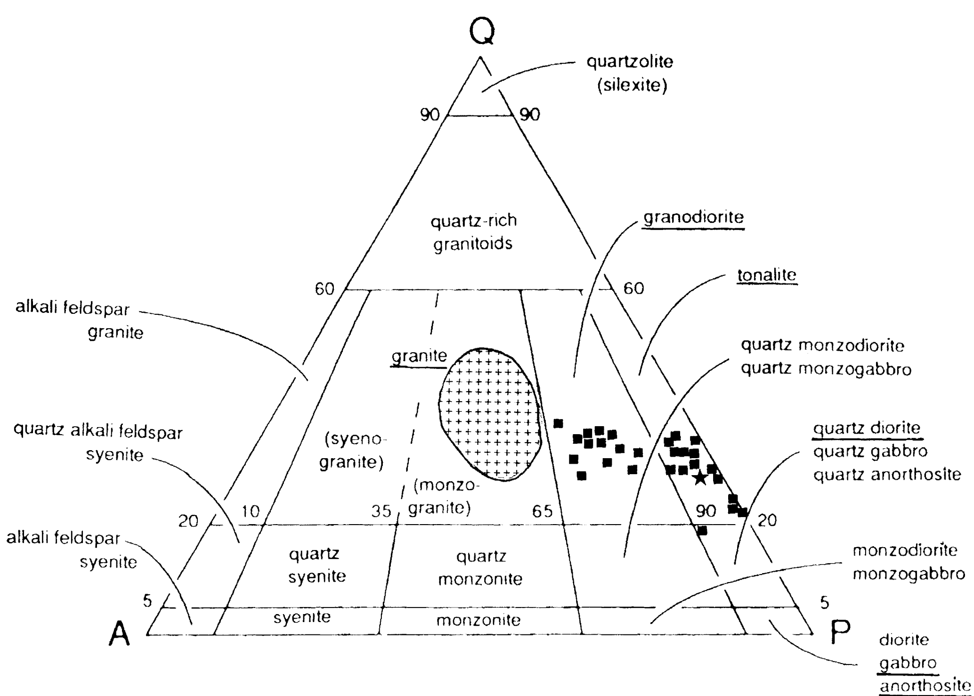

Fig. 5. Triangular diagram according to IUGS-classification (Le Maitre, 1989) of Aswan granites (crossed field), granodiorites and tonalites (black squares). The crossed field includes 85 CIPW-normative calculated chemical analyses. A normal petrographic modal analysis of "rose-granite" is problematic due to the extreme large porphyric phenocrysts in a medium-grained matrix. Thus, normative CIPW-calculations come closer to reality. The black star represents 15 petrographic analyses from Mons Claudianus leuco-tonalites. Main rock types used in Ancient Egypt are underlined.

Fig. 6. Unfinished obelisk, 42 m in length, in a quarry of red-pink granite south of Aswan. It is already cut out of the rock on three sides using only stone tools.

periods, an easy preselection of the desired workpieces. However, especially in NK-times when colossal statues and obelisks were demanded, the raw forms of these objects had to be cut from outcropping rock. This was achieved by cutting man-sized trenches all around the required form of the workpiece – a tremendous task in the case of a more than 30 m long monolithic obelisk. For the still extant in situ example of an unfinished obelisk south of Aswan (nearly 42 m long) (Fig. 6), Röder (1965) calculated, according to his own manufacturing experiments with dolerite balls, that a single worker could remove 12 cm^3 of granite material per minute from the solid rock. This equates to about 1.8 m^3, during a year of 300 working days and 8 h per day; with the reconstructable number of 130 worker positions at the unfinished obelisk, Röder calculated an operating time of less than one year. This time could have been reduced if the work was organized in two shifts. This estimation comes close to the working time of seven months for completion of the great obelisks of Queen Hatshepsut (1479–1458 BC) reported on her funeral temple at Der el-Bahari north-west of Luxor.

After achieving the coarse form of a workpiece, the grinding and polishing of the finer carved surface was managed with ground quartz powder in water suspension, derived from a massive hydrothermal quartz vein cropping out some 5 km north of Aswan, at a locality called Gesirah. Ergonomically shaped discarded hemispherical grindstones, again of dolerite, have been found in the Aswan quarry district repeatedly. The final polishing of the granitoid surfaces was achieved with a fine powder fraction of quartz and a pasty water suspension. This of course was more time consuming than presently used hard grinding powders of carborundum or even diamond, but time and the utilisation of a working force were not major problems during Pharaonic times, because the male population was more or less free of work during the annual floods, which averaged three months in length, and for another two to three months before the harvest.

