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The stones of the statuary of the Egyptian museum of Turin: geologic and petrographic characterization

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Abstract A geologic and petrographic study was performed on a rich collection of statues made of stone exposed at the statuary of the Egyptian museum of Turin (NW Italy) to enhance the value of this artistic heritage and set the basis for its best conservation. Magmatic and sedimentary rocks were recognized. Magmatic rocks with an intrusive origin are the most represented and include two main varieties: Red Granite, consisting of a sienogranite with porphyritic texture and pink to red K-feldspars, and Black Granite, which includes granodiorite, quartz diorite and tonalite lithotypes, whose colour ranges from grey to almost black. These magmatic rocks belong to the Arabian–Nubian shield, and the historical quarries are located near Aswan. The sedimentary rocks are represented by Cenozoic white limestones and red sandstones and Cretaceous dark-yellow Nubian sandstones. Finally, we note the occurrence of the so-called Bekhen Stone, originally attributed to a green-black metagreywacke belonging to the Hammamat series of late Precambrian age, outcropping in the central sector of the Eastern Desert, and re-interpreted here as a massive dark-green sandstone. This paper provides a scientific classification of the artefacts exposed in the statuary rooms based on the employed materials and contributes to the enhancement of the valuable collection of stone artefacts preserved in one of the leading ancient Egyptian museums in the world.

Keywords Applied petrography · Cultural heritage · Archaeometry · Ancient Egyptians

1 Introduction

The Mediterranean Basin and the surrounding countries represent a geographic area with a high concentration of natural stones employed by humans since the earliest times in history (Lazzarini 2004). In this context, Egyptian stones are of primary importance among all of the natural stones used in various historical epochs, including both the wide use by the ancient Egyptians and the following use in Roman times (Harrell 1989). The ancient Egyptians had a significant knowledge of rock features and laid the bases for stone quarrying and working. Rocks with different geologic histories and different chemical–mineralogical compositions represent a unique cultural heritage (Klemm and Klemm 2001).

Their mineralogical and petrographic characterization is, therefore, a fundamental step in the valorization of materials that are important from a historical and artistic

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This paper is dedicated to the memory of Margherita Serra† whose youthful enthusiasm was incentive to continue archeometric studies.

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standpoint, directed not only to experts but also to a wider audience. In particular, several stone material collections at the Egyptian Museum of Turin (NW Italy) are preserved in the so-called "Statuary rooms", which were the object of this study.

In recent years, an agreement among the Egyptian Museum, the University of Turin and the Superintendence for Archaeological Heritage of Piedmont was made to cooperatively investigate the stones of Egyptian finds from a scientific viewpoint to enhance the value of this artistic heritage and set the basis for its best conservation and restoration.

The research consisted of a geologic and petrographic approach by conventional and advanced analytical techniques, such as optical and electron microscopes, applied to artefact samples to describe, classify and list the stone finds exposed in the statuary rooms of the Egyptian Museum. Finally, a geologic quarry district could be assigned to each stone material employed for the carved finds based on the existing literature (Hume 1935; Aston et al. 2000; Klemm and Klemm 2001, 2008; Harrell and Storemyr 2009; Harrell 2012, 2013) and a comparison of the artefacts with rock samples collected through a geologic campaign in Egypt.

The systematic mapping of the different rock types present in the statuary has allowed us to identify, based on macroscopic observations, groups of materials with similar compositions.

The choice of the statues to be sampled and the sizes of the fragments to be removed has been carried out to balance the conflicting needs to proceed with micro-invasive techniques, instead of compromising the integrity of pieces with an inestimable historical and artistic value, and have a sufficient amount of material to obtain statistically significant results.

Based on these evaluations and the constraints imposed by the conservative curators of the Museum, nine artworks were sampled that allow us to represent the variety of the identified rock groups, which are traditionally defined as Black and Red Granites, Bekhen Stone, Nubian Sandstone and Gebel Ahmar sandstone. No calcareous artefacts could be sampled, so the analysis was based only on the macroscopic observations of the artefacts exposed in the Egyptian Museum. A complete list of the sampled materials is shown in Table 1.

The main goal of the fieldwork was to perform selective rock sampling to cover the different stone varieties observed in the statuary rooms of the museum. The Red Granites were taken from the historical quarry site of the Unfinished Obelisk in Aswan, whereas the Black Granites were collected near Gebel Ibrahim Pasha in the southern part of the quarry district of Aswan. Eight quarry samples with variable compositions from granite to granodiorite and tonalite were chosen from all of the collected materials for a minero-petrographic comparison with the sculpture stones. The samples of Bekhen Stone were collected along the Wadi Hammamat according to the historic quarries. Nubian Sandstones were collected on the western side of the Nile River, at Gebel Tingar in front of the town of Aswan. Lastly, a representative sample of the Gebel Ahmar Sandstone was taken in correspondence to the historical quarry located in the Heliopolis district near Cairo. The rock samples collected in the historical Egyptian quarries and their geographical locations are shown in Table 2.

2 Geological setting

Egyptian rocks have a long and articulated geological and quarrying history. They were largely employed as "Natural Stones" during Pharaonic and Roman times. Egyptian rocks can be divided into three geologic complexes according to the age of formation, the lithological nature and the location of the outcrops: (1) the Arabian–Nubian Shield, (2) the Nubian Sandstone Formation and (3) the Cenozoic succession (De Putter and Karlshausen 1992).

2.1 Arabian–Nubian shield

The Arabian–Nubian shield crops out in south-eastern Egypt, in a belt with an elongated trend approximately parallel to the coast of the Red Sea. It covers approximately 10 % of the Egyptian territory (Fig. 1).

The Arabian–Nubian shield mainly consists of Precambrian metamorphic rocks of both continental and oceanic nature. The structurally deepest units are upper amphibolite facies quartz-rich and quartzofeldspathic paragneisses, granitoid gneisses (including pre- and syn-kinematic intrusions), amphibolites and associated migmatites. These high-grade metamorphic rocks occupy the cores of dome-like structures measuring up to several tens of kilometres in diameter. The overlying units consist of low-grade metamorphic rocks that mainly include the following: (1) ophiolitic melange (serpentinites, metagabbros and metabasalts) intruded by gneissic syn-tectonic Older Granites (El-Sharkawi and Elbayoumi 1979; Shackleton et al. 1980); (2) island arc basic to silicic metavolcanics, plutonites and metasediments (Stern 1981); (3) anchizonal to low-grade metamorphosed molasse sediments (the Hammamat Group) (Akaad and Noweir 1969; El-Kalioubi 1996) and (4) calc-alkaline silicic to basic volcanics (the Dokhan Volcanics) (Ressetar and Monrad 1983; Stern and Gottfried 1986), which are spatially associated with Hammamat exposures.

