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The stones of the Statuary of the Egyptian Museum of Turin: geologic and petrographic characterization

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

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8 **Abstract** A geologic and petrographic study was per-
9 formed on a rich collection of statues made of stone ex-
10 posed at the statuary of the Egyptian museum of Turin
11 (NW Italy) to enhance the value of this artistic heritage and
12 set the basis for its best conservation. Magmatic and
13 sedimentary rocks were recognized. Magmatic rocks with
14 an intrusive origin are the most represented and include
15 two main varieties: Red Granite, consisting of a sieno-
16 granite with porphyritic texture and pink to red K-feld-
17 spars, and Black Granite, which includes granodiorite,
18 quartz diorite and tonalite lithotypes, whose colour ranges
19 from grey to almost black. These magmatic rocks belong to
20 the Arabian–Nubian shield, and the historical quarries are
21 located near Aswan. The sedimentary rocks are represented

by Cenozoic white limestones and red sandstones and 22
Cretaceous dark-yellow Nubian sandstones. Finally, we 23
note the occurrence of the so-called Bekhen Stone, 24
originally attributed to a green-black metagreywacke be- 25
longing to the Hammamat series of late Precambrian age, 26
outcropping in the central sector of the Eastern Desert, and 27
re-interpreted here as a massive dark-green sandstone. This 28
paper provides a scientific classification of the artefacts 29
exposed in the statuary rooms based on the employed 30
materials and contributes to the enhancement of the valu- 31
able collection of stone artefacts preserved in one of the 32
leading ancient Egyptian museums in the world. 34

Keywords Applied petrography · Cultural heritage · 35
Archaeometry · Ancient Egyptians 36

A1 This contribution is the extended, peer reviewed version of a paper
A2 presented at the session “Archaeometry and Cultural Heritage: the
A3 contribution of Geosciences” held during the conference “The future
A4 of the Italian Geosciences, the Italian Geosciences of the future”,
A5 organized by the Società Geologica Italiana and the Società Italiana di
A6 Mineralogia e Petrologia, Milano, September 10–12, 2014.

A7 This paper is dedicated to the memory of Margherita Serra[†] whose
A8 youthful enthusiasm was incentive to continue archeometric studies.

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1 Introduction 37

The Mediterranean Basin and the surrounding countries 38
represent a geographic area with a high concentration of 39
natural stones employed by humans since the earliest times 40
in history (Lazzarini 2004). In this context, Egyptian stones 41
are of primary importance among all of the natural stones 42
used in various historical epochs, including both the wide 43
use by the ancient Egyptians and the following use in 44
Roman times (Harrell 1989). The ancient Egyptians had a 45
significant knowledge of rock features and laid the bases 46
for stone quarrying and working. Rocks with different 47
geologic histories and different chemical–mineralogical 48
compositions represent a unique cultural heritage (Klemm 49
and Klemm 2001). 50

Their mineralogical and petrographic characterization 51
is, therefore, a fundamental step in the valorization of 52
materials that are important from a historical and artistic 53

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 co-operatively 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

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 gemeneferbakh	Bekhen Stone	XXVI dynasty Saitic age (664–525 B.C.)	Sais (Nile Delta)

