Utilization of Satellite Remote Sensing in Ostia Antica

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1. Overview

1.1. Background and purpose

Application of satellite remote sensing in archaeology has been increasing since the arrival of first commercial high-resolution satellite, IKONOS, in 1999. High-resolution satellite, which resolution is less than 1m, has enabled the detection of much smaller archaeological features comparing with the previous middle resolution satellite images represented by Landsat TM. Remote sensing is especially effective when trying to cease a whole picture of the wide extent of an interested area, or in a case when chances of actual excavations are limited. In this study area, there is already a study of Keay et al. (2014), which used satellite images, lidar, and GPR to detected underground features around the Portus, ancient port in Roman period, just 3km north of Ostia Antica. The aim of our study is to understand the distribution of the underground features around the Ostia Antica, if there are, and to get a picture of their extent. However, when considering the function of the Ostia Antica as port city, information about the connection with the surrounding area in wider extent should be taken into account. The understanding of spatial structure of wide area (i.e., spatial context) is essential to understand the true nature of Ostia Antica. Thus, interpretation is implemented not only around Ostia Antica but around the whole coastal plain and its adjacent hillsides.

1.2. Study area

Interpretation has been implemented widely around Ostia Antica, which covers around ca. 420 ㎢ (Fig. 1)。Study area contains different environments of coast area, hillside, and low land in Tevere river basin. However, there can be difference in accuracy of feature detection due to the different coverages of each satellite data types.

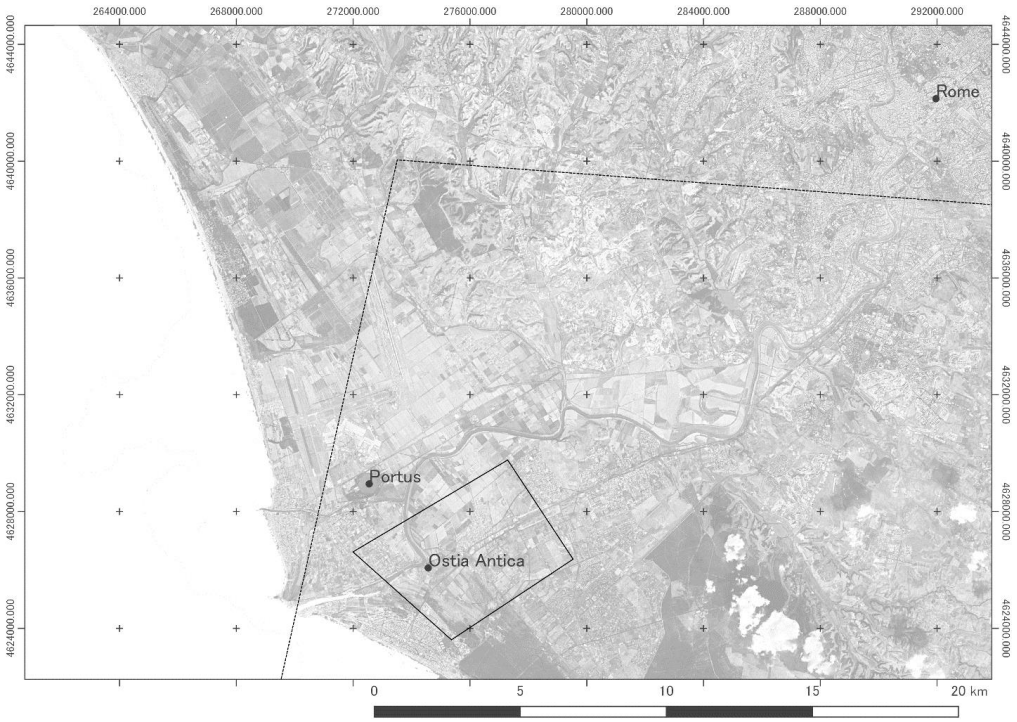

Fig. 1 Interpreted area (Whole area in this map is covered by CORONA KH-9 (1980/09/16) ; CORONA KH-7 (1964/03/14)covers the dotted line area; Worldview-3(2016/6/18) covers the smallest solid line area)

1.3. About the satellite images used in this study

Several satellite images were used in this study (Tab. 1). CORONA satellite image is mainly photographed during the 1960 to 1970s (There are also images from the 80s). Although there are many types of camera systems in CORONA satellite, KH-4 is the most common image used in case of archaeology. This is because its resolution is comparatively high (6 feet) and matches with the demanded scale for archaeological application. We prepared KH-9 and KH-7 since our study area lacked KH-4. KH-9 has a vast coverage with middle resolution of 20-30 feet (6m), which can be still useful for archaeological work. KH-7 is not very common in archaeological work, since its photographed area is limited. However, KH-7 has a high-resolution of 1m, which is almost comparable with the recent high-resolution satellites. Luckily, study area was within the coverage of KH-7. We also purchased Worldview-3 image, which is one of the image with the highest resolution (31cm) among the nowadays satellites. In spite of its resolution, recent development in the area made the detection of the feature from Worldview-3 difficult.

Tab. 1 Used images

Satellite image	Photographed date	Resolution	remarks
CORONA KH-7	1964/03/14	2-4 feet (c.a. 1m)	High-resolution in 60s.
CORONA KH-9	1980/09/16	20-30 feet(c.a. 6m)	Covers wide area and capable of stereo-viewing.
WorldView-3	2016/6/18	31cm	High-resolution, contains IR wave length.

2. Interpretation of the image

2.1. The flow of the procedure

The main phase of procedure[1] is 1) preparation of the images, 2) interpretation, 3) digitizing, 4) validation. Downloaded CORONA satellite images do not have proper projection nor coordinates. Firstly, ortho-rectification is required to add these projection and coordinates. Every images can be overlaid each other in GIS after the first phase. Interpretation is done based on the detection of the soil marks[2] and crop marks[3]. Additionally, 3D visualization with KH-9 is used to aid the interpretation by observing the micro-topography and small difference of the heights. Interpretation results are digitized as GIS data by tracing the ortho-rectified image. The set interpretation classes are, lineament (bright color), lineament (dark color), road, structure, river, old river, channel, old channel, coast line/change of height, only visible in Worldview-3, only visible in Google Earth (11 classes in all). Interpretation was done with a least knowledge about the distribution of the archaeological features and sites. This is to avoid the biased interpretation from the prejudice. Finally, the results were evaluated by comparison with the already known sites and other study papers.

2.2. Marks detected in the image

Basically, the higher the resolution, the higher of the possibility of detection as is seen in Fig. 2. In fact, there were some cases which KH-9 only provided vague image for the underground features, while other images gave much clearer view (Fig. 2). However, it is known that the visibility and detectability of the features largely differs by the condition of the soils, seasons, and years (Masini et al., 2018). In Fig. 3, example of underground feature clearly visible in KH-9, which is not visible in most of the Google Earth image is introduced.

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[1] Basic procedures followed that of one of the authors work (Watanabe, 2017).

[2] The difference of moistures held in the soil due to the underground structure effects the growth of the vegetation. “Crop mark” is a mark which is detected in the aerial images due to this difference of vegetation growth.

[3] The difference of moistures held in the soil due to the underground structure effects the color of the ground surface. “Soil mark” is a mark which is detected in the aerial images due to this difference of soil moisture.

