REPORT ON THE PETROLOGY OF WADI HAMMAMAT BEKHEN-STONE

by

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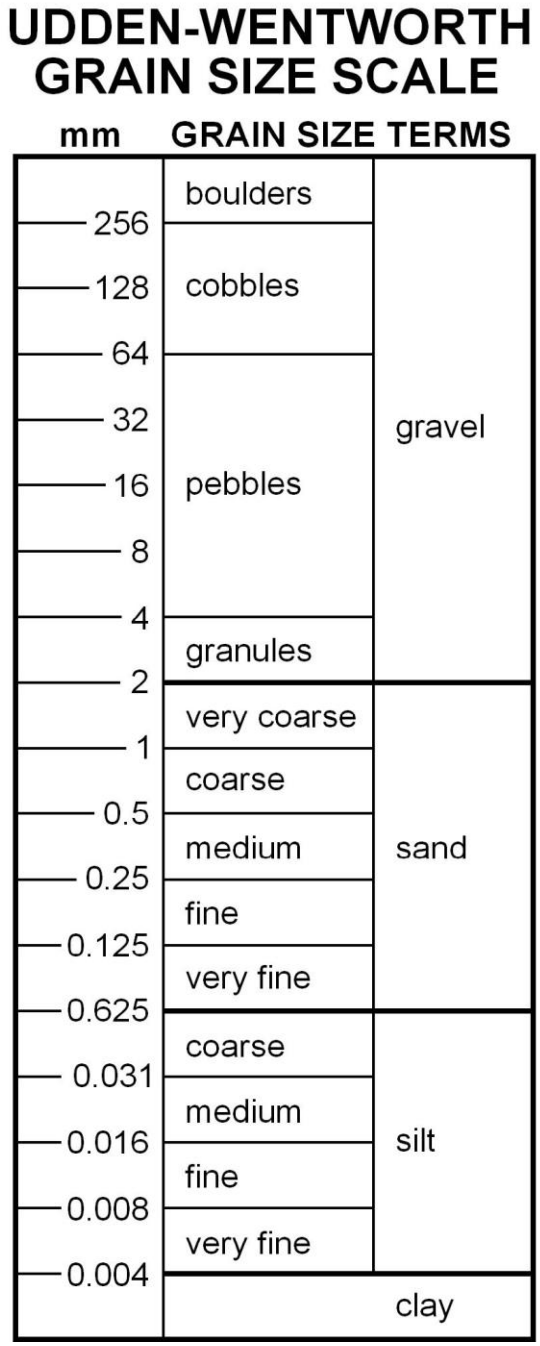
INTRODUCTION

There are two ancient quarries in Wadi Hammamat. The best known of these, which is famous for its rock-cut inscriptions, produced what the ancient Egyptians called 'bekhen-stone.' As will be described below, bekhen-stone includes the following geologic rock types: greywacke sandstone and three mudrock varieties – siltstone, mudstone and claystone. Conglomerate (or metaconglomerate) was also produced from the bekhen-stone quarry, but probably was not considered to 'bekhen-stone' by the ancient Egyptians. A second quarry just for conglomerate exists about 1 km west of the bekhen-stone quarry. Apart from a petrological description of the conglomerate taken from Harrell et al. (2002) and reproduced in the Appendix, this rock variety is not considered in the present report. It is only the petrology of the bekhen-stone that is of concern here.

PETROLOGICAL TERMINOLOGY I

Geologists in North America and the United Kingdom (as well as much of the rest of the world) use the Udden-Wentworth grain size scale for describing rocks like those in Wadi Hammamat.