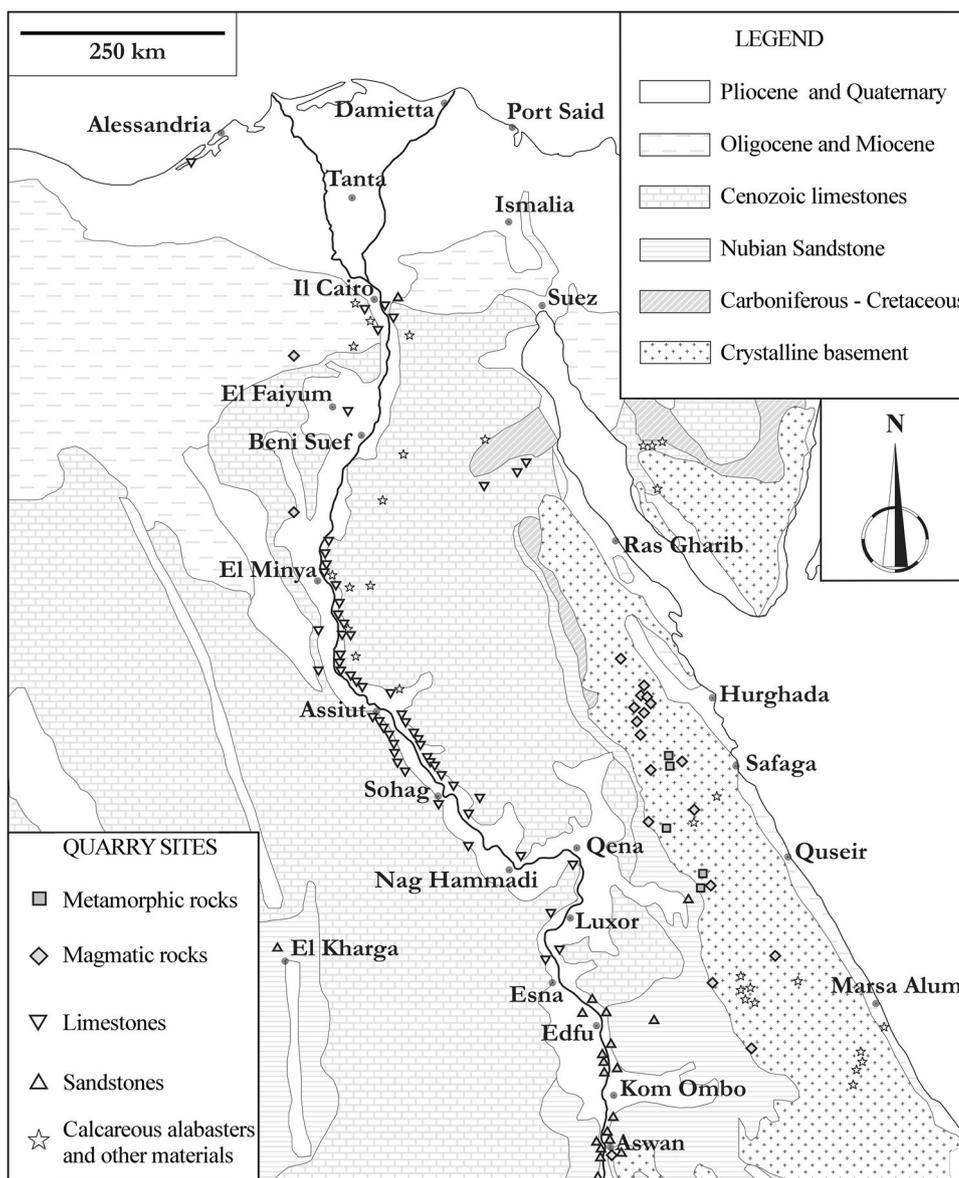
Table 2 Rock samples collected in the historical Egyptian quarries

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

155 and Harrell 1995; Klemm and Klemm 2008; Harrell and
 156 Storemyr 2009). Among the stone materials occurring in
 157 the “Statuario”, a particular stone material, the so-called
 158 Bekhen Stone, crops out in the north-eastern sector of the
 159 Arabian–Nubian shield (Wadi Hammamat). From a geo-
 160 logical point of view, the Bekhen Stone belongs to the
 161 Hammamat Complex. It is classically interpreted as a
 162 meta-sedimentary succession of late Cambrian age (ca.
 163 590 Ma) that resulted from the dismantling of igneous
 164 rocks with bimodal composition (andesitic and granitic)
 165 from a probable magmatic arc (Holail and Moghazi 1998).
 166 According to some authors (Akaad and Noweir 1969;
 167 Grothaus et al. 1979), the Bekhen Stone has experienced a
 168 low-grade metamorphic event of “Pan-African”
 169 (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 gran-
 ites, which are variably deformed with an intrusion age that
 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 Ro-
 mans). Based on petrography and geological mapping in the
 quarry district of Aswan (ancient Syene), numerous varieties

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



185 of granite rocks were distinguished, which are not always
 186 strictly of “granite” composition but may rather be attributed
 187 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 comagmatic but underwent variable degrees of magmatic

differentiation during their ascent (Ragab et al. 1979; Gindy 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

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

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

229 2.3 Cenozoic succession

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

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

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

256 3 The Egyptian Museum of Turin

257 The Egyptian Museum of Turin is located in the Academy
258 of Science building and includes two rooms (statuary) on
259 the ground floor, where a rich collection of statues made of
260 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.).

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

273 The preliminary macroscopic observations and de-
274 scriptions and the subsequent petrographic study of the
275 stone artefacts preserved at the Egyptian Museum of Turin
276 allowed us to more precisely define their lithological nature
277 with the recognition of different igneous and sedimentary
278 rocks (Fig. 2).
279
280

