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Tell El-Hibeh Limestone: Ancient and Modern Egyptian Quarrying Technology with EDXRF Block Provenance Analysis

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Abstract

Limestone and its interbedded marl deposits form an economic resource that was utilized at El-Hibeh, ancient Teudjoi/Ankyrononpolis, a tell mound in middle Egypt. The archaeological site contains the small Amun temple, at least two limestone (packstone) quarries, statues, sarcophagus lids and bases, limestone (packstone) construction blocks with and without relief, and major mudbrick structures. The temple blocks are made from a local packstone-limestone that has been saturated by Nile River water and is deteriorating at a rapid pace. The limestone at El-Hibeh is a packstone. Several packstone quarries occur in the archaeological site. One appears to be of recent vintage and was mined using modern drilling and blasting techniques. Another is an ancient quarry that utilized natural sedimentary and structural features of the packstone-marl deposits to manufacture blocks for various utilitarian purposes.

This study assessed the differences in economic activities, apparent values, and methods of production of packstone through a broad time span (Dynasty 22 to present day). We analyzed the clay content of the packstone with SEM-EDX, and studied the relationship between the clay and the accumulation of sodium chloride (salt) from the evaporation of Nile river water. While the marl clay content of the sedimentary deposits was an advantage for some modern and ancient economic enterprises, it has been a serious detriment to ancient packstone preservation. But interestingly, this apparently had not affected the value of the packstone, both for building blocks, sarcophagus production, and as a material for carving during ancient times. Further, it appears that the hib-clays and gypsum were utilized during the Roman period for manufacture of plaster. In order to assess the production methods for the ancient quarry we utilized portable EDXRF spectrometry to source the locations where the ancient blocks were acquired within the quarry by analyzing both the local unfinished blocks and the quarry walls. An assessment of the regional structural joints and joints in the ancient quarry provided an understanding of the mechanism of stone block production.

Keywords: El-Hibeh; SEM-EDX; Portable EDXRF; Limestone Geochemical; Provenance; Limestone Quarry; Salt Corrosion of Limestone; Packstone

Introduction

El-Hibeh, ancient Teudjoi/Ankyrononpolis, is located on the east bank of the Nile River in Middle Egypt, about 55km south of the modern town of Beni Suef, with abundant packstone, desert sediments and Nile River alluvium (Figure 1). Packstone is a major component of the site of El-Hibeh. It is the most prevalent geologic feature on the site other than desert carbonate sand, and was culturally modified in a number of ways for various projects, such as building blocks for the small Amun Third Intermediate Period temple (tenth century BCE), for stone carving, and for sarcophagi throughout millennia (Figure 2). No real study has ever been conducted at the site to determine where the packstone comes from for these various projects, nor to understand quarrying methods and quarry selection. Many packstone outcrops are present throughout the site, some of which may have been utilized for stone block production. It was presumed that the majority of packstone structures found at El-Hibeh were quarried locally, primarily because of the abundance of packstone, leaving no reason to haul it in from a greater distance. Many questions also remained concerning the selection of packstone: were blocks selected due to their proximity to building projects, or was there an understanding of quality, and were blocks chosen based on the physical properties of the outcrops and horizons within the outcrops? The aim of this study was to look at one known quarry and extract as much data as possible, placing it in relation to the rest of the site and hopefully providing some answers to abundant questions. The limestone throughout the site of El-Hibeh is of shallow marine origin, and is more of a dense packstone than formal all chemical cemented limestone. The sediments most likely represent a shallow mixing zone, where carbonate material was derived from fringing reefs and was mixed with terrigenous materials, such as clays. These sediments were then pressed together to form the packstone seen at El-Hibeh. The packstone beds are interspersed with marl (siltaceous carbonate and clay mixtures) and gypsum beds (selenite and anhydrite). In ancient times, this stratigraphy was taken advantage of for tomb construction. Shafts were built through packstone, and then the chambers were carved into the much softer marl. Evidence of this method of tomb construction is present in numerous locations throughout the site.

Figure 1: Location of El-Hibeh.

Figure 2: Satellite image of El-Hibeh showing the location of the temple, the square enclosure (the upper left hand area of the photograph), the limestone hills east of the archaeological site, and to the west and south of the site are agricultural areas in Nile silt.

