Geoarchaeological remote sensing survey for cultural heritage
management. Case study from Byblos (Jbail, Lebanon).

Jean-Paul Derooin^{1*}, Rania Bou Kheir^{2†} and Chadi Abdallah³

¹. Université de Reims Champagne-Ardenne, Faculty of Science, GEGENAA EA
3795, FR CNRS 3417 Condorcet, 2 esplanade Roland Garros 51100 Reims,
France, jean-paul.derooin@univ-reims.fr, phone 33 (0)3 26 77 33 76, fax 33 (0)3
26 91 32 94, Dr, Professor of Geology and Remote Sensing.

* Corresponding author.

². Lebanese University, [†]deceased

³. National Council for Scientific Research, Remote Sensing Center, Beirut,
Lebanon, chadi@cnrs.edu.lb, Dr, Associate Researcher in Remote Sensing and
GIS

Abstract

The ancient city of Byblos (Jbail, Lebanon) provides one of the primary examples of urban organization in the Mediterranean world. This multimillenary city bears an exceptional testimony to the beginnings of the Phoenician civilization. The site covers an area of 10 ha located along the coast. The present paper deals with the synthetic mapping of the archaeological site and its environment using remote sensing techniques. Very high resolution imagery is vital for monitoring any archaeological site in its widest context. In the specific case of Byblos the comparison of the Orbview 3, Ikonos 2 and Geo-Eye 1 digital data indicates that a spatial resolution of about half-a-meter is necessary for archaeological purposes and particularly for mapping the walls and the buildings. The use of Corona archive acquired in 1970 allows mapping the archaeological site and its coastal environment before the Lebanese civil war. This multitemporal approach allows us to evaluate the sensitivity of the archaeological site to external factors such as the coastal erosion, the cliff degradation, and the urban growth. It also helps to better plan the improvement of the site for touristic purposes.

Keywords: Geoarchaeology/Byblos/Lebanon/Remote sensing/VHR
satellites/Geo-Eye/Ikonos/Orbview 3/Corona

Research aims: This work deals with surveying the coastal archaeological site of Byblos, Lebanon. The site is located on a cliff along the Mediterranean Sea. In

order to map changes along the cliff, multitemporal very high resolution (VHR) remote sensing data have been used over about 45 years.

1. Introduction

The field of cultural heritage management strives to identify, interpret, and protect archaeological artifacts and sites. Remote sensing technologies have made important contributions to this field in the last two decades [e.g. Agapiou2015].

Combinations of remote sensors are allowing archaeologists to predict the location of new sites or to find subterranean features and determine the historical extent of known sites. Once the sites have been identified, remote sensing technologies including GIS can help analyze the spatial uses of the site and detect risk of natural or anthropogenic hazards.

Remote sensing geoarchaeology uses the techniques, methods, and concepts of the aerial and space sciences to address archaeological questions. Examined here are the techniques of remote sensing geoarchaeology that are geared toward documenting the internal structure of the archaeological sites of Byblos, surveying site formation and disturbance processes and the impact of humans on this coastal Mediterranean landscape.

Byblos is one of the most famous archaeological places in the world, particularly because it was an important Phoenician center along the Levantine coast (Fig. 1). The site ($34^{\circ}07'08''\text{N}$ - $35^{\circ}38'46''\text{E}$) is located on a mound adjacent to the current town of Jbail along the Mediterranean coast of present-day Lebanon, about 35 km north of Beirut (Fig. 2 and Fig. 8, A).

Insert Figure 1 about here

Insert Figure 2 about here

The archaeological site is a typical “tell”, a mound containing the debris of human occupation that has accumulated at a site, built up in successive layers over the centuries through a sequence of habitation, destruction, and reconstruction. As early as 1984 UNESCO inscribed Byblos as a cultural World Heritage Site, recognizing the historic value of the ruins of many successive civilizations found there.

The ruins of Byblos were rediscovered by successive French missions. Ernest Renan found the site in 1860. Excavations were begun by Pierre Montet in 1921 [Montet 1928] and continued by Maurice Dunand until the mid-1970s [Dunand, 1973 and 1976], then interrupted by the Lebanese civil war. The archaeological excavations have revealed that the site of Byblos was occupied at least for over 6,000 years, i.e. from the Late Neolithic period onward [5].