Many ornamental rocks used in historical times by the ancient Egyptians occur within the old basement (Brown

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Table 1 Description of the studied sculptures preserved in the Egyptian Antiquity Museum of Turin

No. Cat.	Description	Lithology	Dinasty	Provenance
Cat. 1409	Statue of Sphinx	Sandstone	New Kingdom, 18th Dynasty; reign of Ramses III (1186–1155 B.C.)	Thebes, temple of goddess Mut
Cat. 694	Statue of goddess hathor	Tonalite	New Kingdom, 18th Dynasty; reign of Amenhotep III (1390–1352 B.C.)	Coptos (Qift)
Cat. 1380	Statue of Ramses II	Tonalite	New Kingdom, 18th Dynasty; reign of Amenhotep III (1390–1352 B.C.)	Thebes, temple of goddess Mut
Cat. 260	Statue of goddess Sekhmet	Granodiorite	New Kingdom, 18th Dynasty; reign of Amenhotep III (1390–1352 B.C.)	Thebes, funerary temple of Amenhotep III
Cat. 251	Statue of goddess Sekhmet	Granodiorite	New Kingdom, 18th Dynasty; reign of Amenhotep III (1390–1352 B.C.)	Thebes, temple of goddess Mut
Cat. 247	Statue of goddess Sekhmet	Granodiorite	New Kingdom, 18th Dynasty; reign of Amenhotep III (1390–1352 B.C.)	Thebes, temple of goddess Mut
Cat. 2203	Sarcophagus of shepmin, royal scribe of god Amon	Bekhen Stone	XXX dynasty Roman age (378–341 B.C.)	Thebes, necropolis of el-Khokha, Tomb n. 32
Cat. 2202	Sarcophagus of IBI, high priest of Tebe	Bekhen Stone	XXVI dynasty Saitic age (664–610 B.C.)	Thebes, necropolis of Asasif, Tomb n. 36
Cat. 2201	Sarcophagus of judge gemenefherbakh	Bekhen Stone	XXVI dynasty Saitic age (664–525 B.C)	Sais (Nile Delta)

Table 2 Rock samples collected in the historical Egyptian quarries

Sample	Lithology	Provenance	Coordinate
EG 1	Bekhen stone	Wadi Hammamat	25°59′37″N 33°34′23″E
EG 2	Bekhen stone	Wadi Hammamat	25°59′37″N 33°34′23″E
EG 16	Nubian sandstone	Gebel Tingar	24°04′33″N 32°51′48″E
EG 24	Red granite	Aswan	24°04′25″N 32°53′58″E
EG 25	Red granite	Aswan	24°04′25″N 32°53′58″E
EG 38	Pink granite	Aswan	24°04′35″N 32°53′43″E
EG 39	Pink granite	Aswan	24°04′35″N 32°53′43″E
EG 21	Granodiorite	Aswan	24°04′18″N 32°53′27″E
EG 22	Granodiorite	Aswan	24°04′18″N 32°53′27″E
EG 35	Granodiorite	Aswan	24°04′18″N 32°53′27″E
EG 31	Tonalite	Aswan	24°04′18″N 32°53′27″E
EG 32	Tonalite	Aswan	24°04′18″N 32°53′27″E
EG 52	Gebel Ahmar sandstone	Heliopolis (Cairo)	30°03′08″N 31°18′08″E

and Harrell 1995; Klemm and Klemm 2008; Harrell and Storemyr 2009). Among the stone materials occurring in the "Statuario", a particular stone material, the so-called Bekhen Stone, crops out in the north-eastern sector of the Arabian–Nubian shield (Wadi Hammamat). From a geological point of view, the Bekhen Stone belongs to the Hammamat Complex. It is classically interpreted as a meta-sedimentary succession of late Cambrian age (ca. 590 Ma) that resulted from the dismantling of igneous rocks with bimodal composition (andesitic and granitic) from a probable magmatic arc (Holail and Moghazi 1998). According to some authors (Akaad and Noweir 1969; Grothaus et al. 1979), the Bekhen Stone has experienced a low-grade metamorphic event of "Pan-African" (525–535 Ma) age.

The Arabian–Nubian shield is also characterized by a significant abundance of granitoids. Traditionally, they are subdivided into two main age groups: (A) older grey granites, which are variably deformed with an intrusion age that AQ3 varies between 850 and 610 Ma; and (B) younger pink granites, which are essentially undeformed, post-tectonic granites with intrusion ages of 600–550 Ma (Said 1990; Tawadros 2001; and references therein). Among the many varieties, some of which are still quarried, are included the Red Aswan Granite, in which some of the major statues and obelisks of the ancient Pharaohs are carved, the Black Granite, the Fawakhir Granodiorite and the M. Claudianus tonalite (a white meta-tonalite exploited by the ancient Romans). Based on petrography and geological mapping in the quarry district of Aswan (ancient Syene), numerous varieties

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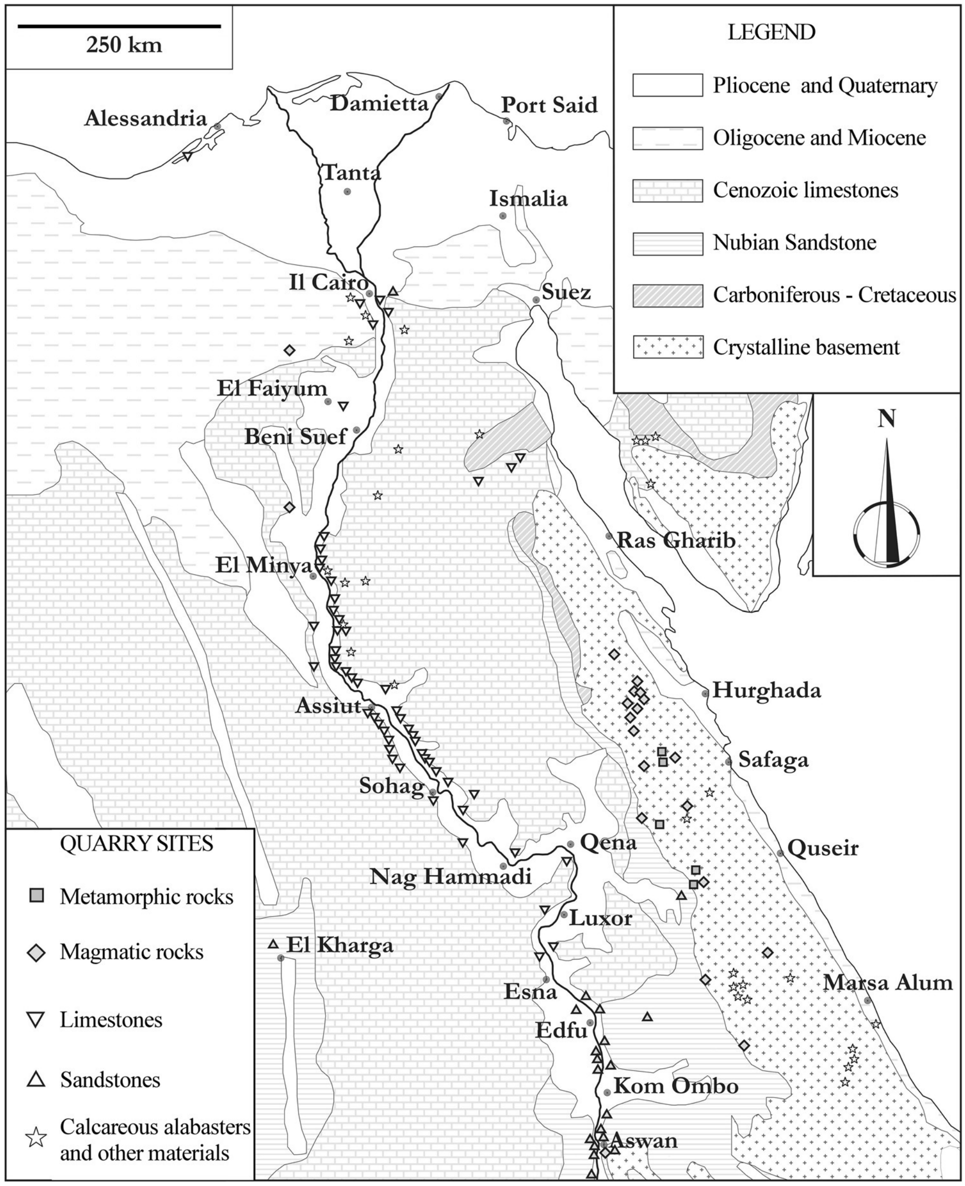

