Black and red granites in the Egyptian Antiquity Museum of Turin: A minero-petrographic and provenance study

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BLACK AND RED GRANITES IN THE EGYPTIAN ANTIQUITY MUSEUM OF TURIN. A MINERO-PETROGRAPHIC AND PROVENANCE STUDY.

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ABSTRACT

A recent project to investigate the stony artefacts preserved in the Egyptian Antiquity Museum of Turin has been undertaken with the aim to supply their systematic classification and to suggest the provenance site of the original raw materials. This paper focuses on seven sculptures dating back to the New Kingdom (XVIII-XIX dynasties): the statue of Ramses II, three of the twenty-one sculptures of goddess Sekhmet, the statue of God Hathor, the Ram-headed sphinx and the sarcophagus lid of Nefertari. Petrographic observations have shown that all the sculptures are made of granitoid rocks, with variable composition from granite to granodiorite and tonalite. The observation of strong macroscopic analogies with the so called black and red granites outcropping in the Aswan area, has suggested a common origin of all the raw materials used for their realization. In order to verify this provenance hypothesis, several samples were collected in the Aswan quarry districts. According to results of a minero-petrographic and geochemical comparison between the statues and the Aswan quarry samples, it was possible to identify the source area of the stony sculptures and finally to highlight the importance of an archaeometric approach to the solution of archaeologic problems.

Key words: Egyptian Sculpture, New Kingdom, Aswan Granitoids, Electron Microprobe Analysis, Provenance

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INTRODUCTION

Since 1824, when a huge collection of ancient Egyptian antiquities came to Turin after the expedition of Bernardino Drovetti (Curto, 1984), it was clear that such an artistic heritage could supplied a fundamental key to understand Egyptian civilization.

After a first systematic cataloguing by Jean François Champollion, the collection of the Museum of Egyptian Antiquities 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 could provide the opportunity of improving our knowledge about ancient Egyptian materials and technologies.

A cooperation between the Museum of Egyptian Antiquities, the University of Turin and the Egyptian National Research Centre started with the aim to study the stones of Egyptian finds, by a scientific viewpoint, in order to enhance the value of this artistic heritage and to set the base for its best conservation. This research represents the first systematic geological and minero-petrographical study performed on some of the best known sculptures preserved in the Museum (Borghi et al., 2007, 2009a).

This paper focuses attention on the *black* and *red granites* artefacts, representing even 75% of the sculptures actually exposed in the “Statuary” rooms of the Museum. The choice to study granitoids came from the statement of their economic and historic relevance from Dynastic period up to nowadays. Indeed, through all Egyptian history, granitoids were maybe the most appreciated stone materials for sculpture and architecture, both for their chromatic features and for their technical properties.

Moreover, especially for *black granites*, the need of a detailed minero-petrographic analysis arose from the difficulty of a stone artefact classification based only on macro- and mesoscopic observations (Middleton and Klemm, 2003). Therefore, five *black granite* statues, belonging to the Drovetti collection, were sampled in a micro-invasive way: three sculptures of goddess Sekhmet (cat. 260, 247, 251), the statue of Ramses II (cat. 1380) and the statue of goddess Hathor (cat. 694). The opportunity of studying the fine-grained black rocks used for the sculptures of goddess Hathor (cat. 694) and of Ramses II in Majesty (cat. 1380), symbol of the Egyptian Museum of Turin, provided the opportunity to analyse and classify two of the best known masterpieces of Egyptian art.

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The choice to analyse even three of the 21 statues of goddess Sekhmet (cat. 260, cat. 247, cat. 251) originally located in the same Egyptian temple but ichnographically different, derived from the need of answering the archaeological questions concerning their provenance (Yoyotte, 1980). Indeed, it was uncertain if they were all realized at the same time and by the same workshop.

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As regards *red granites*, it was noted that most exposed sculptures were made of rocks closely akin to Aswan granite. Just in one case, the Ram-headed Sphinx (cat. 836), macroscopic differences in colour index, grain size and isoorientation of feldspar phenocrysts suggested a different provenance of the raw material and determined the choice of picking up a small fragment for the minero-petrographic analysis. Moreover, the historical study of this artefact could take advantage from a scientific study about the raw material used for its realization. In fact, according to archaeologists, the statue could have been brought to Karnak from its original location in the temple of Soleb, in Nubia (D'Amicone, 2006). Finally, the sample collected from the sarcophagus lid of Nefertari (suppl. 5153) during the recent restoration of the sculpture, was analysed in order to test the accuracy of the results, as the provenance of the raw material used for its realization was already certain.

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Final goal of the project was to understand the provenance of the materials used in Pharaonic period, setting the base for the identification of the ancient quarry sites. According to a preliminary geologic study, strong macroscopic analogies between the ancient stony artefacts and the different granitoids outcropping in the southern part of Egypt, near Aswan (Hume, 1935; Aston et al., 2000; Klemm and Klemm, 2001), were evidenced. It was thus formulated the hypothesis that all the rocks used for the sculptures may have been extracted in the quarry district of Aswan. To test this hypothesis, a minero-petrographic comparison between the stone specimen taken from the statues and rock samples collected from Aswan quarry sites, was performed.

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The geochemical analysis was performed taking into account the problem of representativeness of the samples. The artistic and historic value of the sculptures, together with the medium-to-coarse grain size of the constituent rocks, is in fact incompatible with the collection of representative amounts of rocks to perform a classical whole rock analysis. For this reason, it was chosen to make a single phase analysis through SEM-EDS, looking for compositional parameters that could be useful to refer an unknown sample to a particular quarry site. Therefore, we focused on the main phases that show a wide geochemical variability to infer the provenance of the rocks. In fact, amphibole, biotite and plagioclase geochemistry reflects chemical and growth conditions which could discriminate different source areas.

THE SCULPTURES

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THESCULPTURES

Objective of this research are seven masterpieces of New Kingdom monumental art (Table 1 and Fig.1). Most of them belong to the Drovetti collection, acquired by Carlo Felice in 1824 to constitute the principal found of the newborn Museum of Egyptian Antiquities (Vassilika, 2006). They were all collected in Southern Egypt, mainly from the Theban area, with the exception of the sculpture of goddess Hathor (cat. 694) coming from Coptos and the sarcophagus lid of Nefertari (suppl. 5153). This last important archaeological find was brought to Turin after the archaeological expedition by Ernesto Schiapparelli in the Valley of the Queens at the beginning of the XX century (Leblanc and Siliotti, 2006).

SARCOPHAGUS LID OF NEFERTARI (SUPPL. 5153; Fig. 1a**)** The tomb of Queen Nefertari was discovered in the Valley of the Queens by Ernesto Schiaparelli, Director of the Turin Egyptian Antiquity Museum, in 1904. Nefertari's tomb is considered to be the most beautiful of all the Queens' tombs, both for its design and its brilliantly coloured painted decoration. Though Nefertari's burial place was destroyed in antiquity, the tomb plundered and left open, several fragments of burial equipment, including fragments of a gilded wooden coffin and the *red granite* sarcophagus lid were found by Schiaparelli (Leblanc and Siliotti, 2006). The sarcophagus lid has recently been restored and it is now exposed on the first floor, in the Museum section dedicated to the Schiapparelli's archaeological activity in the Valley of the Queens.

RAM-HEADED SPHINX (CAT. 836; Fig. 1c**).** By analogy with a similar sculpture preserved in the Aegyptisches Museum und Papyrusammlung of Berlin, the sphinx was supposed to have been originally located in the Nubian Temple of Soleb. It was probably during the Late Period (XXV dynasty) that the statue was brought to the Temple of Mut at Karnak, were it was found in 1818 during the Drovetti expedition. The Ram with curved horns, associated to god Amun since XII dynasty, offers his protection to Amenhotep III, who stands between the front legs and below the animal's head (D'Amicone, 2006).

SCULPTURES OF GODDESS SEKHMET (CAT. 260, CAT. 247, CAT. 251; Fig. 1d, 1e and 1f). The selected statues belong to the collection of twenty-one sculptures of goddess Sekhmet actually exposed in the Statuary rooms. Sekhmet was the avenging lion-headed goddess, who showed the sun disk as her attribute. By vanishing foreign enemies, the reigning Pharaoh was likened to the combative, fire-spitting Sekhmet. As the city of Thebes rose in power, the Egyptian priests decided that Mut, consort of the chief god Amon, should be associated to the popular Sekhmet. There may have originally been 730 statues of Sekhmet, one seated and one standing for each day of the year

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(Bryan, 1997). The seated Sekhmet are thought to have been dragged to the Temple of Mut for a second use, from the funerary Temple of Amenhotep III, located on the west bank of the river Nile (Vassilika, 2006).

SCULPTURE OF GODDESS HATHOR (CAT. 694; Fig. 1g). The statue comes from Coptos and belongs to the later Donati collection, brought to Turin in 1756. It refers to the New Kingdom (XVIII dynasty) and in particular to the Reign of Amenhotep III (1390 – 1352 a.C.). The figure was one of the several divinities commissioned by the Pharaoh to celebrate his jubilee in Coptos. Hathor was a mother goddess, her cow-horn head-dress showing her association with the celestial cow. Hathor nurtured the god Horus, incarnate as the ruling king of Egypt (D'Amicone, 2006).

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SCULPTURE OF PHARAOH RAMSES II (CAT. 1380; Fig. 1b**)**. This sculpture, belonging to the later Drovetti collection, is world renowned as Turin's portrait masterpiece of Egypt's longest reigning and most famous Pharaoh. He wears the Blue Crown of war and, in a stylistic debt to the Amarna period, a long full robe with an enormous bell sleeve. Below his feet are the nine bows, representing enemy tribes, and an Asiatic and Nubian prisoner underscoring the king's supremacy over Egypt and his possessions. To the sides of the king's legs are smaller figures of Queen Nefertari and their son Amonherkhepeshef (D'Amicone, 2006).