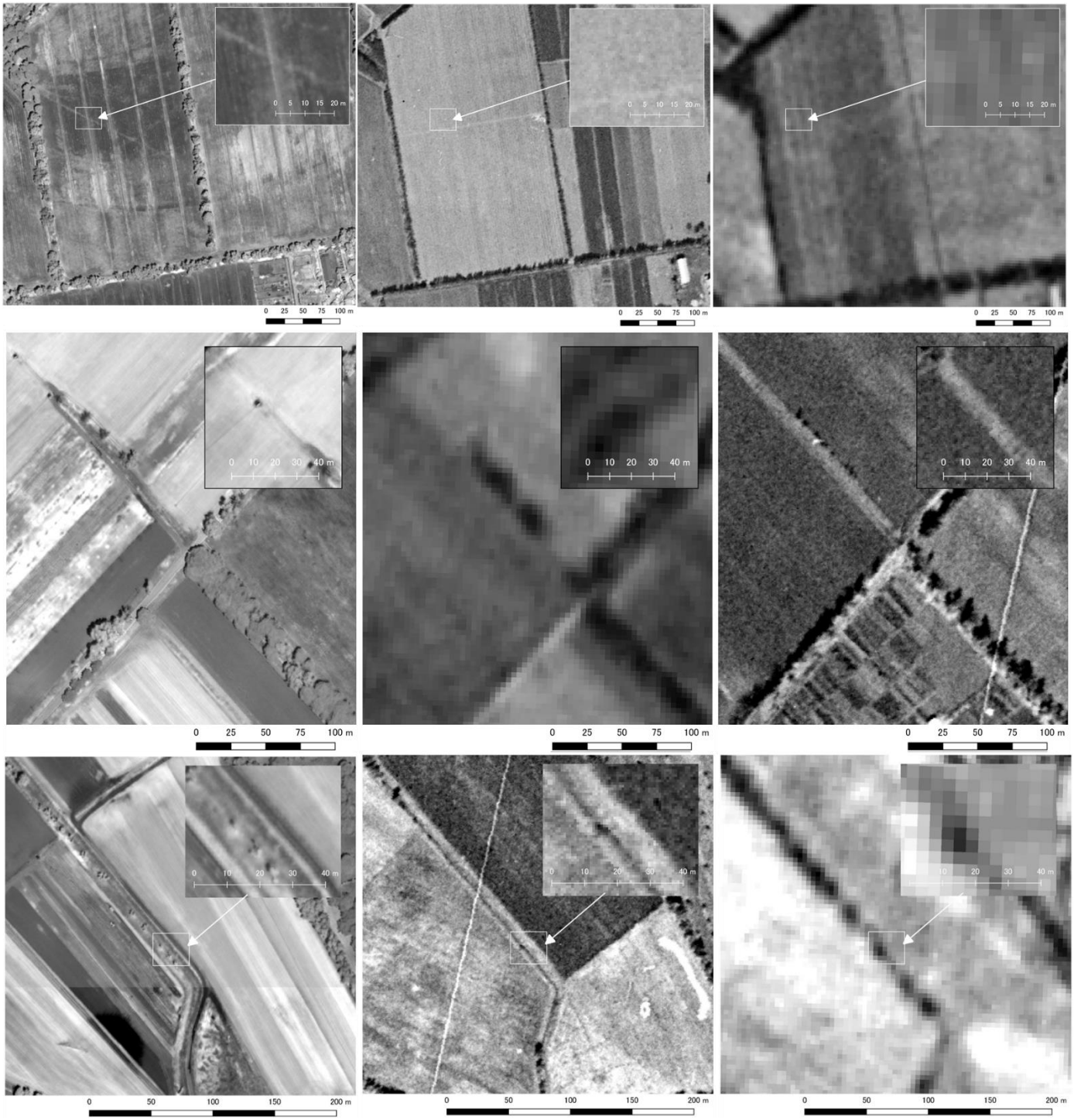

Fig. 2　Examples of marks detected (Left：Worldview-3　Middle：CORONA KH-7　Right：CORONA KH-9)

Top：Lineament (dark color) (Buried road in north of Ostia.)

中図：Lineament (bright color) (Coarse pavement by stone is confirmed in survey.)

下図：Road with channel (Still in use. Coarse pavement and sherds confirmed in survey.)

Remote sensing is capable for detecting “something” underground, however, it is generally difficult to confirm what it exactly is without actual excavation. Logically, it is suggested that underground stone structure and reburied pits or depression can be distinguished by surface soil colors. However, this is not

always the case since it can be influenced by the colors and textures[4] of the surroundings. Thus, total consideration of colors, shapes and the spatial contexts will be taken into account to estimate the "something" into whatever archaeological features. Not only the clear marks displaying structure plans but also the isolated marks with aggregated shapes are considered as "structure". Also, the parallel lineament with water in its middle is classified as channel, while parallel lineament without water is classified as old-channel. These patterns observed in the images must be the dumped soils during its construction or its dredging (Fig. 4)

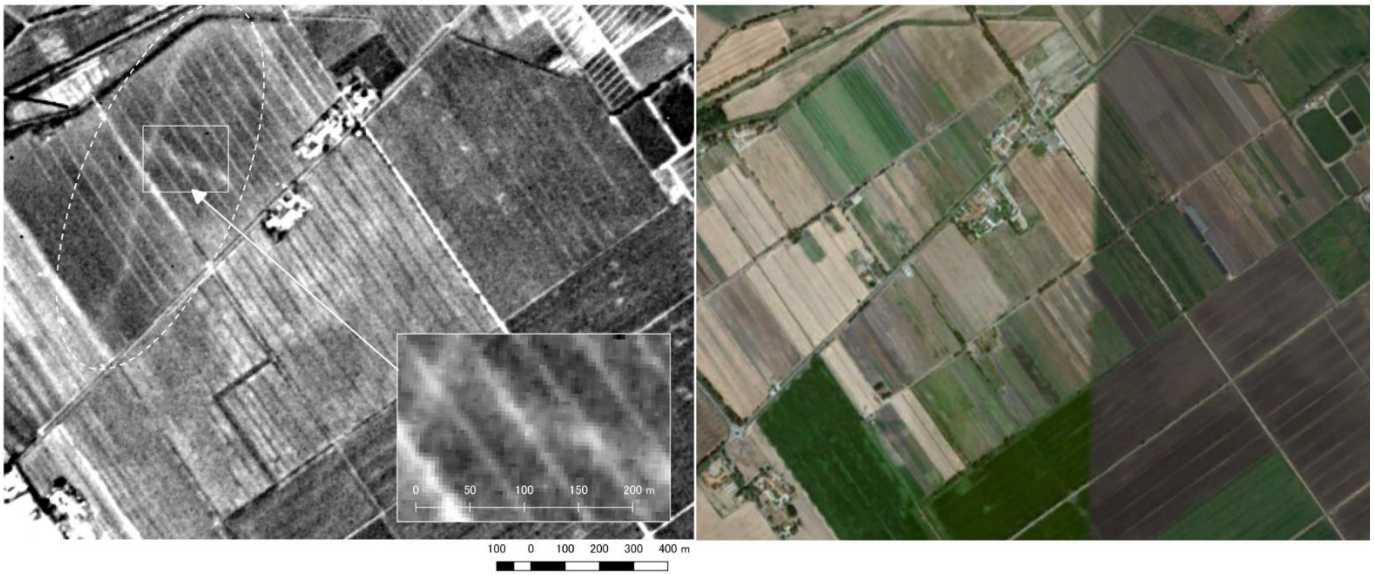

Fig. 3　Example of mark clearly visible in KH-9 but not visible in Google Earth.

