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Geological Studies as a Source of Data on the Maritime Trade between the Cimmerian Bosporus and the Mediterranean in the 1st Millennium BCE

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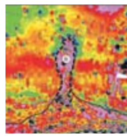


Abstract *– This article contains the results of an analysis of the stone material found during the geological research of one of the hydrotechnical structures in the Phanagoria harbor (Taman peninsula, Black Sea). Because of the lack of building stone deposits on the peninsula, large amounts of stone had to be imported. The goals of our research were: 1) to determine the volume of stone used during the construction of the 'Eastern Pier'; 2) to identify the type of rock and its provenance; 3) to estimate the scale of stone import to Phanagoria. It has been established that about 50 % of stone material came from the Crimean-Caucasian region, while the rest of it originated in other regions, including the Southern coast of the Black Sea and the Aegean islands.*

Inhalt *– Dieser Beitrag stellt die Ergebnisse einer Analyse des Steinmaterials vor, das während des geologischen Surveys archäologischer Befunde im Hafen von Phanagoria (Taman-Halbinsel, Schwarzes Meer) gefunden wurde. Da auf der Halbinsel kein zum Bauen geeigneter Stein ansteht, mussten große Mengen von Steinen importiert werden. Die Ziele unserer Forschung waren: 1) das Volumen des für den Bau der ‚Östlichen Mole' genutzten Steinmaterials zu bestimmen; 2) die Gesteine und ihre Herkunft zu bestimmen; 3) den Umfang des Steinimports nach Phanagoria zu schätzen. Es wurde festgestellt, dass etwa 50 % des Steinmaterials aus der Region Krim/Kaukasus kommt, während der Rest aus anderen Regionen stammt, darunter der Südküste des Schwarzen Meers und der ägäischen Inseln.*

For many centuries Phanagoria, a city founded by Greeks in the 6th century BCE on the South coast of the Taman Bay (Black Sea), was an important transit center on the trade route from the Mediterranean to Azov Sea (fig. 1). The city did not possess a comfortable natural harbor, but, undoubtedly, had a developed port structure. Because of the Black Sea level's transgression, the coastal part of the city and its port were submerged and covered by marine sediments. A magnetic marine map of the water area opposing the central part of the city shows a linear anomaly created by a large rock congestion. The following research is dedicated to the study of the composition of stone that creates this congestion.

Research methods

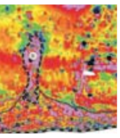
The open stone settings in Phanagoria's water area are only visible near the coast, up to 20 cm depths. Outside of the wave-breaking area all objects are hidden under loose sand, clay and silt deposits as well as perennial seaweed blanket, making any visual survey of the seabed uninformative. Since the area of the submerged part of the city and the port's water area is at least 0,15 km^2, the chance of successfully studying the city and the port by laying survey pits randomly is too low. Because of that, the main focus of underwater research in Phanagoria is on remote sensing methods – hydromagnetic survey[1] and acoustic profiling[2].

Hydromagnetic survey is the most efficient method of the Phanagorian water area research. Its efficiency is conditioned by the fact that the Taman Peninsula consists mostly of clay and has a very low natural magnetic background. On this background, the objects with stronger magnetic characteristics (volcanic, plutonic or metamorphic rocks) as well as ceramics produce significant anomalies[3]. A cameral analysis of magnetic data allows the researchers to find

1 Кузнецов – Ольховский 2016.

2 Olkhovskiy et al. 2017.

3 Lanza – Meloni 2006; Смекалова и др. 2007.



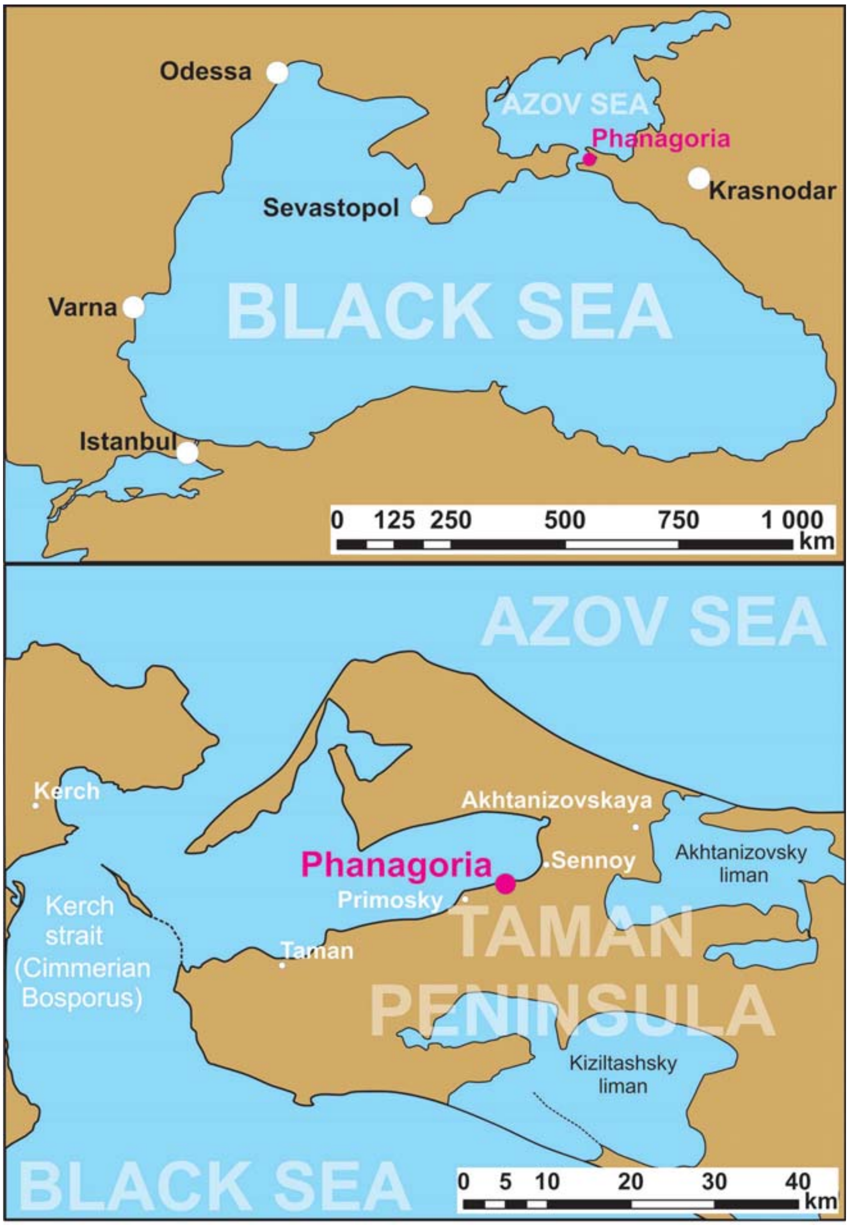


Fig. 1: Phanagoria on regional and local maps

anthropogenic objects under a layer of seabed deposits. For example, this way clusters of ballast stones can be found[4].

