“Palaeogeographic evolution of the coastal zone of Byblos (Lebanon, Eastern Mediterranean), using marine remote sensing techniques”
Abstract

Byblos has been the most inhabited place through the ages, so it is a key region in understanding the development and the evolution of seafaring and shipping, providing one of the richest and most continuous maritime archaeological records in the Mediterranean. Archaeological surveys have shown a continuous contact of Byblos people with Egyptians. The Egyptians were in need of cedar wood which was plentiful in Byblos area, in trade of Egyptian pottery, palettes, jars, copper ores and artifacts.

The Byblos marine remote sensing survey is an ongoing research project conducted by College de France and Laboratory of Marine Geology and Physical Oceanography within the framework of the "Byblos et la mer" project. The project is designed: a) to obtain detailed bathymetry of the coastal zone of Byblos, b) to define the seismic stratigraphy of the recent sediment sequence, c) to define the evolution of the coastline configuration at the Byblos over the last 18000 yrs BP based on the mapping of palaeo-bathymetry and potential morphological features related with submerged palaeo-shorelines, d) to detect targets (surface and subsurface) of potential archaeological interest.

The survey was planned and carried out between the 8th and 21st of June 2014. In order to meet the objectives, the following set of geoacoustical systems was used: a sub bottom profiler 3.5 kHz, an “EG&G 272 TD” side scan sonar and a digital single-beam echosounder Elac Nautic Hydrostat. A Hemisphere V100 GPS system with accuracy of approximately 1.5 m was used for the navigation and the positioning. A total area of 8 km² was covered by the marine remote sensing survey.

Byblos coastal area shows great palaeographical interest as the coastal plateaus, which are detected by the present survey, are indicators of sea level. Three main shallow plateaus were found underwater in the coastal area of Byblos which might be sea level change indicators. The Jasmine bay is also of great importance because of a local anomaly found in the bathymetry north of the Jasmine islet, which might witness an anthropogenic intervention. Moreover, many targets of potential interest were detected on the seafloor and should be ground-thruthed.

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1. STRUCTURAL & GEOLOGICAL FRAME OF LEBANON

The eastern Mediterranean is a tectonically active area dominated by subduction, continental collision and transform faults that surround the Levantine basin, caused by the relative motions of Anatolian, African, Arabian and Sinai crustal plates (Salamon et al., 2003; Faccenna et al., 2006; Reilinger et al., 2006; Schattner, 2010; Sivan et al. 2010). Since the Neogene the northern part of the margin, north of the Carmel structure, is being reactivated due to relative motion between Sinai and Arabian plates along a nearby transform plate boundary — the Dead Sea fault (DSF) (Schattner et al., 2006; Elias et al., 2007; Carton et al., 2009; Sivan et al. 2010). At present, both Arabian plate and

Fig. 1.1 Simplified geological map of Lebanon together with the 1993 reflection seismic line offshore Tripoli(S0,S1). Map compiled from Dubertret (1955), Ukla (1970) and Beydoun and Habib (1995).
Sinai sub plate are moving northward towards Eurasian plate yet in different rates. The resulting relative slip rate across the Dead Sea fault is 4-5 mm/y (Gomez et al., 2007; Sivan et al. 2010)(fig.1.1). The Levant continental margin is a remnant of the Late Paleozoic–Early Mesozoic continental breakup phases that formed the eastern Mediterranean basin (Garfunkel, 1998). Continuous and gentle subsidence accentuated by local Jurassic rifting along the Levant Margin is believed to have been accompanied by the deposition of widespread, mostly shallow-marine, Triassic and Jurassic sediments (Stampfli et al., 2001). The Palmyride Basin was destroyed during Syrian Arc.

