SCIENTIFIC EXAMINATION OF MARBLE FRETWORK FROM JAHANGIR TOMB, LAHORE, PAKISTAN

S.Gulzar and J.P. Burg*

School of Architecture and Planning, University of Management and Technology, Lahore, Pakistan
*Department of Earth Sciences, Swiss Federal Institute of Technology, Zurich, Switzerland
Corresponding author's e-mail: saima.gulzar@umt.edu.pk

ABSTRACT: The white marble fretwork from 17th century Mughal architecture was investigated to formulate the conservation and restoration strategy and for reproduction in compatible materials. Stone fretwork, one of the distinguished and established Mughal decorative art became rare after the decline of Mughal's in the Indian subcontinent. Samples were collected from various historic fretworks of the Jahangir Tomb, a Mughal heritage site atShahdara (Lahore). These samples were studied by optical microscopy and X-ray diffraction for petrographic and mineralogical characterization and for understanding the manufacturing process/ technique. The analytical results showed that theoriginal rock was transported from quarries in the present-day Indiawere dolomitic marbles. The work provided directionto select appropriate marble for restoring fretwork in the Mughal buildings.

Keywords: Marble, Fretwork, Jahangir Tomb, Pakistan, Mineralogy, Petrography.

(Received 07-11-2015 Accepted 01-09-2016)

INTRODUCTION

The Mughals laid great emphasis on the decoration of their monumental buildings. They employed all forms of embellishment including glazed tiling, stone mosaic and inlay works, fresco/mural paintings and stone fretwork for aesthetically appealing surfaces of their magnificent architecture (Nath, 1976 andRehman, 2011). Stone fretwork locally known as "JALI "is one of the beautiful and delicate decorative art introduced and establishedin the Indian subcontinent by Mughal rulers during their reign (1526-1857AD). The fretwork tracery of red sandstone and marble was employed for utilitarian as well as aesthetic purposes (Awan, 2008).Delicate white marble fretwork is mainly seen as screens (locally known as jalies) used to cover balconies (locally known as jharokas) or to divide internal spaces within big arched opening and to serve as railing or parapet (Figure 1). The frets for internal spaces were used to produce a pleasing effect by allowing sufficient light and cool air while excluding sharp glare(Wheeler, 1970 andNath, 1976, 1989). This particular decorative technique almost disappeared like many others(arabesque, stalactite, stone inlay etc.) in Pakistan. The prerequisite to reduce or prevent the loss of such decorative art is the characterization of historic materials, classification of their present deterioration state and exploring the compatible materials for restoration.

MATERIALS AND METHODS

Fret samples were collected from different locations (ornamental as well as utilitarianfretwork)of Jahangir Tomb inShahdara Complex(Table-1).Several analytical methods including petrograhy, microscopy and XRD were employed for their characterization. The Olympus BH@ BHSP polarizing microscope equipped with Nikon digital camera was used to characterize the mineralogical, texture, cementing material and grain features (grain size of calcite and dolomite in relation to boundary shapes).Light Optical Microscopy (L.O.M.) was also performed on 30µm, polished thin sections to analyze the grain size, colour and texture of samples.

A Bruker, AXS D8 Advance powder diffractometer with CuKα radiation was used on sample powders forfurther determination of the mineralogical components and crystalline phases. The patterns were obtained with a Lynxeye super speed detector, step scanning from 5^o to 80^o with a count for 0.5 s per step and 40 kV and 40 mA in the X-ray tube.

RESULTS AND DISCUSSION

The analytical work revealed that marble was used in combination with red sandstone for the characteristic representation of Mughal architecture instead of the black/ green schist and basalt used during earlier architectural periods for monumental ornamentation in Indian subcontinent (Chandra, 2003 and Awan, 2008).Investigations and analytical study of marble samples depictedmetamorphic recrystallization,so that the fret marble was found to be a coarse grained rock of interlocking carbonate crystals with few percent of quartz, hematite, limonite and mica.

Petrographic-Microscopic Analysis: The examination of thin sections revealed that all marble samples(Table-2) consist of both calcite ($CaCO_3$) and dolomite (Ca, Mg $(CO_3)_2$) in similar proportions with trace amounts of quartz and clay. Epidote($\{Ca_2\}\{Al_2Fe^{3+}\}(Si_2O_7)$ $(SiO_4)O$ (OH))was also identified in few samples as a granular aggregate usually the secondary alteration product of plagioclase ((Na, Ca)(Si, Al)$_4O_8$). Calcite grains in various sizes were found in mortar fabric, typical of Makrana marbles with the calcite maximum grain size of 500µm was reported by (Natani, 2000; Awan, 2008 andOriglia, 2011). This distinguishing feature was further eloborated in the interlocking of coarse grained calcite surrounded by medium grained (200-280µm) calcite.The studied samples also indicated non-uniform metamorphic conditions due to pressurized boundaries in coarse crystals with broken edges.