BLACK AND RED GRANITES FROM ASWAN

Through all Egyptian history, plutonic rocks had been intensively carved for sculptural and architectonic purposes. If the diffuse use of granitoids could partially be explained by the relative abundance of these materials in Egyptian territory, we can imagine that other reasons may have brought the great Pharaohs of the new Kingdom to an intense exploit of these materials. The use of black stones is in fact probably linked to the importance of this colour as symbol of regeneration and fertility. As to the *black granites* is commonly associated asymbolic meaning, the *red granites*, on the other hand, could allude to the natural colour of the skin (De Putter and Karlshausen, 1992). It was thus for aesthetic, as for technical and cultural reasons, that ancient Egyptians used to invest immense resources for the extraction and working of *black and red granites*.

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Analysing the geological map (Fig. 2a), it can be clearly observed that only in the Southern part of Egypt, nearby Aswan, plutonic rocks outcrop in close proximity to the course of Nile River, main way of communication through all Egyptian history. Thus, the importance of Aswan, besides being

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linked to its strategic position as a frontier station for the commerce with central Africa, is also connected to its geological conformation, that allowed to avoid expensive transports of the carved hardstones through the desert roads (Sampsell, 2004).

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Aswan quarry district is located south and south-east of the city (Fig. 2b) and covers an area of about 20 km^2. Almost one hundred sites for the extraction of plutonic rocks (Fig. 2c) have been identified on the oriental coast of Nile and on the islets (Illig and Löhner, 2001).

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As regards the quarry activity, it has been possible to estimate an amount of *red granites* carved in the Aswan district from Old Kingdom to Roman times in the range of some million tons (Klemm and Klemm, 2001). Moreover, at least in Egyptian times, the so called *black granites* were quarried and appreciated as the famous red ones.

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GEOLOGICAL SETTING

Aswan plutonic rocks belong to the Western margin of the Arabian-Nubian shield, that covers approximately 10% of the Egyptian territory. It outcrops in the south – eastern sector, almost parallel to the Red Sea coast and in the lower sector of the Sinai peninsula. The Arabian-Nubian shield is characterized by a significant abundance of granitoids. Traditionally, they are subdivided into two main age groups: A) the older grey granites which are variably deformed with an intrusion age variable between 850 and 610 Ma; B) the younger pink granites, which are essentially undeformed, post – tectonic granites, with intrusion ages of 600-550 Ma (Tawadros, 2001, and references therein). The Aswan granitoids belong to the second group and, based on geological mapping (Gindy, 1956; Gindy and Tamish, 1998), can be distinguished in four type of post-collisional, largely undeformed, granitoids (Fig. 2b): 1) the coarse-grained porphyritic granitoid ranging between granodiorite to tonalite in composition (*black granite*); 2) the porphyritic "Monumental" Granite with rapakiwi texture (*red granite*); 3) the fine – grained, mostly pink Saluja-Sehel granite; 4) the so-called High Dam Granite, which is acoarse-grained, equigranular biotite granite.

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Several authors have suggested that all four plutonic units are co-magmatic, with the magmas being derived from the same or similar source, but having undergone variable degrees of magmatic differentation during ascent (Ragab et al., 1978; Gindy and Tamish, 1998).

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Both *red* and *black granites* have been recently dated at 606 ± 2 Ma, based on single grain ID-TIMS U-Pb zircon dating method (Finger et al., 2008). Therefore, these plutonic rocks resulted to be contemporary, as also proposed by Gindy and Tamish (1998), basing on field relationships. Moreover, according to their peculiar geochemical features (shoshonitic affinity) these granites can be classified as A-type granitoids (Whalen et al., 1987) and can be related to a post-collisional partial melting of the subduction mantle wedge at the contact of the Saharan Metacraton and the Arabian Nubian Shield (Finger et al., 2008).

The Monumental Granite (*red granite*) is represented by a very coarse- to mainly coarse-grained, porphyritic granite, pinkish to occasionally reddish in colour, whose ancient name *marmor syeniten* or *lapis syenites* derive from the Greek denomination of Aswan city, and whose unmistakable colour has been appreciated since Old Kingdom up to nowadays for artistic purposes (Harrell, 1989). The main distinguishing feature of this rock is the presence of pink to reddish-pink K-feldspar phenocrysts.

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Grey-coloured granodiorites and tonalites (*black granites*), interfingered with the *red granites*, also outcrop South of Aswan. Contact relationships indicate that the *black granites* came first. The exact distribution of each variety has not been satisfactory mapped up to now, but it is possible to recognize a change from the granite varieties around Gebel Ibrahim Pasha to tonalites towards the Nile river.

SAMPLE COLLECTION AND ANALYTICAL CONDITIONS

The selection of the statues to be analysed was made in cooperation with the curators of the museum, trying to balance between the need of representing the compositional variability of plutonic rocks in Egyptian sculpture and the obvious conservative limitations. The samples were collected removing small fragments from superficial fractures or from un-carved stone portions. The sculptures chosen for analyses were considered to be roughly representative of the most used granitoids used in Dynastic period. In fact, based on their macroscopic features, only granitoids type 1 (*black granites*) and type 2 (*red granites*) were observed in the Egyptian Museum of Turin.

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Taking into account this observation, representative samples of *red and black granites* from chosen areas in the Aswan quarry districts were collected through a geological campaign. Main goal of the

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field work was to perform a selective rock sampling to cover the different stone varieties observed in the Statuary rooms of the Museum.

Red granites were taken from the historical quarry site of the Unfinished Obelisk in Aswan (Fig. 3a) whereas *black granites* were collected near Gebel Ibrahim Pasha (Fig. 3b) in the southern part of the quarry district of Aswan.

Eight quarry samples, with variable composition from granite to granodiorite and tonalite, were chosen between all the collected materials for the minero-petrographic comparison with the sculpture stones.

Petrographic examination was undertaken using a polarizing microscope; a scanning electron microscope (SEM; Cambridge Stereoscan S360), equipped with an energy-dispersive spectrometer (EDS; Oxford Instruments), was used for electron microscopy and microchemical analysis, with an accelerating voltage of 15 kV and a dwell time of 60 s. Natural silicates and oxides were chosen as standards. A ZAF data reduction program was used. The mineral compositions are expressed as wt.% oxides and recalculated using the MINSORT computer program of Petrakakis and Dietrich (1985) as atoms per formula unit (a.p.f.u.). Structural formulae of amphibole were calculated on the basis of 23 O atoms. $Fe^{3+}/(Fe^{3+} + Fe^{2+})$ value of amphibole was estimated using the method described by Stout (1972). The nomenclature is that of the IMA-approved system published by Leake (1978). Structural formulae of biotite were calculated on the basis of 22 O atoms. Unless otherwise specified, the mineral symbols are from Kretz (1983).

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RESULTS AND DISCUSSION

Petrographic features

The mineralogical assemblage and the micro-structural features of both stone sculpture fragments and Aswan quarry samples were defined through a petrographic analysis, performed by light and scanning electron microscope.

Red Granites

Typical feature of coarse-grained Aswan *red granites* is the occurrence of pink to reddish centimeter-sized alkali-feldspar porphyrocrysts (Figs. 4a). The fabric varies from isotropic to almost

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gneissic, while the colour index is about 10-15%. The main mineralogical assemblage is constituted by alkali-feldspar, quartz, plagioclase, biotite and amphibole (Fig. 4b).

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Alkali-feldspar comprises about 35- 40 vol.% of the analyzed rocks. It occurs both as centimeter-sized porphyrocrysts, with an evident microcline twinning and a constant perthitic texture, and as smaller anhedral grains in the matrix.

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Quartz comprises ca. 25 vol.% of the rocks as anhedral grains, often in polycrystalline aggregates with undulose extinction.

Plagioclase is present both as anhedral grains of sub-millimeter dimensions, and as phenocrysts of tabular shapes with an antiperthitic texture. The percentage is lower than 20 – 25 vol.% and the crystals are often zoned and altered due to saussuritization and/or sericitization processes.

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Biotite (~10 vol.%) is associated with minor relative amounts of amphibole (~5 vol.%). It occurs as flakes or anhedral millimeter-sized grains with strong pleochroism from deep brown to yellowish green.

Amphibole (common hornblende) is generally subhedral, prismatic with an irregular rim. Pleochroic from yellow-green to dark green, amphibole grains show frequent inclusions of the main accessory minerals.

As regards accessory minerals , it was possible to underline a significant prevalence of titanite, mainly in contact or included in mafic minerals. Apatite, showing an evident compositional zoning, is present as euhedral grains with prismatic, hexagonal or acicular shapes. whose dimensions never exceed 100 μm. Ilmenite and magnetite are also abundant, both as single euhedral crystals and as larger aggregates, often included or in contact with mafic minerals. Sporadic crystals of zoned zircon (< 50 μm), allanite and pyrite also occur.

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The sample collected from the sarcophagus lid ofNefertari (suppl. 5153) shows macroscopic evidences comparable to those of the Aswan *red granites*. Also at the microscopic scale the rock shows mineralogical and textural features similar to the Red Aswan granite (Fig. 4c) On the other hand, the Ram-headed Sphinx (cat. 836, Fig. 4d) differs from all the samples collected in Aswan quarry district. First of all, colour index is higher (>15 vol.%) and amphibole is absent. Under polarizing microscope biotite shows an evident isoorientation and it is darker in colour. Alkali-feldspar is almost absent in the matrix, being concentrated only in the centimentric phenocrysts. Moreover, opaque minerals (Fe-Ti oxides) are less abundant.