Hydromagnetic survey in the water area of Phanagoria has been done in two ways:

– On depths up to 0,9 m – with a *GEM GSM-19WG* gradiometer at a scale of 1:200 or 1:100, with an interprofile interval of 2 m and a 0,2 second frequency in vertical and horizontal gradient modes. Standard deviation of survey is ±0,31 nT. The total area of survey is 0,046 km^2. Gridding is done using the *GSM-19WG* OEM navigation receiver.
– On depths of more than 0,9 m – with a *MarineMagnetics SeaSpy-2* magnetometer at a scale of 1:500, with an interprofile interval of 4 m and a 0,25 second frequency. Standard deviation of survey is ±0,3 nT. The total area of survey is 0,698 km^2. Gridding is done using a *Trimble SPS 461* rover in RTK mode, which received corrections through radio from a *Trimble R7* base.

During the magnetic survey data post-processing carried out using the *Geosoft Oasis Montaj* software the natural daily variation of magnetic field read by a *MarineMagnetics Sentinel* magnetovariational station were taken in consideration.

In the eastern part of the magnetic field map a linear anomaly about 190–200 m long and 60 m wide, perpendicular to the shore, was found (fig. 2, A). On the western edge of this anomaly a branch, about 100 m long and 35 m wide, can be seen. The contours of the anomaly are outlined along the maximum gradient border, which corresponds to the abrupt change from pink to blue on the map.

A structural seabed deposit research in the area of the linear anomaly showed a large stone mound. Its artificial composition is attested to by its geometry and the lack of natural processes that would be able to form such an object in the Taman Bay. We suggest that this mound is what remains of some port structure – either a pier or a breakwater. In this article the mound will be referred to as 'The Eastern Pier'.

In the western part of the magnetic map another large linear anomaly, also positioned perpendicular to the shore, can be seen (fig. 2, B). Probing and pitting showed that this anomaly is also formed by a large artificial mound ('The Western Pier'). So far, we cannot specify when it was built or what was it used for.

The positioning of the two mounds is not random – they were erected on the tips of naturally-formed cuneal sand spits bulging into the sea and limiting the internal water area of the harbor. Convex positive magnetic anomalies stretched along the shore are created by clusters of heavy minerals (including highly magnetic magnetite and ilmenite[5]) in the ancient breakwater area.

In order to study the construction and composition of the 'Eastern Pier' we have excavated two pits:

4 Boyce et al. 2009.

5 Lanza – Meloni 2006.

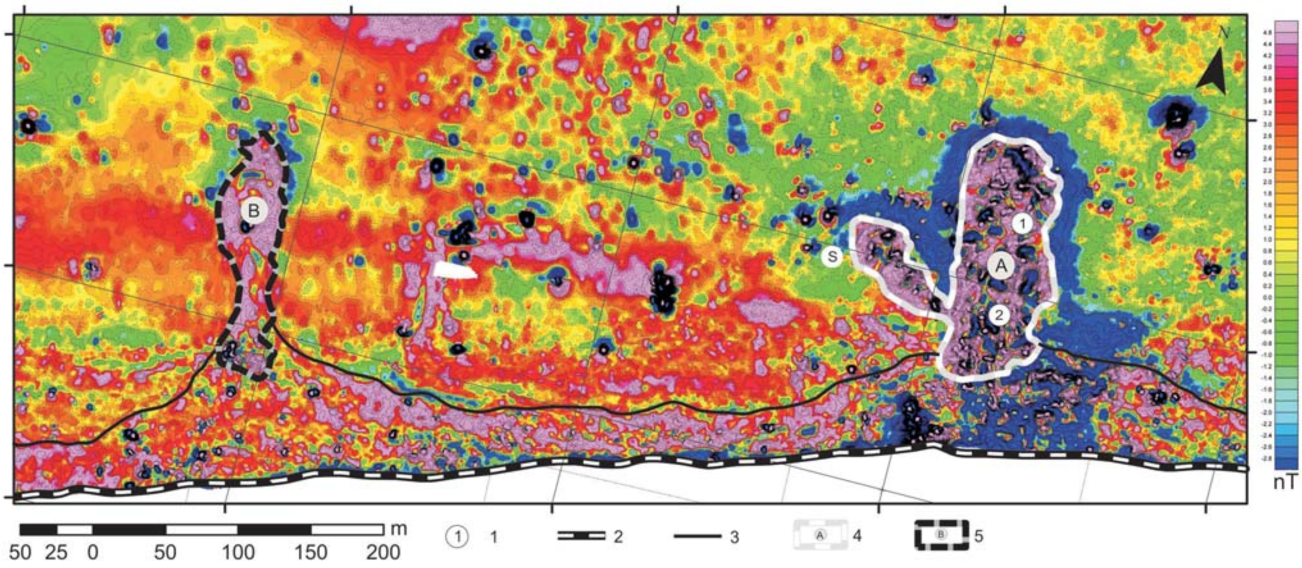
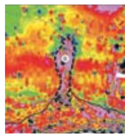


Fig. 2: Map of the local part of the Phanagorian water area magnetic field. 1: pits #1 and #2 – 2: modern coastline – 3: paleoshore line – 4: 'Eastern Pier' contour (A) – 5: 'Western Pier' contour (B) – S: excavation near the 1st century BCE ship



– Pit #1, 2 × 2 m, was excavated in the seaward part of the 'Eastern Pier' on the depth of 1,4 m. The depth of the pit is 2,5 m below the modern sea bottom (fig. 2, point 1);

– Pit #2, 2 × 2 m, was excavated in the coastal part on the depth of 0,5 m. The depth of the pit is 2,5 m below the modern sea bottom (fig. 2, point 2).