Microscopic analysis of samples M1 and M4 which were collected from decorative screens showed medium to coarse grained texturewith a grain size of between 100µm and 300µm (Figure 2).This type of marble was quarried mainly in Makrana, India. It was further classified as dolomitic marble Table-1.Makrana marbles that belonged to the Precambrian (Pre-Vindhyan) Raialo Series also reported by (Wadia, 1957 and Krishnan, 1982), which was medium to coarse grained, saccharoidal and white outcrops,exposed to the southwest of Makrana near Ras (26º19´:74º11´) was found in Rajasthan (Natani, 2001 and Brown and Dey, 2008). Calcite was found to be the main mineral (>75%) with a smallvariationof 1-2% in different samples. The crystals showedstraight boundaries with no shape preferred orientation (Attanasio, 2003 andAttanasio*et. al.*, 2013). Dolomite (22%) with a grain size of 80µm to 200µm wasidentified as another essential mineral. Epidote(1.3-1.7%) wasasubhedral grains; optical studies identified both zoisite and clinozoisite. Interstitial and fine grains of muscovite were also identified. Small anhedralquartz grains occurred in the calcite-dolomite matrix. Hematite and limonite weregenerally identifiedas traces in the form of randomly distributed specks.

Microscopic analyses of samples M2, M3 and M5 from screens used in balconies were foundmineralogicallysimilar to samples M1 and M4 but they lackedepidotewhich suggested a different source/location of quarries(Table 2).These well-crystallized, non-foliated dolomitic marbles (Figure 2c) were also quarried at Raialo, in Jaipur, in the vicinity of Makranawere reported by (Natani, 2002 and Brown and Dey, 2008). Calcite (150-500µm grain size) and dolomite (100-220µm grain size) wereobserved well twinned and cleaved (Figure2d) in these samples also reported by (Zöldföldi, 2008 andBorghi*et. al.*, 2009).

X-Ray Diffraction Analysis (XRD):X-ray diffraction analysis further complemented the microscopic analysis and confirmeddominance of calcite (CaCO3) and dolomite (Ca, Mg $(CO_3)_2$) with subsidiary quartz, muscovite,haematite/ limonite (H/L) and clay (Figure 3a and 3b).

Table 1: Description and mineralogical composition of the investigated marble samples.

Sample #	Location	Setting	Mineralogical Composition			Local Name	Petrographic Name/ Group
			Major	Minor	Trace		
M1	Jahangir Tomb main building	Geometric panel from minaret	calcite, dolomite	epidote, muscovite, quartz	hematite/ limonite, mica	Makrana Sang-e-marmar	Dolomitic marble
M2	Jahangir tomb facade	Screen	calcite, dolomite	muscovite, quartz	hematite/ limonite, mica	Makrana sang-e-marmar	Dolomitic marble
M3	Jahangir tomb chamber	Geometric panel	calcite, dolomite	muscovite, quartz	hematite/ limonite, mica	Makrana sang-e-marmar	Dolomitic marble
M4	Jahangir tomb internal chamber	Decorative screen inside	calcite, dolomite	epidote, muscovite, quartz	hematite/ limonite, mica	Makrana sang-e-marmar	Dolomitic marble
M5	Jahangir tomb main building	Balcony	calcite, dolomite	muscovite, quartz	hematite/ limonite, mica	Makrana sang-e-marmar	Dolomitic marble

Fretwork Technique: The making of fretwork was a sequential process after selection of stone slabs dressed and prepared according to the required size. The first step was marking the uniform border within which the intended pattern could be traced on the slab. The space delimited by the borders was evenly divided in the form of graph (locally known as *AllachaBandhana*).The designs were then transferred using the graph marked on the slab. Another method was using stencils on metal sheets and then glued on the marble slab. The marble slab was carved and engraved with chisel following the design on the slabs (known as *DandahyBandhana*). The honey-comb holes or fret were mainly hexagonal (*Chheh Mass*) and octagonal (*Aath Mass*) along with some floral, geometrical and plant patterns. Carving was skillfully made deeper and deeper in different grades of fineness. Slabs were turned over when pits were 5-7cm deep and the same carving process was repeated on the reverse side of the slab until perforated. Finally the fretwork was rubbed and finished by using emery (coarse corundum for polishing). The fretwork was then fixed with lime mortar in its designated place.

