Archaeology & History in Lebanon Issue fifteen : Spring 2002, p. 42-51

Abdel-Fattah M. Abdel-Rahman
Muntaha Saghieh-Beydoun

A PETROGRAPHICAL AND CHEMICAL STUDY ON GRANITES, MARBLES AND LIMESTONE FROM THE *CARDO MAXIMUS* IN BEIRUT CITY CENTRE (SITE CODE BEY 004)

ABSTRACT

Petrographic examinations show that the granitic rocks vary in texture from coarse-grained to pegmatitic varieties, and contain strongly zoned plagioclase. Mineralogically, these granitic rocks are composed of variable contents of quartz, orthoclase, plagioclase, hornblende, and biotite. Geochemically, the granitic rocks have a wide compositional range in their major and trace element abundance. Total rare earth elements (REE) ranges from 216-506 ppm. Standard variation geochemical diagrams show that the granitic rocks are calc-alkaline in nature, and are particularly identical to Pan-African granitic rocks. The petrographic and chemical features of the examined rocks were found to be typical of those that crop up in western Saudi Arabia and in Eastern Egypt (including Sinai). Features of the red granites in particular are similar to those of the Aswan (Pan-African orogenic) granites.

The marbles consist essentially of non-foliated, granoblastic polygonal fabric, which is made up of a mosaic of fine to coarse-grained calcite crystals. The examined marble varieties exhibit a narrow range of major and trace element composition. The REE compositions of the examined marbles have been compared to those of Italian, Greek, and Turkish marbles; the data show that the examined marbles exhibit lower REE abundance than marbles from those regions. The pink limestone sample examined contains well-developed sub-microscopic pisolitic structures. This pattern is very different from that of the Lebanese limestone.

1 ARCHAEOLOGICAL BACKGROUND

BEY 004 extends from the edge of the western escarpment where the grand serail stands eastwards covering an area about 10,000 sq. meters (plan 1). The topography of the site is such that there is a shallow gradient from south to north and a slightly sharper one from west to east (fig.1). Excavations have revealed a dense urban layout of ancient Beirut during the Hellenistic, Roman, Byzantine, and Medieval periods.

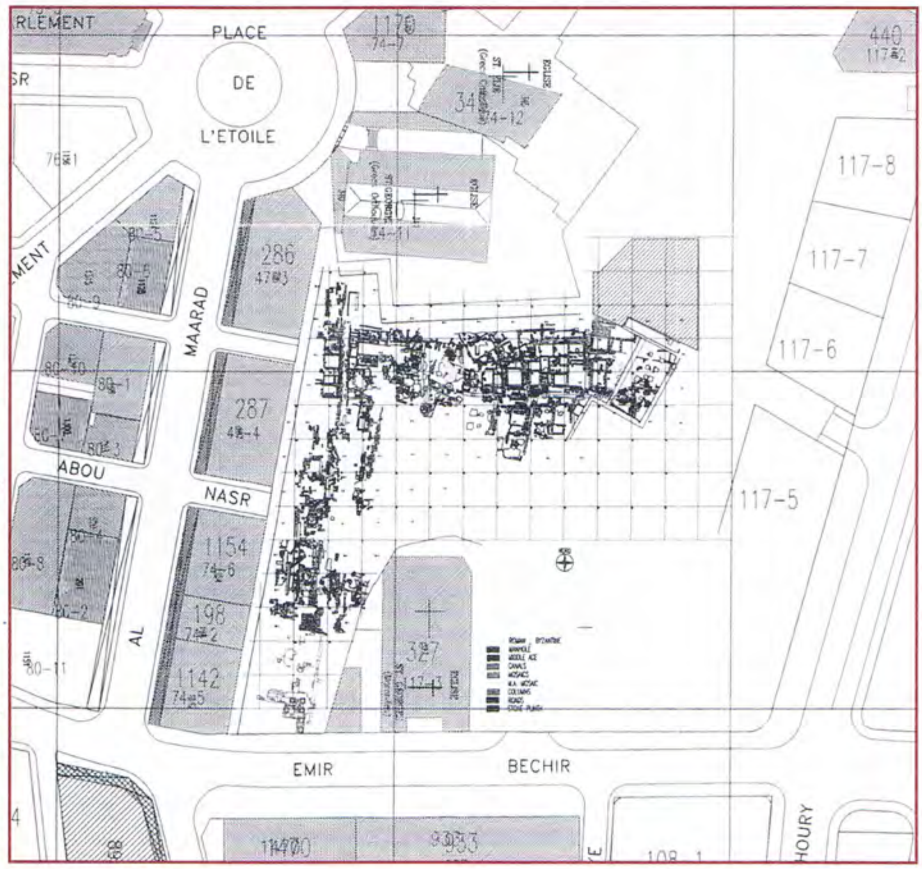


Fig. 1 Section taken from the grand serail to BEY 004.

Fig. 2 The *Cardo Maximus* in BEY 004.

Fig. 3 An east/west stratigraphic section taken across the *Cardo Maximus.*

Fig. 4 Photo showing the deep foundation of the stylobate.

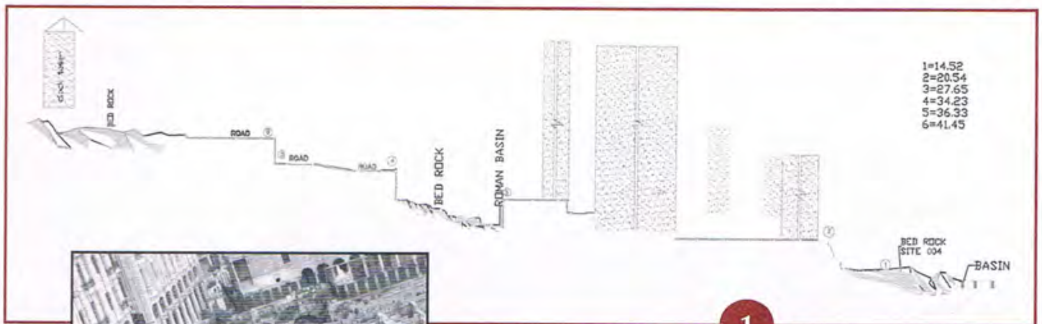
* We are indebted & very grateful to Dr John Hayes who first read this inscription.