The stone material from the pits was carried onto the shore and studied.

All the stone shards that are more than 12 cm in length were measured in three dimensions and divided in four groups based on the level of their roundness: rounded (completely smooth, ellipsoid pebbles), half-rounded (all the surfaces are smooth, but the shape is different from ellipsoid), angularly rounded (partially angular edges) and unrounded (all the surface is angular). It was also separately noted when a stone was broken on purpose, for example, in case of half of a rounded ellipsoid pebble.

All the stone shards were divided in six groups based on their rock composition: limestones, sandstones and siltstones, volcanic rocks, plutonic rocks, metamorphic rocks and monomineral quartz aggregates. Such division allows a comparison of material sampling from pits #1 and #2 based on the rock composition.

Pit #1 sampling consists of 450 samples. Pit #2 sampling consists of 510 samples (330 from the bottom part of the mound and 180 from its top part). Altogether the sampling used to characterize the composition and construction of the 'Eastern Pier' consists of almost one thousand samples.

Apart from the 'Eastern Pier' stones, a rock ballast of the ship that sank in Phanagoria's harbor in the 1st century BCE was studied. It amounts to 100 samples (fig. 2, point S) as well as 500 pebble samples found in the seabed deposits near the ship.

An important characteristic for volcanic and plutonic rocks is their chemical composition. Because of that, a geochemical research was carried out on 58 samples from pit #1. For all 58 samples, a petrogenic oxide content was defined (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, CaO, MgO, Na_2O, K_2O, P_2O_5, LOI), and for 38 of them also a diffuse element content (Li, Rb, Sr, Y, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, Bi, Th, U, Sc, Ti, V, Cr, Mn, Ni, Cu, Zn, Zr, Nb, Hf, Ta).

The process of petrogenic oxides definition was carried out in the laboratory for mineral substance analysis of IGEM RAS in Moscow using the X-ray spectral fluorescent analysis method on a PANalytical Axios^{mAX} wavelength dispersive XRF spectrometer according to the NSAM VIMS 439-RS technique. The LOI parameters were defined according to the NSAM VIMS 118-H technique[6]. The lower limit of detection is 0.05–0.1 % massive.

The definition of diffuse element content was carried out using a mass spectrometry method with inductively coupled plasma (ICP-MS) on a high-definition mass spectrometer with double focusing, Element-2, in the laboratory of the Department of Geochemistry of the Geological Department of the MSU with standard sintering methods sorting[7].

Pre-published data and geochemical database GEOROC[8] was used to make a comparison with geochem-

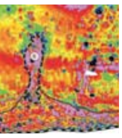
6 Методика № 439-РС 2010.

7 Bychkova et al. 2017; Bychkova et al. 2018.

8 <http://georoc.mpch-mainz.gwdg.de/georoc/>.

Fig. 3: A carcass boulder from pit #1, carcass section

Fig. 4: Filling pebbles from pit #1, 1,0–1,5 m below the modern sea bottom



ical parameters of rock from other regions.

Factual data

A description of the 'Eastern Pier' construction and composition

The upper surface of the stone mound in pit #1 is almost equal to the modern sea bottom level. Section thickness is 2,5 m. In pit #2, a stone mound 1,9 m thick is overlayed by an argillaceous mound 0,3–0,35 m thick, as well as by sea deposits 0,3 m thick. Cut thickness is 2,5 m. The bottom tier of 'Eastern Pier' stones in both pits lays on white quartz sand with no stone or ceramic shards present.

The 'Eastern Pier' construction is fundamentally similar in both pits: it is made of large rounded boulders 50–70 cm in diameter, which create the structure's carcass (fig. 3). The space between the boulders is filled with smaller heterogenous pebbles (fig. 4). The filling is often done using deliberately broken rock fragments (pit #1), a mix of rock fragments, ceramic shards and clay (pit #2), or argillaceous sand without rock material (pit #2). The large boulders will be further referred to as 'carcass', and the material between them as 'filling'.

Pit #1 cut description.
The large carcass boulders in pit #1 vary in size from 40–65 mm to 300–310 mm, with an average size of 160 × 114 × 70 mm (249 examples). The carcass is characterized by different levels of rounding: the unrounded fragments make up to 57 % of the stones (141 pieces), the angularly rounded fragments 17 % (43 pieces), the half-rounded fragments 15 % (36 pieces) and the fully rounded fragments 11 % (27 pieces). It is worth noting that the bottom 0,5 m is composed of unrounded angular fragments, which are overlaid by well-rounded boulders, while in the top part the unrounded angular blocks are present again. The filling is done using the unrounded (and rarely half-rounded) fragments of carbonate (limestone and marl) and, to a lesser degree, other (volcanic and slate) rock from 10–20 mm to 100–120 mm in size (209 pieces studied). Deliberately broken rounded stones are often present in the carcass's filling. It is likely that the builders of the 'Eastern Pier' had to break bigger stones in order to fill in the space between the carcass's boulders.

Both the carcass and the filling consist mainly of carbonate rock – aphanite and organogenic-detrital limestones and marls (49 % in the carcass, 47 % in the filling), effusive rock is less common – basalt, andesite, dacite and rhyodacites (27 % in both the carcass and the filling), granites (3 % in the carcass, 1 % in the filling), sandstone, mostly polymictic with carbonate cement (16 % in the carcass, 12 % in the filling). Metamorphic (chlorite and sericite schists) and metasomatic rock can be seen rarely.

Pit #2 cut description.
In pit #2, the 'Eastern Pier' is overlayed by two more layers: an argillaceous mound and contemporary sea deposits.

The argillaceous mound, 0,3–0,35 m thick, consists of sandy loam and clayey sand, brownish in color, non-layered with large amounts of ceramic and rock shards, small rounded volcanic pebbles (1–3 cm in diameter) and clam shells. Rocks, shells and ceramics are positioned vertically or inclined in the layer, without any order, which is not characteristic for natural deposit formations[9]. This is why we consider this mound to be an artificial layer of the 'Eastern Pier' and not a naturally formed deposit.