Although the temple still stands, it has suffered considerable loss of structural integrity and relief decoration. SEM-EDX analysis of packstone chips spalled off temple blocks identified significant amounts of sodium chloride (halite) and expandable clays in the packstone. These mineralogical attributes are of significant economic utility with respect to the manufacture of hib plasters (gypsum and marl clay) and cement; they are however, detrimental to the stability of packstone blocks subjected to cyclic Nile River water saturation and subsequent drying. We used portable NITON EDXRF analysis for studying the intraquarry provenance of construction and sarcophagus limestone. Two very different types of packstone quarries (Figure 3) located at the ancient town site of El-Hibeh were investigated for the purpose of determining their work methodologies. One quarry, circa 1900's, utilized drilling and blasting methods to remove large quantities of hib clay containing marl layers, [1], and packstone chips and cobbles presumably for modern plaster and/or cement production. This type of activity may have contributed to the modern name of the village of Hiba. A second quarry, pharaonic in age, employed natural regional structural joint sets for building block removal. Unfinished packstone blocks and packstone outcrops in this quarry were studied by portable EDXRF to ascertain if it is possible to classify the intra-feature outcrop locations that unfinished blocks were acquired from. This mode of geochemical sourcing is most difficult as there are few trace elements that occur within the natural packstone for fingerprinting the rock for such precise spatial classification. We chose the square enclosure quarry primarily due to the ease of distinguishing it as a quarry. The square enclosure is also a unique and little understood feature of the site, and the subject of another investigation [2]. So the more we know about all components making up the square enclosure structure, the better our chance of understanding its functions. This area at first seemed to be a well-contained quarry. A total of 27 major blocks in various stages of dressing, including some appearing to be completely unworked and others near completion, lay strewn all over the SE quadrant of the enclosure, right in front of a small packstone outcrop. For identification, we gave the quarry the designation SEQ, and divided the outcrop into four lateral horizons: A, B, C, and D. A zone of marl and gypsum separates each packstone layer-horizon so that the packstone layers are sandwiched between much softer, non-lithified sediments. We then sampled along the horizons with the Niton unit, paying particular attention to the joint systems and lateral facies changes. The goal was to sample the chemistry along each horizon and take physical measurements to determine if it was possible to get distinctive results for the joints with the hope of matching quarry blocks up with the horizon they originally came from chemically and physically.

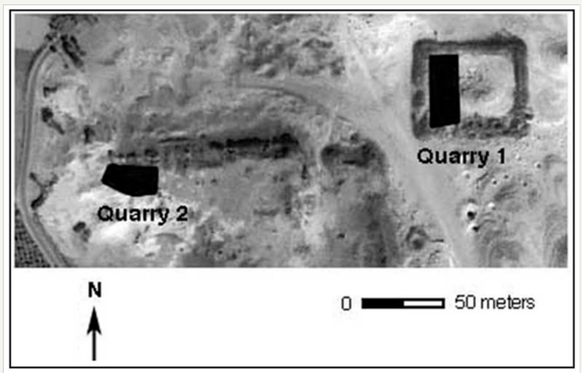

Figure 3: Satellite image of El-Hibeh, showing the location of the two quarries: Quarry 1 is an ancient Quarry and Quarry 2 is of late historic age. Quarry 1 is inside the Square Enclosure which is made from mudbrick.

Packstone Corrosion at El-Hibeh

Packstone is a poorly cemented limestone where the clastic and authigenic carbonate grains are poorly cemented together ostensibly through overburden pressure. In the case of the El-Hibeh packstone, there is also a significant portion of clastic clay and some authigenic selenite interbedded with the packstone, and also included as major mineralogical components of the packstone itself. These mineralogical attributes of the packstone provide for significant issues in archaeological preservation as well as contributions to the economics of the resource. For example, plaster production during Roman time at El-Hibeh was supported because of the presence of the local marl Hib resource, but this is not the case for earlier resource use. Consequently through time, from the 22 Dynasty to almost present day different components of this packstone resource were utilized differently throughout the site due to changing economic needs of the population. These economic attributes provide for different degrees of site preservation through time, in addition to byproduct accumulations from mining (quarrying) and manufacture. The packstone Amun temple was built into the local packstone and it was situated on the river's edge, although, today the riverbank lies approximately 300 meters from the El-Hibeh tell mound (Figure 4). Outcrop weathering scars are present in this area, suggesting that the removal of packstone blocks occurred during ancient time and although we did not address the provenance of the temple blocks it appears reasonable to assume at this point that they are extremely local and specific to the immediate area of the temple itself.

Figure 4: Amun Temple

Packstone stability is a function of volume expansion due to montmorillonite-kaolinite clay swelling and salt (NaCl) crystallization (SEM/EDX), which has caused structural-decay in limestone blocks lying within the vadose soil zone and/or the capillary fringe above the soil horizon. The local water table varies and has varied seasonally over time, and today it seems to lie considerably above the temple's packstone floor most or all of the year. Water ponding is not unusual within the temple. Local crop irrigation upslope of the temple and just south of the tell mound makes it even worse during certain times of the year (Figure 2).

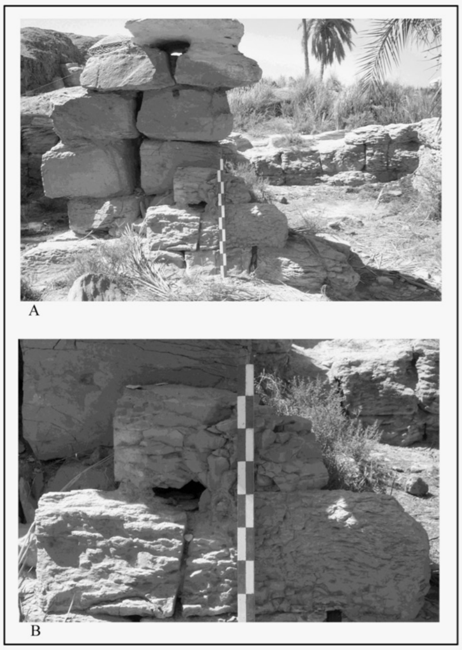

Figure 5: Highly fractured yellowish packstone temple blocks and resulting destabilization of the temple wall. Photograph B shows the undulating bedding plain-like stacked and repetitive fracture system.