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**Fig. 1.2** Modified tectono-stratigraphic column for Lebanon with the interpreted depositional environments of the various rock units (Dubertret, 1955; Renouard, 1955; SaintMarc, 1980; Picard and Hirsch, 1987; Walley, 2001; Nader, 2004)
deformation (inversion and folding) which was initiated during the latest Cretaceous (Brew et al., 2001; Walley, 2001; Wood, 2001; Nader, 2004). The stratigraphy of the Levantine margin consists of cyclically deposited sub- and supratidal carbonates, evaporites and continental clastics (Benjamini et al, 1993; Buchbinder and Le Roux, 1993; Nader, 2004). Marine deposition occurred in Lebanon without interruption until the Late Jurassic when major tectonic movements began (Dubertret, 1955; Renouard, 1955; SaintMarc, 1980; Picard and Hirsch, 1987; Walley, 2001). This tectonism affected this Jurassic carbonated succession, deforming central-northern Mount Lebanon (Dubertret, 1955; Walley, 1998; Nader, 2004). Marine conditions returned during the Aptian followed by a major transgression in the Cenomanian, with a rock unit thickness of 600m. Due to the emergence of Mount Lebanon related to the deformation of the Syrian Arc, shallower marine conditions characterized Late Turonian (Nader, 2003). Marine deposition persisted in isolated depocenters until the Middle Eocene (Dubertret, 1955), when Mount Lebanon emergence from Late Eocene to Late Oligocene was observed during a second phase of Syrian deformation (fig 1.2).
In the Neogene, the opening of the Red Sea and activity on the DSF system accentuated the uplift of Mount Lebanon, which resulted in the present topographic structure. The Lebanese carbonate platform is cross-cut by a major transform fault, the Yammouneh Fault, which represents the northern extension of the DSF system along with other relatively minor faults (Sabbagh, 1961; Dubertret, 1975; Beydoun, 1977; Khair et al., 1993; Nader et al. 2006). Summarizing, in order to better understand the evolution of the Levantine margin as well as the Levantine basin, 2d -maps are presented (fig. 1.3), (Hawie et al., 2013), showing the palaeo-geographic evolution from the Jurassic to present day.

Fig. 1.3 Paleo-geographic maps summarizing the depositional environments prevailing in the Mesozoic and Cenozoic periods. The offshore facies have been deduced from the seismic interpretation (see results) and published data from the Levant Basin (e.g. Gardosh et al., 2008; Bowman, 2011; Montadert et al., 2013) while the onshore sedimentary facies are based on previous works cited in the text (e.g. Dubertret, 1975; Saint-Marc, 1972, 1974; Bou-Dagher Fadel and Clark, 2006; Hawie et al., 2013).
1.1 STUDY AREA

The offshore area of Byblos, our study area, is located in the eastern Mediterranean, north-central Lebanon and located about 42 km north of Beirut and is limited to an area of 11 km² (fig. 1.1.1).

The bedrock of Byblos area consists of shallow marine carbonate platform with some volcanic covered from quaternary loose deposits (siliciclastic, conglomerate). The carbonate platform is cross-cut by a major transform fault (Yammouneh Fault), which represents the northern extension of the Dead Sea Fault system along with other relatively minor faults (Sabbagh, 1961; Dubertret, 1975; Beydoun, 1977; Khair et al., 1993; Nader et al. 2006), slicing the platform into large canyons, which were widened by the erosion over the times. The main sediment income comes from “Nahr Ibrahim” river which is located closest to the study area and as secondary source is “Nahr el litany”, “Nahr el aouali” and a smaller participation of the Nile River.

Fig. 1.1.1 Map showing the purview of the study area and the tracklines
The study deals with the most recent stratigraphy of the offshore region concentrating on a thick unit with a maximum of 15m thickness of stratified sediments which overlies the acoustic basement as it was found by the 3.5kHz sub bottom profiler (fig.1.1.2).