The argillaceous mound is overlayed by seabed deposits (loams and sandy loams) not more than 0,3 m thick. The gray sandy homogenous sandy loams are indistinctively layered, with multiple small shells (1–3 cm in size) mixed in. There are hardly any ceramic shards in them, some pebble and gravel are present. Because of its density

9 Shrock 1948.

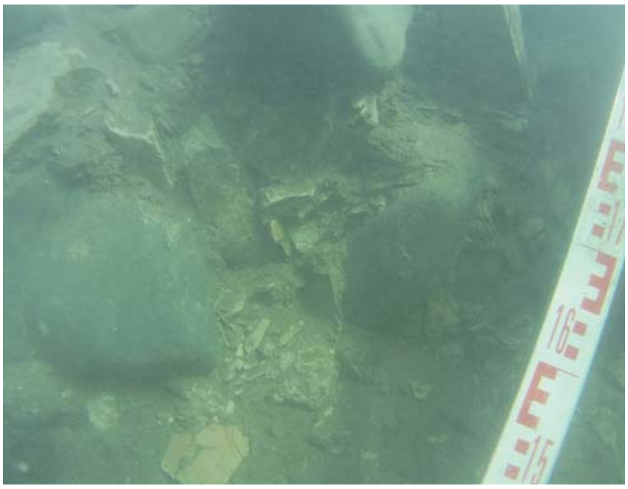
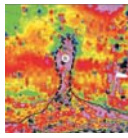


Fig. 5: Dark boulders (carcass) and a mixture of crushed rock, clay and ceramic fragments (filling) in pit #2

Fig. 6: Metamorphic rock pebble from the cluster (point S)



and coherency, this layer holds the subvertical slope firmly and is easily separated from the more coarse and friable bulk layer below it. Bivalve mollusks shells are positioned bulge up horizontally along the layering. So we consider this layer to be natural sea deposits and not an artificially poured layer. Rock material in this layer is sporadic, so it was not studied or measured.

The rock material of the argillaceous mount has an average size of 97 × 67 × 34 mm (180 pieces). The unrounded fragments make up 45 % of the material (81 pieces), the angularly rounded 27 % (48 pieces), the half-rounded 22 % (39 pieces), and the rounded 7 % (12 pieces). The majority of fragments is limestone (68 %); volcanic rock (13 %), sandstone (9 %) and metamorphic rock (6 %) are also present.

The construction of the 'Eastern Pier' stone mound in pits ## 1 and 2 is very similar. The carcass found in pit #2 consists of large fragments with an average size of 182 × 122 × 75 mm and a varying degree of roundness (530 pieces). 63 % of fragments are unrounded, 12,1 % angularly rounded, 12,4 % half-rounded and 12,7 % rounded.

The carcass of the 'Eastern Pier' consists mainly of volcanic rock (49 %), mostly dark-green basalt and basaltic tuff. Second largest component is limestone of various types (40 % of stone material). Other types of rock make up a relatively small percentage: 6 % sandstone, 3,5 % metamorphic rock, less than 1 % plutonic rock.

The differences in pits' stratigraphy are pointed out in the different filling material. In pit #2, the space in carcass is filled with small rock fragments, in the upper part of the layer – with viscous gray loam (**fig. 5**). Closer to the underlying layer the filling is done with clean fine-grained quartz sand and, less often, argillaceous sand. The underlying layer, just like in pit #1, is represented by white and beige fine-grained and close-grained quartz sand with no rock or ceramic fragments.

The 'Eastern Pier' construction period

During the pits ## 1 and 2 clearing, a large amount of archaeological ceramic fragments was found in the filling of the 'Eastern Pier'. In pit #1, 16 fragments were found. Among these fragments, Thasos, Chios, Heraclea, Mendes and Knidos amphorae from the 5th–4th century BCE were identified. In pit #2, 733 fragments, related to two different chronological horizons, were found. In the filling, Chios, Lesbos, Mendes, Thasos, Heraclea, Sinope, and Kos amphorae, as well as red-figure pottery, all dating to the 5th–3rd century BCE, were identified. In the overlaying artificial layer, Crimean globular amphorae, dated to the 8th–11th century CE, were identified.

We think that, during the 'Eastern Pier' construction, ceramic fragments were used to fill the space between the carcass boulders. That means that these fragments can serve as a chronological marker indicating the construction period.

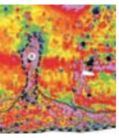
Ballast stone cluster description

Apart from the large anomalies, the magnetic map of the water area of Phanagoria also shows numerous local anomalies. A selective check showed that many of them are formed by clusters (1–2 m in diameter, 10–20 cm thick) of rounded and half-rounded volcanic or limestone pebbles. The majority of pebbles has a size from 2–3 cm to 8–10 cm.

During the excavation of a part of sea bottom West of the 'Eastern Pier' (**fig. 2, point S**), single layer clusters (0,5–1 m in diameter, up to 10 cm thick) of well-rounded pebbles were found in the 5th–3rd century BCE layers (**fig. 6**). The pebble size varies from 1–2 cm to 10–12 cm. 50 % of pebbles are limestone (including 7 % organogenic bryozoan-algal), 19 % sandstone, 15 % volcanic rock (basalt and andesite), 8 % white quartz, and 7 % metamorphic rock (light-gray gneisses).

The specificity of these clusters is the presence of gneiss and quartz, which cannot be seen in the 'Eastern Pier' filling.

In the upper layer of seabed deposits (point S), dating to the 1^{st} millennium CE, the composition ratio changes abruptly: 83 % limestone (including 45 % organogenic bryozoan-algal), 4 % volcanic rock, and 0,8 % metamorphic rock (fig. 7).



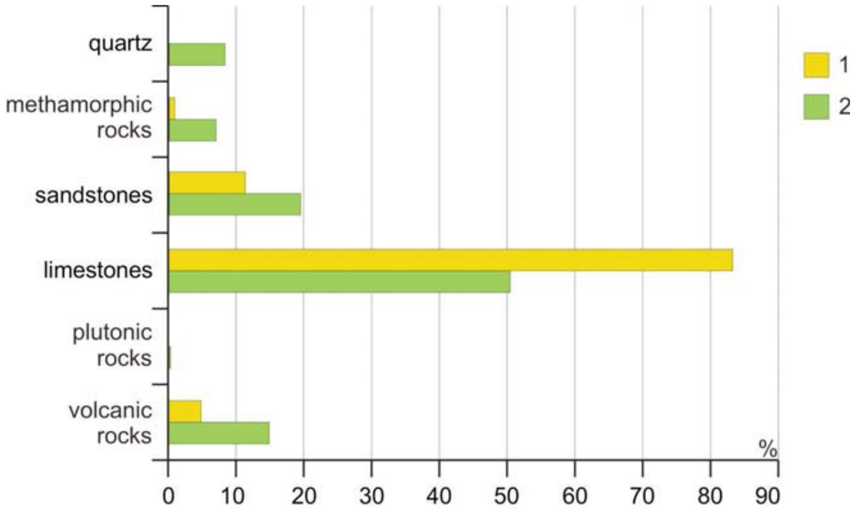


Fig. 7: Rock composition distribution in pebble clusters. 1: in layers dating to I millennium CE – 2: in layers dating to I millennium BCE

