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Marble Extraction and its Industry: a Multidisciplinary Case Study of the Vathi Quarry on Tinos Island[1]

Abstract

Through an analysis of the tool marks, imprints on the parent rock, unfinished objects, and the waste left behind, quarries provide a wealth of information about the organisation, manufacturing process, transportation, and the broader stone trade and production they supported. Adopting an intra-cross-craft approach, scholars studying stone craft can gain a deeper understanding of the various stages of production, starting at the primary level of the quarry and the more expansive stages of artefact production. Recent investigations on the island of Tinos have brought to light several quarries that had not previously undergone in-depth exploration. This paper considers such a newly examined quarry as a case study. Through an interdisciplinary methodology, it aims to present new perspectives on both the ancient and modern marble industries in the Cycladic Islands. This paper seeks to expand our understanding of the marble terrain in each region from a range of topographical, archaeological, geological, and historical perspectives and highlight the use of marble with unique qualities, extraction techniques, and production processes.

Keywords: Quarry, technology, marble, geology, Cyclades, Greece

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Introduction to Marble Extraction

The large-scale extraction of marble as a raw material began with the extensive construction of monumental religious architecture in Greece during the Archaic period. Stone construction evolved considerably starting in this period, eventually supplanting wooden architecture, which had been the norm. Quarrying and stonemasonry activities were at that time also becoming central to community identity. The main Greek quarries were fully active in the 6th century BC (*e.g.*, Naxos, Paros, Thasos, *etc.*).[2] With a few exceptions, there were no new quarries or stone processing technologies during the Hellenistic period, with production and extraction limited to the small, local scale. These exceptions were Penteliko near Athens and the quarries of Paros. During the Roman period, quarrying continued in large quarries, and many more quarries were opened due to increasing demand. These central facilities remained integral to the Roman Empire's marble supply chain, working alongside smaller local quarries to facilitate the widespread distribution of this important raw material.[3] The methods of stone extraction and the tools utilised changed depending on the material and its properties, personal preferences, experience, and training of those working in the quarries, and the customer's priorities. In short, to extract the marble block from its parent rock, craftsmen had to know and consider the length of the natural cracks and identify the right location for placing the wedges and the levers. Then, deep holes were cut in the rock. Metal wedges had to be tested to fit in each hole. After the extraction and the first phase of processing the volume (removing unnecessary material to make the transfer easier), the unfinished object was ready for transport. The transport was completed by sea or land, depending on the location of the quarry. For example, quarries near the sea offered a significant advantage due to the cost-effectiveness of short- and long-distance sea shipping compared to land transport.[4]

Typically, quarries were organised to include several key components such as the extraction area, debris dump, sliding ramps to the storage platform, storage platform and the position of the hoisting machine, tool repair workshops, the sacred area containing a small sanctuary, workers' accommodation, guard tower, and loading area.[5] These characteristics could be altered according to the local infrastructure, the locality, the nature of the quarry, and whether the quarry was meant to be temporary or permanent. Once the quarry was selected, depending on its location and the quality of the marble, with the necessary elements in place, the preparations for the extraction of the raw material could be started.[6]

The methods of stone extraction, as well as the tools, changed according to the material (marble, granite, *etc.*), the personal preferences, experience, and training of the quarrymen, and the customer's order. However, some general steps had to be followed for this procedure. Quarrying was undertaken with the quarry pick and possibly with a pointed chisel and wedges.[7] A pointed chisel and a hammer would be used to define the soon-to-be extracted block, and some of the larger unnecessary parts of the stone blocks would be removed. At this point, the blocks would start gaining their shape.[8] The main characteristics of the marble extraction process were the ease or difficulty of splitting the marble in each direction, knowing how to exploit this quality, the faults hidden within the stone, and its resilience, purity, and responsiveness to the precision workmanship. As soon as the trench was cut, shallow holes – either round or square – would be carved out at the bottom of the block while it was still attached to the parent rock. Wedges would be placed within these holes and hammered until the block was split from the rock.[9]

Introducing the Case Studies on Tinos Island

The island of Tinos, located in the Aegean Sea in Greece, is the fourth largest island in the northern Cyclades (Fig. 1). Archaeological research on Tinos is limited compared to other Cycladic islands. However, current interdisciplinary studies have contributed significantly to a better understanding of the cultural and historical importance of the island of Tinos throughout history.[10]

In recent years, scholarly attention has been directed towards meticulously examining distinct marble production centres from antiquity, specifically within localised settlements. The process of ordering raw materials and trading this product still remains a multifaceted endeavour, encompassing intricate relationships with the quarry, quarrymen, customers, and geographical considerations of the mobility and transport of this raw material, as well as seasonality. Different markets retailed different

[2] Waelkens *et al.* 1988, 14–15.

[3] Fant 2008, 122–135.

[4] Fant 2012, 528–532.

[5] Koželj 1988, 31.

[6] Koželj 1988, 32.

[7] Wootton *et al.* 2013a; 2013b.

[8] Rohleder 2001, 70–72.

[9] Korres 2000, 16.

[10] For a similar interdisciplinary approach to a quarry study, see Anevlavi *et al.* 2021.

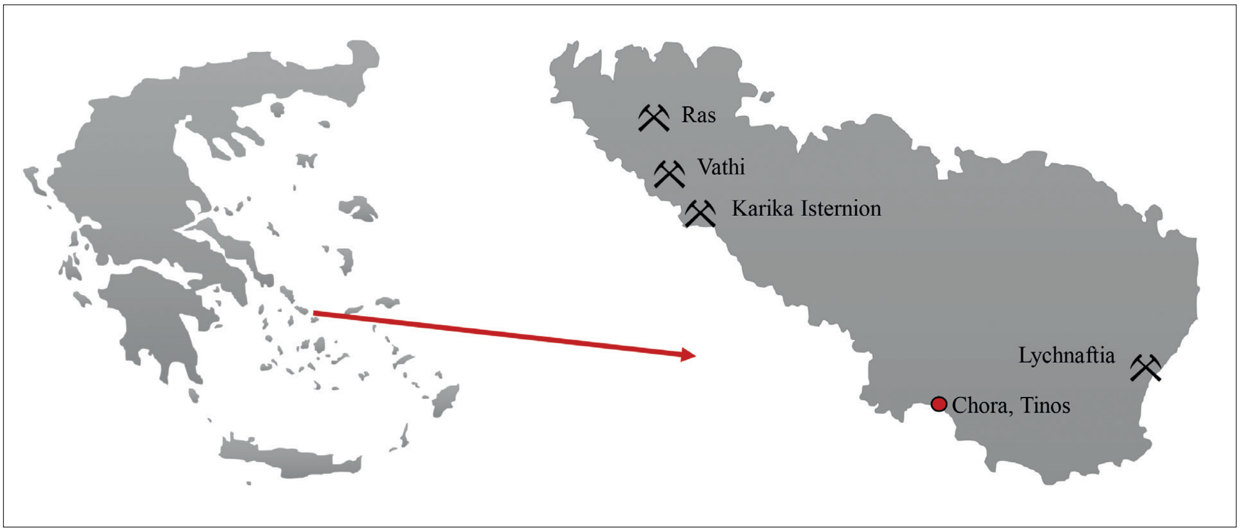

Fig. 1. Map of Tinos island (edited by T. Jakobitsch, V. Anevlavi; ÖAI/ÖAW).

kinds of marble objects. Their needs were shaped by the demands of specific styles dictated by customers and the larger social and cultural shifts in the region. Production centres and local workshops were located throughout the ancient world, usually near urban centres. Major marble production hubs were favoured as primary sources of raw materials. The practice involved transporting the raw materials from these central locations to the respective workshops. In the meantime, the production proceeded according to each period's traditional, local decorative designs and patterns.

