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Original article

A multi-analytical approach for determining the origin of the marbles in Temple-A from *Laodicea ad Lycum* (Denizli-Western Anatolia, Turkey)

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ABSTRACT

Laodicea ad Lycum is the major and most important Hellenistic city in the Lycos Valley. The ancient city is located at 6 km northeast of Denizli and the most contemporary and significant archaeological site in southwestern Turkey. A large marble temple complex, which is simply named Temple-A, is a remarkable structure. The marbles of Temple-A can be classified into four groups, based on color, crystal size, crystal boundaries and foliation status. These groups are identified as (i) lilac-purple-veined, (ii) white, (iii) gray-veined and (iv) gray-blackish marbles. Microscopically, the lilac-purple veined, gray-veined and gray-blackish marbles display heteroblastic mosaic texture, and the white marbles display a homoeoblastic polygonal texture. The marble groups chiefly consist of calcite + dolomite ± augite (lilac-purple veined), calcite (white), calcite + dolomite ± quartz ± muscovite ± opaque minerals (gray-veined) and calcite ± quartz ± pyroxene ± zircon (gray-blackish). The minero-petrographic, geochemical and C–O stable isotope results reveal that most of the marbles sampled Temple-A at Laodicea share the same characteristics and composition of the marbles exploited in the ancient quarries of Hierapolis and Domuzderesi.

1. Introduction

In ancient times, marbles were commonly used for sculpture and as a building material, especially during the Greek and Roman periods in addition to later times. In the Mediterranean region, there are many high-quality marble sources, which were used in antiquity and are still exploited today. Minero-petrographic, geochemical and provenance analyses of these marbles have great importance for historical and archaeological studies as well as for restoration of ancient artworks, monuments and buildings, and for determining imitations. In recent years, aimed to ascertain the provenance of marble sample of unknown origin, multiple analytical approaches have been performed to define a representative minero-petrographic, chemical-isotopic and physical database of the most important marbles used in antiquity [1–18].

Although there is a well-documented marble quarry history, the methods of utilization and diffusion, minero-petrographic, geochemical and isotopic characteristics of the marble in the Mediterranean region, the marbles of the Temple-A in *Laodicea ad Lycum* (Denizli-West Anatolia, Turkey) had never been investigated in any depth. The targets of this paper are:

- a comprehensive mineralogical, petrographical, chemical and isotopic (C and O) characterization of the marbles in Temple-A;
- a comparison with local marbles extracted in the quarries located near *Laodicea ad Lycum* to determine possible provenance.

2. Brief historical background of the Laodicea Antique City and Temple-A

Laodicea ad Lycum is the major and most important Hellenistic city marked by the river Lykos (Çürüksu) in the Lycos valley. The ancient city is located 6 km northeast of Denizli, in southwestern Turkey (Fig. 1a, b). The city was originally founded by the Seleucid (Syrian) king Antiokhos II on behalf of his wife, Queen Laodike, in the 3rd century B.C. In the time of Emperor Tiberius (14–27 A.D.), the city soon became the richest and most glorious

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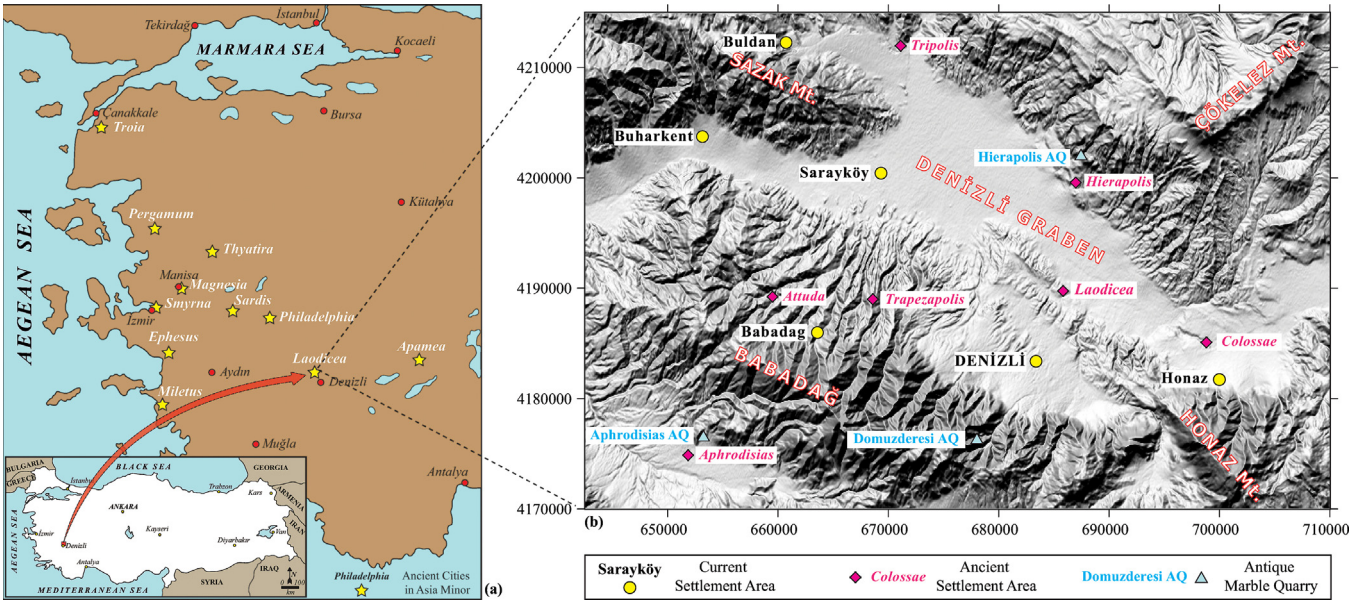