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Black Granites

The rock samples collected in the southern part of the quarry districts of Aswan, at Gebel Ibrahim Pasha, are represented by two different varieties of grey coloured granitoids: granodiorite and tonalite. They are both characterized by an high colour index (20-30 vol% in granodiorite and 35-40 vol.% in tonalite). In detail, the tonalite varieties show an homogeneous dark colour and a medium grain size, with an homeoblastic and massive fabric (Fig. 5a).

.On the other side, granodiorites show a porphyritic texture, with isooriented aggregates of polycrystalline sialic minerals comprising ca. 25 vol.% of the whole rock (Fig. 5c).

For both rock varieties, the fundamental constituents include quartz, feldspar (both alkali-feldspar and plagioclase), biotite and amphibole. On a microscopic length scale, the tonalite samples are marked by an hypidiomorphic medium-grained matrix with rare idiomorphic phenocrysts of plagioclase (Fig. 5b). Granodiorite samples are marked by a coarser grain size with an hypidiomorphic texture and a regular dispersion of mafic minerals in the sialic matrix (Fig. 5d).

Plagioclase is present both as anhedral grains in the matrix and as tabular phenocrysts. The relative amount is about 25-30 vol.% in granodiorites and 30-35 vol.% in tonalites. It constantly shows sericitic alteration and a weak compositional zoning. The presence of myrmekitic and antiperthitic textures is also common.

Alkali-feldspar occurs as microcline, is idiomorphic and commonly microperthitic. The relative amount is about 15-20 vol.% in granodiorites, while it is much more subordinate in tonalite samples (< 5 vol.%).

Quartz volumetric percentage ranges from about 25 vol.% in granodiorites to ca. 30 vol.% in tonalites. It occurs as anhedral grains with undulose extinction, often intergranular with other grains of feldspar.

As regards mafic minerals, it was noticed a significant decrease of biotite relative amount from granodiorite to tonalite samples. Biotite occurs as subhedral grains in prismatic section and as anhedral grains in basal section. Strongly pleochroic from deep brown to yellow-brown, it often shows resorption shapes in contact with amphibole grains.

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Amphibole (common hornblende) is generally anhedral to subhedral, often poikilitic. Pleochroic from yellow-green to dark green, amphibole shows frequent inclusions of the main accessory minerals.

Both biotite and amphibole include accessory minerals like apatite, titanite, Fe-Ti oxides and zircon. The relative abundance of phosphates can be considered a distinguishing feature of Aswan granitoids. In particular, it was observed a significant and gradual increase of apatite relative amount from granodiorites to tonalites, in agreement with petrographic observation of Klemm and Klemm (2001) and geochemical data reported by Finger et al. (2008).

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Microscopic veinlets of granite sometimes crosscut the main assemblage. Their pinkish colour is is determined by reddish K-feldspar crystals along the vein borders..

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Moreover, the presence of sialic mineral aggregates is a typical and widespread occurrence only in granodiorites. These aggregates resulted to be constituted by poikilitic plagioclase, quartz and microcline in the pinkish rim (Fig. 5e). Microcline, mainly concentrated in the outer rim, shows a weak isoorientation in the direction of the aggregate elongation and is characterized by cross-hatched twinning and by microperthitic intergrowth with albite. From the border toward the core of the aggregates, the Kfs content decreases, while plagioclase and quartz increase.

The three statues of the goddess Sekhmet resulted to be constituted by granodiorite rocks. Strong minero-petrographic analogies between two of them (cat. 260, cat. 247) and the granodiorite samples from Aswan, seemed to support the archaeological hypothesis of a common provenance of the sculptures. Nevertheless, the seated Sekhmet, identified as cat. 251, significantly differs from the other granodiorite samples. Indeed, the relative amount of biotite is higher (~ 20 vol.%) and the crystals are always characterized by evident resorption shapes, with inclusions of quartz and plagioclase (Fig. 5f). Antiperthitic plagioclase is more pervasive and the alkali-feldspar inclusions are generally isooriented. Besides, as regards accessory minerals, the amount of titanite and Fe-Ti oxides is higher than that of apatite. The presence of small baryte crystals is finally characteristic of this rock sample.

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Minero-petrographic observations on the statue of goddess Hathor (cat. 694) and of Ramses II (cat. 1380) permitted to define the rocks as tonalites. In detail, Ramses II stone consists of a dark grey coloured and medium-fine grained igneous rock (Fig. 5g). It has an holocrystalline texture and is composed by plagioclase (ca. 35 wt.%), quartz (ca. 20 wt.%) and a high (ca. 40 wt.%) content of femic minerals (hornblende and biotite). The main accessory minerals (Fig. 5h) are apatite, ilmenite and magnetite. Zircon, monazite, allanite, baryte and pyrite also occur as small and minor accessory phases. Microscopic features confirm the intrusive nature of this rock.

Plagioclase is mainly euhedral and poikilitic containing most accessory minerals. Quartz is less abundant than plagioclase and occurs as anhedral grains with sutured or interlocking boundaries. Green amphibole, most likely hornblende, has an higher modal abundance than biotite. Strongly pleochroic from dark green to yellow, amphibole generally occurs in subhedral prismatic crystals. Biotite shows strong pleochroism from yellow-brown to dark brown, locally with irregular resorption shapes. More detail are reported in Borghi et al. (2009b).

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Though the statue of Ramses II shows finer grain size and a more homogeneous texture in respect with the statue of goddess Hathor, the mineral assemblage is compatible with a common origin from the collected tonalite samples.

MINERAL CHEMISTRY

Electron microprobe analyses allowed to define the chemical composition of silicate mineral phases occuring in the rock sculpture fragments and to compare them with rock forming minerals belonging to samples collected in Aswan quarry district. Tables 2,3 and 4 display some representative analyses of amphibole, biotite and plagioclase respectively.

In Figs. 6 and 7 the microchemical analyses of amphibole and biotite (a representative set of data are reported in table 2 and 3) from the sculpture fragments are plotted in the corresponding classification diagram (from Leake, 1978 for the amphibole composition and from Foster, 1960 for the biotite composition). In order to point out analogies and differences between Aswan granitoids and the stony artefacts, the whole set of analyses performed on the Aswan quarry samples (several tens for each mineral specimen) was used to draw the granite, granodiorite and tonalite grey fields in the respective classification diagram.

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Red Granites

The chemical composition of the main mineral phases (amphibole, biotite and plagioclase) in the Aswan rock samples is relatively uniform.

The amphibole composition ranges from ferro-edenitic hornblende to magnesian hastingsitic hornblende and hastingsitic hornblende (grey field in Fig. 6a). In detail, amphibole is characterized by an high (Na + K) value in the site A, always ≥ 0.50 a.p.f.u (average value 0.55), a Ti contens lower than 0.20 and a Si value ranging between 6.27 and 6.70. Furthermore, the Na content in the B site is low (range 0.16 – 0.20), while the X_{Mg} [$Mg/(Mg+Fe^{2+})$] ratio never exceeds 0.30, being quite lower than that of granodiorite and tonalite rocks.

In accordance with the macroscopic evidences, tri-octahedral micas can be classified (Foster, 1960) as Fe-biotites (grey field in Fig. 7a). The X_{Mg} ratio is meanly 0.30, while the Si contents range between 5.51 and 5.78 a.p.f.u. The (FeO + MnO) value ranges between 26 and 32 wt.%, while MgO content from 5-8 wt.%.

Plagioclase shows compositional zoning (Fig. 8) from almost pure albite to oligoclase (An content up to 27%). Alkali-feldspar maximum Ab content is about 9% (Table 4a).

Phosphates are represented by fluorapatites. The evident compositional zoning often observed through BSE images is linked to a net increase of REE relative amount in the brighter zones. Zircon grains are always zoned, with a general increase of HfO_2/ZrO_2 ratio in the core.

EDS minero-chemical data of amphibole (Fig. 6a) and biotite (Fig. 7a) of the sarcophagus lid of Nefertari (suppl. 5153) perfectly fits with the Aswan *Red granite* corresponding fields. The Ram-headed Sphinx (cat. 836) is instead clearly distinguishable from the other granitic samples. In particular, biotite shows a net increase in MgO content (average value 9.3 wt.%), associated to a significant decrease of FeO+MnO (ranging between 21 and 26 wt.%) (Fig. 7a). Moreover, plagioclase zoning is less evident and the relative content of anorthite ranges from 17 to 30% (Fig. 8).

Black Granites

The chemical composition of the mafic minerals (amphibole and biotite) belonging to the granodiorite and tonalite samples of the Aswan quarry sites, plot in clearly separate fields (Figs. 6b, c and 7b), confirming their different plutonic variety.

As regards Ca-amphiboles, a significant chemical variation has been evidenced. Differences are mainly linked to the occupancy of A site, the X_{Mg} value and the relative substitution of Si with Al^{IV}. The occupancy of A site generally decreases from granodiorites ($(Na+K)_A$ mean value 0.53 a.p.f.u.) to tonalites ($(Na+K)_A$ mean value 0.49 a.p.f.u.). The X_{Mg} values resulted higher for tonalite amphibole (ranging between 0.38 to 0.61 a.p.f.u.) with respect to the granodiorite amphibole (from 0.29 to 0.48 a.p.f.u.) (Table 2a and Figs. 6b and 6c). Therefore, amphibole compositions of *black granites* spread over several classification fields.

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In particular, tonalite amphiboles with $(Na + K)_A$ content < 0.50 range in composition from Mg-hornblende to Fe-hornblede (Fig. 6b), while amphiboles with $(Na + K)_A$ content > 0.50, vary from Fe-edenitic hornblende to Mg-hastingsitic hornblende (Fig. 6c). On the other hand, granodiorite amphiboles plot in the fields of Fe-hornblende and Fe- tschermakitic hornblende if $(Na + K)_A$ < 0.50, or from Fe-edenitic hornblende to Mg-hastingsitic hornblende when $(Na + K)_A$ > 0.50. The latter, however, show a lower X_{Mg} value with respect to tonalite amphiboles.