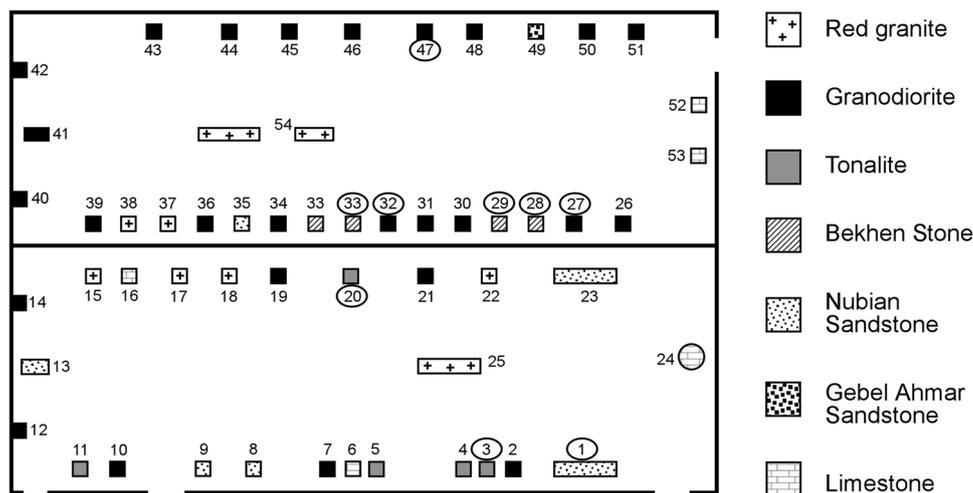
4 The igneous rocks

281 Most of the analysed statues are composed of granitoid
282 rocks. In particular, eight artefacts in the statuary rooms
283 were carved in Red Granite from Aswan; 26 statues in
284 granodiorite, 21 of which represent the goddess Sekhmet
285 standing or sitting and five in tonalite, including the statue
286 symbol of the Museum represented by Ramses in majesty.
287 Following the criteria of macroscopic analogies between
288 rock samples and stone artefacts to test the provenance
289 hypothesis, a minero-petrographic comparison between
290 small specimens picked up from the statues and rock
291 samples collected from Aswan quarry sites was performed.
292

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

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

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



311 4.1 The Red Granite

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

319 Many artefacts in the statuary of the Egyptian Museum
320 of Turin are carved in Red Aswan Granite, among
321 them the statue of the Pharaoh Amenhotep II
322 (1427–1401 B.C.) (Cat. 1375) in the act of offering gifts
323 to the gods and then usurped by the Pharaoh Ramesses
324 II in the act of walking (Cat. 1381). This artefact is the
325 first royal statue from Egypt that arrived in Italy in 1759
326 with the Donati collection. In addition, a statue of a ram,
327 three sarcophagi attributed to the XIX dynasty and an
328 offering table from the Late Period are carved in Red
329 Granite.

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

344 Regarding accessory minerals, it was possible to underline
345 the significant prevalence of titanite, mainly in

346 contact with or included in mafic minerals. Apatite is
347 present as euhedral grains with prismatic, hexagonal or
348 acicular shapes, the dimensions of which never exceed
349 100 μ . Ilmenite and magnetite are also abundant, both as
350 single euhedral crystals and larger aggregates, which are
351 often included in or in contact with mafic minerals.

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

354 4.2 The Black Granite

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

360 In the statuary of the Egyptian Museum, there are 21
361 statues of Sekhmet (goddess of medicine, depicted with the
362 head of a lion and the body of a woman) carved with
363 granodiorite. These statues are part of a series of nearly
364 identical sculptures from the temple of the goddess Mut
365 and the funerary temple of Amenhotep III (1390–1352
366 B.C.), which were originally located along the eastern and
367 western shores of the Nile in Luxor, respectively. The
368 statue attributed to Tuthmosis I (1494–1482 B.C.; Cat.
369 1374), which represents one of the oldest stone statues
370 preserved at the Museum of Turin (Fig. 3d), is also carved
371 in granodiorite.

