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Classification of Asia Minor marbles based on crystal size for archaeometric assignment

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Abstract: This study was carried out to determine the range of crystal sizes of Asia Minor marbles and to classify the marbles according to crystal size. Asia Minor marbles have been used as building stones since ancient times. The literature already includes studies on their crystal sizes; however, different studies performed on marbles of the same locality have reported different crystal size classes, which has caused complexity. To eliminate this complexity, this study used multidirectional petrographic analyses on the eight known Asia Minor marbles. Thin sections were photographed under a polarizing microscope, and the crystal sizes of the samples were measured using computerized image analysis. An average of 500 size measurements were taken for each sample to determine the mean and maximum crystal sizes of each marble. For archaeometric evaluation of the marbles, a crystal size classification is suggested. According to this suggested classification, crystal sizes of 100–250 μm, 250–1000 μm, and >1000 μm are defined as fine crystal, medium crystal and coarse crystal, respectively.

Key words: Asia Minor marbles, marble crystal size, marble crystal size classification

1. Introduction

Asia Minor has historically been the home of highly developed and wealthy civilizations largely due to its location along migratory and commercial routes, its proximity to Europe, its fertile soil, and its suitable climate for human habitation. As the geology of Asia Minor includes many high-quality marble deposits, these civilizations used marble extensively to construct monuments and statues. Moreover, these marbles were exported beyond the borders of Asia Minor even in ancient times. The most well-known marbles exported from Asia Minor in ancient times were the Marmara white grey marbles and the Afyon white marbles. Roman and Byzantine builders used these two marbles to construct buildings in Istanbul (Angı, 2010, 2013), and both of these marbles were important for supplying the Roman Empire's marble needs (Gardner and Lieu, 2004). Additionally, the white and black marbles of ancient quarries that were recently discovered in Muğla Göktepe were used in the making of many sculptures during the Roman period (Yavuz and Elçi, 2011; Attanasio et al., 2015).

Crystal size is a parameter closely related to the functional properties of marble, such as cutting and processing suitability, and material properties that include porosity, water absorption, abrasion, load resistance and long-term durability. Also, crystal size was the most important parameter that determined the location and type of use of marbles in ancient times. Medium and coarse marbles were generally used in the construction of buildings or monuments, whereas fine marbles were used for sculptures and similar artifacts because they allowed for more detailed processing. For this reason, crystal size has long been key for determining the quality and preferability of marble in the natural stone sector.

Although the literature includes studies on the crystal sizes of Asia Minor marbles, no standard classification has been developed as a reference for crystal sizes and ranges. Moreover, various studies of marbles from the exact same locations in Asia Minor have reported different grain size ranges and different grain size classes. A definition for the crystal size range of crystalline natural stone is missing from the European Committee for Standardization (CEN) standard EN 12407 (CEN, 2019) on natural stone test methods, petrographic examination. The EN 12407 standard classifies crystalline natural stones as coarse, medium, or fine based on grain size even though there is no scale to show which metric ranges these classifications correspond to. A short summary of national and international studies on the crystal sizes and classes of Asia Minor marbles is given in Table 1.

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Table 1. Crystal sizes and classes of Asia Minor marbles determined by previous studies.

Crystal size class	Crystal size (μm)	Reference marbles	Defined by
Zero	<100	Afyon white	Kun, 2013
Very fine	<50	None	Bozkurt, 1989
	600 (MGS) 200 (MGS)	Göktepe white Göktepe black	Attanasio et al., 2015
Fine	50–100	None	Bozkurt, 1989
	59–119	Goktepe black	Yavuz and Elçi, 2011
	600–1200	Muğla/Kestanecik Kozağaç	Kuşçu, 1992
	600–1700	Milas dolomitic	Bağcı et al., 2010
	218–1289	Muğla sugar	Çelik et al., 2011
	<1000/1000–2000	Yatağan	Çelik, 2004
	800–2000	Yatağan	Bacakoğlu and Çalapkulu, 1999
	60–1200	Yatağan	Uz and Özdamar, 1999
	<1000	None	Köktürk, 1991
	1000–5000	Uşak	Çelik and Kırılıveren, 2012
	100–2000	Muğla Milas	Kun, 2013
Fine–medium	500–5000	Menderes massive	Kun et al., 1999
	450–500 400–500 350–400	Afyon tigerskin Afyon grey Afyon white	Bağcı, 2020
	450–550 1000–4000	Milas pearl Muğla bellissimo	Bağcı et al., 2010
Medium	100-1000	None	Bozkurt, 1989
	2000–5000	Bursa Mustafa Kemal	Kun, 2013
	1000–5000	None	Köktürk, 1991
	1000–2000	Muğla royal	Bağcı et al., 2010
	172–424/175–375	Göktepe white Göktepe grey	Yavuz and Elçi, 2011
	22–769	Muğla	Yavuz et al., 2002
	64–4004	Aphrodisias	Rockwell,1996; Lazzarini et al., 2002
Medium–coarse	1000–4000	Milas white	Bağcı et al., 2010
Coarse	>1000	None	Bozkurt, 1989
	>5000	Kırşehir white	Kun, 2013
	>5000 to 1–2 cm	None	Köktürk, 1991