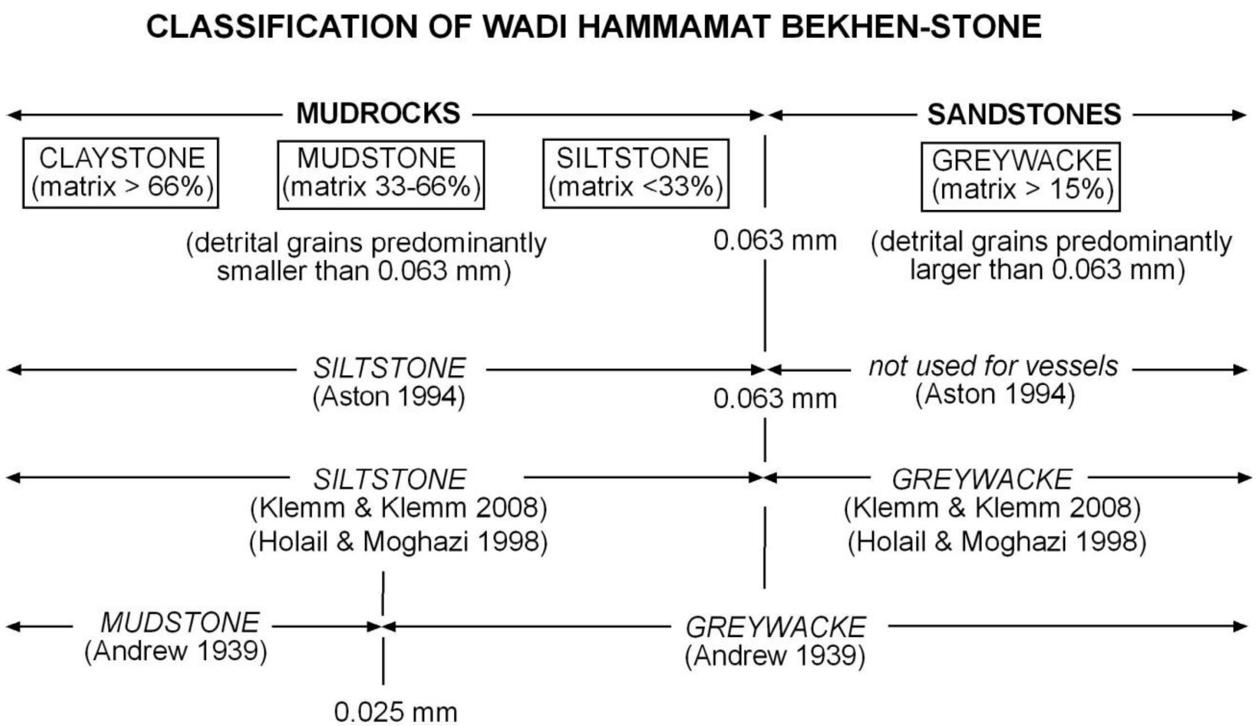
Sediment grains in the ‘clay size’ range (i.e., less than 0.004 mm) consist almost entirely of clay minerals (hence it’s name), but clay mineral grains can also be ‘silt size.’ The Udden-Wentworth scale, which was originally proposed for sediments, is the basis for the textural classification of ‘siliciclastic’ sedimentary rocks. Such rocks have a ‘clastic’ or fragmental texture and grains composed of ‘silicate’ minerals like quartz, feldspar and others. Rocks with mostly gravel size grains are called ‘conglomerate’ and if the grains are predominantly sand size then the rock is ‘sandstone’. Rocks with mostly silt or clay size grains are collectively referred to as ‘mudrock’ (where silt + clay = ‘mud’) or ‘shale’ with still other terms sometimes applied. All of these textural rock varieties occur among the Wadi Hammamat quarry stones.

To further classify these rocks, two additional terms need to be introduced: ‘detrital grains’ and ‘matrix’. Detrital grains are silt-, sand- or gravel-size grains that were transported and deposited by rivers or other surface processes. Gravel grains are mainly rock fragments, and sand and silt grains are mostly mineral fragments composed of quartz with lesser amounts of feldspar and other minerals. Some sand grains can also be rock fragments. Matrix consists mainly of phyllosilicate minerals (clays and micas) and fills the interstitial spaces (intergranular voids) between the detrital grains. In sands and gravels the matrix may also include detrital silt, but in finer-grained sediments the matrix is defined as consisting only of clay minerals and/or micas. The clay/mica matrix in siliciclastic rocks can be either primary (detrital) or, more commonly, secondary (post-depositional precipitates).

During progressive burial diagenesis, clay minerals increase in crystallinity and size, and begin to transform into the more stable illite and chlorite clays. At the still higher temperatures and pressures of early metamorphism, the illite transforms into ‘coarse’ muscovite mica and sericite (= fine-grained muscovite), and the chlorite clay transforms into chlorite mica. The matrix remains recognizable even after these changes.

Among sedimentary petrologists in North America and the United Kingdom at least, it is almost universally the case that siliciclastic sedimentary rocks with a predominant detrital grain size finer than sand (i.e., less than 0.0625 mm) and lacking fissility (i.e., do not easily break into thin, platy pieces due to internal laminations or parallel-oriented clay mineral grains) are divided into three categories based on the relative percentages of silt- and clay-size grains: ‘siltstone’ (66-100% silt), ‘mudstone’ (33-66% silt) and ‘claystone’ (0-33% silt) (e.g., Potter et al. 1980: Table 1.2; Tucker 1991: Fig. 3.1; Blatt 1992: Table 6.1; Boggs 1992: Table 7.8; and Stow 2005: Table 6.1). In practice, however, these categories are defined by the relative amounts of detrital silt and clay matrix. This is because grains approaching clay size are difficult to see microscopically, clay-size grains are almost always clay minerals, and clay minerals can be silt size. If the clay minerals have been transformed into mica by diagenesis or metamorphism then the mica is considered part of the matrix. There are several varieties of sandstone recognized but only one of these is relevant here and this is ‘greywacke’. Greywacke is a widely used but imprecisely defined term. The only commonality among the many published definitions is that greywacke sandstones have an abundant, interstitial clay/mica matrix. By any of the definitions, however, the sandstone quarried in Wadi Hammamat is greywacke. However, because of its abundant feldspar, it can also be called a ‘feldspathic’ or ‘arkosic’ greywacke.

The rock classification used here for the Wadi Hammamat bekhen-stone is shown below along with the terminology used by others.



Aston (1994: 27-32), Holail & Moghazi (1998) and Klemm & Klemm (2008: 307-309) refer to all mudrocks as ‘siltstone’ irrespective of the amount of silt they contain and this is clearly inappropriate. If all sandstones contain mostly sand-size grains then logically all siltstones should contain mostly silt-size grains. By the same reasoning, rocks with mainly clay-size grains should be called claystones.

