



*Maritime Archaeology Graduate Symposium 2019*  
29<sup>th</sup> – 31<sup>st</sup> March 2019 Short Report Series.

doi: <https://doi.org/10.33583/mags2019.01>

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## **Provenance Studies of the Ballast Stones found in the North Bay of Tel Dor, Israel**

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### **Abstract**

An ancient trade ship's stability was influenced by presence of ballast stones, loaded and unloaded varying with cargo densities. The result of this variability is an ancient harbour's collection of discarded and saved ballast stones, with origins reflecting a ship's route. Both Fourier Transform Infrared Spectroscopy (FTIR) and thin-section petrography were used jointly on ballast stones collected from the North Bay of Tel Dor, Israel, to identify their origins. This is a new approach to study geological artifacts.. With proposed origins of non-local ballast stones, further assertions of seafaring interactions between Tel Dor and surrounding regions can be made.

### **Key words**

*Petrography, Fourier Transform Infrared Spectroscopy, Ballast Stones, Levant Coast, Trade Routes*

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### **Introduction**

Tel Dor has been an invaluable source of ancient finds due to its status as a heavily active maritime centre in the eastern Mediterranean with this status spanning many periods (Raban, 1995; Arkin-Shalev, 2015). The ancient tel is located with a view of the open sea and is composed of four natural bays, a rare occurrence along the Levantine coast. Of these bays, the North Bay of Tel Dor seems to offer the most shelter, making it an ideal location for long term and intensive usage and is therefore the subject of high interest to archaeologists exploring the connectivity of the eastern Mediterranean region as a whole.

Departing from the tracing of foreign material culture intended for trade purposes, this study investigates materials left by ships that came to the harbour with these foreign imports, specifically ballast stones utilised on ancient seafaring vessels. In locations of high cargo traffic, where goods were loaded or unloaded, there will inevitably be ballast stones that were either discarded or supplied to these trade ships accordingly.

This study on the composition of geological artifacts used Fourier Transform Infrared (FTIR) spectroscopy and petrography in tandem, FTIR being selected due to its ease of use in regards to sample testing and its relative newness to the arsenal of laboratory methods utilised in the world of archaeology (Weiner, 2010:71), while petrography was selected because of the extensive information of a specimen it can reveal and its tried-and-true history in geological studies. By examining the compositions of the ballast stones found in the North Bay of Tel Dor and assigning provenience to the stones, ancient voyage routes can be inferred based on where they were collected and loaded onto trade vessels. By reconstructing voyage routes, the significance of Tel Dor's harbour to the inter-connectivity network of the eastern Mediterranean can be examined with more depth. Not only will these ballast stones be a rich source of information of this specific harbour's trade network, but they can also add to the larger base of knowledge of ancient ballasting practices and harbour functions overall, as previous ballast studies have focused on examples associated with shipwrecks and not on discarded piles within an ancient harbour.

In order to fully understand the scope of the ballast stones collected at Tel Dor and the research methods utilised to achieve this goal, the following questions were posed in this study:

What is the provenience of the ballast stones?

What does the provenience of the ballast stones reveal about the maritime routes leading to Dor?

Can the characteristics of the ballast stones indicate any information on ancient ballasting practices?

How can FTIR spectroscopy be integrated with petrography in order to execute geological studies?

## **Ballast Stones**

### ***Ballast Purpose***

Ballast stones were used in ancient times as a way to improve stability of a ship during its voyage. Instability of a ship is dependent upon the vertical distance between the metacentre and the centre of mass of a loaded ship. If the centre of mass is below the metacentre, this will allow the ship to right herself up to a certain angle of the heel. The addition of ballast will allow the ship's centre of mass to be lowered to remedy any tilting thus making the ship more seaworthy (Fig. 1) (McGrail, 1989: 354-357). When loading cargo onto a ship, ballast was placed on top of soft materials, known as dunnage, in order to prevent damage to the ship herself and the precious cargo. Once the ship was loaded, additional ballast was added according to the weight needs of that particular shipment to ensure a safe voyage (Gorzalczany, 2006: 67). As the voyage of a ship progressed and cargo of varying weight and densities was taken on and off board, ballast stones were accordingly added or removed at each port. Due to these practices, it would stand to reason that each port would contain a heterogeneous assembly of ballast stones reflecting the ship's route.