Three case studies on the island of Tinos are currently being investigated, focused on white marble and green serpentinite quarries. The first case study is the Ras quarry (serpentinite). Ras (only ancient use) is a very small quarry of serpentinite rock with traces of ancient tool marks. Extensive ancient quarry facades, several metres high, are visible, with traces of pick marks. The serpentinite from Ras exhibits a unique texture, with a bright/light green serpentine network developing within the massive dark green serpentine matrix, and it differs from the currently quarried ophicalcite (Tinos Verde). Small concentrations (< 1%) of other minerals include talc, chlorite, and iron oxides.[11] The site consists of two small-scale open pits facing north and south, respectively, and two areas of debris (pit A: 228 m^2; pit B: 121 m^2; debris pile A: 456 m^2; debris pile B: 808 m^2).

The second case study, the marble quarry in Karika Isternion on Tinos, is particularly interesting for the present research context. It is one of the most important ancient quarries on the island, with traces of recent quarrying, as it was in operation until 1950–1951. The quarry, now inactive, operated in the late 1990s as an aggregates quarry. Within the boundaries of the modern inactive quarry and covering an area of at least 10 hectares, numerous and extensive ancient quarry faces are visible, sometimes several metres high, with traces of quarry picks. Characteristics include trenches for separating the stones from the parent rock and holes for inserting round wedges. Unique for Tinos, but also a significant finding for the Cyclades in general, is a 7–8 m high and 16.30 m long rock face on which a series of engraved inscriptions (graffiti) have been preserved. The marble in this quarry is white with grey parallel veining.[12]

This paper presents information concerning the third quarry from this group, the Vathi quarry. Our goal for this pilot study has been to examine its diachronic use and geochemically fingerprint the area in preparation for future archaeometric investigations. As part of this research, we have identified several key questions which are fundamental to understanding this quarry and marble quarrying on Tinos more generally:

1) What are the characteristics of each quarry?
2) How do the quality and material conditions act as decisive criteria for the processing and specific usage of white marbles?
3) How was the demand for marble on Tinos met? Were the local quarries mainly used for their marble needs?

[11] Sideridis *et al.* 2025.

[12] The current location is under study by V. Anevlavi, S. Kravaritou, and A. Angelopoulou.

4) How did Tinos fit into the stone trade's overall development trajectory and its relationship with supra-regional marble quarries such as Prokonnesos, Thasos, Penteli, *etc.*?
5) What was the usage of the local and imported types of marble in architecture on Tinos (structural elements, decoration, furnishing, *etc.*), and what were the criteria for these choices?

The investigation of manufacturing in the past through cross-craft interaction has provided a better understanding of the linkages between various crafts and their implications for the final product. Based on the intra-cross-craft process, our research combines information on quarries, mining, and transportation techniques, and tools and tool marks in various stone (and especially marble) quarries in antiquity. Not only was Tinos one of the main marble production centres, but it is also the birthplace of many sculptors of the 19th and 20th centuries, providing masterpieces across the Eastern Mediterranean. By investigating the crafting process of ancient artefacts and their provenance, we aim to connect ancient sculpting traditions with the continuity of quarry extraction, the location of the stone sources, the use of the material, and traditional sculpting knowledge on the island throughout the centuries. The critical exploration of marble remnants derived from notable structures and artefacts on Tinos Island will be integral to our forthcoming research.

The Vathi Quarry, Tinos

Vathi quarry has many characteristics of a typical quarry organisation (Fig. 2). Vathi produces a white marble with grey parallel veins and fine- to medium-grained size, while the upper layer is gneiss.[13] The main facade is approximately 80 m^2. The known height of the facade is 17 m, while the longest preserved length is 30 m. In the northern part of the facade, one can observe scattered blocks of diverse sizes, marked with distinctive pick marks and wedge holes.

Extensive modern activity has been conducted in the area both before and after World War 2, significantly impacting the quarry. The cutting of an opening into the mountain has disrupted the pristine facade. According to local workers, this opening was cut for investigative purposes, aiming to assess the breadth of the marble layer and explore the feasibility of explosive extraction.[14] The original size of the facade has also been modified by modern debris from activity last century, as well as more recently (2021). The extraction waste was used for small-scale building construction. In that way, the quarry was kept clean from the continuous production of debris, and, at the same time, small facilities were created for the workmen. This extensive modern activity has erased any possible ancient tool marks. No ancient traces can be seen in the modern passage to the port. However, the current transport route may be based on the ancient one. The walls along this path are constructed with debris.[15] Additional information about the Vathi quarry is provided by a previous study by Florakis,[16] who examined the quarry's use during the 19th century and extracted information and photographs from the archives of the local workmen and owners.[17]

Relative Chronology of the Vathi Quarry

The Vathi quarry on the island of Tinos presents two main geological formations: an upper dark brown gneiss layer and a white marble formation underneath, both with evident traces of extraction. The geological information is given below. Although a substantial part of the two superposed formations is visible, it is no longer possible to appreciate the full extent of the extraction fronts. This is because the quarry is undergoing significant transformation due to new extractions nearby, with the old quarry being filled with vast amounts of rubble from this new exploitation. As already noted, the maximum height of the white marble extraction front still visible today is 17 m.

Extraction Traces in the Gneiss Layers

Although most of the extraction traces are visible in the white marble formation, it is important to determine whether the covering dark brown gneiss formation was also quarried for stone production or whether it was just eliminated to access the white marble formation. At about 1/3 of the total height of this formation beneath the rock surface, traces of the cutting of a vertical extraction trench are preserved along this facing (Fig. 3:A, B). This trench was cut with a quarry pick, and the face of the quarry worker was directed to the southwest side of the quarry front. This can be deduced from the curvature of the individual traces of the quarry pick. This trench must have had a sufficient width, allowing the quarry worker to move within it (about 60 cm wide[18]) because

[13] Florakis 2005, 17.
[14] Florakis 2005, 15–21.
[15] No ancient characteristics can be observed.
[16] Florakis 2005, 19.
[17] Florakis 2005.
[18] Doperé 2012, 113; Doperé 2013, 203; De Ceukelaire *et al.* 2014, 48; Doperé 2014, 62, 64.