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

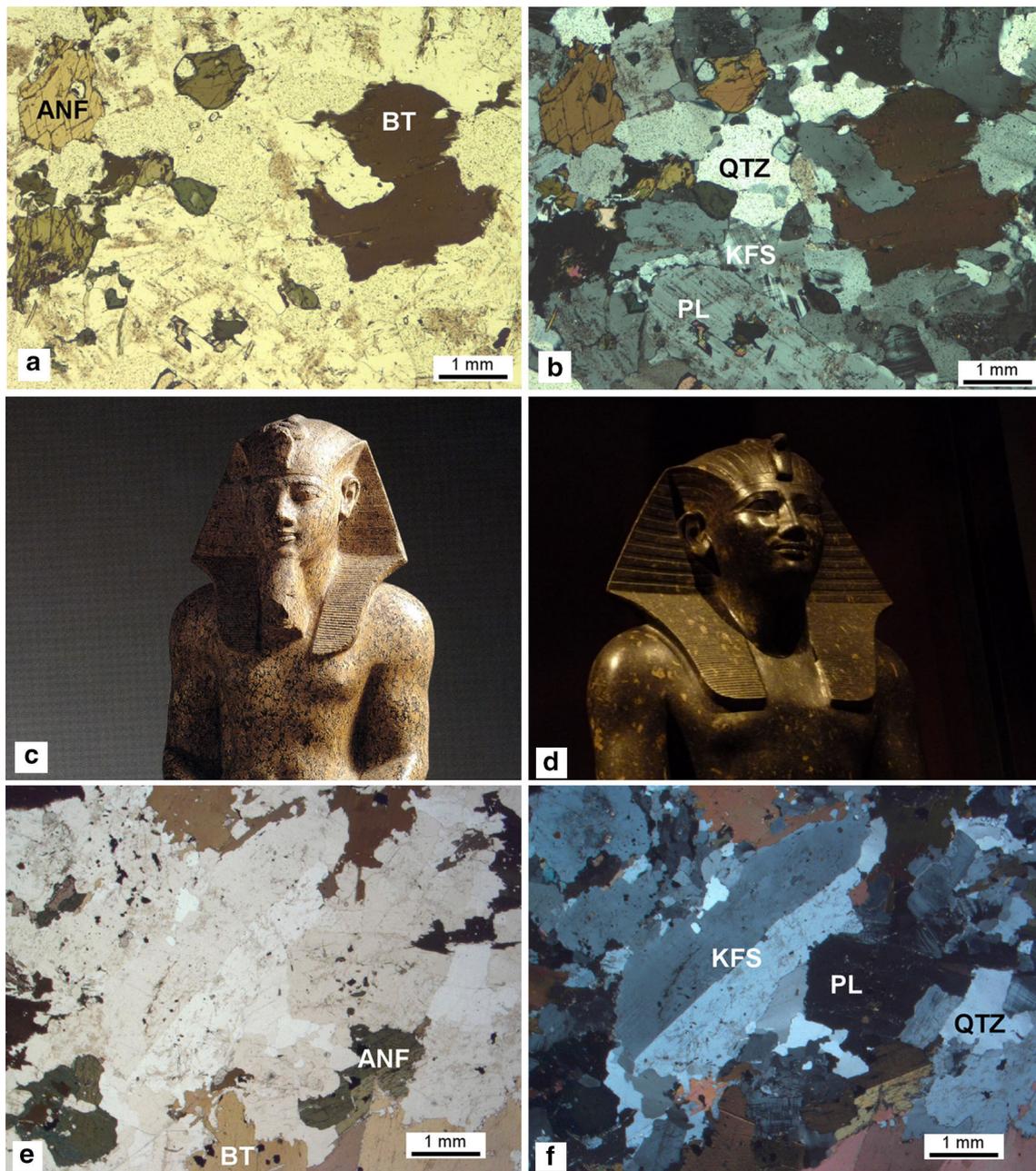


Fig. 3 Photomicrograph of a thin section of Aswan *Red Granite* collected at the unfinished obelisk quarry of Aswan (**a** parallel nicols, **b** crossed nicols) showing the main mineralogic assemblage: alkali feldspar (Kfs), quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl); **c** detail 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 Thutmose I statue

exposed at the Egyptian Museum of Torino (Cat. 1374) carved using the granodioritic 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)

380 A typical and widespread feature of this rock is the
 381 presence of partially iso-oriented sialic mineral aggregates,
 382 which are clearly recognizable on the statues (Fig. 3d).
 383 These aggregates consist of poikilitic plagioclase and sub-
 384 ordinate quartz in the core and reddish K-feldspar in the
 385 rim. Microscopic veinlets of pink granite locally cross the

main granodiorite body and are due to the occurrence of 386
 reddish K-feldspar along the vein border (Serra et al. 2010). 387
 In some artefacts, the natural stone looks rather dark and 388
 homogeneous, as in the case of the statue of the pharaoh 389
 Ramses II in Majesty (Cat. 1380), one of the greatest 390
 masterpieces of Egyptian civilization and a symbol of the 391

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

416 The rock is composed of biotite, green amphibole, pla-
 417 gioclase, quartz and much more subordinate K-feldspar
 418 (<5 %) (Fig. 4b, c). Amphibole is slightly more abundant
 419 than biotite, even if both femic minerals tend to occur as
 420 aggregates. Plagioclase and quartz occur in comparable
 421 amounts, but the plagioclase is euhedral, partially sericitic
 422 and sporadically occurs as phenocrysts, whereas the quartz
 423 is mostly interstitial and locally with undulose extinction.
 424 Apatite is widespread and present in larger amounts with
 425 respect to the granodiorite samples. Other accessory min-
 426 erals are titanite, Fe–Ti oxides, zircon, epidote (allanite)
 427 and pyrite (Serra et al. 2010). Unfortunately, this rock is
 428 particularly susceptible to deterioration as a result of hy-
 429 drothermal alteration (Klemm and Klemm, 2008). In par-
 430 ticular, the pyrite component in this rock tends to break
 431 down mainly into sulphuric acid and iron hydroxide.