Discussion

The size and volume of the structure

Geometric size of the anomaly on the magnetic map, confirmed by an underwater research, define the size of the stone mound to be 190–200 m long and 60 m wide. The vertical thickness of the mound opened by pits is 2,5 m, but it is still hard to know, whether the modern width and height of the mound are identical to the size of the structure during its functioning period. We have reasons to suggest that the surface part of the 'Eastern Pier' was partially disassembled and used as building material for later buildings.

At the same time, large boulders and pebble was virtually not used in construction of a dock dating to the 3^{rd}– 6^{th} century CE located 300 m to the West of the 'Eastern Pier'[10].

We estimate the volume of the remaining part of the stone mound to be 30.000 m^3. Taking into account the spaces between the rocks, the approximate weight of the mount is 36.000–45.000 tons. In our calculation, it is taken into account that the spaces between the stones make up 25–40 % of the mound's volume with an average rock density 2 g/cm^3. The density is defined as an average value between limestone (1,5–2 g/cm^3) and volcanic/plutonic rock (2,7 g/cm^3 and up).

Rock material transportation method

Origins of rock material used in the 'Eastern Pier' construction is an important question. Usually, the majority of building material comes from the nearest quarries, but there are no rock outcrops near Phanagoria, only clay and sand with thin lenses of iron ore and siderite. Thus, all the rock material came to Phanagoria from outside and, undoubtedly, by sea.

We have originally suspected the stone which came to Phanagoria as ship ballast to be used during hydrotechnical construction. As it is known, ship ballast is divided into non-unloadable (constant weight) and unloadable (rotative weight)[11]. Dispersed clusters of various rock in ancient port water areas are considered to be discarded ship ballast[12]. There are many local pebble clusters in the water area of Phanagoria, and they cannot be explained by natural processes, because pebbles of 2–10 cm in diameter are moved by rivers or seasonal streams, which are not found on the nearby coast.

Another feature pointing to the oversea origins of the pebbles is the large presence of volcanic rock, marble and gneiss in the pebble clusters (fig. 7). The pebble cluster material differs largely from the material of the 'Eastern Pier' in size and composition: there is hardly any gneiss in the 'Eastern Pier', while it makes up a significant percentage of clusters; there are almost no rounded pebbles in the 'Eastern Pier' filling but there is a lot of unrounded and angularly rounded. We think that the pebble clusters appeared in the water area of Phanagoria as a result of continuous discard of rotative ship ballast, which was done in order to minimize the sea gauge of ships before entering the shallow harbor or before loading.

A size comparison of stones from the 'Eastern Pier' with the constant ballast of the ship that sank in the Phanagoria port approximately in the mid-1^{st} century BCE[13] shows their significant difference (fig. 8). The average size of ballast stones is 93 × 68 × 44 mm, that of the 'Eastern Pier' stones is 160 × 114 × 70 mm. The ballast consists of:

- unrounded fragments (16 %);
- angularly rounded fragments (14 %);
- half-rounded fragments (34 %);
- rounded fragments (37 %).

The 'Eastern Pier' consists of:

- unrounded fragments (57 %);
- angularly rounded fragments (17 %);
- half-rounded fragments (15 %);
- rounded fragments (11 %).

[10] Kuznetsov – Olkhovskiy 2014.

[11] Buckland – Sadler 1990; McGrail 1989.

[12] Bar 2018; Morhange et al. 2016; Boyce et al. 2009.

[13] Кузнецов – Ольховский 2016.

