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Effect of Air Pollution on Archaeological Buildings in Cairo

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1. Introduction

Islamic Cairo is a part of central Cairo noted for its historically important mosques and other Islamic monuments. It is overlooked by the Cairo Citadel. Islamic Cairo was founded in 969 AD as the royal enclosure for the Fatimid caliphs, while the actual economic and administrative capital was in nearby Fustat. Fustat was established by Arab military commander 'Amr ibn al-'As following the conquest of Egypt in 641 AD, and took over as the capital which previously was located in Alexandria. Al-Askar, located in what is now Old Cairo, was the capital of Egypt from 750 AD to 868 AD. [1] Ahmad Ibn Tulun established Al-Qatta'i as the new capital of Egypt, and remained the capital until 905 AD, when the Fustat once again became the capital. After Fustat was destroyed in 1168 AD /1169 AD to prevent its capture by the Crusaders, the administrative capital of Egypt moved to Cairo, where it has remained ever since. [2] It took four years for the General Jawhar Al Sikilli (the Sicilian) to build Cairo and for the Fatimid Calif Al Muizz to leave his old Mahdia in Tunisia and settle in the new Capital of Fatimids in Egypt. Fustat became a regional center of Islam during the Umayyad period. Later, during the Fatimid era, Al-Qahira (Cairo) was officially founded in 969 AD as an imperial capital just to the north of Fustat. [3] Over the centuries, Cairo grew to absorb other local cities such as Fustat, but the year 969 AD is considered the "founding year" of the modern city. In 1250 AD, the slave soldiers or Mamluks seized Egypt and ruled from their capital at Cairo until 1517 AD, when they were defeated by the Ottomans. [4] By the 16th century, Cairo had high-rise apartment buildings where the two lower floors were for commercial and storage purposes and the multiple stories above them were rented out to tenants. Napoleon's French army briefly occupied Egypt from 1798 AD to 1801 AD, after which an Albanian officer in the Ottoman army named Muhammad Ali Pasha made Cairo the capital of an independent empire that lasted from 1805 AD to 1882 AD. [5] The city then came under British control until Egypt was granted its independence in 1922 AD. Cairo is a world heritage city. It contains possibly the finest collection of monuments in the Islamic world. It contains some of the best surviving monuments of the medieval period in the Islamic world. [6]. The wealth, prosperity, and power of Cairo are reflected in the grand architecture of the monuments that are crowded together into the Fatimid city and just beyond, Fig. (1). [7] Cairo's Islamic monuments are part of an uninterrupted tradition that spans over a thousand years of building activity. No other Islamic city can equal Cairo's spectacular heritage, nor trace its historical and architectural development with such clarity. [8] Cairo contains the greatest concentration of Islamic monuments in the world, and its mosques, mausoleums, religious schools, baths, and caravanserais, built by prominent patrons between the seventh and nineteenth centuries, are

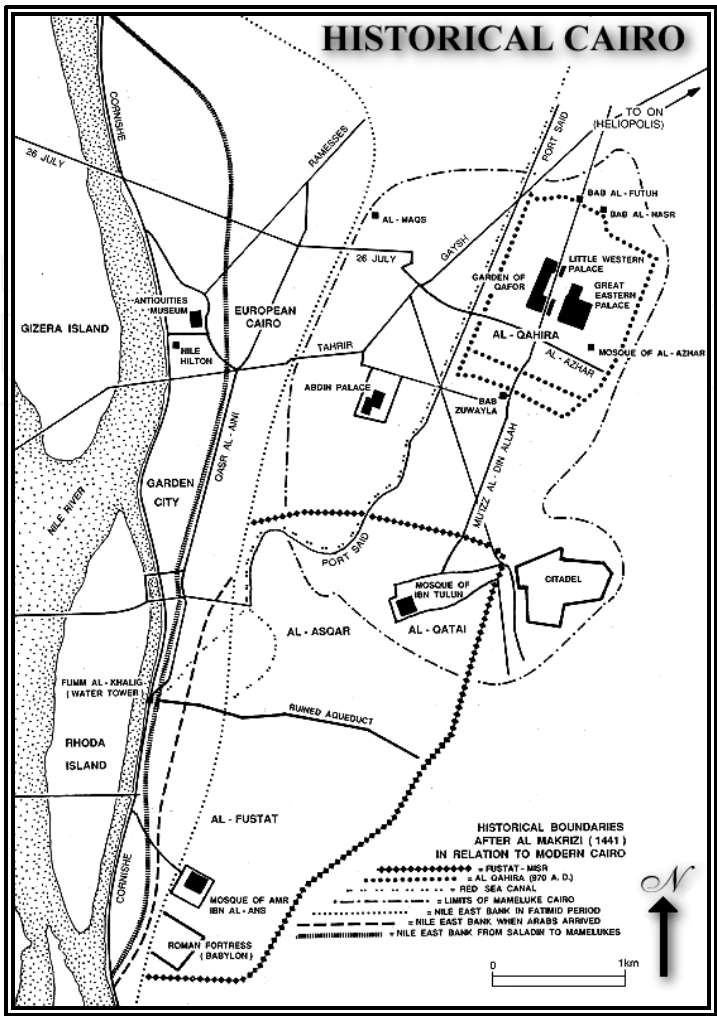


Fig. 1. Shows a map of historical Cairo.
<http://www.touregypt.net/Map08.htm>.

among the finest in existence [9] , fig. (2) Shows some of Islamic archaeological buildings in Cairo. The air pollution in Cairo is a matter of serious concern. Greater Cairo's volatile aromatic hydrocarbon levels are higher than many other similar cities. Air quality measurements in Cairo have also been recording dangerous levels of lead, carbon dioxide, sulphur dioxide, and suspended particulate matter concentrations due to decades of unregulated vehicle emissions, urban industrial operations, and chaff and trash burning. There are over 4,500,000 cars on the streets of Cairo, 60% of which are over 10 years old, and therefore lack modern emission cutting features like catalytic converters. Cairo has a very poor dispersion factor because of lack of rain and its layout of tall buildings and narrow streets, which create a bowl effect. Cairo also has many unregistered lead and copper smelters which heavily pollute the city. The results of this have been a permanent haze over the city with particulate matter in the air reaching over three times normal levels. [10] Pollutants are deposited on the surface of stone from the air. Where the surface of the stone is totally dry, the stone is discolored as the deposits increase. Where the surface of the stone is moist, the pollutants are converted to acids that eat away the surface of the stone by dissolving the binder in the stone causing the stone particles or grains to separate and erode away easily. [11] Carbon dioxides, Nitric oxides, and Sulphur oxides product mineral acids in humid conditions. They dissolve the calcium and magnesium carbonates in limestone,

marble, lime mortars, and plasters in archaeological buildings. Archaeological buildings in Cairo suffer from different deterioration phenomena for example, black crust formation, chemical alterations, disintegration between surface mineral grains, pitting, cracks, missing parts, erosion, and white stains. [12]. This chapter aims to study deterioration and decay of building materials in archaeological buildings in Cairo because of air pollution, Discussion and explanation of deterioration phenomena which forming in archaeological building in Cairo according to air pollution and Discussion of different methods and materials of treatment, restoration and conservation of building material in archaeological buildings from deterioration phenomena related to air pollution.

2. Sources of air pollution in Cairo

Air pollution plays a major role in the deterioration of building materials used in historic buildings. Industrial facilities such as factories and plants emit toxic gases into the atmosphere. Another major source of toxic emissions in Egypt is the widespread open-air burning of trash and waste. Waste landfills also give off methane, which, although not toxic, is highly flammable and can react in the air with other pollutants to become explosive. [13] There are numerous sources to air pollution in Egypt, as in other countries. However, the formation and levels of dust, small particles and soot are more characteristic in Egypt than presently found in industrialized countries. Some of the sources for these pollutants, such as industries, open-air waste burning and transportation, were also well known problems in most countries only 10 to 20 years ago. Another important source for particulate matter is the wind blown dust from the arid areas. Suspended dust (measured as PM10 and TSP) can be seen to be a major air pollution problem in Egypt. PM10 concentrations can exceed daily average concentrations during 98% of the measurement period. On the other hand it seems that the natural background of PM10 in Egypt may be close to or around the Air Quality Limit value. These levels can be found also in areas where local anthropogenic sources do not impact the measurements. Further measurements may be used in the future to quantify the relative importance of the different sources relative to a background level that varies dependent upon the area characteristics. In addition to particles, also SO₂ in urban areas and in industrial areas, as well as NO₂ and CO in the streets may exceed the Air Quality Limit value. Major industrial pollutants include sulphur oxides, nitrogen oxides, carbon monoxide and carbon dioxide. [14] For instance, Cairo is surrounded by various industrial sites. Thirty Kilometers to the south of Cairo is Helwan, where different factories produce iron, steel, coke, chemicals, automobiles, and cement. To the north of Cairo are Shubra Al – Khayma, Musturud, and Abu Zabal. In this area factories produce dyes, textiles, glass, ceramics, and chemical products. All of these factories emit different pollutants (gaseous, liquid, solid), which are carried by the dominant winds (north and northeast, and west or south, southwest) down to Cairo, many of the historic buildings are located. Every day Cairo receives a high dose of pollutants composed of 52 percent monocarbon oxide (CO), 14 percent sulphur dioxide (SO₂), 21 percent hydrocarbons, 10 percent dust, solid materials, and 2 percent (NO_x) nitrogen oxides, The dust particles from the Muqattam hills to the east of Cairo was 27 gm / m² / month in 1962. This increased to more than 60 gm / m² / month in 1988, with a particularly high amount in the summer when the aerosols of dust in the air were more than 500 gm / m² / month [15]. Many Egyptians rely upon extremely old vehicles for transportation. These inefficient vehicles cause the carbon present in fuel to ineffectively react with oxygen during combustion, producing carbon monoxide or condensing to form particles of soot. The hydrocarbons do not combust completely and are released as gaseous hydrocarbons or absorbed by particles, increasing the particulate mass



