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Multitemporal aerial and satellite images for the study of the ancient city in Albania: remote sensing application at Apollonia and Phoenike

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***Abstract* – Thanks to the analysis of some recent satellite images, within a CNR-ISPC research project aimed at the realization of a "Historical Aerotopographic Atlas of the ancient city of Albania", it is possible to present a preliminary study of two important ancient cities of Albania, Apollonia and Phoenike, aimed at enhancing some aspects of urban topography. In particular, historical space photos and recent satellite images were particularly useful for identifying traces likely to refer to buried buildings or parts of buildings, in sectors of archaeological areas where archaeological excavations have not yet been conducted.**

I. INTRODUCTION

The study of the ancient cities of Apollonia and Phoenike is part of the research activities promoted within the International Joint Archaeological Laboratories 2021-2022 Project by the National Research Council and is a joint endeavour between the Institute of Heritage Science (CNR-ISPC) and the Institute of Archaeology - Academy of Albanological Studies of the Polytechnic University of Tirana [1]. As part of this project, a "Historical Aerotopographic Atlas of the ancient city of Albania" is being built. The atlas collects, studies and interprets a rich series of aerial photographs taken by Italian institutions (Military Geographic Institute, SARA society of Rome) between 1928 and 1941 and space photos acquired by American spy satellites between the late sixties and early seventies of the last century (Corona KH-4B, Gambit KH-7 and Hexagon KH-9 satellites). This data set will be an essential tool for the study of the ancient cities, until today scarcely used in archaeological research in Albania, and for the knowledge of the transformations of their territories and the reconstruction of historical landscapes at different scales. Indeed, it offers the possibility of identifying a series of data, partly lost today, about the ancient topography of the settlements and the territorial and paleo-environmental contexts in a diachronic perspective from Prehistory to the Middle Ages. For two cities, in particular, Apollonia and Phoenike (Figure 1), which do not present continuity of occupation and are promising for the application of remote sensing techniques using also recent satellite data, high-resolution panchromatic and multispectral images have also been acquired. In this paper, we focus on the contribution that the processing and the archaeological photo-interpretation of these images has brought to the knowledge of these two ancient cities.

II. STUDY AREAS

The ancient city of **Apollonia** is situated in the central eastern part of Albany, in the district of Fier, than 10 km from the Adriatic Sea; it was founded by Kerkyreans and Corinthians in the late 7th cent. BC and over time it expanded over the whole hilly slope including an area of about 85 ha., enclosed by a large city-wall around 4.5 km long and 3 m thick [2, 3]. **Phoenike** is approximately 100 km SE from Apollonia and is located on a hill above a modern town which bears the same name, Finiq and that looked out over the valley of the Bistrica River; it was an ancient Greek city in Epirus and capital of the Chaonians. The first structures date back to the 5th cent. BC, when acropolis started to house a number of public buildings. The earliest phase of the fortification dates back to the middle of the 4th cent. BC, when the urban area was limited on the east side of the hill. The second phase dates back to the middle of the 3rd cent. BC, when the urban area was extended in the centre and west side of the hill [4].

III. PROCESSING AND ARCHAEOLOGICAL INTERPRETATION OF HISTORICAL SPACE PHOTOS AND RECENT SATELLITE IMAGES

Remote data were be applied in the work with the aim traces of ancient human transformations of the landscape create subtle features, namely surface anomalies that are only visible when viewed from above.

Apollonia. The archive of high-resolution satellite images includes, for the area of Apollonia, many images for the years 2004-2005, 2007, 2010-2016, 2018-2022. Some of these are more interesting than others, such as a WorldView-2 acquired in January 2020 and a Pleiadés-1A, collected in February 2022, both with a best spatial resolution of 0.5 m.

Less significant but useful for documentation purposes is also a GeoEye-1 image taken during summer 2019, with the same spatial resolution (Figure 2). The images taken in the winter months seem, in general and more particularly for the lower city, more interesting because of the lack of grass and the shadows generated by the early morning sun have favored the observation of micro-relief marks in two different sectors: the area close to the Nymphaeum and around the Baths [5] (Figure 3).