2.6. Deposits of Nubian sandstone along the river Nile valley

Apart from limited deposits of Carboniferous sandstone far remote from the Nile valley, almost no magmatic or sedimentary rocks were formed in Egypt from the Neoproterozoic until the Cretaceous, starting with the widespread and thick sedimentary sequences of the Nubian sandstone. They consist mainly of a diagenetically medium cemented, siliceous and rarely calcified quartz sandstone, in part intercalated with centimetre- to metre-thick clay horizons. The river Nile has eroded escarpments up to 50 m high into these sediments at quite a few localities along its length. These sites are thus ideal for quarrying activities. One of the most prominent sites intensively used for quarrying since the MK is the river gorge at the Gebel el-Silsileh, some 70 km north of Aswan, where numerous quarries exist, in many cases with well preserved rock inscriptions and well datable stelae.

This excellent documentation of the different quarries correlatable with historically precisely defined working periods allows the assignment of the different chisel mark patterns of the worked quarry walls (Klemm and Klemm, 1993) to certain historical epochs, as indicated in Fig. 7. This dating scheme of chisel marks fits all sandstone and limestone quarries worked from ancient Egypt up until the Arab periods.

The systematic use of Nubian sandstone as building material (apart from a small local pyramid at Hierakonpolis) started during the MK, under the rule of Mentuhotep II (2046–1995 BC) with quarry sites north of Gebel el-Silsileh. It culminated during NK and Ptolemaic times, mainly in the construction of sandstone temples, such as Elephantine, Kom Ombo, Esna, Edfu,

Fig. 7. Ancient sandstone quarry from Ptolemaic times, at Gebel el-Silsileh. The traces on the remaining walls show the block sizes and give a hint of the quality of the chisel technique. These characteristic features can help to date quarry sites without datable inscriptions.

Luxor, Karnak, Dendera and the funeral temples at Qurna (except for parts of the Hatshepsut-temple). The best known examples for the further use of Nubian sandstone in ancient Egypt are the sandstone statues of Mentuhotep II (Cairo museum), an uncountable number of stelae, and hundreds of sphinxes and holy ram statues decorating ceremonial alleys in Karnak and Luxor.

The rather friable and poorly cemented Nubian sandstone survived as a monumental stone in the relatively dry arid climate of Egypt for millennia. Unfortunately, however, it suffers intensely from salt deterioration by which it has become affected since the 20th century as a result of the deleterious effect on the annual floods of the river Nile due to the construction of the Aswan High Dam. The intensification of artificial irrigation increases the salt content of the soils and consequently of the basal parts of the ancient monuments as well. This problem is thus far poorly understood and is almost ignored by the Egyptian authorities, but will destroy many monuments within the near future if left unresolved. The financial cost of solving this problem cannot be shouldered by the Egyptian government alone, and significant international help is required.

A particularly resistant, silicified type of Nubian sandstone was formed during the Miocene, when ascending meteoric waters precipitated their dissolved silica content in the uppermost sandstone portions beneath the soil cover. This resulted in a steady overgrowth of the sand grains and cementation of the pore spaces (Fig. 11), forming a very hard quartzite, which is partly intensively red coloured by co-precipitated iron staining. This siliceous sandstone was quarried especially in the hill ranges of Gebel Tingar–Gebel Gulab, west of Elephantine Island, at Aswan and mainly used for stelae, columns and special statues. The stelae of Amenhotep III at his mortuary temple and his baboon statue at El-Ashmuneim, as well as the Memnon Colossi (one of the seven miracles of the world) were made from this material (Klemm et al., 1984). In contrast to our geochemical and petrographic analytical results, Heizer et al. (1973) and Bowman et al. (1984) assign the provenance of the Memnon Colossi to the Gebel Ahmar, at Cairo (compare Figs. 10 and 11).

The total amount of Nubian sandstone mined in ancient Egypt, calculated from the still well preserved quarry sites, was in the order of fifteen million tons, with the quarry volume of Gebel-Silsila alone responsible for eight million tons.