MGS = maximum grain size.

In this study, the macroproperties of Asia Minor marble samples having fine, medium, and coarse grain quality were investigated in order to establish their grain size range, grain size class, and a standard definition. The marble samples selected for this study were Afyon white (Docimeaen), Bursa Mustafa Kemal Paşa white, Marmara white grey (Proeconesus), Muğla Yatağan white (Caria), Denizli Çal Kabalar smoked white, Aydın Karacasu white (Caria), Uşak Karahallı pinkish white, and Balıkesir Manyas white (Figure 1).

2. Materials and methods

To determine the petrographic characteristics and grain sizes of the eight known marble types of Asia Minor, which have been used since ancient times, four thin sections were prepared from each sample in different directions—parallel to, perpendicular to, and oblique to the stratification—from quarries that are currently active in marble production. Detailed petrographic analyses of the prepared thin sections were performed using an Olympus BX41TF (Tokyo, Japan) polarized microscope. Thin sections were photographed with a digital camera compatible with the microscope. For grain size measurements, a TCA-300 microscope camera (Trakka Systems) integrated with ImageView software was used. For each marble sample, approximately 500 crystals were measured to determine their average and maximum grain sizes. The marbles were then classified as fine, medium, or coarse based on the average crystal size, and this information was used to create a marble grain size scale.

3. Results

3.1. Petrographic properties of Asia Minor marbles

The marbles of Asia Minor are of metamorphic origin. They are mainly monomineralic, with calcite as the dominant mineral and quartz as a minor accessory mineral. These