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Also biotite composition turned out to be an useful parameter to distinguish Aswan granitoids. In fact, the whole set of biotite analyses performed both on tonalite samples (light grey field) and on granodiorite samples (dark grey field) plot in a close but not overlapping field as shown in Fig. 7b. More in detail, the X_{Mg} ratio shows a weak increase from granodiorites to tonalites, while FeO content gradually decreases. Thus, (FeO+MnO) values range from 23 to 28 wt.% in granodiorite and between 19 and 25 wt.% in tonalites. MgO content varies between 6.0 and 9.5 wt.% in granodiorites, between 7.5 and 11.5 wt.% in tonalites.

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As regards sialic minerals, compositional zoning of plagioclase is less evident in tonalite varieties than in granodiorites (Fig 8). Indeed, in granodiorite samples plagioclase composition ranges from almost pure albite in the rim to An ~ 33% in the core, while in tonalites An content ranges from about 14% to 29%. Alkali-feldspar is almost pure orthoclase both in granodiorites and in tonalites.

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As observed in *red granites,* phosphates are represented by F-rich and similarly zoned apatites.

Minero-chemical analyses on *black granite* sculptures confirm the petrographic evidences suggesting significant affinities between the ancient materials and Aswan *black granites*. As regards the statues of goddess Sekhmet (cat. 260, cat. 247 and cat. 251), it was possible to clearly distinguish two compositional groups. Indeed, amphibole composition in cat. 260 and cat. 247 samples correspond to that of Aswan granodiorite samples, whereas cat. 251 sample shows higher Si and X_{Mg} content, plotting in the Aswan tonalite field. Statue of goddess Sekhmet cat. 251 can be distinguished also by the composition of biotites. In fact, biotite analysis overlap Aswan tonalite field, as well. As can be seen in Fig. 7b, cat. 251 biotites show (FeO+MnO) values sensibly lower (average 23 wt.%) than that of other two goddess Sekhmet samples, while MgO content is constantly higher (average 10 wt.%). Plagioclase shows limited compositional zoning both in cat. 260 and 247 with an An content corresponding to the oligoclase field, while in cat. 251 plagioclase is more zoned varying from oligoclase (in the core) to andesine in the rim.

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In accordance with petrographic evidences, both amphiboles and biotites in the statue of goddess Hathor (cat. 694) and of Ramses II (cat. 1380) plot in the Aswan tonalite fields (Fig. 6b, 6c and 7). In particular, most amphiboles of both goddess Hathor and Ramses resulted mainly ferro-hornblende, with few exceptions as Fe-edenitic hornblende. Finally, also plagioclase compositions range in the field drawn for Aswan tonalite samples (Fig. 8) and not in granodiorites field.

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CONCLUSIONS

This paper represent the first attempt to classify some of the best known stone masterpieces preserved in the Egyptian Antiquity Museum of Turin (Italy) according to minero-petrographic criteria. Firstly, this project allowed a proper classification of the materials employed by Ancient Egyptians to carve the sculptures. Furthermore, the research provided reliable hypotheses about the provenance site of the original stones. In particular, this study was inspired by previous papers (e.g. Harrell and Brown, 1994; Harrell et al., 2002) that have provided information about the origin of the used raw materials basing on a comparison between quarry samples and ancient stone artefacts.

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With regard to the petrographic classification, it was established that all the seven analyzed statues of the Egyptian Antiquity Museum of Turin resulted to be constituted by granitoid rocks. In particular, the sarcophagus lid of Nefertari (suppl. 5153) and the Ram-headed Sphinx (cat. 836) have been carved with a coarse-grained pink granite. The source rock is pinkish to occasionally reddish, coarse-grained, occasionally gneissic and porphyritic. The statues of goddess Sekhmet (cat.

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260, cat. 247, cat. 251) are made of a medium-grained dark grey granodiorite, porphyritic and with pinkish aggregates of sialic minerals occupying almost 20 vol.% of the whole rock. The statue of Ramses II (cat. 1380) and the statue of goddess Hathor (cat. 694) are made of a medium-grain size and homeoblastic melanocratic tonalite.

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Compositional analyses on the main phases allowed evidencing a good correlation between the studied statues and the rock samples collected in the quarry district of Aswan. The strong micro-chemical similarities observed in this raw material provenance study are even more noteworthy as the magmatic suite outcropping in correspondence of Aswan town is considered (Finger et al., 2008) to be unique within the Late Neoproterozoic granitoid terrain of the Arabian-Nubian Shield on the base of its geochemical pattern.

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The minero-chemical dissimilarities between one of the statues of god Sekhmet (cat. 251) and the other two, seem to suggest that the Sekhmet sculptures located in front of the Temple of Mut at Karnak were not all carved with the same material and maybe not at the same time.

The Ram-headed Sphinx (cat. 836) resulted to be different from Aswan *red granites*, confirming the archaeological hypothesis that the sculpture was moved to Karnak from the original location in the Soleb Temple. In fact, in the northern part of ancient Nubia, large outcrops of granite have been carved and intensively exploited in antiquity for sculptural and architectonic purposes. Indeed, the Ram-headed Sphinx sample shows petrographic data, as the coarse grained size, the gneissic structure and the absence of amphibole, that can be related to the so called High-Dam Granite described by Finger et al. (2008).

In conclusion, the petrographic and minero-chemical study showed strong analogies between most of the materials used for carving the statues and the Aswan quarry samples, supporting the archaeological and geological hypothesis of a common origin for most plutonites used for sculpture and architecture in New Kingdom.

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The data we've obtained so far set the base for stimulating continued research in the direction of defining petrochemical and mineralogical parameters which can allow the identification of the ancient quarry sites exploited to produce Egyptian sculptures.

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The chance to obtain a precise provenance determination of the raw materials represents a prerequisite not only for the development of historical knowledge but also for the choice of materials in restoration works.

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ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1 – Photographic presentation of the studied masterpieces belonging to the Egyptian Antiquity Museum of Turin. (a) Sarcophagus lid of Nefertari (suppl. 5153); (b) Ramses II in Majesty (cat. 1380); (c) Ram-headed Sphinx (cat. 836); (d), (e) and (f) Statue of goddess Sekhmet (respectively cat. 260, cat. 247, cat. 251); (g) Statue of goddess Hathor (cat. 694).

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Fig. 2 – (a) Geological sketch of Egypt; (b) Geological map of Aswan quarry district (modified after Finger et al. 2008); (c) Active granitoid quarry south of Aswan.

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Fig. 3 – Satellite image maps (modified from Google Earth) with sampling locations (a: red granite; b: tonalite and granodiorite) in Aswan quarry district.

Fig. 4 – ***Red granites*****:** (a) General overview of a Aswan quarry sample of granite. (b) Crossed polarized light image of Aswan *red granite*. (c) Plane polarized light image of the sample of the sarcophagus lid of Nefertari (suppl. 5153) with the main mineralogic assemblage: alkali-feldspar (Kfs), quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl). (d) Backscatter electron image of the main phases in the sample taken from the Ram-headed Sphinx: plagioclase (Pl), quartz (Qtz) and biotite (Bt).

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Fig. 5 – ***Black granites***: (a) General overview and (b) crossed polarized light image of Aswan tonalite. (c) General overview and (d) crossed polarized light image of Aswan granodiorite with the main mineralogic assemblage: alkali-feldspar (Kfs), quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl). (e) Crossed polarized light image of a sialic mineral aggregate in Aswan granodiorite. (f) Backscatter electron image of the sample taken from the Statue of goddess Sekhmet (cat. 251). Antiperthitic plagioclase (Pl) and biotite (Bt) resorption shapes with inclusion of quartz (Qtz) are common features of this rock. (g) General overview (plane polarized light) of Ramses II (cat. 1380) rock fragment with the main mineralogic assemblage: quartz (Qtz), plagioclase (Pl), biotite (Bt) and hornblende (Hbl). (h) Backscatter

electron image of the accessory minerals included and in contact with biotite grains (Bt) in the sample taken from the Statue of Ramses II: ilmenite (Ilm), apatite (Ap) and allanite (Aln).

Fig. 6 – Amphibole classification diagram for calcic amphiboles according to Leake (1978).

(a) Amphibole chemical distribution in *red granite sculpture* fragments (symbols in figure). Grey field corresponds to chemical composition of amphiboles from *red granite* samples collected in the Aswan quarry district; (b) and (c) Amphibole chemical distribution in *black granite sculpture* fragments (symbols in figure). Grey fields correspond to tonalite (light grey) and granodiorite (dark grey) amphiboles of the samples collected in Aswan quarry district.

Fig. 7 – Variation in chemical composition of biotite expressed as (FeO+MnO) versus MgO (wt.%).

(a) Red granitic sculpture fragments: Grey field corresponds to chemical composition of biotites from *red granite* samples collected in Aswan quarry district; (b) Black granite sculpture fragments. Grey fields correspond to tonalite (light grey) and granodiorite (dark grey) biotites of the samples collected in Aswan quarry district.

Fig. 8 – Range of anorthite-albite relative ratio for both sculpture fragments and plutonic rock samples collected in the Aswan quarry district.

