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Preliminary Results of Geological and GIS Studies from Surface Surveys at the Ancient City of Arneai (SW Türkiye)

Arneai Antik Kenti Yüzey Araştırmaları: Jeoloji ve CBS Çalışmalarının Ön Sonuçları (GB-Türkiye)

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Abstract: A comprehensive surface survey was conducted in 2025 at the ancient city of Arneai, a site documented only to a limited extent in the scholarly literature. The investigations were carried out by an interdisciplinary team supported by modern technologies, focusing on the general geology of the city and its building stones. The ancient city of Arneai is located within the Tauride tectonic belt, which includes the Taurus Mountains. The oldest geological unit in the study area is the Upper Cretaceous Beydağları Formation which is overlain by Paleocene, Eocene, and Miocene units. Carbonate units are prevalent in the region. These units, predominantly limestone, were used as building stones in antiquity. Building stones for the ancient city were extracted from local (in-situ) limestone bedrock. Scattered, generally fragmented terracotta materials found on the surface appear to have two distinct colors. The red soil material is estimated to have higher iron content than the yellowish material. The small amount of slag material identified during the survey suggests the presence of small-scale smelting furnaces (possibly for lead production). These preliminary results provide a framework for future systematic archaeological excavations and detailed geological investigations.

Keywords: Arneai, geoarcheology, geology, structural geology.

***Öz**: 2025 yılında, bilimsel literatürde oldukça sınırlı düzeyde belgelenmiş olan Arneai antik kentinde kapsamlı bir yüzey araştırması gerçekleştirilmiştir. Modern teknolojilerle desteklenen disiplinler arası bir ekip tarafından yürütülen incelemeler, kentin genel jeolojisi ve yapı taşları üzerine odaklanmıştır. Arneai antik kenti ve çevresi, Toros Dağları'nı da kapsayan Torid tektonik kuşağı içerisinde yer almaktadır. Bölgedeki en yaşlı jeolojik birim, üzerinde Paleosen, Eosen ve Miyosen birimlerin yer aldığı Üst Kretase yaşlı Beydağları Formasyonu'dur. Bölgede karbonatlı birimler yaygınlık göstermektedir. Ağırlıklı olarak kireçtaşından oluşan bu birimler, antik çağda yapı taşı olarak kullanılmıştır. Antik kentin yapı taşlarının, yerel (in-situ) kireçtaşı ana kayasından üretildiği gözlemlenmiştir. Yüzeyde bulunan, genel olarak parçalı haldeki dağınık terakota (pişmiş toprak) malzemeler iki farklı renkte görülmektedir. Kırmızı renkli malzemenin, sarımsı malzemeye oranla daha yüksek demir içeriğine sahip olduğu tahmin edilmektedir. Yüzey araştırması sırasında tespit edilen az miktardaki cüruf malzemesi, (muhtemelen kurşun üretimi için kullanılan) küçük ölçekli ergitme ocaklarının varlığına işaret etmektedir. Bu ön sonuçlar, gelecekte yapılacak sistematik arkeolojik kazılar ve ayrıntılı jeolojik incelemeler için bir çerçeve sunmayı amaçlamaktadır.*

***Anahtar Kelimeler:** Arneai, jeoarkeoloji, jeoloji, yapısal jeoloji.*

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INTRODUCTION

Located in the mountainous terrain of the Central Lycia region, the ancient city of Arneai is situated on a steep mountain promontory south of the village of Ernez (formerly Günçalı) within the Finike district of Antalya province (Figure 1) (Arlı, 2025). To reach the city, one must travel about 29 km on the Finike-Elmalı road, pass the village of Gökbük, and then take the shortcut on the left towards Kaş (Arlı, 2025). Then 12 km past this junction, the village of Yazır appears, 7 km further, another junction leads to a village road. Proceeding 4 km down this road is the village of Ernez (Arlı, 2025). Arneai, which encompasses İnönü and Asar Hills, remains one of the lesser-known cities in the Lycian region.

To date, no systematic excavation or comprehensive surface surveys have been conducted at the site. Systematic surface surveys within the urban territory by a multidisciplinary research group commenced in 2025.

The earliest data regarding the city was provided by C. Texier, who visited in 1836 (Texier, 1862). Sharing his observations on the city's location, name, and extant architectural remains, Texier noted that the settlement's modern name, Ernez, could be easily identified with the Arneai mentioned by Stephanos Byzantios (Texier, 1862). In 1847, T. A. Spratt and E. Forbes also mentioned Arneai in their joint work (Spratt and Forbes, 1847; Arlı, 2025). However, in their work entitled 'Travels in Lycia', both researchers stated they intended to visit the city but were unable to enter due to a plague quarantine, limiting their observations to distance viewing (Spratt and Forbes, 1847; 2008; Arlı, 2025). Nevertheless, they concurred with H. Loev, who had the opportunity to visit the city prior to the outbreak, noting the phonetic similarity between "Ernez" and "Arneai", and confirming that the ruins on the hill corresponded to the ancient city (Spratt and Forbes, 1847; 2008; Arlı, 2025).

In addition to these sources, researchers visiting in the late 19th century examined the city's inscriptions and published archaeological data (TAM II 756-783). In the early 20th century, another researcher who conducted investigations at the site provided accounts concerning the city and documented its Byzantine-period structures (Rott, 1908). Toward the end of the 20th century, G. E. Bean published a brief introductory text on Arneai, drawing on earlier accounts (Bean, 1962, 1978).

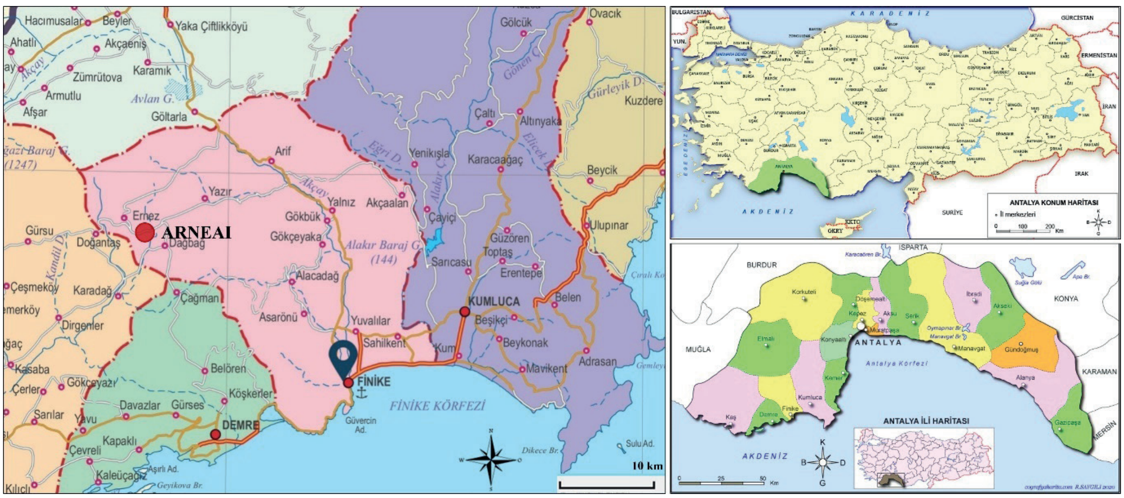

Figure 1. Location map of the ancient city of Arneai (URL-1).

Şekil 1. *Arneai antik kenti yer bulduru haritası (URL-1).*

Beyond these existing records, this study aims to share archaeological data obtained from the comprehensive, interdisciplinary surface survey conducted at Arneai.

Accordingly, this paper presents preliminary results about the general geology of the ancient city and its surroundings, as well as characteristics of its building stones (including ceramics), based on the fieldwork within the scope of surface surveys conducted in 2025.

The ancient city is located south of Ernez village, centered around Kale Hill (726 m) and the Asar Ridge (Figure 2). However, initial investigations indicate that the ruins extend over a much wider area than the immediate vicinity of Ernez village.

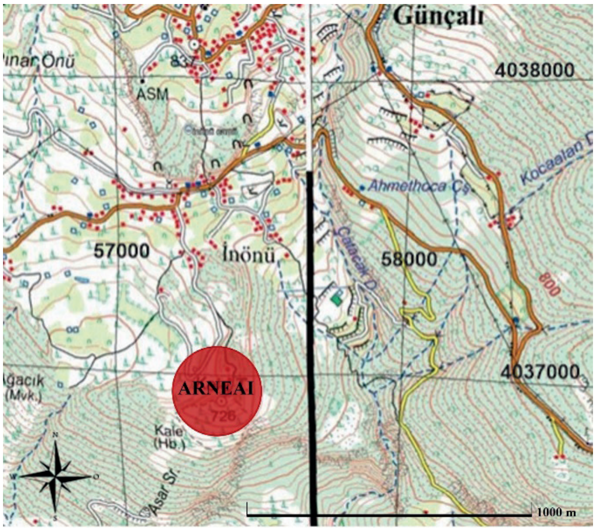

Figure 2. Topographic map of the ancient city of Arneai and surroundings (European Datum 1950, 6 degree).