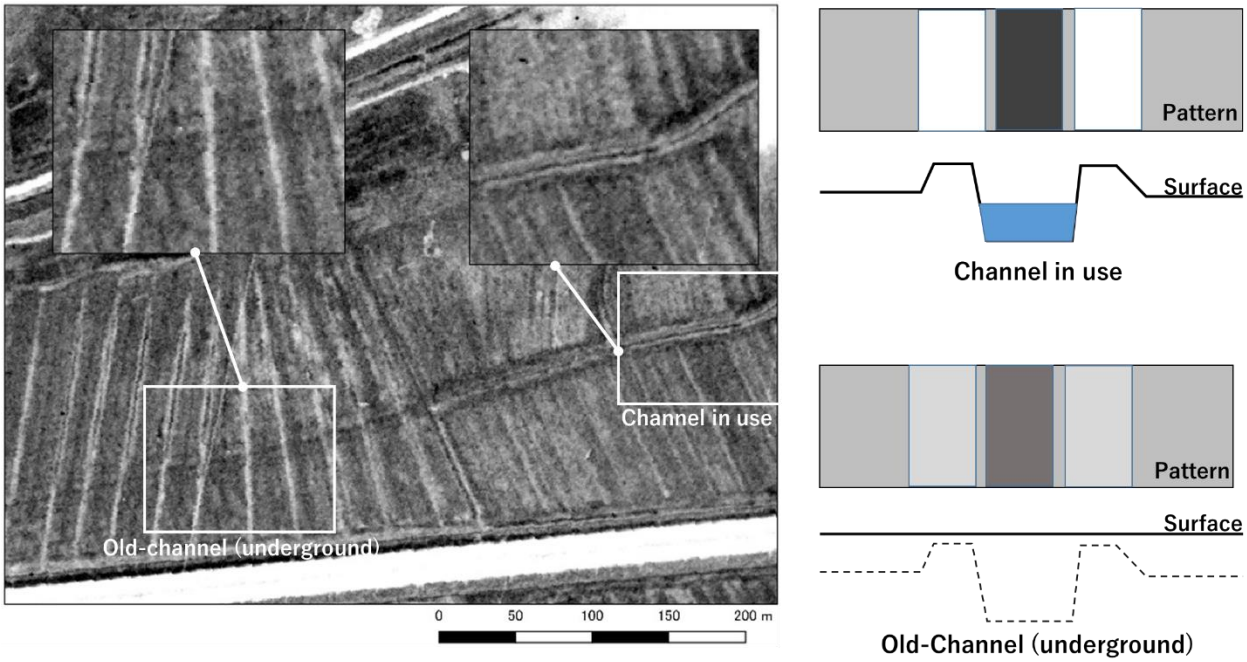

Fig. 4　Patterns of the channel

[4] We decided to separate the class besides this difficulty. It was expected that some tendency of "dark color" and "bright color" may be observed if we do this.

Image enhancement is commonly used in remote sensing which is useful to improve the visibility. There are many enhancement techniques for this purpose. However, since the area contains different texture and colors, it was difficult to apply effective enhancement for whole area. Rather, it was practical to quickly apply different enhancement parameter for changing observing area. Thus, simple linear enhancement was effective enough in our case（Fig. 5）.

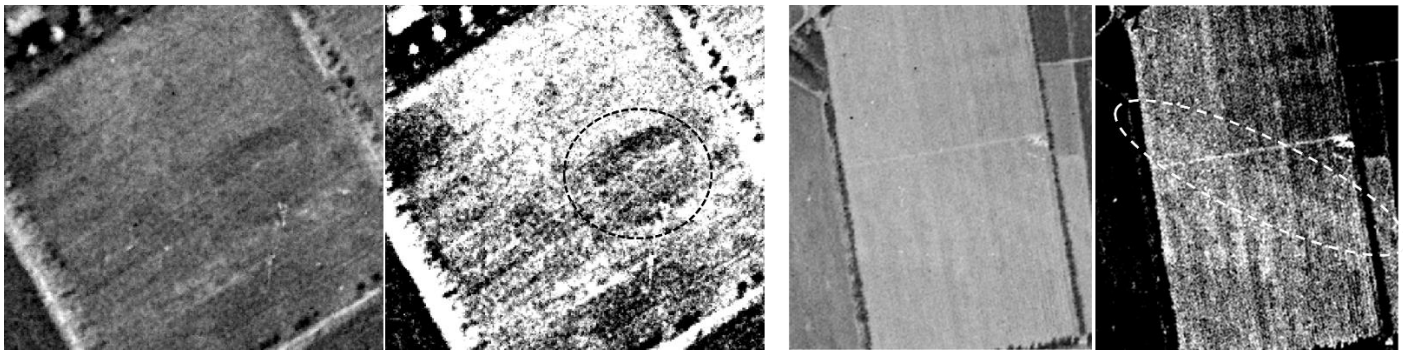

Fig. 5　Improvement of visibility by image enhancement　(left："structure" right："lineament")

Most of the Old-river and coastline/change in height were detected from stereo-viewing of KH-9. However, stereo-viewing is adapted to the whole area, to aid the final decision for classification. Interpretation result of KH-7 is prioritized when there are conflicting results in interpretation, since it is the oldest and has comparatively high-resolution. Of course there may be miss-interpretation, and moreover, features of any period can be contained inside the result. As referred, this is one of the reason for interpreting wide area, to grasp the whole picture of the surroundings of Ostia Antica. The drafted whole picture may enable to grasp the spatial context, which can be an aid to consider the detected marks themselves.

3.　Result of interpretation

3.1.　Detected features and the evaluation of the result

The result of interpretation for whole study area is shown in Fig. 7. Precise evaluation of the result can only be stated from the actual excavation. At least, the comparison with the study of Keay et al. (2014) may give basic idea about the reliability of our result. Comparison showed that most of the referred marks (which was detected from satellite and aerial photo) in Keay et al. (ibid.) were detected in the result. Satellite images they used was the Worldview-2 (80cm resolution), which proved the KH-7 to be comparative with the conventional high-resolution satellites(Fig. 6). Until the 19th century, there were two lagoons in the region, Maccarese Lagoon in the north and Ostia Lagoon in the south (Goiran et al., 2010). There were barely a "structure" detected within in the area of the old-lagoon. Although the outer extent of KH-7 may have lower chances of detection, this fact also supports the interpretation result to be reliable[5].

[5] As referred, to avoid the effect of prejudice, knowledge about the area was collected after the basic interpretation. Author did not have any knowledge about the existence of the old-lagoon.