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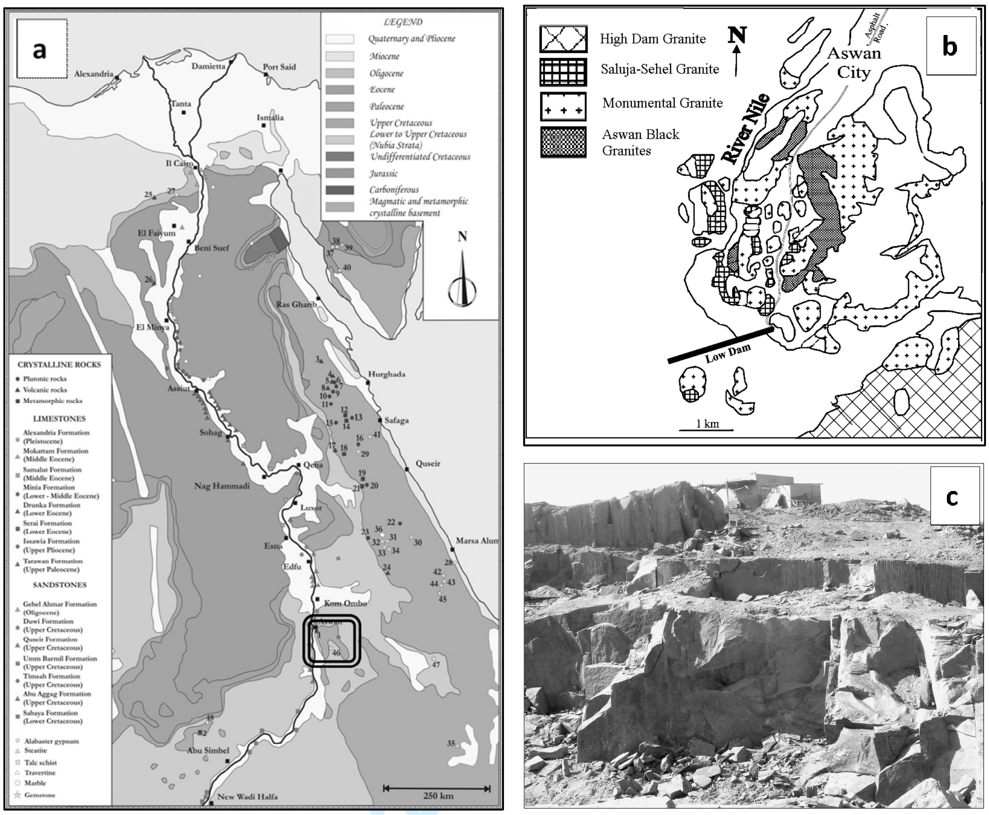
Figure 1

Figure 2



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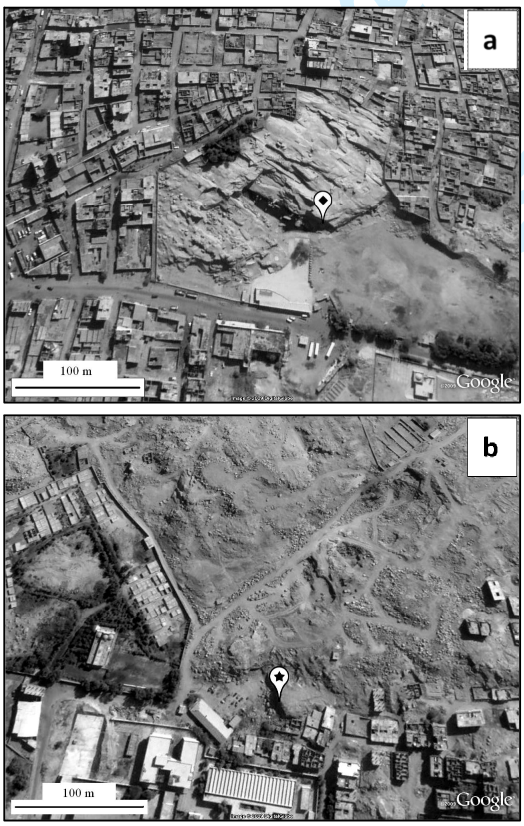

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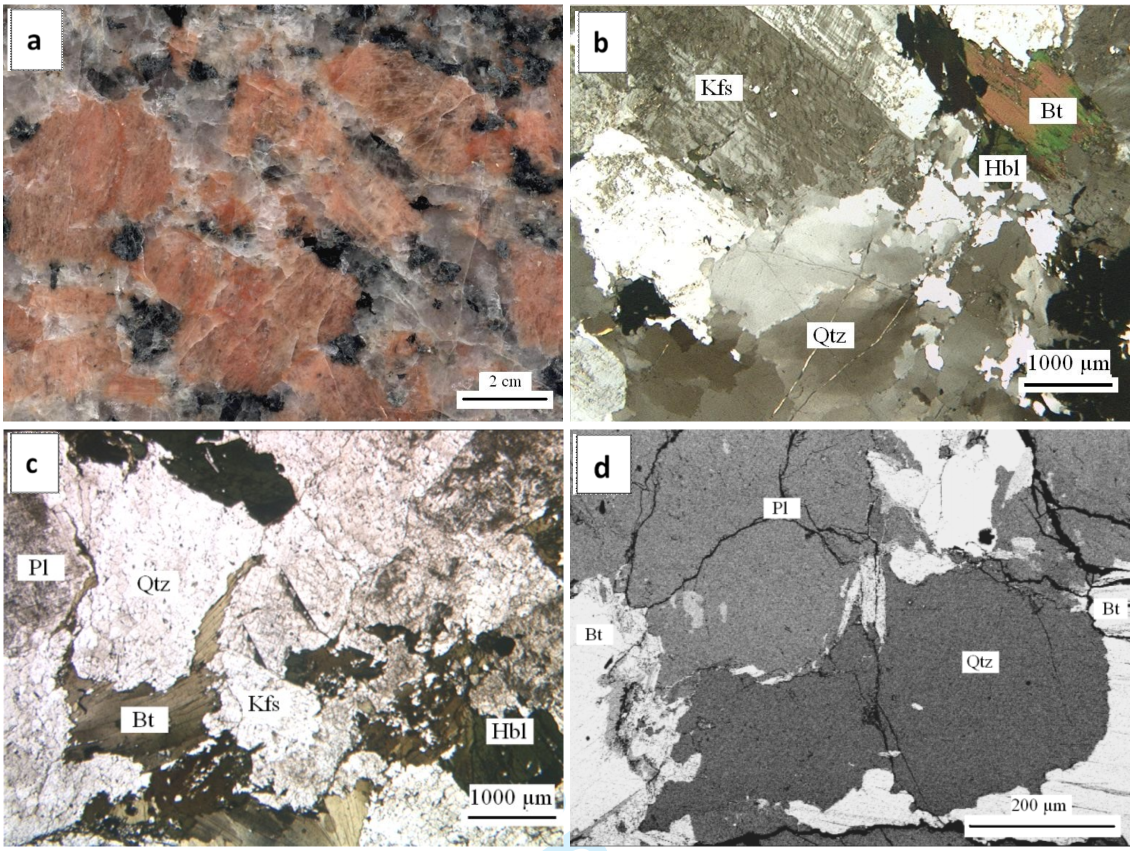
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Figure 5