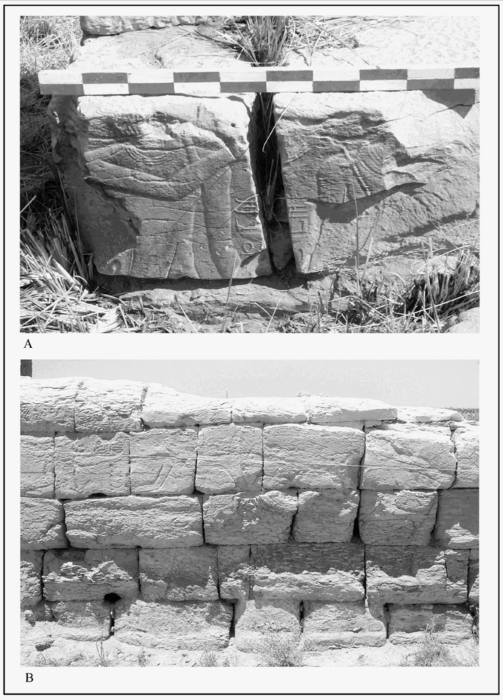

Figure 6: Packstone block relief: Photograph A shows blocks near the present sediment surface, and B shows the back exterior wall of the temple with relief still visible above the old excavated-soil zone line.

Temple block corrosion has not been limited to soil zone reactions (Figure 5). The self-supporting granular framework of the packstone also has disintegrated in upper temple wall blocks lying significantly above the capillary fringe (Figure 6).

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Here, corrosion apparently results from aerosol–dewdrop shrink swelling and thermal loading of smectite. The packstone's natural cementation provides inadequate cohesion under these conditions. Temple relief decoration survives (Figure 6) in wall areas partially shaded from solar radiation, sufficiently above the soil capillary surface, and/or constructed of better quality packstone blocks with low hib-clay content. SEM-EDX analysis of the spalled packstone fragments at the base of the packstone temple back wall supports the notion that the hib-clay content of the packstone is the major contributor by soaking up the Nile water accumulation within the packstone (Figure 7). This water contains sodium and chlorine ions, responsible for halite crystallization during evaporation. During halite crystallization there is a significant volume expansion at the location of the salt, and this disrupts the inter-grain cohesion of the packstone resulting in internal fracturing. The packstone crumbles as a result of this action. Consequently, the best method for temple preservation would be to bury it and keep it saturated with Nile water, thus, inhibiting the formation of salt and also dissolving the salts that presently exist in the rock.

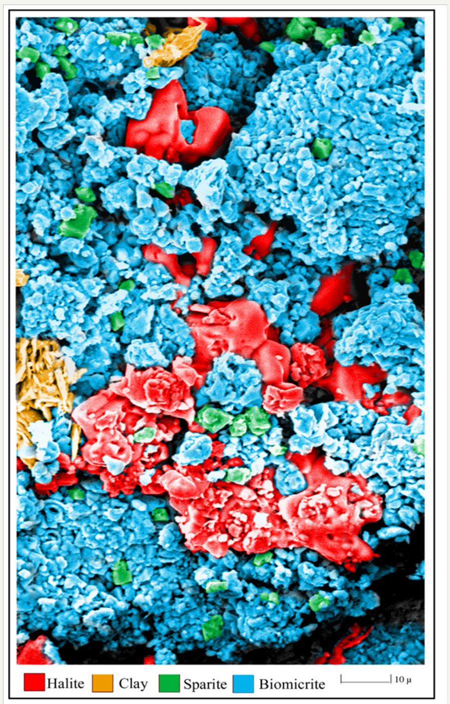

Figure 7: False color SEM backscatter photograph of packstone temple rubble. Biomicrite are small calcite grains that are mostly fossil fragments, sparite are larger well crystalized clacite grains, halite is sodium chloride (salt) and clay is dominated by montmorillonite-kalonite mineralogy.

Below this relief the packstone is deteriorated as this portion of the wall was situated below the surface soil horizon when the temple was first excavated and thus the blocks were already saturated with Nile water and when they dried sodium chloride salts in the hib-clays expanded and destroyed the packstone cohesion.

There is no technique presently known that will provide a barrier for salt formation in the packstone due to the extensive porosity of the rock. Complete vacuum epoxy impregnation does not seem feasible. Nile water impregnation of the temple packstone must have occurred prior to the rise of the level of the Nile due to the construction of the Aswan dam; however, it is likely that this was confined to periods of flooding and not significant enough to warrant concern.

The Packstone Quarries of El-Hibeh

Figure 3 shows the location of the two quarries studied at El-Hibeh. Quarry 1 is inside the mudbrick necropolis enclosure [2], which is just north east of the main tell mound. The actual function of the enclosure is not well understood, but about one third of the area within the enclosure, on the east side of the enclosure, is a small limestone hill structure with scattered unworked and partially worked packstone blocks. Quarry 2 is located near the northwestern portion of the site in an elevated packstone outcrop. There are extensive marl, hib-clay, and pebble to sandsized selenite anhydrite debris on the ground in piles and scattered though out the area. This is apparently the waste from pulling packstone from the outcrop face, in addition to packstone not yet taken from blasting operations. The location of this debris field makes it feasible to load trucks on the main road immediately down slope of the mining area. We have no idea of how this modern quarry area was utilized in ancient time as to date there have been no test excavations in this area; however, there are ancient anthrosols that are presently eroding out from underneath the modern quarry debris, and so future analysis of this area may provide more enlightened view of its history through time.