2.7. Deposits of eocene limestone in Egypt

From about 10 km south of Luxor up to the area of Cairo, the river Nile is flanked by escarpments of Eocene Limestone of quite varying consistency. The limestones vary from marly, dense rocks with many flint-nodules in the vicinity of Luxor (Thebes Formation, Ypres) to chalky porous lithologies at Sidi Mousa, near Sohag (Serai Formation, Ypres). In the area around Assyut dense limestones occur, rich in fossils and peloids and partly so in ooids (Drunka Formation, upper Ypres). In the region from Mallawi to Samalut they become extremely rich in fossils with almost a shell framework of many nummulite types, dominated by *N. gisehensis* (Minia Formation and Beni Khalid Member, middle Lutetian) (Fig. 8). Further towards the north, up to Helwan, only a few quarries of restricted local importance were used during ancient times, but from there on to the Mokatam Hills, south of Cairo an impressive number of galleries, worked relatively deeply into the escarpment or open cast quarries, were mined during the entire historical periods of Egypt. This mining concentrated on the very dense and highly resistant, fossil-poor limestone of Tura-Maasara and Mokatam on the eastern flank of the Nile valley.

On the escarpments and plateaus of the western flank of the Nile valley, in contrast, the generally less resistant limestones were largely exploited for the tremendous volumes of stone for the core material of the more or less completed 27 stone pyramids and funeral temples of the Old Kingdom. The comparatively best quality limestone occurs at the Giseh plateau, where we consequently find the best preserved Great Pyramids. The casing of the pyramids from the time of King Snofru (2639–2604 BC) onwards also required enormous tonnages of resistant limestone blocks, which were mined exclusively from the quarry sites of the eastern flank of the Nile, mainly from Tura-Maasara, some 30 km away from Giseh.

Some enigma still remains today as to the source of the very resistant casing limestone material used for Djoser's (2690–2640 BC) and his successors' pyramids and temple districts. Geochemically it is very close to the limestone material cropping out in the Sakkara area, where these pyramids were built. Extensive field work

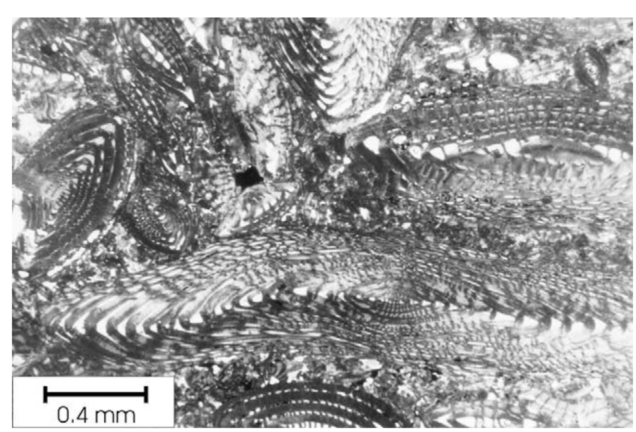

Fig. 8. Thin section of nummulitic limestone with *N. gizehensis*. (Beni Khalid Member of Minia Formation, middle Lutetian). El Sawaita quarry site, Middle Egypt. Crossed polarizing filters.

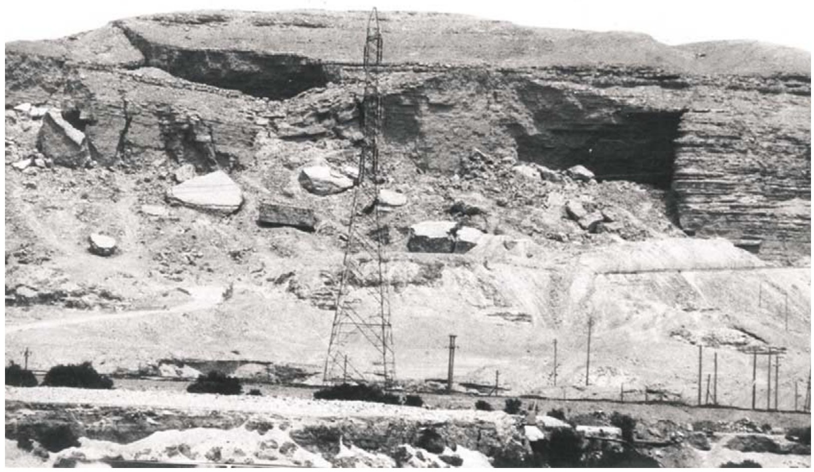

Fig. 9. Partly collapsed large underground quarries within the limestone escarpment of Tura, southeast of Cairo. The gallery quarries continue some 80 m into the escarpement.

did not reveal an identified quarry, but only many loose blocks occurring along the Sakkara plateau. Thus, it might be concluded that a limited occurrence of this limestone material was totally mined out and only remaining loose blocks witness its former existence in this area.