The archaeological remains cover only 10 hectares on a cliff of Quaternary sandstones, the so called “ramleh”, overlying Cretaceous limestones and marls [1+ Fevret Sanlaville 1965]. The coast is characterized by well-developed uplifted subtidal bioconstructions. Elevated fossil benches along the Lebanese coast were first reported 40 years ago and interpreted as elevated eustatic shorelines, lasting from the 2nd century BC to the 3rd century AD, a period called the “Tabarjan” [1, 2]. Pirazzoli (1976) interpreted them as possible evidence for the “Early Byzantine Tectonic Paroxysm” (EBTP) [3]. In northern Lebanon, evidence of megablocks

left by extreme waves around Tripoli and Byblos was presented by Morhange et al. (2006) [4].

Although less studied than the buried urban harbours of Berytus (Beirut), Sidon (Saida), and Tyre (Sour) [6, 7] (see also Fig. 2), Byblos (Jbail) was a major ancient Mediterranean harbour located in an area characterized by cliffs and an abrasion platform along the shoreline. Therefore, the place is particularly sensitive to environmental changes such as the sea level rise [8], landslides or block tilting.

2. Methods

2.1. Research aims

Geoarchaeological investigations have been launched in Byblos in order to (1) identify the main building stones used on the site from the Bronze Age onward and (2) synthetically map the archaeological site using remote sensing techniques. The present paper deals with this second goal with a focus on the general land use and the environment of the archaeological remains. Byblos provides an exceptional testimony to the urban organization in the Mediterranean world. Excavations at Byblos allow identifying a continuous setting from the Neolithic period onward, including the Bronze Age, the successive Phoenician, Egyptian, and Roman periods, and finally the Middle Age.

Since the early 2000's, very high resolution (VHR) imagery opened new perspectives for archaeological and cultural heritage studies. The interest of the Corona archive imagery has been highlighted by many authors [9-11]. The use of VHR imagery partly available on Google Earth for archaeological prospection has

been also mentioned for the study of remote areas [12]. Therefore, we combined and compared all the VHR imageries available on the test site.

2.2. Satellite data used

We used very high resolution Ikonos 2, Orbview 3 and Geo Eye 1 recent imageries in order to precisely map the site with spatial resolution equal or less than one metre (Table I). Moreover, we exploited Corona KH-4B data acquired in 1970. These data are vital to evaluate the state of the archaeological investigations at Byblos before the Lebanese civil war, which started in 1975. It is also important to consider the site in its widest context from the coastal plain to the Mount Lebanon foothills including topographic and hydrologic features. The comparison of the current and archive remote sensing datasets allows us to evaluate the sensitivity of the archaeological site to external factors such as the coastal erosion, the cliff degradation or the urban growth.

2.3. Data processing

The choice of the best date is an important aspect because some data cannot be used. Radiometric quality of the data and cloud cover at the time of registration are the main problems encountered. The set of satellite data has been geometrically rectified and resampled at the resolution of the GeoEye 1 data. The most important geometric correction is that applied for the Corona data. For the other data a relatively simple resampling is applied. For Geo-Eye 1 and Ikonos 2 we used pansharpening, the process of merging high-resolution panchromatic and

lower resolution multispectral imagery to create a single high-resolution color image.

Using the dataset we focus here on the general mapping of the monuments with a specific emphasis on the role of the spatial resolution for a detailed mapping.

Then, we envisage the archaeological site in its widest context with a study of the urban growth perceived by land-use changes. We finally place the site in the natural environment of the coastal cliff which suffers degradation and erosion/sedimentation phenomenon as well.

3. Results

3.1. Map of the different monuments

The Ikonos scene acquired in June 2005 was processed to obtain a true color composite. It allows delineating the main archaeological remains of Byblos (Fig. 3). The buildings and remains are named chronologically (see figure captions). Yellow numbers (2-3) correspond to the Prehistoric period, purple numbers (4-13) correspond to the Bronze Age, red numbers (14-17) correspond to the Amorite and Hyksos periods, light green number (18) corresponds to the Iron Age (Persian period), dark green numbers (19-21) correspond to the Roman period and blue numbers (22-23) correspond to the Medieval period.