Structural Geology of Packstone Hills

Figure 8: Joint set photographs from Quarry 1 (Ancient Quarry in the Square Enclosure) Photograph A is of a master joint set taken in quarry 1 between chemical sampling point A2 to A4. The joint line going from the lower right corner to the upper left in the photograph is trending as 105 degrees. We calculate that possibly 6 blocks could have been removed from this joint set. Photograph B is looking down the 195 degrees joint line. We figure four blocks could have been removed from this joint set area. There is one block still in the joint that has not been removed (dimensions are: along 105 degrees=70cm in length and along 195 degrees=120cm in length). The total measurements of this joint set scar are: along 105 degrees=180cm, and along the 195 degrees line 315cm. The average thickness for the scar blocks is 64cm.

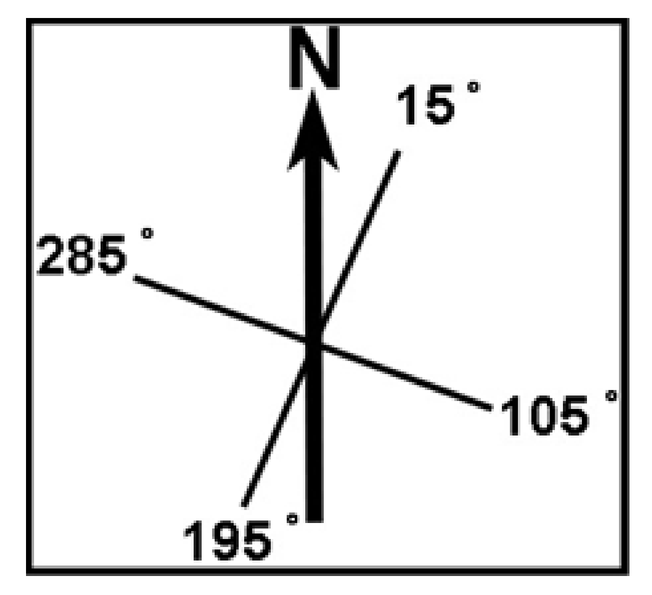

Figure 9: Packstone tensile orthogonal joint sets for El-Hibeh, Egypt. The north arrow is show for reference.

The packstone hills and outcrops of the Central Eastern Desert south of Beni Suef in the specific area around the El-Hibeh tell mounds are not related to the regional tectonic framework of Egypt. This is substantiated by the work done by Youssef [3] and Said [4]. Said [4] reports four major shear fault systems that are oriented at: 55°, 70°, 80° and 150°. Measurement of joint sets found in the local packstone throughout El- Hibeh area (including the tell mound and limestone hills to the east) are tensile displacements with a 15° to 195° liniment strike and an orthogonal joint set to that of 105° to 285° strike (Figure 8). This makes the regional orthogonal net oriented 15° to the NE (Figure 9). As far as we know at the present time this tensile orthogonal net is related to the compaction-shrinking of the local packstones and not controlled by the regional Precambrian platform.

The importance of these observations center around the production of quarry blocks at El-Hibeh. It appears from quarry block scars that the regional orthogonal joint sets were utilized for the production of packstone blocks. For a single block, one block edge is normally bound by one of the two joint sets. In some cases, it appears that both joint sets defined the block dimensions. Obviously, this reduces the amount of quarrying effort needed to remove a block from the outcrops. The upper and lower portions of the block are normally bounded by marl and/or gypsum interbeds, so that the work effort to remove a block utilizing normal orthogonal joint sets is minimal.

Modern Packstone Quarry Technology (Packstone Quarry #2)

This quarry (labled BM06Q) is located in the northern most elevated portion of packstone outcrops at El-Hibeh. The packstone outcrop utilized for production trends at an acute angle to the 105-265 degree regional joint set. The joint sets are visible at each stratigraphic horizon, but the edge of the rock face is not parallel to the joint set (Figure 10 & 11). There is no indication that the joint sets were utilized for block production. Rather, intense drilling and blasting (Figure 12) was utilized as a means to win rock from the outcrop faces, and the result was the cutting of a rock face that does not conform to regional structure. Massive piles of blasted rubble that have not been fully removed remain at the base of the outcrop (Figure 13). There are no preform blocks of packstone at the quarry. The most easterly end of the outcrop forms a rock face that is at an acute angle to the quarry face on the west, and this face is parallel to the regional joint set. It has not been utilized for quarry production. There are no quarry blocks present in the area, and the face is undisturbed except for natural weathering. The weathering of the rock face in this area indicates that this outcrop surface has been exposed for a considerable period of time, as the packstone beds have very well-rounded surfaces and the marl-gypsum interbeds are indented as they are more susceptible to all forms of environmental attack dominated by water and heat. Consequently, the eastern boundary for the modern quarry occurs at the boundary between the changes in the strike of the outcrop as shown in Figure 10.

