Mineral fingerprinting of Egyptian siliceous sandstones and the quarry source of the Colossi of Memnon

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The two colossi that stood before the first pylon of the mortuary temple of Amenhotep III at Thebes (the Colossi of Memnon) are composed of single blocks of siliceous sandstone or quartzite, similar to that occurring in quarries near Cairo (Gebel Ahmar) and Aswan (Gebel Gulab–Gebel Tingar). In this study, mineral fingerprinting, using the method of heavy-mineral analysis, points conclusively to a Gebel Ahmar source for the two Colossi. It also identifies Gebel Ahmar as the source for the two quartzite colossi associated with the second pylon and for fragments of quartzite statues that previously stood in the peristyle court. The study has further revealed a contrast in mineral composition between the two northern colossi and the two southern colossi, indicating that they were extracted from different parts of the Gebel Ahmar quarry complex.

Introduction

The two colossal seated statues of Amenhotep III, popularly known as the Colossi of Memnon, are the most striking features of ancient Thebes on the west bank of the Nile at Luxor (Figure 1). Both statues were originally made of monolithic blocks of brown to red siliceous sandstone (quartzite). The block that forms the southern colossus is today about 14 m high (Sourouzian et al. 2006, p. 325), but would once have included a double crown of Upper and Lower Egypt. Together with their pedestals, both statues are estimated to have stood 21 m or 40 Egyptian cubits high and to have weighed some 750 metric tonnes (Sourouzian et al. 2006, p. 349). They were erected in front of a large brick pylon at the entrance of the mortuary temple of Amenhotep III, built during the 18th Dynasty of the New Kingdom (between 1390 and 1353 BC).

Each of the seated figures of Amenhotep III is flanked by standing representations of the king's mother Mutemweja

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on the north sides and of Queen Tiye on the south sides. On each statue a figure of a princess, whose name is lost, once stood between the legs of the king. The thrones are decorated by Nile gods tying the heraldic plants of Upper and Lower Egypt, thereby representing the uniting of the land of Egypt under the reign of Amenhotep III.

A devastating earthquake in the year 27 BC may have caused the broad fissure still visible today in the northern Memnon Colossus and the collapse of the upper part of statue. The colossus subsequently became famous for producing a lamenting sound, apparently produced by warmth from the rising sun acting on early morning humidity within the fissures. Greek visitors regarded this as a greeting of the Ethiopian hero Memnon (slain by Achilles at Troy) to his divine mother Eos. More than a hundred inscriptions in Greek and Latin attest to the miraculous phenomenon of the early morning lamentations. During his visit to Thebes in AD 200, Septimius Severus resolved to restore the colossus, using large blocks of sandstone believed to have come from quarries at Aswan. The work was not completed, however, perhaps as a result of the death of the emperor. A unintended result of the project was the silencing of the 'voice of Memnon'.

The rock used to form the Colossi of Memnon is technically known as 'siliceous sandstone', 'silicified sandstone' or 'orthoquartzite', but Egyptologists have long referred to it simply as 'quartzite' and it is this terminology that is used here. It must be kept in mind, however, that the geological term 'quartzite' usually refers to a metamorphic rock whereas in this case it is applied to one that is entirely sedimentary. Quartzite, which was prized for its durability and distinctive colouration, was widely used by the ancient Egyptians for small to colossal statuary, sarcophagi, *naoi* (shrines), offering tables, stelae, architectural elements (especially door frames and internal tomb linings), and occasionally barque shrines and obelisks.

The quarry source of the Memnon quartzite blocks has long been the subject of discussion, as summarised by Varille (1933), Heizer et al. (1973), Stadelmann (1984) and Klemm et al. (1984). Although earlier authors have reported the occurrence of quartzite at several localities along the Nile Valley (see Heizer et al. 1973, p. 1221), it is now clear that true quartzite is restricted to Gebel Ahmar, near Cairo, and the Aswan area (Harrell 2002, Harrell and Madbouly 2006) (Figure 2). At Aswan, quartzite was extracted from the quarry complex at Gebel Gulab and Gebel Tingar on the west bank of the Nile (Heldal et al. 2005) and from quarries near Wadi Abu Aggag on the east bank (Harrell and Madbouly 2006).

Early discussion on the source of the Memnon quartzites focussed on the interpretation of Pharaonic inscriptions and on the logistics of transporting such large blocks from distant quarry sources. In a review of the existing literature, Stadelmann (1984) concluded that Gebel Ahmar was definitely the source of the Memnon quartzites. Studies on the geology and geochemistry of the quartzites have led to diverging opinions on their quarry provenance, however.

Geological investigations initially focussed on the possibility of distinguishing between the Cairo and Aswan quartzites on the basis of their physical

Figure 1. The Colossi of Memnon on the west bank of the Nile at Luxor.