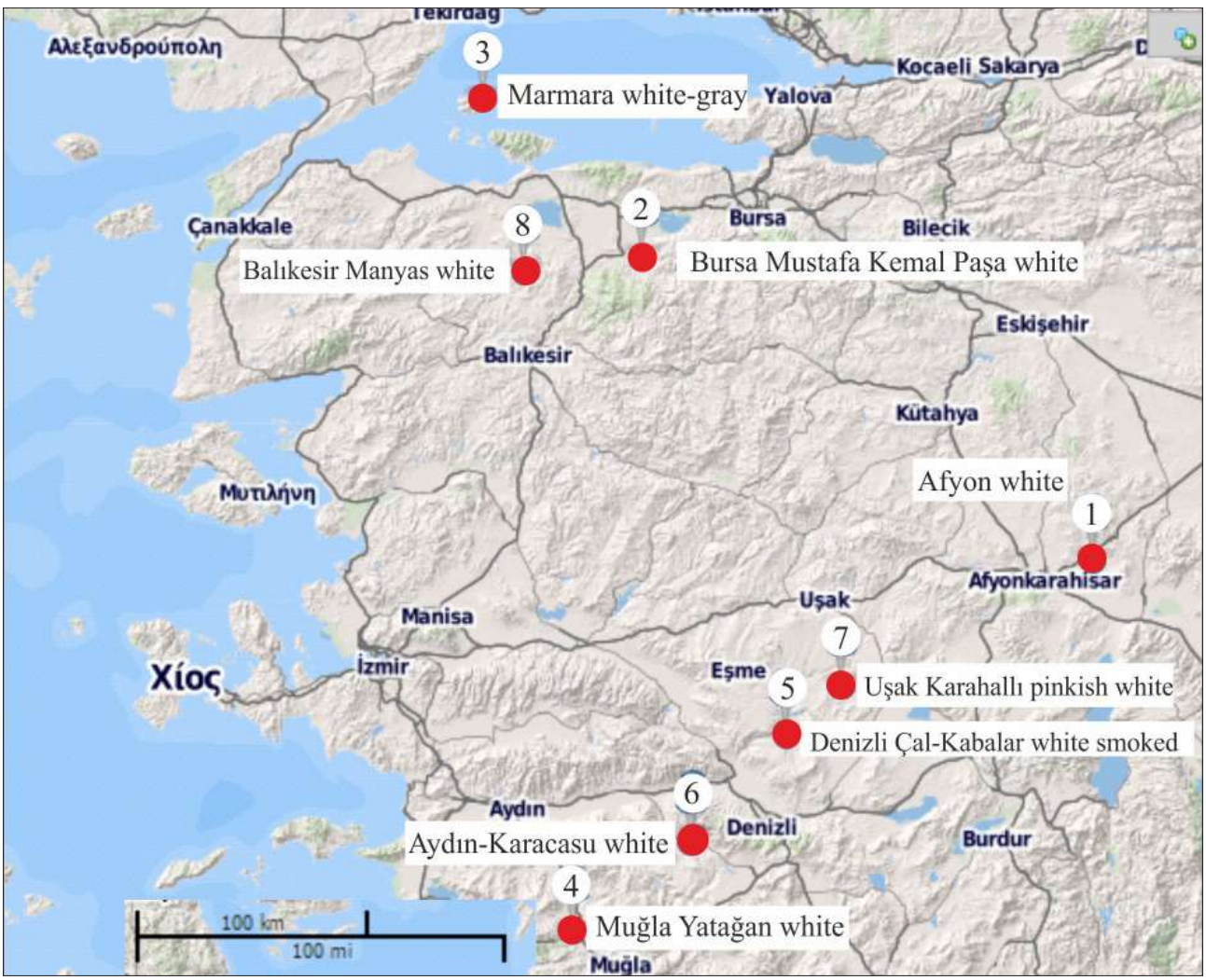


Figure 1. Locations of marble mines in Asia Minor.

marbles are primarily monochromatic and white, but some samples have grey veins and pinkish areas, and they show polychromatic characteristics. Macroscopically, Afyon is white and fine crystalline, whereas Balıkesir Manyas is white and coarse crystalline. The remaining marbles are medium crystalline. According to the petrographic analysis, the textures of the marbles are either granoblastic or heteroblastic, with only one equigranular sample and the other showing an inequigranular crystal size distribution. Only two crystal boundary geometries, polygonal and interlobate, were observed among the marbles. Five marble specimens have subhedral > anhedral crystal shapes, while three have euhedral > subhedral crystal shapes. Calcite crystals, the main component, exhibit polysynthetic twinning and deformation twinning. Orientation is also observed in some samples. In certain samples, 120° grain boundaries are prevalent and clear, whereas in other samples, there are significant variations. Thin-section images of the marbles are shown in Figure 2, and their petrographic properties are shown in Table 2.