BEKHEN-STONE SAMPLES EXAMINED IN THIN SECTIONS

<u>Provided by Elizabeth Bloxam</u>

1947.71A	Naqada IB-IIA artifact (unprovenanced)
215567	Naqada IIC-IIIA artifact (from Abadiyeh)
215777	Naqada III artifact (from Hierakonpolis)
215862B	Naqada III artifact (unprovenanced)
215918	artifact of uncertain age (from Hierakonpolis)
215921	Naqada III artifact (from Hierakonpolis)
245741	Naqada IIC artifact (from el-Amrah)
unknown	no information provided and no label on the thin section

<u>Collected by James Harrell in Wadi Hammamat</u>

NQ-6	vessel/palette quarry (2010 survey)
NQ-7a	vessel/palette quarry (2010 survey)
NQ-7b	vessel/palette quarry (2010 survey)
WH-M-1	tailings below ancient quarries on north side of Wadi Hammamat (2001 survey)
WH-M-2	wadi cobble near mouth of Wadi Faux (1990 survey)

WH-SS-2	tailings below ancient quarries on north side of Wadi Hammamat (1989 survey)
WH-SS-3	tailings below ancient quarries on north side of Wadi Hammamat (1989 survey)
WH-SS-4	tailings below ancient quarries on north side of Wadi Hammamat (1990 survey)
WH-SS-5	tailings below ancient quarries on north side of Wadi Hammamat (1990 survey)
WH-SS-6	tailings below ancient quarries on north side of Wadi Hammamat (1997 survey)
WH-SS-7	tailings below ancient quarries on north side of Wadi Hammamat (2001 survey)

THIN SECTION DESCRIPTIONS BY TEXTURAL ROCK TYPE

Definition of abundance terms:
trace (<1%), scarce (1-5%), common (5-25%) and abundant (>25%).

Claystone (samples 1947.71A[1], 215567, 215862A and 215918)

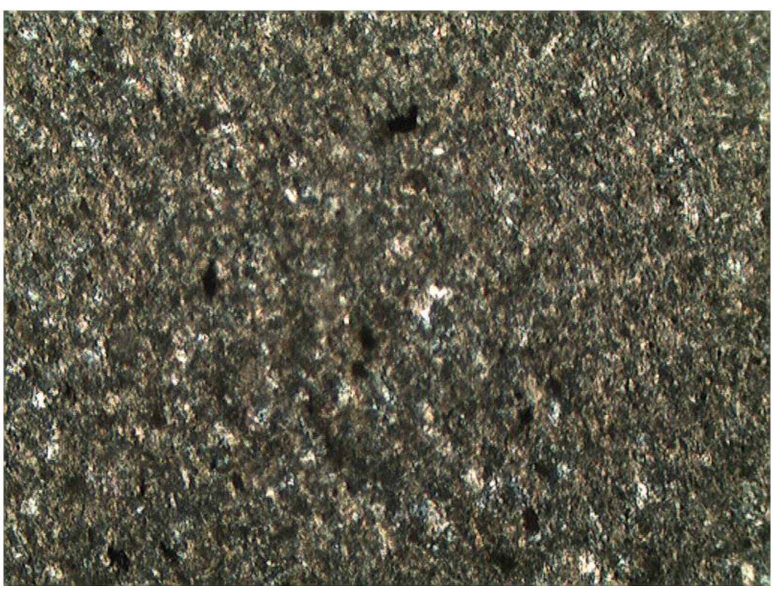
Color: grayish-green.

Detrital grains: medium- to coarse-grained silt consisting of common quartz, and trace plagioclase feldspar.

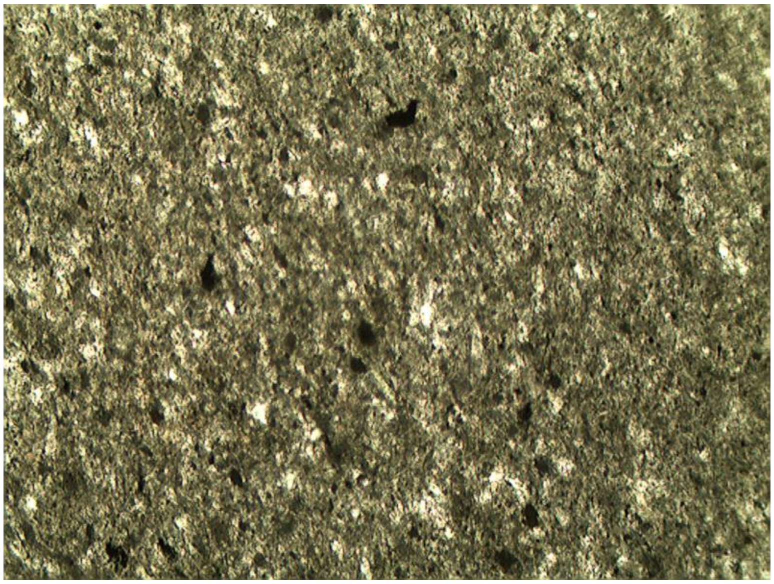
Clay/mica matrix: common chlorite, and common sericite.