From the time of King Snofru onwards, due to a lack of this high quality source, the next best quality limestones from the eastern flank of the Nile valley were exploited for casing material of the pyramids. These fine limestones were also mined for many different purposes during the entire Egyptian history, until today, when they mainly supply the extensive lime and cement industries of Tura and Helwan. The ancient gallery quarries, driven deeply into the escarpment serve today in most cases as safe military ordinance depots, unfortunately off limits for both archaeological and scientific investigations (Fig. 9).

The entire region of the Giseh plateau up to the escarpments of Sakkara and Mokatam-Tura-Maasara belongs stratigraphically to the Mokatam Group, which is subdivided into quite a number of diverse members and facies, all of them belonging to the upper Lutetian. They are described in detail by Klemm and Klemm (1993), Strougo (1985), Moustafa et al. (1985) and Aigner (1982, 1983).

The amount of limestone mined in ancient Egypt is in the order of some 20 million tons, bearing in mind that the Cheops pyramid alone contains 2.7 million m^3 of almost exclusively limestone of local and Tura-Mokattam provenance.

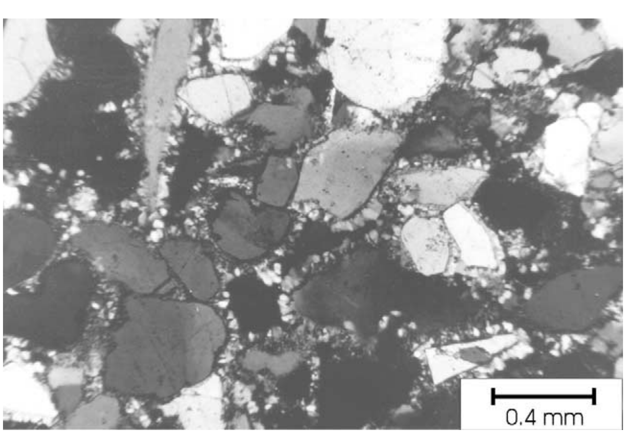

Fig. 10. Thin section of quartzite (silicified sandstone) from Gebel Ahmar near Cairo. Due to a basalt-intrusion the interstitial space of the Oligocene sand grains is filled up with small quartz crystals precipitated from induced hydrothermal fluids. Crossed polarizing filters.

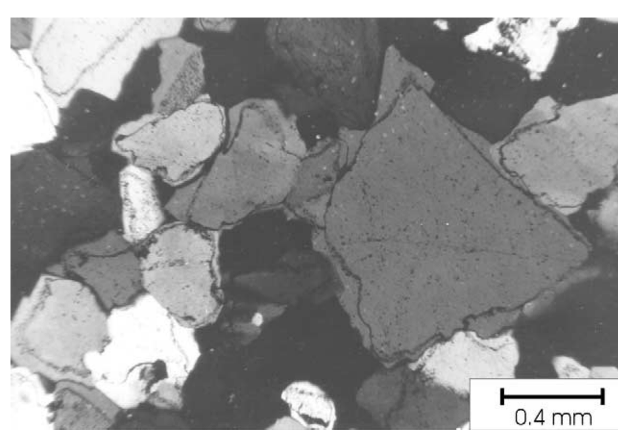

Fig. 11. Thin section of quartzite from Gebel Tingar, west of Aswan. The interstitial space became filled by coaxial crystal overgrowth on the Cretaceous sand grains, caused by precipitation of ascending, silica saturated pore waters towards the Miocene land surface. Crossed polarizing filters.

2.8. Oligocene quartzites from Gebel Ahmar, Cairo

Another, especially for Egyptology, important hard rock type occurs at the Gebel Ahmar (Red Hill), today more or less covered by the urban sprawl of the eastern extension of Cairo-Abassiya. This hill with its reddish quartzite consists of an Oligocene sandstone, highly silicified by hydrothermal vents, due to underlying Miocene basaltic intrusions. During this event the pore space was filled up by fine silica crystals, solidifying the loose conglomeratic sandstone in places to iron-enriched quartzite (Figs. 10 and 11). In ancient times the early morning sun illuminated this red hill in a bright lumen, this rock variety most probably thus became especially favoured by Pharaohs celebrating the cult of the sun, such as Djedefra, Amenhetep III and Echnaton. Therefore these Pharaos all left impressive statues of this material to posterity.

Due to the intensive overprint during mining in the Arab and 20th century times and due to the many poorly silicified portions of Gebel Ahmar, no realistic estimation of the tonnage extracted by ancient Pharaonic working at this locality is possible, but it might not have exceeded some ten thousand tons. Today the former Gebel Ahmar is covered by a sports stadium and an amusement park with gardens and therefore the Red Hill has also changed its name to Gebel Akdar (Green Hill).