### ***Selecting Ballast***

According to inscriptions dated to 210 BC, there was a corporation of *saburraii*, or ballastmen, who were specialists working in ports with knowledge of specific practices in regards to acquiring ballast for arriving and departing trade ships (Casson, 1995: 370). The ballast stones collected could come from a number of sources. Stones loaded on to ships at a specific port tended to be of a local nature as these would have been the most readily available. However, in areas of particularly high traffic, the ballastmen would have kept and reused ballast coming off of foreign vessels, resulting in designated piles of “good ballast” within the port that would have been heterogeneous in origin (Gifford, 2008: 40-41). These ballastmen and their subsequent ballast piles were vital in the maintenance of a high traffic port, as unsystematic unloading could cause shallowing of a previously functional harbour (Nantet, 2008: 518-519). In order to fulfill the task of supplying ballast to outgoing vessels, the ballastmen would have had specific criteria in selecting stones for use as mobile ballast, versus stones that would have remained on the vessel as permanent ballast to provide the ship with a minimum level of stability (Lamb, 1988: 5-6). Smaller (hand held), river-worn stones with sufficient density were selected because they could remain relatively stable during voyage so as to not ruin the balance of the ship or inadvertently damage the hull and cargo during transport.

## **Tel Dor**

Tel Dor is located along the northern coast of Israel, with a view of the open sea, and is composed of four natural bays – a rarity along the very straight Levantine coast, as can be seen on the map (Fig.2). This allowed Dor to establish a longstanding relationship of the town to maritime connectivity with the entire eastern Mediterranean. Of these bays, the North Bay of Tel Dor seems to offer the most shelter, making it an ideal location for long term and intensive usage during ancient times (Raban, 1995; Shalev, 2015) and is therefore the subject of high interest to archaeologists exploring the connectivity of the eastern Mediterranean region as a whole.

### ***Tel Dor North Bay Elements***

Though this study focuses on ballast presence as a by-product of a high traffic harbour instead of ballast associated with a shipwreck, dating the deposition of the ballast stones is difficult. In order to understand these ballast piles in the context of the harbour, we must look at how and when the area itself was used.

Early underwater surveys found large quantities of pottery and stone anchors from the Persian and Hellenistic periods, with some broken parts dating to the Roman and Byzantine periods as well, suggesting maritime activity throughout all four.

The North Bay has a high concentration of harbour installations, especially in the southern part of the bay, indicating intense seafaring and trade activities in this area. There are about a dozen marble columns (Fig. 3), theorized by Raban to be a pergola or medieval jetty made of about a dozen various sized and spaced Roman marble column drums (Raban, 1995: 289). They were originally thought to be a quay, but recent studies have interpreted them as part of a loading site associated with the shipping of tel remains (Shalev, 2015: 152-153). There are also three washing channels built, it is assumed, to prevent sand from entering the bay and to maintain depth for the bay’s functionality. Each of these three channels was used during a different time period and

corresponds to a different sea level of the Mediterranean, with the latest being quarried after the Byzantine period (Fig. 3) (Raban, 1995: 291-296).

The main structure of this area is rectangular complex (Fig. 3) that was dated to the Roman period and stood until the Byzantine period and has been interpreted as a public storage space as well as a side boundary to an inner harbour for small freighters and fishing boats (Raban, 1995: 289-295).

## **Materials and Methods**

### ***Materials***

The main difficulty in the collection of ballast materials from this harbour setting is distinguishing between ballast and naturally deposited stones, as well as between construction materials that fell into the harbour's waters and those that had been used as ballast. Four main criteria were used in selecting samples for this study. In regards to shape, prior to this study it was theorized that stream-worn stones (Fig. 4) were preferred for ballast because the lack of sharp edges reduced the chance of damage to the hull of the ship or the cargo she carried (Lamb, 1988: 5). Since it has been assumed the ballast stones within the piles found at Tel Dor's North Bay are mobile ballast (Lamb, 1988: 6), this study focused on hand-sized stones of weights conducive to being handled by a single person. These criteria allow for the inclusion of samples that were used as ballast as a secondary purpose, specifically discarded stone cargo, like architectural components like floor or roof tiling (Fig. 5). Lastly, due to the abundance of *kurkar*, a specific type of beach rock in the area, this would have been the most quarried stone of the harbour and the kind most commonly used in ballasting ships leaving Dor. Working under this assumption, any stone that did not appear to be *kurkar* would be deemed non-local and could give evidence of trade routes to Dor. The sampling is therefore purposefully skewed to target possible non-local ballast. Despite this, some samples collected for this study did end up being *kurkar* due to misidentification during collection. A total of 37 samples was collected from six different underwater and coastal sites within the southern harbour (Fig. 6).