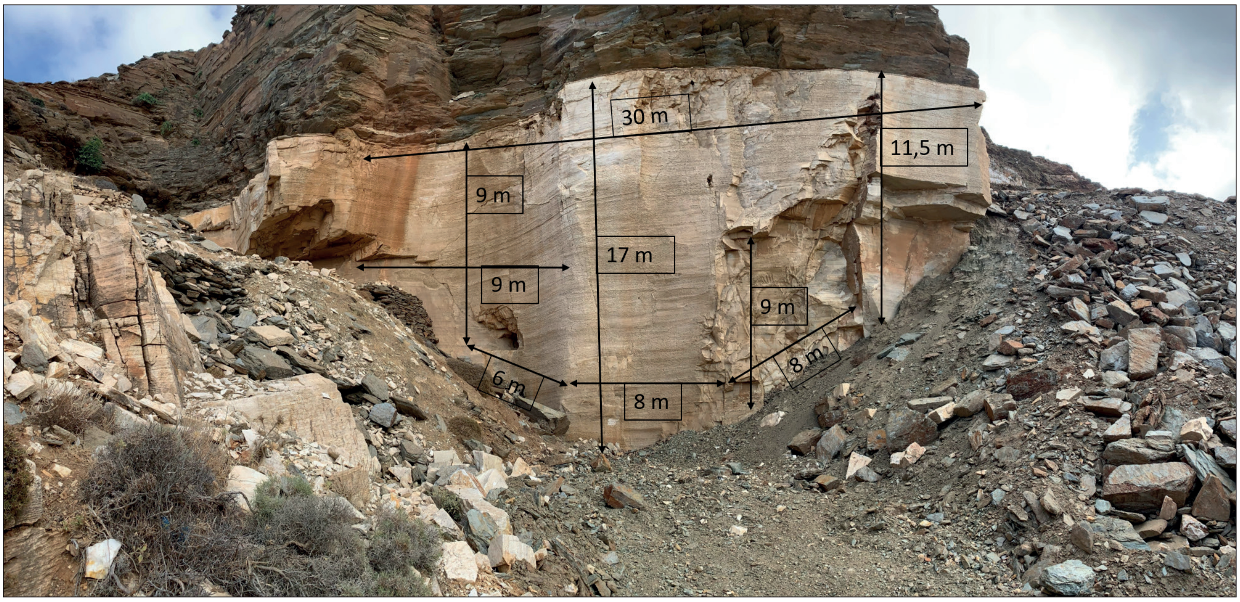

Fig. 2. The main facade of the Vathi quarry (photo by V. Anevlavi and T. Jakobitsch; ÖAI/ÖAW, ©Ephorate of Antiquities of the Cyclades).

the upper part of the traces is situated under a small overhang of the layers. Such traces could not have been generated unless the quarry worker stood within the trench. It is difficult to understand why they did this, but the fragility of part of these layers could have prompted them to do so. Several metres below these traces, another similar series of quarry pick traces is visible. Given their proper extraction, the presence of at least two traces of a vertical extraction trench shows that stone blocks were carefully isolated from the surrounding rock formation.

Compared to the irregular rock facings immediately below the top rock surface, it is clear that the vertical flat facings between them and the traces of the above-described vertical extraction trench were quarried as well. However, no extraction traces are visible because the natural fracturing of this rock formation was used to split blocks by simply using a lever. It is clear that both techniques, extraction trenches and levers, were in use for the extraction of blocks in this gneiss quarry. The last horizontal extraction surface, before the final destruction of this quarry, descended according to a slow, roughly stepwise slope from top left to bottom right (Fig. 3:A).

The Destruction of the Gneiss Quarry

This gneiss quarry was abandoned and destroyed to allow rapid access to the underlying white marble formation. The destruction was done systematically by deep, mechanically drilled circular perforations, thereafter filled with explosives. These vertical perforations can be easily seen in the whole zone between the original slope of the quarry and the top of the marble layer (Fig. 3:A). Therefore, it can be concluded that the activities in the first gneiss quarry came to an end because priority switched to the extraction of the white marble formation. Mechanical drilling and using explosives to eliminate the gneiss cover and quarry were part of the extraction process at the end of the 19th and early 20th centuries.[19] This also marks the start of the extraction of the white marble formation underneath.

The Extraction of the White Marble

All the white marble extraction fronts show parallel horizontal linear extraction traces (Fig. 4:A, B) made with a quarry pick. They resulted from cutting vertical extraction trenches between the blocks and the quarry wall while the quarry worker was standing above his trench with a quarry pick. Where the pick hit the wall of the trench, a line was slowly formed by a tight succession of point impacts (Fig. 4:B). The surface in between the successive lines (about 4 cm) shows the negative traces of upward flaking, each time starting from the new bottom of the trench, while this was progressively deepened out. At first sight, the white marble extraction front shows a quite uniform distribution of the parallel horizontal

[19] Doperé 2012, 125; De Ceukelaire *et al.* 2014, 54; Doperé 2014, 92.