The Cardo Maximus

A monumental colonnaded street was uncovered at the western edge of the excavation crossing the site from its southern to its northern limits, at a slightly northwest/ southeast tangent (fig. 2). The shallow gradient of the street course in BEY 004, reveals a 3 meter difference in elevation within a stretch of 110 meters long (the distance between northern and southern limits of the site).The street is defined by two colonnades of red and grey granite overlying thick stylobates. Each stylobate (1.30m wide) consists of three rows of large limestone blocks overlying deep 'rubble block form' foundations (w.1.90 m) that are laid in rock cut trenches (figs.3-4). This impressive infrastructure work is a standard Roman requirement for monumental walls or stylobates that were intended to carry hundreds of tons of monolithic columns (J. P. Adam, 2001, p.106; Vitruvius, 1960, 86). Heavy buttressing appears at regular intervals all along the western stylobate at points where columns were supposed to have been placed. Obviously, this buttressing was necessary because the western stylobate was built on sloping ground, and these deep buttresses served as revetments or supports for points of maximum strain.

Extant moulded stone plinths or pedestals for carrying columns (1m sq. & 0.60 m high) overly the stylobates at regular intervals of 2.50 m (distance deduced from where plinths seem to be undisturbed).

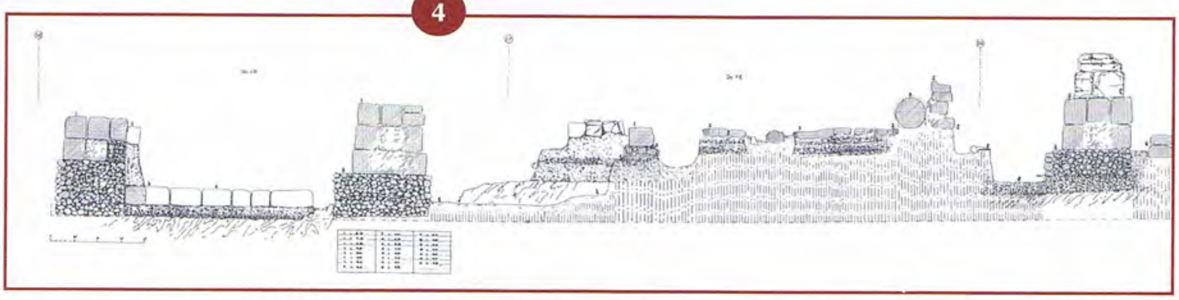
The width of the street, which is not uniform all through, is about 12.60 meters in the south, and 14 meters in the north. The reason for this variation has been recently revealed whereby remains of an earlier phase were uncovered at the foot of the north /eastern stylobate, specifically in square VIB. If we draw a line from square IIA northwards following the true alignment of the *Cardo*, this line would perfectly fit the western side of the early phase in square VIB, and corrects this deviation. Pottery and stratigraphy date this earlier phase, which is contemporary with the southern part of the street, to the beginning of the 1st century AD. Most probably, the colonnades with their stylobates were added about a century later. A fragment of an architrave inscribed with the names of Nerva and Trajan* was found along the *Cardo*, thus deducing that the colonnades with Corinthian capitals and marble architraves were added most probably during the reign of Trajan (AD 98-117. Granites from Egypt were first imported by the Romans during the reign of Augustus, but they did not become a familiar feature in the architecture of the capital and or the provinces, till the rule of the Flavian emperors reached a peak during the Trajanic period (Ward-Perkins, 1994, pp. 87, 118 & 134, n.17). Extant backwalls or portico walls were traced along both sides of the street and at a distance of 5.50 meters from each stylobate. These side lanes must have constituted covered walkways between the colonnades and the side buildings. Colonnaded streets with covered walkways are a characteristic feature of Levantine cities during the Roman period, as these provided shade from the heat, and



1


2


3


4

perhaps space for stalls (Segal, 1997, pp. 47-48). These wide streets were not only thoroughfares but also constituted the main arteries of the city where a great deal of commercial and social activities took place. Scholars believe that these shaded walkways between the colonnades and the side buildings were the stoa and the agora (*ibid.*, p.10).

5


Fig. 5 **A limestone column in NE *Cardo*.**

Fig. 6 **Half a marble column.**

Fig. 7 **Grey granite columns on podia.**

Fig. 8 **Red granite column.**

Fig. 9 **Marble Corinthian capital.**

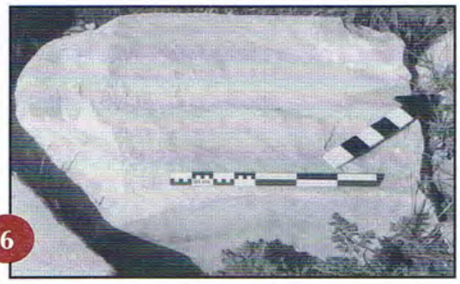
Four types of columns were documented along the *Cardo*:

1. limestone columns of which three large fragments were found in the extreme northeastern limit of the street (fig. 5).
2. Part of a marble column was uncovered just south of the limestone fragments (fig. 6).
3. Grey granite columns are documented from squares IIS-IIIS on the Cardo and in the DGA excavation, just south of the Cardo, four columns were uncovered standing on podia (fig. 7).
4. The rest of the columns are of red granite (fig. 8).

All the capitals are of the Corinthian style, and like the architraves are made of white marble (fig. 9). The two distinctive elements in the colonnades of Berytus are:

1. The colonnades in 004 consist mainly of red and grey granite that was imported from Aswan in Egypt (J. P. Adam, 2001, p. 21), while colonnades in most Levantine cities are made of local stone -example Jerash (limestone), and Bosra (basalt).
2. In Berytus, columns (shafts and bases) rest above square stone plinths that overlie the stylobates, while in most Levantine cities, columns rest directly on the stylobates.

The colonnades rose to a probable height of 7.00 meters (or slightly more). The height of the shaft alone is 5.50 meters, and its pedestal is 0.60 meters. If we add to the latter, the height of the limestone column bases, the Corinthian capitals and the architraves, the colonnade would certainly attain a height of between 7.00 and 7.50 meters.