Şekil 2. *Arneai antik kenti ve çevresinin topoğrafik haritası (ED50-6 derece).*

GEOGRAPHIC INFORMATION SYSTEMS (GIS) and TOPOGRAPHIC ANALYSIS

To establish the geographic information system (GIS) infrastructure for the archaeological surface surveys of the ancient city of Arneai, stereographic images were first obtained along specific lines using an unmanned aerial vehicle (UAV-Drone). Subsequently, 3D orthophotos of the study area were generated. As Google Earth satellite imagery often lacks sufficient resolution, this issue was resolved by integrating 3D images derived from drone footage into GIS software, enabling the acquisition of clearer visuals of ancient structures.

A DJI Mavic Pro drone was used for aerial imaging. Stereographic flights were planned using Fly Drone Controller software, ensuring 60% overlap between images and flight lines. Flight altitudes were maintained between 60–80 m based on software guidance. Due to the scale of the site, the survey area was segmented, and the data subsequently merged to create a unified dataset. To minimize the noise inherent in photogrammetric data, a 5x5 median convolution filter was applied to the digital elevation model (DEM) (Figure 3). Image alignment, dense point cloud generation, and 3D modeling processes were performed using Agisoft Metashape Professional. The high-resolution orthophoto obtained at the end of this process documents the current state of the study area (Figure 4A). The high-resolution dataset generated in Agisoft Metashape was subsequently exported to Global Mapper software for advanced topographic analysis. Filtered dataset enabled the production of a refined hillshade (relief) map, which significantly improved the visibility of micro-topographic features—such as terrace walls and collapsed structures—that are otherwise obscured in standard satellite imagery (Figure 4C).

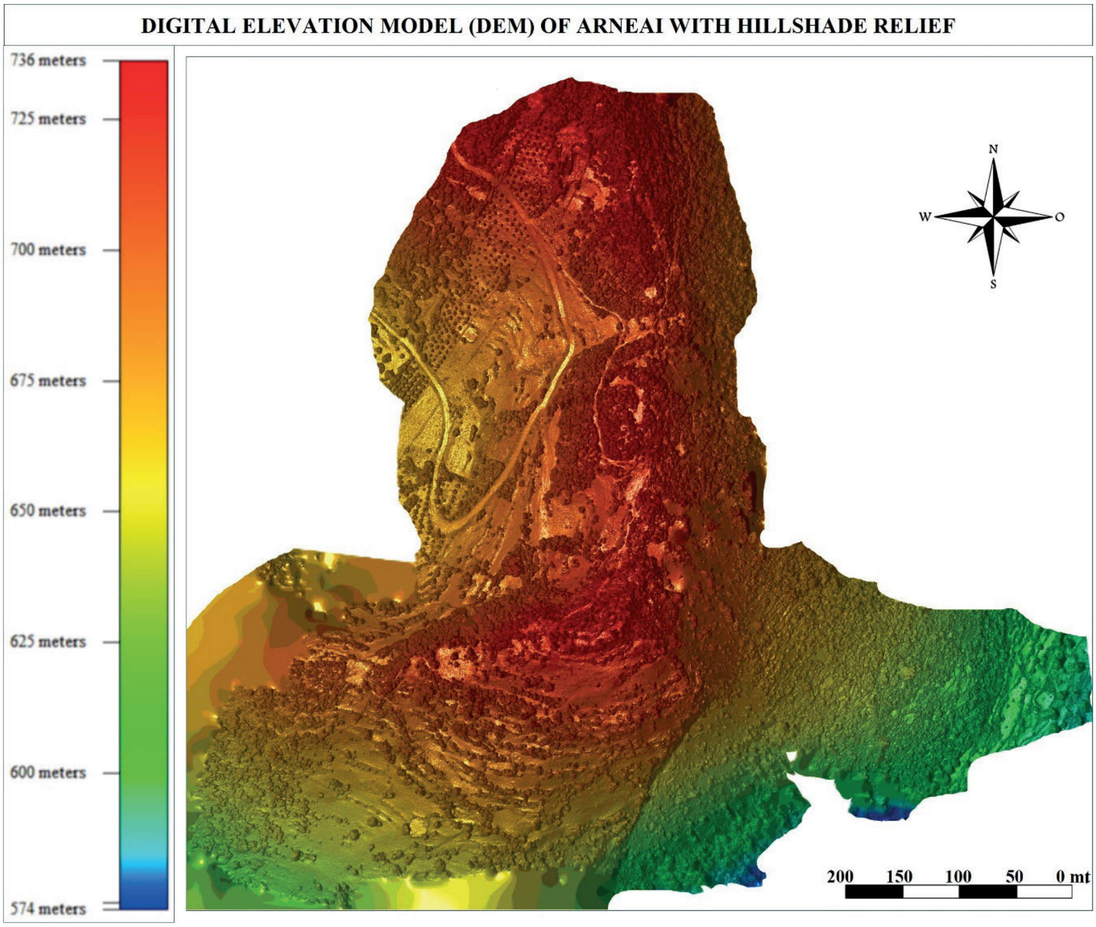

Figure 3. Digital elevation model (DEM) of Arneai. The model is enhanced with a 5x5 median convolution filter and hillshade relief to visualize the micro-topographic features and elevation ranges (574 m to 736 m) of the settlement area.

Şekil 3. *Arneai Sayısal Yükseklik Modeli (SYM). Yerleşim alanındaki mikro-topografik özellikleri ve yükseklik aralıklarını (574 m - 736 m) görselleştirmek amacıyla; model, 5x5 Median Convolution Filter (Ortanca Konvolüsyon Filtresi) ve Hillshade (gölgeli kabartma) analizi ile zenginleştirilmiştir.*

Within the scope of geomorphological slope analysis conducted to evaluate the spatial organization of the settlement, the data were classified into five categories (0-5°, 5-15°, 15-25°, 25-45°, and 45-90°) to distinguish between habitable plains and steep terrain (Figure 4B). These analyses scientifically demonstrated the ancient city's adaptation to the rugged Lycian topography and terracing strategies. To ensure full compatibility with the existing 1/25,000 scale topographic maps of the region, all GIS data were projected in the ED50 (European Datum 1950) 6-degree geodetic system. The spatial data obtained constitute the primary dataset for discussing the correlation between the architectural distribution of the settlement fabric and topographic constraints. Preliminary assessments of whether the architectural remains identified in the 2025 surface survey are randomly distributed or spatially organized reveal a clustered spatial pattern rather than a random distribution; this indicates that the placement of structures was largely conditioned by topographical suitability and functional planning principles.

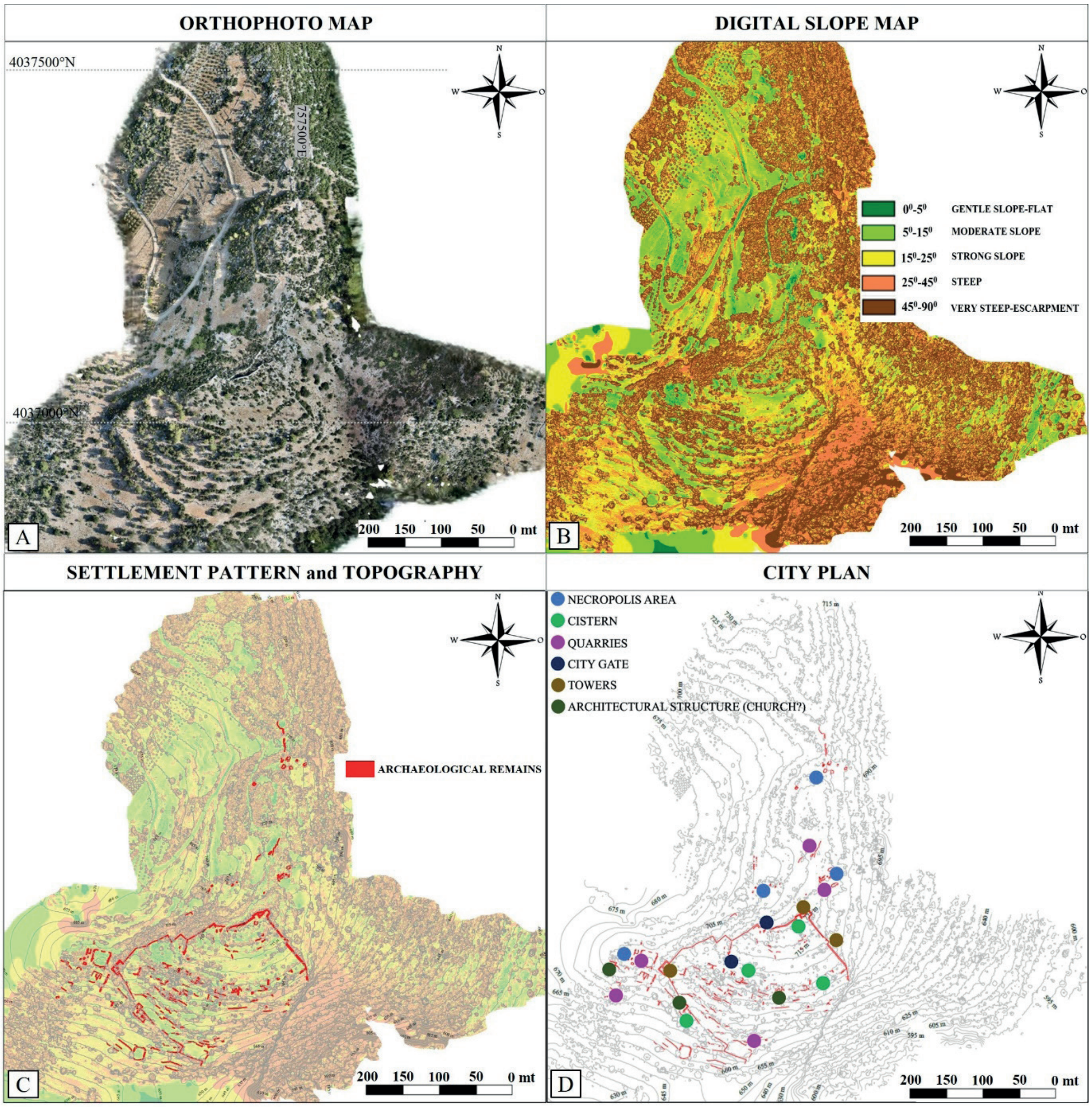

Figure 4. Integrated GIS analysis of Arneai: (A) orthophoto map, (B) digital slope map, (C) settlement pattern and topography, (D) city plan.