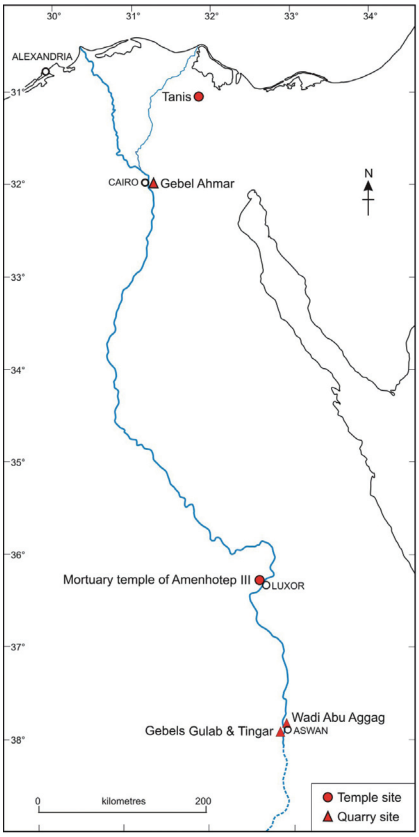

Figure 2. Location map.

and petrological characteristics. This approach seemed promising in view of the marked difference in age between the two deposits, with the Cairo quartzites being of mid-Tertiary age (Oligocene, ca. 30 Ma) and the Aswan quartzites of Late Cretaceous age (Turonian, ca. 90 Ma). However, the standard geological techniques of field examination, grain-size analysis and thin-section analysis failed to identify reliable distinguishing features. Both quartzites originated as sands deposited in fluvial channels and display a similar range of bed-forms. Also, they both possess similar, mineralogically mature, quartz-dominated detrital sand fractions. The two deposits also underwent similar post-depositional (diagenetic) changes, with cementation by silica leading to the local development of highly indurated, silica-cemented sandstone (quartzite) and impregnation by iron minerals leading to the development of a wide range in yellow, brown and red colouration. Only in the pebble fraction do the quartzites differ in their detrital composition, with pebbles of chert (finely crystalline quartz) being present only at Gebel Ahmar (Aston et al. 2000, p. 53). Since the majority of the sandstones lack pebbles, however, this distinction is of only limited applicability.

Another distinction that has been made between the two quartzites concerns the nature of the silica cement, which occurs in two forms. One type of cement, known as 'syntaxial quartz overgrowth cement', is composed of relatively large quartz crystals that have grown in crystallographic continuity with the individual detrital quartz grains that they surround (see Klemm and Klemm 2008, fig. 347). The other type of cement, here referred to as 'microcrystalline quartz fringe cement', is composed of clusters of small quartz crystals that radiate outwards from the surface of the sand grains (see Klemm and Klemm 2008, fig. 334). Shukri (1954) recognised both types of cement at Gebel Ahmar and said the fringe cement varies from normal to chalcedonic quartz. Niazi and Loukina (1987) also reported secondary chalcedony (and opal) in the Gebel Ahmar sandstone and attributed this kind of silicification to precipitation from hydrothermal solutions of volcanic origin. Klemm and Klemm (1993, 2001, 2008) state that the fringe cement is characteristic of the Cairo sandstones and that quartzites lacking it must therefore have come from Aswan. Conversely, Aston et al. (2000, p. 53) state that although fringe cement is indeed present at Gebel Ahmar, the dominant cement is of the syntaxial quartz overgrowth type, similar to that seen in the Aswan quartzites.

It is thus apparent that while the presence of chert pebbles or quartz fringe cement is indeed indicative of a Cairo quarry source, these criteria cannot be used to determine the quarry provenance of the quartzite artefacts that are pebble-free and possess only syntaxial quartz overgrowth cement. Aston et al. (2000, p. 53) indicate that a more effective method of distinguishing between the two sets of quartzites is on the basis of the degree of surface rounding displayed by the constituent quartz sand grains, with those of the Gebel Ahmar quartzites being consistently more rounded than those of the Aswan quartzites.

Because of the difficulty (as then perceived) of distinguishing between the two quartzites by conventional petrological means, Heizer et al. (1973) proposed that a better approach would be to study their geochemistry. Using the then innovative technique of neutron activation, they showed that the Cairo and Aswan quartzites differed in their contents of europium (Eu) and iron (Fe), and used this difference to identify a Cairo source for the Memnon statues but an Aswan source for the blocks used in the Roman repairs of the late 2nd or early 3rd century AD. This conclusion was also supported by a multivariate statistical analysis of Heizer et al.'s (1973) data by McGill and Kowalski (1977). A more comprehensive data set was subsequently published by Bowman et al. (1984) and Stross et al. (1988). Their findings, summarised in Figure 3, reaffirmed those of Heizer et al. (1973). A separate geochemical study by Klemm and Klemm (1993, see also Klemm and Klemm 2008) showed that the Cairo and Aswan sandstones could be distinguished by their differing contents of a wide range of elements (Co, Fe, Mn, Pb, Rb, Sr, Zn) (Figure 4) and used these differences to identify an Aswan source for the Memnon quartzites. The two geochemical studies thus came to diametrically opposed conclusions, with both sets of data plots seemingly providing conclusive support for their respective interpretations.