6


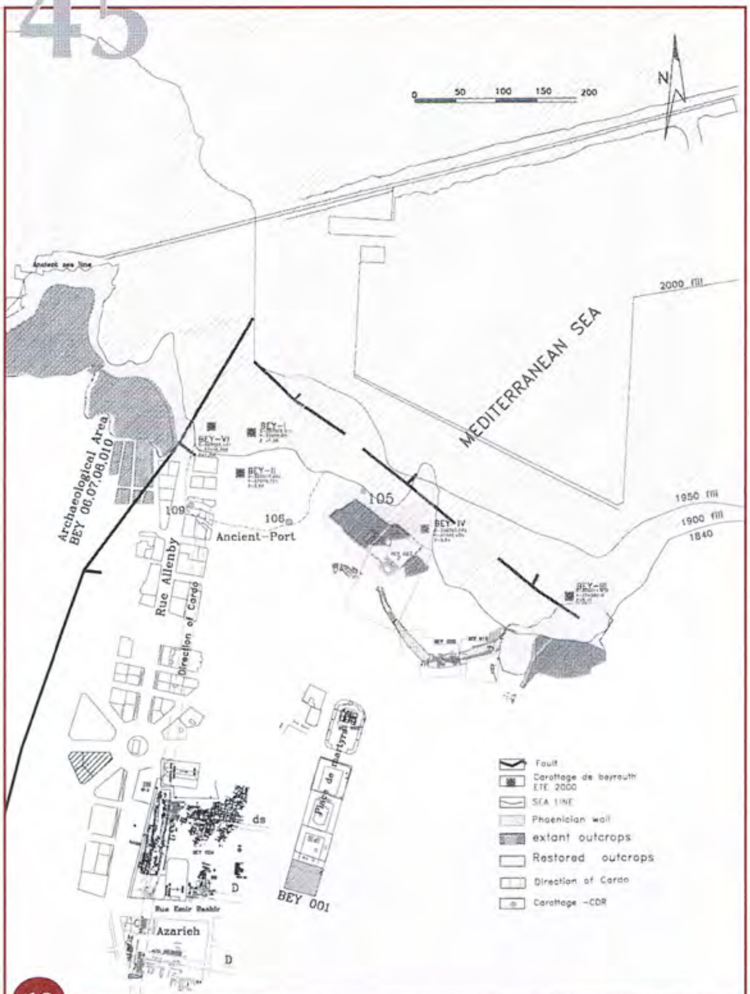
7


The grey granite columns have a wider diameter, and are taller. Variation in the size of columns is a normal occurrence along colonnaded streets (Ball, 1984, 385 ff.). In Berytus, the grey granite columns that were used to mark the façade of important public buildings often projected inwards towards the street. Three such instances occurred along the course of the *Cardo*, one along the western side of the street in squares IIS-IIIS, the second in the DGA excavations where these columns probably fronted a temple dedicated to Astarte, as we found hundreds of Astarte bro-

8


9


ken clay figurines in the vicinity. The third such interruption appears in front of the nymphaeum, where four columns mark the location of



10

this fountain building (Lauffray, 1976, fig. 9; Saghieh-Beydoun, 2002, in press).

The distance that the *Cardo* crosses between the southern edge of the Azarieh building and the northern limit of BEY 004, is about 250 meters (fig. 10). The run of this street towards its conjectured northern limit would be around 600 meters long. Because, if we were to project the Cardo towards the north continuing along the same alignment, the street would end at a certain point near the ancient harbour. The results of last year's core sampling in the area between the northern ends of Allenby and Foch streets, proved beyond doubt that here we are in the middle of a closed port.

The *Cardo* therefore provided the main link between the harbour, city centre and the precincts of the sacred area now under Azarieh building.

Fig.10 The course of the '*Cardo Maximus*' from under the Azarieh building northwards to the ancient harbour. The alignment of the *Cardo* beyond BEY 004 is conjectural.

2 Methods of analysis

Petrography. The granite, marble and limestone samples collected have been analysed petrographically in thin sections, using the polarizing microscope at the American University of Beirut. The photomicrographs were taken by a camera fixed on the petrographic microscope.

Chemistry. Major element chemical analysis of whole rock samples representing the silicates (granites) and the carbonates (marbles and limestone) were done using the X-ray fluorescence spectrometry at McGill University (Montreal). Minor elements were analysed using the same instrument. The rare earth elements were analysed by the induced coupled plasma mass spectrometry (ICP-MS) at the Memorial University of Newfoundland. The chondrite values used for normalization are those of Taylor & McLennan (1985), compiled from Anders & Ebihara (1982), and Evensen *et al.* (1978).

3 Petrographic analysis

The granitic rocks

(i) The grey granodiorite

The grey granodiorite is a medium-to coarse-grained hypidiomorphic granular rock, consisting of quartz (15 %), plagioclase (51 %), K-feldspar (21 %), biotite (5 %), amphibole (5 %), and accessory phases (3 %). Quartz forms interstitial anhedral grains (0.5 – 2 mm across). Plagioclase forms euhedral, zoned crystals, ranging in size from 1 to 3mm long. Alkali feldspar forms anhedral (typically 2 – 3mm across), moderately turbid, and typically non-perthitic grains. Biotite forms subhedral to euhedral (Fig. 11a) yellowish brown crystals, with crenulated margins. Grain size ranges from 0.4 to 2.8 mm long, and from 0.2 to 0.7 mm wide. It should be noted that biotite associated with calcic-amphibole (hornblende) is more typical of biotite occuring in calc-alkaline rocks (Abdel-Rahman, 1994). Calcic amphibole (mostly hornblende) occurs as green, subhedral to euhedral (Fig. 11a) slightly pleochroic grains (0.5 – 1 mm long), and is occasionally twinned. Accessory phases are represented by titanite, and zircon, typical of calc-alkaline rocks. These features are identical to those that characterize the Pan-African calc-alkaline granodioritic rocks (e.g., Abdel-Rahman & Martin 1987).

11 a

Fig. 11 (a) Photomicrograph of grey granodiorite (sample n°1), showing some of the minerals present; biotite (Bt), hornblende (Hb), quartz (Qz), and K-feldspar (Kf). (b) Photomicrograph of pinkish-grey granodiorite (sample n°8), showing zoned plagioclase (Pl), horn blende (Hb), biotite (Bt), and K-feldspar (Kf). Crossed polars. Width of field of view is 2 mm.