Table 2: Mineralogical and petrographic features of the investigated marble samples

Sample	Sample M1	Sample M2	Sample M3	Sample M4	Sample M5
	Mineralogical composition (%)				
Calcite	75±1	77±2	77.5±2	79±1	77±2
Dolomite	21±1	20±1	21±1	18.5±1	20±1
Epidote	1.5±0.5	-	-	1±0.5	-
Quartz	1±1	0.5±1	0.5±1	0.5±1	1±1
Clay	Tr	Tr	Tr	Tr	Tr
Others	1.5±0.05	2.0±0.01	1.0±0.01	1±0.05	2.0±0.01
	Grain size (µm)				
Calcite	100 -300	150-400	150-500	100-270	150-500
Dolomite	80-250	100-200	100-220	70-200	100-220
Observation	good cleavage	good cleavage	good cleavage	good cleavage	good cleavage, quartz presence
Texture	granular	Granular	granular	granular	granular
Boundaries	pressure solutions visible in boundaries	visible boundaries, rounded	broken boundaries	pure and clear boundaries	visible boundaries, rounded edges

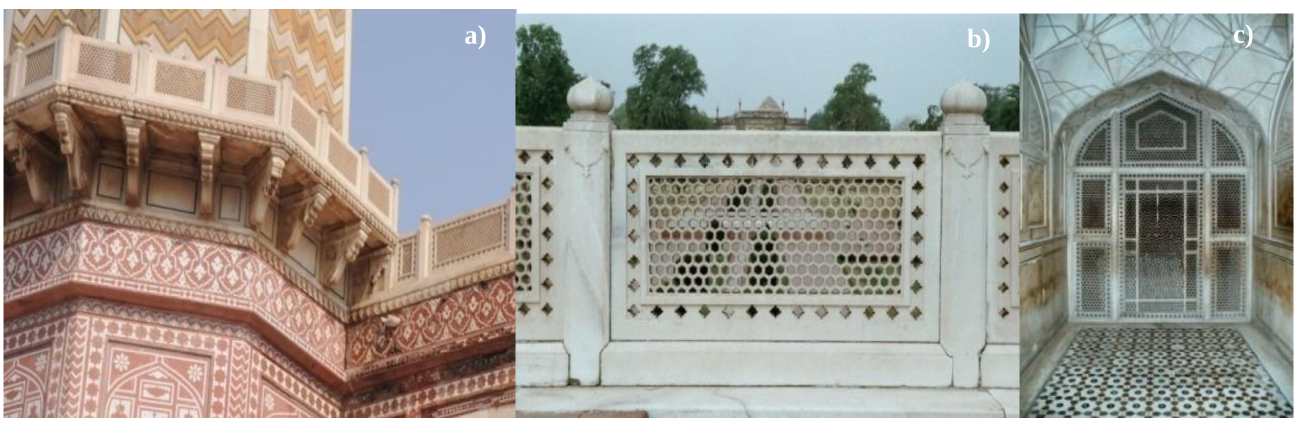
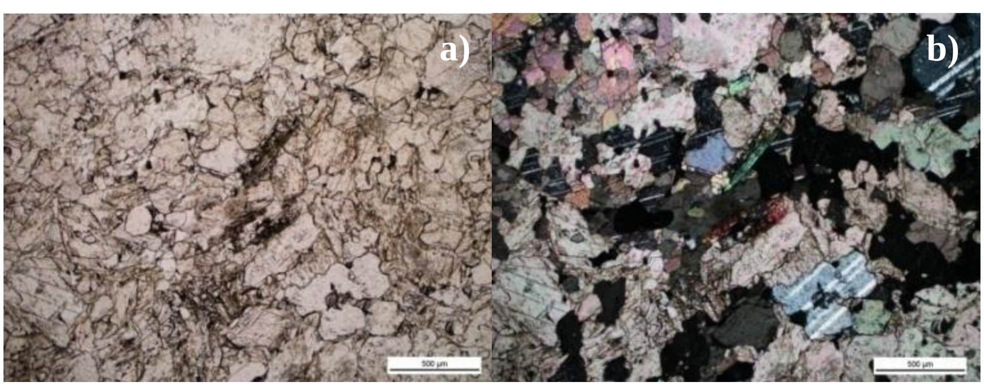