Şekil 4. *Arneai entegre CBS analizi; (A) Ortofoto haritası, (B) Sayısal eğim haritası, (C) Yerleşim dokusu ve topografya, (D) Şehir planı.*

Specifically, the architectural remains tend to concentrate in areas with moderate slopes between 10° and 15°, where construction costs and terracing requirements are relatively lower. This clustered organization reflects a deliberate settlement strategy adapted to the rugged geomorphology of Central Lycia.

The urban development of Arneai represents a sophisticated adaptation to the rugged Lycian topography, where architectural planning was strictly dictated by geomorphological and geological constraints. To quantify this relationship, a series of advanced GIS-based spatial analyses were performed using a high-resolution DEM (Figure 3).

Quantitative data derived from the reclassified slope analysis indicate that approximately 70% of the architectural remains identified during the initial survey season are concentrated on moderate gradients between 10° and 15°. This specific range appears to serve as a deliberate engineering threshold; while gentler slopes (0° to 10°) were prioritized for public buildings to minimize substructure costs, residential units were strategically distributed across steeper terraces (15° to 25°). Areas exceeding 45° gradient functioned as natural defensive barriers; in these sections, the precipitous terrain superseded the need for artificial fortification, highlighting a cost-effective defense strategy (Figure 4B).

The city's defensive network and visual command were evaluated through viewshed analysis conducted from the acropolis (736 m) and identified watchtowers (Figure 3, 4C, 4D). The results indicate comprehensive visual dominance over the entire valley and the surrounding *territorium*, enabling synchronized control of the urban core and its rural hinterland. This strategic positioning is further supported by the city's hydrological adaptation. Drainage networks were engineered parallel to contour lines to manage surface runoff, while cisterns were strategically positioned at higher elevations to facilitate gravity-fed water distribution (Figure 4D). Hydrological analyses derived from the DEM show that water management strategies in Arneai are closely related to the natural topography. Drainage channels identified during the first surface survey season appear to have been planned parallel to contour lines. Furthermore, the placement of cisterns at higher elevations suggests the deliberate use of gravity-assisted water distribution systems. These preliminary findings are significant in demonstrating that hydrological adaptation was a fundamental component of the city's planning strategy.

In addition to standard line-of-sight analyses, the reciprocal line-of-sight relationships between the acropolis and potential watchtower locations were assessed to reconstruct the settlement's defensive communication network. The results indicate that the main observation points were in direct visual contact with both the urban core and the surrounding valley systems. This interconnected visual network likely enabled rapid communication and regional surveillance in mountainous terrain. These preliminary findings suggest that the strategic placement of defensive structures reflects not only military concerns but also an advanced understanding of topographical visibility and terrain control (Figure 5).

Surface finds and architectural data identified during the 2025 surface surveys were subjected to kernel density analysis in the Global Mapper environment (Figure 6). The density layer, generated using search radius parameters that optimally reflect the spatial continuity and clustering pattern of the data, was overlaid with the settlement plan and topographic data (overlay analysis). The resulting analytical map strongly supports the interpretation that socio-spatial activity within the settlement was not randomly distributed. It forms a single high-density hotspot (very high density) in the sheltered terrace between elevations of 645 m and 670 m and in the center of the main architectural fabric. This analysis is consistent with the interpretation that settlement organization was shaped by defense, accessibility, and topographic adaptation strategies.

The relationship between the archaeological fabric and the geological substrate was further elucidated through overlay analysis. The primary building material consists of *in-situ* limestone sourced from five ancient quarries identified in the immediate vicinity of the settlement. The spatial proximity of these quarries to major construction zones indicates a highly organized logistical strategy aiming to reduce transport costs. Furthermore, functional zoning reflects a clear geological correlation: necropolis areas were established on monolithic limestone outcrops suitable for rock-cut tombs, whereas domestic and public sectors were positioned on more workable local limestone units. The subsequent repurposing of exhausted quarries as workshops or artisanal areas further illustrates the efficient and multi-phased utilization of Arneai's geological resources.

GEOLOGICAL SETTING OF ARNEAI AND ITS SURROUNDINGS

General Geology

Regionally, the ancient city of Arneai is situated within the Tauride tectonic belt (Figure 7) (Ketin, 1966; Okay and Tüysüz, 1999). The region is represented by oceanic crust rocks from the Tethys Ocean and overlying dense marine carbonate and clastic sediments, which were uplifted following closure of the ocean. The region, now known as the "Taurus Mountains", extends eastward as a high limestone mountain range into Iran and the Himalayas (Zhao et al. 2020).

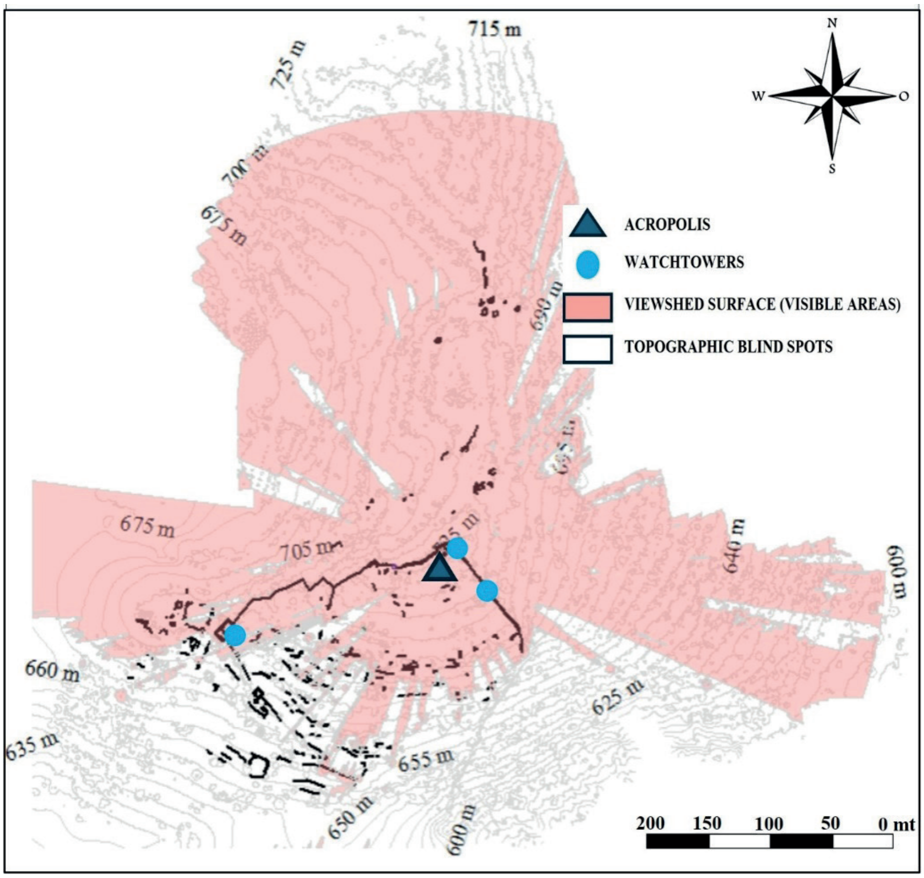

Figure 5. Intervisibility and viewshed map of Arneai. The computational model integrates topographic contours to visualize the tactical line of sight and optical surveillance coverage radiating from defensive checkpoints within the settlement topography (595 m to 725 m).