2.9. Basalt deposits of Ancient Egypt

Mainly restricted to Old and early Middle Kingdom, extensive quarring took place in the western Fayum desert, in the upper Oligocene to lower Miocene olivine basalt occurrences of Gebel Qatrani (Widan el-Faras). From these quarries a partly preserved desert road leads to the former shore of the Birket Qarun lake, some 10 km removed from the present shore line. The reduction of the lake size was achieved by sophisticated channel constructions with the aim of reclaiming land, during the Middle Kingdom, almost 4000 years ago. As a result, the simple water transport of the basalt blocks to the construction sites, where the material was required, was no longer possible.

Some other basalt occurrences probably worked in ancient Egypt exist in Abu Roash, 10 km north of the Giseh plateau, in Abu Zabal, east of Cairo and, another, much more doubtful site, near Gebel el-Ter and Behenasa, in Middle Egypt. This olivine basalt decays relatively fast once fresh material is exposed to the sun, especially in the arid Egyptian climate with an extreme day–night temperature difference. This type of rapid disintegration destroyed also the ancient quarry sites from which no unequivocal worked walls could be detected, in contrast to Harrell and Brown (1995), who claimed to recognize remains of quarries in shallow swales and benches, but without any tool marks.

Due to its rapid weathering, this basalt was used mainly for pavements, as in mortuary temples, such as the one on the eastern side of Cheops's pyramid at Gizeh and those at the fifth Dynasty temples at Abusir. Basalt was also used for small statues, but to our knowledge never for bigger statues and sarcophagi, as is often wrongly labelled in Egyptological museums. These frequent mistakes are mostly based on a confusion with greywacke from the Wadi Hammamat or, as in the case of the Rosetta stone, with granodiorite from south of Aswan.

Due to the always deteriorated quarry sites an estimation of the amount of basalt mined in antiquity is difficult, but according to the remaining antique evidence from pavements and a few statues, it probably did not exceed some thousand tons.

2.10. Deposits of "Egyptian Alabaster" (calcite-alabaster)

One of the most desired stone types in ancient Egypt from Predynastic until Graeco-Roman times is the so called "Egyptian Alabaster", in fact a translucent shelly banded calcitic rock, very much resembling real alabaster, but totally free of gypsum. The most prominent deposits of this rock type in Egypt occur in the former Ptolemaic province Alabastrites in Middle Egypt, where the later Roman occupants confused it with the similarly appearing, but softer gypsum rock occurring in the vicinity of Volterra, Tuscany. The Romans transferred the name "lapidum alabastrites" to this calcitic rock. Undoubtedly, the genealogical primacy rests in the Egyptian calcitic rock, but in international petrography alabaster stands for the gypsumferous variety. Egyptologists strongly defend the a prior definition and we suggest the lithological term Egyptian Alabaster or even calcite-alabaster. Harrell (1990) strongly contested this

Fig. 12. Quarries of Egyptian alabaster (calcite alabaster) at Qawatiya, east of Miniya. The mining follows vein systems in Eocene limestone, filled by calcite re-precipitated from hydrothermal, calcium carbonate saturated fluids. The veins were exploited both in open cast workings and in underground galleries.

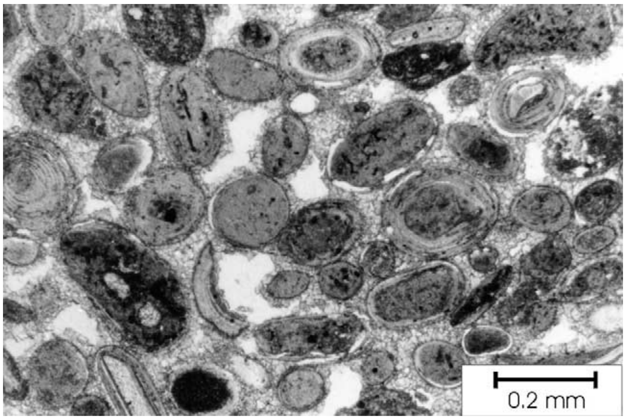

Fig. 13. Thin section of oolitic limestone occurring as ridges parallel to the Mediterranean coast southwest of Alexandria. Crossed polarizing filters.

nomenclatorial compromise, insisting in the term "travertine" for this rock type. But the normally very low temperature of precipitation and extremely porous nature of travertine leads to a totally different appearance; it is not translucent and was never used in ancient Egypt.