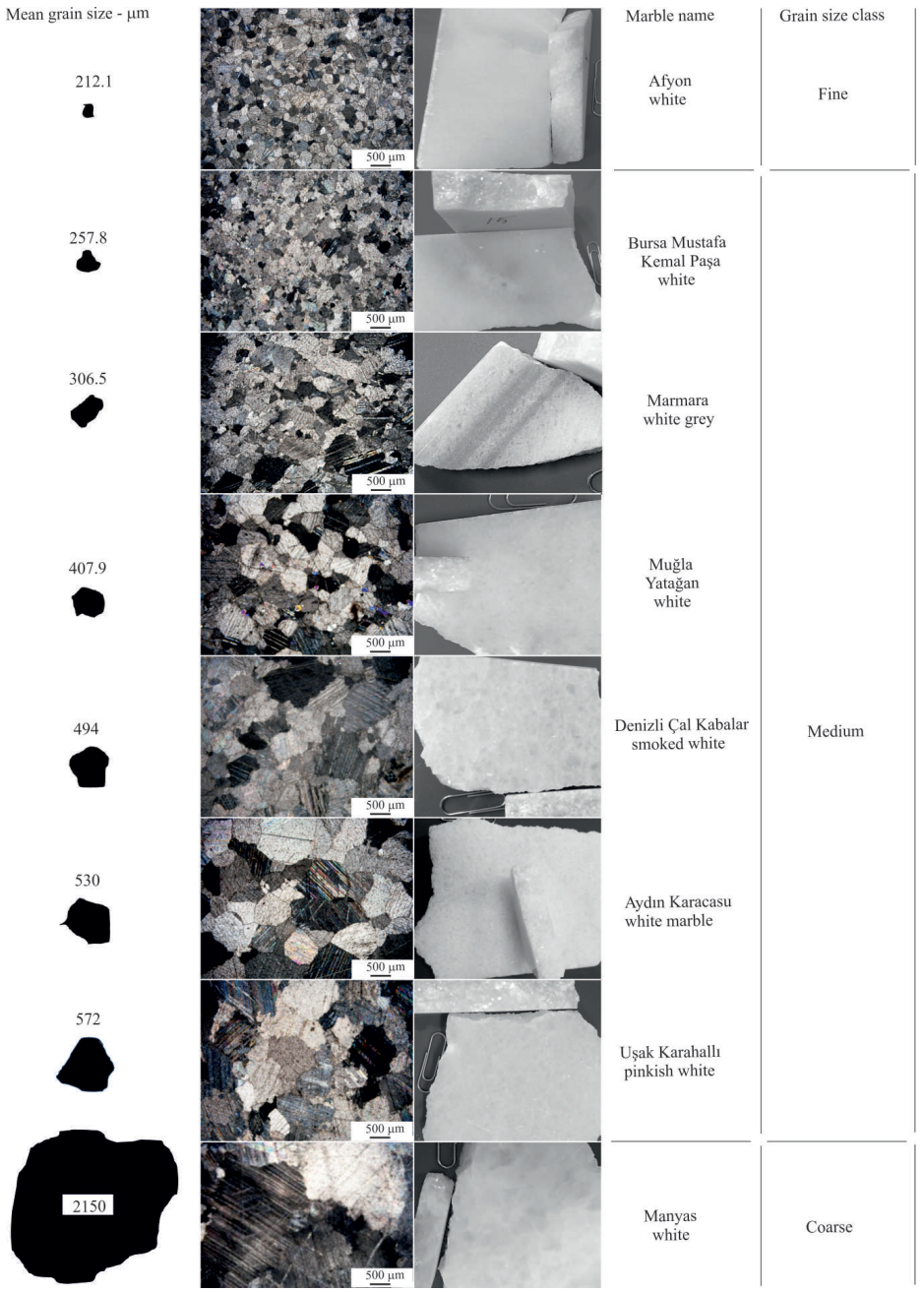


Figure 2. Mean crystal size measurements of Asia Minor marbles (Hacımustafaoğlu, 2019).

Table 2. Petrographic characteristics of Asia Minor marbles.

Crystal size distribution and boundary geometry	Crystal shape	Texture	Crystal properties	Minerals				
				Main (99%)		Accessory (1%)		
				C	D	Q	M	O
1 Afyon white								
Equigranular polygonal	euhedral > subhedral	G	Monomineralic, polysynthetic twinning in calcite, 120° (triple points) angle common, monochromatic, fine crystal	+	–	±	–	–
2 Bursa Mustafa Kemal Paşa white								
Inequigranular interlobate	subhedral > anhedral	H	Monomineralic, polysynthetic twinning, crystal orientation, deformation twins, widespread deviation of 120° angle, monochromatic, medium crystal	+	–	+	–	–
3 Marmara white grey								
Inequigranular interlobate	subhedral > anhedral	H	Monomineralic, polysynthetic twinning, thick lamellae, crystal orientation, deformation twins, few 120° angles, less quartz, polychromatic (white/grey colored bands), medium crystal	+	–	+	–	–
4 Muğla Yatağan white								
Inequigranular polygonal	euhedral > subhedral	H	Monomineralic, diffuse polysynthetic twinning, no crystal orientation, 120° angle diffuse, prominent disseminated quartz, monochromatic, medium crystal	+	–	+	–	–
5 Denizli Çal Kabalar smoked white								
Inequigranular interlobate	subhedral > anhedral	H	Monomineralic, diffuse polysynthetic twinning, no crystal orientation, 120° angle diffuse, prominent disseminated quartz, monochromatic, medium crystal	+	–	±	–	+
6 Aydın Karacasu white								
Inequigranular polygonal	euhedral > subhedral	G	Monomineralic, diffuse polysynthetic twinning, no crystal orientation, 120° angles predominant, monochromatic, medium crystal	+	–	±	–	–
7 Uşak Karahallı pinkish white								
Inequigranular interlobate	subhedral > anhedral	H	Monomineralic, polysynthetic twinning, thick lamellae, crystal orientation, deformation twins, few 120° angles, polychromatic (white/pink bands), medium crystal	+	–	–	–	+
8 Balıkesir Manyas white								
Inequigranular interlobate	subhedral > anhedral	H	Monomineralic, widespread polysynthetic twinning, thick lamellae, crystal orientation, deformation twins, widespread deviation of 120° angle, monochromatic, coarse crystal	+	–	±	–	–