432 5 The sedimentary rocks

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

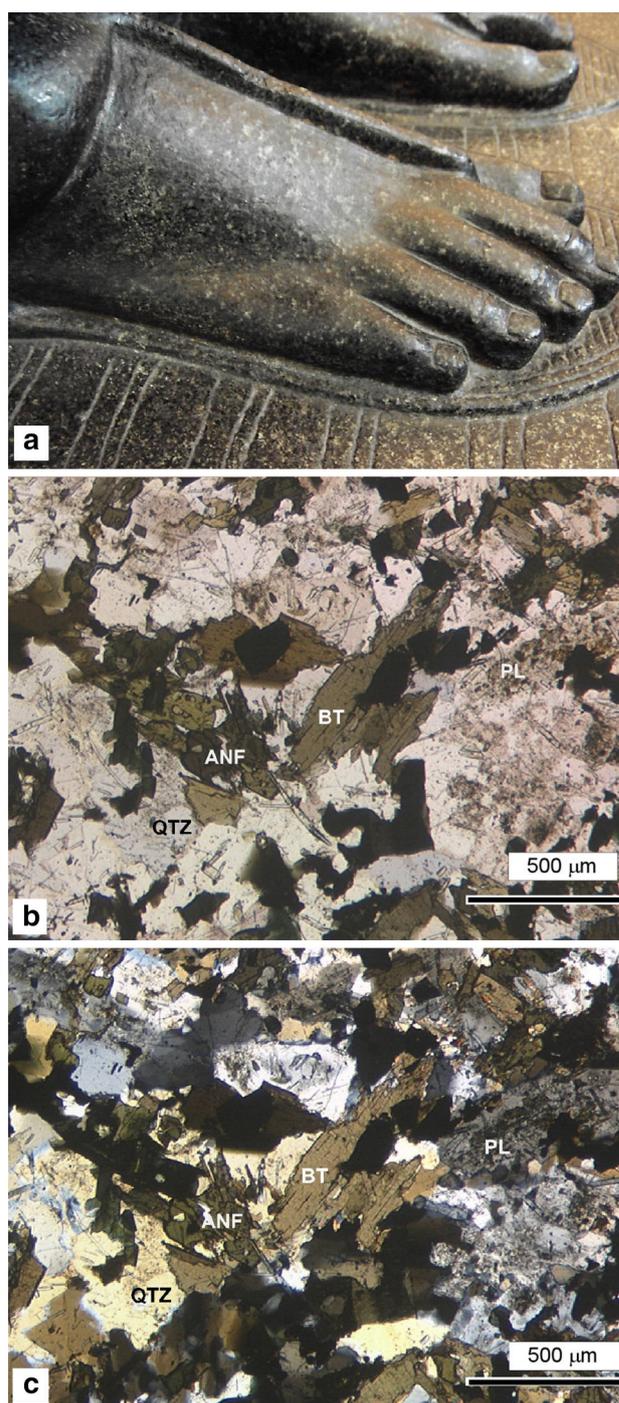


Fig. 4 a Detail of the Ramses II in Majesty statue exposed at the Egyptian Museum of Torino (Cat. 1380); The phaneritic texture defined by plagioclase and femic minerals is apparent; **b–c** Photomicrograph of a thin section of the Ramses II statue tonalite (**b** parallel nicols, **c** crossed nicols)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

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

445 5.1 The Bekhen Stone

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

451 The historic quarries of Bekhen Stone are located in the
452 central sector of the Eastern Desert, along the Quift –
453 Quseir road from the Nile Valley to the Red Sea. In this
454 site, impressive quarrying activity is documented by almost
455 600 rock inscriptions over a time interval from the Pre-
456 dynastic to late Roman period (approximately 4000 B.C.
457 until 300 A.D.). These inscriptions indicate the uniqueness
458 of this site and its extraordinary importance for ancient
459 Egyptian culture. The Bekhen Stone quarries are also
460 mapped in the famous Papyrus of Mines, manufactured
461 during the reign of Ramesses IV (1151–1145 B.C.), found
462 near Thebes in the early nineteenth century and now ex-
463 hibited in the Egyptian Museum of Turin. It was ascribed
464 to the Wadi Hammamat area and represents the world’s
465 oldest surviving geological map (Harrell and Brown 1992).

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

480 Italian dealers in marble called the darker and black
481 variety “Basanite” and the green variety “Basalto Verde
482 Antico” (i.e., “Ancient Green Basalt”) (Gnoli 1988). Be-
483 cause of its intense colouration and very small grain size,
484 the macroscopic identification of this rock may be difficult;
485 indeed, it was frequently confused with basalts (Nicholson
486 and Shaw 2000; Penny 1993).

487 Microscopically, it shows a granular texture typical of
488 clastic sedimentary rocks and is composed of tightly
489 packed quartz and feldspar grains and lesser amounts of
490 lithic, chlorite, muscovite and epidote grains (Fig. 5a, b).
491 Texturally, it is a fine to very fine sandstone (grains finer
492 than 250 micron) and quite well sorted. No evidence of a

muddy matrix is present. The grain roundness is very low
493 and angular shapes prevail. Thus, the rock may be classi-
494 fied as lithic arkose. However, it has been always cited in
495 literature as a greywacke (Klemm and Klemm 2001, 2008).
496 This term, according to many authors (e.g. Blatt et al. 1980;
497 Boggs 2009), should be abandoned because it has gener-
498 ated much confusion through time. In any case, it should be
499 reserved to sandstones with an amount of matrix larger
500 than 10 % (Dott 1964) and thus does not apply to the
501 Bekhen Stone. Quartz is represented by monocrystalline
502 grains that commonly show undulose extinction. Poly-
503 crystalline quartz grains also occur. All of the feldspar
504 grains show a degree of alteration to sericite, which ranges
505 from slight to complete. Lithic grains are mainly repre-
506 sented by very fine-grained, dark grains, which may be
507 referred to as fragments of volcanic rock groundmass.
508 Moreover, as cathodoluminescence is greatly enhanced,
509 quite common calcite-bearing grains can be identified.
510 Some of them are only made of sparry calcite, but others
511 are polymineralic grains consisting of white mica and
512 calcite or chlorite, calcite and fine-grained dark portions
513 possibly made of graphite (Fig. 5a, b). These lithic grains
514 show a marked foliation and are surely referable to
515 metamorphic rocks with a sedimentary origin and impure
516 carbonate composition (e.g. organic-rich marls). The
517 phengite composition reported by Borghi et al. (2007) for
518 some crystals of white mica can be referred to this type of
519 grain. No cement can be identified in thin section. The
520 hard coherence of the rock is due to the strong indentation
521 among the grains, which developed from intergranular
522 chemical compaction during burial (pressure dissolution).
523 Different from what is reported in the literature (Klemm
524 and Klemm 2001; Harrell 2013), the petrographic features
525 of this lithotype show that the Bekhen Stone is a
526 sedimentary rock that has not experienced metamorphic
527 transformations but only burial diagenetic processes. In
528 some instances, this is also supported by the possibility of
529 recognizing millimetre-thick parallel lamination directly
530 on the statues (Fig. 5c). It cannot be excluded, however,
531 that these sandstones locally experienced contact meta-
532 morphism related to the intrusion of the so-called
533 Younger Granitoids of Precambrian age. 534