The main spring (1) at the origin of the settlement is precisely located at the center of the mound. It is about 22m deep. The synthetic view allows detecting all the former networks and buildings of the archaeological site. The most recent are clearer, for example the Roman setting with the Roman road (19), the Nymphaeum

(20) and the Roman Theater (21, see also Fig. 8, C). The largest monument is the Crusader Citadel (22, Fig. 8, A) in the north of the site, but the place of the Persian Fortress (18, Fig. 8, H) in the north-east is also obvious. Close to the Royal Necropolis (16) and the Roman Theater (21), the track of the 1922 coastal landslide is clearly visible (25). This landslide revealed to the archaeologists the location of the Royal Necropolis. Due to the shadow, the Amorites quarries (15) exploiting the Quaternary sandstones (ramleh) are well expressed as the spring.

Insert Figure 3 about here

3.2. Evaluation of the spatial resolution

Even if the spatial resolution of Ikonos (1m) is sufficient for mapping the monuments in their widest context, a detailed analysis of each building needs the better resolution as possible. In the specific case of Byblos, we compared recent VHR data from Ikonos 2 (1 m ground resolution) and Geo-Eye 1 (0.5 m ground resolution), this latter being available on Google Earth (Fig. 4). The comparison is carried out using an area including the indented ramparts (11, Fig. 3), the glacis of the Hyksos period (17, Fig. 3), the Crusader Citadel (22, Fig. 3), and the Residential Quarter of the Bronze Age (9, Fig. 3). Basically, with its 50cm-off nadir resolution, Geo-Eye is the first civilian mission allowing the mapping of archaeological remains to be correctly done. For example, the shape of the indented ramparts (1, Fig. 4) and the walls of the Residential Quarter (2, Fig. 4) can be compared in each image. Photograph D (Fig. 7) precisely shows the indented ramparts and the Residential Quarter in the field. Note that Geo-Eye was

acquired in August, when Ikonos was acquired in June, i.e. with a higher sun elevation and subsequently less expressed shadowing (see for example the south-west wall of the Crusader Citadel, 3, Fig. 4).

Insert Figure 4 about here

3.3. Evolution of the land use.

Having proved the interest of VHR remote sensing data for the study of both the archaeological remains and the general settlement, the comparison of the current and archive remote sensing datasets can also help to evaluate the sensitivity of the archaeological site to external factors. Based on Corona imagery and recent Geo-Eye data, Figure 5 shows how the land use deeply changed during the last 45 years. In 1970, Jbail is a small city (B, Fig. 5) mainly concentrated to the north of the archaeological site (A, Fig. 5) and directly linked with harbour activities. The new harbour was built recently (F, Fig. 5, see also Fig. 7, B) and other fittings such as a pier were constructed in the north of Ras Byblos. In 1970 along the coast, the first kilometer is mainly dedicated to agricultural activities (C, Fig. 5, in dark tone) with some isolated farms. To the East, a 500m-large fringe with more concentrated houses and farms appeared (D, Fig. 5) and then the arid limestone massif mainly dedicated to pastoral activities (E, Fig. 5). In 2013, the setting is totally different and Jbail comprises 40,000 inhabitants (probably two to three times the number in 1970, although no census is available at that date). No more traditional agricultural activities in the coastal region of Jbail, replaced by new buildings extending more than 2km (H, Fig. 5, see also Fig. 7, H), and modern

equipment (for example, touristic fitting related to El Skhiny Bay, G, Fig. 5) or the motorway linking Beirut to Tripoli (I, Fig. 5). Only some areas of greenhouses and large fields could be observed, particularly in the south of the urban area (J, Fig. 5).

Insert Figure 5 about here

3.4. Survey of the coastal erosion and cliff degradation.

The comparison of the Corona KH-4B imagery (left) and Ikonos imagery (right) highlights changes due to the coastal erosion and the cliff degradation during the last decades (Fig. 6). In this Mediterranean site, the main erosional problems are due to the sea-level changes. The abrasion platform is currently at the outcropping limit (see Fig. 7, E).

The coastal erosion is important in the southern part, in the El Skhiny Bay, where a lot of touristic fittings have been made during the two last decades (Fig. 6 and Fig. 7, G). The extent of the harbour fittings involves erosion to the south and sedimentation to the north due to the interference with the littoral drift.

The cliff degradation is particularly visible close to the 19th century building, at Ras Byblos (Fig. 6 and Fig. 7, F). The track of the 1922 landslide is clear and other mass-movement could occur along the coast of the archaeological site.