Şekil 5. *Arneai Görünürlük (Viewshed) ve Karşılıklı Görüş Haritası. Savunma kontrol noktalarından yayılan taktiksel görüş hattını ve optik gözetleme hakimiyetini yerleşim topoğrafyası (595 m - 725 m) üzerinde görselleştirmek amacıyla; bilgisayarlı model, eş yükselti eğrileri ile bütünleştirilmiştir.*

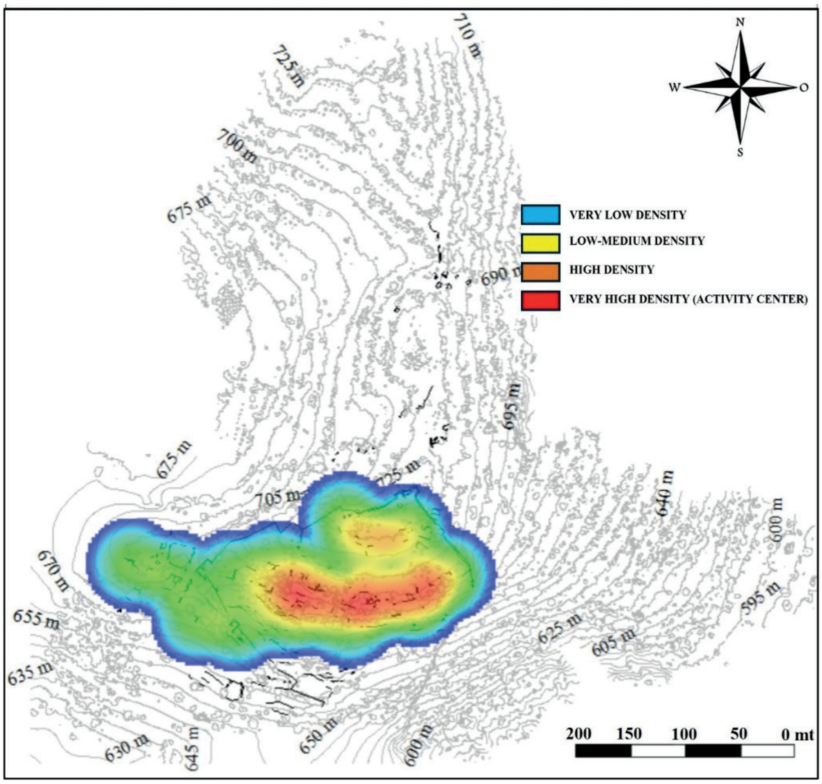

Figure 6. Kernel density estimation (KDE) map of Arneai. The model is integrated with topographic contours to visualize the spatial concentration and distribution hierarchy of architectural remains and artifact assemblages on the settlement terraces (635 m to 725 m).

Şekil 6. *Arneai Çekirdek Yoğunluk (Kernel Density) Haritası. Yerleşim teraslarındaki (635 m - 725 m) mimari kalıntıların ve buluntu gruplarının mekânsal yoğunlaşmasını ve dağılım hiyerarşisini görselleştirmek amacıyla; model, topoğrafik eş yükselti eğrileri ile bütünleştirilmiştir.*

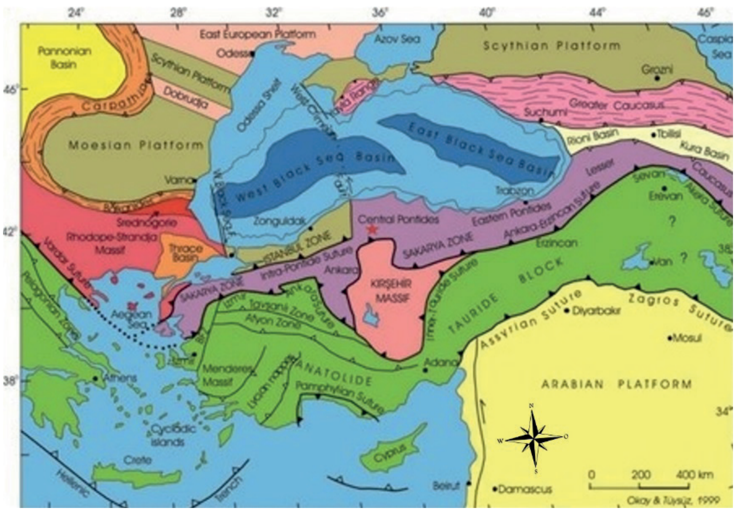

Figure 7. Tectonic units of Anatolia (Okay & Tüysüz, 1999).

Şekil 7. *Anadolu'nun tektonik birlikleri (Okay ve Tüysüz, 1999'dan değiştirilmiştir).*

The ancient city of Arneai and its surroundings are located within the tectonic unit known as the Beydağı Autochthon (Şenel, 1997). The base of the Beydağı autochthon consists of Upper Cretaceous (Cenomanian) limestones deposited in a shelf environment. These are overlain by Paleocene and Eocene limestone-dominant sedimentary units (Şenel and Bölükbaşı, 2010; Şenel et al. 1994; Rathur, 1967). Clayey horizons are observed within the Paleocene units. Upper Cretaceous limestones represent the oldest unit in the region (Figure 8).

The research area lies within the Teke Peninsula, part of the Western Taurus system. The main geological units consist of the widespread Beydağları autochthon, the overlying Lycian nappes, and the Yeşilbarak nappe, which represents lateral continuity between them. The allochthonous Lycian nappes were transported onto the Beydağları autochthon from the north/northwest during the early Langhian period. This tectonic emplacement caused intense deformation in the autochthonous units, resulting in folding, faulting, and southward thrusting (Susuzdağ thrust). Current geological data reveal that large-scale fault systems were active in the late Pliocene and subsequent periods. The area acquired its present morphological characteristics through the combined effects of post-Langhian erosional processes and these tectonic structures (Şenel and Bölükbaşı, 2010). The geological units defined in this study are discussed based on the formation nomenclature used by Şenel and Bölükbaşı (2010) (Figure 9).

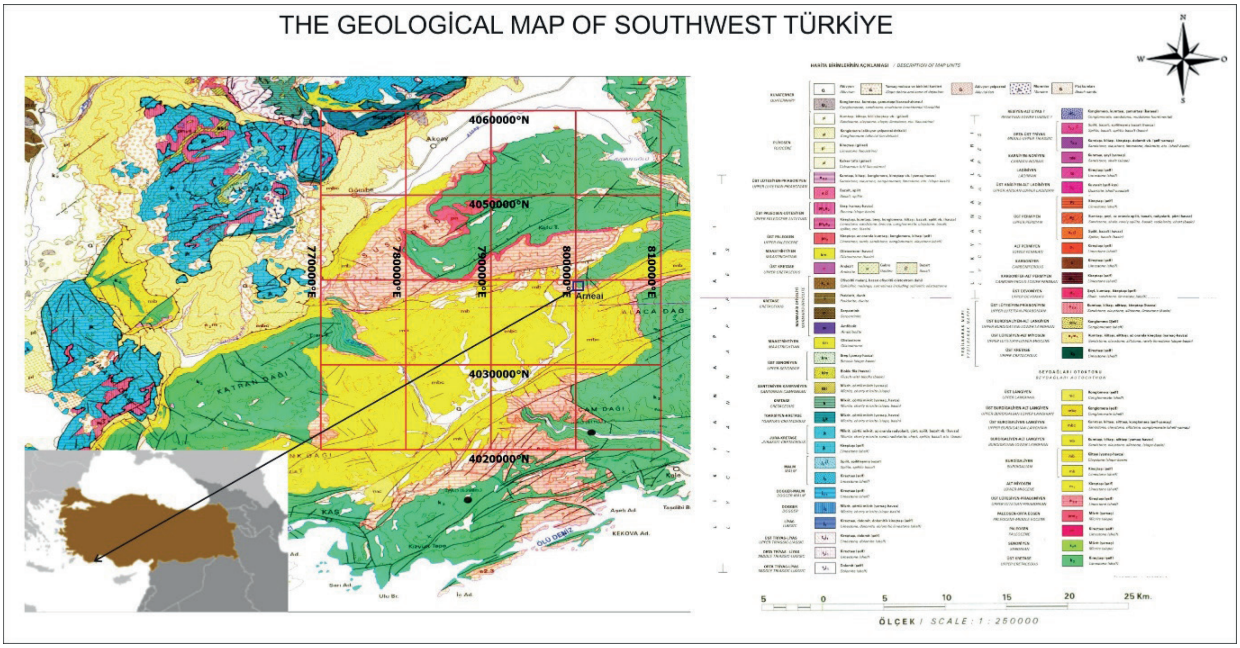

Figure 8. Regional geological map of the ancient city of Arneai and its surroundings (Şenel and Bölükbaşı, 2010) (ED-50, 6 degree).

Şekil 8. *Arneai antik kenti ve yakın çevresinin bölgesel jeoloji haritası (Şenel ve Bölükbaşı, 2010) (ED50-6 derece).*