Diagenetic or metamorphic minerals: trace epidote, scarce to common coarse muscovite, common calcite, and scarce hematite.

[1]1947.71A has some mudstone laminae.



Claystone (sample 215567). Crossed polarizers. Field of view 0.75 mm wide.


Claystone (sample 215567). Same view as above but uncrossed polarizers. Field of view 0.75 mm wide.

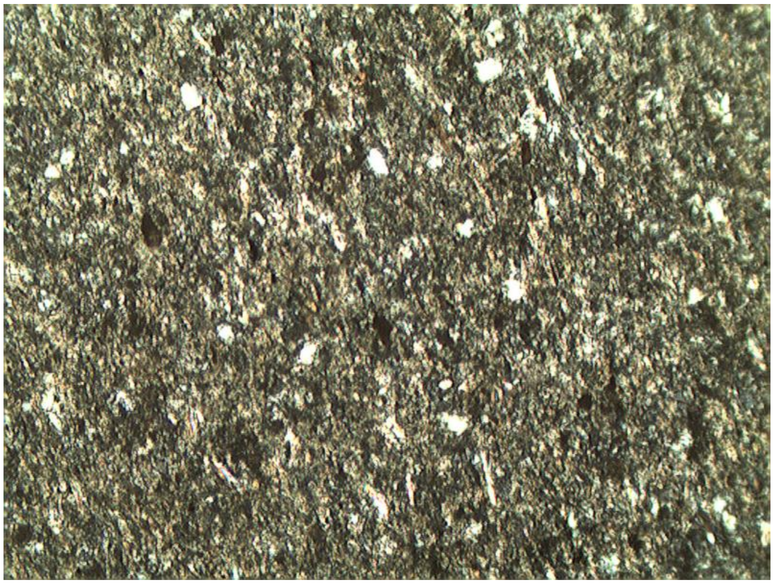
Mudstone (samples 215777 and 215862B)

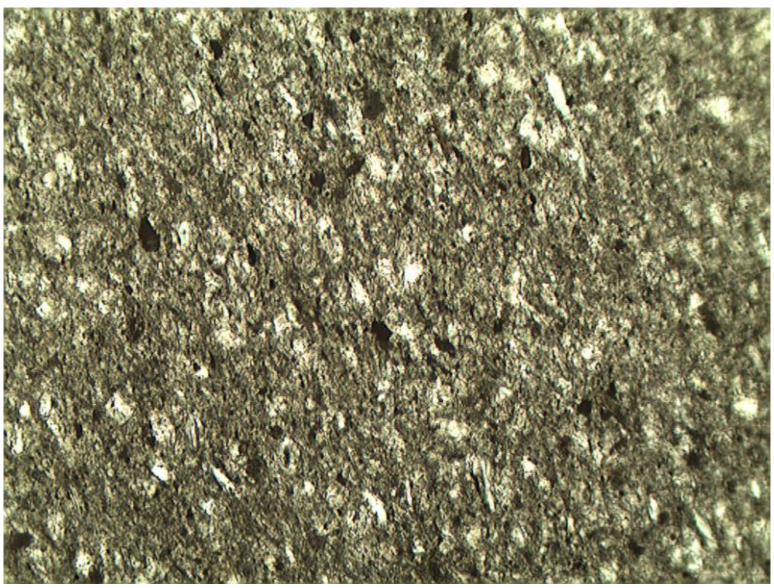
Color: grayish-green.

Detrital grains: medium- to coarse-grained silt and trace very fine-grained sand consisting of common quartz, and trace plagioclase feldspar.

Clay/mica matrix: common chlorite, and common sericite.

Diagenetic or metamorphic minerals: trace epidote, scarce coarse muscovite, common calcite, and scarce hematite.


Mudstone (sample 215777). Crossed polarizers. Field of view 0.75 mm wide.


Mudstone (sample 215777). Same view as above but uncrossed polarizers. Field of view 0.75 mm wide.

<u>Siltstone</u> (samples 245741, NQ6, NQ7a, NQ7b, WH-m-1, WH-m-2[1], WH-ss-2[2] and WH-ss-6[3])

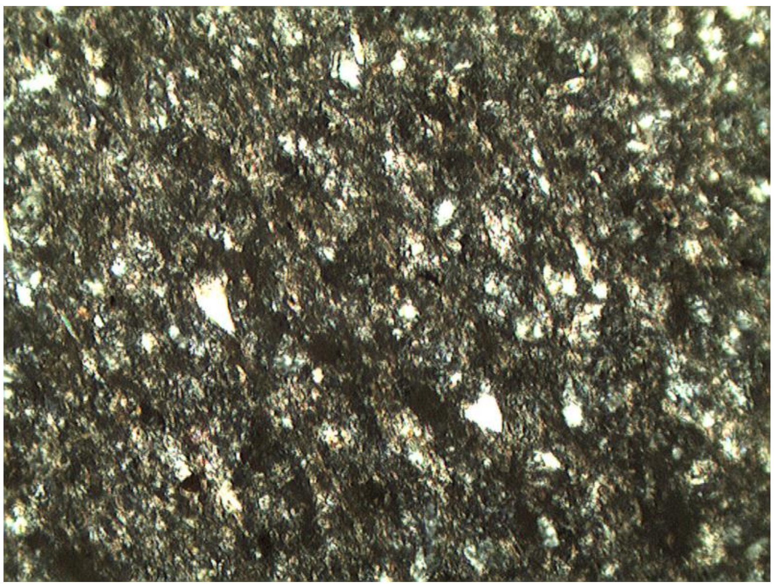
Color: dark gray (when hematite-rich) to mostly grayish-green (when hematite-poor).