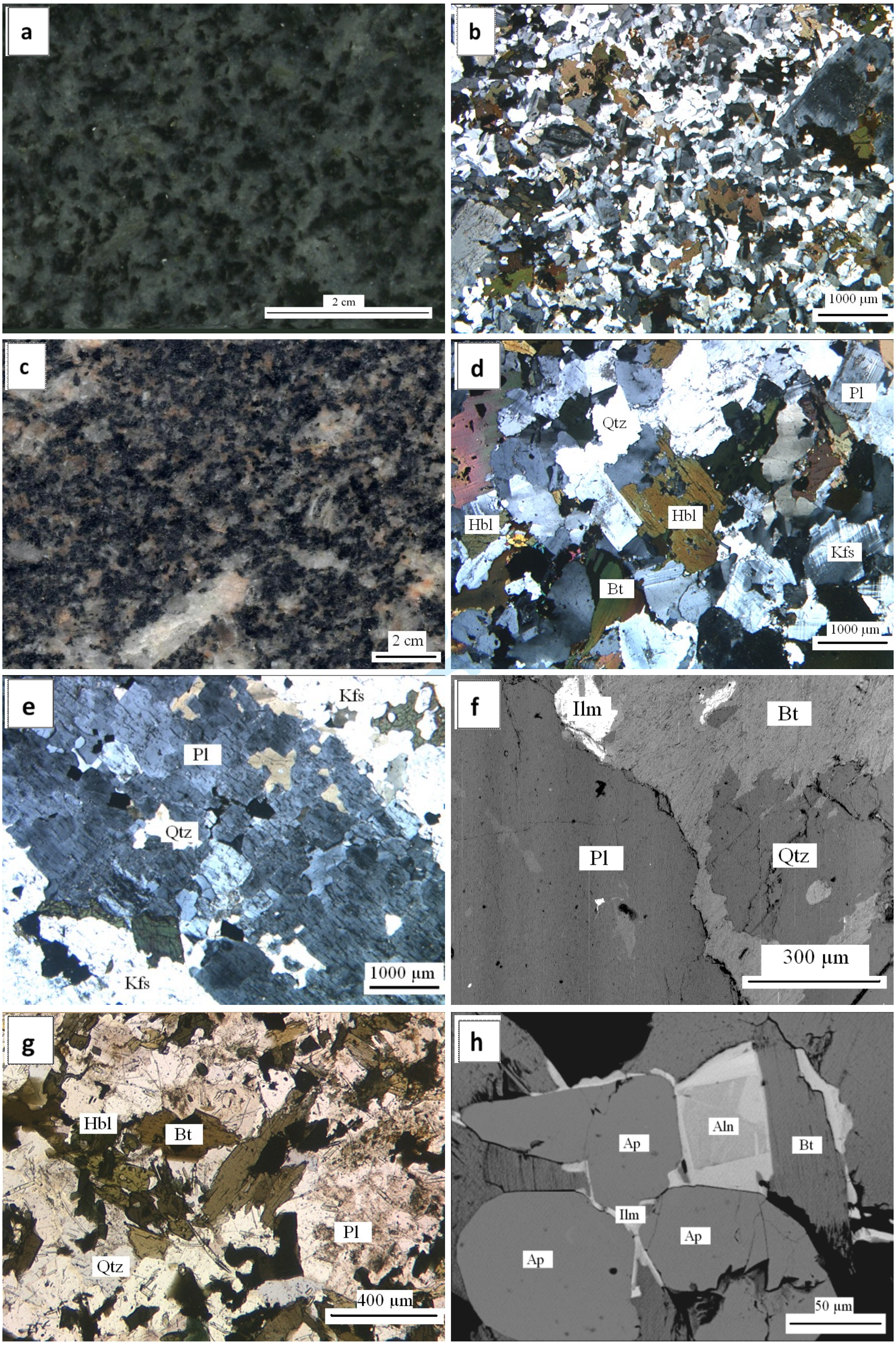
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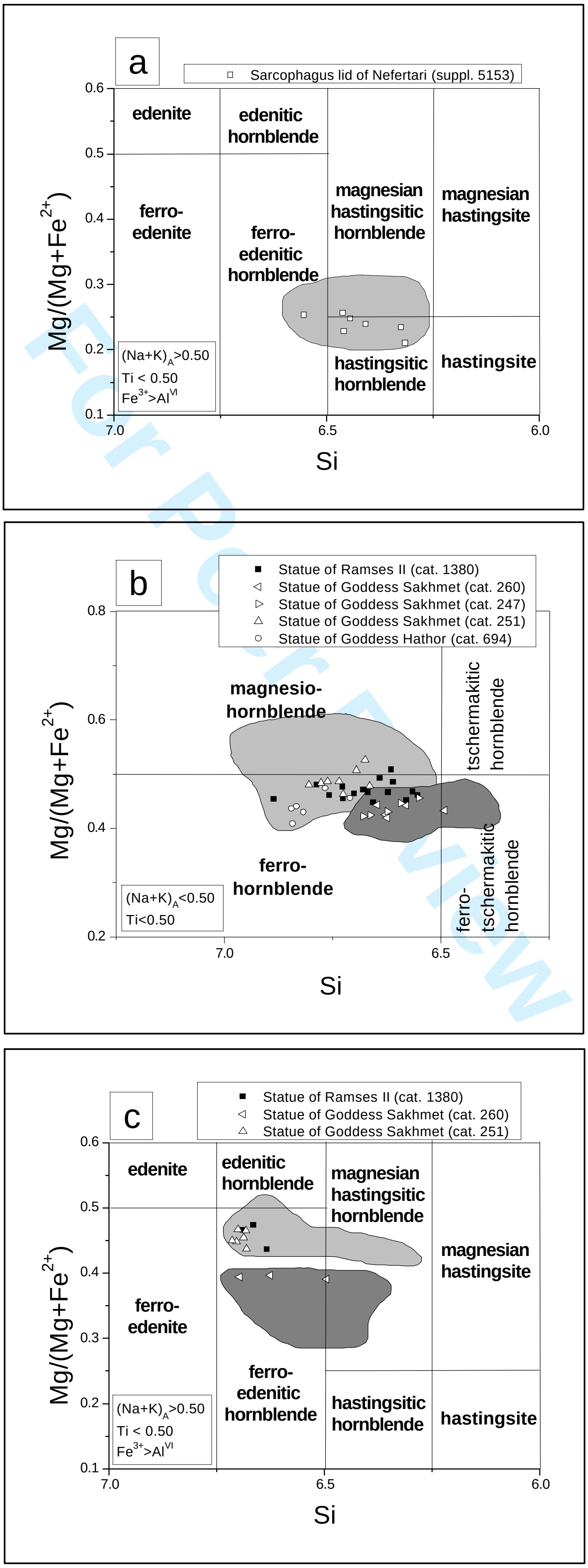
Figure 6


a
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edenite
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magnesian hastingsitic hornblende
magnesian hastingsite
hastingsitic hornblende
hastingsite
(Na+K)A>0.50
Ti < 0.50
Fe3+>AlVI
Mg/(Mg+Fe2+)
Si
b
Statue of Ramses II (cat. 1380)
Statue of Goddess Sakhmet (cat. 260)
Statue of Goddess Sakhmet (cat. 247)
Statue of Goddess Sakhmet (cat. 251)
Statue of Goddess Hathor (cat. 694)
magnesio-hornblende
ferro-hornblende
tschermakitic hornblende
ferro-tschermakitic hornblende
(Na+K)A<0.50
Ti<0.50
Mg/(Mg+Fe2+)
Si
c
Statue of Ramses II (cat. 1380)
Statue of Goddess Sakhmet (cat. 260)
Statue of Goddess Sakhmet (cat. 251)
edenite
edenitic hornblende
magnesian hastingsitic hornblende
magnesian hastingsite
ferro-edenite
ferro-edenitic hornblende
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(Na+K)A>0.50
Ti < 0.50
Fe3+>AlVI
Mg/(Mg+Fe2+)
Si

Figure 7

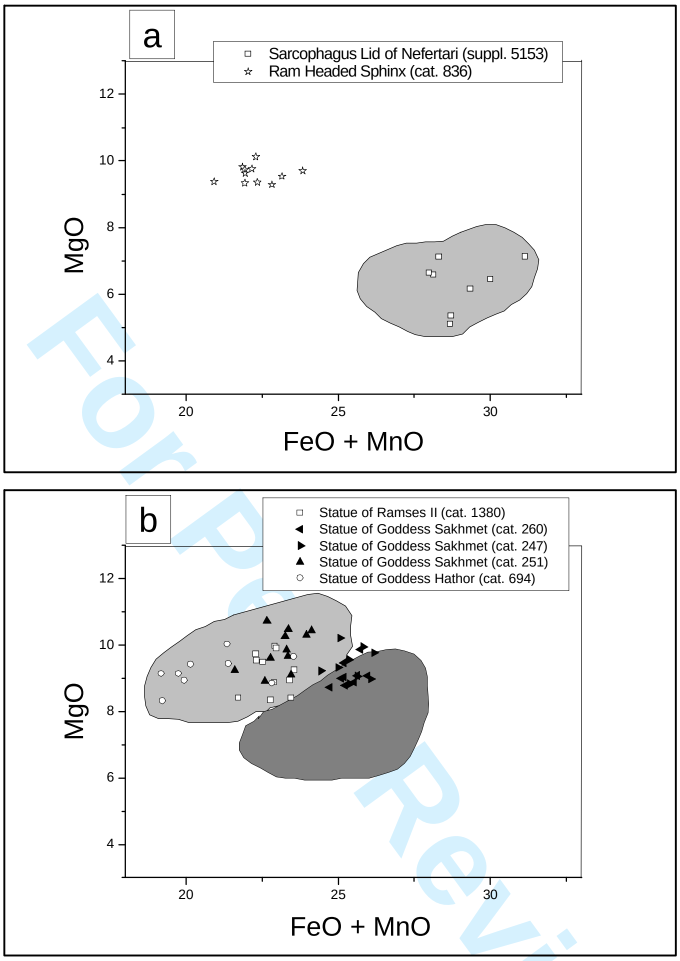
a
Sarcophagus Lid of Nefertari (suppl. 5153)
Ram Headed Sphinx (cat. 836)
MgO
FeO + MnO
b
Statue of Ramses II (cat. 1380)
Statue of Goddess Sakhmet (cat. 260)
Statue of Goddess Sakhmet (cat. 247)
Statue of Goddess Sakhmet (cat. 251)
Statue of Goddess Hathor (cat. 694)
MgO
FeO + MnO

Figure 8

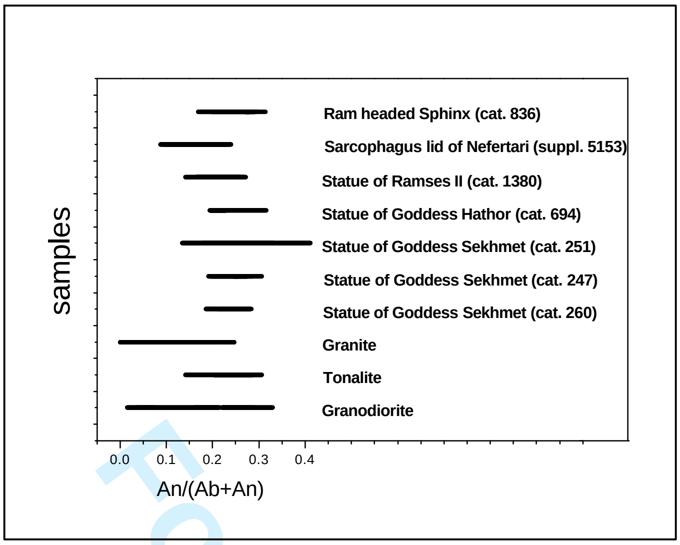
Ram headed Sphinx (cat. 836)
Sarcophagus lid of Nefertari (suppl. 5153)
Statue of Ramses II (cat. 1380)
Statue of Goddess Hathor (cat. 694)
Statue of Goddess Sekhmet (cat. 251)
Statue of Goddess Sekhmet (cat. 247)
Statue of Goddess Sekhmet (cat. 260)
Granite
Tonalite
Granodiorite
samples
0.0
0.1
0.2
0.3
0.4
An/(Ab+An)

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

SCULPTURE		PERIOD	PROVENANCE	COLOUR INDEX (CI) AND CLASSIFICATION
Sarcophagus lid of Nefertari	suppl. 5153	New Kingdom, XIX dyn. Reign of Ramses II, 1279 – 1213 BC	Thebes, Valley of the Queens, tomb no. 66 Ernesto Schiapparelli collection (1903 - 1906)	CI ≈ 10-15% (hbl+bt) granite
Ram-headed Sphinx	cat. 836	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Thebes, Temple of *Goddess Mut* Drovetti collection (1824)	CI ≈ 15% (bt) granite
Statue of Goddess Sekhmet	cat. 260	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Thebes, Funerary Temple of *Amenhotep III* Drovetti collection (1824)	CI ≈ 25% (hbl+bt) granodiorite
Statue of Goddess Sekhmet	cat. 247	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Thebes, Temple of *Goddess Mut* Drovetti collection (1824)	CI ≈ 20% (hbl+bt) granodiorite
Statue of Goddess Sekhmet	cat. 251	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Thebes, Temple of *Goddess Mut* Drovetti collection (1824)	CI ≈ 20% (hbl+bt) granodiorite
Statue of Goddess Hathor	cat. 694	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Coptos Donati collection (1759)	CI ≈ 30-35% (hbl+bt) tonalite
Statue of Ramses II	cat. 1380	New Kingdom, XVIII dyn. Reign of *Amenhotep III*, 1390-1352 BC	Thebes, Temple of *Goddess Mut* Drovetti collection (1824)	CI ≈ 20% (hbl+bt) tonalite

Table 2a - Representative electron microprobe analyses of amphibole in Aswan quarry sample.