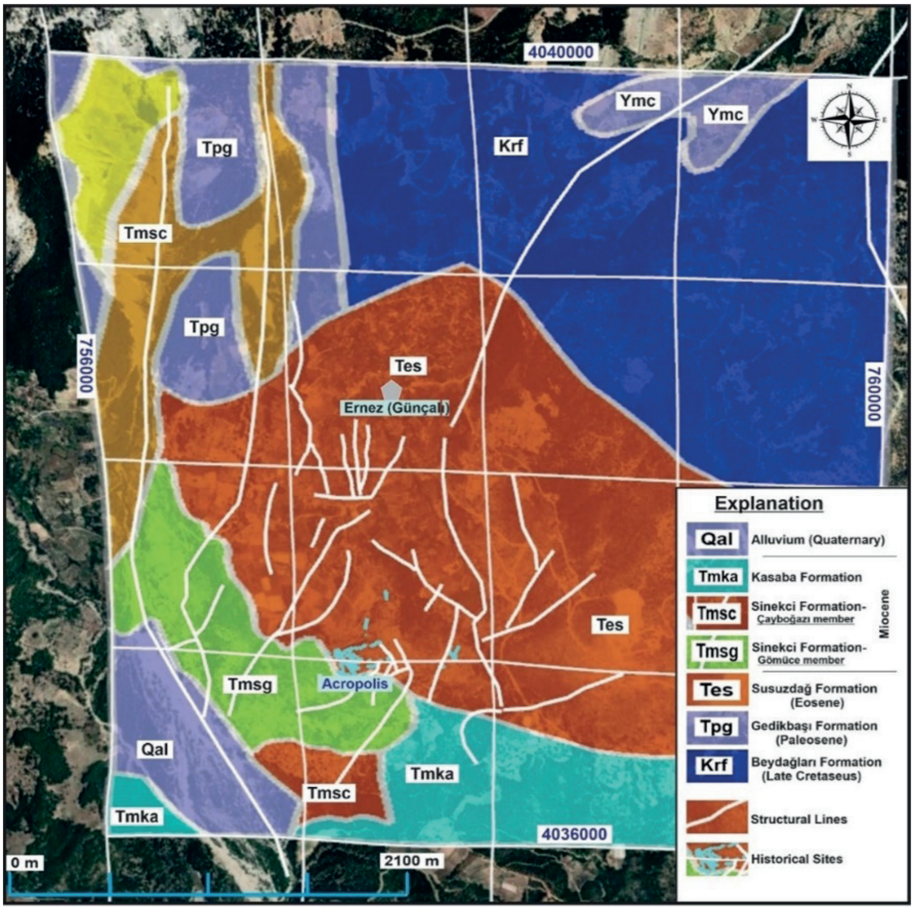

Figure 9. Geological map of the ancient city of Arneai and its surroundings (simplified based on MTA, 2010 data, from Şenel and Bölükbaşı, 2010; European Datum 1950, 6 degree).

Şekil 9. *Arneai antik kenti ve çevresinin jeoloji haritası (Şenel ve Bölükbaşı, 2010 verileri kullanılarak* MTA, 2010*'dan basitleştirilmiştir) (ED50-6 derece).*

Beydağları Formation (Krf)

The Beydağları Formation, composed of Liassic-Late Cretaceous neritic carbonates, is represented by Late Cretaceous limestones with reefal characteristics containing rudist fossils in places (Figure 9).

The formation consists of medium-to-thick layered reefal gray to light-gray weathering surfaces and beige, cream, or off-white fresh fracture surfaces. It includes local layers of off-white, chalky clayey limestone, as well as beige and light-gray dolomite and dolomitic limestone. Dolomitization and recrystallization are common in and around the rudist reefs. The unit is hard, densely fractured, and exhibits karstic dissolution cavities. Fractures are calcite-filled, while wider fissures are locally filled with aragonite.

Gedikbaşı Formation (Tpg)

The Gedikbaşı Formation is represented by medium-to-thick bedded, hard, and densely fractured neritic limestones. Weathered surfaces are gray or light gray, while fracture surfaces are beige, cream, or light brown. Due to lithological similarities, it is difficult to distinguish from the Beydağları Formation. These limestones, which are locally milioidal and algal, also contain occasional dolomite and dolomitic limestone layers. The formation is dated to the Paleocene based on fossil content.

Susuzdağ Formation (Tes)

The Susuzdağ Formation consists of medium-to-thick layered limestones rich in nummulites and alveolina. Weathered surfaces are gray to light gray, while fracture surfaces are beige, cream, or off-white. The unit is dated to the Eocene. Fossils and trace fossils of algae, corals, lamellibranchs, echinoids (sea urchins), pelecypods, and gastropods are frequently encountered (Figure 10).

The unit, which includes dolomite, dolomitic limestone, and recrystallized limestone layers in places, is characterized by terrestrial dissolution cavities. These cavities, known locally as "in" (caves/dens), have been used by humans from antiquity to the present (Figure 11). These caves formed naturally through karstification processes, evidenced by stalactite and stalagmite formations (Figure 12). Humans likely modified these natural formations by expanding and shaping them in post-geological periods. Figure 11 shows a clayey horizon at the base of the caves. Rainfall percolating through fractured limestone throughout geological history reached this clay layer; unable to seep further down, the water dissolved the rock just above the clay, forming these caves.

In this unit, where karstification is widespread, small-scale structures such as poljes and dolines (sinkholes) developed. These types of structures are collapse formations created by the erosion of limestone by surface waters. A fairly large, polje-like structure (approximately 1 km in diameter) is also clearly visible in satellite imagery just north of the ancient city (Figure 13A-13B).

The ancient city and Ernez village are located on the Susuzdağ Formation, which consists of solid and easily workable limestone. These limestones were used as building stones in the fortification walls and architectural structures of the ancient city. Limestones from the same formation were used for the construction of rock tombs and sarcophagi.

Figure 10. Pelecypoda (**A**) and sea urchin (**B**) fossils in Susuzdağ Limestones.
Şekil 10. *Susuzdağ Kireçtaşları içerisinde gözlenen pelecypoda (**A**) ve deniz kestanesi (**B**) fosilleri.*

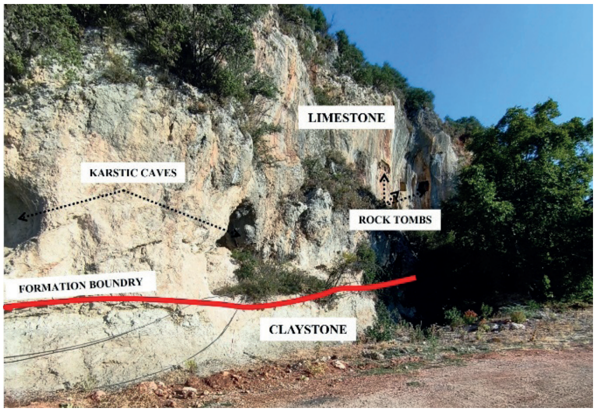

Figure 11. Karstic caves and rock tombs developed and carved in Susuzdağ Limestones.

Şekil 11. *Susuzdağ Kireçtaşları'nda gelişmiş karstik mağaralar ve oyulmuş kaya mezarları.*

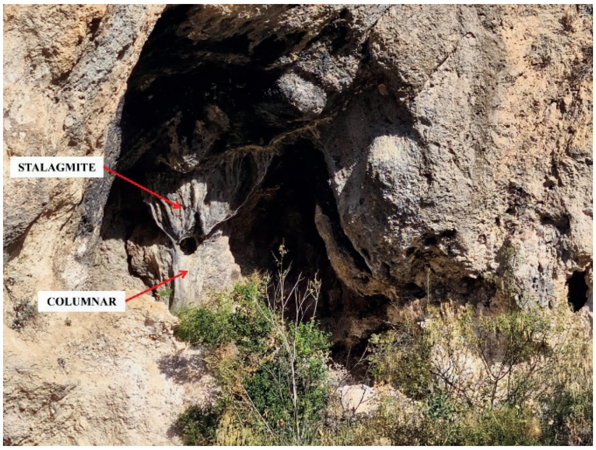

Figure 12. Stalagmite and columnar forms observed in karst cavities.

Şekil 12. *Karstik boşluklarda gözlenen dikit ve sütun formları.*

Sinekçi Formation (Tms)

The Sinekçi Formation, consisting of algal limestone, clayey limestone, and claystone from bottom to top, comprises base algal limestones identified as the Gömüce Member (Tmsg); middle clayey limestones known as the Kıbrısdere Member (Tmsk); and uppermost claystones called the Çayboğazı Member (Tmsç). The age of the Sinekçi Formation and its subunits is given as Miocene (Şenel and Bölükbaşı, 2010).

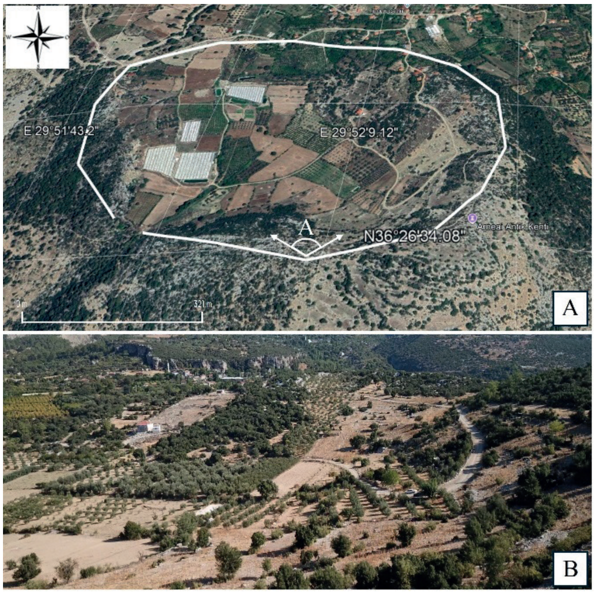

Figure 13. A) Possible polje observed north of the castle in Arneai ancient city. **B)** View of the polje from point A.

Şekil 13. A) *Arneai antik kenti kalesinin kuzeyinde gözlenen olası polye.**B)** Polyenin A noktasından görüntüsü.*

Kasaba Formation (Tmka)

The Kasaba Formation, which contains thin-to-medium-thick bedded, green, greenish-grey, dark grey, light grey, beige, cream, and light brown sandstone, siltstone, claystone, and conglomerate, is represented north of Katran Mountain by grain-supported, coarse-grained conglomerates and a small amount of sandstone. The age of the formation is given as Miocene, like the Sinekçi Formation (Şenel and Bölükbaşı, 2010).