Fig. 1 Geological sketch of Egypt (from Fiora et al. 2007, modified)

of granite rocks were distinguished, which are not always strictly of "granite" composition but may rather be attributed to other intrusive rocks, such as granodiorite, tonalite and quartz diorite (Gindy 1956; Gindy and Tamish 1998; Klemm and Klemm 2008). According to Finger et al. (2008), four types of post-collisional, largely undeformed, granitoids can be distinguished: (1) coarse-grained porphyritic granitoids, ranging from granodiorite to tonalite in composition (Black Granite); (2) the porphyritic 'Monumental' Granite, with a rapakivi texture (Red Granite); (3) the fine-grained, mostly pink Saluja–Sehel granite; and (4) the so-called High-Dam Granite, which is a coarse-grained, equigranular, biotite-bearing granite. Several authors have suggested that all four plutonic units are co-magmatic but underwent variable degrees of magmatic differentiation during their ascent (Ragab et al. 1979; Gindy AQ4 and Tamish 1998). Both the Red and Black Granites have been dated to 606 ± 2 Ma based on a single-grain ID–TIMS U–Pb zircon dating method, suggesting the same age of emplacement (Finger et al. 2008).

2.2 Nubian Sandstone Formation

This formation consists of a sandstone succession of Jurassic to Palaeocene age (160–60 Ma, Klitzsch et al. 1979). It crops out mainly in South Egypt and extends to the Valley of the Nile between the Sudan border and the area of Esna (Fig. 1). The thickness of the Nubian Sandstone Formation ranges from approximately 350 m in Nubia to over 500 m at the oasis of Dakhla. From a

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lithological point of view, the Nubian Sandstone Formation consists mainly of quartz arenites with a small amount of heavy minerals, such as zircon and rutile. The sedimentation environment, which is continental and/or transitional in the oldest part of the formation, becomes strictly marine in the upper part (Ward and McDonald 1979).

The Nubian Sandstone is also found frequently in the region of Aswan, where it was extracted for the construction of statues in the Pharaonic era. The great temples of ancient Thebes and Abu Simbel were also made with Nubian Sandstone; in addition, the temple of Ellesjia is worth remembering, which was originally carved on the slopes of the Arabian plateau running along the right bank of the Nile and rebuild and exposed since 1970 at the Egyptian Museum of Turin after its rescue in 1965 from the waters of Lake Nasser (Curto et al. 2010).

2.3 Cenozoic succession

The Cenozoic-age sedimentary succession crops out in central and northern Egypt. These rocks consist mainly of limestone, deposited between the Paleocene and Miocene. The most represented deposits, which are exposed along the banks of the River Nile in the stretch between Luxor and Cairo, are Eocene in age (53–34 Ma). The Lower Eocene is represented by deep-water marls and shales and thick deposits of limestone, such as the Thebe Group. Thanks to their fine grain size and high coherence, these materials were widely used in Pharaonic art despite the obvious lack of homogeneity.

The Middle Eocene marks the beginning of the marine regression and consists of two main formations: the Minia Formation, consisting of shallow water marine limestone and the Mokattam Formation, composed of shallow water limestones rich in nummulites. This formation outcrops abundantly in the north-western desert, particularly in the Giza plateau, where it was used for the construction of the pyramids.

During the Oligocene (34–23 Ma), a relative sea level drop led to the emersion and deposition of continental sandstones (Gebel Ahamar Formation) (Tawadros 2001). Rare basalts that outcrop in Middle and Upper Egypt, whose emplacement is probably due to the early extensional movements that accompanied the opening of the Red Sea, are also Oligocene in age.

3 The Egyptian Museum of Turin

The Egyptian Museum of Turin is located in the Academy of Science building and includes two rooms (statuary) on the ground floor, where a rich collection of statues made of stone is exposed. Most of the statues on display come from the Temple of Amon in Luxor (Thebes), Egypt's highest shrine during the New Kingdom (1540–1070 B.C.).

Since 1824, when a huge collection of ancient Egyptian antiquities came to Turin after the acquisition of the Bernardino Drovetti collection (Curto 1984), it was clear that such an artistic heritage could supply a fundamental key to understanding Egyptian civilization. However, after an initial systematic cataloguing by Jean François Champollion, the collection of the Egyptian Museum was studied and ordered following only archaeological and historical criteria. Recently, the development of archaeometric studies has suggested that the application of a scientific approach can provide an opportunity to improve our knowledge of ancient Egyptian materials and technologies.

The preliminary macroscopic observations and descriptions and the subsequent petrographic study of the stone artefacts preserved at the Egyptian Museum of Turin allowed us to more precisely define their lithological nature with the recognition of different igneous and sedimentary rocks (Fig. 2).

4 The igneous rocks

Most of the analysed statues are composed of granitoid rocks. In particular, eight artefacts in the statuary rooms were carved in Red Granite from Aswan; 26 statues in granodiorite, 21 of which represent the goddess Sekhmet standing or sitting and five in tonalite, including the statue symbol of the Museum represented by Ramses in majesty. Following the criteria of macroscopic analogies between rock samples and stone artefacts to test the provenance hypothesis, a minero-petrographic comparison between small specimens picked up from the statues and rock samples collected from Aswan quarry sites was performed.

The Aswan quarry district has been active since the fourth millennium B.C. and is currently the most well-known primary mining district for the so-called Red Granite and Black Granites for commercial interests. The quarry district is located south and south-east of the town on the right bank of the Nile River and covers an area of approximately 20 km (Illig and Löhner 2001).

The main group consists of an unmistakable variety of pink or pinkish-red, coarse-grained and locally porphyritic granite commonly called Red Granite. At Gebel Ibrahim Pasha and near Messitot, there are also extensive outcrops of Black Granites interspersed with veins of Red Granite (Middleton and Klemm 2003). We could not find a comprehensive and precise map of the distribution of these rocks within the district in the literature, which is probably due to the simultaneous presence of small-scale (a few hundred metres) outcrops with different compositions (Klemm and Klemm 2001).