Figure 10: Photograph composit of Quarry 2

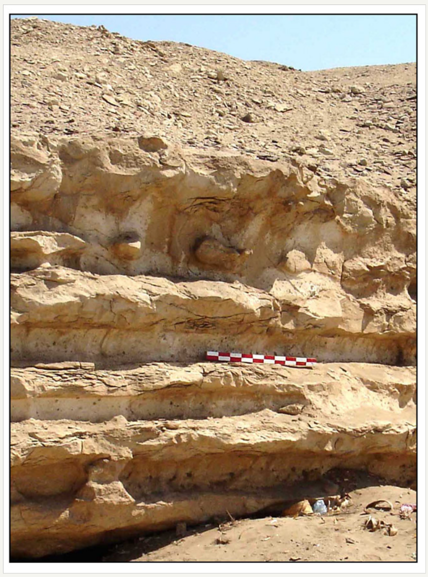

Figure 11: Natural outcrop face for Quarry 2 area showing normal weathering: the rounding of the packstone layers and preferential weathering of the hib-marl clay indented beds. As this weathering in the desert takes considerable time, it is an indication that no recent disturbances occur here.

Figure 12: Drill holes for rock blasting

Figure 13: Debris field from modern mining

EDXRF NITON Spectrometer Chemistry of the Modern Quarry (BM06Q)

We acquired trace and major element data (Sr, Fe, and Ca) from five locations at BM06Q (Figure 14), (Table 1). These major and trace element concentrations were obtained in parts per million and are plotted on a triangular diagram (Figure 15) showing the relative concentrations of each (calcium concentrations were divided by 100 to enhance the plot). The purpose of providing these data is for comparison with other quarry locations at El-Hibeh and not to ascertain the provenance of packstone debris that was apparently the main product from this quarry. The rational for using these elements is presented in the next section.

Figure 14: EDXRF sampling locations

Table 1: EDXRF NITON Spectrometer Data.

Sample No.: BM06Q	Sr ppm (+/-)	Fe ppm (+/-)	Ca ppm (+/-)
339	997.1 (17.5)	1400 (100)	460100 (1300)
340	779.9 (15.9)	1500 (100)	420700 (1200)
341	1100 (<100)	2600 (100)	432500 (1200)
342	2000 (<100)	5400 (200)	411600 (1200)
343	1000 (<100)	856.2 (89.0)	444500 (1300)

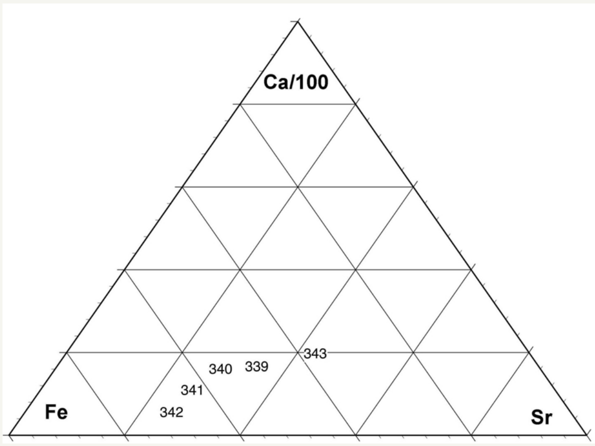

Figure 15: EDXRF spectrometer data for Fe, Sr and Ca for outcrop faces in the BM06Q modern quarry. The location and tabled geochemical data are provided in Figure 13 & Table 1.

Ancient Packstone Quarry (SEQ) Mining Technology and Block Provenance

The ancient packstone quarry (Figure 16) within the mudbrick walls of the Square Enclosure is composed of four packstone layers each separated by Hib-clay marls (Figure 17). The gypsum concentration in the marl layers is not as notable as it is in some of the other outcrops at El-Hibeh. Of special interest for us was the fact that unworked and partially worked limestone-packstone blocks were located immediately within the quarry boundaries (Figure 18). So that it is obvious, without utilizing geochemistry that these blocks originated in that location. This provides a much more controlled test of the utility of EDXRF analysis. We utilized only three elements for this analysis because very few elements showed consistent presence in all of the blocks and outcrop faces. Manganese for example could have been utilized because only very few sample locations did not have detectable concentrations above background. Since manganese is most likely also affected by desert weathering reactions (for example the production of desert varnish as an oxyhydroxide), we decided that it was a problematic choice and therefore did not use it). Consequently, we decided to utilize just three elements: calcium, strontium and iron (Table 2). The geochemistry for each of these elements is reasonable with respect to provenance fingerprinting. The source components (Figure 7) for the packstone are bicarbonate hash, clay impregnated with iron oxyhydroxides, a few silicate minerals, siliceous biogenetic debris, and some sulfates. Consequently, we are investigating minor changes in sedimentary deposition and diagenesis as the prime mechanisms for obtaining a provenance characterization as we are interested in the variation or ratio between the carbonate (Ca) deposition and terrigenous component (Fe). For this packstone, the carbonate deposition also includes some chemical formation of spar calcite (Figure 7) and therefore the ratio of strontium (Sr) to calcium is of interest. Hence, it is a reasonable first attempt to utilize these three elements for limestone-packstone fingerprinting. Initially, we used cleaned, flat surfaces on the weathered limestone to obtain samples. After working up the data, we realized the error. These surfaces have been sitting exposed for so long that they became heavily contaminated. Also, salts from weathering have infiltrated the layers, raising the values of some elements. And numerous calcite fracture zones were found, containing all sorts of impurities. This calcite lining occurred when two blocks were separated by a fracture-joint set. The calcite crystals formed between the two, and now are often exposed when one of those blocks was removed. Sampling had to be redone completely, with only freshly broken surfaces analyzed. A chisel was used to break a few centimeters off of a nice surface, and once clean, pure limestone was reached the analysis could be performed. One of the key elements in distinguishing whether or not clean limestone was reached was scandium. In our first run, all the samples contained this element. The second time, scandium was present in none of the samples. In this study we were more interested to see if EDXRF provenance analysis could be accomplished with the NITON field portable spectrometer than actually obtaining finite information on the origin of the El-Hibeh packstone architectural blocks. Further, with today's advancements in portable EDXRF analysis, there are several other light and heavy elements that would probably aid this analysis. Future studies will likely obtain more comprehensive predictions then have been accomplished here.