The present study takes the approach of establishing mineral rather than chemical fingerprints for the potential source quarries and comparing these with data for the Pharaonic quartzite artefacts. The method used is the long-established technique known as 'heavy-mineral analysis' (e.g., Krumbein and Pettijohn 1938, Milner 1962), which focusses solely on the detrital sand grain components, i.e., the material that was originally deposited as unconsolidated sand. Because the analysis is independent of variation in the proportions of mud matrix and cement minerals, obtaining a representative suite of samples is more straight-

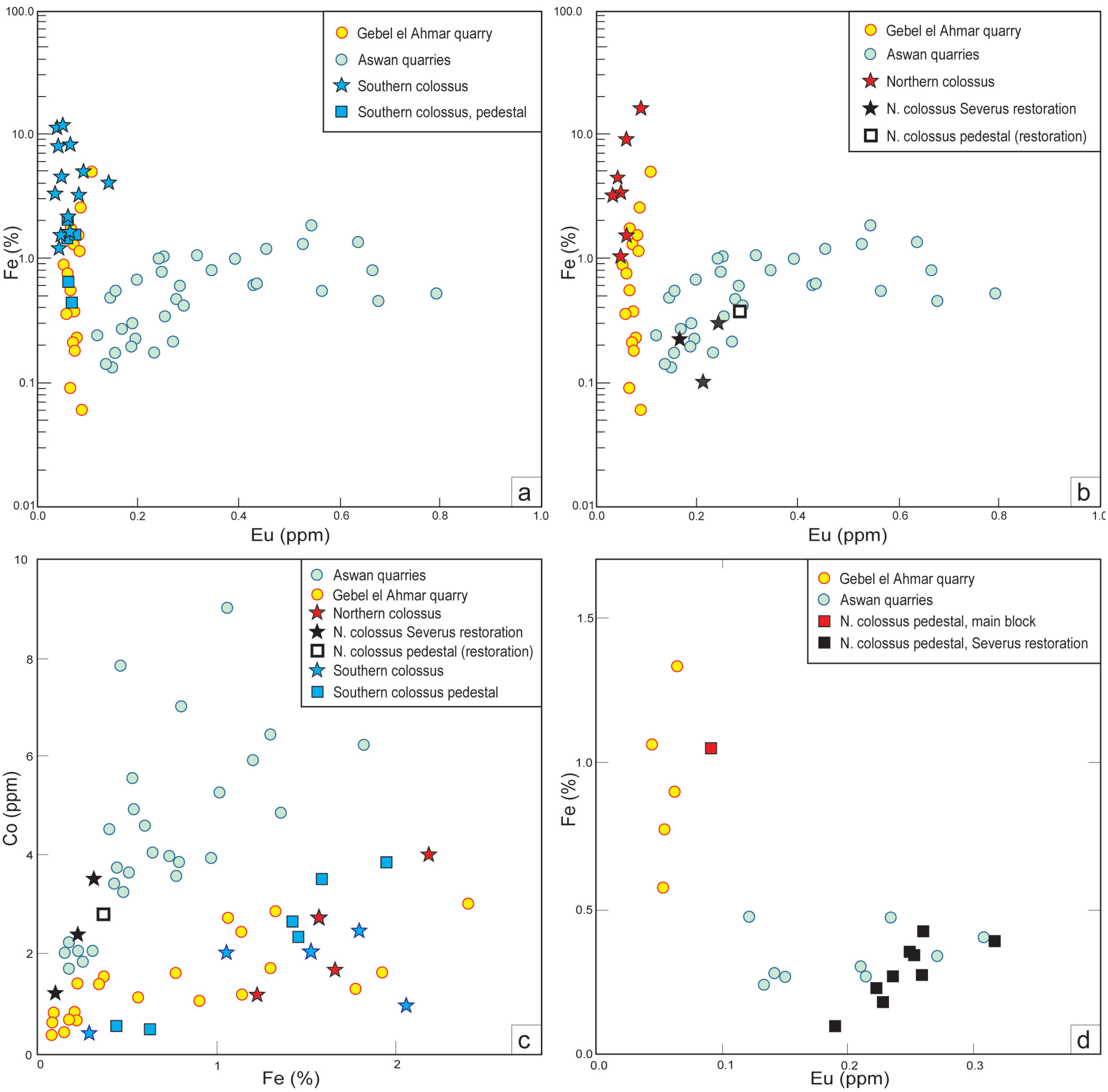

Figure 3. Geochemical data presented by Heizer et al. (1973) and Bowman et al. (1984). Iron and europium abundances for the southern Memnon Colossus (a) and northern Memnon Colossus (b) plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Heizer et al. (1973, fig. 3 left). (c) Cobalt and iron abundances for the South and North Memnon Colossi plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Heizer et al. (1973, fig. 3 right). (d) Iron and europium abundances for the northern Memnon Colossus pedestal. Redrawn from Bowman et al. (1984, fig. 4).

forward than for bulk-rock geochemical analysis. Heavy-mineral analysis was carried out on 8 samples from Gebel Ahmar, 7 samples from the Gebel Gulab – Gebel Tingar area, 5 samples from Wadi Abu Aggag, 8 samples from statuary at the mortuary temple of Amenhotep III, Thebes, and a single loose quartzite fragment from the ancient city of Tanis in the northeast delta area.