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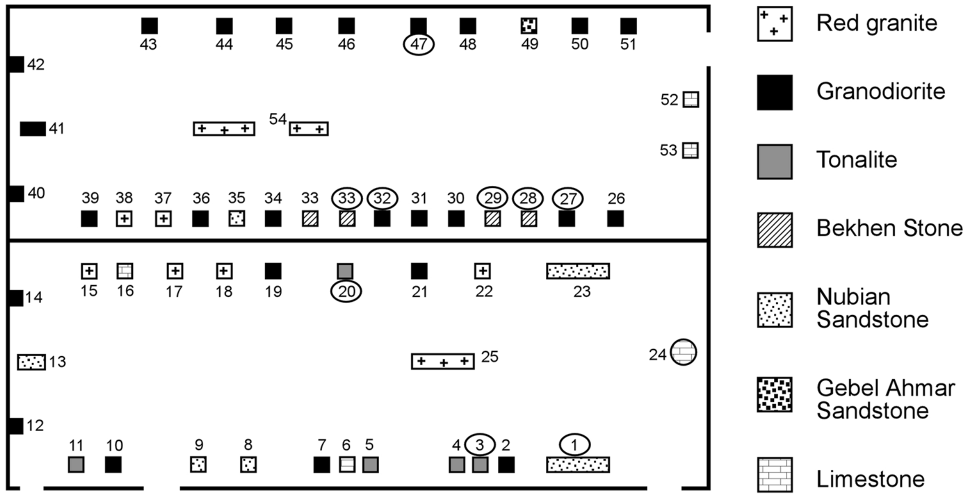

Fig. 2 Sketch of the arrangement of the artefacts exposed in the statuary rooms of the Egyptian museum in Turin. The *encircled numbers* indicate the sampled artefacts

4.1 The Red Granite

For the rock types with strictly granitic composition, it is easy to see how the macroscopic appearance of most of the works on display corresponds to that of the famous Red Granite from Aswan. The grain of the rock makes it possible to recognize the crystalline phases based on the colour characteristics, simplifying the recognition of this material even without resorting to sampling.

Many artefacts in the statuary of the Egyptian Museum of Turin are carved in Red Aswan Granite, among them the statue of the Pharaoh Amenhotep II (1427–1401 B.C.) (Cat. 1375) in the act of offering gifts to the gods and then usurped by the Pharaoh Ramesses II in the act of walking (Cat. 1381). This artefact is the first royal statue from Egypt that arrived in Italy in 1759 with the Donati collection. In addition, a statue of a ram, three sarcophagi attributed to the XIX dynasty and an offering table from the Late Period are carved in Red Granite.

Red Granite represents the main magmatic body outcropping in the Aswan area east of the Nile River. Its peculiarity derives from the occurrence of large reddish K-feldspar porphyrocrysts, which confer an unmistakable and unique aspect to this stone. The fabric varies from isotropic to almost gneissic, whereas the colour index is approximately 10–15 %. The main mineralogical assemblage consists of alkali feldspar, quartz, plagioclase, biotite and amphibole (Fig. 3a, b). Alkali feldspar comprises approximately 35–40 vol% of the analysed rocks and occurs both as centimetre-sized porphyrocrysts, with evident albite-pericline twinning and a constant perthitic texture and smaller anhedral grains in the matrix (Serra et al. 2010).

Regarding accessory minerals, it was possible to underline the significant prevalence of titanite, mainly in contact with or included in mafic minerals. Apatite is present as euhedral grains with prismatic, hexagonal or acicular shapes, the dimensions of which never exceed 100 µ. Ilmenite and magnetite are also abundant, both as single euhedral crystals and larger aggregates, which are often included in or in contact with mafic minerals.

Sporadic crystals of zoned zircon, allanite and pyrite also occur.

4.2 The Black Granite

The Black Granite includes two main varieties: granodiorite and tonalite, which outcrop on the eastern side of the Nile River between Aswan and El-Shellal and on fluvial islets near these areas, as widely documented by Klemm and Klemm (2001, 2008).

In the statuary of the Egyptian Museum, there are 21 statues of Sekhmet (goddess of medicine, depicted with the head of a lion and the body of a woman) carved with granodiorite. These statues are part of a series of nearly identical sculptures from the temple of the goddess Mut and the funerary temple of Amenhotep III (1390–1352 B.C.), which were originally located along the eastern and western shores of the Nile in Luxor, respectively. The statue attributed to Tuthmosis I (1494–1482 B.C.; Cat. 1374), which represents one of the oldest stone statues preserved at the Museum of Turin (Fig. 3d), is also carved in granodiorite.

The granodiorite samples have a holocrystalline texture, tending to porphyritic, and a medium/large grain size. The mineralogical assemblage is represented by quartz, plagioclase, reddish K-feldspar, biotite and green amphibole (Fig. 3e, f). The colour index is approximately 30 %. Plagioclase is dominant with respect to quartz and K-feldspar, is generally anhedral or tabular, and sporadically forms myrmekitic or antiperthitic textures.

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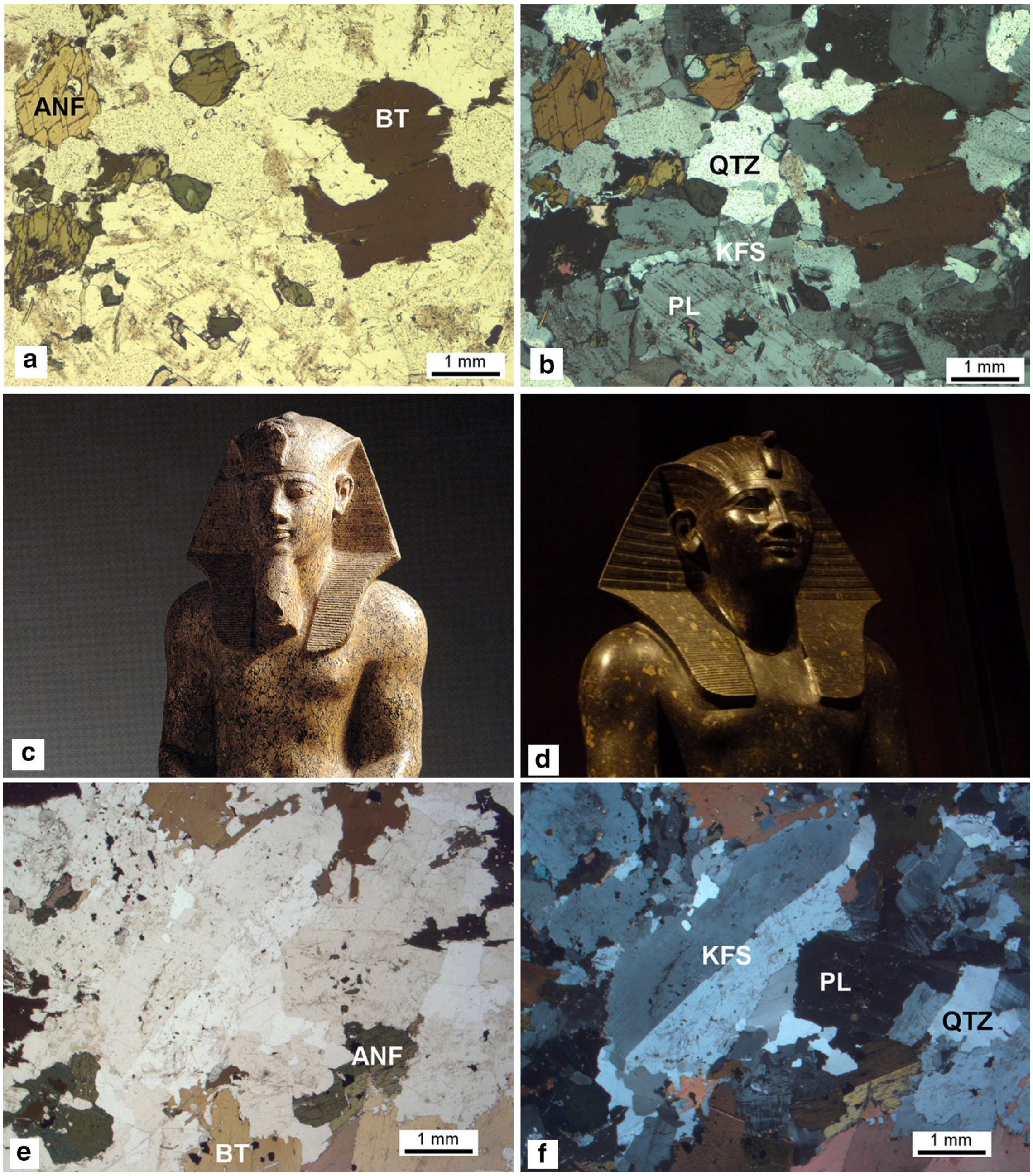