Insert Figure 6 about here

Insert Figure 7 about here

4. Discussion and conclusions.

Basically, remote sensing is the discipline dealing with the electromagnetic signal reflected by the earth's surfaces and remotely sensed by airborne or spaceborne sensors. The main goal of remote sensing is to identify features on the earth's surface, which are difficult if not impossible to detect in the field. The main characteristics of the terrestrial surfaces include spectral, textural, and structural aspects. The spectral characteristics of the natural materials allow discriminating different types of vegetation, soils, and rocky surfaces. Therefore, remote sensing covers a wide range of application in archaeology from global to detail (at the meter scale).

Since 1972 and the launch of the first digital sensor on-board Landsat 1, the spatial resolution of the Earth observation satellites has considerably improved. Very high resolution could be defined for pixel size less or equal to 2m. Between 2 and 30m, the spatial resolution is simply high, corresponding to one major advance with the launch of Landsat 4 in 1982. The most classical method in geoarchaeology is the identification of crop marks from aerial photographs, but satellite image is now frequently used [13] and could be at the origin of the feasibility of an archaeological operation within the framework of a surveying inventory [11]. Whereas the spatial resolution is important, the spectral range plays also a key role in remote sensing, because multispectral information is one of the main advantages of the satellite imagery. Unfortunately, the best resolution

could be only obtained in the visible range for physical reasons. Because in geoarchaeology this highest spatial resolution is needed, the panchromatic sensor is generally used, even with Orbview 3 the data of which are mainly acquired in multispectral mode. The spatial resolution of the panchromatic sensor is four times better than the resolution of the multispectral mode. With Ikonos 2 and Geo-Eye 1 we used pansharpening, the process of merging high-resolution panchromatic and lower resolution multispectral imagery in order to take benefit of both the spatial resolution and the multispectral information. Other paths of research such as lidar [14] or hyperspectral imagery [15] have also proved to be of great interest for archaeological prospection.

The remote sensing survey of ancient large cities is relatively rare compared to the studies of rural landscapes. However, using simple Landsat TM colour composite and classical treatments for enhancing spectral features, Aminzaneh and Samani [] identified remnants of guard wall, watchtowers, and other unknown archaeological residues in Persepolis, Iran. Development of the urban structure at Altinum, Venice Lagoon, Italy, has been illustrated by the combined analysis of very high resolution data and field geophysical survey leading to the identification of archaeological structures preserved below the plough horizon [Mozzi et al]. An integrated strategy of prospection, associating both ground-based non-destructive methods and remotely sensed data has been used to understand the character and development of the archaeological landscape of Portus, the port of Imperial Rome [Keay et al]. Ground-penetrating radar (GPR) and high-resolution satellite synthetic aperture radar (SAR) were combined to further interpret the complex archaeological landscape of the Early Angkorian capital, Hariharalaya, Cambodia [Sonnemann]. Leucci et al show that multitemporal remote sensing data allow the

identification of many traces related to filling of channels and ditches in the case of the archaeological site of San Rossore near Pisa, Italy. Agapiou et al [] assess the risk of natural and anthropogenic hazards for cultural heritage by integrating multi-temporal GIS and earth observation analysis, in the area of Paphos District, Cyprus.

Declassified CORONA satellite images from the 1960's and 1970's were first used for crop mark identification in Southern England [16] and in combination with multispectral ASTER data to identify linear features and new sites in the former Mesopotamia [17]. CORONA data were also exploited in the Altai Mountains by Goosens et al. [9] using the stereoscopic capability of the images. More recently, the potential and the limits to the application of a research strategy using remote sensing in mountain archaeology has been discussed using testsite in North Caucasus, Russia [Reinhold et al]. In the present study, the CORONA imagery reveals the past landscape before the Lebanon civil war and the considerable urban growth of this place located along the Mediterranean coast. It is also a reference to survey the coastal changes.

As soon as the early 2000's archaeologists began using the new generation of very high resolution satellite imagery [18, 19]. Very high resolution (VHR) imagery is the unique data source for archaeological prospection in Byblos or in other parts of Lebanon, a country where aerial photography suffers a restricted use. Although VHR imagery is available since the very last years of the 20th century, Geo-Eye 1 with its 50cm ground resolution is the first to provide relevant information for drawing the remains in the Byblos site. Ikonos 2, Orbview 3 and Geo-Eye 1 imageries help to detect the changes in the land use, the cliff degradation, and the erosion/sedimentation along the coast. The erosion of the northern part of the El

Skhiny Bay (Fig. 7, G) is probably the most dangerous phenomenon to monitor in the next decades. Landslides such as the 1922 landslide could also occur in the area close to Ras Byblos.