Table 2: EDXRF Spectrometer data for quarry scars and unfinished quarry blocks from Quarry 1 (Ancient Quarry in the Square Enclosure).

Sample	Sr (ppm)	Fe (ppm)	Ca (ppm)
A1	745.3 ±15.7	6300 ±200	282500 ±1000
A2	738.8 ±14.7	3100 ±100	431700 ±1300
A3	708.0 ±15.2	2100 ±200	297200 ±900
A4	1000 ±20	1500 ±100	419600 ±1200
A5	998.3 ±18.8	1700 ±100	323200 ±1000
B1	734.8 ±16.0	2500 ±100	299500 ±1000
B2	874.1 ±16.8	1600 ±100	404900 ±1200
B3	870.3 ±16.4	3200 ±200	391200 ±1200
B4	942.5 ±16.9	1100 ±100	453000 ±1300
B5	988.3 ±16.2	4000 ±200	442600 ±1300
B6	725.6 ±15.3	1500 ±100	394500 ±1100
B7	783.1 ±17.7	1800 ±100	270500 ±900
B8	921.7 ±10.1	2000 ±100	431000 ±1300
B9	997.1 ±17.1	1500 ±100	494600 ±1400
B10	930.4 ±16.3	2100 ±100	451800 ±1300
B11	1000 ±20	2200 ±100	365600 ±1100
C1	998.4 ±18.0	1100 ±100	326300 ±1100
C2	1100 ±20	774.1 ±90.4	366500 ±1100
C3	1100 ±20	1100 ±100	437400 ±1300
C4	743.6 ±15.5	1100 ±100	406300 ±1200
C5	1000 ±20	1600 ±100	481000 ±1300

C6	1200 ±20	681.3 ±78.1	481000 ±1300
C7	726.4 ±14.2	573.9 ±72.5	448700 ±1200
C8	1100 ±20	1000 ±100	448500 +/-1300
D1	1100 ±20	1300 ±100	470000 ±1300
D2	1100 ±20	777.3 ±83.6	463600 ±1300
D3	1000 ±20	874.8 ±88.8	378800 ±1100
QB1	995.9 ±17.1	1300 ±100	460500 ±1300
QB2	1100 ±20	1700 ±100	502000 ±1300
QB3	1000 ±20	1500 ±100	517800 ±1400
QB4	1100 ±20	2200 ±100	458900 ±1300
QB5	1200 ±20	1400 ±100	534000 ±1500
QB6	610.0 ±14.8	2200 ±100	281100 ±900
QB7	890.2 ±16.0	1500 ±100	414300 ±1100
QB8	1100 ±20	1400 ±100	423700 ±1200
QB9	889.5 m±15.3	4800 ±200	486100 ±1400
QB10	869.3 ±15.6	3900 ±200	470800 ±1400
QB11	952.8 ±16.0	1700 ±100	522100 ±1400
QB12	798.9 ±15.9	1100 ±100	430400 ±1200
QB13	780.7 ±14.8	3400 ±200	425400 ±1200
QB14	950.1 ±17.6	3300 ±200	340100 ±1100
QB15	809.7 ±14.9	3000 ±100	486700 ±1400
QB16	742.7 ±16.7	4000 ±200	296300 ±1000
QB17	750.0 ±16.9	3800 ±200	306200 ±1000
QB18	763.3 ±15.6	3900 ±200	386700 ±1200
QB19	858.6 ±15.9	2900 ±100	440600 ±1200
QB20	868.0 ±15.8	1700 ±100	483400 ±1400
QB21	845.0 ±16.1	1700 ±100	413500 ±1200
QB22	816.4 ±15.7	1400 ±100	386100 ±1200
QB23	837.3 ±15.8	2200 ±100	405900 ±1200
QB24	755.6 +/-15.0	2100 ±100	376200 ±1100
QB25	815.1 ±14.9	3800 ±100	487400 ±1400
QB26	897.5 ±16.1	4500 ±200	455500 ±1300
QB27	866.4 ±15.5	3700 ±200	439800 ±1300

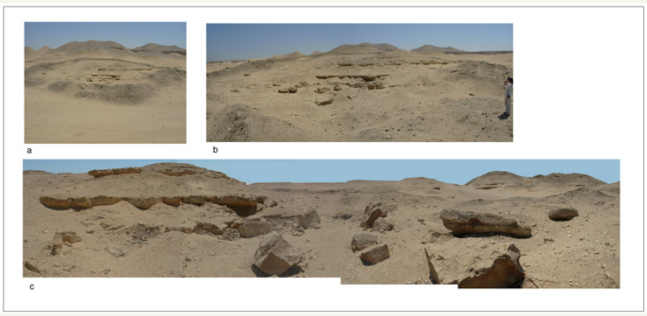

Figure 16: Overview of Ancient Quarry 1 within the mudbrick square enclosure. The photographs are taken looking northeast.