The only correlation between on shore and offshore seismic data is the schematic section of Hawie et al, 2013, where the bedrock consists of Early to Late Cretaceous thick limestone and marl while the upper unit includes Neogene loose sediments (silicidastic, conglomerates) (fig. 1.1.3).
2. SEA LEVEL FLUCTUATIONS AND CHANGE INDICATORS

2.1 SEA LEVEL

Sea level is defined by the position of the sea surface relative to the adjacent land. Sea-level change is a measure of the relative shift in position of these two surfaces. A principal process contributing to sea-level change on glacial time scales is the exchange of water between continental ice sheets and the oceans, upon which may be superimposed vertical land movements driven by active tectonic processes. The growth and decay of the ice sheets change the ocean volume, modify the gravitational field and deform the ocean basins and their margins, or geoid, of the planet. These three effects modify sea level. The deformational and gravitational effects are spatially variable, functions largely of the distance from the ice sheets, but are predictable if the growth and decay history of the continental ice is known. In contrast, the changes due to tectonic processes, tend to be less predictable, more episodic than the glacially-driven change and of shorter wavelength. When combined, the two contributions result in a complex spatial and temporal pattern of sea-level change. On time scales, of order >106 years, geological processes may become dominant in affecting sea level, such as plate-tectonic-driven modification of ocean-basin geometry. On shorter time scales, (years and decades ) and for which it has been instrumentally monitored, oceanographic and climatic forcing (including thermal expansion) of the ocean surface may become important. The Mediterranean basin has experienced major sea level change during glacial cycles, evidence for which occurs in both the geological and archaeological records, of decreasing resolution with time, throughout the last glacial cycle. (Lambeck & Purcell, 2005)

2.2 THE MEDITERRANEAN

The Mediterranean margins and islands have provided a fruitful area for such studies for a number of reasons. First, Mediterranean is a small tidal-range environment, the observational evidence can often be related precisely to mean sea level. Second, there is a wide range of geological and archaeological evidence available from most of the region. While this data remains inadequate to construct a purely empirical model for sea-level change that has predictive capabilities across the region, it does provide an important database for testing and calibrating the quantitative models of change during a glacial cycle. The Mediterranean region is useful in that older interglacial shorelines are
preserved in many locations so that it becomes possible to examine whether changes in tectonic rates have occurred on time scales from years to $\sim 10^5$ years. Third, there are a number of active tectonic processes whose understanding would be considerably aided if rates of vertical movement can be measured over a range of time scales of $10^0 - 10^5$ years (Lambeck & Purcell, 2005).

### 2.3 SEA LEVEL PREDICTION

In order to predict the sea level changes several thousands of years before present Lambeck & Purcell, 2005, have created a model which expresses the relative sea level change as $\Delta \zeta_{\text{rsl}} (\phi, t) = \Delta \zeta_{\text{esl}} (\phi, t) + \Delta \zeta_I (\phi, t) + \Delta \zeta_T (\phi, t)$, where represents the change at location $\phi$ of the sea surface relative to land at time $t$ compared to its present position at time $t_P$. $\Delta \zeta_{\text{esl}}$ represents the ice-volume equivalent sea-level contribution (esl), the second term, $\Delta \zeta_I$ is the isostatic contribution, and the last term $\Delta \zeta_T$ is a tectonic contribution for tectonically active areas. The isostatic term is schematically divided into two contributions: the glacio-isostatic part $\Delta \zeta_{\text{ig}} (\phi, t)$, and the hydro-isostatic part $\Delta \zeta_{\text{ih}} (\phi, t)$. 
2.4 ARCHAEOLOGICAL SEA LEVEL INDICATORS

Geological indicators are a powerful source of information from which the relative sea level change can be estimated for selective periods back to the last interglacial (Ferranti et al., 2008), while the archaeological and instrumental data fill a gap between geological and present time. A particularly good estimate of relative sea level change can be obtained for the last 2 ka from archaeological coastal installations (Lambeck et al., 2004b; Antonioli et al., 2007; Anzidei, 2011). The Mediterranean, with its small tidal range and continuous human settlement throughout historical times, has the most complete archaeological record relevant for sea level studies, with a large number of coastal archaeological sites that are often well dated and well preserved with functional features that can be precisely related to sea level at the time of their construction. Hence, they can be successfully used to constraint past local sea levels. Fish tanks, piers, docks, pools, quarries, harbors and slipways constructions, generally built around 2±0.3 ka BP are reliable indicators and provide a valuable insight of the regional variation in sea level during the last two millennia (Flemming, 1969; Schmiedt, 1974; Caputo and Pieri, 1976;