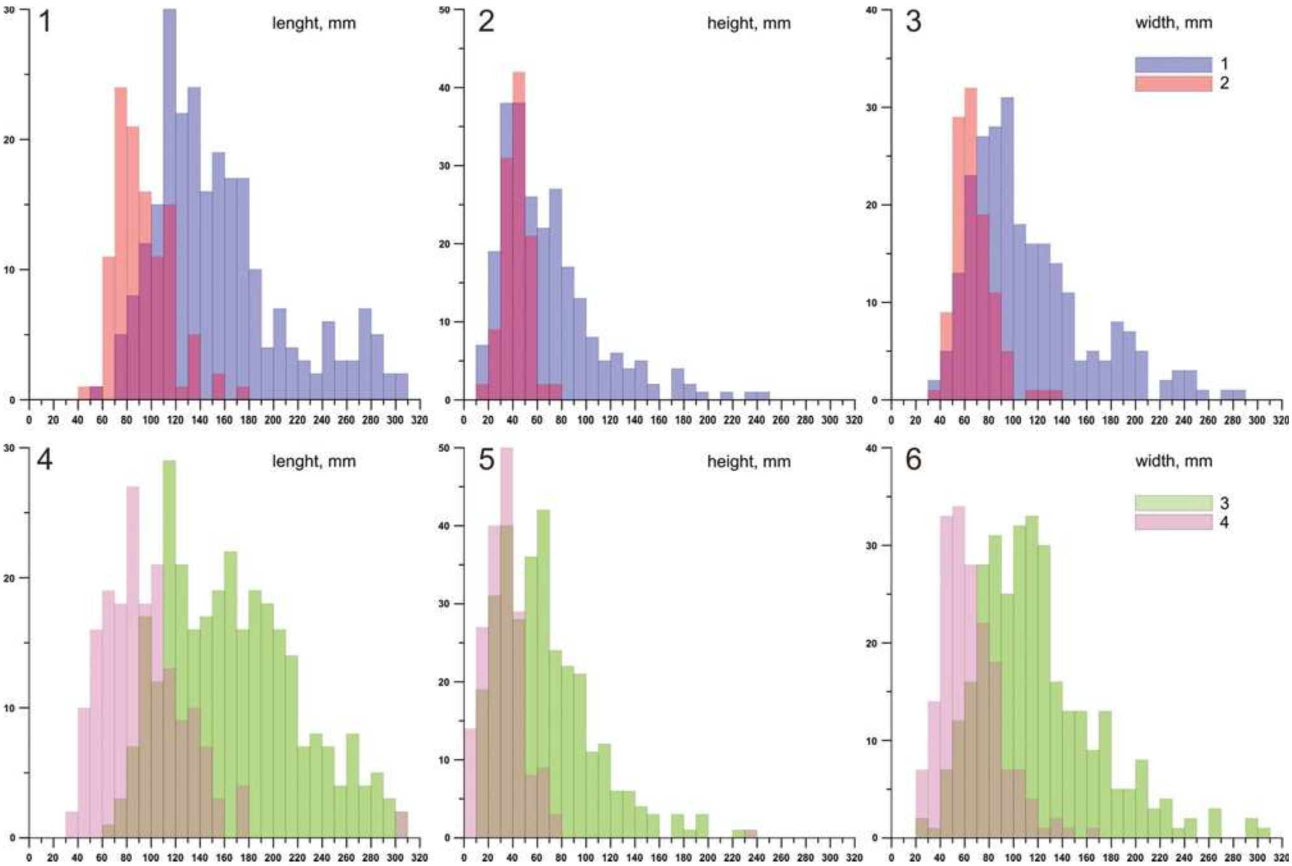


Fig. 8: Fragment size bar chart. 1, 2, 3: fragments from pit #1 (1) and ship ballast stones (2) – 4, 5, 6: fragments from pit #2, from the argillaceous mound over the 'Eastern Pier' (1) and from the 'Eastern Pier' carcass (2)

So, the rounded stones are a majority in the ballast, and the intentionally split ones in the 'Eastern Pier' filling. The stone material from the ship's constant ballast and its variable ballast (pebble clusters) are not similar to the filling material of the 'Eastern Pier': the ballast consists of smaller rounded or half-rounded pebbles, while almost all the stones used in the 'Eastern Pier' filling are unrounded and intentionally split. This allows a conclusion that the rock material used in the 'Eastern Pier' construction is not a recycled ship ballast.

The 'Eastern Pier' projected weight is very significant. It is not hard to calculate that in order to transport 40.000 tons of rock one would need to make hundreds, or even thousands voyages by sea. Obviously, a procurement of such an amount of rock as a secondary ship cargo would take a significant amount of time, and the construction of the 'Eastern Pier' of Phanagoria would take a couple of decades. That is why we think that the import of rock material needed for the 'Eastern Pier' construction in Phanagoria was a large-scale and relatively short transport operation, and the rock was transported as primary cargo.

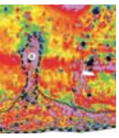
An analysis of rock material was carried out to allocate possible building periods in the 'Eastern Pier' construction chronology. In the upper part of the pit #1 cut, carbonate rock (limestone and marl) is dominant (fig. 9, 1), while at a 1,5 m depth volcanic rocks content increases sharply (35–40 %). The change in rock composition is gradual, which does not allow the allocation of separate stages or long breaks in the 'Eastern Pier' construction.

The rock constitution of the 'Eastern Pier' carcass and its filling is very similar: the difference in ratio of various rocks does not exceed 5 % (fig. 9, 2). This allows a suggestion that intentionally split boulders were used as filling, or that a significant amount of pre-split rock was brought to Phanagoria along with the boulders. The appearance of characteristic volcanic rock (basalt, tuff, andesite) extracted from pits ## 1 and 2 is so similar that there is no doubt as to them originating from the same source.

The rock composition from pit #2 is very diverse (fig. 10): the stone mound consists mostly of imported volcanic rock, while limestone from the Kerch Peninsula is dominant in the argillaceous mound. One should think that the argillaceous mound was constructed in a period when Phanagoria could not procure suitable rock for hydrotechnical construction.

Rock material supply sources

A detailed study of a wide sample selection of the 'Eastern Pier' rock material allows not only to determine the rock type, but also to identify the possible rock provenance. Crimean-Taman region is notable for its complex and specific



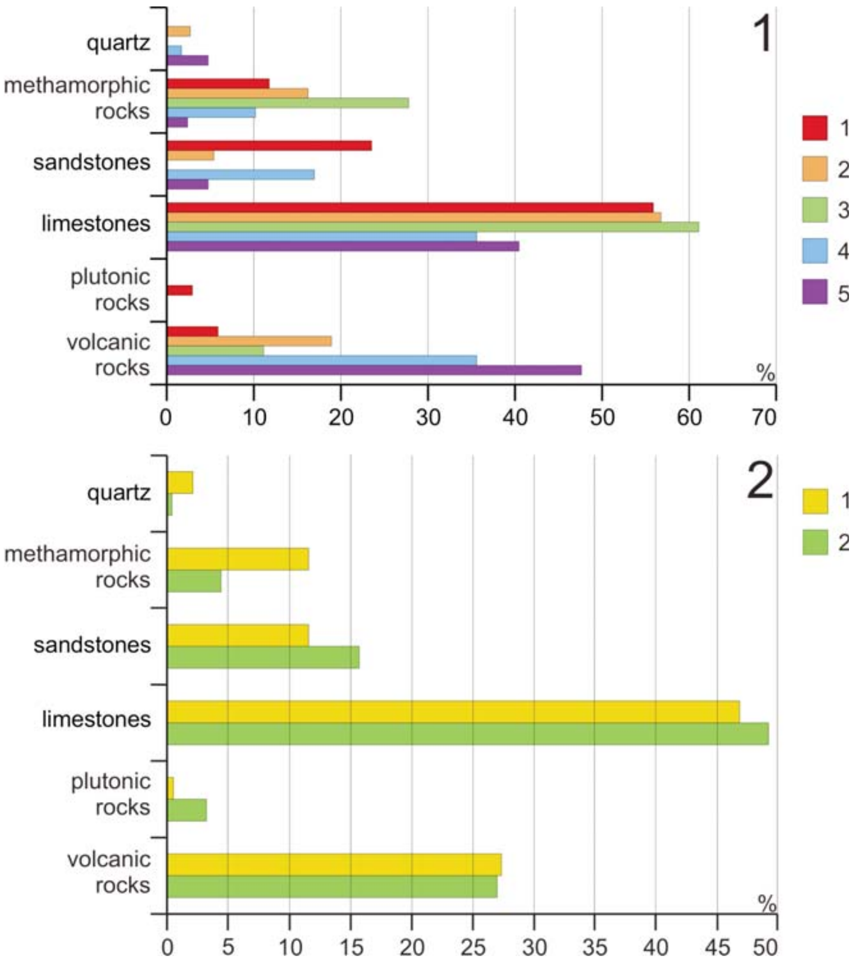


Fig. 9: Rock composition distribution in the 'Eastern Pier' fragments from pit #1. Diagram 1: filling fragments composition distribution. 1: 0–0,5 m from surface interval – 2: 0,5–1,0 m from surface interval – 3: 1,0–1,5 m from surface interval – 4: 1,5–2,0 m from surface interval – 5: 2,0–2,5 m from surface interval. Diagram 2: carcass and filling rock composition comparison. 1: filling rock fragments – 2: carcass rock fragments