Fig. 2. Shows some of Islamic Archaeological buildings in Cairo: (A) El- Sultan Hassan Madrasa (1362 AD / 764 AH) and El - Refae Mosque. (B) El-Mosabeh Mosque(1792 AD / 1192 AH). (C) El- Ghouri Mosque in El - Sayeda Aisha Square (1504 AD / 909 AH). (D) El - Mahmoudya Mosque (1568 AD / 975 AH). (E) Qaitbay Sabil (1479 AD / 884 AH). (F) Taghri Bardi Mosque (1439 AD / 843 AH). (G) Azbak El- Yusufi Mosque. (H) Singer and Slar Mosque (1303 AD / 703 AH). (I) Lagen El - Sayfi Mosque (1296 AD / 696 AH).

in the air. The speed at which pollutants disperse in the air is determined by meteorological conditions such as wind, air temperature and rain. Egypt and Cairo, particularly, have a very poor dispersion factor due to lack of rain and the layout of streets and buildings, which are not conducive to air flow. [16] Emissions that arise from the combustion of solid fossil fuels are of prime concern. Coal and oil both contain sulphur in varying amounts, and both therefore produce sulphur dioxide when burnt. There are a number of nitrogen oxides (NO_x), but the one of principal interest as an air pollutant likely to have adverse effects on human health and soiling properties is nitrogen dioxide (NO₂). Nitrogen compounds are also contributors to the wet and dry deposition of acidic compounds on vegetation and buildings. Particulate matter is a term that represents a wide range of chemically and physically diverse substances that can be described by size, formation mechanism, origin, chemical composition, atmospheric behavior and method of measurement. The concentration of particles in the atmosphere varies across space and time and as a function of the source of the particles and the transformations that occur to them as they age and travel. Particles less than 10 mm in diameter (PM₁₀) are often measured that include both fine and coarse dust particles. [17].

3. Materials and methods

Limestone and marble samples of original stones and crusts were collected from different deteriorated parts of Archaeological buildings, according to the decay and the damage levels fig. (3) as follows: - Limestone samples from El- Ghouri Mosque, El – Mahmoudya Mosque, Taghri Bardi Mosque and Lagen El – Sayfi Mosque. - Marble samples from Qaitbay Sabil, Taghri Bardi Mosque and Azbak El- Yusufi Mosque. Analytical study have been carried to selected samples by Polarizing Microscope [PLM], Scanning Electron Microscope [SEM], Energy dispersive X-ray analysis [EDX], X-ray diffraction (XRD) and FTIR analysis.



Fig. 3. Shows some details of Islamic Archaeological buildings, (A) , (B) , (G) El – Mahmoudya Mosque (1568 AD / 975 AH). (C) , (D) Qanibay Al – Ramah Mosque (1503 AD / 908 AH). (E) Qaitbay Sabil (1479 AD / 884 AH) (F) , (H) , (I) , (L) Taghri Bardi Mosque (1439 AD / 843 AH). (J) Lagen El – Sayfi Mosque (1296 AD / 696 AH). (K) Azbak El- Yusufi Mosque (1494 AD / 900 AH).

The x-ray diffraction analysis of samples was carried out using philips x-ray diffractometer. The operating conditions were: Generator applied on a Cu $k\alpha$ radiation (1.5418 \AA) with Ni filter, 40 KV, 20 mA target tube. Scavenging velocity 2° per minute and chart velocity 5 mm per minute were applied in Bulk sample powder. Fragments of crusts collected were prepared for observation using scanning electron microscope (SEM), operated at accelerating voltage of 30 kV. Infrared spectra were recorded employing a Nicolet Nexus 870 FTIR spectrometer. A small amount of samples were mixed with KBr and pressed into pellets, then scanned from 4000 to 400 cm^{-1} .

4. Results and discussion

Limestone samples were examined by Polarizing Microscope (PM) and, it is found that: Samples consist mainly of fine-grained calcite besides presence of iron oxides, quartz, clay minerals and fossils include nummulite fossils these components increase the rate of stone decay [18], fig. (4, A-F). On the other hand the thin section of fragments taken from marble objects shows that the major mineral is calcite, The crystals appeared in mosaic texture, The crystals have irregular faces and highly variable grain size, the cleavage planes of the calcite crystals and the presence of rare and very little amount of opaque minerals [19] fig. (4, G-I). When the limestone samples were examined by [SEM], it is found disintegration between calcite crystals and the stone lost the binding materials between grains by the effect of salts crystallization fig. (5, A-D). Examination of marble samples by [SEM] shows that, erosion of calcite crystals, presence of salts because of chemical reaction with climatic conditions, alteration of calcite into gypsum because of air pollution effect, voids and disintegration between grains by crystallization of salts stresses and lose of binding material [18] fig. (5, E-F). XRD data fig. (6) (A-D) shows that, the examined limestone samples consist of Calcite CaCO_3 , Card No. (5-0586) in addition to Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Card No. (6-0046), Quartz SiO_2 , Card No. (5-0490), Halite Card No.(5-0628) and Dolomite Card No.(11-078) . XRD data of the marble samples shows that, they consist of Calcite CaCO_3 , Card No. (5-0586) in addition to Dolomite $\text{Ca,Mg}(\text{CO}_3)_2$, Card No. (11-078), and Halite, NaCl Card No. (5-0628) fig (5-a). and Anhydrite, Card No (6-0226) fig (5-c). The surface of the marble is covered by a crust of Hydrated Calcium Sulphate (Gypsum) related to reaction with air pollution in presence of moisture. Gypsum crusts are the most common type of growth found on building surfaces. Gypsum is Calcium Sulphate Dihydrate, with the chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Gypsum crusts are formed on calcareous stones following SO_2 deposition to the surface in the presence of moisture, followed by the dissolution of Calcite and the precipitation of Gypsum. The black color of gypsum crusts is the result of the accumulation of particulate matter within the crust [20]. When the water evaporates from soluble salts as chlorides, it leaves behind concentrations of salt solutions which crystallize on the stone surfaces and between mineral grains of stone, this process cause disintegration and deterioration of stone [21]. Energy Dispersive X-ray analysis (EDX) of Limestone samples shows that it consists of calcium element (Ca), sulphur element (S) , Silicon element (Si) and Sodium element (Na) in addition to traces from other elements. The relative enrichment of Si, Al and Fe might be derived from the deposition of wind-borne articles since the archeological stone buildings in Cairo are near a road with much traffic [22] fig. (2). Rich-S is originated from SO_2 emitted by anthropogenic sources like combustion of fuels,