Fig. 3 Photomicrograph of a thin section of Aswan *Red Granite* collected at the unfinished obelisk quarry of Aswan (**a** parallel nicols, **b** crossed nicols) showing the main mineralogic assemblage: alkali feldspar (Kfs), quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl); **c** detail of the Pharaoh Amenhotep II statue exposed at the Egyptian Museum of Turin (Cat. 1375) carved using the *Red Granite* of Aswan; **d** detail of the Pharaoh Thutmosis I statue exposed at the Egyptian Museum of Torino (Cat. 1374) carved using the granodioritc variety of the Aswan *Black Granite*. The presence of sialic mineral aggregates is clearly recognizable; **e**, **f** photomicrographs of a thin section of *Black Granite* sample from Aswan quarry (**e** parallel nicols, **f** crossed nicols). A large orthoclase (KFS)—plagioclase (PL) aggregate is surrounded by biotite (BT) and amphibole (ANF)

A typical and widespread feature of this rock is the presence of partially iso-oriented sialic mineral aggregates, which are clearly recognizable on the statues (Fig. 3d). These aggregates consist of poikilitic plagioclase and subordinate quartz in the core and reddish K-feldspar in the rim. Microscopic veinlets of pink granite locally cross the main granodiorite body and are due to the occurrence of reddish K-feldspar along the vein border (Serra et al. 2010).

In some artefacts, the natural stone looks rather dark and homogeneous, as in the case of the statue of the pharaoh Ramses II in Majesty (Cat. 1380), one of the greatest masterpieces of Egyptian civilization and a symbol of the

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Egyptian Museum of Turin (Fig. 4a). Macroscopically, the rock appears fine-grained and homogeneous, so it can be confused with basalt to a careless observer. It is composed of a high percentage of mafic minerals (amphibole, biotite and Fe–Ti oxides) that provide a very dark grey colour to the rock. A recent, detailed petrographic and minero-chemical study of the stone materials used for Ramses in Majesty has suggested that the rock used for this artefact can be classified as a melanocratic tonalite and can be attributed to the darker tonalite variety from the Aswan quarry district (Borghi et al. 2011). Three other statues present in the statuary (statues of Dea, a Hapu official and the god Ptah) and an altar support were carved in tonalite. Similar rocks, always from the mining district of Aswan (Gebel Ibrahim Pasha region and Mesitot township), are described by Klemm and Klemm (2008). They also indicate that this stone material was used for the construction of statues in the Pharaonic era, such as the statue of Thutmose II from Deir el-Bahari, two Sakhmet statues from Hildesheim and the Kingdom Head from the Munich Museum. The occurrence of four statues carved in tonalite and preserved at the Museum of Turin strengthens the evidence related to the use of this particular material by the ancient Egyptians.

The rock is composed of biotite, green amphibole, plagioclase, quartz and much more subordinate K-feldspar (<5 %) (Fig. 4b, c). Amphibole is slightly more abundant than biotite, even if both femic minerals tend to occur as aggregates. Plagioclase and quartz occur in comparable amounts, but the plagioclase is euhedral, partially sericitic and sporadically occurs as phenocrysts, whereas the quartz is mostly interstitial and locally with undulose extinction. Apatite is widespread and present in larger amounts with respect to the granodiorite samples. Other accessory minerals are titanite, Fe–Ti oxides, zircon, epidote (allanite) and pyrite (Serra et al. 2010). Unfortunately, this rock is particularly susceptible to deterioration as a result of hydrothermal alteration (Klemm and Klemm, 2008). In particular, the pyrite component in this rock tends to break down mainly into sulphuric acid and iron hydroxide.

5 The sedimentary rocks

Both sandstones and limestones are present among the sedimentary rocks. Three sarcophagi and one cover are made of Bekhen Stone, one of the most famous ornamental stones exploited in Egypt. Six other artefacts of yellow

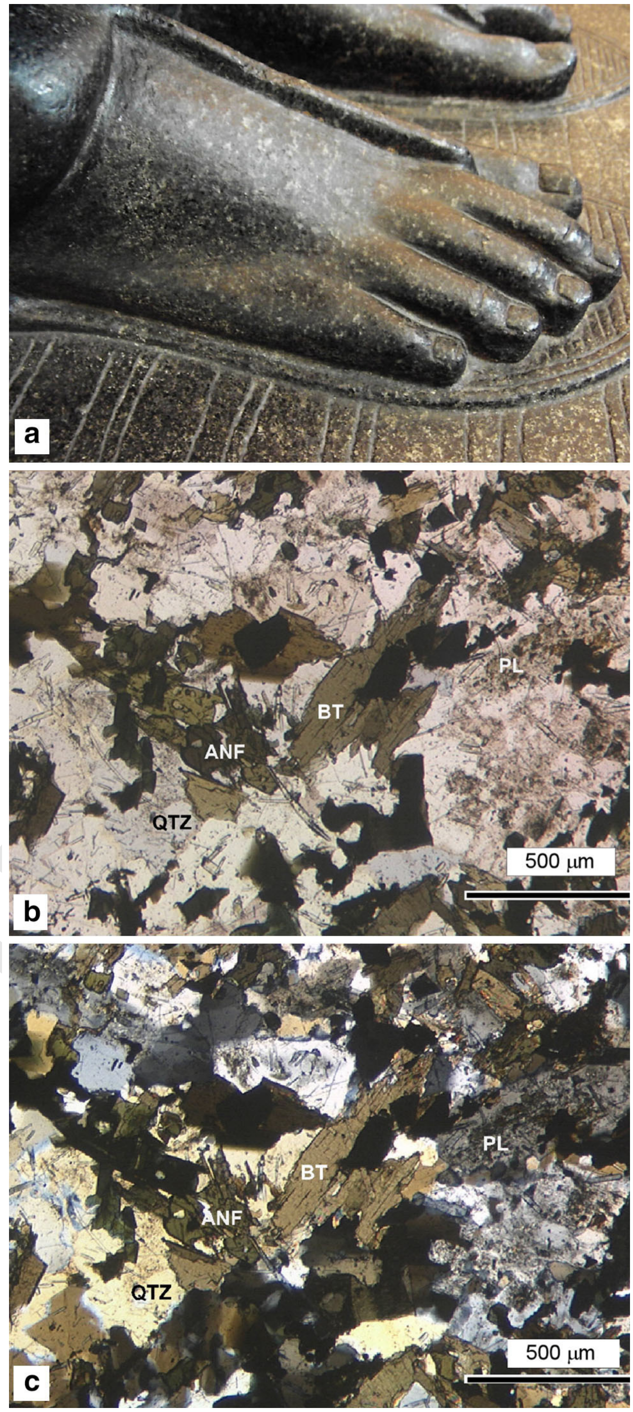

Fig. 4 **a** Detail of the Ramses II in Majesty statue exposed at the Egyptian Museum of Torino (Cat. 1380); The phaneritic texture defined by plagioclase and femic minerals is apparent; **b–c** Photomicrograph of a thin section of the Ramses II statue tonalite (**b** parallel nicols, **c** crossed nicols) showing the main mineralogic assemblage: quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl)

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Nubian Sandstone and only one statue fragment of the red Gebel Ahmar Sandstone are present. Finally, four finds of white limestone are exposed.