### ***Field Methods: The underwater samples***

The underwater samples were collected from an identified ballast pile that is associated with large hewn stones previously found in the 2013 underwater survey of the North Bay (Yasur-Landau and Arkin, 2013: 27-28). The underwater ballast of Dor North Bay was collected on three different occasions. During the first week of February in 2015, the ballast pile surrounding hewn stones was visited and nine samples were collected underwater. In November 2015, seven more samples were collected from this area. Finally, in February 2016, eight samples surrounding a line of hewn stones identified at a later survey of the North Bay were collected underwater.

### ***Field methods: The coastal stones***

In December 2014, a ballast stone was found in between two hewn architectural blocks at the approximate shoreline. In February 2016, a ballast pile was also identified on the coast and eleven samples were collected. The nature of the pile and extent of the pile containing stones of non-local appearance and show shape and size consistent with ballast stones. The eleven stones were chosen for their non-local appearance, but also as an

attempt to capture the different types of rock features based on macroscopic and exterior characteristics in the field. Photos were taken of the samples *in situ*, each specimen was given a basket number, and the GPS point corresponding to the collection place was noted as the stones were collected.

## **Laboratory Analyses**

### ***Macroscopic analysis***

Specific measurements of the samples were recorded and the general shapes of the stones classified using Stoops' chart of sphericity and roundness (Stoops, 2003: 52, fig. 4.14), and the interior colors classified using Munsell's soil color chart (Munsell Color, 2000). For texture classification the stones were broken to reveal interior appearance and their macroscopic textures recorded. Once the interior was exposed, variabilities in texture, color, or other elements of appearance were recorded (Fig. 7).

### ***Fourier Transform Infrared Spectroscopy (FTIR spectroscopy)***

FTIR spectroscopy is a valuable tool in characterising inorganic materials based on the molecular structure of minerals (Weiner, 2010: 91). The technique of FTIR spectroscopy employs shining light beams of multiple wavelengths at a sample and measuring the absorption of each wavelength by the sample. Elevated absorption of light for each wavelength is shown as 'peaks' in the spectra produced. Specific peak values and sets of peaks are characteristic of different minerals (Fig. 8). This method sets itself apart from X-ray diffraction in that it is able to identify both crystalline and amorphous minerals, both of which are expected when looking at geological and archaeological samples.

### ***Petrographic Analysis***

Petrography is one of the most widely used and relied-upon methods for mineral and rock classification. By visually identifying mineral composition as well as characteristics of appearance, rock formation history can be inferred, thus providing a clue to the origin of the stone. For this study, photos were collected of each sample to create an overall picture of the sample's characteristics, including the overall nature of the sample and close-ups of details distinguishing the rock type (Fig. 9). The combination of the previously described FTIR spectroscopy and rock petrography is therefore complementary and allows for the most accurate and quick determination of rock type. The sample AH-1 shown in Figures 7-9 was determined to be *kurkar* beachrock that is local to the Tel Dor coast.

### ***Provenience Studies***

Following the rock type classification and mineral identification from macroscopic, spectroscopy, and petrographic analyses, possible origins of the specimens could be postulated. Geological maps of the eastern Mediterranean coasts and their respective rock types were consulted to find possible sources of the ballast found at Tel Dor (Table 1). Assuming that the outcrops recorded during modern times are consistent with those exposed in ancient times when Tel Dor was an active harbour, outcrops found along the southern (Israeli) and northern (Syrian) Levantine coast, as well as in Cyprus and Turkey, describe possible sources of the foreign ballast stones found within the Northern Bay.

## Origins

Rock types examined in this study include sedimentary rocks, here in white, totaling to 20 specimens, igneous rocks in light grey, totaling four specimens, and metamorphic rocks in dark grey, totaling to 13 specimens. To summarize, the assemblage of rocks used for this study reflects a mixture of both local and foreign rocks. Of the 37 samples, at least 17 samples might be of local origin, while the other 20 are more likely to have been from foreign sources. Most rocks could not be traced to specific geographic origins, but those that could be traced include the chalks, the igneous, and the metamorphic rocks. These non-local stones are hypothesized to be from Egypt, Syria, Turkey, Cyprus, and certain Aegean Islands (Table 2).