![Fig. 2.4.1 Archaeological evidence of relative sea level rise in Israel: a) the acqueduct of Caesarea and b) equipped with tidally channels controlled for water exchange in the basin in order to control fish tanks c) the sluice gate raised in its original position in the Roman age fish tank of Akziv (d) the Roman age dock](image)
Pirazzoli, 1976; Flemming and Webb, 1986; Lambeck et al., 2004a,b; Antonioli et al., 2007; Lambeck et al., in press, and references therein; Anzidei, 2011).

Sivan et al. 2001 used three criteria in order to describe the sea level change for the last 8 ka years BP. The first contains the man-made water-front structures and habitation surfaces of underwater sites which provide information for both upper and lower constraints. Usually man-made coastal structures are correlated to the precise sea level (flushing channels, slipways). Upper bounds are only observed at living floors of underwater sites, under the assumption that the living quarters were above the sea spray level (Galili et al., 1988) (Fig.2.4.2, A). The second criteria contains on-land and underwater ancient wells which provide both upper and lower limits (Galili and Nir, 1993), and that is explained because the wells have to be dug to a certain depth in order to avoid salinization, but need to be effective at the lowest water level as per seasonal low levels or extreme low tides (Fig.2.4.2, B). The last criteria used are the wrecks that represent a mean sea level. Wreckage assemblages are usually scattered the surf zone, and because of the sediment accretion or the weight of the objects (anchors, cargo), they are sank under the sandy sediments (Fig.2.4.2, C).

Fig.2.4.2 Three examples of archaeological sea-level indicators. (a) Living floors provide upper bound. (b) Ancient wells provide upper and lower bounds on sea level. (c) The dispersion line of shipwrecks and heavy objects from the wreckage approximates the palaeocoastline (Sivan, 2010).
2.5 BIOLOGICAL SEA LEVEL INDICATORS AND CORRELATION WITH TECTONISM IN LEBANON

Apart from archaeological evidence, glacio-hydro-isostatic and ice-volume equivalent, a quite accurate manner to find the sea level change and the specific chronology are the biological indicators. In Lebanon and specifically in Byblos the most common biological indicator is the *Dendropoma petraeum*. *Dendropoma* are fixed vermitids (mollusk) and they are found along rocky shorelines. These endemic mollusks colonize and construct reef-like structure of variable morphologies at the rims of abrasion platforms and are considered great relative sea level indicators in the eastern and the southern Mediterranean with an accuracy of ±10 cm, due to the well-defined growth zone and their narrow habitat the upper part of the subtidal zone (Lipkin and Safriel, 1971; Barash and Zenziper, 1985; Laborel and Laborel-Deguen, 1994; Antonioli et al., 1999; Sivan, 2010; Laborel et al., 1994, 1996; Pirazzoli et al., 1996). At present the coastline of Byblos is full of *Dendropoma* platforms that during the low tide they are revealed. Guy Sisma-Ventura et al., 2009 with specific analysis of $d^{18}O$ and $d^{13}C$ can show as differences in temperature.

In order to better understand the construction of these endemic mollusks sivan et al. studied the Lebanon and Israel area and took cores from the edges of abrasion platforms from living *Dendropoma*, vertically down to the K-D contact. As it can be seen in figure 2.5.1 the *Dendropoma* colony is distinguished in two unit. The lowest unit is named “Kurkar”, which marks the biological sea level during the time when the first *Dendropoma* settled on their calcareous sandstone substrate and is denser than the upper part. The upper consists of *Dendropoma* and indicates the phase of temporal stabilization of the sea level (Sivan et al., 2010).
The cores of *Dendropoma* used, were AMS dated (Morhange et al., 2006) corrected for marine reservoir age according to Boaretto et al. (2010), calibrated and are presented as calendar years (Sivan et al. 2010). The results used were focused on those closest to our study area. The river Nahr Ibrahim from which Byblos is most supplied by sediment, seems the place that suites best for our study. The elevation measured from the K-D contact is 60±10 cm. Morhange et al., 2006, measured the *Dendropoma* in Fidar creek (34°05.73’ 35°39.06’) (fig.2.5.2), a place quite close to our study area and found out a *Dendropoma* elevation of 50±10 cm. To sum up an estimated elevation of 60 cm will be used.
Adopting Lambeck & Purcell’s 2005 numerical model:

\[ \Delta \zeta_{\text{rel}} (\varphi,t) = \Delta \zeta_{\text{esl}} (\varphi,t) + \Delta \zeta_{I} (\varphi,t) + \Delta \zeta_{T} (\varphi,t) \],

we can predict the relative sea level for several thousands of years before present. The biological sea level equals to ice-volume equivalent plus glacio-hydro isostasy and vertical tectonic displacement. The only unknown factor is the vertical tectonic displacement but could be easily found using the above mathematical equation. Concerning the ice-volume equivalent, the glacio-hydro isostatic contribution and the archaeological evidence, the results from Lambeck, 2005 were used (fig. 2.5.3). Sivan et al., 2010 managed to reach to a certain result concerning the vertical tectonic displacement. The vertical tectonic displacement was calculated to 100 cm and a rate of 0.62mm/year for the last 200 years. This rate is the closest to reality that is known yet, so it is going to be used extensively for 6ka and 12ka years BP calculations.
3. **EGYPT – BYBLOS: A MARITIME CHRONICLE**

Byblos is believed to have been occupied since 10ka years BP (Peltenburg, 2004), according to fragments found which are believed to have been there by the Phoenicians. Dumper, 2006 suggested that Byblos has been continuously inhabited since 7 ka years BP, and the proof for this are the successive layers of human habitation (Watson, 1990; Moore, 1978). Because of the geographical position and its natural resources such as fresh water springs, timber, limestone (flint tools), Byblos was one of the most suitable places for Neolithic & Chalcolithic people to live and farm. Plastered floors and naviform technology were the oldest findings and are aged 10 ka years BP.
The intensity and nature of Egypto-Levantine relations have varied through time encompassing overland and maritime commerce, diplomacy, alliances emigration, imperialism, and deportations. Egyptian imports first appear in the chalcolithic period with a calcite jar and continued with copper ores, ingots, Egyptian-style architecture, statuary, stone vessels, and other artefacts. Egyptians were in search of timber which was plentiful in Byblos (Cedrus libani is the national tree of Lebanon). The presence of cedar, pine, and cypress/juniper wood and lapis lazuli in Predynastic Egypt was the first clue revealing the maritime trade between the two countries. However the Egypto–Levantine maritime commerce flourishes during 5-4 ka years BP. The Palermo stone is an ancient stela where Egyptians from the First Dynasty and after, noted the most significant events per year. The Palermo stone (fig.3.1) reveals ship-building by Khasekhemwy, whose name appears on a stone vessel at Byblos (Saghieh 1983: 104) and in the 6th row of the stele, they have written that Egyptians were bringing 40 boats filled with cedar-wood. This constant contact with Byblos reveals the intensity of Old Kingdom contact with Byblos may imply some Egyptian administrative control or alliance, securing this port for overland trade with Syria, Mesopotamia, and Afghanistan (Akkermans and Schwartz 2003: 240). The city of Byblos built its’ own navy around by 2450 ka years BP (Elayi, 2009), (All the above information for Egypt-Byblos contact were found in Margreet L. Steiner and Ann E. Killebrew, 2014, Oxford Handbook).
4. SURVEY IN BYBLOS

The survey was planned and carried out between the 8th and 21st of June 2014, by the Laboratory of Marine Geology and Physical Oceanography of the University of Patras in co-operation with the College de France, as part of the project "Byblos et la mer" under the directorship of Martine Francis-Allouche and Nicolas Grimal.