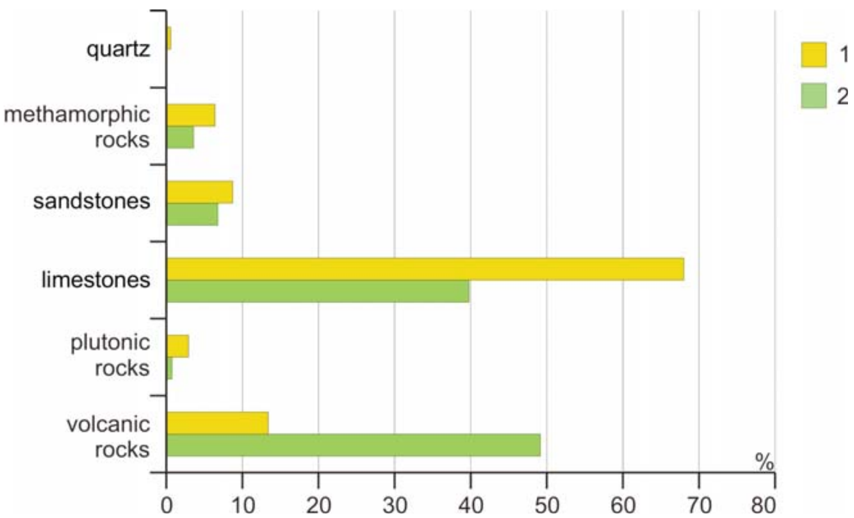


Fig. 10: The 'Eastern Pier' carcass boulder composition distribution from pit #2: 1: from the argillaceous mound – 2: from the stone mound

structure, which allows to make certain conclusions about the rock sources. Up to 50 % of 'Eastern Pier' material is carbonate rock, primarily organogenic clastic bryozoan-algal limestone, characteristic of the region's Miocene deposits. They form reefs near the Western Caucasus shore, near Central Caucasus, less often in the Eastern parts of Northern and Central Caucasus[14] and near the Kerch Strait shores[15]. Thus, at least 50 % of the 'Eastern Pier' material comes from the Kerch Strait coastline or from the Kerch Peninsula.

Among various limestone, gray and dark-gray aphanite homogenous limestone with conchoidal fracture, characteristic of Crimea's Jurassic strata[16] can be seen. But, as no organic remains were found in them, a precise geographic binding is virtually impossible.

Volcanic rock is represented by basalts, andesites and, less so, dacites, trachydacites and trachyriodacitis. Volcanic samples from the 'Eastern Pier' have a low degree of secondary changes, specific porphyry structures, crystal zoning and geochemical features characteristic of marine volcanism environments: reduced Nb, Ta, Zr and Hf content and increased Pb, U, Th and Ba content. The low degree of secondary changes shows that they were formed on a seacoast in a contemporary volcanic region.

The sources of volcanite closest to Phanagoria are the Kara Dag Mountain and the Fiolent regions in Crimea. The volcanites of Cape Fiolent and the adjacent shelf are basalts, trachybasalts and trachyandesites[17]. The Cape Fiolent rocks have a low rare-earth element content (fig. 11, red lines). However, almost all (fig. 11, yellow, green and purple lines) basalt and basaltic andesite samples from the 'Eastern Pier' have a high light rare-earth

[14] Белуженко 2015.

[15] Гончарова – Ростовцева 2011.

[16] Nikishin et al. 2015.

[17] Промыслова и др. 2014; Шнюкова 2018.

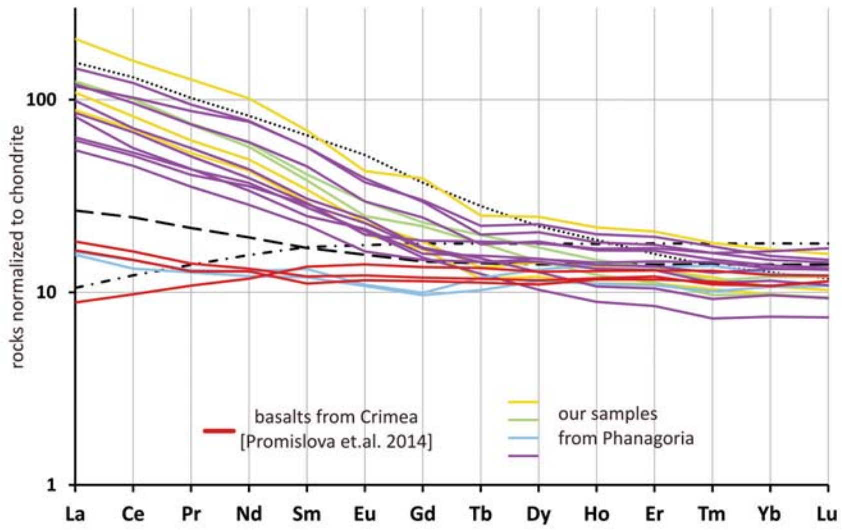


Fig. 11: Diagram of rare-earth elements distribution in the volcanic rock of Phanagoria and from Crimea