## Conclusion

Despite the inability to determine the precise origins of the ballast stones found in the North Bay of Tel Dor, this study's identification of rock types and specific lithologies allows for general conclusions regarding the stones' origins. These multiple origins of the ballast found and studied support Tel Dor's role as an integral part of the maritime network of the eastern Mediterranean. Characteristics of the stones also reveal information regarding ballasting practice and ancient harbour operations. Prior to this study, ballast stone piles were investigated as a part of individual shipwrecks, whereas this research was able to examine ballast stone samples that theoretically came from many seafaring vessels, thus allowing for both a wider and more in-depth perspective on ballasting practices of the time. This study is one of the few conducted to date to have integrated FTIR spectroscopy with petrographic analysis for material studies, specifically geological material. Because rocks are identified based on mineralogical composition, FTIR offers the advantage of both a rapid analysis of samples and the identification of both crystalline and non-crystalline minerals. By combining these methods this study was able to provide a full picture on rock type of each ballast stone collected.

## Acknowledgements

Thank you to my advisors, Drs. Ruty Shahack-Gross and Assaf Yasur-Landau, as well as the directors, staff, and volunteers with the underwater excavations of the Tel Dor Project. Additional thanks to the Department of Maritime Civilizations at the University of Haifa, the Leon Charney of Marine Sciences, the Sir Maurice and Lady Irene Hatter Foundation.

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## Figures

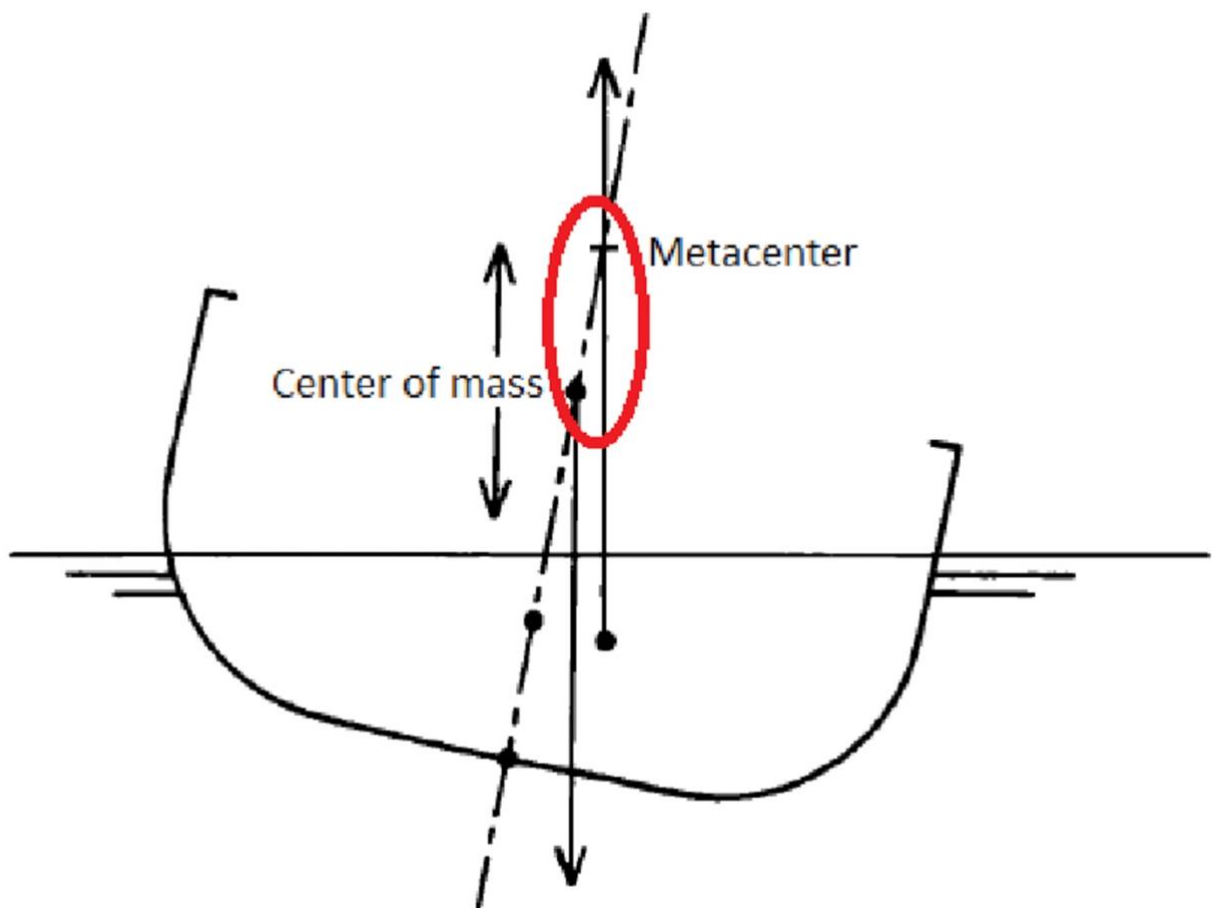


Figure 1: Schematic diagram depicting relationship between metacentre and centre of mass. The centre of mass can be moved up and down, with the distance between the two points (circled in red) affecting the stability of a ship. (McGrail, 1989: 355, fig. 1)