Method

Because of the similarity in bulk composition of the sand fraction in the two quarry areas (they are both composed almost exclusively of quartz) the study focussed on the much scarcer, but more diverse, accessory minerals. Because these accessory minerals are relatively dense, they can be separated from the bulk of the sand using a heavy (dense) liquid. For this reason, they are commonly referred to as 'heavy minerals'.

Separation of the heavy minerals from the lighter quartz and feldspar grains was achieved using bromoform, which has a specific gravity of 2.89. Disaggregation of the sandstones was achieved by impact crushing of quartzite fragments in a pestle and mortar, followed by prolonged treat-

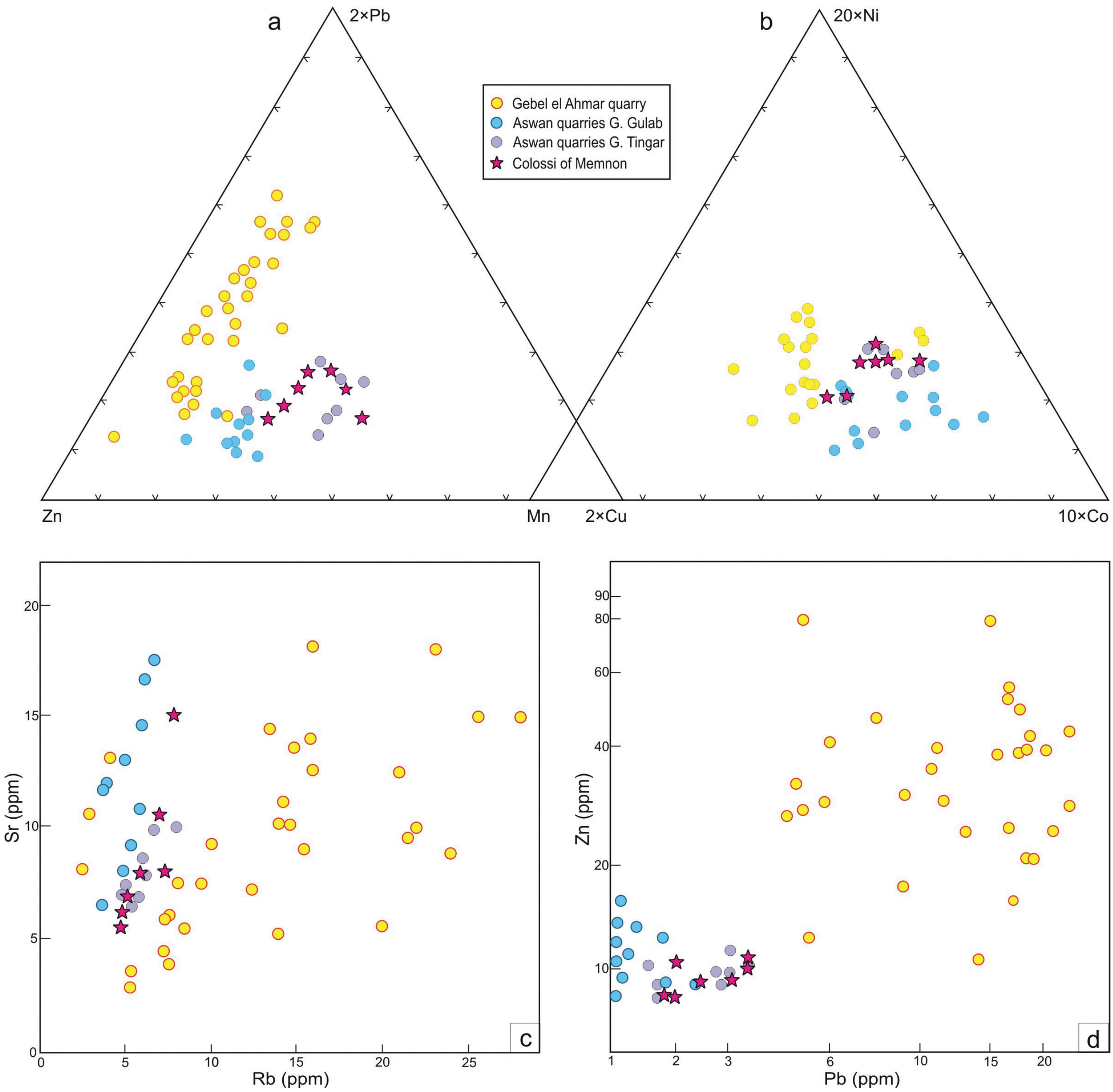

Figure 4. Geochemical data presented by Klemm and Klemm (2008). (a) Zinc, lead and copper abundances for the Colossi of Memnon plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Klemm and Klemm (2008, fig. 351). (b) Nickel, manganese and cobalt abundances for the Colossi of Memnon plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Klemm and Klemm (2008, fig. 353). (c) Strontium and rubidium abundances for the Colossi of Memnon plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Klemm and Klemm (2008, fig. 354). D. Zinc and lead abundances for the Colossi of Memnon plotted with data for quartzites from Gebel Ahmar and Aswan quarries. Redrawn from Klemm and Klemm (2008, fig. 352).