11 b

(II) The pinkish-grey granodiorite

This rock is very similar petrographically to the grey granodiorite, but it contains more strongly zoned plagioclase crystals (Fig. 11b), contains more hornblende than biotite, higher contents of titanite, and its K-feldpar is more typically perthitic. Thus the rock consists of quartz (14 volume %), plagioclase (52 %), K-feldspar (22 %), hornblende (7 %), and biotite (4 %), along with accessory titanite, and zircon (3 %).

(III) The red granite

The red granite consists of quartz (about 29 %), reddish-pink perthitic K-feldspar (36 %), plagioclase (26 %), biotite (6 %), hornblende (2 %), and accessory phases. Quartz forms minute (0.3 mm across) to medium-grains (2.8mm across). Perthitic alkali feldspar (mainly orthoclase) forms medium anhedral granis (4 mm across), as well as large (up to 7.8 mm long) subhedral crystals. Plagioclase forms euhedral crystals, varying in size from 1.1 mm wide - 2 mm long, to 3.5 mm wide – 8.2 mm long. Mafic minerals are represented by interstitial biotite, forming highly pleochroic brown crystals (1mm to 2.5mm long), which are occasionally altered to iron oxides, and by rare, greenish calcic amphibole (hornblende). Zircon and titanite represent the main accessory phases. The petrographic features of the red granite are similar to those of the Aswan granite.

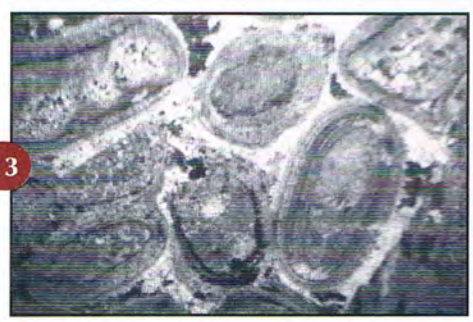
The marbles

The white marbles consist mainly of equidimensional crystals of variable size, and exhibit three textural varieties. These are (i) medium to coarse-grained marble, with calcite granis ranging in size from 1 to 2 mm across, showing granoblastic polygonal textures, (ii) heterogranoblastic texture in which the marble consists of coarse-grained calcite (1 to 2.5 mm across), but with patches of fine to medium-grained (o.3 to 1 mm across) calcite crystals, and (iii) heterogranoblastic marble (with calcite crystals ranging from 0.3 to 1.5 mm across), containing patches of fine-grained crystalline limestone having sparry calcite (0.03 mm across). The grey marble is a fine-grained rock, with a heterogranoblastic polygonal texture, in which calcite grains vary from 0.2 to 0.5 mm across. None of these rocks show foliations or layered fabrics.

12 a

12 b

Fig. 12 Photomicrographs showing granoblastic (a; sample n°2), and heterogranoblastic (b; sample n°4) polygonal textures in white marbles. Note the polysynthetic bands and the rhombic cleavage of the calcite crystals. Crossed polars. Width of field of view is 2 mm.



13

Fig. 13 Photomicro-graph showing that the pink limestone (sample n°5) is made up essentially of circular and elliptical pisolite-supported micritic limestone, with sparry calcite matrix. Crossed polars. Width of field of view is 2 mm.

The pink limestone

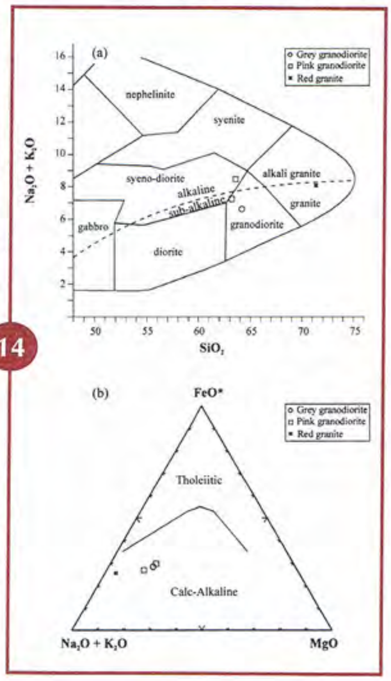
The limestone consists of pisolites (about 60 %), pellets (15 %), microfossils and fossil fragmants (10 %), occurring within an interstitial matrix (15 %). The matrix consists entirely of sparry calcite. The pellets range in size from 0.4 mm to 2 mm across. The pisolites (Fig. 13) form either circular or elliptical masses, ranging in size mostly from 0.3 mm to 1.5 mm across. The micritized rims surround cores which consist either of micrite, or of medium-grained sparry calcite. These features are not very typical of the Lebanese (mostly yellowish, beige, or greyish-white) limestone.

4. Geochemistry

Several investigators have shown that petrographic and chemical data are essential in interpreting the provenance of archaeological materials (e.g., Mandi *et al.*, 1995; Lazzarini *et al.*, 1995; Lapuente, 1995; Max Brown & Harrell, 1995). Data obtained in this study has been compared with data from the literature (e.g., Abdel-Rahman & Martin, 1987; Meloni *et al.*, 1995; Frisch & Abdel-Rahman, 1999; Abdel-Rahman & El-Kibbi 2001). The geochemical features are described below.

4 a. The granitic rocks

The granitic rocks investigated exhibit a wide range of composition, ranging from 63.4 to 71.9 wt. % SiO_2, 13.1-16.2 wt. % Al_2O_3, 1.6-4.6 wt. % CaO, and 0.5-2.4 wt. % MgO. The rocks are moderately enriched in the alkalis (3.0-3.8 wt. % Na_2O, and 3.6-5.3 wt. % K_2O). On the classification diagram of Cox *et al.*, 1979 (Fig. 14a), the grey granodiorite plots in the field of granodiorite, the pinkish-grey granodioritic rocks plot in the fields of granodiorite and syeno-diorite, whereas the red granite plots in the field of granite. As shown on the standard AFM diagram (Fig. 14b), the four granitic rock samples are clearly of calc-alkaline nature. With respect to the trace elements, the granitic rocks show a relatively wide compositional range: Rb (101-197 ppm), Sr (171-885 ppm), Ga (17.1-18.6 ppm), Nb (1.7-33 ppm), Y (17-35 ppm), Zr (138-436 ppm), Hf (5.3-9.4 ppm), and Ta (1.4-2.4 ppm). The concentration of Ba varies from 1070 to 1585 ppm. These values are more typical of Pan-African orogenic calc-alkaline granites (e.g., Abdel-Rahman & Martin, 1987), and are very different from those characteristic of the post Pan-African anorogenic (A-type) granites of the Middle East, such as Mount Gharib (Abdel-Rahman & Martin, 1990), Wadi Dib ring complex (Frisch & Abdel-Rahman, 1999), and Mount El-Sibai (Abdel-Rahman & El-Kibbi, 2001).