Satellite imagery alone cannot provide all the necessary information to understand the historic landscape and an archaeological site such as Byblos, but when it is combined with more traditional techniques it can prove a very valuable tool. The combination of different VHR images is now necessary for a multisensor and multitemporal approach of an archaeological site covering 10 hectares. The satellite imagery can also be used to properly draw a plan of the remains and the tracks to be used by the visitors.

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Figures

Figure 1. The Levantine coast as viewed by the MERIS sensor (European Space agency data)

Figure 2. Map of Lebanon showing the main cities and the Phoenician harbours (names in italics)

Figure 3. Map of the archaeological remains using the Ikonos imagery.

1. The main spring. 2. Chalcolithic habitats (ca 4,000 BC). 3. Proto-urban setting (ca 3,200 to 3,000 BC). 4. Temple with the Obelisks (ca 2,700 BC). 5. 'L-shaped' temple ca 2,700 BC). 6. Temple of Baalat Gebal (ca 2,700 BC). 7. Ancient ramparts (before 2,500 BC). 8. Main gate of the city (Bronze Age, IIIrd and IInd mill.). 9. Residential Quarter (Bronze Age). 10. Foundations of Bronze Age habitats. 11. Indented ramparts (IIIrd mill.). 12. Great Residence (Bronze Age). 13. Pre-amorite buildings (ca 2,500 to 2,200 BC). 14. Foundations of Amorite buildings (2,100 to 2,000 BC). 15. Amorites quarries. 16. Royal Necropolis (IInd mill.). 17. Glacis from the Hyksos period (1,725 to 1,580 BC). 18. Persian fortress (555 to 333 BC). 19. Roman road. 20. Nymphaeum (IInd c. AD). 21. Roman Theater (218 AD). 22. Crusader Citadel (12th c. AD). 23. Saint-John the Baptist

Church (12th c. AD). 24. 19th c. building. 25. 1922 landslide. 26. Abrasion platform.

Figure 4. Comparison of Ikonos and Geo-Eye imageries in an area of the archaeological site of Byblos corresponding to the Crusader Citadel (upper right), the indented ramparts(center) the glacis of the Hyksos period (up) and the Residence Quarter (lower left).

No 1 to 3: 1. Crenulation of the ramparts. 2. Walls of the Residential Quarter. 3. Shadow (south-west wall of the Crusader Citadel) (see text for explanation).

Figure 5: Evolution of the land use between 1970 (Corona KH-4B) and 2013 (Geo-Eye 1). The Corona imagery has been geometrically corrected to be superimposed with the Geo-Eye 1 imagery.

A. Archaeological site of Byblos. B. Jbail historical center. C. Agricultural area extent (1970). D. Farm area extent (1970). E. Pastoral area (1970). F. New harbour and fitting (2013). G. Touristic fitting (2013). H. Urban area extent (2013). I. Motorway Beirut-Tripoli. J. Modern agricultural activities.

Figure 6: Byblos as seen with Corona KH-4B imagery acquired in June 1970 (left) and Orbview 3 imagery acquired in July 2006 (right). 1. Track of the 1922 landslide. 2. Main erosion area near Jeziret El Jasmine.

Figure 7. Photographs.

Captions. A. View of the archaeological site from the Chalcolithic habitats (south) to the Crusader Citadel (north). B. View to the north showing Saqiet Zaidane Bay, the harbour and the area affected by the 1922 landslide. C. The Roman Theater. D. The indented ramparts and the Residential Quarter from the Crusader Citadel terrace. E. The abrasion platform (view to the south). F. Ras Byblos (view to the north-west). G. Jeziret (islet) El Jasmine, El Skhiny Bay, and the eroded shore. H. Development of the urban area (view to the east showing part of the Persian Fortress). A, C, D, and E dated July 2011. B, F, G, and H dated January 2010.

Table I. Satellite data used for the study of Byblos. GE (source is Google Earth)

Satellite/Sensor	Date	Spectral mode	Resolution
Ikonos 2	15 06 2005	Pansharpened (GE)	1m
Orbview 3	31 07 2006	PAN	1m
GeoEye 1	12 08 2010	Pansharpened (GE)	0.5m
Corona KH-4B	08 06 1970	PAN	1.83m

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