	Aswan Granite				Aswan Granodiorite				Aswan Tonalite			
An.	Gr1	Gr2	Gr3	Gr4	Grd1	Grd2	Grd3	Grd4	Tn1	Tn2	Tn3	Tn4
SiO_2	41.9	41.39	41.92	41.45	41.98	43.22	42.75	42.13	43.84	43.73	43.41	43.66
TiO_2	1.58	1.04	1.55	1.58	1.62	1.49	1.06	1.08	1.26	1.74	1.03	0.64
Al_2O_3	8.62	8.71	9.07	8.91	9.08	8.53	8.97	9.3	8.96	8.95	9.41	9.98
FeO	27.32	27.68	26.89	27.35	24.55	23.57	25.24	25.57	21.29	20.61	21.66	20.19
MnO	0.5	0.37	0.54	0.57	0.55	0.51	0.24	0.44	0.56	0.39	0.4	0.62
MgO	4.85	4.87	4.8	4.74	6.54	6.95	5.73	5.41	8.41	8.67	8.22	9.16
CaO	10.78	10.93	11.01	10.98	11.35	11.2	11.38	11.51	11.52	11.7	11.65	11.88
NaO	1.67	1.69	1.51	1.39	1.51	1.62	1.5	1.44	1.24	1.31	1.18	1.24
K_2O	1.27	1.54	1.21	1.35	1.3	1.24	1.37	1.39	1.25	1.33	1.34	0.89
Total	98.48	98.23	98.51	98.32	98.48	98.35	98.23	98.27	98.31	98.44	98.29	98.26
Atomic proportions calculated on the basis of 23 O												
Si	6.505	6.469	6.497	6.45	6.447	6.618	6.619	6.541	6.615	6.603	6.564	6.526
Al^{IV}	1.495	1.531	1.503	1.55	1.553	1.382	1.381	1.459	1.385	1.397	1.436	1.474
Al^{VI}	0.082	0.074	0.153	0.083	0.09	0.156	0.255	0.242	0.208	0.196	0.24	0.285
Ti	0.184	0.122	0.181	0.184	0.188	0.172	0.124	0.126	0.143	0.198	0.117	0.072
Fe^{3+}	0.703	0.733	0.637	0.749	0.647	0.483	0.383	0.426	0.562	0.378	0.583	0.711
Mn	0.065	0.05	0.071	0.075	0.072	0.066	0.031	0.058	0.072	0.05	0.052	0.078
Mg	1.122	1.136	1.108	1.098	1.497	1.587	1.322	1.253	1.89	1.952	1.852	2.041
Fe^{2+}	2.844	2.885	2.849	2.81	2.506	2.535	2.885	2.894	2.125	2.225	2.155	1.813
Ca	1.794	1.83	1.829	1.831	1.868	1.837	1.887	1.914	1.863	1.894	1.887	1.903
Na	0.206	0.17	0.171	0.169	0.132	0.163	0.113	0.086	0.137	0.106	0.113	0.097
Na	0.296	0.342	0.283	0.251	0.317	0.319	0.339	0.349	0.225	0.277	0.233	0.261
K	0.252	0.308	0.239	0.268	0.255	0.242	0.27	0.274	0.24	0.256	0.258	0.171
Xmg	0.283	0.282	0.28	0.281	0.374	0.385	0.314	0.302	0.471	0.467	0.462	0.53
Fe_2O_3	6.06	5.65	5.42	6.25	5.69	4.26	3.35	3.71	5.03	3.38	5.22	6.43
FeO	22.06	20.02	21.82	21.11	19.81	20.13	22.68	22.68	17.13	17.9	17.34	14.76

Xmg = Mg(Mg+Fe2+)

Table 2b - Representative electron microprobe analyses of amphibole in stone sculpture fragments.

	statue of Goddess Sakhmet (cat. 260)		statue of Goddess Sakhmet (cat. 247)		statue of Goddess Sakhmet (cat. 251)		statue of Goddess Hathor (cat. 694)		statue of Ramses II (cat. 1380)		sarcophagus lid of Nefertari (suppl. 5153)	
An.	cat. 260/1	cat. 260/2	cat. 247/1	cat. 247/2	cat. 251/1	cat. 251/2	cat. 694/1	cat. 694/2	cat. 1380/1	cat. 1380/2	suppl. 5153/1	suppl. 5153/2
SiO_2	43.57	43.53	43.94	43.94	44.16	44.23	45.59	45.72	44.65	44.1	41.42	40.9
TiO_2	1.56	1.92	1.7	2.01	1.83	1.88	1.78	1.92	1.7	1.77	1.71	1.57
Al_2O_3	8.78	8.82	8.53	8.47	8.05	8.32	9.46	9.24	8.5	7.97	8.84	9.6
FeO	22.1	22.09	22.12	21.96	21.66	20.23	19.3	19.33	20.81	21.52	27.73	27.55
MnO	0.6	0.38	0.64	0.27	0.48	0.44	0.29	0.51	0.51	0.49	0.6	0.59
MgO	7.63	7.56	7.66	7.71	8.24	8.76	8.3	7.93	8.73	8.78	4.36	4.05
CaO	11.35	11.28	11.24	11	10.85	11.23	10.84	10.31	11.07	11.27	11	10.79
Na_2O	1.52	1.26	1.45	1.47	1.73	1.63	1.7	2.04	1.41	1.61	1.39	1.66
K_2O	1	1.29	1.18	1.29	1.23	1.29	1.22	1.36	1.02	0.91	1.38	1.56
Total	98.11	98.12	98.46	98.12	98.22	98.02	98.49	98.34	98.41	98.42	98.42	98.27
Atomic proportions calculated on the basis of 23 O												
Si	6.628	6.624	6.663	6.679	6.688	6.701	6.825	6.875	6.687	6.641	6.462	6.408
Al^{IV}	1.372	1.376	1.337	1.321	1.312	1.299	1.175	1.125	1.313	1.359	1.538	1.592
Al^{VI}	0.202	0.206	0.187	0.196	0.126	0.187	0.493	0.511	0.188	0.055	0.087	0.181
Ti	0.178	0.22	0.194	0.23	0.208	0.214	0.201	0.217	0.192	0.201	0.201	0.185
Fe^{3+}	0.47	0.434	0.455	0.4	0.502	0.309	0.074	0.006	0.585	0.621	0.676	0.6
Mn	0.077	0.049	0.082	0.035	0.062	0.057	0.036	0.065	0.065	0.063	0.079	0.078
Mg	1.731	1.714	1.732	1.748	1.861	1.979	1.853	1.777	1.949	1.971	1.014	0.946
Fe^{2+}	2.341	2.377	2.351	2.391	2.242	2.254	2.343	2.424	2.022	2.089	2.942	3.009
Ca	1.85	1.838	1.827	1.791	1.761	1.823	1.739	1.66	1.776	1.818	1.839	1.811
Na	0.15	0.162	0.173	0.209	0.239	0.177	0.261	0.34	0.224	0.182	0.161	0.189
Na	0.298	0.209	0.252	0.225	0.269	0.301	0.234	0.254	0.185	0.289	0.259	0.316
K	0.194	0.25	0.229	0.249	0.237	0.25	0.233	0.26	0.196	0.174	0.274	0.312
Xmg	0.425	0.419	0.424	0.422	0.454	0.467	0.442	0.423	0.491	0.485	0.256	0.239
Fe_2O_3	4.19	3.86	4.05	3.56	4.48	2.76	0.66	0.05	5.27	5.57	5.85	5.18
FeO	18.76	19.04	18.83	19.17	18.02	18.15	19	19.6	16.4	16.86	22.92	23.37

Xmg = Mg(Mg+Fe2+)

Table 3a - Representative electron microprobe analyses of biotite in Aswan quarry samples.