G = granoblastic texture, H = heteroblastic texture, C = calcite, D = dolomite, Q = quartz, M = mica, O = opaque. + = exists; – = none; ± = rare.

3.2. Crystal size class of Asia Minor marbles

For each marble type, approximately 500 measurements were used to determine crystal size and crystal size class. Afyon white was found to have the finest crystal size among the marbles of Asia Minor, with a mean grain size of 212.1 μm and a maximum grain size of 433 μm. At the other end of the spectrum, Balıkesir Manyas white has the coarsest crystals among the Asia Minor marbles, with a mean grain size of 2150 μm and a maximum grain size of 1 cm. The mean and maximum grain sizes of all eight Asia Minor marbles are given in Table 3, and a comparison of their mean grain sizes, based on evaluating the macroscopic, microscopic, and measured grain size results is shown in Figure 3. The mean grain sizes determined in the Asia Minor marbles are divided into three categories: fine crystals for the Afyon white marble, coarse crystals for the Balıkesir Manyas marble, and medium crystals for the other samples.

Table 3. Mean and maximum grain sizes of Asian Minor marbles.

Marble names	**Mean grain size ± standard deviation (μm)**	**Maximum grain size (μm)**
Afyon white	212.1 ± 58.65	433
Bursa Mustafa Kemal Paşa white	257.8 ± 82.55	637
Marmara white grey	306.5 ± 130.79	1005
Muğla Yatağan white	470.9 ± 188.61	1131
Denizli Çal Kabalar smoked white	494 ± 253.84	1658
Aydın Karacasu white	530 ± 298.88	1662
Uşak Karahallı pink white	572 ± 322.49	1904
Balıkesir Manyas white	2150 ± 965.17	10,000

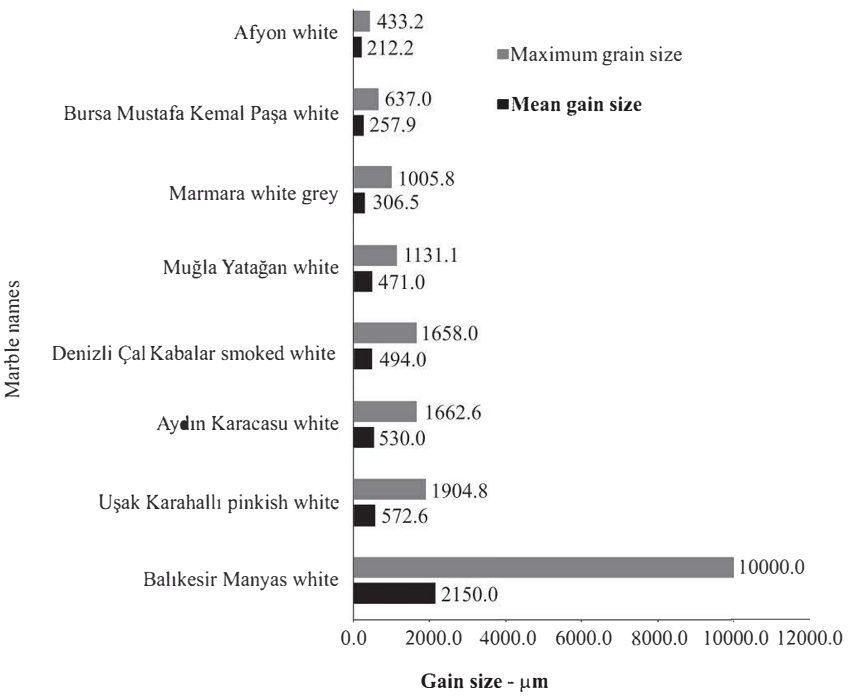


Figure 3. Crystal size comparison of the eight Asia Minor marbles.