ment with an ultrasonic probe to remove clay and other adhering minerals (see Morton and Hallsworth 1994). The samples were then sieved and the 63–125 micron fraction mounted on glass slides, using Canada balsam. The selection of a relatively narrow grain-size range minimises the effect that varying grain size can have on mineral proportions. Although a small proportion of the grains are fragments of larger grains that broke during the disaggregation process, the preservation of elongated grains of easily fractured grains such as kyanite indicates that such fragmented grains have had a minimal effect on the mineral proportions. The slides were examined under a polarising petrographic microscope and the percentage of each heavy-mineral variety was determined by counting grains by the ‘ribbon’ method.

Although heavy-mineral analysis is primarily used to identify the ultimate source of a sand population, it may also be used to differentiate one sandstone from another. The latter application is the one relevant to this study. Such comparisons may be made using the entire detrital assemblage, but this approach has the drawback that mineral assemblages can undergo substantial modification by selective dissolution of the less stable components by fluids that circulate through the sandstone during weathering and burial diagenesis (Morton and Hallsworth 1994, Mange and Wright 2007). Such mineral dissolution is often non-uniform because of variation in porosity and permeability. As a result, unstable minerals can show considerable variation in abundance, even within a single sandstone bed. In a large-scale quarry, comprising a complex succession of fluvial sandstone bodies, the potential for variation within the unstable-mineral population is even greater.

The uncertainty associated with selective dissolution is overcome by restricting comparison to minerals that were stable under the prevailing weathering and burial conditions. These include the ultrastable minerals zircon, rutile, tourmaline and monazite. Other minerals known to be stable under most weathering conditions and during shallow burial are kyanite, staurolite and sillimanite, all of which have been encountered in this study.

Results

The results of the heavy-mineral analysis of quartzites from Gebel Ahmar, the Gebel Gulab–Gebel Tingar quarry complex and Wadi Abu Aggag are shown in Table 1. The minerals are arranged into two groups: those known to have been stable under the prevailing conditions of weathering and diagenesis and those that are likely to have been unstable. It is evident that the latter minerals display substantial variation within each of the three quarry groups. They thus have little potential for mineral fingerprinting of quarry sources.

Among the stable minerals, kyanite, sillimanite and staurolite are clearly more abundant in the Cairo quartzites than in the Aswan quartzites. Sillimanite is the least abundant of the three minerals, but is notable for its absence from the Aswan quartzites. Since the grains of all three minerals show no sign of significant surface etching, the contrast cannot be attributed to differing degrees of post-depositional dissolution but must reflect differences in composition of the original detrital sand assemblages. The relative abundance of kyanite, sillimanite and staurolite, both individually and as a group, can be therefore be used to distinguish between the Cairo and Aswan quartzites. Their abundance relative to the three principal ultrastable minerals (rutile, tourmaline and zircon) is expressed by the index KSi (see caption to Table 1 for formula).

Significant variation also exists in the relative proportions of the ultrastable minerals themselves. However, since tourmaline possesses a much lower specific gravity than the remainder, variation in the relative abundance of tourmaline may in part be the result of density fractionation during river transport. The effects of such density fractionation can be minimised by comparing the relative abundance of rutile and zircon, which have comparable density and shape. This ratio is expressed by the index RuZi (see caption to Table 1 for formula).

The values of the two mineral indices KSi and RuZi are plotted graphically in Figure 5. In addition to showing a clear separation between the Cairo and Aswan quartzites by virtue of their KSi values, the plot also reveals a significant difference in the range of RuZi values between the quartzites of the Gebel Gulab–Gebel Tingar area and those of Wadi Abu Aggag. Apart from one sample, the former quartzites display lower RuZi values. Further study will be required to determine whether this compositional difference could be used to identify quarry provenance for the Aswan area. Also apparent from Figure 5 is the much wider range in composition displayed by the Gebel Ahmar quartzites compared with those from Aswan. A consequence of this wide range in composition is that it is more difficult to obtain a representative set of samples for the Gebel Ahmar quarries than for those of Aswan.