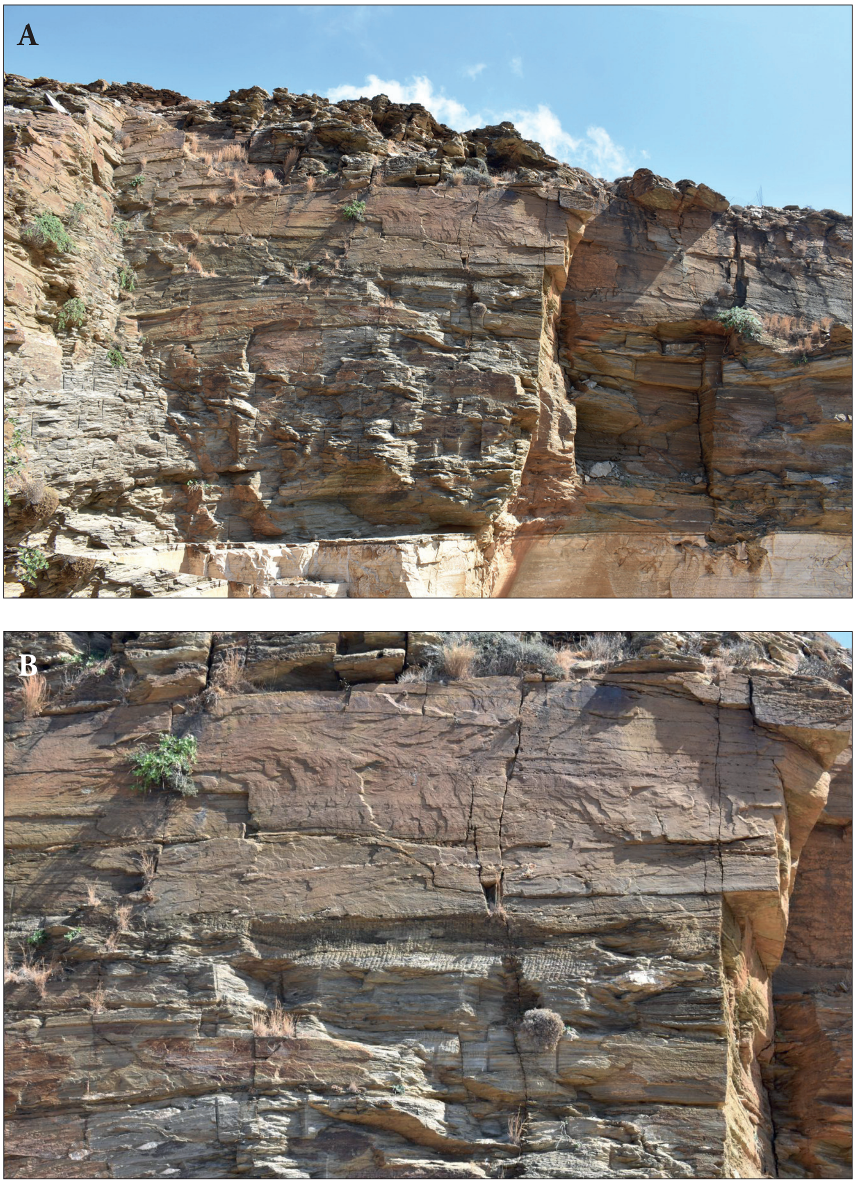

Fig. 3. Vathi quarry on Tinos, the upper gneiss quarry: A – below and left are vertical linear traces of mechanical drilling for explosive quarrying; B – the traces of the quarry pick (photo by V. Anevlavi and T. Jakobitsch; ÖAI/ÖAW, ©Ephorate of Antiquities of the Cyclades).

lines. However, at regular heights, a more roughly treated horizontal band is characterised by fewer parallel lines, sometimes crossing each other, and additional traces of the pointed chisel (Fig. 4:A, C). These coarser horizontal bands correspond to the places where the extracted blocks, already primarily detached from the quarry wall by the vertical extraction trench, were finally broken away from the wall just beneath the deepest point of the extraction trench. Such a break-off zone appeared near the bottom part of the extracted blocks because the set of horizontally placed iron wedges (see below) was put in place somewhat lower than the deepest point of the extraction trench.[20] After the extracted block was lifted from the quarry, the irregularities on the wall caused by this breaking-off had to be rectified with the pointed chisel to allow the further deepening of the extraction trench for the following block to be extracted below the previous one.[21] These more irregular bands can be distinguished on the wall because they are darker due to a more intense shadow created by the coarser treatment of these zones (Fig. 4:A, C). The top bed of the extracted blocks was carved with a pointed chisel.

[20] Doperé 2012, 103–104; Doperé 2013, 187–190; De Ceukelaire *et al.* 2014, 49; Doperé 2014, 59.

[21] Doperé 2012, 103–104; Doperé 2013, 188–189; De Ceukelaire *et al.* 2014, 49; Doperé 2014, 54, 56.