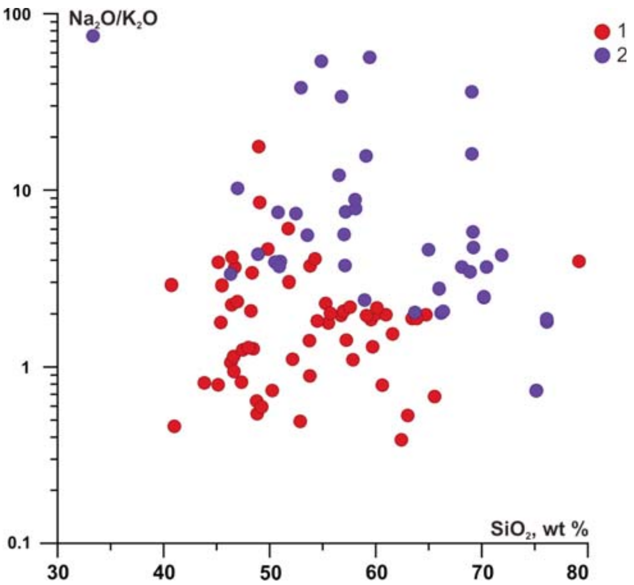


Fig. 12 (l.): SiO_2-Na_2O/K_2O diagram showing the 'Eastern Pier' (1) and the Kara Dag Mountain region (2) rocks

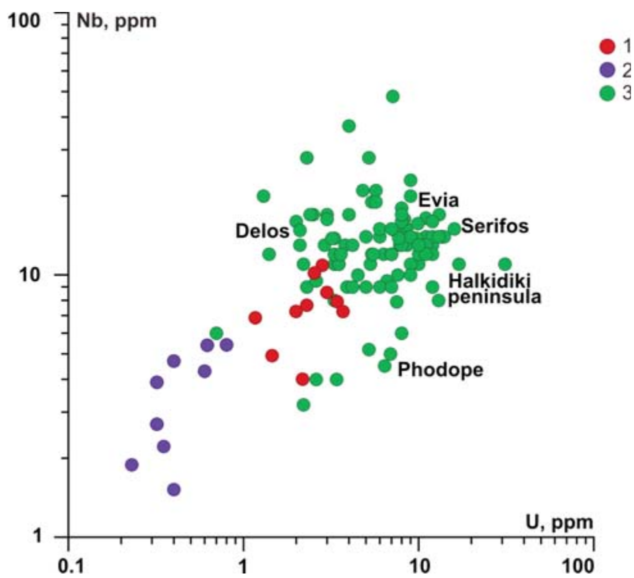
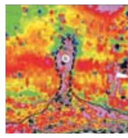


Fig. 13 (r.): U-Nb diagram for granites of Phanagoria (1), Crimea (2) and the Aegean Sea (3). Delos, Evia, Serifos, Phodope, and Halkidiki peninsula are the regions and mountain ranges of the Aegean Sea where granite massifs are present.



element content (La, Ce, Pr, Nd, Sm), and, thus, are fundamentally different from the Cape Fiolent volcanites (fig. 11). So, the volcanic rock of the 'Eastern Pier' does not come from the Fiolent region.

The volcanic rock from the Kara Dag Mountain region is represented by middle Jurassic and early Cretaceous rhyolites, dacites, andesites and basalts[18]. However, the volcanic rock from the 'Eastern Pier' has a lower SiO_2 and a higher K_2O content. This is easily seen on the SiO_2-Na_2O/K_2O diagram (fig. 12), where the points marking the Crimean volcanic rock are put separately from those marking the volcanic rock of the 'Eastern Pier'. So, the 'Eastern Pier' volcanites do not come from Crimea.

To summarize, we can state that 30 % of rock volume (12.000–15.000 tons) of the 'Eastern Pier' is imported from distant territories where modern volcanism is present. The closest region like that is the Aegean Sea area and Northern Turkish coastline, where volcanism with similar geological characteristics is present.

The 'Eastern Pier' plutonic rock is represented by biotite granites. All the granites found come from the same mountain range, according to their petrographic and geochemical features. On Pearce's classification charts[19] their points match the marine volcanism granite fields. Plutonic massifs of Crimea, situated on the seacoast (Ayu-Dag, Qastel and Kosh-Kaya mountains) are composed of rock with different content (gabbro and diorite)[20]. The few Crimean granites[21] have a specific adakite composition and are very different from the 'Eastern Pier' granites. Granitoids are not found in other Crimean regions or on the Black Sea coast of Caucasus[22].

Since the supply of volcanic and plutonic rock to Phanagoria was, most likely, organized from the same region, we have compared the 'Eastern Pier' granitoids to the

[18] Meijers et al. 2010.

[19] Pearce 1996.

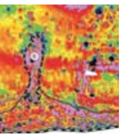
[20] Спиридонов и др. 1990.

[21] Гусев – Гусев 2014.

[22] Nikishin et al. 2015.

Aegean Sea and the Southern Black Sea coastline granitoids by ASI alumina index, K_2O, U and Nb content (fig. 13). It was determined that the Cycladic (Aegean Sea) and Trabzon Area (Northern Turkey) granitoids have the closest geochemical characteristics[23]. We suggest that the plutonic rock could have been brought to Phanagoria from those provenances.

Conclusions



The 'Eastern Pier' is, most likely, what is left of a port structure built in the 5^{th}–4^{th} centuries BCE. We interpret the multiple pebble clusters found in seabed deposits in the water area of Phanagoria as discards of loadable ship ballast. Significant differences in size and roundness degree allow us to state that the 'Eastern Pier' was built not from a recycled ship ballast, but from a specially brought rock material with a total weight of at least 35.000 tons.

Up to 50 % of the 'Eastern Pier' volume (18.000–20.000 tons) is limestone from the Kerch Strait coast or the Kerch Peninsula. Up to 27 % of the 'Eastern Pier' volume (9.500–10.500 tons) is volcanic rock, most likely from the Aegean Sea area or from the Northern Turkish coastline. Up to 5 % of the 'Eastern Pier' volume (1.750–2.000 tons) is plutonic rock, most likely from the Cyclades (Aegean Sea).

In the building foundations in the ancient city of Hermonassa, located 20 km from Phanagoria, large rounded boulders of plutonic and volcanic rocks were found[24]. They are very similar in content, size and appearance to the rock material of the 'Eastern Pier' at Phanagoria. It is likely that deliveries of high-quality building stone from the Mediterranean were done not only to Phanagoria, but to other Bosporan cities as well.

The fact that such large amounts of rock were transported over a distance from 400 km (Northern Turkish coastline) to 1700 km (Cyclades) widens our understanding of scale, intensity and product range of sea trade between the Mediterranean and the Cimmerian Bosporus in the 1^{st} millennium BCE.

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