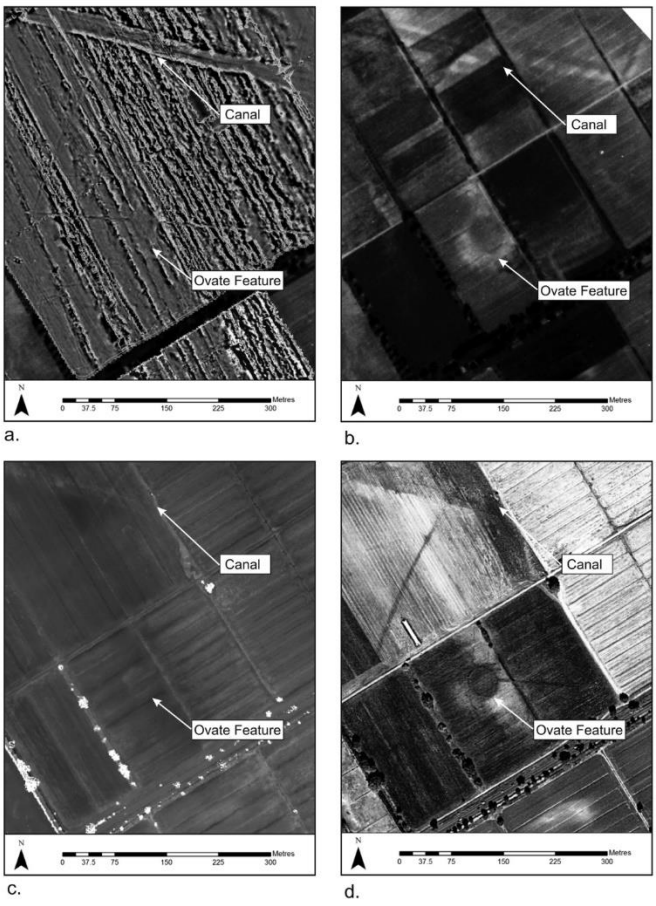

Fig. 7. Composite images of the area to the east of Portus, showing a. the magnetometer survey, b. the 1943 air photograph, c. the LiDAR data and d. the satellite imagery.

Fig. 6　Example of comparison of the results.
left: Keay et al. (2014)
right: Interpretation results in this study.

It is interesting that marks are clustered around the Ostia Antica and Portus. Also, the "structure"s located in the east coast of the old-lagoon draws attention. Virroti et al. (2015) s' study explains the formation of Ostia Lagoon. According to the study, the lagoon was enclosed inland with stable sedimentation environment in the 9th century BC, leaving the artificial canals as the only connection to the sea after this period. In the BC 5th to 4th century, the lagoon is claimed to be 1km inland and some

part of lagoon had 3.5 m to 4 m in depth[6]. The clusters of the detected marks were grouped as A: Portus, B: Portus to north of Ostia Antica, C: Around Ostia Antica and its southeast, D/E: Around the Ostia Lagoon, F: Tevere river, G: Around Maccarese Lagoon. The details of the groups will be explained in the following chapters(Fig. 8).

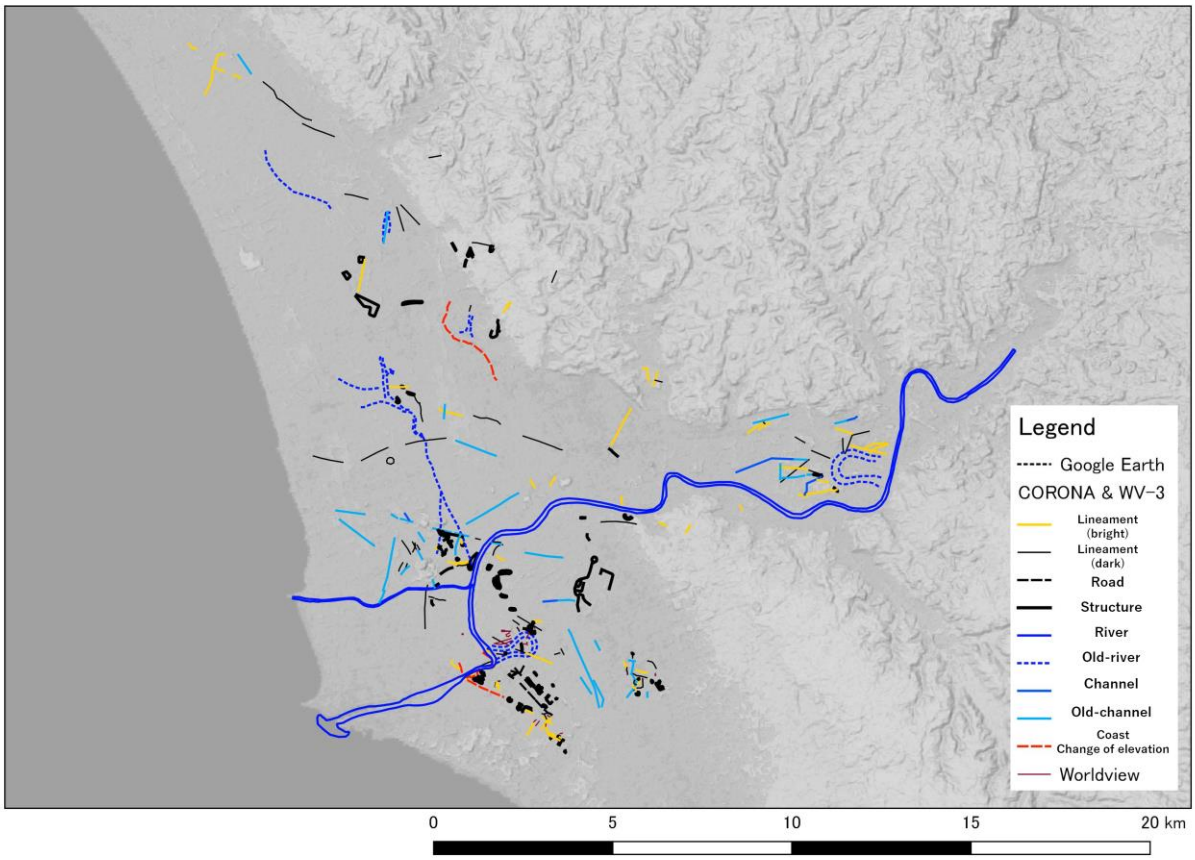

Fig. 7　The result of the interpretation

[6] Vittori et al. refers to the possibility of the lagoon to be used as a shelter for the ships (Vittori et al., 2015).