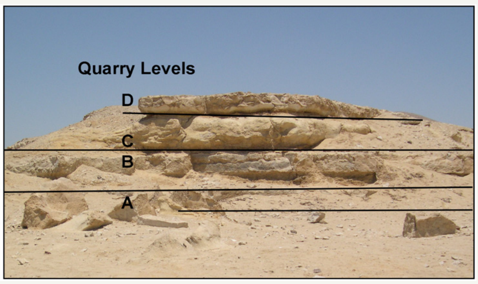

Figure 17: The Central Quarry Hill within the Square Enclosure showing the different packstone (limestone) layers that were studied (A through D). Detailed geochemical data were taken from different sequential locations for each layer.

Figure 18: Some of the unworked and partially worked quarry blocks studied is shown in this figure. QB5 is actually a partial sarcophagus base.

Figures 19 and 20 show that there is a stratigraphic trend at this location for an increase in strontium with the height of the stratigraphic section (going from layer A to Layer D). This observation assists the fingerprinting process as there are obvious differences in carbonate mineralogy and mineral chemistry in the stratigraphic sequence; therefore, strontium is a good choice for fingerprinting.

To collect physical data on the blocks and horizons of the outcrop we measured dimensions of the blocks (length, width, thickness) and took the dimensions of each joint set in the outcrop. Bed thickness is an important measurement, as it automatically dictates the maximum thickness of blocks that could be extracted. It looks as though in many cases multiple blocks could have been pulled from one joint. For instance, with the A2 to A4 master joint, two blocks still sit within the joint, a block with dimensions 110cm X 105cm, and a block 100cm X 70cm. Two blocks of equal size, as well as two blocks with dimensions roughly 100X100 cm could also have been extracted from this joint (Table 3).

Table 3: Quarry bock physical data.

Block	Length (CM)	Width (CM)	Thickness (CM)
QB1	153	82	40
QB2	260	84	40
QB3	120	102	45
QB4	105	68	53
QB5	80	57	32
QB6	56	47	17
QB7	66	42	28
QB8	94	76	52
QB9	125	77	36
QB10	128	76	51
QB11	117	66	40
QB12	120	117	39
QB13	78	73	56
QB14	85	59	48
QB15	87	82	82
QB16	84	63	49
QB17	74	63	39
QB18	120	117	76
QB19	74	65	38
QB20	80	69	38
QB21	97	96	54
QB22	124	68	54
QB23	56	46	26
QB24	42	38	15
QB25	48	37	34
QB26	69	45	29
QB27	98	58	41

Munsell soil color data taken on the blocks and limestone outcrop also proved to be extremely relevant. We looked first at the horizons in the outcrop, and quickly noticed that the color on top was consistently around 10 YR 7/2, and the color at the bottom of the horizon in contact with marl was around 5 YR 6/2- 5 YR 7/2. The surfaces were all weathered and jumbled and light in color. The bottoms, where the packstone was left as an overhang after the marl weathered out, were orange due to iron staining from contact with marl. After looking closely at the quarry blocks, we realized that this pattern held true in every case. With this information it was possible to tell the original orientation of nearly every block.

Discussion

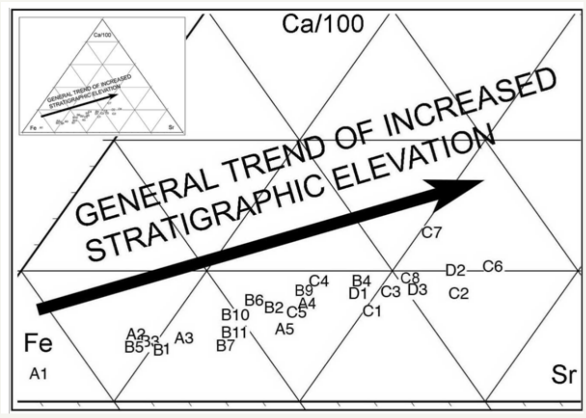

Figure 19: shows that there is a stratigraphic trend at this location for an increase in strontium with the height of the stratigraphic section (going from layer A to Layer D).

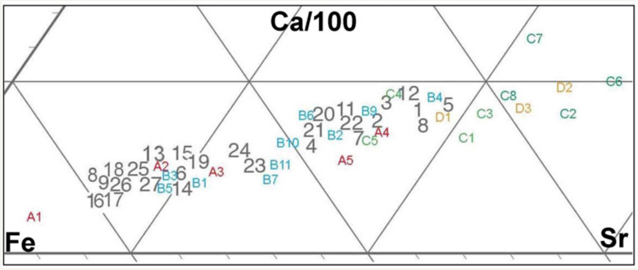

Figure 20: EDXRF spectrometer data for Fe, Sr ad Ca for outcrop faces (letters A-D, and numbers) and quarry blocks (just numbers). For example, quarry block 5 (QB5 in Table 2), which is a sarcophagus base (Figure 18) is geochemically similar to the quarry location of B4 (and D1). It appears however, from these data that level D was probably not utilized to manufacture quarry blocks. Rather most blocks appear to geochemically correlate with the lower quarry levels A and B. Some blocks appear to be derived from level C.