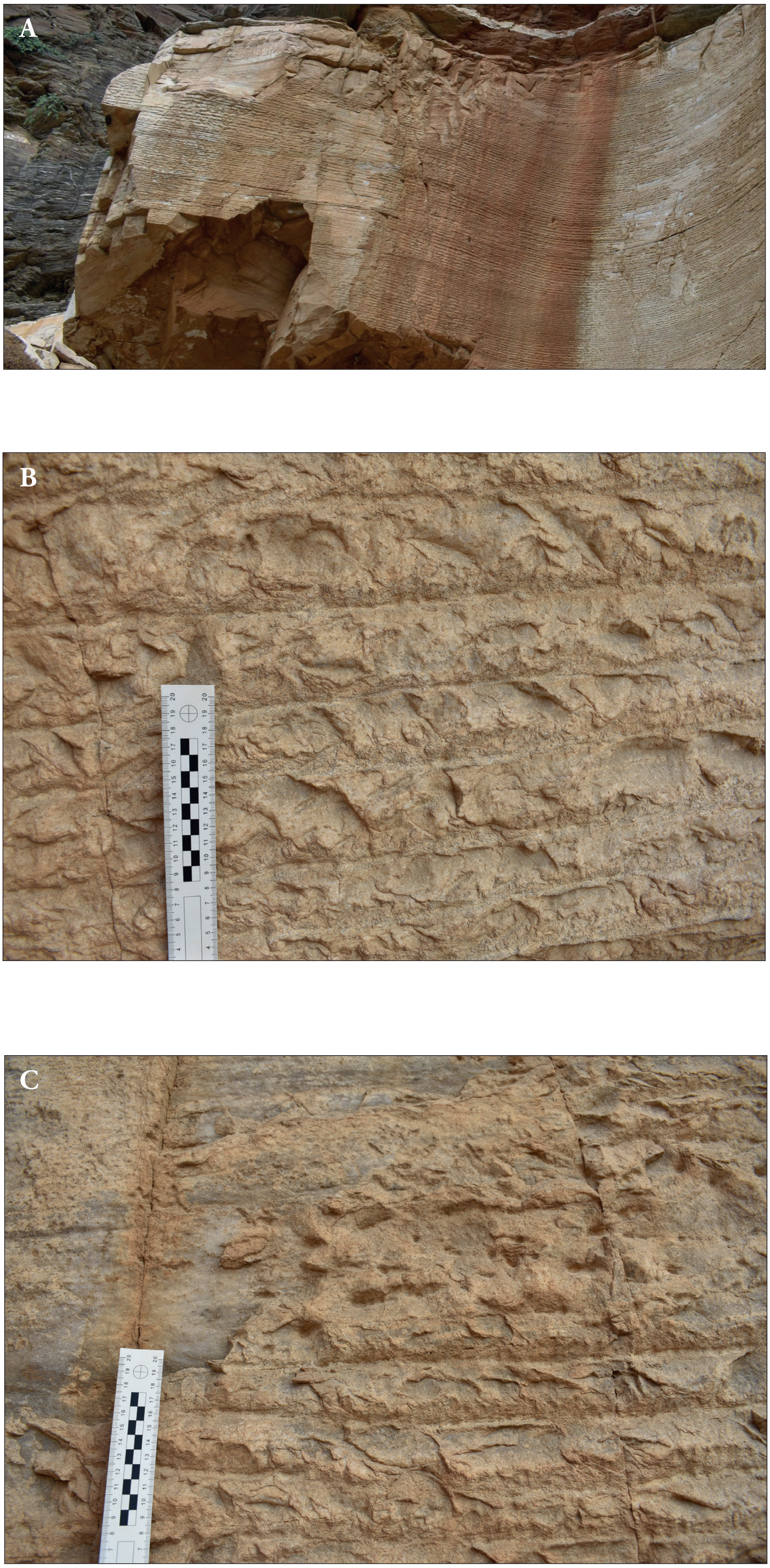

Fig. 4. Vathi quarry on Tinos, the lower white marble quarry, curved part: A – horizontal parallel extraction traces of the quarry pick. The darker horizontal zones correspond to the rectification of the break-off zones with the quarry pick and the pointed chisel; B – horizontal parallel extraction traces of the quarry pick; C – horizontal parallel extraction traces with the quarry pick (below), the rectification of a break-off zone with the pointed chisel (central zone) (photo by V. Anevlavi and T. Jakobitsch; ÖAI/ÖAW, ©Ephorate of Antiquities of the Cyclades).

Fig. 5. Vathi quarry on Tinos: A – block ready to be detached with iron wedges. Rectangular wedge hole carved at the basis of the block; B – four wedge holes with, each time at the right side, a mechanically drilled hole, and at the left side, the proper wedge hole with the traces of carving with the pointed chisel (photo by V. Anevlavi and T. Jakobitsch; ÖAI/ÖAW, ©Ephorate of Antiquities of the Cyclades).

The triangular wedge holes were either carved horizontally or vertically (Fig. 5:A). They were created first by mechanically drilling a horizontal or a vertical circular hole (diameter: 3 cm, depth: 12 cm), followed by the triangular enlargement of the wedge hole with the pointed chisel (Fig. 5:B). This tool was moved obliquely downwards towards the drilled hole. This procedure was repeated three to four times until the depth of the drilled hole was reached. The block to be extracted was then separated from the rock formation underneath or from a vertical wall by introducing a set of iron wedges so that in the quarry (not visible) and on the extracted blocks, half wedge holes remained visible until their final dressing.

The technology of vertical extraction trenches made with a quarry pick was in use during Classical Antiquity.[22] However, mechanical drilling and explosives eliminated the natural rock between the described sloping of the gneiss quarry and the white marble layer, indicating that the white marble quarry is relatively recent. Also, the special technology for carving wedge holes, starting with mechanical drilling, points to a relatively recent chronology. This modern use is confirmed by the dates 1858 on the lintel of the door of one of the houses and 1889 on top of the marble quarry wall, which point to a late 19th century start for the white marble extraction. There is no visible evidence to attribute part of this white marble quarry to Classical Antiquity. Further archaeometric investigations on marble artefacts (well-dated objects) from Tinos, Delos, and the surrounding islands could confirm a possible ancient operation date at this location.

[22] Bessac 2020, 34.

The Destruction of the White Marble Quarry

Today, the white marble quarry itself is being partly buried under debris from a new extraction point. On the right side, southwest of the old quarry, a new extraction point is active, using deep vertical parallel, closely contiguous drilling holes. These series of drilling holes are the recent versions of the more classical vertical extraction trenches. In the meantime, the older white marble quarry front is degrading because of natural fracturing. Some other parts of that quarry were recently destroyed perpendicular to the main white marble wall.

The Geology of the Island of Tinos

For this new study, it is imperative to understand the geological features of the island and their role in the historical extraction of raw materials. Tinos is part of the Attic-Cycladic Crystalline Belt (ACCB), consisting of two tectonic units (Upper and Lower). The ACCB is the result of the convergence and final collision of the Eurasian plate and Apulian microplate during the Tertiary Period, inducing the high temperature-pressure Eocene metamorphism during subduction (giving rise to the formation of the Cycladic Blueschist Unit – CBU) in the region of the south Aegean.[23] This high-grade metamorphic event was succeeded by a greenschist facies overprint during the Oligocene-Miocene, during the exhumation of the sequences.[24]

Three main tectonic units have been recognised on Tinos:[25]

1) The Upper Tectonic Unit (UTU) comprises a metamorphosed dismembered ophiolite complex that is believed to have been metamorphosed under greenschist facies.[26] At these high structural levels, researchers also include the metamorphic Akrotiri Unit.[27]
2) The Lower Tectonic Unit (LTU) or Intermediate Unit is the most voluminous Unit of Tinos and hosts significant marble occurrences (forming three main horizons)[28] along with a variety of metasediments and metabasalts that have reached high pressure (CBU) and subsequent greenschist retrograde metamorphism.[29] The marble-schist sequence represents the original stratigraphic sequence of their sedimentary rock precursors.[30] The sedimentation ages of the LTU are of, maximum, Late Cretaceous age, whereas older ages were yielded for the parts near the base of the Unit, with a clear depositional gap being noted.[31] Isotopic data from the marbles rate $\delta^{13}C(PDB)$ between 1.1 to 2.7 and $\delta^{18}O(PDB)$ between -1.7 to -11.4.[32]
3) The Basal Tectonic Unit (BTU) outcrops in the northwest part of Tinos are dominated by dolomitic marble and phyllites metamorphosed in greenschist facies.[33]

Both the UTU and the LTU have been intruded by the Miocene Tinos Pluton.[34]

The Geochemical Fingerprint of the Vathi Quarry

The importance of coloured marble as a valuable material and commercial product is undeniable in cultural-historical heritage research, and many studies have been devoted to this topic. However, white and whitish marble present significant difficulties when tracing their origin due to their lack of macroscopic solid features and relatively homogeneous composition. Many studies have focused on this effort as the degree of difficulty is high and requires multiple combinatorial techniques. Systematic efforts in recent years have led to the discovery of a large number of quarries of white and whitish marble from antiquity, which broadens research with new hypotheses about the use and distribution of marble in each period and sets new goals in methodology, databases, and distinguishing of sources. For example, the 2003 publication by Lazzarini and Antonelli[35] presents information and physicochemical analyses from quarries on Tinos, more specifically in the areas of Patela (quarries and outcrops), the quarry between Agios Charalambos and Faneromeni, the quarry of Isternia, the quarry around Karelados, and the quarry around Pasalos. However, no reference is made in that publication to the area of Vathi.

The geochemical fingerprinting of the Tinian locations will expand scholarly knowledge and the already existing databases of ancient white marble, supporting future archaeometric investigation at the local and sub-regional scale. The team's current database contains

[23] Matthews *et al.* 1999; Matthews, Schliestedt 1984; Okrusch, Broecker 1990.
[24] Bröcker 1990.
[25] Breeding *et al.* 2003; Hinsken *et al.* 2016; 2017; Melidonis 1980.
[26] Breeding *et al.* 2003; Bröcker, Franz 1998.
[27] Patzak *et al.* 1994.
[28] Melidonis 1980.
[29] Bröcker *et al.* 1993.
[30] Bröcker, Franz 1998.
[31] Hinsken *et al.* 2016.
[32] Lazzarini, Antonelli 2003.
[33] Bröcker, Franz 1998.
[34] Mastrakas, St. Seymour 2000.
[35] Lazzarini, Antonelli 2003.