Detrital grains: medium- to coarse-grained silt (= siltstone[4]) with usually some very fine-grained sand (= sandy siltstone[5]) consisting of abundant quartz, trace to scarce plagioclase feldspar[6], and trace to mainly absent rock fragments[6] and zircon.

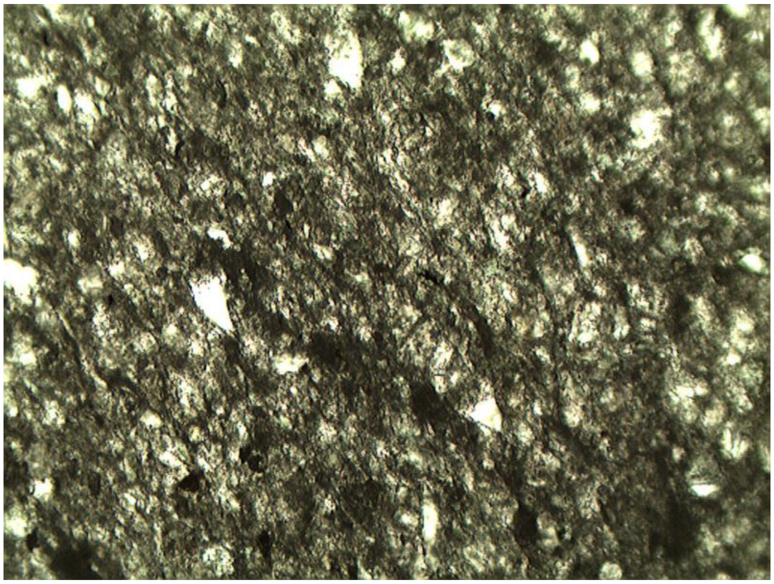
Clay/mica matrix: scarce to mainly common chlorite, and scarce to mainly common sericite.

Diagenetic or metamorphic minerals: scarce to mainly trace epidote, trace to mainly scarce or common coarse muscovite, trace to mainly scarce or common calcite, and scarce to mainly trace hematite.

[1]WH-m-2 has some claystone laminae.
[2]WH-ss-2 is the only dark gray siltstone and has scarce, almost common, hematite.
[3]WH-ss-6 has some mudstone laminae.
[4]Includes WH-m-1 and WH-ss-6.
[5]Includes 245741, 215921, NQ6, NQ7a, NQ7b and WH-ss-2.
[6]Feldspars and rock fragments are very difficult to recognize in silt-size grains and so their abundance may be greater than what is reported here.



Sandy siltstone (sample 215921). Crossed polarizers. Field of view 0.75 mm wide.



Sandy siltstone (sample 215921). Same view as above but uncrossed polarizers. Field of view 0.75 mm wide.

Sandstone (samples WH-ss-3, WH-ss-4, WH-ss-5[1], WH-ss-7 and *unknown*)

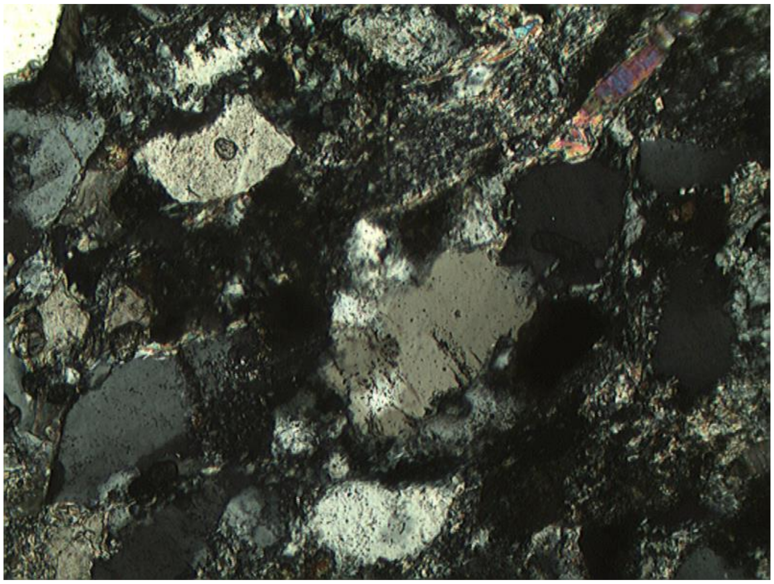
Color: dark gray (when hematite-rich) to mostly grayish-green (when hematite-poor).