Multispectral data were be analyzed using standard filtering algorithms available in software to analys remote data as ENVI software and Quantum GIS:

- Slope-based vegetation indices: Normalized Difference Vegetation Index (NDVI);
- Distance-based vegetation indices: Perpendicular Vegetation Index (PVI), Soil Adjusted Vegetation Index (SAVI).

NDVI, the most widely used, quantifies the vegetation's photosynthetic response to red radiation absorption and near infrared reflectance. For most satellites, NDVI is computed from Equation 1:

$$NDVI=(\rho_{NIR}-\rho_{red})/(\rho_{NIR}+\rho_{red})$$

where ρNIR is the reflectance of the near-infrared wavelength band and ρred is the reflectance of the red wavelength band. The computation of the NDVI was used to highlight the vegetation differences during different periods of time, in an effort to pinpoint any vague indications for the detection of new traces. The vegetation differences of the winter time favoured the detection of traces mainly due to the differentiations in the soil's humidity. Application of certain spatial high pass filters contributed further to the spatial enhancement of smaller features. The most reliable of them proved to be Sobel Right Diagonal 3x3 and Laplace 3x3.

Phoenike. A GeoEye-1 satellite image acquired on 28 September 2021 and a cosmic image taken by the American Hexagon KH-9 satellite on 16 July 1975 have been processed and analysed in order to test the potential of remote sensing applications on the Phoenike site.

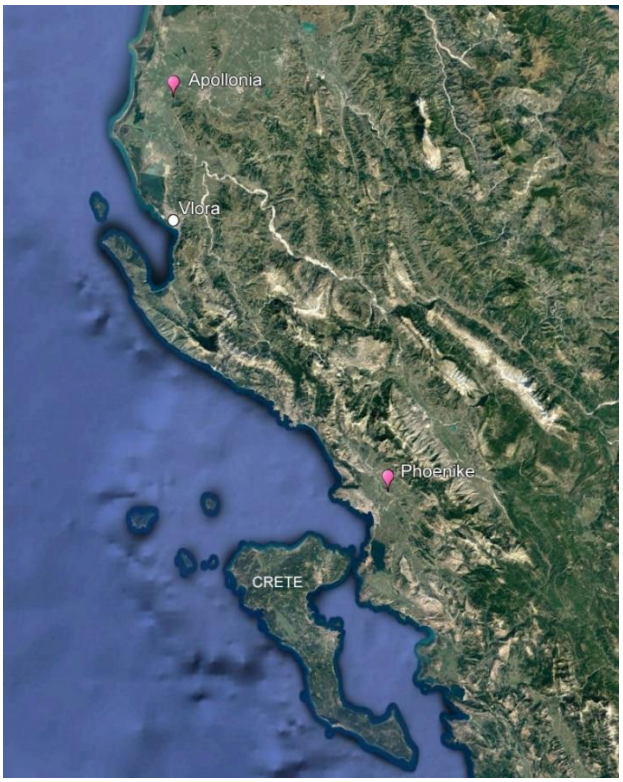

Fig. 1. Location of Apollonia and Phoenike (Albania).

Regarding GeoEye-1 image, the first phase of the processing chain, performed by ENVI Software, was the creation of a pansharpened image through datafusion technique ("Gram-Schmidt" method) of the available panchromatic and multispectral data. This technique was performed to obtain an optimized image which values both the spatial resolution of the panchromatic image (0.50 m - Figure 4) and the spectral resolution of the multispectral image (4 bands but with a resolution of 2 m). The result obtained was a good qualitative image for the discrimination of spatial details and a good quantitative image for the discrimination, especially in this case, of soil marks related to the top of external facings of the ancient walls (Figure 5) and of crop marks related to the shrub vegetation that covers the walls line (Figure 6).