Also plotted on Figure 5 are data for quartzite statues from the mortuary temple of Amenhotep III at Kom el-Hetan

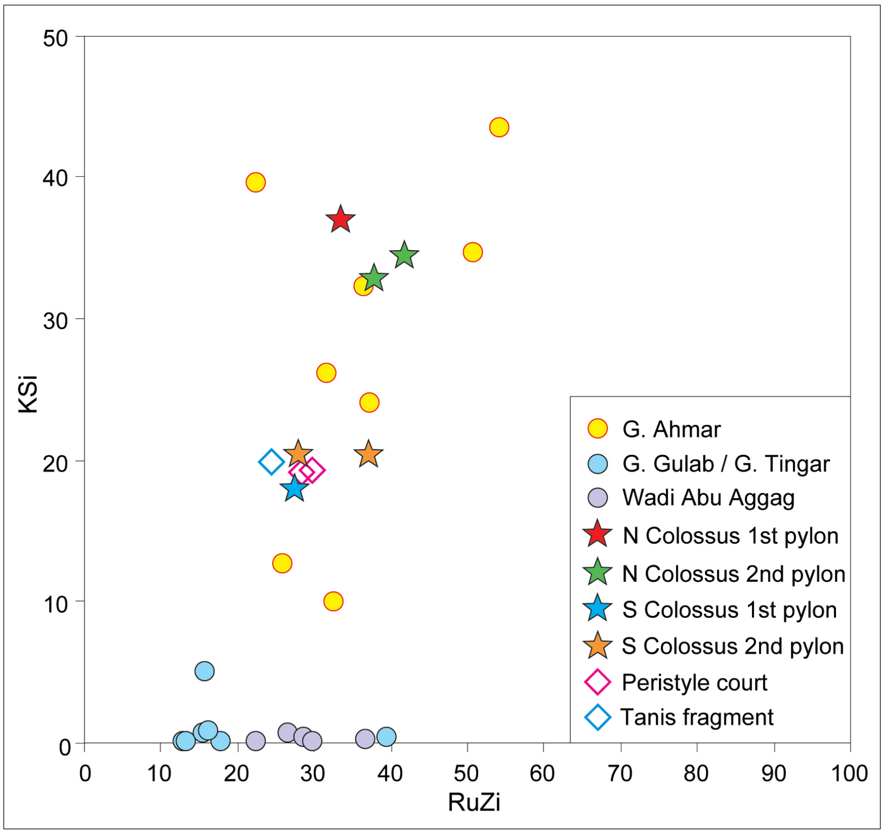

Figure 5. Heavy-mineral data for quartzite artefacts in the Amenhotep III temple, West Bank, Thebes, compared with data for quartzites from Gebel Ahmar and Aswan quarries. KSi = ratio of kyanite, sillimanite and staurolite to the ultrastable minerals rutile, tourmaline and zircon. RuZi = ratio of rutile to zircon. See caption to Table 1 for details of formulae.

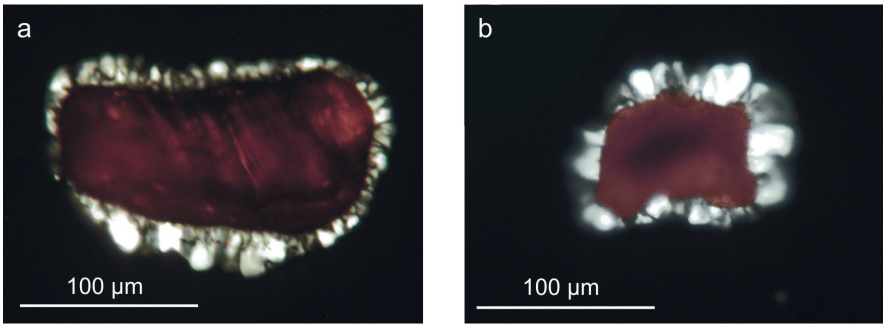

Figure 7. Photomicrograph of microcrystalline quartz fringe cement adhering to heavy-mineral grains from the southern Memnon Colossus. (a) Rutile grain as nucleus. (b) Hematite grain as nucleus.

on the West Bank at Thebes (Stadelmann and Sourouzian 2001, Sourouzian 2006, 2008). These include samples from the north and south colossi of the first pylon (the Colossi of Memnon) and from the remains of the north and south colossi of the second pylon (see Figure 6). Also included are fragments of quartzite statues that previously stood in the peristyle (solar) court. All of these quartzites plot within the field for Gebel Ahmar. A quartzite fragment from Tanis (for location see Figure 1) also falls within the Gebel Ahmar field, as might be expected for a site in the Delta area. The mineral composition of all of the quartzite statues studied thus favours a Gebel Ahmar source. In addition, some heavy-mineral grains from the southern Memnon Colossus possess well-developed fringes of microcrystalline quartz cement (Figure 7), which is generally agreed to be found only at Gebel Ahmar (see above).

An additional feature of these plots is that the temple samples fall into two compositional groups, each with a limited range of index values. This is in marked contrast to the wide range in composition of the samples collected at Gebel Ahmar in recent years. The most likely explanation of this feature is that extraction for monumental and architectural purposes will have focussed on those parts of Gebel Ahmar that contained the most massive and uniform bodies of quartzite. These are most likely to have occurred within the lower parts of major fluvial channel fills. Since the best stone will have been extensively worked, it is likely that the quartzite sampled at outcrop in recent times is not representative of the high-quality quartzite that was worked in ancient times. This conclusion is supported by the contrast in grain size between the recently collected samples (fine grained) and the artefacts (coarse grained). Most probably, the recently collected samples represent the upper part of the fluvial succession, deposited at a time of relatively low energy within the river system.