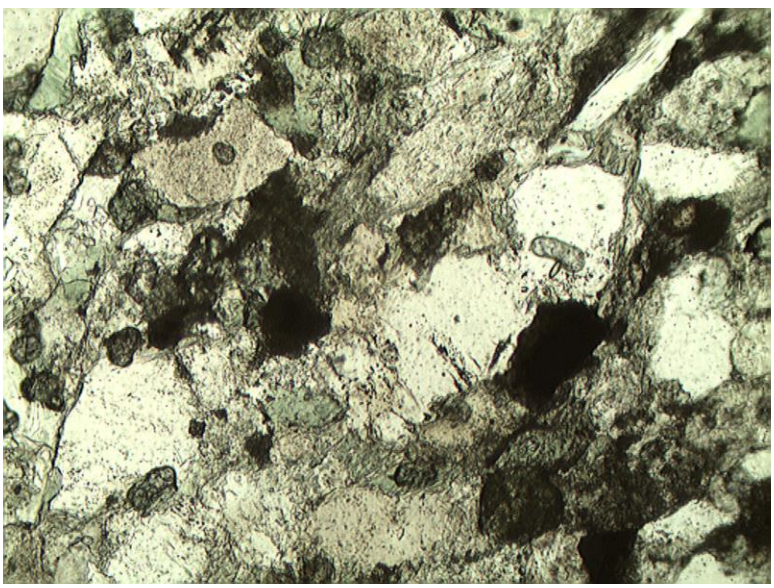
Detrital grains: very fine- to fine-grained sand with occasionally medium-grained sand or coarse-grained silt consisting of abundant quartz, common plagioclase feldspar (mainly oligoclase), trace alkali feldspar, scarce to common rock fragments (mostly volcanic), and trace to mainly absent hornblende and zircon.

Clay/mica matrix: common chlorite, and common sericite.

Diagenetic or metamorphic minerals: scarce to common epidote, scarce to common coarse muscovite, trace to scarce calcite, and common to mainly trace or scarce hematite.

[1]WH-ss-5 is the only dark gray sandstone and has common hematite.


Sandstone (sample WH-ss-7). Crossed polarizers. Field of view 0.75 mm wide.


Sandstone (sample WH-ss-7). Same view as above but uncrossed polarizers. Field of view 0.75 mm wide.

Some Compositional Tendencies

1. As detrital grain size decreases from sandstone to mudrock, the amount of epidote tends to decrease while the abundance of calcite increases.

2. The dark gray color of some rocks is due to a higher than normal abundance of hematite. The amount of green chlorite may be no different than in the grayish-green rocks, but the green color is masked by the sub-metallic black hematite.

PETROLOGICAL TERMINOLOGY II

There is no one petrological term that perfectly encapsulates all the bekhen-stone varieties. In the past these have been erroneously referred to as ‘slate,’ ‘schist’ and ‘basalt’ among other names, and none of these are even close to being correct. Petrie (1914: 8) and Shiah (1942: 203-205) have suggested using the invented term ‘durite’ to refer to all bekhen-stone varieties, but this has never been accepted by geologists and Egyptologists. The term ‘greywacke’ has long been used by Egyptologists for the entire assemblage and has some additional appeal because the one thing all the bekhen-stone varieties have in common is an abundant green clay/mica matrix, which is the principal defining characteristic of greywacke. Although greywacke is only recognized by geologists as a variety of sandstone, it should be acceptable to apply it to the Wadi Hammamat mudrocks if appropriate caveats and qualifications are included.

The Wadi Hammamat quarry stones are sedimentary rocks that have experienced early stage metamorphism. Aston (1994) and Klemm & Klemm (2008) also agree that this is the case. The evidence for metamorphism visible in the thin sections is the presence of epidote, chlorite (much of it coarse-grained) and coarse muscovite, and the incipient schistose foliation indicated by the common parallel orientation of both sericite and coarse muscovite in the mudrocks. Occasional veins of hydrothermal quartz cut through the quarry stones and these are a further indication that the rock has been exposed to metamorphic conditions. The epidote-chlorite-muscovite mineral assemblage is typical of the ‘greenschist facies’ of metamorphism. Had the rocks been subjected to somewhat higher temperatures and/or pressures, they would have been transformed into true metamorphic rocks with the sandstones becoming quartzites and the mudrocks becoming slates and phyllites. The quarry stones, however, are now somewhere between sedimentary and metamorphic rocks, and so it is appropriate to recognize this by adding the ‘meta’ prefix to the sedimentary rock names. This is, however, optional and some geologists would not apply this prefix.

Recommendation

The bekhen-stone varieties should be collectively referred to as **greywacke** or, better, **metagreywacke**.

DISCUSSION

It may be that the palettes and vessels were carved principally from the mudrock and larger objects (e.g., statues, sarcophagi, naoi, etc.) were cut mainly from the sandstone. Further work is needed to verify this suggestion but all present evidence is consistent with it: i.e., the vessels studied by Aston (1994) and the artifacts (palettes, in part) studied in this report are all mudrock, and the sarcophagus studied by Wissa (1994) as well as all the statues, sarcophagi and naoi informally examined by me in museums are sandstone. The reason one rock type was chosen over the other for a particular application is probably the fracture spacing in quarry outcrops rather than appearance or any other property. For palettes and vessels the quarrymen wanted a small fracture spacing that allowed them to extract thin slabs for palettes or small blocks for vessels, and for larger objects a greater fracture spacing was required. This led to the development of ‘small block’ quarries in the Late Predynastic and Early Dynastic periods and then ‘large block’ quarries in subsequent periods. Fracture spacing is closely correlated with bedding thickness in sedimentary rocks (i.e., thicker beds generally have wider spacings), and sandstones tend to be more thickly bedded than mudrocks. If this is the case in Wadi Hammamat, then it would explain why mudrock was used for small objects and the sandstone (with both thicker layers and wider fractures spacings) was exploited for larger ones.