automobile emissions, foundries and smelters. EDX data shows high content of calcium related to calcite mineral, silicon and aluminum due to clay minerals, silicon due to quartz mineral, iron related to iron oxides, sodium and chlorine due to presence of halite salt fig (7)(A-D). Rich-Ti-Mn is associated with industrial and urban emissions. The fly-ash particles play an active role in the damage processes affecting stone, since the content of transition metal oxides contribute to the catalytic oxidation of atmospheric gaseous SO_2 and to the sulphation of calcium carbonate. XRD, SEM, EDX results show that black crusts are essentially composed by gypsum crystals, fly ashes and soot, including some limestone and marble materials. Fly ashes usually are rich in Si and Al with higher or lower amounts of K, Fe, Ca, Ti and Cl. Combustion of fuel and natural gas in car engines and house heating originates carbon rich soot about one hundred times smaller than fly ashes. [23]. The term “atmospheric particulate material” refers to all airborne particles, so it is by definition non-specific. It includes material from such diverse sources as, for example, vehicle emissions, the resuspension of surface dusts and soils and chemical reactions between vapours and gases in the atmosphere, which result in the formation of secondary particles [24]. Therefore emission inventories of PM relate to primary sources of PM only (not secondary sources) [25]. The principal types of primary particulate material are Petrol and diesel vehicles, the latter being the source of most black smoke [26]. Controlled emissions from chimney stacks. Fugitive emissions. These are diverse and mostly uncontrolled and include The resuspension of soil by wind and mechanical disturbance [27]. The resuspension of surface dust from roads and urban surfaces by wind, vehicle movements and other local air disturbance [28]. Emissions from activities such as quarrying, road and building construction, and the loading and unloading of dusty materials,[29]. Secondary particles are those arising when two gases or vapours react to form a substance that condenses onto a nucleation particle, [30]. The main sources of secondary particles are the atmospheric oxidation of sulphur dioxide to sulphuric acid and the oxidation of nitrogen dioxide to nitric acid; the sulphuric acid is present in air as droplets, the nitric acid as a vapour, [31]. Hydrochloric acid vapour (arising mainly from refuse incineration and coal combustion) is also present in the atmosphere, and both this and nitric acid vapour react reversibly with ammonia to form ammonium salts,[32]. Sulphuric acid reacts irreversibly in two stages to form either ammonium hydrogen sulphate or ammonium sulphate. These ammonium salts are formed continuously as sulphur dioxide and nitrogen dioxide are oxidised, and ammonia becomes available for neutralization, [33]. FTIR spectra of a limestone sample fig. (8) shows that the characteristic absorption peaks of CaCO_3 is at 1798, 1424, 874, 711 cm^{-1} , the characteristic absorption peaks of, CO_3 -apatite $[(\text{Ca}_5(\text{PO}_4)_3)_2\text{CO}_3]$ is at 565, 604, 1040 cm^{-1} and the characteristic absorption peaks of gypsum is at 672, 1623, 3408 cm^{-1} . The results of infrared spectroscopy are also confirmed by XRD analysis which provides information on the crystalline components. The limestone contains Calcite and Quartz, and Gypsum. In consideration of the high average relative humidity and rainwater in the environmental conditions in Cairo, the most probable process of crust formation on stone substrate is the absorption of sulphur dioxide in rainwater, liquid atmospheric aerosols or moist film supported on a stone surface, [34]where it is oxidized to form a sulphuric acid solution that dissolves the Calcium Carbonate by Gypsum formation. Kaolinite has been identified on a stone flake collected from a washed-out surface [35]. Its presence can be related to Calcite dissolution, which is strongly enhanced by its exposition to rainwater and

winds[36]. The deposition of wind-born soil dust on the surface may also be a source of kaolinite. [37] The mineralogical, textural and physicochemical differences of the examined crusts suggest that it is unlikely that they have the same origin or the same pattern of development [38]. In Cairo, high relative humidity, frequent fogs, sulphur, nitrogen pollutants, carbonaceous and deposition of airborne particles either on exposed or sheltered areas of Cairo archaeological buildings[39]. In consequence of these processes, these deterioration products grow on sheltered areas leading to thick encrustations, which are washed-out on surfaces exposed to rainwater[40]. On the unsheltered surfaces, newly formed soluble salts, washed-out by water and percolated through the bedding planes of the stone substrate, create a network of parallel and deep fissures, which increase the stone susceptibility to further deterioration [41]. On the other hand archaeological buildings in Cairo suffer from soiling, fig. (3). Soiling is a visual effect resulting from the darkening of exposed surfaces following the deposition and accumulation of atmospheric particles [42]. Deposition, removal and accumulation processes are numerous and complex, [43] depending on the physical and chemical properties of the particles, the nature of the surface, the local meteorology and the pathways followed by rainwater after it hits the building surface[44]. As a result of these complex interactions, there can be substantial variations in the level of soiling observed on building surfaces. It is one of the effects of air [45].

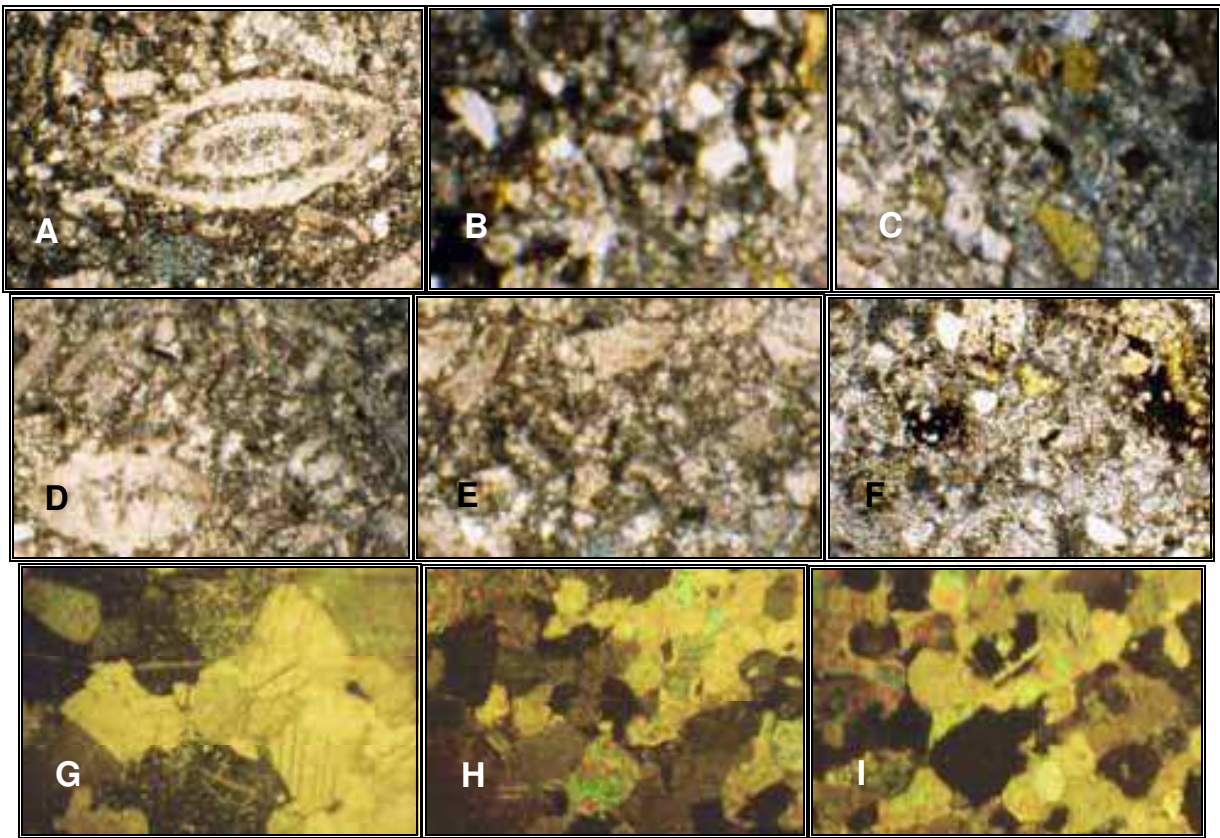


Fig. 4. (A-F) Thin section photomicrographs showing iron oxides, clay minerals, fossil and grains of quartz in a mass ground of fine- grained calcite. 60X (C.N). (G-I) shows that it is a mosaic texture; the calcite crystals have irregular faces and cleavage planes ,120X (C.N).