What we found from running three-element geochemical analysis is that packstone outcrops along the entire site have relatively similar chemistry, so it may be impossible with portable EDXRF analysis to take any block on site (such as those in the temple) and place them in the quarry they originally came from based on chemistry alone. This is in evidence when you look at the geochemistry plot (Figure 15) of the modern quarry and (Figures 19 and 20) plot of the ancient quarry. There is a significant overlap in the packstone geochemistry. However, the three-element plot can be utilized with compelling results to distinguish blocks that are from a known quarry source to their spatial position in that quarry. We believe that additional elements not utilized in this study may be also beneficial in characterizing limestone blocks from different quarries.

Further, this information suggests that given an accurate enough baseline geochemical library it should be feasible to deal with limestone provenance from different archaeological sites within Egypt. For this study, geochemistry does have importance when analyzing blocks within a specified quarry. There are enough minor variations in the strontium/calcium ratio and iron to match particular blocks with specific horizons. When this chemistry is matched with the physical dimensions of blocks and outcrop horizons, it is possible to distinguish from which joint blocks lying on the quarry floor were extracted. Ancient quarry methods for El-Hibeh utilized natural and prevalent structural joint sets that originate as shrink-swell tensile displacements formed during packstone compaction. Quarrying methods appear to be quite simple and do not require extensive effort. One of the most interesting pieces of data to come from this exercise is the discovery that all packstone outcrops on the site exist in the same regional fracture plane. There are a series of fractures running both cardinal directions at 90-degree angles to each other, making up the regional joint systems. These joint systems created two natural sides of blocks, which people took advantage of when blocks of a certain size were desired. The size of the blocks depends on things such as regional stresses and the size of the limestone bed. This implies that any limestone outcrop on the site could potentially have been a quarry, and block selection may have been based on convenience because of the proximity of the outcrop location to the construction site, and size of the horizon, which dictates the sizes of blocks that can be removed. Quality of material may have been a more distant priority. Modern quarry activity – drilling and blasting at El-Hibeh, obviously affected the preservation of cultural materials, but there is evidence from erosion that some cultural data of value may be present beneath the debris field of the modern quarry. This previous activity combined with more recent and blatant insults jeopardizes the preservation of cultural values at the site. There needs to be a more comprehensive effort to assist in the management of valued cultural resources such as El-Hibeh. Purposeful destruction of site contents is obviously counter-productive to the actual values and norms that have been established by the Egyptian Government. Let's hope that the future provides a better framework for preservation than the past.

In the beginning of this paper we were concerned with various issues regarding the technology for stone block removal and use at El-Hibeh. We asked if stone blocks were selected based upon the convenience of location and/or based upon stone quality. In this study we did not analyze stone sculpture from the site (although it exists). We did analyze packstone from two quarries and assorted blocks and in our geochemical data package as well as from visual observation, and see no marked differences in packstone quality. In order to obtain better quality material the inhabitants of El-Hibeh would have had to import stone to the site. This was done with respect to granite and more mafic igneous rocks but not limestone-packstone. Within the site of El-Hibeh, there are obvious variations of packstone quality based upon the overall clay-gypsum content and degree of packing overburden and finally the amount of spar calcite crystallization inside the packstone. There apparently are only two ways to determine the quality of the packstone: by either observing it's weathering profile over a long period of time, or using modern laboratory analytical methods. It is unlikely that the inhabitants had opportunities to make rock quality choices. Our observations of blocks chosen for construction support this concept. It also appears that since packstone outcrops dominate the El-Hibeh topography, there were opportunities to acquire this building material in many locations in the site and no major need to quarry far from the location of use. With this concept in mind, we returned to the square enclosure to further explore the purpose of this ancient quarry. The best guess answer at present is that the packstone was intended for use in funeral related construction. There are burial features within the square enclosure. We presume that future archaeological activity within this feature will be able to shed more light on its function.

Conclusions

A. Packstone structures at El-Hibeh are in jeopardy of being destroyed by salt plucking actions of Nile River water. The only reasonable method for preservation is reburial. Any packstone structures that are excavated in the future should be recorded and then reburied instead of reburial to maintain preservation. Otherwise, archaeological investigations will be contributing to the physical destruction of cultural resources.

B. The modern quarry at El-Hibeh has probably destroyed abundant cultural resources, but it does appear that cultural sediments below the gravel quarry waste hosts intact cultural sediments.

C. The ancient quarry at El-Hibeh in the Square Enclosure probably represents a local production site for funeral related activities.

D. Portable EDXRF analysis of packstone blocks and outcrops has the ability to provide compelling evidence for intra-feature provenance. On minimum basis calcium, strontium and iron provide good fingerprinting.

E. Ancient quarrying technology took advantage of regional tensile compression structural joint sets. At El-Hibeh these sets are 15° east of due north. Above and below each packstone layer there are hib-clay and gypsum marl beds that have no structural integrity. Thus, the quarry blocks are naturally made with four joint faces and two (up and down) hib-clay faces. It appears that the natural blocks are removed from outcrop and then are tooled into useable objects.

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