BIBLIOGRAPHY

Andrew, G. 1939. The greywackes of the Eastern Desert of Egypt, Part I. *Bulletin de l’Institut d’Égypte*, v. 21, p. 153-190.

Aston, B. G. 1994. *Ancient Egyptian Stone Vessels: Materials and Forms*. Heidelberg: Heidelberger Orientverlag.

Blatt, H. 1992. *Sedimentary Petrology* (2nd ed.). New York: W. H. Freeman & Co.

Boggs, S. 1992. *Petrology of Sedimentary Rocks*. New York: Macmillan.

Harrell, J. A., V. M. Brown and L. Lazzarini. 2002. Breccia verde antica – source, petrology and ancient uses. In L. Lazzarini (ed.), *Interdisciplinary Studies on Ancient Stone – ASMOSIA VI, Proceedings of the Sixth International Conference of the Association for the Study of Marble and Other Stones in Antiquity, Venice, June 15-18, 2000*; p. 207-218. Padova: Bottega d'Erasmo - Aldo Ausilio Editore.

Holail, H. M. and A.-K. M. Moghazi. 1998. Provenance, tectonic setting and geochemistry of greywackes and siltstones of the Late Precambrian Hammamat Group, Egypt. *Sedimentary Geology*, v. 116, p. 227-250.

Klemm, R., and D. D. Klemm. 2008. *Stones and Quarries in Ancient Egypt*. London: British Museum Press.

Petrie, W. M. F. 1914. *Amulets*. London: Constable and Company.

Potter, P. E., J. B. Maynard and W. A. Pryor. 1980. *Sedimentology of Shale*. New York/Berlin: Springer-Verlag.

Shiah, N. 1942. Some remarks on the bekhen stone. *Annales du Service des Antiquités de l’Égypte*, v. 41, p. 189-205.

Stow, D. A. V. 2005. *Sedimentary Rocks in the Field: A Color Guide*. London: Manson.

Tucker, M. E. 1991. *Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks* (2nd ed.). Oxford: Blackwell Scientific.

Wissa, M. 1994. Le sarcophage de Merenrê et l'expédition à Ibhat (I). In C. Berger, G. Clerc and N. Grimal (eds.), *Hommages à Jean Leclant.* Volume 1: *Études Pharaoniques*. Cairo: Institut Français d'Archéologie Orientale, Bibliothèque d'Étude 106/1, p. 379-387.

* * * * * APPENDIX * * * * *

SOME PUBLISHED DESCRIPTIONS OF WADI HAMMAMAT ROCKS

Andrew (1939) provides a general description of the rocks in the Wadi Hammamat area and not specifically of the quarry stones. His work is presumably based on thin sections. He recognizes two rock varieties: "mudstone" and "greywacke" with the grain size boundary between them at 0.025 mm. The greywackes he says "have a considerable quantity of original detrital plagioclase...[with] quartz as the principal detrital constituents. The accessory constituents are (in order of abundance) epidote, chlorite, opaque ore (both ilmenite and magnetite have been observed), muscovite, biotite, hornblende, and rarely apatite and zircon...The mudstones...[contain] angular quartz...minute grains of epidote, and scattered opaque ore being the most obvious features."

> <u>Comment</u>
>
> His "opaque ore" is almost certainly hematite. Contrary to his assertion, the amount of epidote never exceeds that of chlorite in the Wadi Hammamat quarry stones.

Wissa (1994) describes the greywacke sandstone sarcophagus of king Merenre (Dynasty 6), which is in his pyramid at Saqqara. Rephrasing and translating from her French text, she reports that the rock consists of quartz grains between 0.14 and 0.23 mm in size plus lesser amounts of feldspar (5-7% of the rock; mostly sodic plagioclase plus rare alkali feldspar/orthoclase) and accessory minerals (2-3% of rock; including epidote, 'white mica' [i.e., coarse muscovite], tourmaline, zircon, sphene and opaques [i.e., hematite]). The matrix consists of sericite and chlorite.

Aston (1994: 28) examined thin sections from five vessels dating to Dynasties 1-4. For these, she says, the detrital grains range in size from "silt (0.004-0.06 mm) to very fine sand (0.06-0.125 mm)...[with] the identifiable grains...mostly quartz, with a little feldspar, and a few grains of detrital epidote and muscovite. Compositionally, clay minerals make up a high proportion of the rock...[and] secondary minerals which developed during diagenesis include chlorite, muscovite, epidote and calcite."