535 5.2 The Nubian Sandstone

536 This sandstone material was much appreciated in the dy-
537 nastic era both for its colour characteristics and easy
538 workability. It was mined in the Nubian area and then
539 transported by ship following the course of the river cur-
540 rent. The quarries that were more fully exploited in the
541 Middle Kingdom were, in fact, seventy kilometres north of
542 Aswan, the city from which most of the hard stone used in
543 this period came.

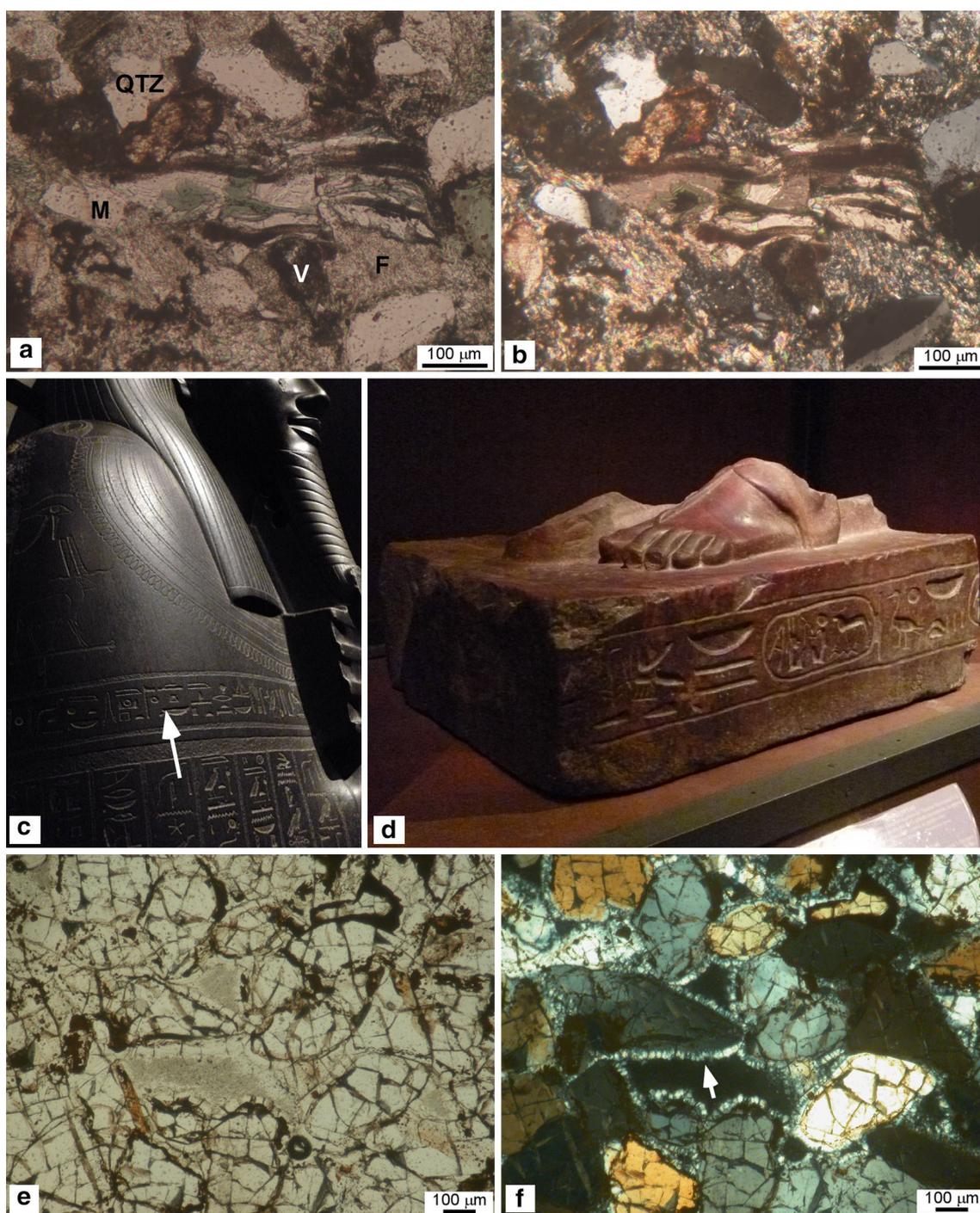


Fig. 5 **a–c** *Bekhen Stone* **d–f** Gebel Ahmar Sandstone. **a, b** Photomicrograph of a thin section of the *Bekhen Stone* (**a** parallel nicols, **b** crossed nicols) collected at the Wadi Hammamat quarry. It is possible to recognize grains made of quartz (Qz), sericitized feldspars (F), dark, fine-grained 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*)