Figure-1: Marble Fretwork (Jali) used for; a) parapet and minaret b) panel and c) screen in the Jahangir Tomb in Shahdara Complex, Lahore



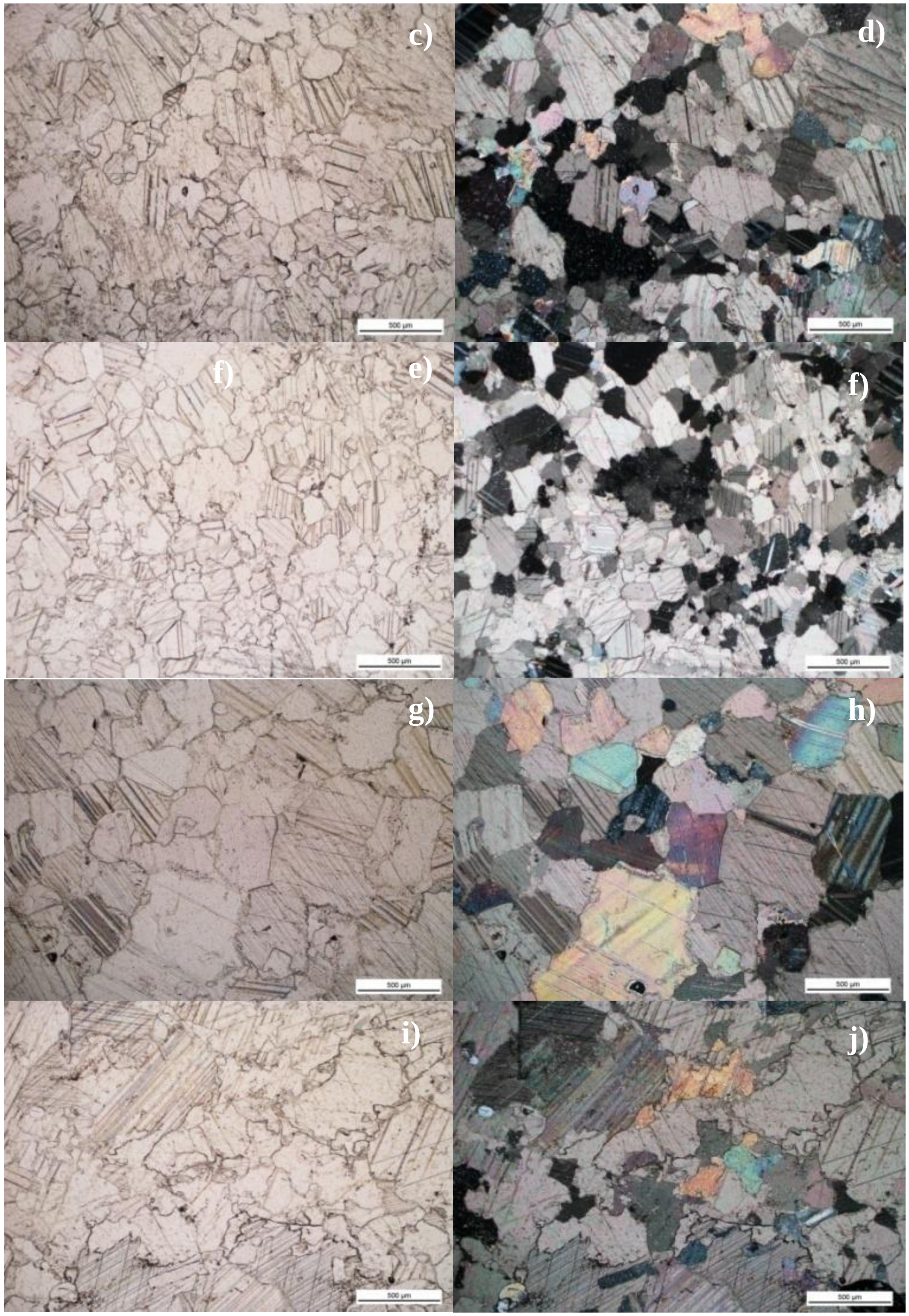


Figure-2: Microphotographs of investigated samples (500µm) showing; a) PPL: Type M1 calcite-rich medium to coarse- grained white marbles from Jahangir tomb, b) CNL: calcite crystals with straight boundaries in type M1, c) PPL: well-crystallized white marble Type M2, d) CNL: twinning and cleavage of calcite crystals in type M2, e) PPL: M3 sample texture, f) CNL: calcite crystals with irregular boundaries in M3, g) PPL: M4 sample with neat cleavage, h) M4 medium to coarse grained marble, i) PPL: M5 with distorted calcite boundaries and j) CNL: M5 calcite crystals interlocking with no specific orientation.