> <u>Comment</u>
>
> Although it is not impossible for epidote to be detrital, it is a rarity. It is also very unlikely that both detrital and secondary (i.e., diagenetic or metamorphic) epidote would occur in the same rock. In this case Aston has misinterpreted the epidote, which is almost certainly entirely metamorphic. Her statement that there's a "high proportion" of clay

minerals suggests that some of the vessels were mudstone or claystone rather than true siltstone.

Holail and Moghazi (1998: 231, Table 1) do not describe quarry stones but rather the rocks generally in the Wadi Hammamat area. They recognize two basic rock types: 'greywacke' and 'siltstone' with the latter including all the mudrock varieties. They say the "siltstones...consist of angular to subrounded chips of quartz, feldspar and opaques in a clay-size matrix...[with] feldspar (mainly oligoclase with minor k-feldspar) and quartz...the most abundant minerals. Calcite and clay minerals are also common...[with] the greenish varieties...characterized by abundant chlorite and illite." In contrast, the "greywackes are...composed of sand-size, subangular to subrounded...grains of quartz, feldspar and rock fragments, packed and scattered in a much finer silty and clayey matrix...[with] quartz (average 30%)...plagioclase feldspar (oligoclase; average 31%) and k-feldspar grains (average 1.8%). Lithic rock [fragments] are diverse and include andesite, metabasalt, granitoids, felsite and reworked siltstone. Matrix material constitutes about 47% of the...greywacke...[and] mostly consists of a matted mixture of silt- and clay-sized grains of quartz, feldspar, clay minerals (mainly illite) associated with chlorite flakes and epidote, opaques, muscovite and apatite."

Comments

Their "illite" is sericite and their "opaques" are hematite.

Harrell et al. (2002: 213-214) provide thin section and megascopic descriptions of the gravel-rich, conglomeratic variety of Wadi Hammamat stone from both the eastern and newly discovered western quarries. The "metaconglomerate contains gravel-sized clasts up to 35 cm across but with the vast majority falling within the 4-25 cm (pebble to cobble) size range...The rock has a coarse sandy matrix compositionally identical to the interbedded metagreywacke sandstone. Within the matrix, and many of the gravel clasts as well, are abundant secondary sericite, chlorite and epidote, where the latter two minerals are by-products of low-grade (greenschist facies) metamorphism and the source of the rock's generally greenish color. In the western quarry, irregular patches (up to several centimeters across) of secondary milky quartz commonly occupy the interstices between gravel clasts. The clasts in both quarries are mostly sub- to well-rounded and thus, contrary to its traditional Italian names, the rock is texturally a conglomerate (according to North American and British usage) and not a breccia...The following approximate percentages and rock types for the [gravel] clasts [are observed]. Volcanic Rocks (~70%): mostly felsic to intermediate tuffs and lavas (rhyolitic, dacitic, latitic and andesitic compositions) with rare mafic lavas and dike rocks (basalts and dolerites). Epidosites, derived from altered tuffs and lavas, are also common. The metavolcanic clasts are mostly green in color but also commonly occur in shades of red, yellow, brown and purple, or some combination of these colors. The tuff clasts, which are the most varied in appearance, commonly show very fine, often contorted, banding. Sedimentary Rocks (~15%): mostly greenish greywacke sandstone and siltstone with lesser amounts of greenish conglomerate similar to the enclosing rock, light gray siliceous sandstone, and rare chert and limestone. Plutonic Rocks (~15%): mostly felsic granitoids (granites, including aplites or microgranites, and granodiorites) with minor intermediate plutonics (diorites and tonalities). The granitoids are light gray to mostly pink in color with occasional purplish tinges. Other rocks (<1%): milky white vein quartz and green serpentinite. Megascopically, the only apparent difference between gravel clasts from the eastern and western quarries is that in the latter pink granitoids are especially abundant, accounting for as much as one-fourth to one-third of the clasts in some portions of the metaconglomerate beds. In both quarries, when the clasts are large cobbles or small boulders, conglomerate and especially pink granitoids are the dominant rock types."

Klemm and Klemm (2008: 308-309) examined thin sections of an unknown number of samples they collected from the Wadi Hammamat quarry. For what they refer to as 'siltstone,' they say that the "grain sizes vary between 0.01 and 0.04 mm...[and include] subangular...quartz sand [sic] grains...lying in a very dense matrix...which essentially consists of a fine network of newly formed, fine needle-like sericite and chlorite aggregates that have intergrown with extremely fine calcite grains...[plus] fine sprinklings of an ore component that looks opaque in thin section...[and] epidote...[and] rare zircon...[and] detrital tourmaline grains." The greywacke sandstones are described as consisting of "subangular quartz grains and often horizons enriched in opaque oxides...[plus] subangular grains of serpentinite fragments and feldspar-quartz intergrowths...[with] quartz grains...between 0.02 and 0.2 mm...[and] interstitial spaces...[filled with] calcite and fine, felt-like aggregates of sericite and chlorite intergrowths...[plus] metamorphically formed epidote...[with] tourmaline and zircon occur[ring] less frequently as detrital components."

Comment

Their "opaque ore component" and "opaque oxide" are hematite, and their "newly formed" minerals are the product of diagenesis or metamorphism. The "serpentinite fragments" and "feldspar-quartz intergrowths" are rock fragments.