Figure 2: Map indicating location of the North Bay of Tel Dor, Israel. (Holdeman, 2017: 1, fig. 1.1)

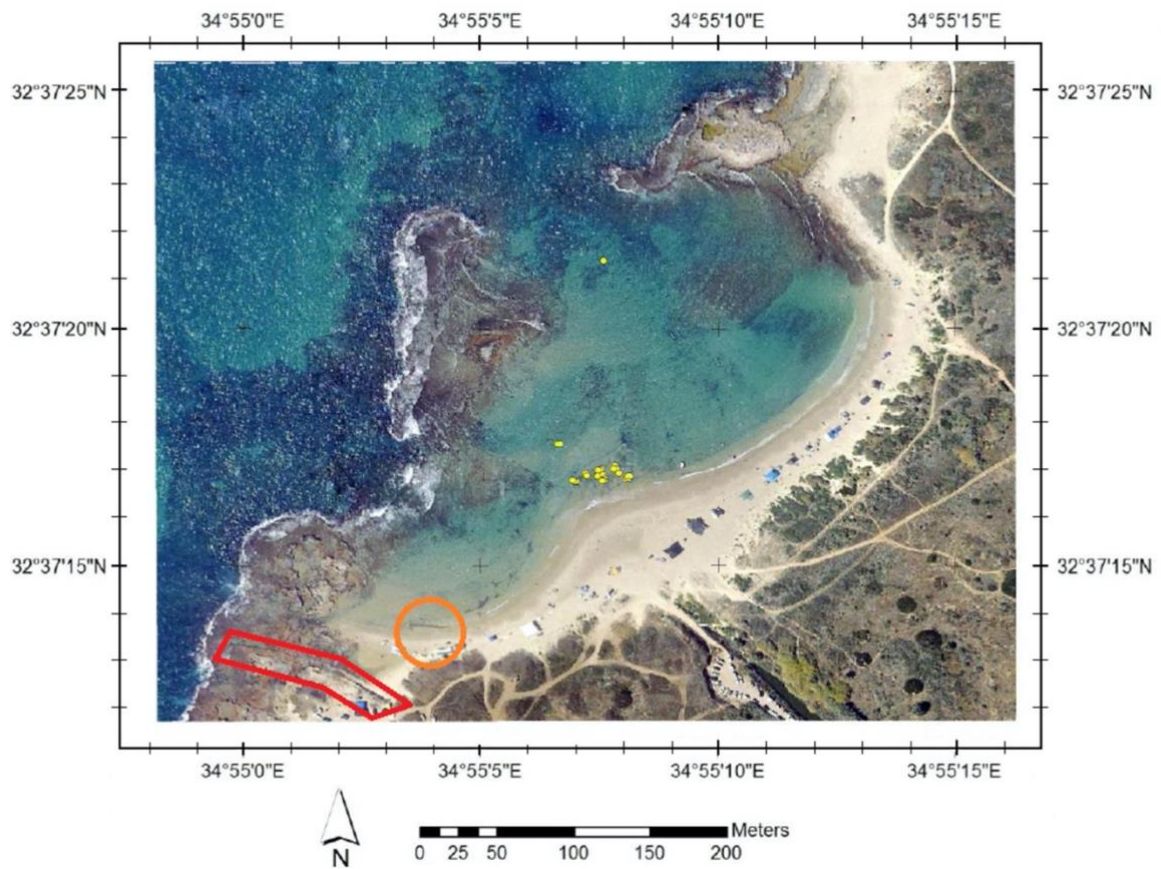


Figure 3: Map of architectural structures in the southern part of the North Bay of Tel Dor. Yellow dots indicate Raban's dozen columns. Most recent flushing channel is indicated by the red rectangle. The most visible wall in aerial view of Raban's rectangular structure is circled in orange. (Shalev, 2015: 41, fig. 4-2)



Figure 4: Example of stream-worn stone that is preferred shape of ballast stone. This is sample AH-9 from the study's assemblage. (Holdeman, 2017: 73, fig. 4.26)



Figure 5: Example of architectural component used as a ballast stone. This is sample AH-37 from the study's assemblage. (Holdeman, 2017: 161, fig. 4.110)