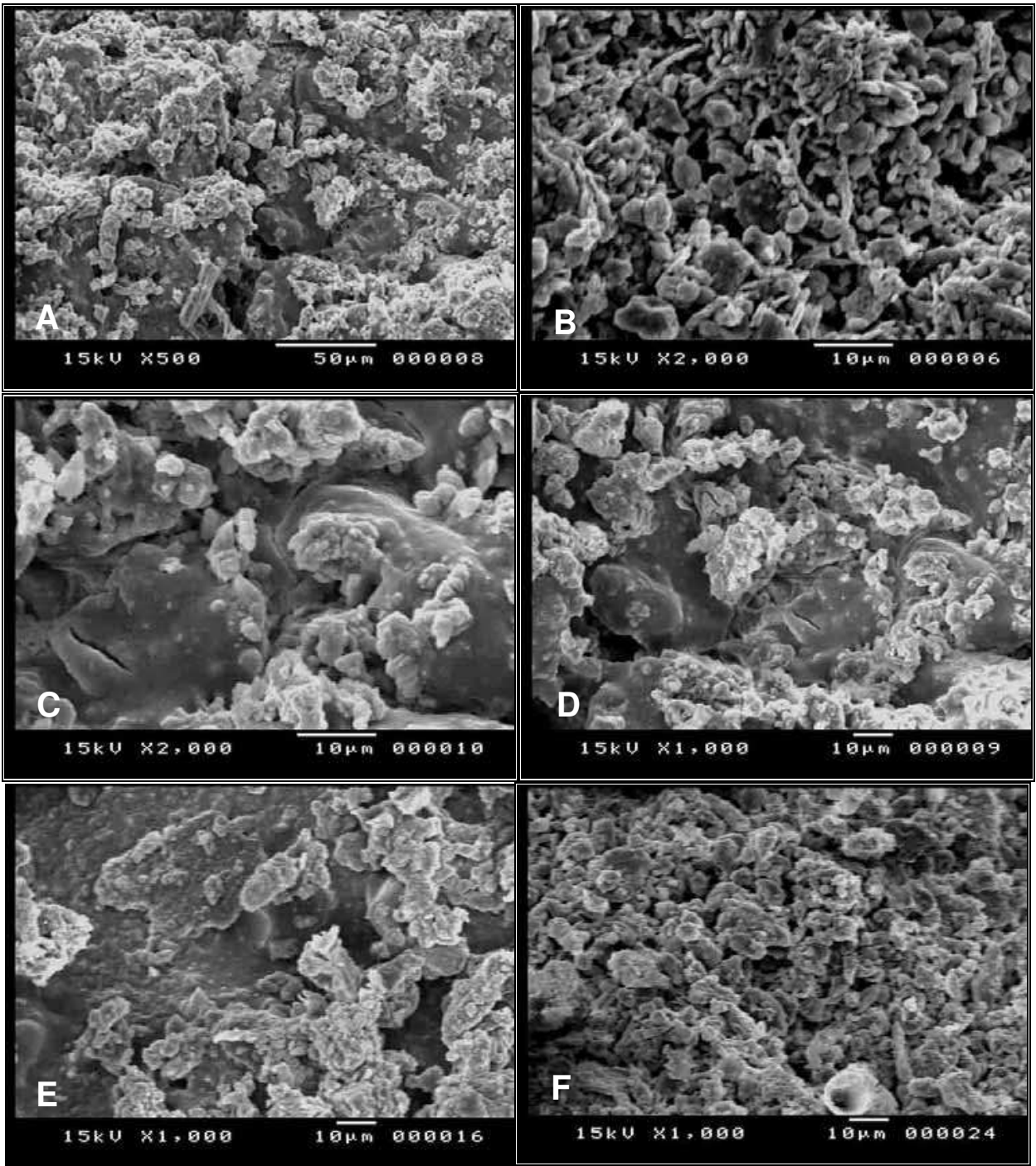


Fig. 5. (A-D) SEM photomicrographs of limestone samples showing the collapse of internal structure, salts crystallization between grains of limestone ornaments. (E-F) photomicrographs of Marble samples showing voids due to lose of binding material erosion, discoloration, a coat of Carbon (C-D), chipping, fly ashes in a black crust and particles from the combustion of fuel oil and coal, containing a quantity of Carbon, Iron, Manganese and Sulphur.

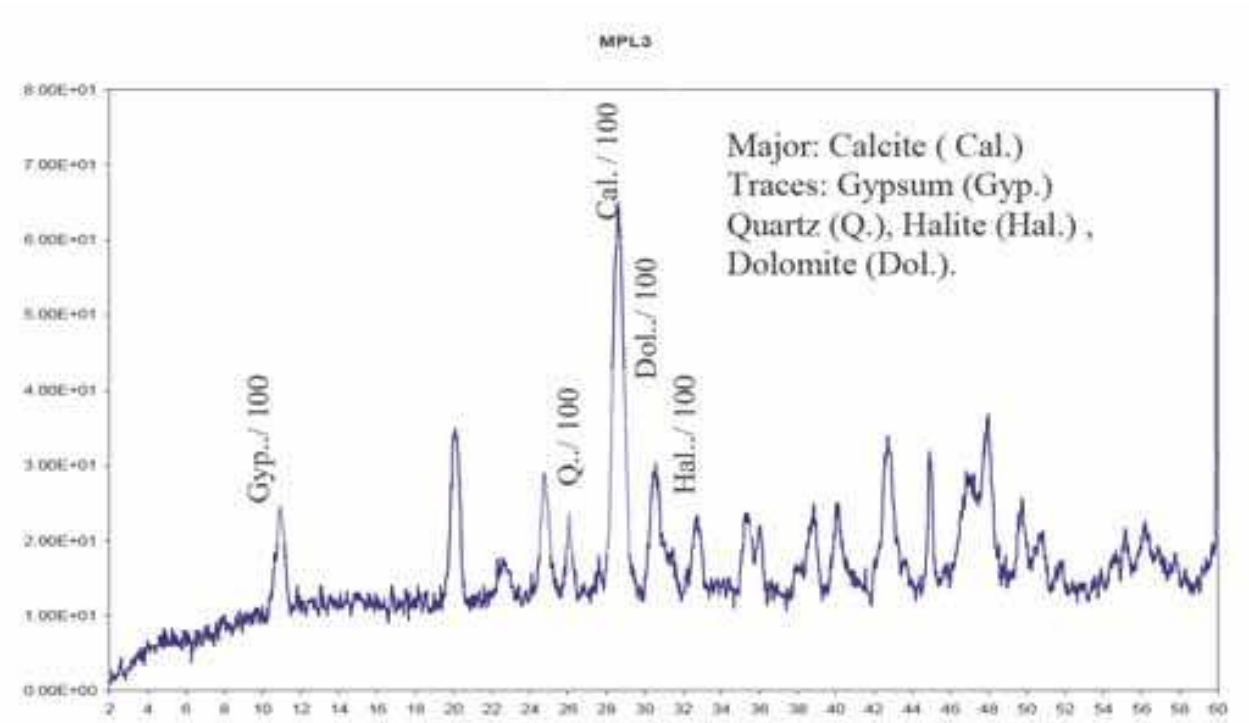


Fig. 6. (A) Shows XRD patterns of Limestone sample from El- Ghouri Mosque.

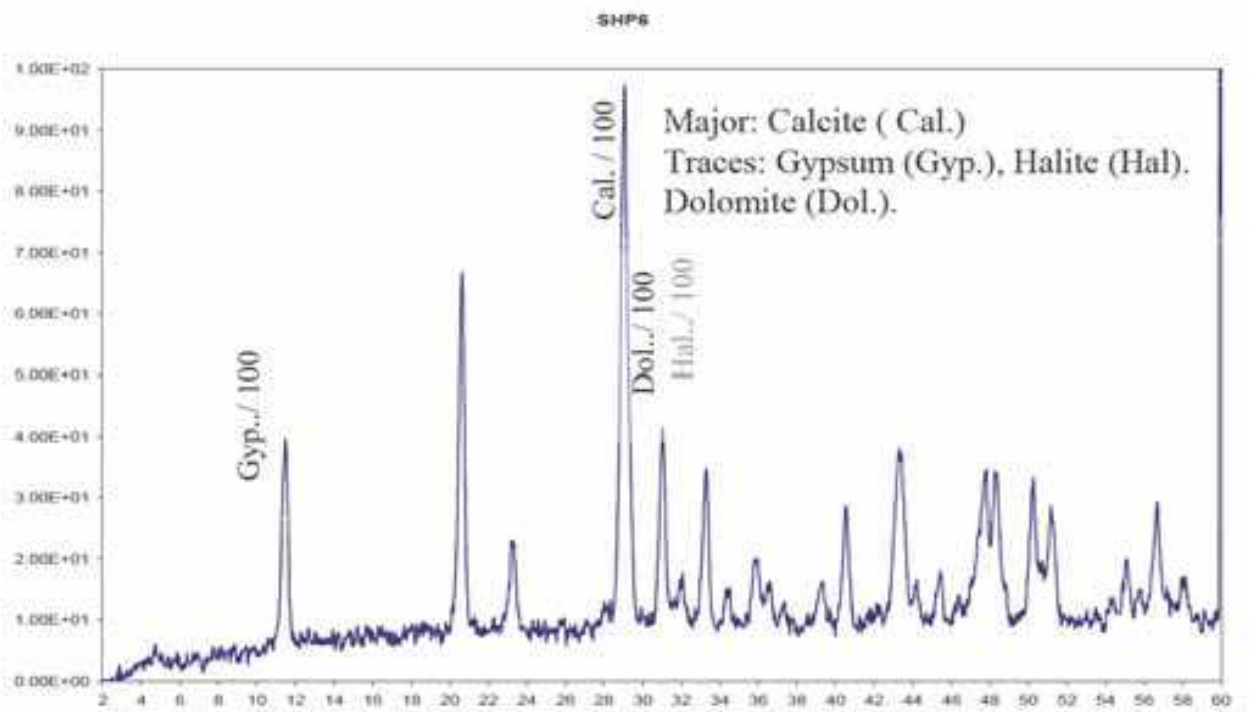


Fig. 6. (B) Shows XRD patterns of Limestone sample from El - Mahmoudya Mosque.