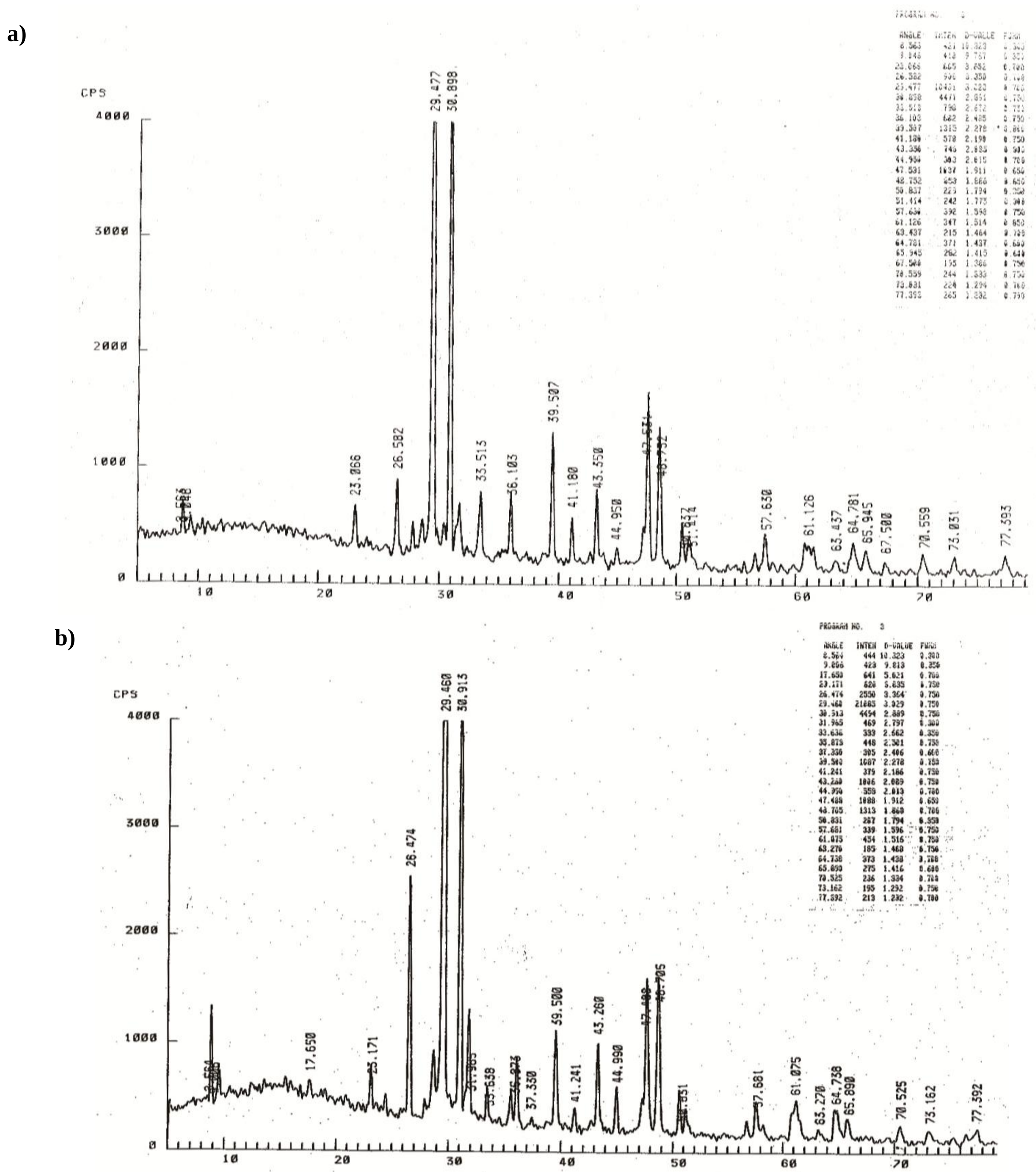


Figure-3: XRD pattern of samples a) M1 and b) M2 with high peaks for calcite (2θ= 29.489) and dolomite (2θ= 30.898), medium peaks for quartz (2θ= 26.582) and low peaks for accessory minerals.