5.1 The Bekhen Stone

In the Egyptian Museum of Turin, several small artefacts belong to the Bekhen Stone, including three black sarcophagi from the Saitic age (664–535 B.C.) and XXX dynasty currently on display in the statuary rooms (Borghi et al. 2007) (Fig. 5c).

The historic quarries of Bekhen Stone are located in the central sector of the Eastern Desert, along the Quift – Quseir road from the Nile Valley to the Red Sea. In this site, impressive quarrying activity is documented by almost 600 rock inscriptions over a time interval from the Predynastic to late Roman period (approximately 4000 B.C. until 300 A.D.). These inscriptions indicate the uniqueness of this site and its extraordinary importance for ancient Egyptian culture. The Bekhen Stone quarries are also mapped in the famous Papyrus of Mines, manufactured during the reign of Ramesses IV (1151–1145 B.C.), found near Thebes in the early nineteenth century and now exhibited in the Egyptian Museum of Turin. It was ascribed to the Wadi Hammamat area and represents the world's oldest surviving geological map (Harrell and Brown 1992).

The Bekhen Stone belongs to the Hammamat Complex, cropping out in the north-eastern sector of the Egyptian desert, at the Wadi Hammamat. Its homogeneous colour ranges from dark green (due to the widespread presence of chlorite) to dark grey and black. Macroscopically, this lithotype consists of non-porous, fine-grained sandstone with an unusual homogeneity and coherence that allowed the realization of works of art characterized by an extremely smooth and metal-like surface. In fact, Plinius compared this rock type to iron both in hardness and colour. Its name is the most ancient name assigned to a stone. Indeed, Bekhen derives from the Egyptian "bhn", whose Greek and Roman translations are "litos basanites" and "lapis basanites", respectively.

Italian dealers in marble called the darker and black variety "Basanite" and the green variety "Basalto Verde Antico" (i.e., "Ancient Green Basalt") (Gnoli 1988). Because of its intense colouration and very small grain size, the macroscopic identification of this rock may be difficult; indeed, it was frequently confused with basalts (Nicholson and Shaw 2000; Penny 1993).

Microscopically, it shows a granular texture typical of clastic sedimentary rocks and is composed of tightly packed quartz and feldspar grains and lesser amounts of lithic, chlorite, muscovite and epidote grains (Fig. 5a, b). Texturally, it is a fine to very fine sandstone (grains finer than 250 micron) and quite well sorted. No evidence of a muddy matrix is present. The grain roundness is very low and angular shapes prevail. Thus, the rock may be classified as lithic arkose. However, it has been always cited in literature as a greywacke (Klemm and Klemm 2001, 2008). This term, according to many authors (e.g. Blatt et al. 1980; Boggs 2009), should be abandoned because it has generated much confusion through time. In any case, it should be reserved to sandstones with an amount of matrix larger than 10 % (Dott 1964) and thus does not apply to the Bekhen Stone. Quartz is represented by monocrystalline grains that commonly show undulose extinction. Polycrystalline quartz grains also occur. All of the feldspar grains show a degree of alteration to sericite, which ranges from slight to complete. Lithic grains are mainly represented by very fine-grained, dark grains, which may be referred to as fragments of volcanic rock groundmass. Moreover, as cathodoluminescence is greatly enhanced, quite common calcite-bearing grains can be identified. Some of them are only made of sparry calcite, but others are polymineralic grains consisting of white mica and calcite or chlorite, calcite and fine-grained dark portions possibly made of graphite (Fig. 5a, b). These lithic grains show a marked foliation and are surely referable to metamorphic rocks with a sedimentary origin and impure carbonate composition (e.g. organic-rich marls). The phengite composition reported by Borghi et al. (2007) for some crystals of white mica can be referred to this type of grain. No cement can be identified in thin section. The hard coherence of the rock is due to the strong indentation among the grains, which developed from intergranular chemical compaction during burial (pressure dissolution). Different from what is reported in the literature (Klemm and Klemm 2001; Harrell 2013), the petrographic features of this lithotype show that the Bekhen Stone is a sedimentary rock that has not experienced metamorphic transformations but only burial diagenetic processes. In some instances, this is also supported by the possibility of recognizing millimetre-thick parallel lamination directly on the statues (Fig. 5c). It cannot be excluded, however, that these sandstones locally experienced contact metamorphism related to the intrusion of the so-called Younger Granitoids of Precambrian age.

5.2 The Nubian Sandstone

This sandstone material was much appreciated in the dynastic era both for its colour characteristics and easy workability. It was mined in the Nubian area and then transported by ship following the course of the river current. The quarries that were more fully exploited in the Middle Kingdom were, in fact, seventy kilometres north of Aswan, the city from which most of the hard stone used in this period came.