The main compositonal group of Pharaonic quartzite samples includes those from the two southern colossi and those from the peristyle court. The close similarity in composition of this group suggests that their host blocks were extracted from a specific part of the Gebel Ahmar site. Since the sample from the city of Tanis (20th to 22nd dynasties: 1190–716 BC) has a similar composition, it may be that this compositional field represents a major, long-term quarry site within the Gebel Ahmar complex.

The subordinate compositional group consists of samples from the two northern colossi. Again, the limited compositional range suggests extraction from a specific site at Gebel Ahmar, but evidently not the same site that supplied the main group of samples. Whether this represents a deliberate selection of different quarrying sites for the two northern and the two southern colossi is not clear, but the possibility of symbolic extraction from northern and southern parts of Gebel Ahmar cannot be ruled out.

Conclusions

This study has demonstrated that the Colossi of Memnon and other quartzite statues within the mortuary temple of Amenhotep III were quarried at Gebel Ahmar, as previously inferred from epigraphic evidence. Data acquired for the quartzites from the Aswan area indicate that it may be possible to distinguish between quartzite quarried on the west bank of the Nile (Gebel Gulab–Gebel Tingar) and quartzite quarried on the east bank (Wadi Abu Aggag).

The proposed Gebel Ahmar source for the Colossi of Memnon is in agreement with the conclusion reached by Heizer et al. (1973) on the basis of chemical analysis. It is counter to the conclusion of Klemm et al. (1984), who proposed an Aswan source, also based on chemical analysis. It seems likely that the discrepancy between the two sets of chemical analysis stems from the original sampling. As pointed out by Klemm

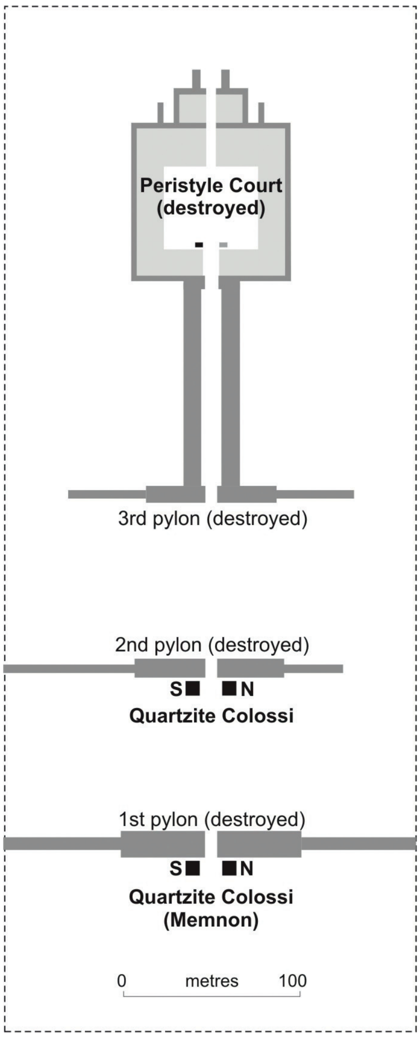

Figure 6. Plan of part of the mortuary temple of Amenhotep III, showing location of the quartzite colossi and Peristyle Court quartzite fragments analysed in this study.

Table 1. Heavy-mineral data and indices for quarry and temple quartzites.