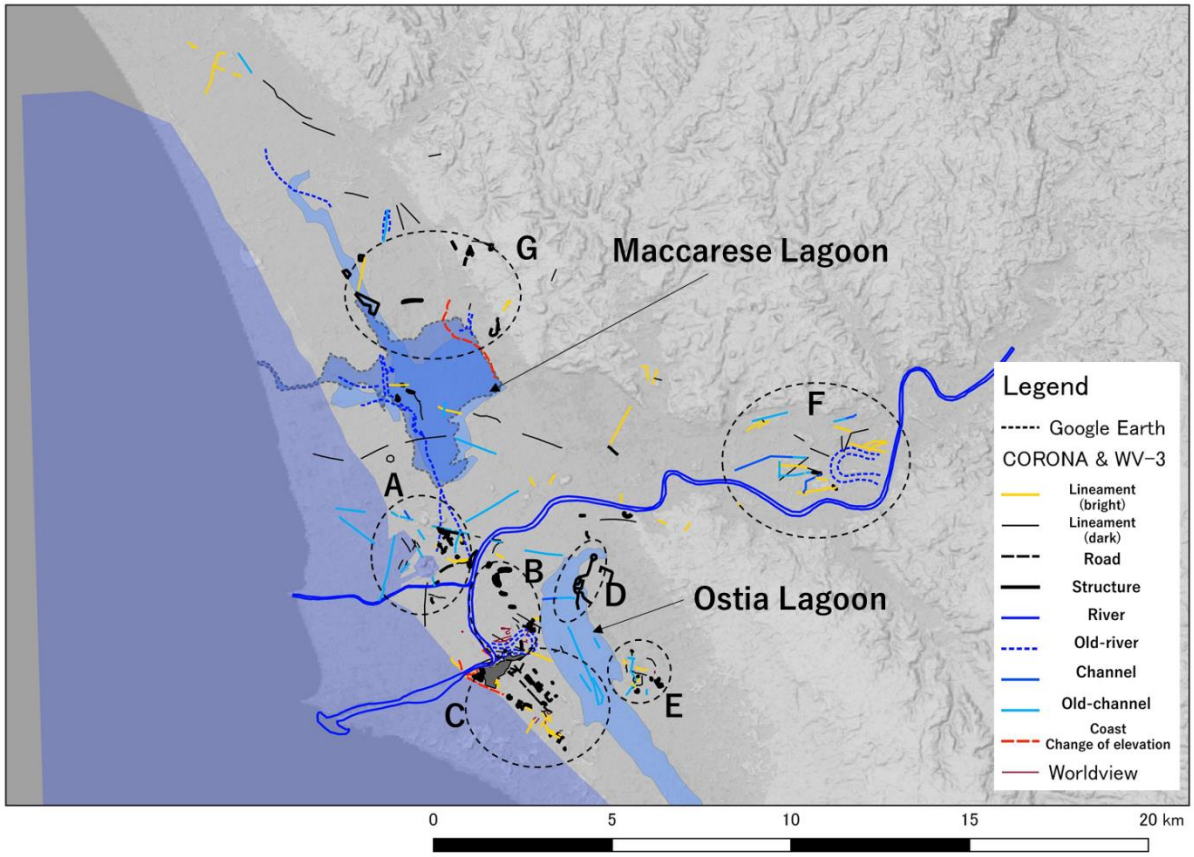

Fig. 8　Groups of clustered marks and the old-lagoon (Lagoon is based on Amenduni(1884))

3.2.　Portus, Portus to north of Ostia Antica（Fig. 8　A・B）

Reconstruction map around the Portus is suggested by Keay et al. (2014). The canal in the north of Portus, aqueducts, and structures by the Tevere river is also detected in the interpretation result. However, the canal which is claimed to be connecting Portus and Ostia Antica (Keay et al., ibid; Giaime et al., 2019) was not able to be detected. In the study of Keay et al. (ibid), body of the canal was detected from GPR survey, while interpretation from the satellite was detecting its edge. In our result, “edge of the canal” was detected as “structure”[7]. On the other hand, “structure” detected by the northern canal and the old-river from the north was not referred in the study of Keay et al (ibid)[8] (“A” in Fig. 10 and “old-river” from the north) . The structure seems to be related with the canal, since there is dike like structure parallel to the canal. The “old-river” can be older than the Portus, since it seems to be connected to the lineament in the south of the Portus. Also, the “structure”s in the east side of Tevere river draws attention. They are rather distributed than continuous, but still their placing forms band like cluster to the north to south which stops at the bank of old channel of Tevere river (“B” in Fig. 10, Fig.

[7] This miss-classification is because the mark seemed as isolated and its shape did not appear to be linear.

[8] This is maybe their purpose was not only detection but to compare the results from different sensors. Thus, only the features which was able to be identified may be reported. In fact, the clear lineament in Fig. 6 “d” is not mentioned in the paper as well.

16). The area is drawn as low land in the old map, which seems to be unsuitable for habitation (Fig. 13). It is possible that these marks are sediments from the flood or during the change of the river channel[9]. It is also noteworthy that clear mark of building was detected in the 2003/7/24 image of Google Earth near Tevere river (Fig. 9).

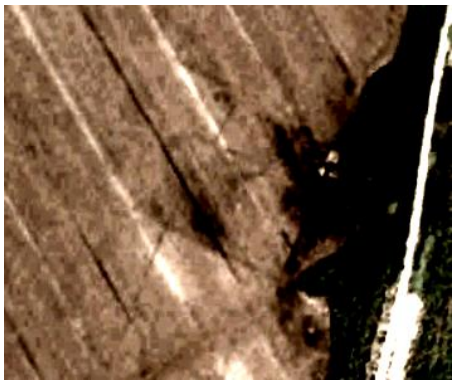

Fig. 9 Mark of "structure" (building) in Google Earth (Enhanced the image of Google Earth)(C in Fig. 10 left)

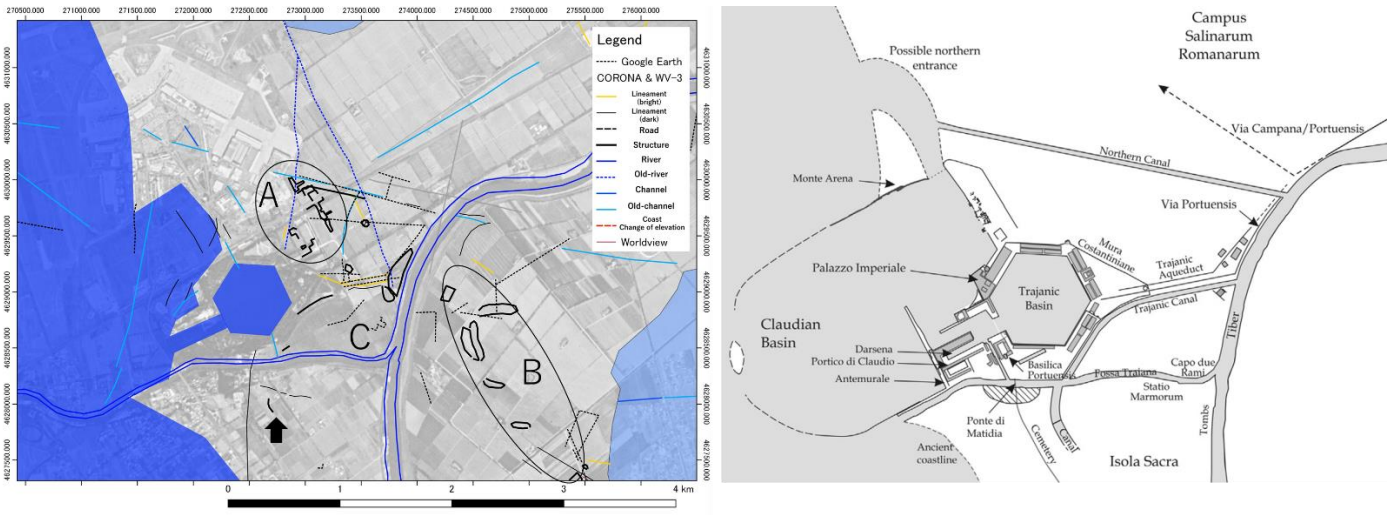

Fig. 10 Comparing the result around the Portus and reconstructed map of Keay et al.(2014)

3.3. Surroundings of Ostia Antica and its southeast (Fig. 8 C)

Marks can be observed in the south of Ostia Antica, which three roads converging to one road heading to the south. The paralleled "road"s in east-west (NW-SE) direction can be the known "Via Severiana". The coarse pavements and pottery sherds were confirmed during the survey. Also there are "lineaments (bright)" which turns its way to the coast. This lineament is branched, and some of the stemmed lineament seems to be connected to the west edge of the Ostia Antica. These "lineament"s can be the road in south of Ostia Antica, which is depicted in the old map (Fig. 13). Also, there are some "structure"s by the "road"s, which can be a buildings related with the "Via Severiana". Several "lineament"s in north-south (NE-SW) direction are observed. Perhaps, these are related with the canals which were connecting the sea and the old-lagoon.