In the ancient city area, pebbles of serpentine, basalt, radiolarite, and chert (e.g., opal) derived from the Kasaba Formation were observed (Figure 14). It is probable that these fragments were transported from the overlying Kasaba Formation via fluvial erosion over geological time.

Figure 14. Radiolarite-chert (**A**), serpentine (**B**) and basalt (**C**) pebbles observed around the ancient city.

Şekil 14. *Antik kent çevresinde gözlenen radyolarit-çört (**A**), serpantin (**B**) ve bazalt (**C**) çakılları.*

Quaternary alluvial units

In the study area, recent Quaternary deposits are observed as river valley and flood plain sediments (Figure 9).

Tectonics

The structural outlines of Ernez (Günçalı) and its surroundings were delineated by evaluating satellite imagery in conjunction with field studies (Figure 9). Fault lines are generally observed in three directions. The first and primary trend is NE-SW (approximately 45° azimuth). Fault lines oriented NW-SE intersect and, in some areas, displace this primary trend. The third set of lines is generally observed trending E-W. These faults may have originated from karstic movements, as they developed along the frontal sections of the karst caves in the cave region (İnler), leaving the caves at a higher elevation relative to their original position (Figure 15).

The main settlement area of Ernez (Günçalı) village acquired its present topography through ancient faulting events. Structural elements are clearly visible when the Beydağ Mountains are observed from the acropolis (Figure 15).

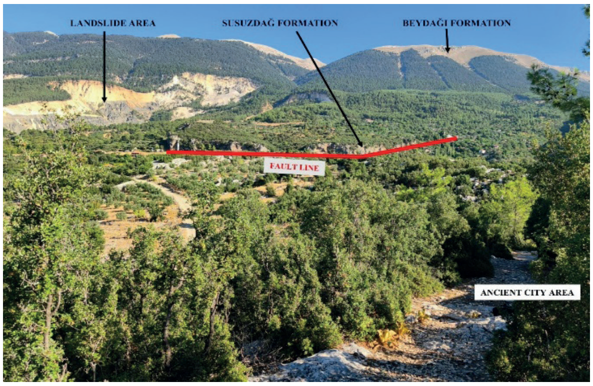

Figure 15. Ancient road leading to the acropolis, Ernez village and landslide-fault lines.

Şekil 15. *Akropolise giden antik yol, Ernez köyü ve heyelan-fay hatları.*

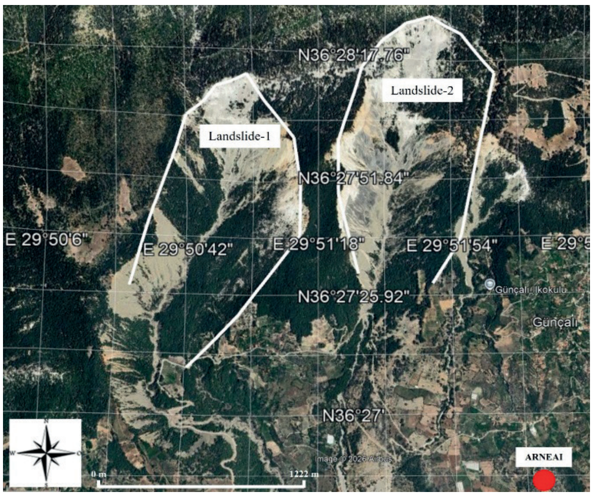

Figure 16. Landslide areas located NW of Ernez (Günçalı) village.

Şekil 16. *Ernez (Günçalı)kuzeybatısındaki heyelan alanları.*

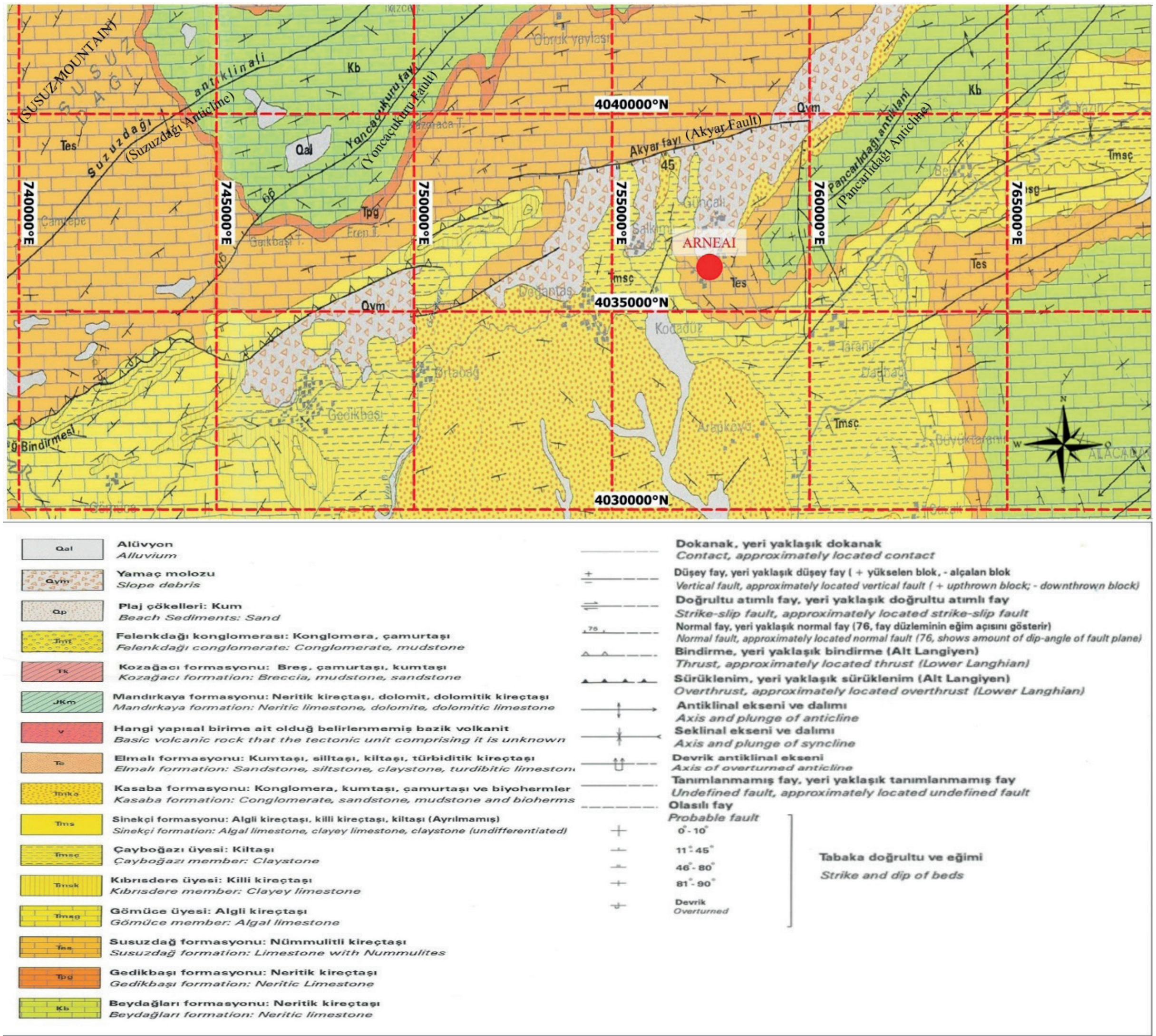

Figure 17. Geological map of Ernez (Günçalı) village and surroundings at a scale of 1:100,000 (Şenel and Bölükbaşı, 2010).

Şekil 17. *Ernez (Günçalı) köyü ve çevresinin 1:100.000 ölçekli jeoloji haritası (Şenel ve Bölükbaşı, 2010).*

To the north and northeast of Ernez village, landslide zones developed due to SW-NE trending dip-slip normal faults associated with the extension of the Beydağları Mountains (Figure 16). In the center of Ernez (Günçalı) village, no major landslide activity is observed, apart from minor movements. The Akyar Fault (Figure 17), a dip-slip normal fault identified by MTA (General Directorate of Mineral Research and Exploration) (Şenel and Bölükbaşı, 2010) passing north of Ernez (Günçalı) village, shaped the current topography; the southward movement of its hanging wall caused subsidence of the southern section (Şenel and Bölükbaşı, 2010).

Faults exhibiting characteristics similar to the Akyar Fault played a significant role in the construction of the ancient city, particularly regarding the fortification walls surrounding the acropolis. While fortification walls encircle the acropolis to the north, west, and south, construction terminates in the southeast, where a natural rock face formed by faulting serves as a defensive barrier.

BUILDING MATERIALS IN ARNEAI

Fortification Walls – Architectural Structures – Rock Tombs – Building Stone Quarries

The ancient city of Arneai was built from construction stones with similar characteristics. Studies show that limestone extracted from local (in-situ) rocks was used for both the fortification walls and the architectural structures (Figure 18).

The use of local materials in city construction is confirmed by the presence of five quarries identified in studies conducted throughout the city in 2025 (Figure 19). Once quarrying operations ceased, it is suggested that these areas may have been repurposed as residential spaces or workshops in later phases (Figure 19).