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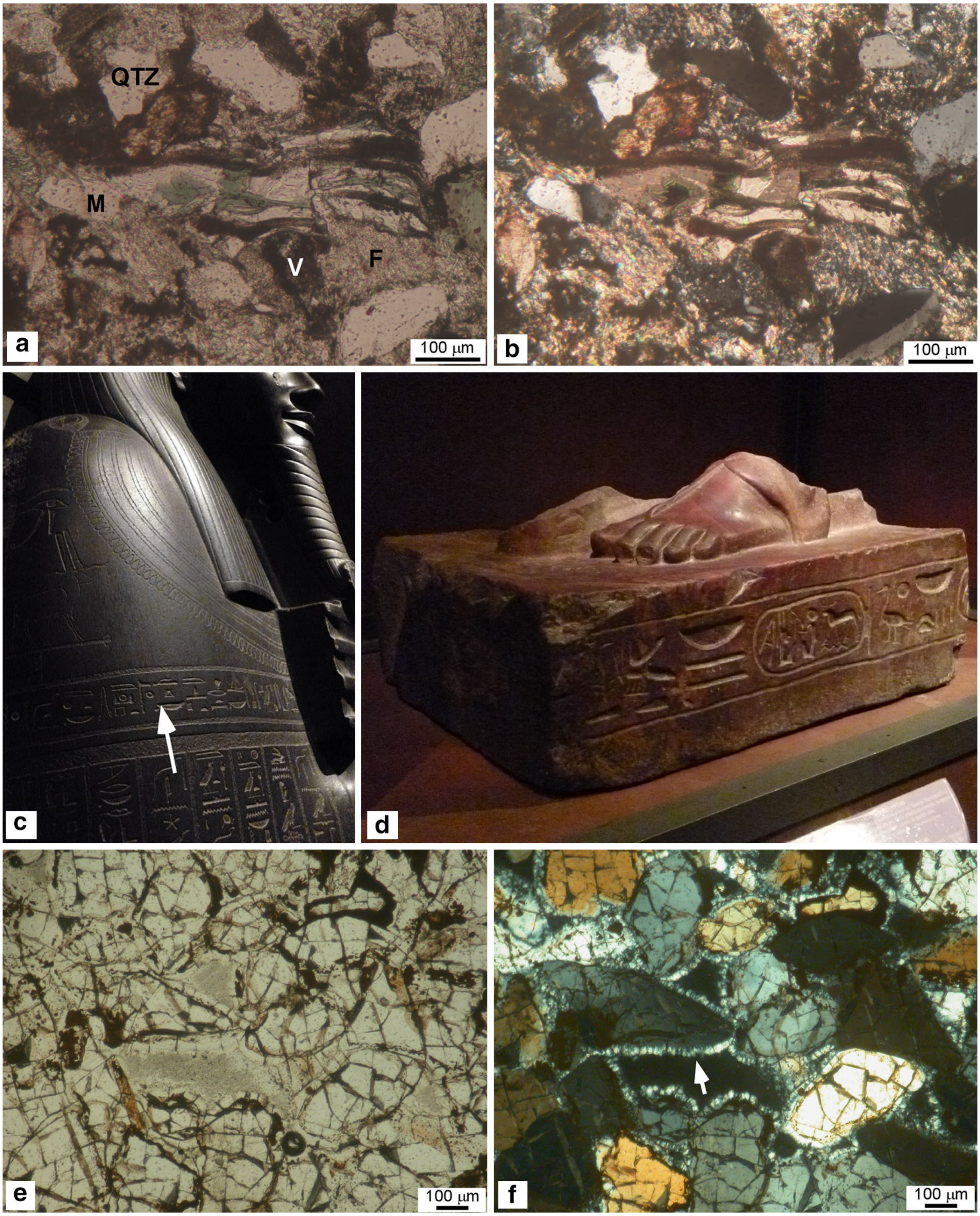

Fig. 5 **a–c** *Bekhen Stone* **d–f** Gebel Ahmar Sandstone. **a**, **b** Photomicrograph of a thin section of the *Bekhen Stone* (**a** parallel nicols, **b** crossed nicols) collected at the Wadi Hammamat quarry. It is possible to recognize grains made of quartz (Qz), sericitized feldspars (F), dark, fine-grained clasts of volcanic groundmasses (V) and a fragment of a foliated metamorphic rock (M) with calcite, chlorite and dark portions possibly made of graphite. Note also the tight packing and indentation among grains due to pressure dissolution; **c** sarcophagus of Ibi, high priest of Thebe, exposed at the Egyptian Museum of Turin (Cat. 2202) and made of *Bekhen Stone*. Note the very smooth surface due to the fine grain and coherence of the sandstone, and the mm-thick parallel lamination (*white arrow*); **d** fragment of a statue of Merenptah Pharaoh (Cat. 1382) made of Gebel Ahmar Sandstone. Note the vivid red colour due to the presence of Fe oxides; **e**, **f** photomicrograph of a thin section of the Gebel Ahmar Sandstone quarry (**a** parallel nicols, **b** crossed nicols). All the grains are made of monocrystalline quartz and are intensely fractured. The black portions consist of Fe oxides that partly coat the grains. A cement rim consisting of fibrous microcrystalline quartz is clearly recognizable within still open pores (*white arrow*)

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The Nubian Sandstone was used to carve the two Sphinxes in leonine bodies (Ca. 1408–1409) dating to the New Kingdom from Karnak. Originally made to be located along the driveway to the Temple of the Goddess Mut, an eternal reminder of the pharaoh's power and protection of sacred buildings, the two Sphinxes are now located at the sides of the entrance hall of the statuary rooms. The colossal statue (5.16 m) of Pharaoh Seti II (1204–1198 B.C.) (Ca. 1383) from the Temple of Amon, now placed on the back wall of the first statuary room, was also carved in Nubian Sandstone. With a twin statue now in the Louvre Museum, it framed the entrance of the temple dedicated to the sacred boat of Amon in the first courtyard of Karnak. In addition, the head of the Statue of Aries (Cat. 836) of the temple of the god Khonsu south of Karnak, referable to the New Kingdom, and a fragment of the lower part of the Red Crown of Lower Egypt (Cat. 1387 bis) are carved in Nubian Sandstone.

Macroscopically, this lithotype consists of a sandstone characterized by an overall yellowish colour with localized pinkish patches. Large-scale cross-bedding is very common and clearly recognizable on the statues (Fig. 6a). The laminae are centimetres thick and highlighted by sharp grain size changes. Microscopically, the sandstone is mainly composed of quartz grains and thus may be classified as a quartz arenite. The sorting is quite low and the grain roundness is very variable: the grains range in size from 200 µm to over 3 mm, and both well-rounded and angular grains occur. This sandstone may be defined as mature from a compositional point of view but not texturally. Quartz is represented by monocrystalline grains that commonly show undulose extinction and are partly fractured. Polycrystalline quartz grains also occur. Some muscovite and scattered heavy mineral grains (rutile, staurolite and tourmaline) may be identified. The quartz grains are commonly coated by a film made of clay minerals (illite and kaolinite) and Fe oxides that give the local pink colour to the rock. The rock is still highly porous, and only a minor amount of cement can be locally observed. It consists of amorphous silica (opal) that locally forms 20-µm-thick rims within open pores (Fig. 6b). Concave–convex boundaries are common and document intergranular pressure dissolution processes that took place in only slightly lithified sands during deep burial.