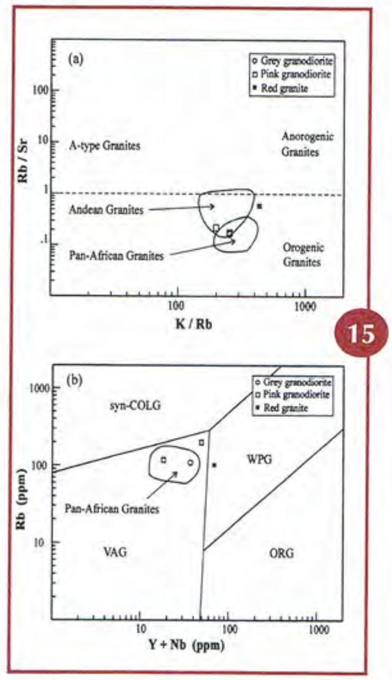


Fig. 14 **(a) SiO_2 versus Na_2O+K_2O variation diagram (after Cox *et al.*, 1979), classifying the examined granitic rocks. The boundary between alkaline and sub-alkaline rocks is after Miyashiro (1978). (b) Standard AFM diagram showing the calc-alkaline nature of the granitic rocks investigated.**

Fig. 15 **(a) K/Rb versus Rb/Sr diagram showing that the examined granitic rocks exhibit Rb/Sr ratios lower than one, which is typical of orogenic calc-alkaline granites. Fields of the Andean orogenic granites and the Pan-African calc-alkaline granites are after Atherton *et al.* (1979) and Abdel-Rahman & Martin (1987), respectively. The boundary (marked by the dashed line at Rb/Sr = 1) separating the fields of orogenic and anorogenic granitic complexes is after Abdel-Rahman & El-Kibbi (2001). (b) Rb versus (Y+Nb) variation diagram (after Pearce *et al.* 1984). Fields are: ORG, ocean-ridge granites; VAG, volcanic arc granites; syn-COLG, syn-collisional granites; and WPG, within-plate granites. Most samples plot in the VAG field.**

On the The Rb/Sr versus K/Rb diagram (Fig. 15a), data points of the investigated granites possess Rb/Sr ratios of less than one, similar to granitic suites forming in association with compressional (orogenic) tectonic regimes such as the Andean granites (Atherton *et al.* 1979) and the Pan-African calc-alkaline orogenic granites (Abdel-Rahman & Martin, 1987), suggesting that the investigated granitic rocks are clearly of the orogenic granite type. Using standard tectonic discrimination diagrams, three of the four data points plot in the field of volcanic-arc granite (VAG; Fig. 15b) of Pearce et al. (1984), whereas the red granite sample plot near the boundary between the VAG and the WPG granite types. Thus, most of the data suggests that the rocks are typical of orogenic granites, and were emplaced in a subduction-related tectonic environment during an orogenic event such as the Pan-African orogeny. This is also consistent with the subsolvus nature of these rocks.

The chondrite-normalized REE patterns for these granites (normalized to the chondrite values of Taylor & MacLennan, 1985) are presented in Figure 16 a. This diagram shows that the red granite exhibits slightly higher REE values (total REE; 506 ppm) than the grey granodiorite or the pinkish-grey granodiorites (total REE; 216 ppm and 354 ppm, respectively). Overall, the chondrite-normalized REE patterns of these granites are generally parallel to subparallel and exhibit small Eu-negative anomalies (Fig. 16 a). The REE patterns compare rather well with those typical of Pan-African calc-alkaline granit. (see Discussion).

16

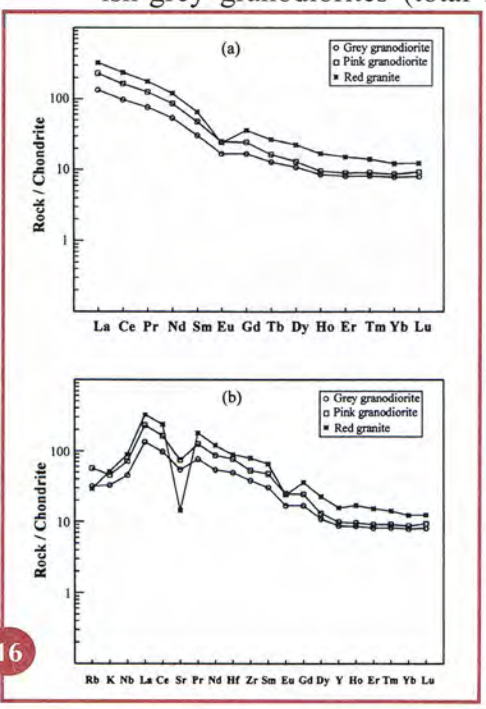


Fig. 16 (a) Chondrite-normalized rare-earth profiles of the granitic rocks investigated. (b) Chondrite-normal ized multi-element profiles of the granitic rocks investigated. Normalization values are taken from Taylor & McLennan (1985).

The chondrite-normalized incompatible element patterns (Fig. 16 b) indicate that the grey and pinkish-grey granodiorites exhibit conformable, parallel to subparallel, smooth profiles, but with the red granite profile showing marked depletion in Sr and Eu, compared to the granodioritic rocks. The investigated granitic rocks generally exhibit trace-element profiles comparable to those typical of orogenic calc-alkaline granites, such as the Pan-African granites of eastern Egypt and western Saudi Arabia (e.g., Abdel-Rahman & Martin, 1987; Abdel-Rahman, 1995).

4 B. The marbles

The marbles exhibit a narrow compositional range: 54.7-55.5 wt. % CaO, 0.4-1.2 wt. % MgO, 0.11-1.5 wt. % SiO2, 0.10-0.37 wt. % Al2O3, and 42.7-43.5 wt. % LOI. Trace element compositions (in ppm) are: Sr (132-249 ppm), Rb (3.7-5.0 ppm), Ga (1.1-1.8 ppm), Y (0.3-9.8 ppm), Pb (3.8-9.4 ppm), and Th (4.6-5.0 ppm).