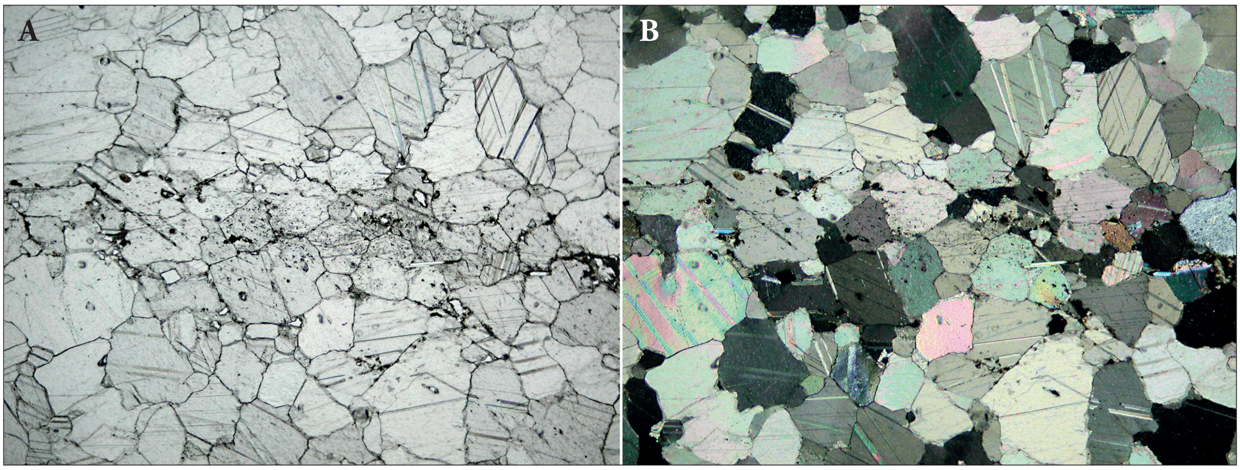

Fig. 6. Marble from Vathi quarry on Tinos: A – this marble generally exhibits a fine-grained heteroblastic texture where the larger grains (up to 1 mm MGS) occur in the very white layers or varieties (parallel light, the length of the image is 6 mm); B – along the schistosity, layers of a thickness up to several mm occur with dull calcite crystals due to the frequent occurrence of very small fluid inclusions in these crystals, most probably due to late fluid percolation along these shearplanes (cross-polarised light, length of the image is 6 mm) (photo by W. Prochaska; ÖAI/ÖAW).

about 5,700 quarry samples, covering the most important marble quarries from antiquity. The current data shows a particular density in Asia Minor (Dokimeion, Ephesus, Heraclea, Aphrodisias, Prokonnesos), where not only is regional classification already possible, but local quarries can also be differentiated from each other.[36] The database has been compiled from various studies over the last 20 years by Walter Prochaska (author) from the University of Leoben in collaboration with the Austrian Archaeological Institute in Vienna. The specimens are sorted in the repositories of the Austrian Archaeological Institute, and an open-access online platform with all relevant information is under construction.

For the present study, detailed sampling, recording, and identification of the chemical elements of the quarry at the Vathi sites were carried out. The analyses of these samples provide the geochemical fingerprint for the site and serve as a pilot study for future projects targeting the origin of marble archaeological artefacts.

The overall fabric of the Tinos marble is that of a slightly schistose rock, essentially made of calcite without any visible dolomitic component. This marble generally exhibits a fine-grained heteroblastic texture where the larger grains (up to 1 mm MGS[37]) occur in the very white layers or varieties (Fig. 6:A). The grain boundaries are modestly intermeshing. The MFG[38] is well below 1 mm. Along the schistosity, layers of a thickness up to several mm occur, with dull calcite crystals due to the frequent occurrence of very small fluid inclusions in these crystals (Fig. 6:B), most probably due to late fluid percolation along these shearplanes. Accessory minerals, mainly mica, quartz apatite, zircon, and organic matter, occur within these layers.

The geological samples were characterised by isotopic, chemical, and trace elements analyses (Tab. 1). More specifically, stable isotope analysis ($^{13}C/^{12}C$ and $^{18}O/^{16}O$), trace element analysis, and analysis of the fluid inclusions.[39]

The results obtained provide the unique geoinformation for the Vathi quarry. The analysis demonstrated that the staple isotopic values for oxygen are between -5 and -9.2, while the carbon values are between 0.8 and 2.3 (Fig. 7). The ion-chromatography data encompass lithium, sodium, potassium, magnesium, calcium, fluorine, chlorine, bromine, iodine-jod, nitrate, and sulphite ions in ratios, and DS (the amount of sodium, potassium, and chlorine in ppb in the extracted solution). The chemical values from the ICP-MS analysis include magnesium, manganese, iron, strontium, chromium, vanadium, yttrium, cadmium, boron, lanthanum, cerium, praseodymium, dysprosium, holmium, ytterbium, lead, and uranium (in ppm). The numerical data obtained

[36] A further 6,000 samples from various groups of artefacts from archaeological sites and museums, including sculptures, reliefs, sarcophagi, inscriptions, and particular architectural features, can be added to this database.

[37] Maximum Grain Size.

[38] Most Frequent Grain.

[39] For the detailed instrumentation reference and the sample preparation procedure, see Prochaska, Attanasio 2021; Prochaska, Attanasio 2022; Prochaska *et al*. 2024.

from this analysis will be systematically integrated with the relevant information from archaeological artefacts in our future research. Employing statistical comparisons, we aim to ascertain the provenance of these artefacts. It is crucial to highlight that, for a meaningful comparison, both geological and archaeological samples must undergo consistent treatment.

In this preliminary phase, we are now endeavouring to discern differences within the Tinos quarries through an examination of the isotopic data. Specifically, we focus on a comparative analysis between two Tinian locations, Vathi and Karika, and a significant Cycladic source located on the island of Paros. The selection of this initial set of locations lays the foundation for our future research. The rationale behind presenting this pilot study now is multifold. Firstly, it is a crucial exploratory step for insights into the isotopic variations between these locations. By doing so, we establish a baseline for validating the feasibility of our approach and discerning potential nuances within this Cycladic data. Secondly, by starting with a focused analysis involving Tinian locations and a notable Cycladic source on the island of Paros, we can highlight immediate patterns and variations that may exist. This focused approach allows us to draw initial comparisons and contrasts, paving the way for a more comprehensive future investigation. Presenting this pilot study now is strategic in the sense that it sets the stage for a more expansive research endeavour. As we move forward, our analysis will extend to incorporate additional sources from the island of Naxos, thereby expanding the geographic scope of our investigation. This phased approach enables us to incrementally build upon our findings, ensuring a thorough and rigorous exploration of the fingerprinting of marble sources in the Cyclades.