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

562 Macroscopically, this lithotype consists of a sandstone
 563 characterized by an overall yellowish colour with localized
 564 pinkish patches. Large-scale cross-bedding is very com-
 565 mon and clearly recognizable on the statues (Fig. 6a). The
 566 laminae are centimetres thick and highlighted by sharp
 567 grain size changes. Microscopically, the sandstone is
 568 mainly composed of quartz grains and thus may be clas-
 569 sified as a quartz arenite. The sorting is quite low and the
 570 grain roundness is very variable: the grains range in size
 571 from 200 μm to over 3 mm, and both well-rounded and
 572 angular grains occur. This sandstone may be defined as
 573 mature from a compositional point of view but not textu-
 574 rally. Quartz is represented by monocrystalline grains that
 575 commonly show undulose extinction and are partly frac-
 576 tured. Polycrystalline quartz grains also occur. Some
 577 muscovite and scattered heavy mineral grains (rutile,
 578 staurolite and tourmaline) may be identified. The quartz
 579 grains are commonly coated by a film made of clay mi-
 580 nerals (illite and kaolinite) and Fe oxides that give the local
 581 pink colour to the rock. The rock is still highly porous, and
 582 only a minor amount of cement can be locally observed. It
 583 consists of amorphous silica (opal) that locally forms
 584 20- μm -thick rims within open pores (Fig. 6b). Concave-
 585 convex boundaries are common and document inter-
 586 granular pressure dissolution processes that took place in
 587 only slightly lithified sands during deep burial.

588 5.3 Gebel Ahmar Sandstone

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

592 Macroscopically, this lithotype consists of structureless
 593 sandstone characterized by a quite vivid reddish colour
 594 (Fig. 5d). Microscopically, it is mainly composed of quartz

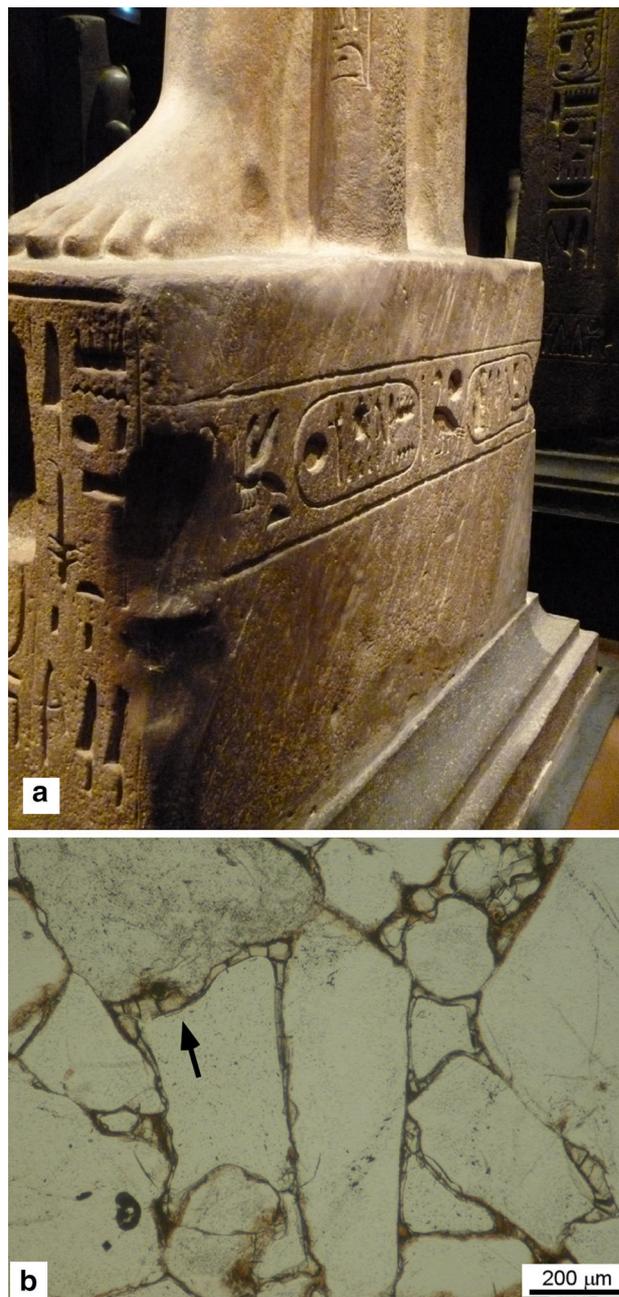


Fig. 6 Nubian Sandstone. **a** Large-scale cross-bedding is clearly recognizable on the statue of Sethi II Pharaoh (Cat. 1383). **b** Photomicrograph of a thin section collected at the Gebel Tingar quarry. All the grains are made of monocrystalline quartz. A cement rim consisting of amorphous silica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