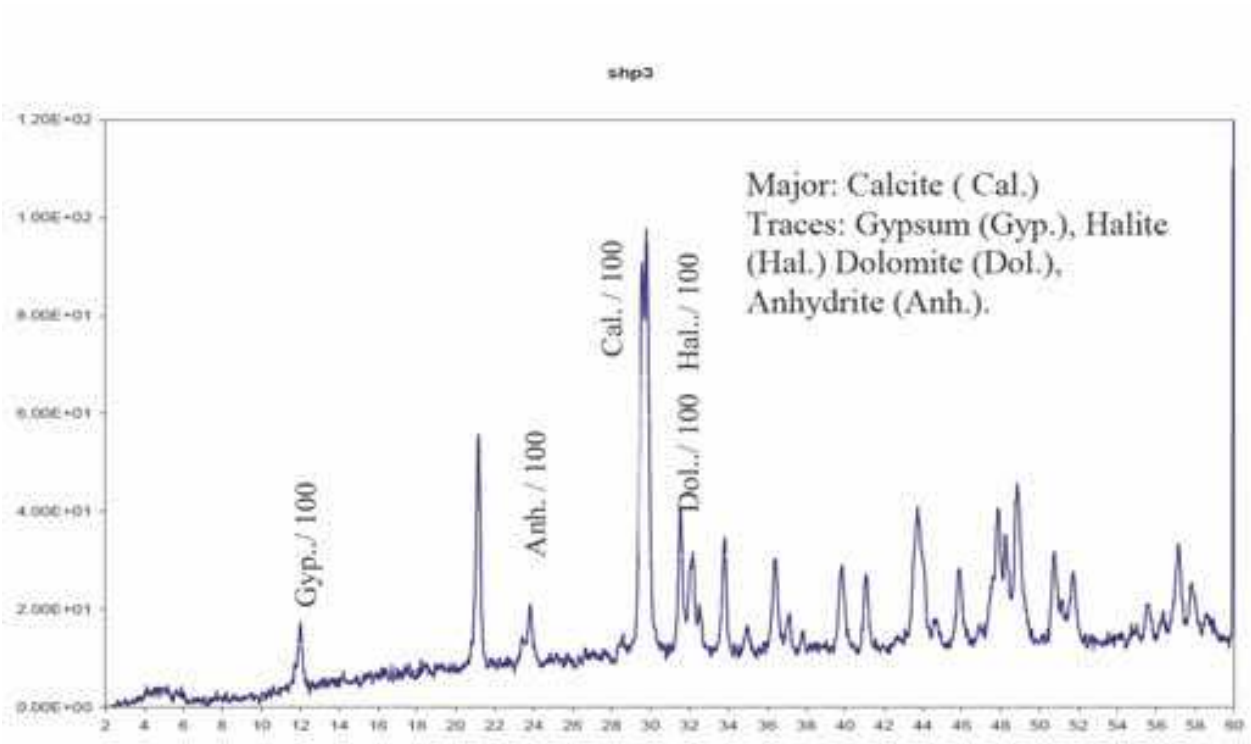


Fig. 6. (C) Shows XRD patterns of Marble sample from Taghri Bardi Mosque.

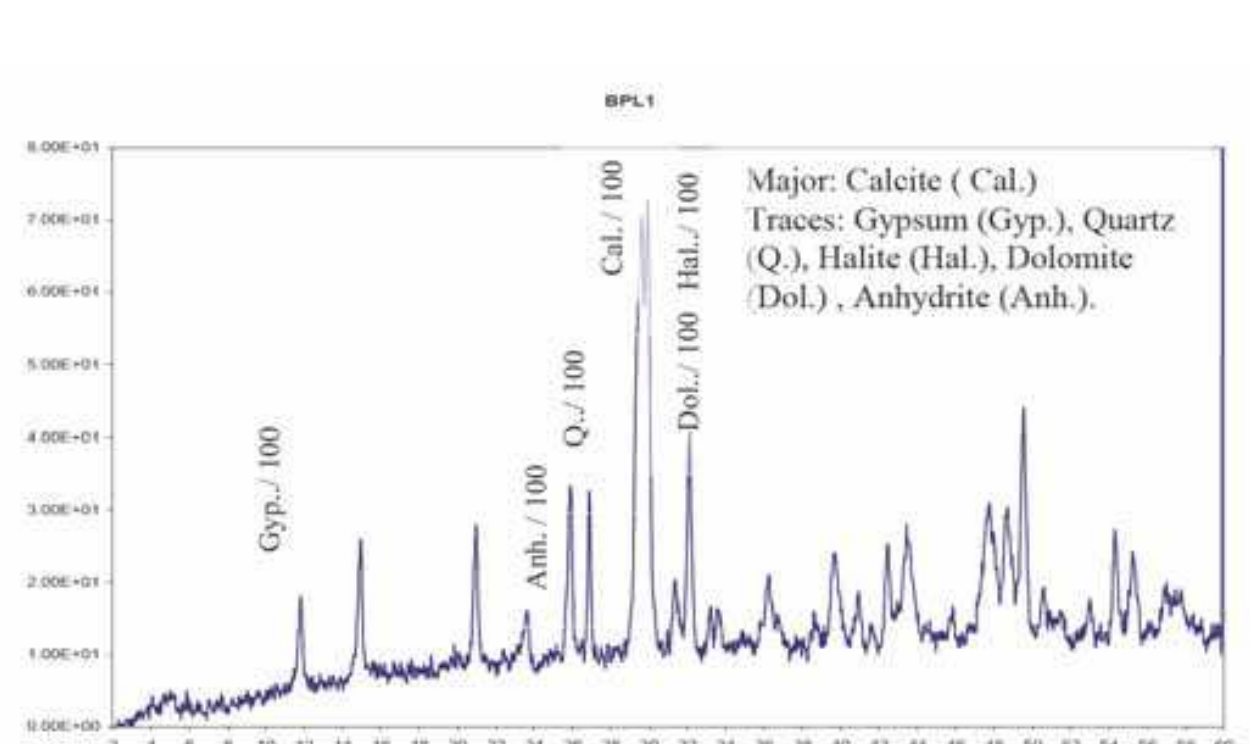


Fig. 6. (D) Shows XRD patterns of Marble sample from Qaitbay Sabil.

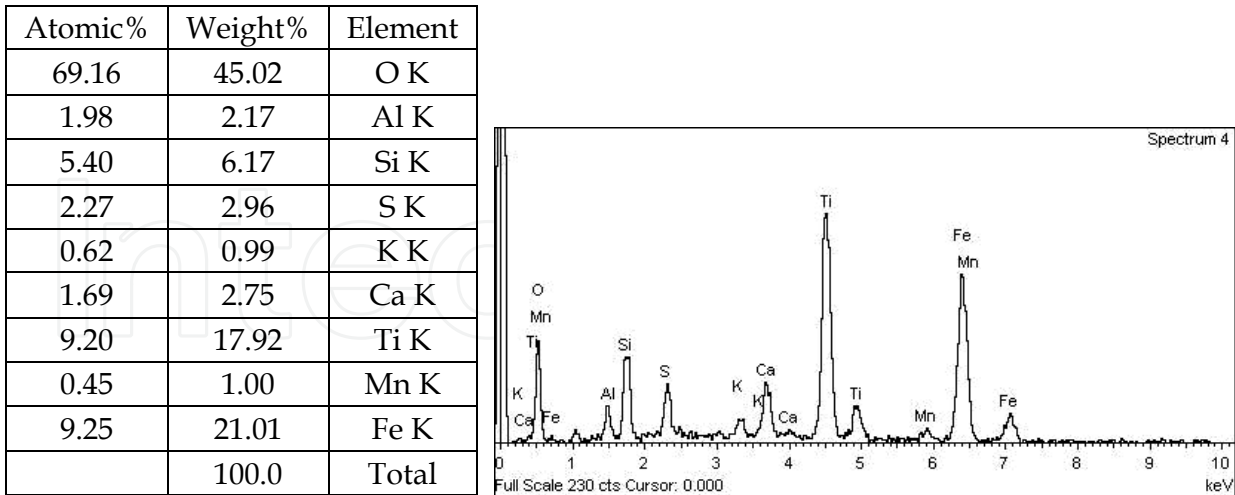


Fig. 7. (A) shows EDX patterns of limestone sample from El- Ghouri Mosque.