The chondrite-normalized REE patterns for the marbles (normalized to the chondrite values of Taylor & MacLennan, 1985) are presented in Figure 17. It is clear that patterns of the coarse-grained white marbles are very similar to that of the grey marble, and these two marble types are somewhat depleted in the REE compared to chondrite (total REE for the marbles ranges from 0.9 to 1.8 ppm). In general, these REE patterns are somewhat parallel, and do not exhibit Eu-anomalies. These patterns appear to be similar to those of the Italian marbles (see Discussion).

17

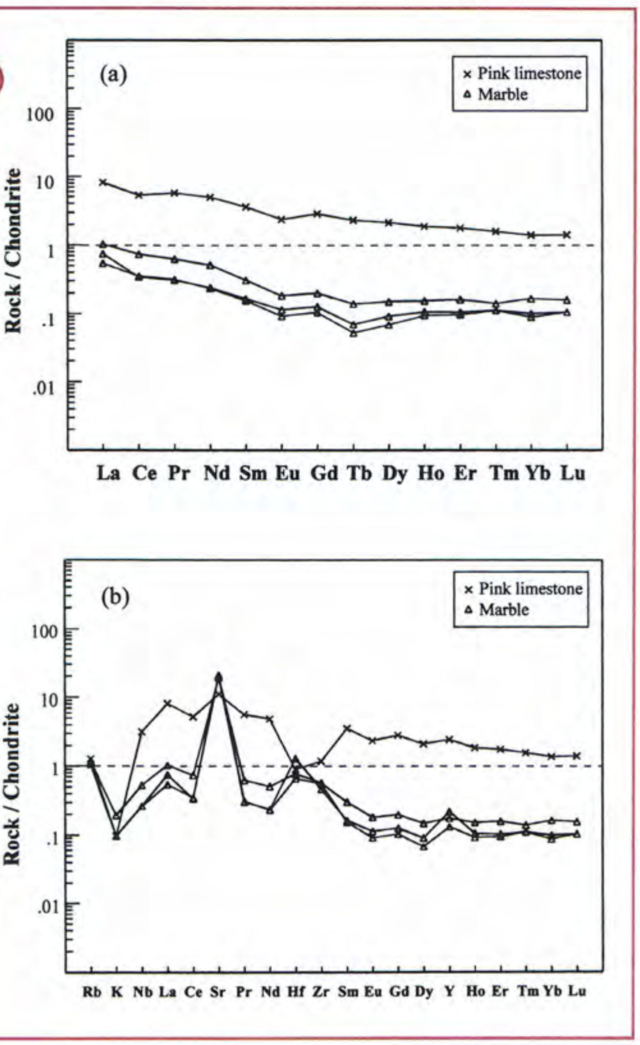


Fig. 17 (a) Chondrite-normalized rare-earth profiles of marbles and limestone. (b) Chondrite-normalized multi-element profiles of marbles and limestone. Normalization values are taken from Taylor & McLennan (1985).

The chondrite-normalized incompatible element patterns of the marbles (Fig. 17 b) show that patterns of the white marbles are also very similar to that of the grey marble. These patterns exhibit conformable smooth profiles, and most have lower than elemental chondrite values. The mineralogical and chemical features of the investigated red granite are identical to those of the red granite of Aswan. As described above, the mineralogical and chemical characteristics of the grey and pinkish-grey granodioritic rocks examined in this study are typical of those of the calc-alkaline orogenic granites exposed in eastern Egypt (cf. Fig. 15). This interpretation is further supported by the excellent match between the chondrite-normalized REE patterns of the examined granitic rocks and the patterns of Pan-African calc-alkaline granites and granodiorites of northeastern Egypt (Fig. 18). Although such features are also typical of those of calc-alkaline orogenic granites from other regions, the source of the examined granodiorites is more likely to be the granodiorites of northeastern Egypt, Sinai, or northwestern Saudi Arabia.

The petrography of the various marble samples investigated show that these rocks consist of medium to coarse-grained, granoblastic to heterogranoblastic calcite, commonly showing polygonal crystals with triple junctions, so characteristic of well-developed marbles. The crustal segment of Lebanon is made up essentially of thick, Jurassic-Cretaceous carbonate formations (forming nearly 3.5 km thick sequence), which were extruded by basaltic lavas (Dubertret, 1955; Beydoun, 1977). Due to an expected phase of thermal metamorphism as a result of the basaltic volcanism, minor marble material possibly occurring in the form of very thin aureoles ranging from a few millimeters to a few centimeters in width, and/or in the form of small marble xenoliths within some basaltic flows, may have formed in some localities in Lebanon. So far, neither marble, nor any kind of metamorphic rocks have been mapped or reported to be present in Lebanon. This, combined with the texture and the nature of the white and the grey marbles examined in this study confirm that the marbles must have been imported.

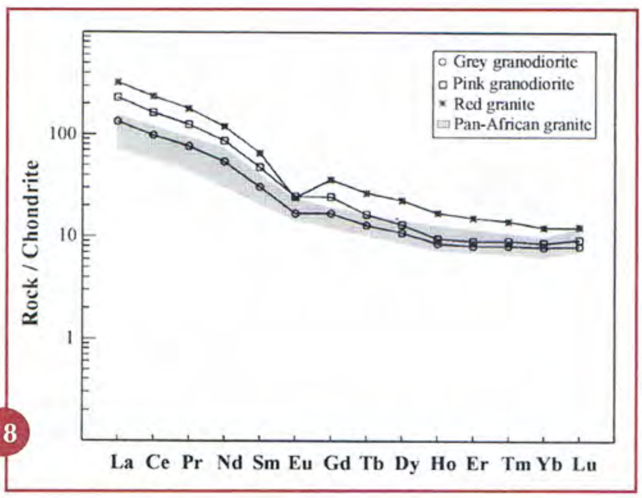


Fig. 18 Chondrite-normalized rare-earth profiles of the granitic rocks investigated, superimposed on an envelope representing the REE patterns of typical Pan-African calc-alkaline granitic-granodioritic rocks from northeastern Egypt (taken from Abdel-rahman & Martin, 1987). Note the close match between the REE profiles of the examined granites and the Egyptian granites. Normalization values are taken from Taylor & McLennan (1985).