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,

602 f). Rare lithic grains consisting of chert and siltite clasts
 603 and scattered tourmaline grains also occur. The reddish
 604 colour is given by the presence of iron oxides as coatings
 605 around the quartz grains. Locally, these oxides completely
 606 fill the pores among the grains. Two phases of cementation
 607 are recognizable. The first consists of quartz overgrowths
 608 around quartz grains. Thin Fe oxide films highlight the
 609 grain–cement boundary. The second cement consists of
 610 fibrous microcrystalline quartz occurring as 10–20- μ m-
 611 thick rims within open pores (Fig. 5e, f). Because of this
 612 clearly recognizable quartz cement, these rocks are also
 613 known in the literature as silicified sandstones (e.g. Harrell
 614 2012; Klemm and Klemm 2008). Concave–convex
 615 boundaries are common and document intergranular pres-
 616 sure dissolution processes that took place in only slightly
 617 lithified sands during deep burial.

618 5.4 Limestone

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

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

629 No thin sections of this stone material are available;
 630 therefore, the description is only based on the macroscopic
 631 observation of the statue of the god Amon seated on the
 632 throne of Egypt, attributed to the reign of Horemheb
 633 (1319–1295 B.C.) from the temple of Karnak in Thebes,
 634 now placed on the back wall of the second room of the
 635 statuary (Fig. 7). The statue is made of an ivory-coloured,
 636 fine-grained limestone in which scattered fossils may be
 637 distinguished, such as bivalves and gastropods. Both types
 638 ^{AQS} of skeletal grains are of size less than 1 cm and show a
 639 smooth mm-thick shell with no ornamentation. The origi-
 640 nal shell is not preserved but is replaced by a mosaic of
 641 sparry calcite. The rock is crossed by stylolites and veins
 642 filled with sparry calcite. Based on these macroscopic
 643 features and, particularly, the absence of visible macro-
 644 foraminifera such as nummulitids, which are very common
 645 in Cenozoic marine sediments in Egypt, this limestone
 646 could be referred to the more compact and fine-grained
 647 succession from the Lower Eocene Thebe Group, such as
 648 the El Dababiya Formation cropping out approximately
 649 35 km south of Luxor (Klemm and Klemm 2008). Other-
 650 wise, this rock can be attributed to units in the Mokattam
 651 Group described in the literature as fine-grained and poor
 652 in macrofossils, such as the Observatory Formation (Upper



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

Lutetian). However, considering the provenance site of the 653
 statue (Karnak Temple), the former attribution is more 654
 plausible. 655

656 6 Conclusions

657 This paper summarizes the results of a comparison be- 657
 658 tween quarry samples and ancient stone artefacts from 658
 659 some of the well-known stone masterpieces preserved in 659
 660 the statuary of the Egyptian museum of Turin (Italy) and 660
 661 provides an archaeometric classification based on 661
 662 geologic and petrographic criteria (Fig. 2). In addition to 662
 663 a proper characterization of the materials employed by 663
 664 the ancient Egyptians, the research also provided reliable 664
 665 hypotheses about the provenance site of the original 665
 666 stones, thanks to previous papers (e.g. Harrell and 666
 667 Storemyr 2009; Klemm and Klemm 2008) that have in- 667
 668 spired this study and supplied information about the lo- 668
 669 cations of the possible original source quarries of the raw 669
 670 materials. 670

671 This study has indicated that many varieties of rocks are 671
 672 present in the statuary rooms of the Egyptian museum of 672
 673 Turin: they were chosen and selected by ancient Egyptians 673
 674 not only for their physical–mechanical properties but also 674
 675 for the symbolic meaning that the colour played in the 675
 676 Egyptian civilization. The extensive use of dark stones 676
 677 (Black Granites and Bekhen Stone) is connected with the 677
 678 meanings of fertility and resurrection traditionally at- 678
 679 tributed to this colour. Likewise, it was assumed that the 679
 680 widespread occurrence of pink and red granites from 680
 681 Aswan district in the statuary production can be attributed 681
 682 to the desire to play symbolically with the natural colour of 682
 683 human skin. 683

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

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Query	Details Required	Author's Response
AQ1	Please check the usage of the term 'finds' throughout the article, and amend if necessary.	
AQ2	Please check the sentence 'The choice of the statues to be sampled and the sizes of...' for clarity, and amend if necessary.	
AQ3	Please check and confirm Said (1960) has been changed to Said (1990) so that this citation matches the list.	
AQ4	Please check and confirm Ragab et al. (1978) has been changed to Ragab et al. (1979) so that this citation matches the list.	
AQ5	Please check the edits made in the sentence ' Both types of skeletal grains are...' for clarity, and amend if necessary.	
AQ6	Please provide accessed date for reference Harrell (2012).	