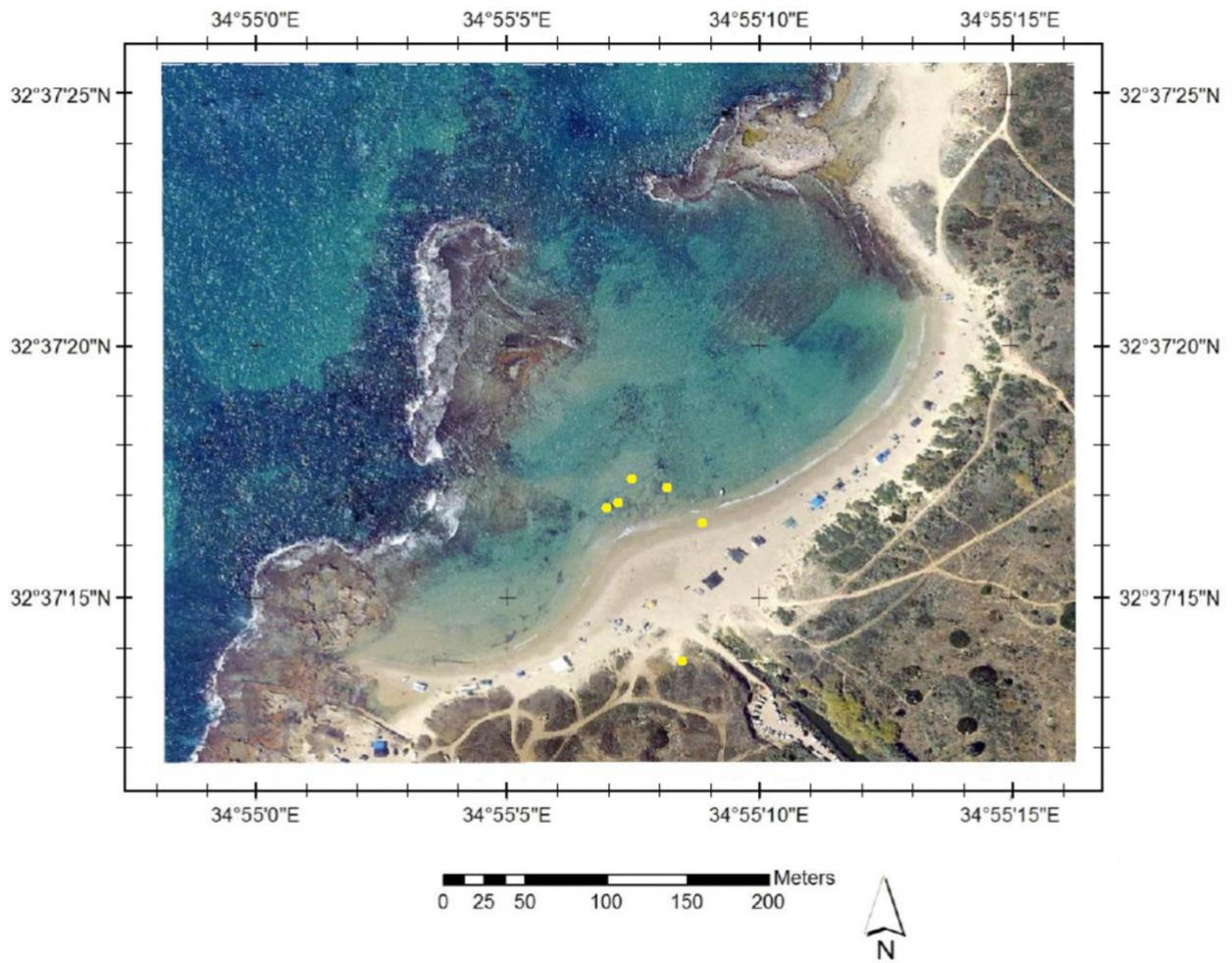


Figure 6: Points in the North Bay of Tel Dor for collection of ballast stones for this study. (Holdeman, 2017: 34, fig. 3.1)



Figure 7: Example of macroscopic analysis done on this study's assemblage. The sample shown here is AH-1 and shows the interior to be composed of coarse sand that is grey, light grey, pale yellow, and white, with the white components resembling shell fragments. The inset shows the overall interior of the sample, while the main photo shows a close-up on the coarse sands and shell fragments. (Holdeman, 2017: 44, fig. 4.1 and 4.2)