4. Discussion

The most significant factors influencing a marble's quality and functional application are crystal size, mineralogical characteristics, and petrographic characteristics from a sectoral point of view. This is because these properties are closely related to the material characteristics of the marble, which ultimately determine its quality and functional application areas. These characteristics also help to identify the locations of marbles of archaeological findings and distinguish them from one another. Afyon white has the highest sales price among the Asia Minor marbles and is the most preferred marble in the sector. This is because Afyon white, unlike other Asia Minor marbles, has a uniformly small crystal size (<250 μm) and polygonal grain boundary geometry.

The studied Asia Minor marbles are dominantly monomineralic, and the major mineral is calcite. One aim of this study was to eliminate the confusion about different grain sizes and grain class definitions of Asia Minor marbles in the literature. Moreover, a standardised scale is proposed for use as a reference for determining crystal sizes and categories. According to this proposed scale, crystal sizes of 100–250 μm, 250–1000 μm, and >1000 μm are defined as fine, medium, and large crystals, respectively (Table 4). Therefore, Afyon white is classified as fine crystal, Balıkesir Manyas white is coarse crystal, and the other six (Bursa Mustafa Kemal Paşa white, Marmara white grey, Muğla Yatağan white, Denizli Çal Kabalar snoked white, Aydın Karacasu white, and Uşak Karahallı pinkish white) are classified as medium crystal marbles.

Table 4. Recommended grain size scale for Asia Minor marbles (Hacımustafaoğlu and Yağmurlu, 2017).

Crystal size range (μm)	Crystal size class
100–250	Fine
250–1000	Medium
>1000	Coarse

5. Conclusion

In the past, marbles from Asia Minor were an important building material preferred for the construction of ancient cities and sculptures. In fact, marbles from Asia Minor continue to be an important building material today, used as cladding or flooring in the interiors and exteriors of modern buildings and in the creation of works of art. These marbles have crossed the borders of Asia Minor from ancient times until today, as many countries currently import modern marbles from Asia Minor. Crystal size is an important parameter in identifying and classifying the marbles of Asia Minor, which are spread across a very wide geography. Moreover, crystal size is closely related to the quality of marble, but there has been little international and academic standardization of crystal size descriptions. The fact that international standards do not define a specific crystal size metric range for marbles and that different researchers define crystal size measurements for Asia Minor marbles from the same region differently has caused serious confusion for both academic and export purposes. This study proposes a crystal size classification for the marbles of Asia Minor that not only is useful for identifying the quarry sources of structures or statues in ancient cities or for identifying suitable marbles for restoration, but also serves as a crucial parameter in determining the quality of marble in today's marble sector.

References

Angı OS (2010). Natural stones used ın the antique buildings and monuments on historical peninsula of ıstanbul their characterıstıcs and state of conservation. İBB-KUDEB Restorasyon ve Konservasyon Çalışmaları Dergisi 6: 31-42 (in Turkish with an abstract in English).

Angı OS (2013). Natural stones used ın Hagia Sophia and their present conservation state. Journal of Restoration and Conservation Studies 14: 44-57.

Attanasio D, Bruno M, Prochaska W, Yavuz AB. (2015). A multi-method database of the black and white marbles of Göktepe (Aphrodisias). Archaeometry 57: 217-245. https://doi.org/10.1111/arcm.12076

Bacakoğlu TF, Çalapkulu F (1999). Mugla Region Marbles. Proceedings of the 52nd Geological Congress of Turkey pp. 39-46, Ankara, Türkiye. (in Turkish with an abstract in English).

Bağcı M (2020). Mineralogical, petrographic, and geochemical characterization of colored İscehisarmarbles (Afyonkarahisar, W-Turkey). Turkish Journal of Earth Sciences 29 (6): 946-975. https://doi.org/10.3906/yer-2001-20

Bağcı M, Kibici Y, Yıldız A, Akıncı ÖT (2010). Petrographical and geochemical investigation of the Triassic marbles associated with Menderes massif metamorphics, Kavaklıdere, Muğla, SW Turkey. Journal of Geochemical Exploration 107 (1): 39-55. https://doi.org/10.1016/j.gexplo.2010.06.005

Bozkurt R (1989). Mermer ve Elmas tel kesme ile Ocak işletmeciliği, Ankara University Faculty of Engineering-Architecture. Publication No: 98, Eskişehir Türkiye (in Turkish).