Genetically this calcitic rock type was formed as a result of the intrusions of olivine-basaltic magmas during the lower Miocene, contemporary with the formation of the Red Sea graben and the river Nile fault structures. The calcite alabaster occurs exclusively in Eocene limestones in veins and elongated karst systems, always perpendicular to these dilation directions (Fig. 12). CO_2-rich magmatic degassing products mixed with the pore space waters of the limestones, dissolved them partly and reprecipitated the calcite within the temperature range of 100–170 °C in the open veins and karst systems at higher levels (Klemm and Klemm, 1991).

Due to its translucent character the calcite alabaster had an irresistible attraction for the ancient Egyptians and they created all kind of vases, bowls, sarcophagi, altars, temple pavements and even colossal statues out of it. Alone in the funeral chambers beneath Djoser's pyramid, in Sakkara, some thousands of calcite alabaster vessels were found. In spite of this enormous demand and because of the mostly small size of the vessels, not more than about some hundred thousand tons of calcite alabaster were mined in ancient Egypt. But recently a new occurrence, 10 km west of Qurna has been opened, delivering the raw material for tourist attractions such as small figurines and vases, sometimes artificially altered to give them the impression of antiquities.

2.11. Deposits of the oolitic limestone of the Mareotis

Within two hill ranges running parallel to the Mediterranean Sea, respectively, lying some 500 m and 5 km off the coast, between Alexandria and Burg el-Arab, a soft oolitic limestone occurs. It is easy to work and was used in ancient Egypt mainly during Graeco-Roman and Byzantine times, predominantly as building material for Alexandria and its surrounding villages, but also for sarcophagi.

This limestone formed in the Holocene and consists of fine, 0.2–0.5 mm ooids (Fig. 13), diagenetically cemented by calcite. When moist it can be carved, even with a normal knife, but hardens significantly after drying. Röder (1967) identified 11 ancient quarries, worked mainly during the fourth and fifth centuries AD to construct the many early Christian settlements along the Mediterranean coast; the quarries for ancient Alexandria most probably occurred at El Mex, today covered by the modern city.

The total amount of this oolitic limestone which has been mined was in the order, at most, of half a million tons only, based on Röder's (1967) listed localities and quarry maps. But in this calculation the lost Mex quarries are not included, which might not have been mined in the same order.

3. Conclusions

The enormous amount of stone material worked and moved, partly over long distances, during ancient Egyptian history still remains admirable if one considers that it was mined during a time interval of almost three thousand years. On the other hand, only during periods of strong royal power could intensive quarrying efforts for magnificent constructions be enforced, whereas during the relatively long periods of weak government, almost no remarkable building activity took place.

We must take into consideration that in ancient Egypt, due to the annual flood, for nearly three months each year work in the fields became impossible and, that after a short sowing time, which was easily done (Herodot, II, 14), another two or three months minimal labour followed until harvest time, when intensive male employment was required. In other words, a relatively large portion of the male population was free of regular daily work for almost five months of the year. In spite of the legendary well organized administration, it could become a problem for the central government to control the entire country along the extremely extended oasis of the river Nile valley. To prevent local separatist movements or rebellions against the feudal system of the royal court and the mighty priestly hierarchy, a steady occupation of the country's population was necessary. This could be arranged best by employing at least a significant number of the male subjects in quarry workings and sacral constructions, which was possible only if a suitable daily supply system was guaranteed by the government. Such a well executed logistical organization was a characteristic speciality of the powerful ancient Egyptian system. As long as this complex interplay of governmental care and continuous accomplishment of daily duties in honour of the Pharaoh and the divinities worked, the ancient Egyptian world was kept in order. Anything else caused chaos, according to their beliefs.

The remaining ancient monuments in Egypt do not correspond to the huge amount of stone material mined, according to the volumes estimated from the surviving quarries. This discrepancy finds its explanation in an extensive loss of monuments since their erection. Especially since the early 19th century a further loss of about 30% of the monuments listed in Napoleon Bonaparte's "Déscription de l'Égypte" (Napoléon Bonaparte, 1809–1828) has taken place.

Due to modern environmental changes like progressive soil salination and industrial pollution and many other reasons also, the remaining monuments are increasingly becoming dangerously deteriorated; if within the near future no serious efforts for their conservation are begun, this irretrievable witnesses of human culture will, at least partly, be lost forever, a problem which modern Egypt should not be left to shoulder alone.

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