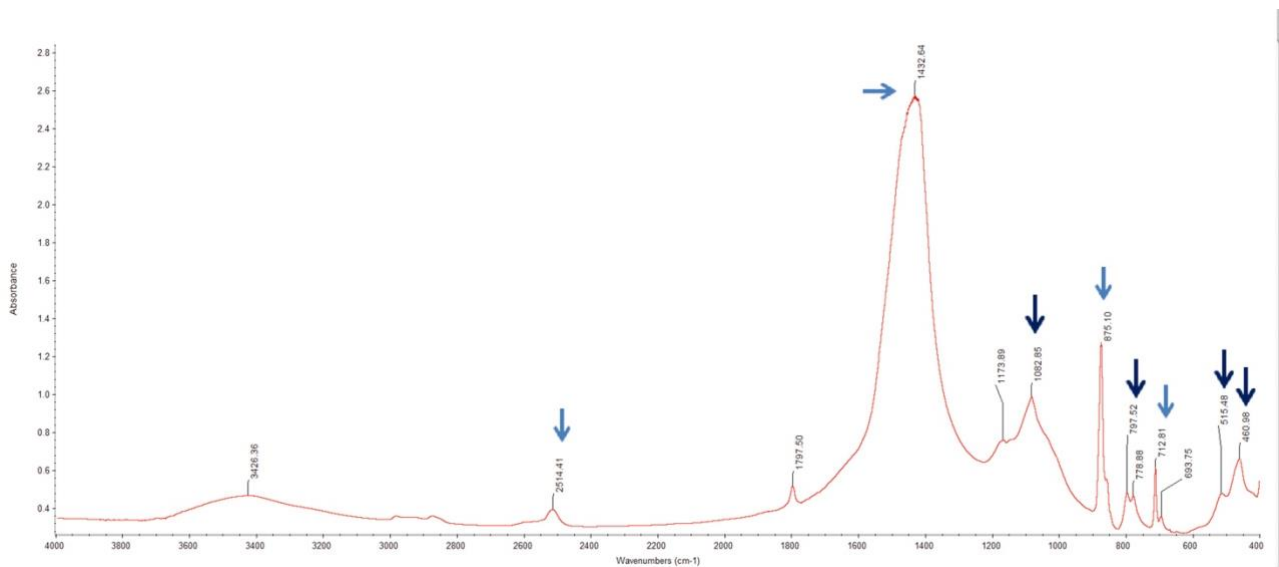


Figure 8: Spectra result from Fourier Transform Infrared (FTIR) analysis used on this study's assemblage for sample AH-1. The major peak of the whole spectra (ca. 1420 cm<sup>-1</sup>, shown with light blue arrows) show a

calcite dominance accompanied by quartz (major peak at ca. 1085 cm<sup>-1</sup>, shown by dark blue arrows).

(Holdeman, 2017: 46, fig. 4.3)

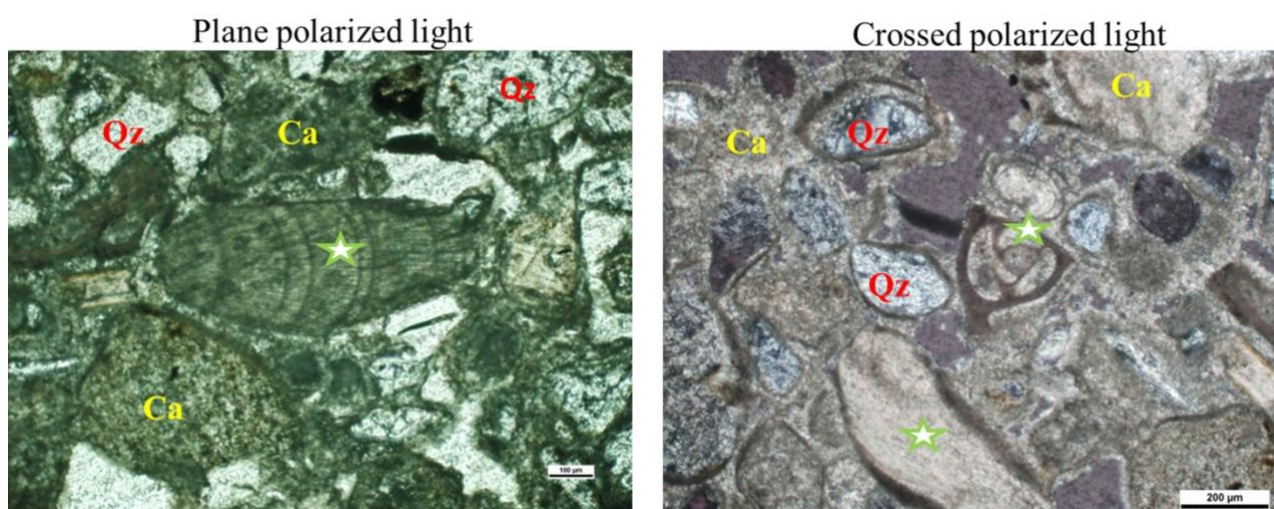


Figure 9: Results of petrographic analysis done on the study’s assemblage for sample AH-1. The images show calcite (Ca), quartz (Qz), and shells and foraminifera (starred) visible in both polarized and crossed polarized light. (Holdeman, 2017: 47-48, fig. 4.4)