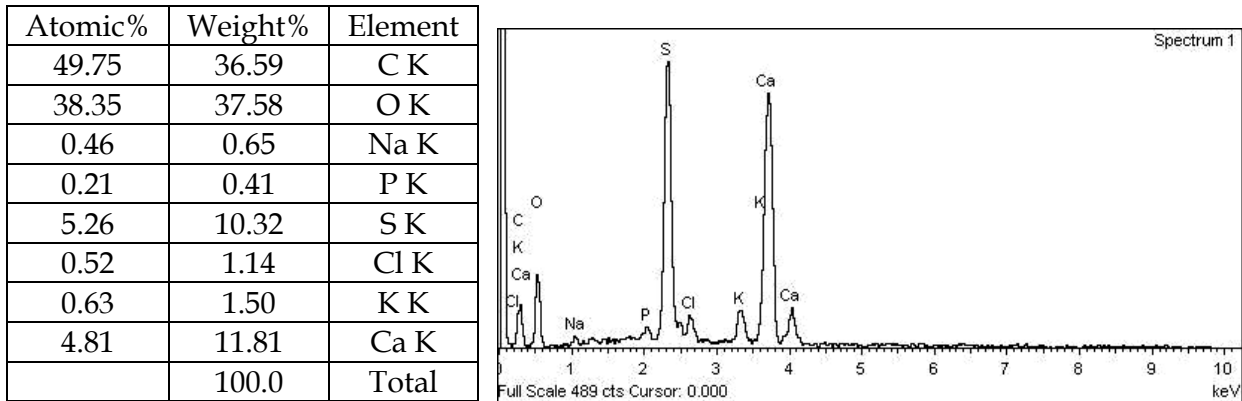


Fig. 7. (B) shows EDX patterns of limestone sample from El - Mahmoudya Mosque.

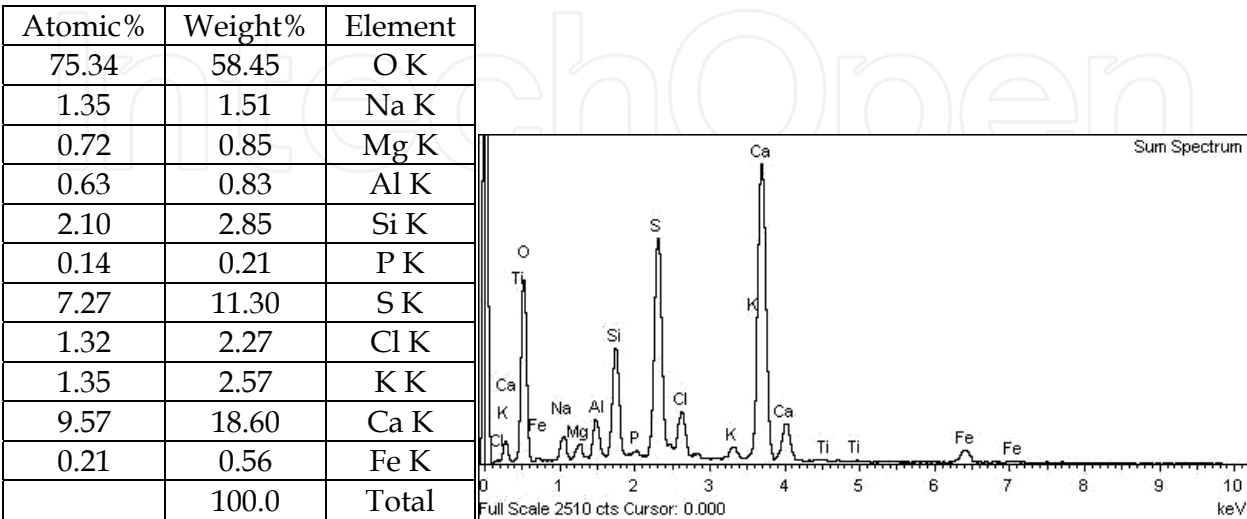


Fig. 7. (C) shows EDX patterns of Marble sample from Taghri Bardi Mosque.

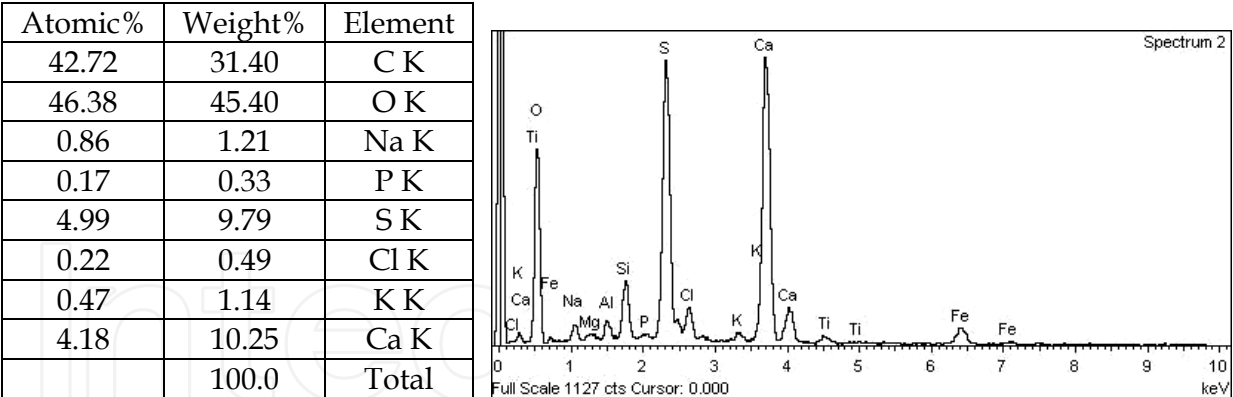


Fig. 7. (D) shows EDX patterns of Marble sample from Qaitbay Sabil.

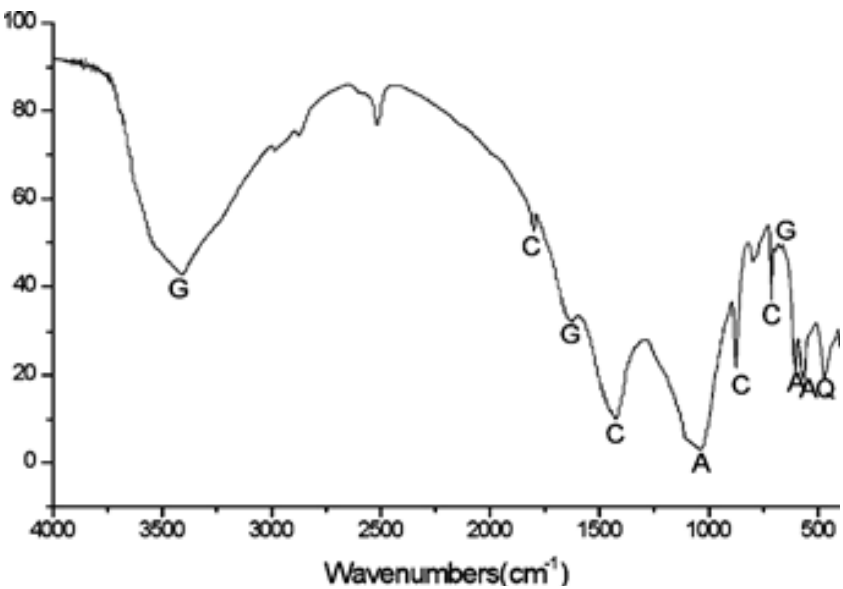


Fig. 8. FTIR spectra of limestone sample from El – Mahmoudya Mosque C, calcite (1798, 1424, 874, 711 cm⁻¹); G, gypsum (672, 1623, 3408 cm⁻¹); A, apatite (565, 604, 1040 cm⁻¹); Q, quartz (469 cm⁻¹).

5. Treatment and conservation processes

There are many methods and materials of treatment, restoration and conservation of building material in archaeological buildings from deterioration phenomena related to air pollution Cleaning Methods and Materials. These methods include cleaning, extraction of salts, consolidation and Water-Repellent Coatings.

5.1 Cleaning

Masonry cleaning methods generally are divided into three major groups: water, chemical, and abrasive. Water methods soften the dirt or soiling material and rinse the deposits from the masonry surface [46]. Chemical cleaners react with dirt, soiling material or paint to effect their removal, after which the cleaning effluent is rinsed off the masonry surface with water. Abrasive methods include blasting with grit, and the use of grinders and sanding discs, all of which mechanically remove the dirt, soiling material or paint (and, usually, some of the

masonry surface). Abrasive cleaning is also often followed with a water rinse. Laser cleaning, although not discussed here in detail, is another technique that is used sometimes by conservators to clean small areas of historic masonry. It can be quite effective for cleaning limited areas, but it is expensive and generally not practical for most historic masonry cleaning projects. Although it may seem contrary to common sense, masonry cleaning projects should be carried out starting at the bottom and proceeding to the top of the building always keeping all surfaces wet below the area being cleaned, [47]. The rationale for this approach is based on the principle that dirty water or cleaning effluent dripping from cleaning in progress above will leave streaks on a dirty surface but will not streak a clean surface as long as it is kept wet and rinsed frequently.