Conclusions: The built heritage of Pakistan suffered great damages due to the lack of information about historic materials, technology and diagnostic procedures. This studyrevealed that fretwork decoration samples from the Jahangir Tomb, Mughal heriatge site at Lahore were dolomitic marbles transported from Makrana, in Rajasthan. The petrographic-microscopic and XRD analysis showed that the largest grain size was 500µm in a mortar fabric. Epidote, quartz, muscovite, H/L and clay were accessory minerals.The complete characterization of the originally employed historic materials also provided information on the techniques, which should be respected for successful restoration programs. The present study employing scientific methodology defined the material composition that would guide selection of appropriate materials for restoration of fretwork.

Acknowledgements: The authors would like to acknowledge the Department of Archaeology and Museums Lahore for their help during the field observations and sampling. We would also like to thank Department of Earth Sciences ETH-Zurich, for their assistance in analytical work.

REFERENCES

Attanasio, D.(2003).Ancient White Marbles: analysis and identification by paramagnetic resonance spectroscopy. L'ERMA, di BRETSCHNEIDER; Rome(Italy). 283p

Attanasio, D.,M. Bruno, W. Prochaska and A.B.Yavuz (2013).The Asiatic marbles of the Hadrian's Villa at Tivoli. J.Archaeol. Sci.40(12): 4358-4368

Awan, M.Y. (2008). Building stone and state of conservation of the built heritage of Pakistan.Pak. J. Engg. and Appl. Sci. (3): 8-18

Borghi,A., G. Vaggelli,C. Marconand L. Fiora (2009). The piedmont white marbles used in antiquity: an archaeometric distinction inferred by a minero-petrographic and c–o stable isotope study,Archaeometry. 51(6): 913-931

Brown, J.C. and A.K. Dey (2008).Mineral wealth: India, Pakistan, Bangladesh and Burma: a guide to the occurrence and economics of the useful minerals.Vishal Kaushik Printers; Delhi (India).367 p

Chandra, S., (2003).History of architecture and ancient building materials in India.6th Ed. Tech Books International; New Dehli (India).412 p

Geological survey of India (2001).Geology and mineral resources of Rajasthan, Misc. Publ. 30 (12): 23-27

Krishnan, M.S. (1982).Geology of India and Burma.6th Ed. CBS Publihshers and Distributors; Delhi (India). 125 p

Natani, J.V. (2000).Geoenvironmental impact assessment studies of Makrana Marble mining area, Nagaur district, Rajasthan. Rec. Geol. Surv. Ind. 133 (7): 64-65

Natani, J.V. (2001). Geoenvironmental impact assessment studies of Makrana marble mining area, Nagaur district, Rajasthan. Rec. Geol. Surv. Ind. 134 (7): 63-64

Natani, J.V. (2002). Regional assessment of Marble and calc-silicate rocks of Rajasthan. Rec. Geol. Surv. Ind. 135 (7):53-55

Nath, R. (1976). History of decorative art in Mughal architecture.1st Ed.MotilalBanarsidas; Delhi (India). 92 p

Nath, R. (1989). Colour decorations in Mughal architecture (India and Pakistan): The historical research documentation programe-Jaipur.2nd Ed. Anuj Printers; Jaipur (India). 26 p

Origlia, F.,E.G.M. Meccheri, J.E. Spangenberg, I.T.Memmi andE. Papi (2011).Mineralogical, petrographic and geochemical characterisation of white and coloured Iberian marbles in the context of the provenancing of some artefacts fromThamusida(Kenitra, Morocco). Eur. J. Mineral. 23 (6): 857-869

Rehman, A. (2011). Conservation of historic monuments in Lahore: Lessons from Successes and Failures.Pak. J. Engg. and Appl. Sci. (8): 61-69

Wheeler, M. (1970).Splendours of the East: temples, tombs, palaces and fortresses of Asia.Weidenfeld and Nicolson; London (United Kingdom).25 p

Zöldföldi, J., P. Hegedüsand B. Székely (2008).Interdisciplinary data base of marble for archaeometric, art historian and restoration use. In: Yalcin, Ü.,Özbal, H. and Pasamehmetoglu, G.(eds.): Ancient Mining in Turkey and the Eastern Mediterranean.Atilim University; Ankara (Turkey).251 p.