Subsequently the false colours RGB composition of the 4 bands (1- blue; 2- green; 3- red; 4-near infrared) facilitated the preliminary visual analysis of the archaeological elements making it more immediate. In some cases, further modifications also on the histogram of the processed images by the application of linear stretching have enhanced the spectral and radiometric differences of ground surface characteristics (Figure 5).

The elaborated products obtained in .geotiff format have been managed into a GIS platform and compared with the cosmic spatial photo (Figure 7) and the recent edit plan of Phoenike which were also loaded once manually georeferenced.

Fig. 2. Apollonia of Illyria in a GeoEye-1 panchromatic high-resolution image (August 23, 2019).

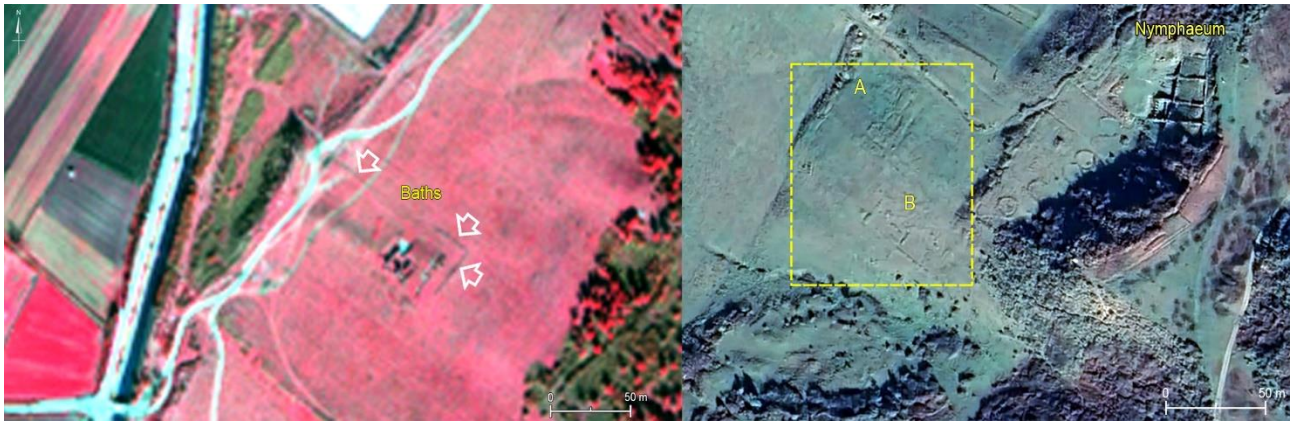

Fig. 3. Apollonia of Illyria. Traces of buried structures close to the Nymphaeum and the Baths in two details of high-resolution satellite images (on the left: WorldView-2, 2020, infrared; on the right: Pleiadés-1A, 2022).

Fig. 4. Phoenike in a GeoEye-1 panchromatic high-resolution satellite image (September 28, 2021).

Figure 5. Phoenike. Sections of the ancient walls clearly visible in an enhanced RGB composition of pansharpened image obtained by datafusion of panchromatic and multispectral data of a GeoEye-1.

IV. CONCLUSIONS

The analysis of the available remote sensing data set regarding Apollonia of Illyria has highlight the presence of possible buried structures immediately SW of the Nymphaeum and in the area of the Baths. Close to Nymphaeum many traces apparently pertaining to two different buildings are visible (Figure 3, A-B). The alignment of the buried structures seems to adapt to the general orientation of the monuments brought to light in the lower city and to the hypothesized urban layout. Close to the thermal baths, the satellite images reveal the presence of a linear track, partly given by residual humidity and partly by micro-relief marks, which seems to draw a sort of rectangular perimeter around the excavated monument (Figure 3).

Regarding Phoenike, the availability of GeoEye-1 satellite image has allowed to test the potential of remote sensing applications through specific data processing chains for the investigation of some sections of the ancient city walls (Figures 5-7). While, the availability of a cosmic image taken by the American Hexagon KH-9 satellite in 1975 has made it possible to identify a section of the north-eastern walls of Phoinike in a more complete and clearer way than what is visible in the recent satellite image and in the more recent plan of the city (where in this sector, the layout of the wall is incomplete for a short segment) (Figure 7).