## Tables

Table 1: List of geological maps and resources used to identify coastal outcrops of the eastern Mediterranean as possible origins of ballast stones examined in this study.

Geographic Region	Geological resource
<b>Israel</b>	Singer, 1967 Frechen et al, 2004 Hirsch, 2005 Rosenfeld and Hirsch, 2005
<b>Cyprus</b>	Geological Survey Department, Cyprus, 1979 Bragin <i>et al</i> , 2005 Krasheninnikov and Kaleda, 2005 Portnyagin, 2005 Silantyevev and Krasheninnikov, 2005 Silantyevev <i>et al</i> , 2005 Sillantyevev, 2005a,b Ertek <i>et al</i> , 2008 McCay and Robertson, 2012
<b>Turkey</b>	Pinar-Erdem, 1974: 119-123 Brinkman, 1976



	Bozkurt and Oberhänsli, 2001 General Directorate of Mineral Research and Exploration, 1989
<b>Syria/Lebanon</b>	Beydoun, 1977 Brew <i>et al</i> , 2001 Al-Riyami <i>et al</i> , 2002 Chan, 2004 Ministry of Petroleum and Mineral Resources S.A.R., 1986 Krashenionnikov, 2005a,b c Ma et al, 2011
<b>Levant</b>	Gvirtszman, 2010

Table 2: List of possible origins for each identified rock type. White rows are sedimentary rocks, light grey rows are igneous rocks, and dark grey rows are metamorphic rocks. (Holdeman, 2017: 163-164: Table 5.1)

<b>Rock Type</b>	<b>Sample</b>	<b>Coastal Areas Containing Rock Type</b>
<b>Beach rock</b>	AH-1, AH-4, AH-6, AH-17, AH-24	Rock type found throughout the eastern Mediterranean coast
<b>Limestone</b>	AH-2, AH-13, AH-16, AH-23	Rock type found throughout the eastern Mediterranean coast
<b>Chalk</b>	AH-8	Israel, northern Lebanon, southern
<b>Chert</b>	AH-7, AH-25	Rock type found throughout the eastern Mediterranean coast
<b>Dolomite</b>	AH-3, AH-10, AH-11, AH-20, AH-22, AH-27	Rock type found throughout the eastern Mediterranean coast
<b>Conglomerate/ Breccia</b>	AH-14	Rock type found throughout the eastern Mediterranean coast
<b>Microgabbro</b>	AH-5, AH-19, AH-29	Cyprus, Troodos Ophiolite Complex Turkey, southwestern Syria, northern
<b>Pegmatitic quartz</b>	AH-18	Egypt, Nile Valley Egypt, Aswan
<b>Sandstone (slightly metamorphosed)</b>	AH-30	Cyprus, Mamonia Complex
<b>Low grade marble (without recrystallization)</b>	AH-9	Cyprus, Mamonia Complex

	AH-34	Cyprus, Kyrenia Ridge
<b>Low grade marble (with recrystallization)</b>	AH-28	Cyprus, Kyrenia Ridge
<b>Dolomite marble</b>	AH-10	Syria, Bassit-Baer Massif
<b>Quartzite</b>	Ah-21	Cyprus, Mamonia Complex Turkey, Menderes Massif
<b>Purple quartzite</b>	AH-32	Syria, Palmyrides
<b>Tonalite/quartz diorite gneiss</b>	AH-12	Turkey, Marmara Island  Turkey, Menderes Massif Egypt, Mon Claudius quarry
<b>White marble</b>	AH-31	Aegean Island, Thasos Aegean Island, Paros Aegean Island, Egeo Aegean Island, Delos Greece, Abdera Turkey, Menderes Massif Turkey, Marmara Island
<b>Grey-blue marble</b>	AH-33, AH-37	Turkey, Menderes Massif Crete, Ntikali Italy, Carrara Aegean Island, Egeo
<b>Brecciated marble</b>	AH-36	Aegean Island, Skyphos