5.2 Removal and extraction of salts

The notion of the poultice has been adapted for the cleaning of historic buildings and a true poultice is intended to draw out deep-seated contaminants and staining from the surface of masonry and sculpture. In current practice the word poultice is extended to a wide range of cleaning materials and techniques, not all of which achieve a true poultice effect on the substrate. What might be termed the true or plain poultice contains water and the poultice medium only, relying on these ingredients to achieve the mobilisation and removal of the contaminant. The most common poultice medium is clay, although paper and cotton fabrics are also used, and talc, chalk and even flour are traditional poultice materials. A mixture of clay and paper fabric produces an absorbent and plastic mixture that is often favoured by conservators of stone sculpture. This plain or true poultice is normally used for desalination, to draw out soluble salts, or as a cleaning method on substrates such as limestone that respond to water cleaning. In these cases the poultice is allowed to dry out and the soiling and/or salts are drawn into the poultice by capillary action with the moisture. Multiple applications may be necessary to draw the salts from within the surface pores, [48]. Whatever the medium, the poultice is mixed with water to form a material that will adhere to the substrate. Clay forms a sticky mass that adheres well to stone and other surfaces. These plain poultices can be conveniently mixed by hand as required on site with the addition of water to the poultice medium. Alkaline poultice cleaners and strippers are commonly used for cleaning or degreasing masonry surfaces and for paint removal. Sodium hydroxide is the most common alkaline cleaning agent in proprietary cleaners for a range of masonry substrates, including limestone, sandstone, brick and terracotta and is the most common ingredient in proprietary paint removers. Care must be taken in the use of sodium hydroxide based cleaners to minimise risks to the building and the user. Sodium hydroxide based cleaners and strippers must be neutralised with acid afterwash. Adjacent, dissimilar building surfaces must be protected and personal protective equipment worn by the cleaning operative. In the field of stone conservation ammonium carbonate is added to clay and clay/paper poultices to remove soiling from limestone. Ammonium carbonate is a less alkaline cleaner than sodium hydroxide. It works by reacting with calcium sulphate on the soiled surface to form calcium carbonate and soluble ammonium sulphate that can be rinsed off with water. These 'active' or 'chemical' poultices are all applied to a pre-wetted surface to minimize penetration of the chemical into the masonry surface and covered with plastic film to prevent the poultice drying out. The cleaning additives in these mixtures chemically dissolve the soiling or staining which is held to the surface of the poultice, and then both the cleaning agent and the contaminant are removed with the clay. Rinsing with water and, where necessary neutralization, follows to remove any soiling that remains on the surface

and also to remove residues of the chemical cleaners. Strictly speaking these materials are clay-based cleaning packs rather than true poultices, but the word poultice is now widely used in the building cleaning industry [49].

5.3 Consolidation

Stone strengtheners based on ethyl silicates are generally applied by spraying or flooding. It is usually also possible to treat moveable parts by immersing them in a bath. Compresses can serve as an alternative to immersion. They ensure maximum length of contact between the stone strengthener and the stone [48]. Equipment employed for flooding includes electrical pumps, airless sprays and simple hoses. The pressure has to be kept as low as possible since the aim is to apply the material to the surface so that it will be absorbed naturally by the stone's capillary system; the excess will run off and be absorbed immediately by untreated areas below [49]. Several wet-on-wet treatments are generally needed, applied at intervals of 20 to 30 minutes. The exact number of treatments, quantity of material and desired minimum penetration depth have to be ascertained by preliminary tests and trials. The construction materials must be dry since the active ingredient in the stone strengthener, i.e., the ethyl silicates, reacts with moisture. The moisture required by the stone strengthener for chemical deposition of the silica gel is supplied by the construction material which always has a certain sorption moisture content varying in equilibrium with the atmospheric humidity [50]. The best working conditions are a relative humidity of 40 to 70 % and a surface temperature on the construction material of 10 to 25 °C. Each coating operation be so arranged that the entire surface can be covered in one working day. Otherwise there is the danger that gel which has been deposited in the pore system will prevent the strengthener from penetrating further; this in turn might cause gel to be deposited in the surface regions of the stone and to gloss or crust formation. Very often instead of the whole object only small sections are treated such as a precious ornament, detail or areas that are severely damaged; in such cases it is advisable to follow up the last treatment with a solvent wash. Suitable solvents are hydrocarbons, methyl ethyl ketene and ethyl alcohol [47]. Freshly treated surfaces must be covered for 2 to 3 days against the rain. Considerable loss of the active ingredient by evaporation may occur at temperatures exceeding 25 °C; at such temperatures the freshly consolidated surfaces have to be protected against direct sunlight. Temperatures below 5 °C cause the stone strengthener to react very slowly; this may result in discoloration or glaze on the surface [51]. The total time needed for the stone strengthener to deposit the silica gel depends on the relative humidity and the temperature; it varies from one to at most three weeks. Therefore before any further restoration work is carried out, a period of roughly one week should elapse. This will allow 90 to 95 % of the silica gel to be deposited. On no account should water be added to the ethyl silicate preparation in an attempt to speed up the reaction; this can result in extensive glazing of the surface that is extremely difficult to remove if indeed this is at all possible.

5.4 Water-repellent coatings

Water-repellent coatings are formulated to be vapor permeable, or "breathable". They do not seal the surface completely to water vapor so it can enter the masonry wall as well as leave the wall. While the first water-repellent coatings to be developed were primarily acrylic or silicone resins in organic solvents, now most water-repellent coatings are water-based and

formulated from modified siloxanes, silanes and other alkoxysilanes, or metallic stearates [49]. While some of these products are shipped from the factory ready to use, other water-borne water repellents must be diluted at the job site. Unlike earlier water-repellent coatings which tended to form a "film" on the masonry surface, modern water-repellent coatings actually penetrate into the masonry substrate slightly and, generally, are almost invisible if properly applied to the masonry. They are also more vapor permeable than the old coatings, yet they still reduce the vapor permeability of the masonry [48]. Once inside the wall, water vapor can condense at cold spots producing liquid water which, unlike water vapor, cannot escape through a water-repellent coating. The liquid water within the wall, whether from condensation, leaking gutters, or other sources, can cause considerable damage. Water-repellent coatings are not consolidants. Although modern water-repellents may penetrate slightly beneath the masonry surface, instead of just "sitting" on top of it, they do not perform the same function as a consolidant which is to "consolidate" and replace lost binder to strengthen deteriorating masonry. Even after many years of laboratory study and testing, few consolidants have proven very effective. The composition of fired products such as brick and architectural terra cotta, as well as many types of building stone, does not lend itself to consolidation. Some modern water-repellent coatings which contain a binder intended to replace the natural binders in stone that have been lost through weathering and natural erosion are described in product literature as both a water repellent and a consolidant. The fact that the newer water-repellent coatings penetrate beneath the masonry surface instead of just forming a layer on top of the surface may indeed convey at least some consolidating properties to certain stones. However, a water-repellent coating cannot be considered a consolidant. In some instances, a water-repellent or "preservative" coating, if applied to already damaged or spalling stone, may form a surface crust which, if it fails, may exacerbate the deterioration by pulling off even more of the stone [52].

6. Achievements and planned activities for improvement of air quality in Cairo

Air quality represents a major priority for the Egyptian Ministry of state for Environmental Affairs, Egyptian Environmental Affairs Agency as it has dangerous impacts on the public health and it is effect on archaeological buildings. This concern encompasses a number of trends [53]:

6.1 Alleviating the vehicles' emissions

Through the coordination and effective cooperation between the Ministry of Environment and the Ministry of Interior, the decree of the Minister of Interior was issued:

- a. To link between the issuance of the licenses of the Vehicles and its emissions testing, and the start of the implementation of this decree in the Qalubia and Giza governorates. Such decree provides a new hope of the improvement of air quality and the first step of overcoming the problem of the vehicles' emissions, to be applied in many other governorates. This decree is essential for the reinforcement of Law No. 4 for 1994 on the protection of Environment. [53].
- b. The Ministry of State has already, in collaboration with USAID through the Cairo Air Improvement Project, delivered the traffic departments in Giza and Qalubia

governorates 38 devices for vehicles' emission testing, in addition to training those who are designated to the technical inspection of vehicles using diesel and benzene. It is worth mentioning that the application of the issuance of the vehicles' licenses in both governorates has started from June 1, 2003 on vehicles' emissions testing to combat the emissions of Carbon monoxide and Hydrocarbons.