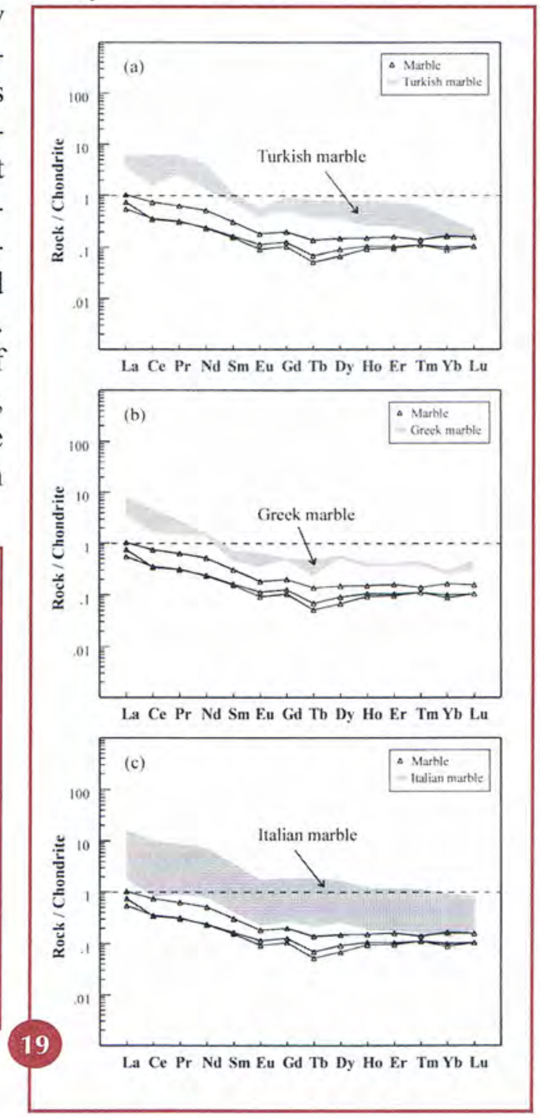
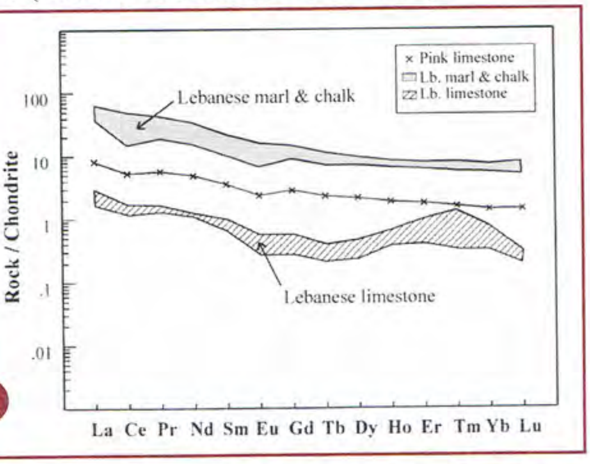


Fig. 19 Chondrite-normalized rare-earth profiles of the marbles investigated, superimposed on three envelopes (in a, b, c) representing the REE patterns of typical Turkisk, Greek, and Italian marbles, data of which is taken from Meloni *et al.* (1995). Normalization values are taken from Taylor & McLennan (1985).

In order to determine the possible provenance of the marbles, the chemical data produced for this study has been compared with available data on marbles for other regions. The use of major elements for the interpretation of the possible provenance of the examined marbles produced inconclusive results. The use of the rare earth elements in particular, were found to be a very powerful tool for the determination of the possible provenance of marble. Therefore, The chondrite-normalized patterns of the examined marbles have been compared to the patterns of marble from Italy, Greece, and Turkey. The results (shown in Fig. 19) indicate that the examined marbles exhibit lower rare earth element abundance than marbles from these regions. However, the REE patterns of the examined marbles are somewhat parallel to the patterns of the Italian marbles, but have a slightly different slope than the patterns of the Turkish marbles, and of the Greek marbles. This may suggest that the examined marbles were imported from Italy. Alternatively, the examined marbles may have been imported from any of the three countries (Italy, Greece, or Turkey), but were obtained from marble quarries other than those reported in the literature and used here for comparison.

The pisolitic pink limestone sample examined is not typical of the Lebanese limestone. Although some minor pinkish limestone with thin veins and veinlets cross cutting limestone outcrops have been observed in the Jezzine area (near the Chouf area), no such rocks have been found in the form of larger scale outcrops necessary to enable quarrying. It should be noted that these pinkish carbonate veins may have formed by precipitation of Fe-rich carbonate materials due to circulation of groundwater along faults, joints and other rock fractures. In order to document whether or not the examined limestone is local or imported, chemical data on the pink limestone was compared with the available chemical data on the Lebanese carbonate rocks, which are reported in Abdel-Rahman & Nader (2002). Not surprisingly, the investigated pisolitic pink limestone was found to exhibit very different rare earth element compositions compared to the carbonate rocks of Lebanon (limestone, chalk or marl). This is clearly illustrated in Figure 20, as the chondrite-normalized pattern of the pink pisolitic limestone neither matches the REE patterns of the Lebanese Cretaceous limestone formations, nor the patterns of the Lebanese marl and chalk of the various Cretaceous formations (Abdel-Rahman & Nader 2002).



20

Fig. 20 **Chondrite-normalized rare-earth profile of the pink limestone investigated, superimposed on two envelopes representing the REE patterns of Lebanese limestone, and of Lebanese marl & chalk, data of which is taken from Abdel-Rahman & Nader (2002). Normalization values are taken from Taylor & McLennan (1985).**

References

Abdel-Rahman, A. M. 1994. "Nature of biotites from alkaline, calc-alkaline, and peraluminous magmas". *Journal of Petrology* 35, 525-41.

Abdel-Rahman, A. M. 1995. "Tectonic-magmatic stages of shield evolution: the Pan-African belt in northeastern Egypt". *Tectonophysics* 242, 223-40.

Abdel-Rahman, A. M. 1996. "Pan-African volcanism: petrology and geochemistry of the Dokhan Volcanic Suite in the northern Nubian shield". *Geological Magazine* 133, 17-31.