[9] There is a study of Salomon et al. (2018) about the change of the channel of the Tevere river

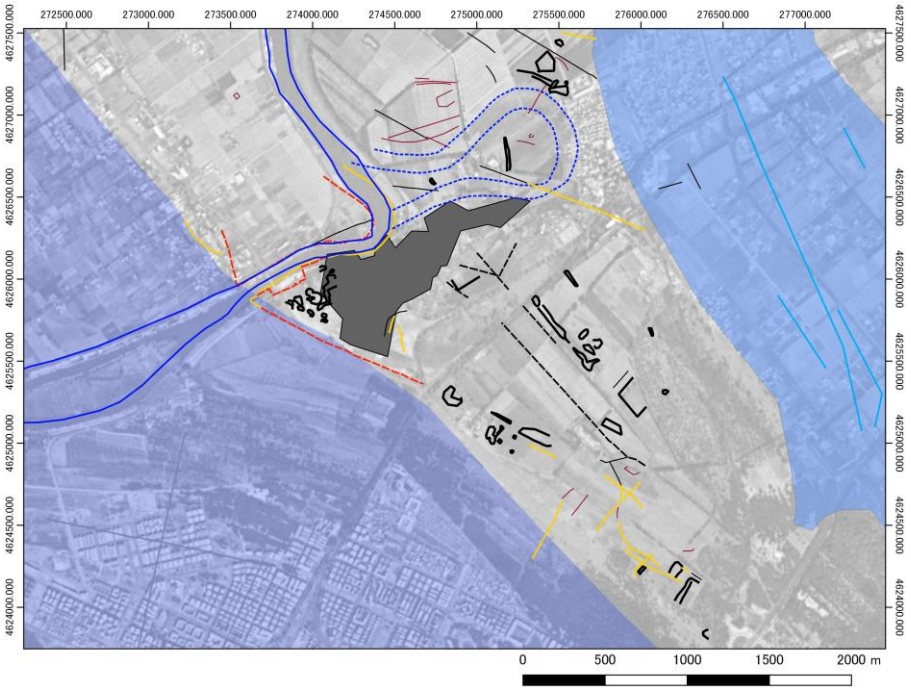

Fig. 11　Result of surrounding of Ostia Antica and its south east.

3.4.　Surroundings of the Ostia Lagoon（Fig. 8　D・E）

“Old-channel” is detected in the center of Ostia Lagoon. Its east edge bends toward the sea and seems to be connected to the nowadays small river. The location and the shape of this “old-channel” implies that this mark to be the “Fossa Papale” in the old map (Fig. 12). Two clusters of “structure”s is observed in the eastern coast of the old-lagoon. Especially, there is a mark of circle-shaped “structure” and “lineament” connected together which draws attention. One of the “old-channel” seems to be heading its way to this circle. One of the possibility of this cluster in north is, that it is related with the salt production which took place in the northern half of Ostia Lagoon (Vittori et al., 2015). Another possibility is the relation with the transportation via lagoon or the canal. Resembling structure is also found near canal by the Portus, which is shown in Fig. 6. There are not much clues to estimate about the Southern cluster.

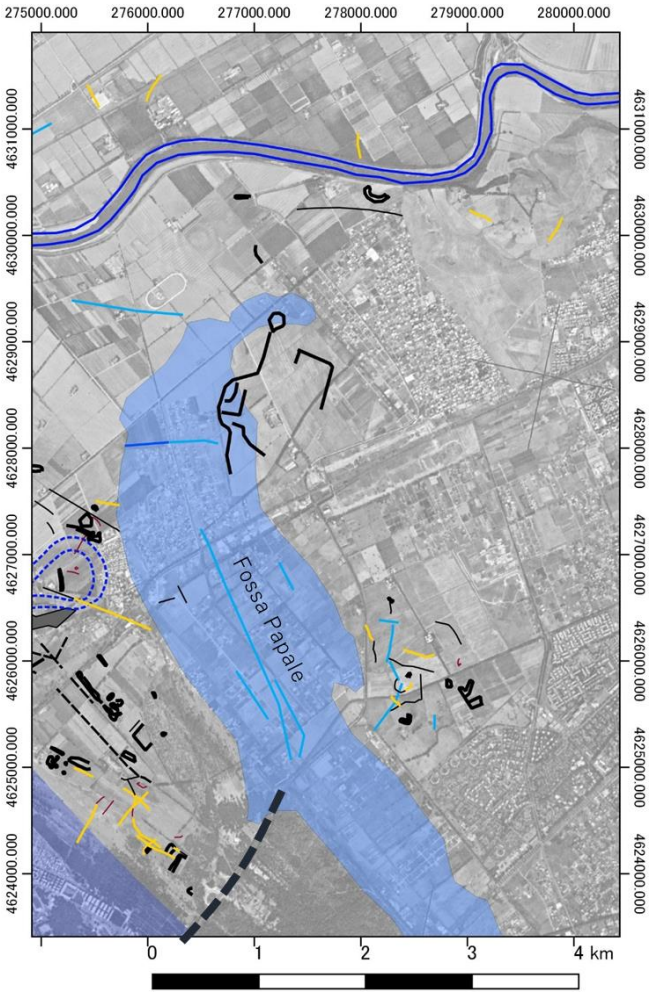

Fig. 12 Result around the Ostia Lagoon

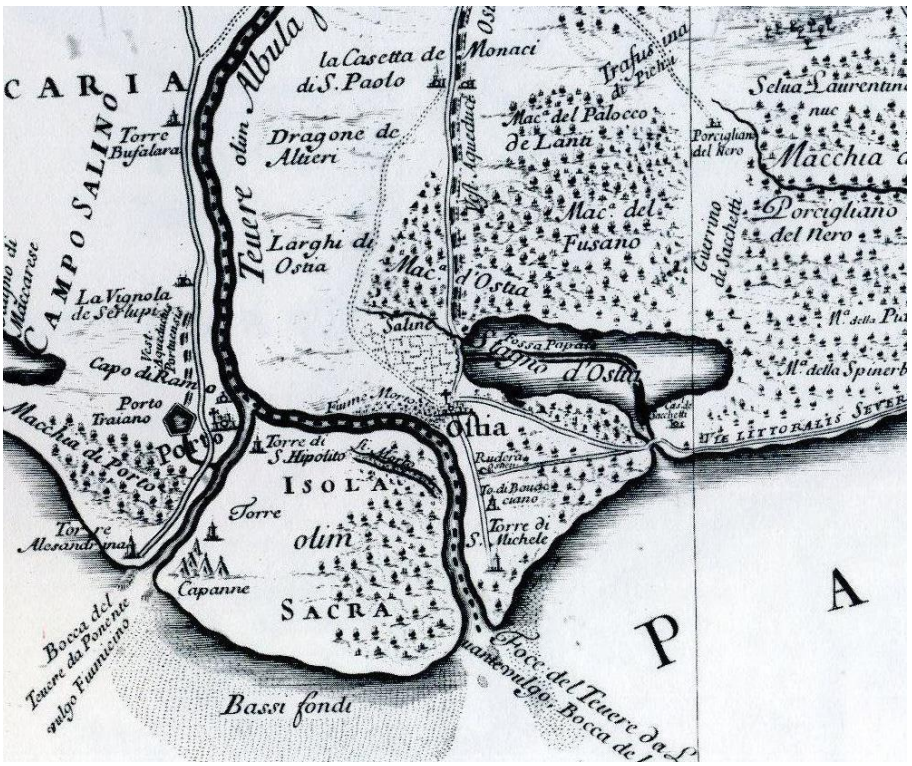

Fig. 13 Study area in old map (Figure is from Simoni(2013), which original is statedd to be of G. F.