- c. The cooperation between the Ministry of Environment and the Ministry of Interior has resulted in the establishment of the environment police: the first police stations to be inaugurated will be in the Regional Branch of the Egyptian Environmental Affairs Agency in Greater Cairo and El-Fayoum as well as in Beni Siweif.

6.2 Relocation of the heavily polluting activities outside the populated areas

Due to the variety of pollution sources especially within Greater Cairo, the Ministry of Environment has formulated a plan of the relocation of the polluting activities outside the populated areas, among them the smelters, quarries, potteries, crackers, brick factories and coal and lime facilities as well as 1206 mining factories and 6000 textiles factories.

This funding plan is based on the contribution of the owners of these activities, applying the principle "Polluter pays". The estimated budget of this plan is L.E. 1745 million; the share of the government is about 15% of its total. In addition to that, the government provides soft loans for the relocation of these polluting activities to the desert. The owners of these activities contribute to the remainder of cost for 4 years starting from July 1, 2003 to June 30, 2007.

The Ministry has, in cooperation with the competent governorates, identified the places of relocation of these polluting activities in El-Amal region in the Ain El Sokhna Road for all Cairo smelters and in Akrasha region for Qalubia smelters, in addition to relocation of coal facilities to the industrial zone in Belbeis as well as the brick factories to Arab Abu Saad region. [53].

6.3 Combating the industrial pollution

As for the plan of the Ministry of Environment for pollution sources control in the big factories, it has prepared a plan in two phases as follows:

The first phase: factories in need of limited funds for approximately L.E. 23.13 million to combat pollution discharged from them.

The second phase: factories in need to huge funds for about L.E. 545.9 million. In this respect, the EEAA is implementing some of the projects that make available the funding and technical support for the industrial establishments, such as the Industrial Pollution Abatement Projects providing grants and soft loans offered by the World Bank as well as technical assistance as a grant from the Finnish Government. In addition, there is the Environment Protection Fund for the Public Sector Industries funded by the German Construction Bank that provides Euro 25.56 million as a grant from the German Government, representing a partial funding of 50 % of the necessary investments for the implementation of industrial waste treatment projects as well as soft loans presented from the Egyptian banks participating in this project[54].

6.4 The environmental inspection on the establishments

Since the start of the practical application of Law No. 4 for 1994 and after the termination of the grace period provided by the Law and its Executive Regulation, the Ministry has

established the Environmental Inspection Unit at the central level and prepared a manual of the policies and procedures for the inspection unit, which is considered the first manual in this field. This manual has specified the role and authorities of the environmental inspection in comparison to the other supervisory agencies concerned with the inspection on the establishments. This manual reemphasizes that the periodical follow-up and inspection are the effective means of the non-replication of violations.

6.5 The safe use of the treated sewage water in the irrigation of forests

For further improvement of air quality and the reduction of dust and sand rates, arising from Al-Khamaseen wind, the Ministry of State for Environmental Affairs is implementing the Green Belt Project around Greater Cairo (Cairo-Giza-Qaluibia) along 100 km on the sides of the circular road with a width of 10-25 m, [55].cultivating it with Acacia and Cypress trees.

This project aims at protecting the citizens of the Greater Cairo from dust and sands and conserving their health. In addition, it provides job opportunities to the graduated youth whether in the implementation of the project or its maintenance, besides using the treated sewage water for the irrigation of these trees to be economically made use of.

This project is implemented in four phases in the three governorates: starting from Cairo Governorate in the region from El-Moneib Bridge to Misr Ismailia Desert Road, in Qaluibia Governorate to El-Kanater establishment, and in Giza Governorate to El-Moneib Bridge. The total cost of the project is L.E. 13.7 million. [53].

The Green Belt is not the last project implemented by the Ministry for the improvement of air quality but there is also the National Programme for the Safe Use of Treated Sewage Water, in collaboration with the Agriculture, Irrigation, Housing, Local Development and Environment Ministries as well as the different governorates.

The concept of this project depends on the investment of treated sewage water since Egypt produces about 3 billions m³ annually at the cost of 14 Piastres/meter with a total of approximately L.E 14 million, and turns this problem into a social, environmental and economical value. Instead of disposing this treated water into water channels and contaminating it, it can be used in afforestation.

This project achieves several social, economic and environmental benefits as it basically improves air quality through the plantation of trees that are the source of Oxygen for they intake Carbondioxide and produce Oxygen[53]. In addition, it helps in combating desertification, protecting water resources and soil from pollution, building green belts and wind obstructers, to be used in producing woods instead of importing them. It also helps in providing job opportunities for the youth and establishing the new urban communities side by side with these forests. [54]. There are successful attepts for this project in Serabuim area in Ismailia, Sadat City, Asuit, Sohag, Luxor, Qena, New Valley, Tour Sinai, El-Saaf , and Aswan.

This national project is carried out at several phases. The first phase is executed in an area of 82940 thousand Fedan around 72 Sewage stations in the different governorates all over the Republic at the cost of L.E. 5 thousand/ Fedan, providing a collective revenue during the lifetime of the forest, i.e. 12 years. The implementation is carried out for 8 thousands Fedan annually.

6.6 Manufacturing the construction materials from rice straw using unconventional technology

There is no doubt that success that will come out of the real partnership between the Government and the Private Sector in the relocation of polluting activities outside the

residential regions, based on environmental principles and standards supported by environment friendly technologies will directly assist in combating the Black Cloud phenomenon that we suffer from in October annually. Scientists from the Scientific Research Academy, the National Research Center, the Environment Research Council, the Meteorology Organization and the Specialized National Councils have a consensus that the real reasons for the Cloud are confined to a climate phenomenon, namely, the existence of high pressure that appears every year at the same time, accompanied by a thermal change and stability of wind, which all lead to the accumulation of pollution in Cairo air. [53].

7. Conclusion

The danger to archaeological buildings from air pollution comes from two main sources – gases that increase the corrosivity of the atmosphere and black particles that dirty light-colored surfaces. Acid rain comes from oxides of sulphur and nitrogen, largely products of domestic and industrial fuel burning and related to two strong acids: sulphuric acid and nitric acid. Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) released from power stations and other sources form acids where the weather is wet, which fall to the Earth as precipitation and damage both heritage materials and human health. In dry areas, the acid chemicals may become incorporated into dust or smoke, which can deposit on buildings and also cause corrosion when later wetted. Atmospheric chemistry is, of course, far more complex than this and a variety of reactions occur that may form secondary pollutants that also attack materials. Particulate matter is much more complicated because it is a mixture rather than a single substance – it includes dust, soot and other tiny bits of solid materials produced by many sources, including burning of diesel fuel by trucks and buses, incineration of garbage, construction, industrial processes and domestic use of fireplaces and woodstoves. Particulate pollution can cause increased corrosion by involvement in a number of chemical reactions and, often more importantly, it is the source of the black matter that makes buildings dirty. The influence of heavily polluted atmosphere in the urban environment results in different weathering patterns, mainly in the form of crusts. It might be assumed that the analytical results of Polarizing Microscope, XRD, SEM, EDX and IR. alone are not sufficient to clarify and interpret the growth mechanisms of crusts. However, they do provide valuable information about changes in compositions of crusts and original rock, and the relationship between crusts composition and air pollution. The compositions of the crusts collected from areas on the archaeological stone buildings with different decay patterns show that the deterioration is mainly due to the atmospheric pollutants and its extent is strongly dependent on the surface exposition to the environment. According to the obtained results, an appropriate conservation plan will be developed, that includes the steps of cleaning and consolidation, in order to identify the most suitable materials and methodologies to remove the deterioration crusts avoiding the loss of original substrate and ensuring an increased cohesion to deteriorated stone.

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Monitoring, Control and Effects of Air Pollution

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The book addresses the subjects related to the selected aspects of pollutants emission, monitoring and their effects. The most of recent publications concentrated on the review of the pollutants emissions from industry, especially power sector. In this one emissions from opencast mining and transport are addressed as well. Beside of SO_x and NO_x emissions, small particles and other pollutants (e.g. VOC, ammonia) have adverse effect on environment and human being. The natural emissions (e.g. from volcanoes) has contribution to the pollutants concentration and atmospheric chemistry governs speciation of pollutants, as in the case of secondary acidification. The methods of ambient air pollution monitoring based on modern instrumentation allow the verification of dispersion models and balancing of mass emissions. The comfort of everyday human's activity is influenced by indoor and public transport vehicles interior air contamination, which is effected even by the professional appliances operation. The outdoor pollution leads to cultural heritage objects deterioration, the mechanism are studied and the methods of rehabilitation developed. However to prevent emissions the new technologies are being developed, the new class of these technologies are plasma processes, which are briefly reviewed at the final part of the book.

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