Abdel-Rahman, A. M. & Doig, R. 1987. "The Rb-Sr geochronological evolution of the Ras Gharib segment of the northern Nubian shield". *Journal of the Geological Society of London* 144, 577-86.

Abdel-Rahman, A. M. & El-Kibbi, M. 2001. "Anorogenic magmatism: chemical evolution of the Mount El-Sibai A-type complex (Egypt), and implications for the origin of within plate felsic magmas". *Geological Magazine* 138, 67-85.

Abdel-Rahman, A. M. & Martin, R. F. 1987. "Late Pan-African magmatism and crustal development in northeastern Egypt". *Geological Journal* 22, 281-301.

Abdel-Rahman, A. M. & Martin, R. F. 1990. "The Mount Gharib A-type granite, Nubian shield: petrogenesis and role of metasomatism at the source". *Contributions to Mineralogy and Petrology* 104, 173-83.

Abdel-Rahman, A. M. & Nader, F. H. 2002. "Characterization of the Lebanese Jurassic-Cretaceous carbonate stratigraphic sequence: a geochemical approach". *Geological Journal* 37, 1-23.

Adam, Jean-Pierre. 2001. *Roman Building, materials and techniques*, trans. from French by Anthony Mathews, Routledge, UK.

Anders, E. & Ebihara, M. 1982. "Solar-system abundances of the elements". *Geochimica et Cosmochimica Acta* 46, 2363-80.

Atherton, M. P., McCourt, W. J., Sanderson, L. M. & Taylor, W. P. 1979. "The geochemical character of the segmented Peruvian Coastal batholith and associated volcanics". In *Origin of Granite Batholiths: Geochemical Evidence* (eds M. P. Atherton and J. Tarney), pp. 45-64. Cheshire: Shiva.

Ball, Warwick: 1986 "The North Decumanus and North Tetrapylon at Jerash", in, *Jerash Archaeological Project 1981-1983*, vol. I, ed. F. Zayadine, Department of Antiquities, Amman- Jordan.

Beydoun, Z. R. 1977. "The Levantine countries: the geology of Syria and Lebanon (Maritime regions)". In: *The Ocean Basins and margins: Eastern Mediterraneans*, vol. 4A, Nairn A.E.M. et al. (Eds.). Plenum Press: New York, 319-353.

Cox, K. G., Bell, J. D. & Pankhurst, R. J. 1979. *The interpretation of igneous rocks*. Allen and Unwin, London, 450pp.

Dames & Moore 1994. *Preliminary Geological & Geotechnical Study* , BCD, an unpublished report presented to CDR, Beirut.

Davie, M. 1989. "Maps and the historical topography of Beirut", *Berytus* 35, 141-164.

Dubertret L. 1955. *Carte géologique du Liban au 1/200000 avec notice explicative*. République Libanaise, Ministère des Travaux Publiques: Beirut.

Evensen, N. M., Hamilton, P. J. & O'Nions, R. K. 1978. "Rare-earth abundances in chondritic meteorites". *Geochimica et Cosmochimica Acta* 42, 199-212.

Finkbeiner,U. & Sader,H. 1997 "BEY 020 preliminary report of the excavations, 1995", *Baal*, Vol. .II, p. 114-166.

Frisch, W. & Abdel-Rahman, A. M. 1999. "Petrogenesis of the Wadi Dib alkaline ring complex, Eastern Desert of Egypt". *Mineralogy and Petrology* 65, 249-75.

Lapuente, M. P. (1995) "Mineralogical, petrographical and geochemical characterization of white marbles from Hispania". In: Maniatis, Y., Herz, N., Basiakos, Y. (eds), *The study of marble and other stones used in antiquity*, Archetype publications Ltd., London, 151-160.

Lauffray, J. 1976. "Beyrouth, archéologie et histoire, époques Gréco-Romaine", *Aufstieg und Niedergang der Römische Welt* II, 8:135-163.

Lazzarini, L., Masi, U., & Tucci, P. 1995. "Petrographic and geochemical features of the Carystian marble, "Cipollino verde", from the ancient quarries of Southern Euboea (Greece)". In: Maniatis, Y., Herz, N., Basiakos, Y. (eds), *The study of marble and other stones used in antiquity*, Archetype publications Ltd., London, 161-169.

Mandi, V., Vassiliou, A., Maniatis, Y., & Grimanis, A. P. 1995. "An evaluation of the contribution of trace elements to the determination of marble provenance". In: Maniatis, Y., Herz, N., Basiakos, Y. (eds), *The study of marble and other stones used in antiquity*, Archetype publications Ltd., London, 207-212.

Max Brown, V. & Harrell, J. A. 1995. "Topographical and petrological survey of ancient Roman quarries in the Eastern Desert of Egypt". In: Maniatis, Y., Herz, N., Basiakos, Y. (eds). *The study of marble and other stones used in antiquity*, Archetype publications Ltd., London, 221-234.

Miyashiro A. 1978. "Nature of alkalic volcanic rock series". *Contributions to Mineralogy and Petrology* 66, 91-104.

Mongne, P., 1996 "BEY 008 bis, zone des souks, dégagement du fossé médiéval", *Baal*, vol. I, p. 270-293.

Meloni, S., Oddone, M., & Zezza U. (1995) "Rare-earth element patterns of white marble samples from ancient quarries in Carrara (Italy)". In: Maniatis, Y., Herz, N., Basiakos, Y. (eds), *The study of marble and other stones used in antiquity*, Archetype publications Ltd., London, 181-186.

Pearce, J. A., Harris, N. B. W. & Tindle, A. G. 1984. "Trace element discrimination diagrams for the tectonic interpretation of granitic rocks". *Journal of Petrology* 25, 956-83.

Saghieh-Beydoun, M. 'Allam, Ala'Eddine & Abul Hosn, 2002 "The monumental street,'Cardo Maximus' and the replanning of Roman Berytus", *Baal*, vol. .3, (forthcoming).

Segal, A. 1997 *From Function to Monument*, Oxbow monograph 66, Oxford.

Taylor, S. R. & Mc Lennan, S. M. 1985. *The continental Crust: its Composition and Evolution*, 312p. Oxford: Blackwell.

Vitruvius 1960. *The Ten Books on Architecture*, trans. by M. H. Morgan, Dover Publications, Inc., New York.

Ward-Perkins, J. B. 1994. *Roman Imperial Architecture*, Yale University Press, USA.