			Unstable minerals %						Stable minerals %									Mineral indices			
Location	Sample No	Details	Ap	Ca	Cp	Ep	Gt	Ti	Ky	Mo	Ru	Si	Sp	St	To	Zr	count	RuZi	count	KSi	count
Gebel Ahmar	GA1		0.0	1.9	0.5	0.5	0.9	0.0	18.3	0.0	20.2	1.9	0.0	10.8	16.4	28.6	213	36.5	96	32.2	205
	GA2		0.8	0.0	0.0	0.0	3.9	0.0	1.6	0.0	19.4	1.6	0.0	6.2	7.0	58.9	129	32.6	43	9.8	122
	GA3		0.0	0.7	0.0	3.3	0.0	0.0	9.8	0.0	24.2	9.2	0.0	14.4	15.0	23.5	153	50.7	73	34.7	147
	GA6		1.8	0.9	1.8	0.0	0.9	0.0	24.6	2.6	9.6	5.3	1.8	7.0	10.5	33.3	114	22.4	49	39.6	106
	GA7		0.0	0.4	0.0	0.0	1.1	0.0	19.2	0.2	16.9	3.6	0.0	20.0	24.3	14.3	474	54.1	148	43.5	467
	GA8		0.4	0.4	0.0	1.2	0.4	0.0	13.4	1.6	20.2	2.0	0.0	8.1	17.8	34.4	247	37.0	135	24.1	241
	CD1		0.0	0.2	0.0	0.0	0.0	0.0	8.2	0.0	21.6	0.6	0.0	3.9	3.3	62.3	514	25.8	431	12.7	513
	CD2		0.0	0.3	0.0	0.3	0.6	0.0	15.7	0.0	19.6	3.2	0.0	7.1	10.9	42.3	312	31.6	193	26.3	308
Gebels	ASW1		0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.9	17.1	0.0	0.0	0.0	1.7	80.0	350	17.6	340	0.0	349
Gulab/Tingar	ASW2		0.0	0.0	0.6	0.9	0.0	0.0	0.0	1.8	12.2	0.0	0.6	0.0	3.0	80.9	329	13.1	306	0.0	322
	ASW31688		0.7	1.4	2.1	0.7	0.0	0.0	0.0	0.0	12.6	0.0	0.0	0.7	16.1	65.7	143	16.1	112	0.7	136
	ASW31689		0.0	1.3	6.0	11.3	1.3	0.0	2.0	0.7	11.3	0.0	0.0	2.0	4.0	60.3	151	15.7	108	5.0	121
	ASW31690		0.0	1.9	1.9	4.3	0.0	0.0	0.5	0.3	13.6	0.0	0.0	0.0	2.7	74.9	374	15.4	331	0.6	344
	ASW31695		0.0	0.2	0.2	0.0	0.2	0.0	0.2	0.0	33.1	0.0	0.0	0.2	15.2	50.9	643	39.4	540	0.3	640
	ASW31696		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	12.5	0.0	0.0	0.0	2.2	83.9	360	13.0	347	0.0	360
Wadi	HSWA1		0.4	0.0	0.1	0.0	0.6	0.0	0.0	0.3	27.8	0.0	0.1	0.1	22.0	48.4	672	36.5	512	0.2	663
Abu Aggag	HSWA2		0.0	0.0	0.0	0.0	0.1	0.0	0.1	1.1	25.9	0.0	0.1	0.1	7.9	64.6	735	28.6	665	0.3	733
	WAA1		0.8	1.5	1.5	2.3	0.8	0.8	0.0	0.0	19.2	0.0	0.0	0.0	6.2	66.9	130	22.3	112	0.0	120
	WAA2		0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	24.6	0.0	0.0	0.3	6.1	68.4	329	26.5	306	0.6	328
	WAA4		0.0	0.4	0.4	0.0	0.8	0.0	0.0	0.8	27.5	0.0	0.0	0.0	5.7	64.4	247	29.6	226	0.0	242
	WAA5		0.0	0.7	0.0	0.0	0.7	0.0	0.7	0.0	23.6	0.0	0.0	0.0	8.9	65.6	305	26.5	272	0.7	301
Mortuary	HST1	Pylon I N Colossus	1.4	2.8	5.6	1.4	2.8	0.0	9.7	0.0	13.9	9.7	0.0	12.5	12.5	27.8	72	33.3	30	37.1	62
Temple	HST3	Pylon I S Colossus	0.0	11.1	12.5	13.4	2.8	0.9	6.9	0.0	12.0	1.9	0.0	1.9	4.6	31.9	216	27.4	95	18.0	128
	HST4B	Pylon II N Colossus	0.4	3.5	2.7	5.5	1.1	0.5	15.1	0.4	19.3	3.4	0.0	11.2	9.9	27.0	741	41.7	343	34.4	639
	HST4C	Pylon II N Colossus	0.6	0.7	0.2	1.4	0.6	0.2	17.8	1.2	19.6	4.8	0.2	9.0	11.4	32.4	1259	37.7	655	32.8	1211
	HST5A	Pylon II S Colossus	0.3	0.8	1.0	0.8	0.5	0.3	10.5	0.0	25.2	3.4	0.0	5.8	8.6	42.6	591	40.6	424	20.4	568
	HST5B	Pylon II S Colossus	0.8	9.3	5.6	9.3	0.8	1.3	7.7	0.0	14.6	2.9	0.0	4.2	5.6	37.9	377	27.8	198	20.4	275
Tanis	CD3	Loose fragment	0.0	0.9	0.0	0.0	0.0	0.0	13.7	0.0	18.8	1.7	0.0	4.3	2.6	58.1	117	24.4	90	19.8	116

Unstable minerals: Ap = apatite; Ca = calcic amphibole; Cp = clinopyroxene; Ep = epidote; Gt = garnet; Ti = titanite (sphene).

Stable minerals: Cr = chrome spinel; Ky = kyanite; Mo = monazite; Ru = rutile; Si = sillimanite; Sp = spinel; St = staurolite; To = tourmaline; Zr = zircon.
RuZi (rutile:zircon index) = 100xRu/(Ru+Zr), KSi (kyanite-sillimanite-staurolite index) = 100x(Ky+Si+St)/(Ky+Si+St+Ru+To+Zr).

and Klemm (2008, p. 231), Heizer et al. (1973) were able to collect samples from the northern Memnon Colossus itself, whereas Klemm et al. (1984) had to rely on loose quartzite fragments, raising the possibility that they were in fact analysing material from the Roman restoration of the northern Colossus, not from the original blocks. Since the restoration blocks are believed to have come from Aswan (Heizer et al. (1973) and Bowman et al. (1984), this would explain the anomalous results obtained by Klemm et al. (1984).

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