Preliminary assessments based on the DEM created as a result of the first season's work in 2025 reveal a logistical relationship between the identified quarries and the architectural sectors in the area. The resulting routes suggest that the quarries were strategically positioned along corridors that minimized transport difficulty and energy expenditure. Preliminary findings indicate that large architectural concentrations closely coincide with these optimized access corridors, and that quarrying operations and urban development are integrated within a coordinated resource management system. This analysis highlights the role of topography in shaping construction logistics and urban planning in Arneai.

Furthermore, shallow marine limestones (Susuzdağ Formation) containing Eocene nummulite and other fossils were used for all rock tombs and building materials, including sarcophagi (Figure 20).

As observed in Figures 18 and 19, the building blocks are generally yellowish-beige and cream-colored, although some blocks appear whiter or light beige (Figure 21).

The presence of two distinct colors suggests that the building stones were sourced from different quarries or from two separate strata within the same quarry. Quarry locations identified during the 2025 archaeological surface survey of Arneai were mapped (Figure 19). While some ancient cities built on limestone formations, such as Phaselis, possess a central main quarry in addition to local extraction sites, no such main quarry has yet been identified for Arneai (Öner, 2020).

Figure 18. Structure S (A) and southern fortification wall (B).
Şekil 18. *S yapısı (A) ve güney sur duvarı (B).*

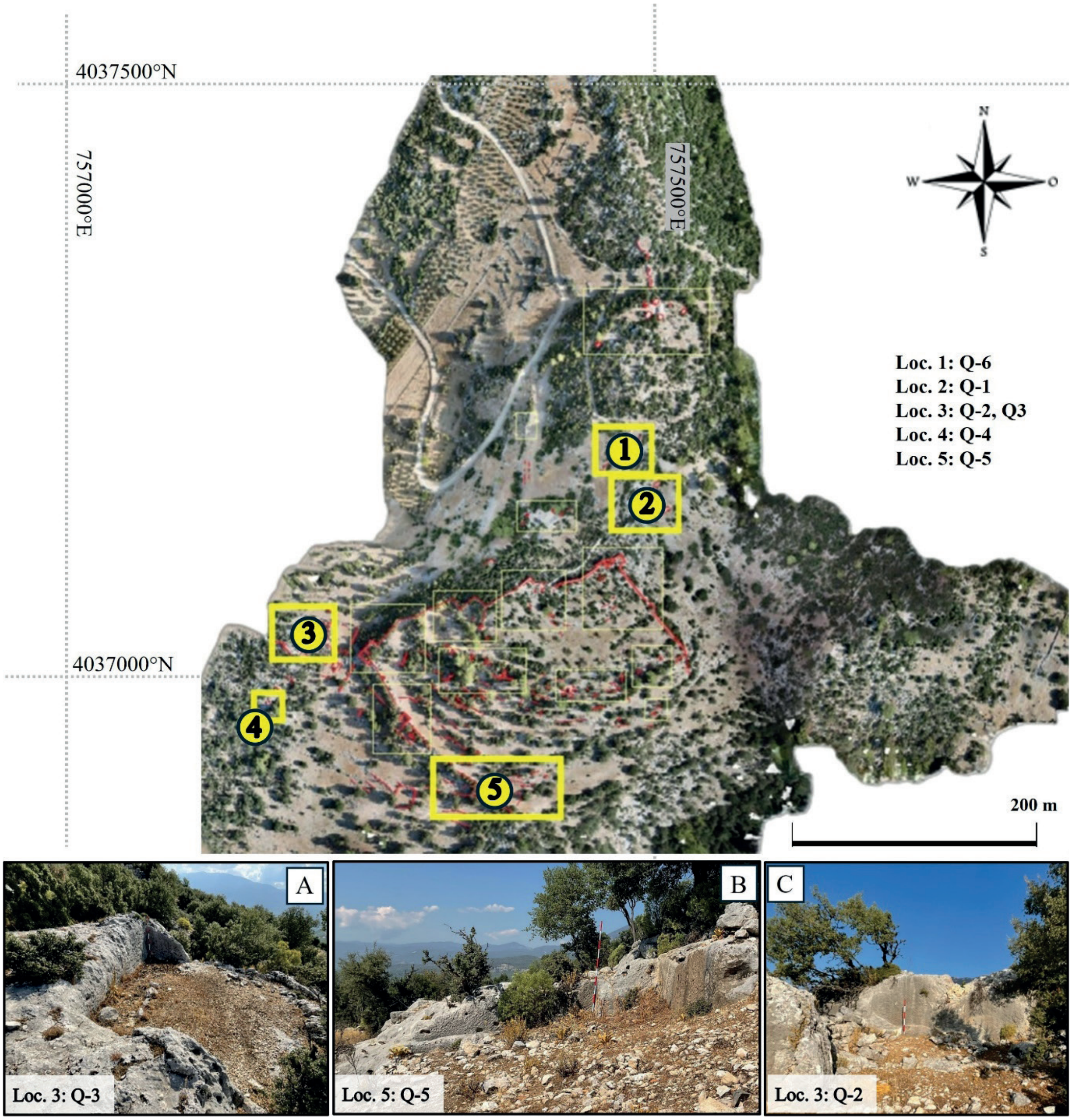

Figure 19. Building stone quarries in the ancient city of Arneai (ED-50, 6 degree). ***A, B*** & ***C*** Examples of building stone quarries.

Şekil 19. *Arneai antik kentinin yapı taşı ocakları (ED-50, 6 derece).* ***A, B*** *ve* ***C****) yapı taşı ocaklarından örnekler.*

Fossils such as nummulites observed in the limestones of the Susuzdağ Formation characterize a shallow, nearshore marine environment. These limestones developed in warm, shallow waters bordering the Tethys Ocean during the Eocene (56 to 34 million years ago). Due to their partial clay content, they are relatively soft and easily workable. Occurring in extensive zones spanning kilometers, particularly in the southern Taurus Mountains, these limestones remain highly valued in the modern marble trade.

Figure 20. Nummulites fossil in limestone (fossil is approximately 1 cm long).

Şekil 20. *Kireçtaşı içerisinde nummulites fosili (fosil uzunluğu yaklaşık 1 cm'dir).*

Figure 21. Whitish-beige block (with chisel marks).

Şekil 21. *Beyazımsı-bej blok (murç izleri ile birlikte).*

Slags

Some metal slag was observed during surface surveys of the ancient city of Arneai. It was generally found scattered in areas in the western and southern parts of the acropolis (Figure 22).

The slag fragments, approximately 3-4 cm in size, are iron-rich residues resulting from ore smelting.

Figure 22. Mining slags.

Şekil 22. *Maden cürufları.*

Chemical analysis is necessary to determine which ore was extracted from these residues. However, it is possible to say that it is not copper. This is because copper slag, in its residual form, oxidizes over time, giving rise to green stains, commonly known as "copper rust." This color was not observed in the material found in the area. Only iron oxide (limonitization) formations, resulting from the thermal decomposition of pyrite (FeS_2), an iron sulfide mineral found together with the metal minerals used, were observed. It is considered possible that these are residues of galena (PbS) ore used in lead production. The absence of dense slag deposits suggests that this was likely a small-scale trial furnace or experimental operation rather than a major production site.

Soil materials

Ceramic materials produced from clay, scattered throughout almost the entire ancient city of Arneai, were also examined. These were identified as fragments of tiles, bricks, amphora fragments, ceramic earthenware fragments, and pipe fragments. Further mineralogical (optical microscopy and XRD) and chemical analyses (major element and, if possible, isotope chemistry) are required to determine the provenance of these fragments and the location of the clay sources. However, preliminary observations of color differences suggest that production utilized materials from at least two separate clay sources, or distinct strata within the same source. The yellow-to-light-green artifacts found in the area are composed of low-iron, carbonate-rich montmorillonite and illite clays. Due to their structure, these clays are unsuitable for fine ware production and were instead used for construction materials such as tiles and bricks. The distinctly brown and reddish finds identified during the survey are composed of iron-rich clay material (Figure 23).

The color variations in the finds identified during the Arneai surface survey may stem from the use of ferrous versus non-ferrous clay layers within the same pit, or materials extracted from entirely different quarries. In this case, the material could have been taken from the area surrounding the ancient city or from outside. The area from which the yellowish ceramic materials were taken is thought to be clay formations (clay formations under the caves) in the "caves" location north of the ancient city (Figure 11).

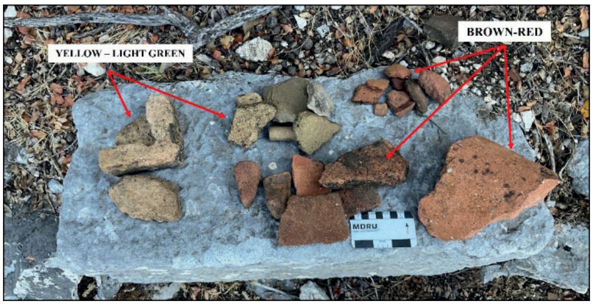

Figure 23. Soil material residues.
Şekil 23. *Toprak materyali kalıntıları.*

These interpretations should be considered preliminary geoarchaeological hypotheses pending future archaeometric analyses such as pXRF, XRD, petrographic thin-section studies, and isotopic characterization.

RESULTS

As the archaeological surface surveys of the ancient city of Arneai were conducted over a short period in September 2025, the findings presented here are preliminary. Despite the limited duration, the use of modern technology provided significant data to guide future research.