Fig. 1. a: simplified map of Western Turkey showing the distribution of the some important ancient cities in Asia Minor; b: Digital Elevation Model (DEM) of investigated area.

city in the Lycos Valley [19,20]. Laodicea is a significant archaeological site in Turkey today. Laodicea covers area more than 5 km^2 and has a highly organized city plan: the main roads and side streets intersect each other; many civilization buildings, such as a stadium (the biggest one in West Anatolia), two theatres (only ancient city in West Anatolia), health complexes (hot water and curing baths) and advanced infrastructure (e.g., canalization) systems are present. A large marble temple complex, simply named Temple-A is located on the north side of Syria Street in Laodicea. Excavations of Temple-A first began in the 2004 season (Fig. S1a). Temple-A lies within a rectangular courtyard surrounded with porticoes (58 m by 42.33 m with 54 columns) (Fig. S1b, c). This temple is a remarkable structure made of marble and travertine blocks (Fig. S1d). The floor of the courtyard is entirely paved with marble slabs. The excavation findings revealed that Temple-A was first built during Antonine Period (2nd century A.D.) and underwent major repairs in the time of Emperor Diocletian (284–305 A.D.). A highly destructive earthquake occurred in A.D. 494, and Laodicea was completely levelled in the devastation, after which the city was never established again. In the A.D. 494 earthquake, the structure was completely damaged. In subsequent years, the temple was partly repaired and continued to be used until later periods. In the Byzantine period, the majority of the temple's architecture blocks were moved and used in other structures [19,20]. In fact, Laodicea was moved to Denizli-Kaleiçi with the name of Ladik in the 7th century A.D., where the site continued to be the inhabited. Laodicea passed under Turkish control in 1176, and the city disappeared from history.

3. Sampling and analytical methods

For detailed determinations, 40 marble samples were taken from the excavation field. The samples are in the form of unshaped and/or plate-shaped marble pieces. They are coming from the excavation of Temple-A. All samples belong to building materials of courtyards, porticoes, pro-naos, and columns. The determination of scientific characterizations of the marbles was performed to the following steps and analyses:

- mineralogic and petrographic parameters (i.e. mineral association, grain size and structure, texture of samples) were examined under polarized light microscope using thin sections;
- qualitative mineralogical composition of the marble samples was determined with X-ray powder diffraction (XRD), using an Inel Equinox 1000 diffractometer (Instrumental condition: Co Kα radiation obtained at 30 kV and 30 Ma, 10–100° 2θ investigated range, 0.030° step);
- confocal Raman spectrometer (CRS) technique was applied to selected marble samples for the more detailed mineralogical characterization. CRS analyses were made on polished thin sections using a Jobin Yvon (Horiba) LabRAM-800HR Confocal Raman spectrometer at the Department of Geological Engineering, Ankara University. This spectrometer is fit with a notch filter-based Raman microscope system (focal length 800 mm) and is equipped with an Olympus BX41 optical microscope, a grating with 1800 grooves per millimeter and a Peltier-cooled charge-coupled device (CCD) detector. Raman spectra were excited by a He-Ne laser (633 nm) at a resolution of 2 cm^{-1} in the range between 100 and 4000 cm^{-1}. Repeated acquisition using the highest magnification was accumulated to improve the signal-to noise ratio;
- major oxides and the trace elements for the samples were analyzed by a Spectro XLAB-2000 Polarized Energy Dispersive X-ray Fluorescence (PEDXRF) spectrometer at the Department of Geological Engineering at Ankara University. For the XRF analyses, 40 marble samples were crushed in a tungsten carbide crushing vessel, and 4 g of powdered sample was mixed with 0.9 g of wax. The mixture was pressed at 20 N in an automatic press to obtain a pressed disc;
- stable isotope analysis was performed by continuous flow–isotope ratio mass spectrometry at Iso-Analytical Limited, Crewe, UK using an ANCA-G gas purification module and 20–20 mass spectrometer (Europa Scientific Ltd, Crewe, UK). Sample, reference and control carbonates were weighed into Exetainer tubes (Labco, UK), flushed with 99.995% helium and converted to carbon dioxide by adding phosphoric acid by injection. The reaction containers were left overnight to allow complete conversion. The phosphoric acid used had been prepared for isotopic analysis