Ameti, 1693)

3.5. Surroundings of Tevere river (Fig. 8 F)

There are cluster of marks detected when tracing back Tevere river toward the Rome for about 10km. “Old-river” channel is observed and the fact that there is not many “structure”s implies that the land to be marshy and unstable. It was the same impression when the place was visited during survey, and in fact, there are not much habitation even now. There must have been a canal to transport goods to center of Rome, but the marks seem to be complicated with new and old canals, which makes estimation impossible.

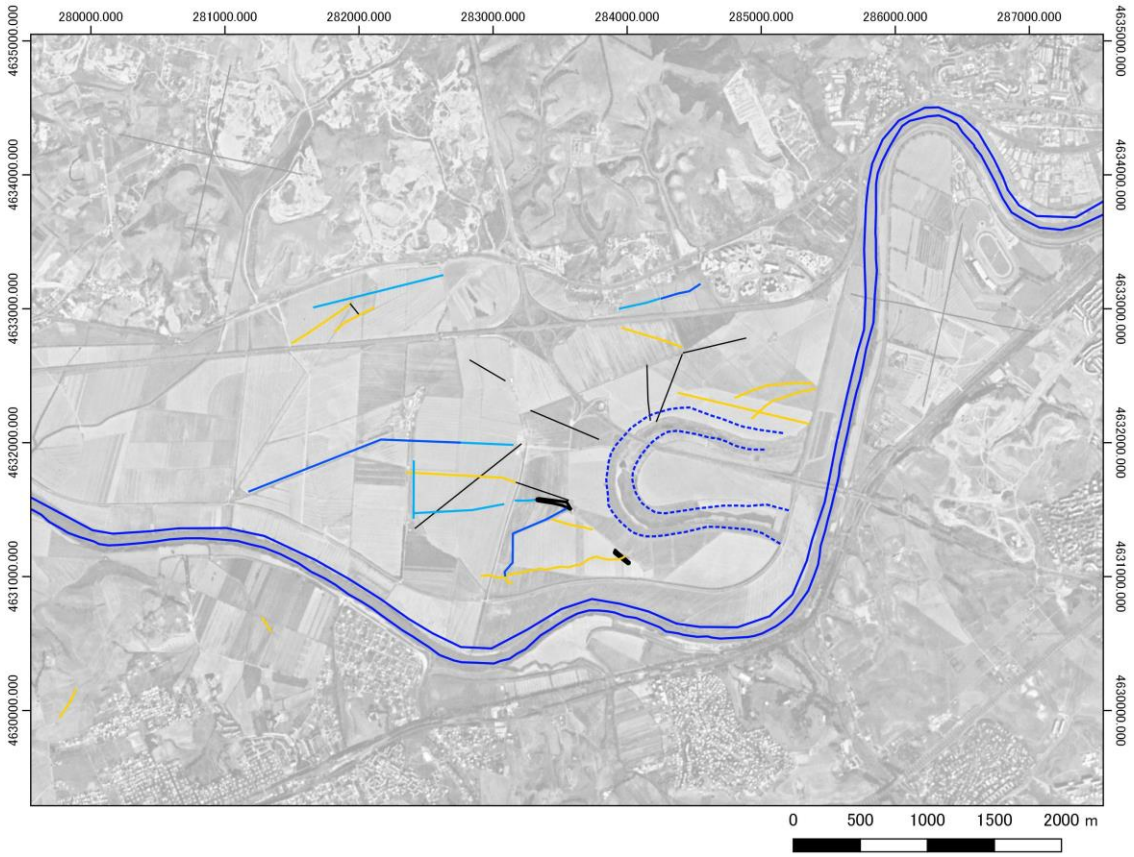

Fig. 14 Surroundings of Tevere river

3.6. Spatial context of the coastal area (around Portus and Ostia Antica)

The interpretation result so far is overviewed in this chapter. Fig. 15 shows the examples of marks and its interpretation result around the coastal area, while Fig. 16 shows the summarized diagram of the area combined with already known information.