	Aswan Granite					Aswan Granodiorite					Aswan Tonalite			
An.	Gr1	Gr2	Gr3	Gr4		Grd1	Grd2	Grd3	Grd4		Tn1	Tn2	Tn3	Tn4
SiO_2	35.45	36.18	36.58	36.26		36.39	35.96	36.41	36.11		37.09	37.05	36.51	36.9
TiO_2	2.16	2.45	2.5	3.52		3.31	3.66	1.58	3.99		2.65	2.85	4.23	2.39
Al_2O_3	15.13	14.68	14.04	14.19		14.43	14.18	14.93	13.91		14.28	14.26	14.1	14.24
FeO	27.55	27.03	27.23	26.17		24.67	25.16	26.02	25.05		23.13	21.87	22.38	22.62
MnO	bdl	bdl	bdl	bdl		bdl	bdl	bdl	bdl		bdl	bdl	bdl	bdl
MgO	6.4	6.59	6.21	6.57		7.45	7.57	8.01	7.47		10.1	10.39	9.21	10.38
K_2O	9.7	9.45	9.86	9.72		10.08	9.82	9.3	9.71		9.27	9.96	9.92	9.89
Total	96.39	96.39	96.42	96.43		96.34	96.35	96.24	96.28		96.52	96.38	96.35	96.42
Atomic proportions calculated on the basis of 22 O														
Si	5.585	5.666	5.746	5.667		5.661	5.607	5.672	5.631		5.678	5.671	5.613	5.666
Al^{IV}	2.415	2.334	2.254	2.333		2.339	2.393	2.328	2.369		2.322	2.329	2.387	2.334
Al^{VI}	0.393	0.377	0.346	0.281		0.306	0.213	0.413	0.187		0.253	0.244	0.168	0.244
Ti	0.255	0.289	0.295	0.414		0.388	0.429	0.185	0.468		0.305	0.328	0.489	0.276
Fe	3.629	3.541	3.577	3.42		3.209	3.281	3.391	3.266		2.961	2.799	2.878	2.905
Mn	-	-		-			-	-		-	-		-	-
Mg	1.503	1.54	1.453	1.53		1.727	1.76	1.86	1.736		2.304	2.371	2.111	2.376
K	1.949	1.887	1.975	1.938		1.999	1.953	1.848	1.931		1.81	1.944	1.947	1.937
Xmg	0.293	0.303	0.289	0.309		0.35	0.349	0.354	0.347		0.438	0.459	0.423	0.45

bdl = below detection limit

Table 3b – Representative electron microprobe analyses of biotite in stone sculpture fragments.

	statue of Goddess Sakhmet (cat. 260)		statue of Goddess Sakhmet (cat. 247)		statue of Goddess Sakhmet (cat. 251)		statue of Goddess Hathor (cat. 694)		statue of Ramses II (cat. 1380)		sarcophagus lid of Nefertari (suppl. 5153)		Ram-headed Sphinx (cat. 638)	
An.	cat. 260/1	cat. 260/2	cat. 247/1	cat. 247/2	cat. 251/1	cat. 251/2	cat. 694/1	cat. 694/2	cat. 1380/1	cat. 1380/2	suppl. 5153/1	suppl. 5153/2	suppl. 5153/1	suppl. 5153/2
SiO_2	35.92	35.93	36.9	36.1	36.1	36.22	37.91	37.84	36.69	36.3	35.21	34.22	36.6	36.57
TiO_2	2.93	3.3	1.92	2.02	3.51	3.49	2.28	3.15	2.34	3.5	2.12	1.98	4.2	4.58
Al_2O_3	14.33	14.71	15.14	15.31	14.03	14.33	16.45	16.7	14.96	14.35	14.17	14.54	14.95	14.6
FeO	24.66	24.26	24.08	24.42	22.81	22.66	21.02	19.9	22.95	23.23	28.89	29.99	21.39	21.53
MnO	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.37	0.44	bdl	0.3
MgO	8.74	9.12	8.98	9.21	9.65	9.8	9.4	9.2	9.99	9.77	6.2	6.87	9.42	9.01
K_2O	9.7	9.02	9.35	9.27	9.57	9.55	9.27	9.53	9.38	9.09	9.33	8.3	9.89	9.8
Total	96.29	96.34	96.37	96.33	95.67	96.05	96.32	96.33	96.31	96.24	96.28	96.35	96.53	96.39
Atomic proportions calculated on the basis of 22 O														
Si	5.587	5.548	5.679	5.578	5.575	5.572	5.719	5.687	5.629	5.584	5.600	5.451	5.581	5.595
Al^{IV}	2.413	2.452	2.321	2.422	2.425	2.428	2.281	2.313	2.371	2.416	2.400	2.549	2.419	2.405
Al^{VI}	0.215	0.225	0.425	0.367	0.128	0.171	0.643	0.646	0.333	0.185	0.256	0.18	0.269	0.228
Ti	0.342	0.384	0.222	0.235	0.407	0.404	0.258	0.356	0.27	0.405	0.253	0.238	0.482	0.527
Fe	3.209	3.133	3.100	3.155	2.946	2.915	2.652	2.501	2.944	2.989	3.843	3.995	2.728	2.755
Mn	-	-	-	-	-	-	-	-	-	-	0.049	0.06	-	0.039
Mg	2.027	2.100	2.061	2.121	2.222	2.247	2.115	2.061	2.284	2.240	1.470	1.631	2.142	2.056
K	1.926	1.776	1.835	1.827	1.884	1.875	1.783	1.827	1.835	1.784	1.893	1.687	1.923	1.913
Xmg	0.387	0.401	0.399	0.402	0.43	0.435	0.444	0.452	0.437	0.428	0.277	0.29	0.44	0.427

bdl = below detection limit

Table 4a - Representative electron microprobe analyses of plagioclase in Aswan quarry samples.

	Aswan Granite				Aswan Granodiorite				Aswan Tonalite			
An.	Gr1	Gr2	Gr3	Gr4	Grd1	Grd2	Grd3	Grd4	Tn1	Tn2	Tn3	Tn4
SiO_2	69.18	66.63	68.74	63.75	68.25	65.58	63.68	61.2	65.54	63.98	62.57	62.2
Al_2O_3	19.1	20.55	19.21	22.51	19.53	22.14	22.83	24.33	21.21	23.7	23.58	23.8
CaO	0.35	2.01	2.56	4.75	0.94	2.78	4.57	6.75	3.34	3.88	5.17	5.93
Na_2O	11.34	10.52	9.22	8.94	10.93	8.84	8.91	7.62	9.63	8.41	8.32	8.06
K_2O	bdl	bdl	bdl	bdl	0.24	0.73	bdl	bdl	bdl	bdl	bdl	bdl
Total	99.97	99.71	99.73	99.95	99.89	99.98	99.99	99.91	99.72	99.97	99.65	99.99
Atomic proportions calculated on the basis of 8 O												
Si	3.016	2.930	3.003	2.817	2.987	2.877	2.811	2.720	2.889	2.810	2.774	2.755
Al	0.981	1.065	0.989	1.172	1.007	1.145	1.187	1.274	1.102	1.227	1.232	1.242
Ca	0.016	0.095	0.12	0.225	0.044	0.131	0.216	0.322	0.158	0.182	0.246	0.281
Na	0.958	0.897	0.781	0.766	0.927	0.753	0.763	0.657	0.823	0.716	0.715	0.692
K	-	-	-	-	0.013	0.041	-	-	-	-	-	-
An	0.017	0.096	0.133	0.227	0.045	0.141	0.221	0.329	0.161	0.203	0.256	0.289
Ab	0.983	0.904	0.867	0.773	0.942	0.814	0.779	0.671	0.839	0.797	0.744	0.711
Or	-	-	-	-	0.014	0.044	-	-	-	-	-	-

Ab = albite; An = anortite; Or = Orthoclase

bdl = below detection limit

Table 4b – Representative electron microprobe analyses of plagioclase in stone sculpture fragments.

	statue of Goddess Sakhmet (cat. 260)		statue of Goddess Sakhmet (cat. 247)		statue of Goddess Sakhmet (cat. 251)		statue of Goddess Hathor (cat. 694)		statue of Ramses II (cat. 1380)		sarcophagus lid of Nefertari (suppl. 5153)		Ram-headed Sphinx (cat. 638)	
	cat.	cat.	cat.	cat.	cat.	cat.	cat.	cat.	cat.	cat.	suppl.	suppl.	suppl.	suppl.
An.	**260/1**	**260/2**	**247/1**	**247/2**	**251/1**	**251/2**	**694/1**	**694/2**	**1380/1**	**1380/2**	**5153/1**	**5153/2**	**5153/1**	**5153/2**
SiO_2	63.13	62.51	64.4	60.94	66.54	61.49	63.02	62.69	63.91	62.31	67.09	63.15	64.74	62.11
Al_2O_2	23.04	23.65	22.42	23.94	21.49	24.28	22.92	22.79	22.73	23.42	20.33	22.36	21.75	23.57
CaO	4.52	5.62	3.97	6.45	3.58	6.7	4.24	5.06	3.85	5.7	1.87	4.84	3.46	5.94
Na_2O	9.28	7.82	9.19	7.85	7.93	7.52	9.74	9.41	8.9	8.44	10.68	8.76	9.42	7.59
K_2O	bdl	bdl	bdl	0.36	0.44	bdl	bdl	bdl	0.59	bdl	bdl	0.13	bdl	0.41
Total	99.97	99.59	99.98	99.54	99.98	99.99	99.93	99.95	99.97	99.87	99.97	99.25	99.36	99.61
Atomic proportions calculated on the basis of 8 O														
Si	2.793	2.772	2.837	2.724	2.911	2.727	2.792	2.783	2.823	2.765	2.941	2.813	2.865	2.763
Al	1.201	1.236	1.164	1.261	1.108	1.269	1.197	1.192	1.183	1.224	1.051	1.174	1.134	1.235
Ca	0.214	0.267	0.187	0.309	0.168	0.318	0.201	0.241	0.182	0.271	0.088	0.231	0.164	0.283
Na	0.796	0.672	0.785	0.681	0.673	0.647	0.837	0.81	0.762	0.726	0.908	0.757	0.808	0.655
K	-	-	-	0.02	0.025	-	-	-	0.033	-	-	0.007	-	0.023
an	0.212	0.284	0.193	0.306	0.194	0.33	0.194	0.229	0.186	0.272	0.088	0.232	0.169	0.295
ab	0.788	0.716	0.807	0.674	0.778	0.67	0.806	0.771	0.78	0.728	0.912	0.76	0.831	0.681
or	0	0	0	0.02	0.028	0	0	0	0.034	0	0	0.007	0	0.024

Ab = albite; An = anortite; Or = Orthoclase

bdl = below detection limit