Drone photography enabled the creation of detailed orthophotos, and coordinates for all identified structures were mapped (ED50). The integration of high-resolution DEM and slope analyses revealed a deliberate urban planning strategy. The concentration of approximately 70% of the architectural remains on 10–15° slopes proves that the city was a highly organized urban center that utilized advanced terracing to adapt to the rugged Lycian terrain. This integration of aerial and field data facilitated the identification of quarries and watchtowers, where viewshed analyses confirmed a comprehensive visual command over the entire valley and the surrounding territorium.

During the archaeological surface survey in the ancient city, observations of building stones indicate that no material was brought from outside the city (eclectic). All building stones were produced from fossiliferous limestones belonging to the Susuzdağ Formation in the area where the ancient city is located. The spatial proximity of the five identified quarries to the primary construction zones suggests an optimized logistical strategy aiming to reduce transport costs, indicating a sustainable resource management system.

The presence of some remnants of mining slag on the surface also suggests that there may have been at least some small ore smelting furnaces in the ancient city.

Fieldwork revealed that the earthen materials (e.g., bricks, tiles, amphoras, pottery, etc.) found on the surface generally have two colors. This color variation can be attributed to the use of two different clay types as raw material sources.

Preliminary investigations of the caves in the İnler locality of Ernez village, located outside the city's acropolis and foothills but within the territory boundaries, indicate that they naturally formed through karst processes. However, traces of human enlargement were also found in some caves. Furthermore, the positioning of cisterns and drainage networks demonstrates sophisticated hydrological adaptation to the terrain's morphology.

Beyond descriptive topographic visualization, the integration of spatial-statistical and landscape archaeological analyses enabled a more comprehensive interpretation of the relationship between geology, topography, and urban organization in Arneai. Kernel density estimation, viewshed analyses, and spatial comparisons between quarry zones, necropolis sectors, and architectural remains collectively suggest that the settlement developed through a highly adaptive spatial strategy shaped by geomorphological constraints, resource accessibility, and defensive requirements. These preliminary findings confirm that the urban fabric of Arneai was not randomly distributed throughout the landscape, but rather reflected a deliberate and environmentally dependent planning system.

Data obtained from archaeological surface surveys of the ancient city of Arneai, conducted over a short period, allow us to make a preliminary assessment of the city's geology. However, archaeological excavations and material analyses to be carried out in the coming years will provide much more detailed information about this city, which has not been extensively studied before.

GENİŞLETİLMİŞ ÖZET

Orta Likya Bölgesi'nde (GB Türkiye) yer alan Arneai antik kenti, Batı Toroslar'ın en az araştırılmış arkeolojik alanlarından biri olmaya devam etmektedir. 19. yüzyılda Texier ve Spratt gibi gezginler tarafından bahsedilmiş olmasına rağmen, 2025 yılında başlayan çok disiplinli yüzey araştırmalarına kadar sahada sistematik bir kazı veya inceleme yapılmamıştır. Bu çalışma, antik kentin yerleşim stratejisini, litolojik tercihlerini ve tektonik konumunu anlamlandırmak amacıyla arkeolojik bulguları, jeoloji ve CBS (Coğrafi Bilgi Sistemleri) verileriyle bütünleştirmeyi amaçlamaktadır.

Araştırmada yüksek çözünürlüklü bir CBS altyapısı kullanılmıştır. Havadan fotoğraf çekimleri, DJI Mavic Pro İHA (Drone) kullanılarak, 60-80 m irtifada ve %60 bindirmeli stereografik uçuş rotalarıyla gerçekleştirilmiştir. Elde edilen veriler, Agisoft Metashape Professional yazılımı ile işlenerek, standart uydu görüntülerinin çözünürlük sınırlarını aşan 3 boyutlu ortofotolar ve yoğun nokta bulutları oluşturulmuştur. Tüm mekânsal veriler, 1/25.000 ölçekli ulusal topoğrafik haritalarla uyum sağlaması amacıyla ED50 6 derecelik jeodezik datum sistemi kullanılarak koordinatlandırılmıştır. Yapılan yeniden sınıflandırılmış eğim analizleri, tespit edilen mimari kalıntıların %70'inin, alt yapı maliyetlerini optimize eden 10°-15° derecelik orta eğimli yamaçlarda yoğunlaştığını göstermiştir. Jeolojik değerlendirmeler, arazi gözlemlerine ve Beydağları otoktonu litostratigrafi adlamalarına dayandırılmıştır.

Arneai, Batı Toros tektonik kuşağı içerisinde yer alan Beydağları otoktonu üzerinde konumlanmaktadır. Stratigrafik istif, başta Susuzdağ Formasyon'u (Eosen) olmak üzere denizel karbonatların egemenliğindedir. Bu birim, yüksek dayanımı ve karstik potansiyeli ile karakterize edilen, nummulites ve alveolina fosillerince zengin neritik kireçtaşlarından oluşmaktadır (Şekil 9).

Bölge, tektonik olarak Susuzdağ Bindirme'si ve bunu izleyen Pliyosen faylanmalarıyla şekillenmiştir. Arazi çalışmaları sonucunda üç ana fay yönelimi belirlenmiştir: KD-GB, KB-

GD ve D-B. Özellikle Akyar Fayı ve ilişkili eğim atımlı normal faylar, kentin topoğrafyasını doğrudan belirlemiştir. Akropolis, fay kontrollü doğal kaya dikliklerinin güneydoğu sektöründe doğal bir savunma hattı oluşturduğu stratejik bir noktaya yerleştirilmiştir; bu durum insan yapısı sur duvarlarına olan ihtiyacı bu bölgede azaltmıştır. Akropolis ve gözetleme kulelerinden gerçekleştirilen Görünürlük (Viewshed) analizleri, yerleşimin tüm vadi ve hinterland üzerinde tam bir görsel hakimiyete sahip olduğunu ve stratejik bir savunma ağının kurulduğunu kanıtlamıştır.

Kentin kuzeyindeki "İnler" mevkii gelişmiş bir karstlaşma sergilemektedir. Geçirimli kireçtaşı ile geçirimsiz kil ara seviyelerinin temas yüzeylerinde, süzülen suların birikmesiyle doğal mağaralar oluşmuştur (Şekil 11). Bu mağaraların antik dönemden itibaren barınma veya depolama amacıyla insan eliyle genişletildiği tespit edilmiştir. Ayrıca, CBS analizleriyle belirlenen yaklaşık 1 km çapındaki polye benzeri çöküntü alanı (Şekil 13A-13B), antik kentin tarımsal ve hidrolojik yönetimini etkileyen olgun bir karstik peyzaja işaret etmektedir.

Arazi gözlemleri, kentin tamamen yerel (in-situ) litolojiler kullanılarak inşa edildiğini doğrulamaktadır. Kent toprakları içinde beş adet antik taş ocağı tespit edilmiştir. En yaygın kullanılan malzeme, anıtsal yapılarda ve kaya mezarlarında işlenebilirliği ve estetik görünümü nedeniyle tercih edilen Susuzdağ Formasyonu'na ait krem-bej renkli kireçtaşlarıdır.

Belirlenen taş ocağı alanları ile nekropol sektörleri ve mimari kalıntıların dağılımı arasındaki mekânsal karşılaştırma, taş çıkarım bölgeleri ile mezar mimarisi arasında güçlü bir mekânsal ilişki olduğunu göstermektedir. Özellikle kaya mezarları ve nekropol alanlarının, işlenebilir Susuzdağ kireçtaşlarının doğal olarak yüzeylendiği kireçtaşı mostraları ve taş ocağı alanları çevresinde yoğunlaştığı görülmektedir. Bu mekânsal örüntü, jeolojik uygunluğun ve taş temininideki kolaylığın, yerleşim içerisindeki mezar ve mimari alanların organizasyonunun belirlenmesinde önemli bir rol oynadığını düşündürmektedir.

Akropolis yakınlarında bulunan 3-4 cm boyutundaki demir zengini cüruf parçaları, arkeometalurjik faaliyetlerin ön belirtisidir (Şekil 22). Cüruflarda "bakır pası" gözlenmemesi, bu malzemenin demir veya kurşun (galen) cevheri eritme işlemi sonucu oluştuğunu; yoğun yığınların olmayışı ise büyük bir üretim merkezinden ziyade deneme amaçlı küçük ölçekli ocakların varlığını düşündürmektedir. Ayrıca, iki farklı renkteki (sarımsı-yeşil ve kırmızımsı-kahverengi) seramik buluntuları, en az iki ayrı kil kaynağının kullanıldığını göstermektedir.

Arneai 2025 yılı yüzey araştırması, jeolojik miras ile antik kent planlaması arasındaki derin bağı ortaya koymaktadır. Kentte tespit edilmiş olan sarnıçların suyun yerçekimi ile dağıtımını kolaylaştıracak yüksek kotlara, drenaj kanallarının ise eş yükseklik eğrilerine paralel yerleştirildiği görülmektedir. Savunma için fay dikliklerinin stratejik kullanımı, yapı üretimi için fosilli kireçtaşlarının işletilmesi ve karstik yer şekillerinden faydalanılması, bu ön sonuçlar, gelecekte yapılacak sistematik kazılar ve detaylı arkeometrik analizler için sağlam bir bilimsel temel oluşturmaktadır.

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