CEN (2019). EN 12407. Natural stone test methods. Petrographic examination. European Committee for Standardization, Brussels, Belgium.

Çelik MY (2004). Muğla beyaz mermerinin tane boyut dağiliminin görüntü analiz yöntemi ile ölçülmesi, 5. Endüstriyel Hammaddeler Sempozyumu, pp. 222-232 (in Turkish with an abstract in English).

Çelik MY, Kırılıveren S (2012). Investigation of the geological and physico-mechanical properties of Çamlıbel - Ulubey (Uşak) white marble. Yapı Teknolojileri Elektronik Dergisi 8 (1): 44-53 (in Turkish with an abstract in English).

Çelik MY, Yeşilkaya L, Ersoy M, Turgut T (2011). Investigation of the relationship between grain size and knoop hardness on carbonate natural stones. Madencilik Dergisi 50 (2): 35-46 (in Turkish with an abstract in English).

Gardner I, Lieu SNC (2004). Manichaean Texts from the Roman Empire. Cambridge, UK: Cambridge University Press. p 117.

Hacımustafaoğlu R (2019). Afrodisias, Hierapolis ve sagalasos antik kentlerinde kullanilan doğaltaşlarin kökeni ve bunlarin petrokimyasal ve fiziko-mekanik özelliklerinin incelenmesi, Batı Anadolu. PhD, Süleyman Demirel Universty, Isparta, Türkiye (in Turkish).

Hacımustafaoğlu R, Yağmurlu F (2017). Petrographic properties of crystalline marbles of Aphrodisias Ancient City, Classification of crystal sizes and Comparison of Grain sizes of Reference Crystalline Marble Samples. IV.International Stone Congress; Izmir, Türkiye. pp. 701-722 (in Turkish with an abstract in English).

Köktürk U (1991). Endüstriyel Hammaddeler, Dokuz Eylül Üniversitesi Mühendislik-Mimarlık Fakültesi Yayınları No:205 İzmir, Türkiye pp. 259 (in Turkish).

Kun N (2013). Mermer Jeolojisi ve Teknolojisi. Akare Matbaacılık, İzmir, Türkiye (in Turkish).

Kun N, Güngör T, Erdoğan B (1999). Stratigraphic positions and characteristics of the marble quarries in the Menderes Massif. 1. Batı Anadolu Hammadde Kaynakları Sempozyumu, İzmir, Türkiye. pp. 47-53 (in Turkish with an abstract in English).

Kuşçu M (1992). Economical and geological properties of the Kestanecik and Kozağaç (Yatağan-Muğla) marble deposits. Jeoloji Mühendisliği 16 (2): 23-36 (in Turkish with an abstract in English).

Lazzarini L, Ponti G, Martinez MP, Rockwell P, Turi B (2002). Historical, technical, Petrographic and Isotopic Features of Aphrodisian Marble. In: Herrmann J, Herz N, Newman R (editors). ASMOSIA V. Interdisciplinary Studies on Ancient Stone: Proceedings of the Fifth International Conference of the Association for the Study of Marble and Other Stones in Antiquity, Museum of Fine Arts, Boston. London, UK: Archetype Publications, pp. 163-168.

Rockwell P (1996). The marble quarries: a preliminary survey. Journal of Roman Archaeology, Supplement No: 20, Aphrodisias Papers 3; pp.105-26.

Uz B, Özdamar Ş (1999). Geological, petrographic, chemical investigation and evaluation of Yatagan (Muğla) marbles. Türkiye'de Mermer Yapı ve Dekorasyon Dergisi (62-63): 42-52 (in Turkish with an abstract in English).

Yavuz AB, Elçi H (2011). Geological and material properties of Göktepe (Muğla) marbles and determination of their uses in the Ancient Roman times.TÜBİTAK, Project No: 107Y030 (in Turkish with an abstract in English).

Yavuz AB, Türk N, Koca MY (2002). The mineralogical, chemical, physical and mechanical properties of Muğla Region marbles, Jeoloji Mühendisleri Dergisi 26 (1): 1-18 (in Turkish with an abstract in English).