The Significance of this Pilot Study for the Archaeology of Tinos

An island with a timeless tradition in the field of marble craftsmanship, Tinos seems to have been one of the key, albeit lesser-known, sources of Aegean marble in antiquity. Apart from the possible export of marble from Vathi to other areas outside Tinos, the question of the potential use of marble from the quarry on the island of Tinos is of particular interest.

The scope of the field of research concerning the use of local marble sources in the workshops of ancient Tinos highlights the number of relevant finds (sculptures, reliefs, inscriptions, *etc*.). Since their detailed presentation is beyond the purpose of this paper, we will only briefly mention the most important. In particular, the extensive use of marble as a building material is found in the buildings (temple, altar, fountain, *etc*.) of the great exurban sanctuary of the ancient city of Tinos, dedicated to the cult of Poseidon and Amphitrite in Kionia (4th century BC to 3rd century AD).[40]

Also noteworthy are the set of inscriptions, marble sculptures, and relief works from the sanctuary,[41] indisputable witnesses of the cultural prosperity of the island during the Hellenistic and Roman periods. The dolphins and seahorses from the sculptural decoration of the Doric temple of the sanctuary (3rd–2nd century BC) stand out among them, as do the marble orthostates from the altar with relief decorations, such as bucrania (bull's heads), flowers, fruits, *etc*. (2nd–1st century BC). Also significant are the statues of Emperor Claudius (1st century AD), which trace their origins to 'Building D', a temple specifically devoted to honouring the Roman imperial family of the Julio-Claudians.

The history of the sanctuary is closely linked to that of the ancient city of Tinos, *asty*, in the location of present-day Chora.[42] Known marble structural elements most probably come from the public buildings of the market of the ancient city ('*Prytaneion*', *palaestra*, theatre, *etc*.) in present-day Evangelistria. From a public building, probably the '*Prytaneion*', comes a series of important marble inscriptions informing us about the constitution of ancient Tinos.[43] Finally, however brief this exposition, the tombstones from the cemetery of Vardalakos in Xomburgo cannot be overlooked. Some of these, made of local marble, are excellent works of art which showcase the skill of the sculptors of Tinos in the Classical period (5th–4th century BC).[44]

A comprehensive future examination of these objects will play a crucial role in determining the potential utilisation of Vathi marble and, by extension, shed light on the broader spectrum of marble selection prevalent on the island of Tinos. Through meticulous analysis, we aim to unravel the historical, cultural, and functional implications embedded within these materials.

Conclusions and Future Approach

The Vathi quarry at Tinos comprises two quarry zones, one in the gneiss formation and the second in the white marble formation. It is not possible to determine

[40] Étienne, Braun 1986, 151–152.
[41] Queyrel 1986, 267–320.
[42] Étienne 1990, 15–30.
[43] Kontoleon 1953, 224–234.
[44] Kourou 2023.

Table 1: The analytical data of the Vathi quarry on Tinos, including stable isotope analysis ($^{13}C/^{12}C$ and $^{18}O/^{16}O$); ion-chromatography data for lithium, sodium, potassium, magnesium, calcium, fluorine, chlorine, bromine, iodine-jod, nitrate, sulphite ions in ratios, and DS (the amount of sodium, potassium, and chlorine in ppb in the extracted solution); and the ICP-MS analysis of magnesium, manganese, iron, strontium, chromium, vanadium, yttrium, cadmium, boron, lanthanum, cerium, praseodymium, dysprosium, holmium, ytterbium, lead, and uranium, in ppm (by V. Anevlavi and W. Prochaska; ÖAI/ÖAW).

lab no.	sample	Li	Na	K	Mg	Ca	F	Cl	Br	J (I)	NO_3	SO_4	DS	$\delta^{18}O$ (PDB)	$\delta^{13}C$ (PDB)
9008	Tinosvat1	0.1	279	193	373	10725	4	541	1.8	1.6	734.3	62.8	1013	-6.1	1.1
9009	Tinosvat2	0.1	443	372	133	11550	5	1049	2.3	1.6	1158.7	128.3	1863	-5.7	2.1
9010	Tinosvat3	0.1	1671	419	446	11792	18	4619	9.0	1.7	1285.0	821.4	6709	-9.1	0.9
9011	Tinosvat4	0.1	273	194	221	9668	6	514	1.5	2.0	1141.4	65.5	980	-5.5	1.7
9012	Tinosvat5	0.1	372	199	702	10661	6	934	2.1	3.2	996.3	98.3	1505	-5.7	2.0
9013	Tinosvat6	0.1	323	108	553	9197	3	743	1.6	2.0	509.9	90.3	1174	-5.9	1.6
9014	Tinosvat7	0.2	383	142	764	9630	13	724	2.2	2.7	689.2	171.4	1249	-6.9	1.8
9015	Tinosvat8	0.2	457	186	756	11335	9	736	2.5	4.0	720.6	1596.0	1379	-5.0	0.8
9016	Tinosvat9	0.3	734	122	1492	14199	6	1540	4.3	5.1	708.9	311.7	2395	-9.2	1.8
9017	Tinosvat10	0.2	413	287	1261	10060	15	1069	2.5	4.0	1383.1	170.0	1769	-6.4	2.1
9018	Tinosvat11	0.2	419	142	750	9936	3	833	2.8	2.4	721.6	174.1	1394	-5.4	1.6
9019	Tinosvat12	0.2	637	143	1278	13971	6	1504	2.9	3.5	678.8	239.0	2285	-8.6	1.7
9020	Tinosvat13	0.1	312	131	724	9667	5	1005	1.3	1.3	404.6	112.9	1449	-5.4	1.6
9021	Tinosvat14	0.3	295	236	n.a.	11744	8	675	1.5	1.0	553.7	103.9	1206	-6.1	1.4
9022	Tinosvat15	0.3	358	137	813	9216	3	702	1.7	2.2	408.6	161.3	1197	-7.7	1.8
9023	Tinosvat16	0.3	793	124	494	10578	5	2236	2.1	1.9	722.3	425.9	3154	-7.5	2.3
9024	Tinosvat17	0.1	3679	305	n.a.	10694	5	10604	12.5	1.1	1368.7	485.1	14588	-5.6	1.2