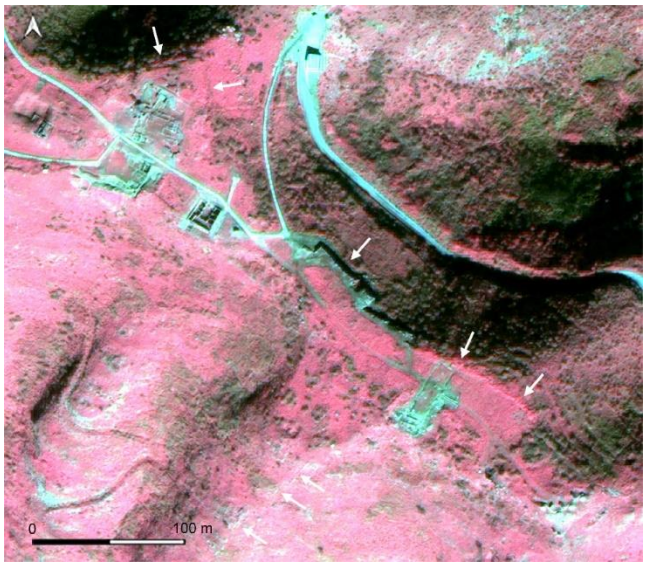

Figure 6. Phoenike. Sections of the ancient walls visible in a false color RGB composition of pansharpened image obtained by datafusion of panchromatic and multispectral data of a GeoEye-1.

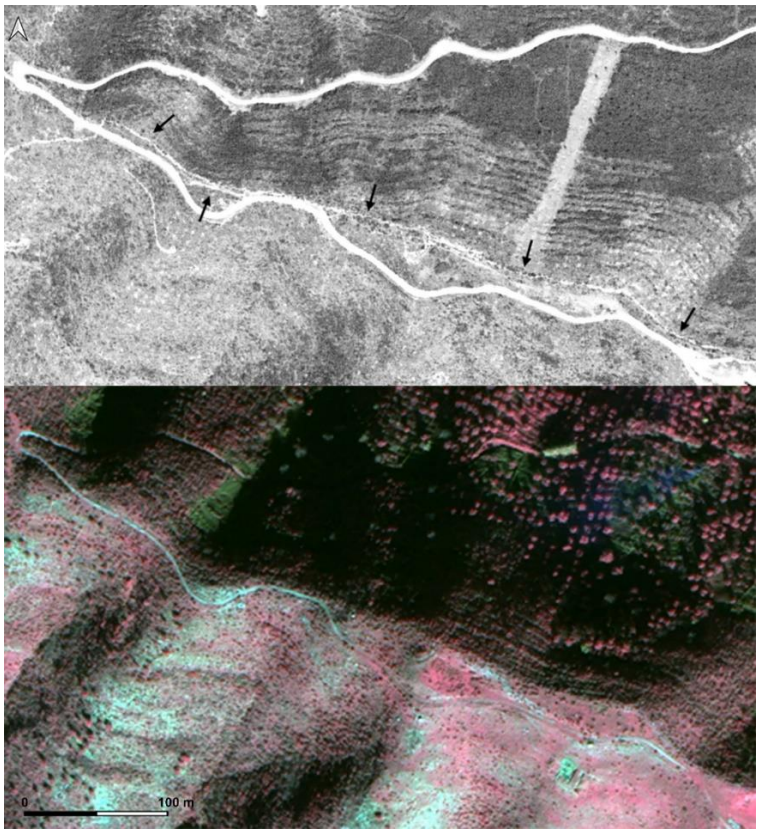

Figure 7. Phoenike. Sections of the ancient walls line clearly visible in a georeferenced KH-9 Hexagon space photos of 1975 (above); the same sections of the walls, little or not at all visible, in a false color RGB composition of pansharpened image obtained by datafusion of panchromatic and multispectral data of a GeoEye-1 (below).

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