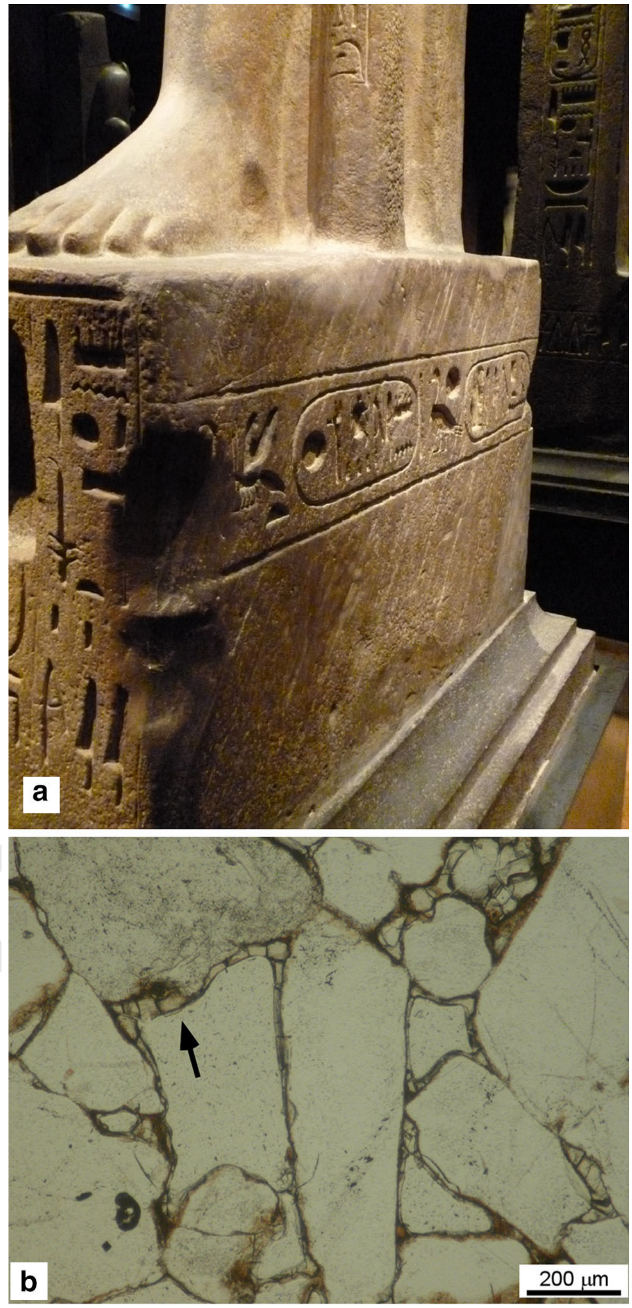

Fig. 6 Nubian Sandstone. **a** Large-scale cross-bedding is clearly recognizable on the statue of Sethi II Pharaoh (Cat. 1383). **b** Photomicrograph of a thin section collected at the Gebel Tingar quarry. All the grains are made of monocrystalline quartz. A cement rim consisting of amorphous silica is clearly recognizable within still open pores (*black arrow*)

5.3 Gebel Ahmar Sandstone

Only one find carved with this material is exposed at the statuary. It consists of a fragment of a statue of the pharaoh Merenptah (Ca. 1382) (Fig. 5d).

Macroscopically, this lithotype consists of structureless sandstone characterized by a quite vivid reddish colour (Fig. 5d). Microscopically, it is mainly composed of quartz grains and thus may be classified as a quartz arenite. The grains are quite well rounded with an average diameter of 0.5 mm. The sandstone consequently shows a medium to coarse grain size with good sorting and may be defined as mature from both a textural and compositional point of view. Quartz is represented by intensely fractured monocrystalline grains with undulose extinction (Fig. 5e,

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f). Rare lithic grains consisting of chert and siltite clasts and scattered tourmaline grains also occur. The reddish colour is given by the presence of iron oxides as coatings around the quartz grains. Locally, these oxides completely fill the pores among the grains. Two phases of cementation are recognizable. The first consists of quartz overgrowths around quartz grains. Thin Fe oxide films highlight the grain–cement boundary. The second cement consists of fibrous microcrystalline quartz occurring as 10–20-µm-thick rims within open pores (Fig. 5e, f). Because of this clearly recognizable quartz cement, these rocks are also known in the literature as silicified sandstones (e.g. Harrell 2012; Klemm and Klemm 2008). Concave–convex boundaries are common and document intergranular pressure dissolution processes that took place in only slightly lithified sands during deep burial.

5.4 Limestone

In the Egyptian Museum, only a few limestone findings are present; the ancient Egyptians preferred to use materials that were more difficult to work but were more durable. In the current exhibition of the statuary rooms, there are only four limestone artefacts (Fig. 2).

The main quarries are located south of Cairo in the Mokattam Group, but this material was extracted in many other places, along a route that goes up from Cairo to the southern city of Luxor, following the course of the Nile River.

No thin sections of this stone material are available; therefore, the description is only based on the macroscopic observation of the statue of the god Amon seated on the throne of Egypt, attributed to the reign of Horemheb (1319–1295 B.C.) from the temple of Karnak in Thebes, now placed on the back wall of the second room of the statuary (Fig. 7). The statue is made of an ivory-coloured, fine-grained limestone in which scattered fossils may be distinguished, such as bivalves and gastropods. Both types of skeletal grains are of size less than 1 cm and show a smooth mm-thick shell with no ornamentation. The original shell is not preserved but is replaced by a mosaic of sparry calcite. The rock is crossed by stylolites and veins filled with sparry calcite. Based on these macroscopic features and, particularly, the absence of visible macroforaminifera such as nummulitids, which are very common in Cenozoic marine sediments in Egypt, this limestone could be referred to the more compact and fine-grained succession from the Lower Eocene Thebe Group, such as the El Dababiya Formation cropping out approximately 35 km south of Luxor (Klemm and Klemm 2008). Otherwise, this rock can be attributed to units in the Mokattam Group described in the literature as fine-grained and poor in macrofossils, such as the Observatory Formation (Upper Lutetian). However, considering the provenance site of the statue (Karnak Temple), the former attribution is more plausible.

Fig. 7 Detail of the statue of Amon (Cat. 0768) made of fine-grained limestone. Stylolites are clearly recognizable as indented *dark surfaces*

6 Conclusions

This paper summarizes the results of a comparison between quarry samples and ancient stone artefacts from some of the well-known stone masterpieces preserved in the statuary of the Egyptian museum of Turin (Italy) and provides an archaeometric classification based on geologic and petrographic criteria (Fig. 2). In addition to a proper characterization of the materials employed by the ancient Egyptians, the research also provided reliable hypotheses about the provenance site of the original stones, thanks to previous papers (e.g. Harrell and Storemyr 2009; Klemm and Klemm 2008) that have inspired this study and supplied information about the locations of the possible original source quarries of the raw materials.

This study has indicated that many varieties of rocks are present in the statuary rooms of the Egyptian museum of Turin: they were chosen and selected by ancient Egyptians not only for their physical–mechanical properties but also for the symbolic meaning that the colour played in the Egyptian civilization. The extensive use of dark stones (Black Granites and Bekhen Stone) is connected with the meanings of fertility and resurrection traditionally attributed to this colour. Likewise, it was assumed that the widespread occurrence of pink and red granites from Aswan district in the statuary production can be attributed to the desire to play symbolically with the natural colour of human skin.

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Apart from colour and grain size, which distinguish different lithotypes (e.g. the extremely smooth and dark Bekhen Stone compared to the yellowish, coarse, and porous Nubian Sandstone), other primary features of the stone, which are related to the conditions in which it formed, may have a strong impact on its external appearance, the best example being the large-scale cross lamination clearly recognizable in all of the statues made of Nubian Sandstone. Some of these features are so outstanding and eye-catching that they appear as artefacts to the eye of a geologically untrained visitor. We cannot know whether ancient Egyptians chose those lithotypes just for those properties, but we are convinced that it should be correct to enable observers to distinguish what was made by humans from what is a natural characteristic of the stone material and understand why that feature is there in terms of geological processes. Information concerning the conditions in which the rock formed and that led to the development of its particular properties, whether related to modes of magma intrusion (occurrence of small veinlets of mostly pink feldspars in the dark granodiorite in the Aswan Black Granite), sedimentary current-related depositional structures (lamination in the Bekhen Stone and in the Nubian Sandstone), or sedimentary diagenetic structures (stylolites), could thus be added to the explanatory notes of some selected pieces to more completely express the splendid artistic and historic value of the exposed statues.

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