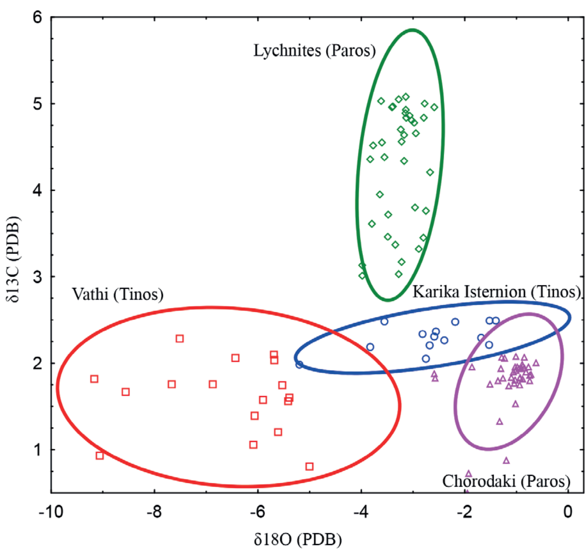

Fig. 7. The preliminary isotopic diagram of the Tinian and Parian sources (compiled by V. Anevlavi and W. Prochaska; ÖAI/ÖAW).

the chronology of either quarry, apart from their logical relative chronology, putting the gneiss quarry first and the white marble quarry second. However, the chronology of the white marble quarry can be made more precise because it fits below the zone of the gneiss formation, which was eliminated using mechanical drilling and explosives. Mechanical drilling was also used for the carving of the wedge holes in the white marble quarry. With these technologies, it is not possible to propose a chronology for the white marble quarry before the end of the 19th or during the 20th century.

Despite its relatively recent chronology, it seems clear that the technologies used for the extraction of the blocks were still close to those used in antiquity, *i.e.*, the use of a quarry pick for the cutting of vertical extraction trenches and the equally classical technology of combining wedge holes and iron wedges to break the blocks from the rock formation beneath. However, the carving technique for the wedge holes, first mechanically drilling a hole, followed by its enlargement with a pointed chisel,

Mg%	Mn	Fe	Sr	Cr	V	Y	Cd	B	La	Ce	Pr	Dy	Ho	Yb	Pb	U
0.45	88.07	146.12	136.95	1.427	0.140	1.407	0.493	2.588	0.335	0.261	0.045	0.076	0.022	0.069	0.284	0.006
0.03	10.73	61.91	122.53	1.391	0.054	1.242	0.175	2.988	0.515	0.468	0.076	0.089	0.022	0.067	0.248	0.013
0.35	208.58	244.33	268.96	1.445	0.097	0.974	0.195	5.987	0.430	0.452	0.072	0.074	0.020	0.061	2.107	0.006
0.26	31.29	346.11	141.67	1.493	0.123	2.750	0.144	2.324	1.228	0.783	0.201	0.209	0.050	0.132	0.292	0.006
0.94	84.41	156.72	154.57	1.444	0.130	2.210	0.202	2.230	0.962	0.929	0.138	0.146	0.035	0.089	0.364	0.008
0.83	71.67	139.86	150.48	1.555	0.122	2.527	0.198	2.484	0.607	0.407	0.082	0.138	0.038	0.115	0.510	0.005
1.44	140.98	361.87	147.80	1.533	0.159	2.278	0.234	2.055	0.823	0.309	0.112	0.146	0.041	0.108	0.336	0.006
0.51	141.11	165.59	163.59	1.543	0.195	1.151	0.154	2.353	0.473	0.326	0.059	0.065	0.017	0.060	0.195	0.014
2.92	151.79	329.45	240.32	1.481	0.157	2.692	0.315	2.651	0.767	0.637	0.119	0.160	0.042	0.126	1.681	0.004
1.55	97.71	216.21	135.34	1.526	0.170	4.069	0.241	2.610	1.215	0.491	0.141	0.198	0.058	0.188	0.337	0.008
0.87	70.24	121.06	143.70	1.508	0.118	1.506	0.213	2.146	0.520	0.185	0.089	0.114	0.028	0.068	0.171	0.006
0.71	57.94	164.02	166.80	1.459	0.105	1.870	0.206	3.055	0.643	0.471	0.093	0.115	0.031	0.080	1.425	0.007
0.83	74.55	222.36	153.71	1.553	0.156	1.462	0.193	3.938	0.560	0.249	0.069	0.094	0.025	0.070	0.376	0.009
0.21	86.43	160.15	147.79	1.451	0.072	1.218	0.167	1.811	0.982	1.247	0.162	0.103	0.024	0.067	0.356	0.006
1.81	96.80	220.32	139.32	1.491	0.160	1.598	0.163	2.695	0.847	0.291	0.141	0.126	0.030	0.081	0.741	0.004
0.46	22.93	93.04	143.11	1.540	0.079	1.794	0.287	3.510	0.545	0.230	0.076	0.125	0.034	0.090	0.430	0.007
0.62	157.45	276.77	133.65	1.503	0.113	0.722	0.276	1.728	0.427	0.265	0.062	0.062	0.014	0.042	0.238	0.007

is again a recent technology, apparently unique, and perhaps of local origin. The dates engraved on a door lintel of one of the quarry workers' houses (1858) and on the top of the white marble wall (1889) also point to the end of the 19th century for the extraction of the white marble.

Moreover, the geochemical data not only provide a unique fingerprint for each location but also serve as a crucial element in our comparative examination. This study contributes significantly to analysing data from ancient quarries on Tinos, including Karika Isternion, Lychnaftia, and others. We aim to juxtapose these findings with quarries from the broader Cyclades region and the ancient world, fostering a comprehensive understanding of marble extraction, production, and use. In essence, this pilot study functions as a foundational exploration, offering a snapshot of isotopic variations among selected locations. Its timely presentation not only establishes the robustness of our research methodology but strategically positions us for a more extensive study, incorporating diverse sources from the Aegean. This staged approach is designed to progressively enhance our comprehension of the quarry, with each phase contributing to the cumulative depth of our research. Anticipated outcomes from the study of ancient quarries on Tinos include completing the information map of ancient quarries in the Aegean. Additionally, we expect to unveil new insights into the organisation of local quarries and workshops, both on Tinos and in the broader Cyclades. For provenance studies, a systematic sampling of ancient objects, such as sculptures and architectural elements, could potentially confirm the historical use of Vathi marble.

The exploitation of the stone landscape of Tinos is of special archaeological and historical interest. The current study of the Vathi quarry, in combination with the forthcoming studies of the marble quarry of Karika and the serpentinite quarry of Ras, will enlighten and enrich our information on stone quarries of the region. Therefore, Tinos provides valuable new insights into the understudied subject of ancient stone production and economy at a local and regional level. The exploitation of these sources could reveal information on the type of material and qualities used for a specific set of objects (*e.g.*, sculptures, sarcophagi, *etc*.), with parallel information on the tools, techniques and facilities, the motifs and styles, skills and knowledge, transportation, distribution, trade, and customers.

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