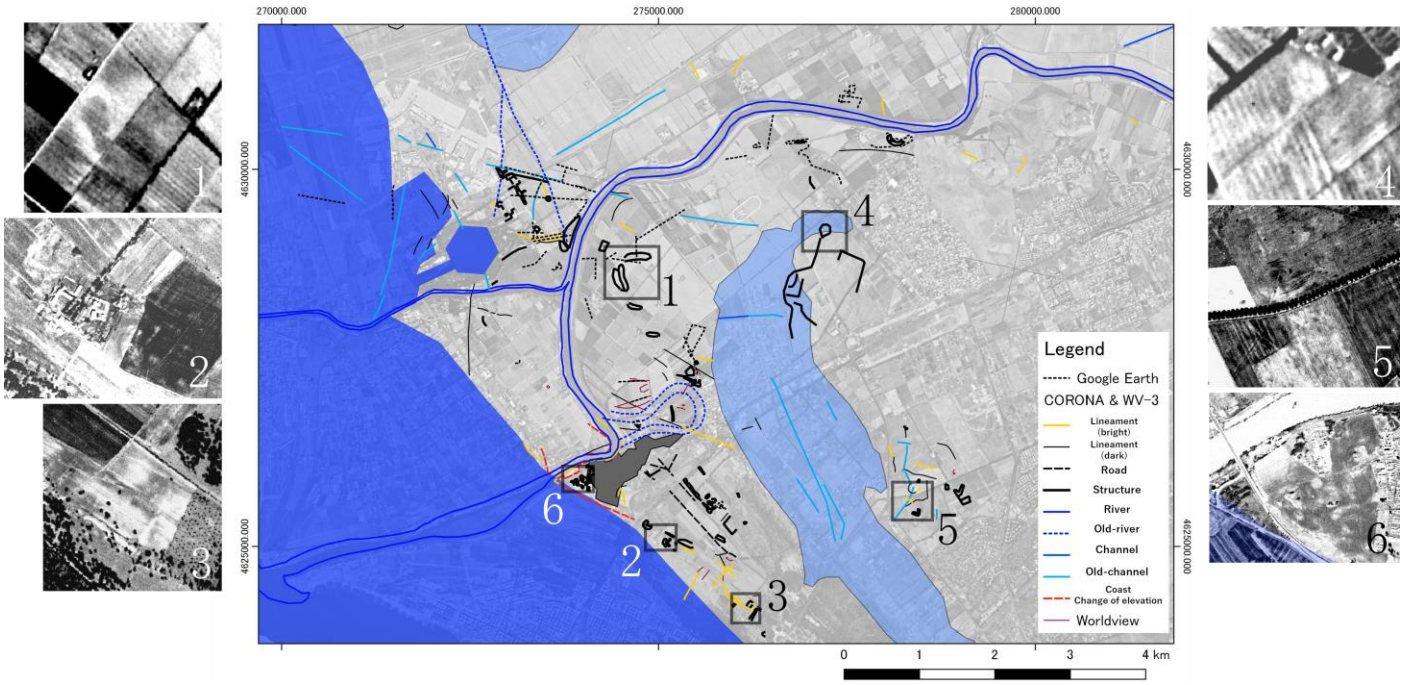

Fig. 15 examples of marks and its interpretation result

The diagram shows the area to be largely divided in coastal area and the area of the east coast of the old-lagoon area. The area east of lagoon is located in the foot of hills in the eastern bank of Tevere river, which is already slightly higher than the surroundings. This comparatively stable area may be considered as an entrance to the land route to the Rome. One of the main route from Ostia Antica (Via Ostiensis) is passing through the salt farm in the old map (Fig. 13). Development of the salt farm is claimed to be started in 7th century BC by Ancus Marius (Vittori et al., 2015), and it is probable that this route was already there when the salt farm was developed. According to Vittori (ibid.), evidence of boring core shows a peat environment through the first half of the 2nd millennium to the first half of the 1st millennium (805 - 553 BC). Considering the estimated depth of some part in the lake in 5th to 4th century BC (i.e. 3.5 – 4.5 m), perhaps the desiccation of the land was still in progress, which may have required for detours (at least road embankment) or canals for access. The absence of land transportation between Portus and Ostia Antica, and possibility of detours from Ostia Antica may be suggested for question to be considered. For example, the “structure” and “lineament” found in the south of Tevere river may include canal or detours. If there are canals connecting the Tevere river and the Ostia Lagoon, this will enable the direct connection between the lagoon and Portus (and coasts near Portus). These problems will be left for future discussion since we do not have enough evidence.

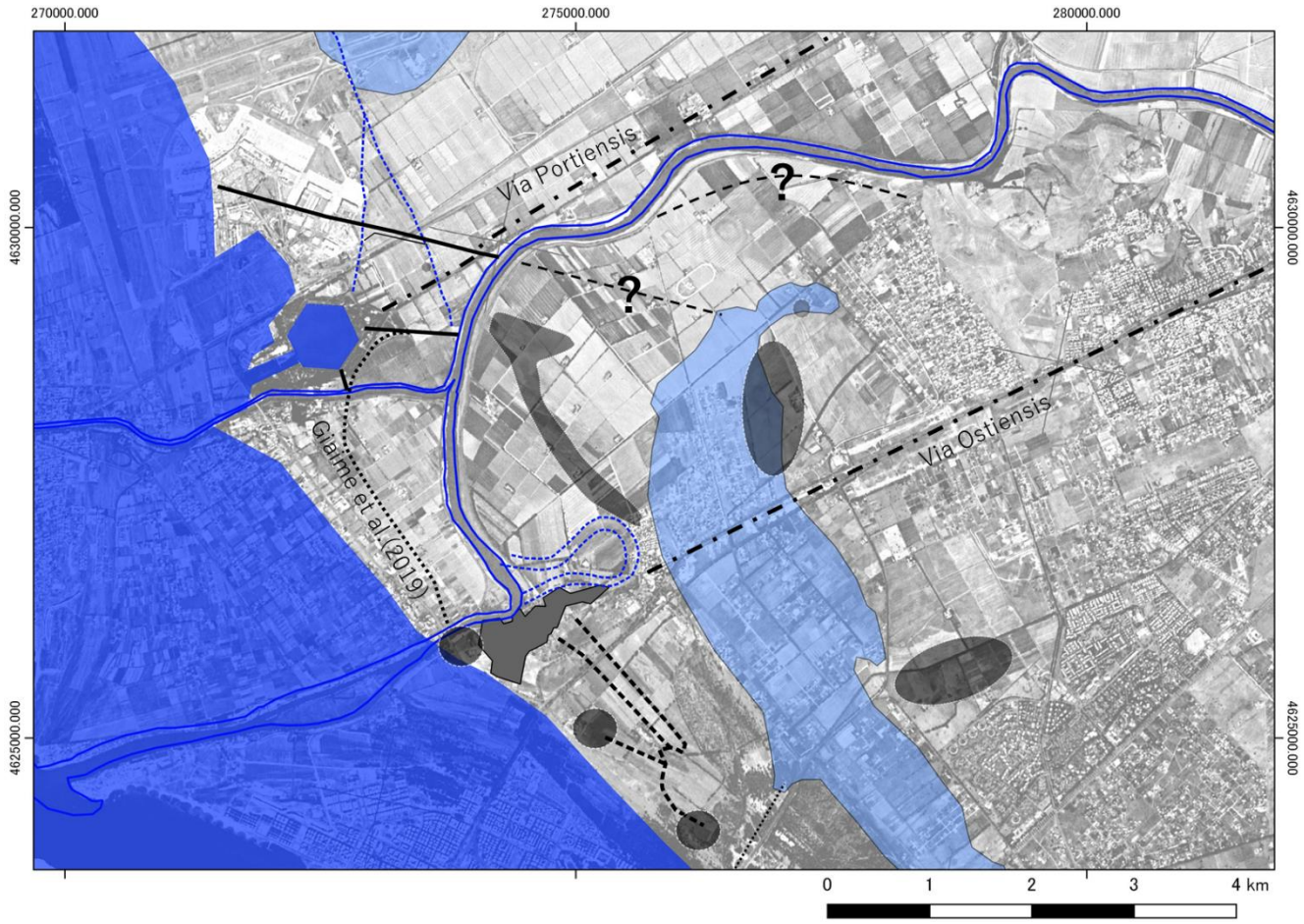

Fig. 16　Diagram map of the coastal area (around Portus and Ostia Antica) . Clustered "Structure"s and clear "lineament"s and "road"s are depicted. The canal between Portus and Ostia Antica is based on the figure from Giaime et al. (2019) (Giaime et al.(ibid.) states that the figure is made based on Goiran et al., 2010, 2014; Vittori et al., 2015; Salomon et al., 2017, 2018).

3.7.　Surroundings of Maccarese Lagoon（Fig. 8 G）

"Structure" was detected in the edge of the Maccarese Lagoon, reconstructed in the map of Goiran et al. (2010) (Fig. 17 A). This reconstruction map of the lagoon shows shorter length in the north-south direction comparing with the others. According to Belloti et al. (2007), the lagoon was comparably dried in 3rd century BC, leaving some part as coastal pond (located at nowadays Fiumicino Airport). The reconstructed map seems to be corresponding to this period. Another mark which draws attention is the opening from the hill side connected to the lagoon. It can be a later period structure for flushing stream water from the hill, but it also gives an impression as a slope from the lagoon. It is interesting that there is a clear trace of circle shaped structure (fort?) in just 400m to the south east from this opening(Fig. 17 C). There are another clear trace of building like "structure"s in the hill side, 1.5km northwest from the opening (Fig. 17 D). Perhaps, this context implies the relation of landing point from lagoon and the structures as its destination.

Fig. 17 Results around Maccarese Lagoon (Photo inside the figure is from KH-9 (upper) and Google Earth (lower)).

4. Summary

The purpose of the study was to seek for the surrounding features around Ostia Antica, to get the picture of their extent. However, not only around Ostia Antica but also the whole coastal plain and adjacent hillsides were interpreted to understand the spatial context of Ostia Antica. As expected, density of the trace of underground features were detected around the Portus and Ostia Antica. The background of this tendency should be the reflection of the intense human activity in the area. Still in stage of initial hypothesis, the diagram was proposed by grouping the clusters of the traces and estimating the connection from "lineament"s. Clear trace of "structure" and relation with old-lagoon (Maccarese Lagoon) was also considered. Perhaps, the circumstances seen near the both old-lagoon (Maccarese and Ostia Lagoon) can be considered as a concrete picture of connection between the coastal to the inland. As it was already stated, remote sensing cannot assure its periods nor its identity of the detected trace. However, besides these limitation, we hope the study may have proposed materials for the further discussion.

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