The Byblos marine remote sensing survey is an ongoing research project designed to:

- obtain detailed bathymetry of the coastal zone of Byblos,
- define the seismic stratigraphy of the recent sediment sequence,
- define the evolution of the coastline configuration at the Byblos over the last 18 ka yrs BP based on the mapping of palaeo-bathymetry and potential morphological features related with submerged palaeo-shorelines, and
- detect targets (surface and subsurface) of potential archaeological interest.

Modern underwater remote sensing technology introduces many advantages that extend the range of conventional diving work providing the means to survey in a detailed and systematic fashion, large seafloor areas. The advantages of such surveys are: (i) investigation of the seafloor in high speed and therefore by cost-effective means, (ii) ability to detect buried targets by non-destructive methods, (iii) ability to detect obscure large geometrical shapes on the macroscopic scale due to the broader available seabed view than that of the visual field of a diver, (iv) less environmental constrains such as for carrying out the survey (low visibility, dirty and polluted waters, strong currents), (v) precision of seafloor mapping, and (vi) reduced diving hours and unnecessary risks.

The underwater remote sensing techniques most commonly applied to under-water archaeology employ: (i) single and multi-beam echosounders (ii) side scan sonar (acoustic imaging), (iii) laser line scan (optical imaging), (iv) subbottom profiler, (v) marine magneto-meter and (vi) undersea vehicles.

There are two general approaches regarding the application of these techniques in underwater archaeology: They are being increasingly used to: (i) detect, locate and map ancient and historical shipwrecks lying on the seafloor or partly buried in it (Phaneuf et al., 2002; Chalari et al., 2003; Papatheodorou et al., 1999; Papatheodorou et al., 2001a; Papatheodorou et al., 2001b; Papatheodorou et al., 2001c; Papatheodorou et al., 2005; Papatheodorou et al., 2008a), (ii) to detect, locate and map submerged sites of archaeological interest (submerged ancient cities, settlements, ports and man-made
structures) and (iii) to evaluate the coastal palaeogeography evolution (van Andel and Shackleton, 1982; van Andel and Lianos, 1984; Papatheodorou et al., 2001d; Geraga et al., 2000; Chalari et al., 2008; Papatheodorou et al., 2008b; Chalari et al., 2009; Pakkanen et al., 2010; Ferentinos et al., 2012, Papatheodorou et al., 2014, Ferentinos et al., 2015).

5. FIELD WORK

Field activities in the Byblos coastal zone during June 2014 survey period are dealing with:

- the detailed bathymetry of the coastal zone,
- the morphology of the seafloor and
- the study of the seabed seismic stratigraphy.

Emphasis was given on the examination for possible submerged morphological features related to palaeo-bathymetric markers and palaeoshorelines, and targets of potential archaeological interest.

The marine remote sensing survey was carried out using a 3.5 kHz Geopulse sub-bottom profiler, a single beam echosounder and an EG&G side scan sonar. A Hemisphere V100 GPS system with accuracy of approximately 1.5 m was used for the navigation and the positioning.

Fig. 5.1 (a) The inflatable vessel which was used for the shallow waters, equipped with (b) the echosounder, (c) the subbottom profiler and (d, e) the side scan sonar systems.
In order to meet the objectives of the survey two vessels were used: (i) an inflatable vessel (Fig. 5.1) for the shallow waters (0-10m) and (ii) a 14m-long wooden vessel (DISCOVER 1) for the deeper waters (Fig. 5.2). Both vessels were suitably modified to meet the specific needs for the remote sensing survey (Fig. 5.1, 5.2).

5.1 SIDE SCAN SONAR SURVEY

The side scan sonar survey aimed at: (i) the mapping of the geomorphological and textural features of the seafloor and (ii) the detection and positioning of targets which may represent man-made features. The side scan sonar system emits acoustic pulses providing a plan view (acoustic image) of the seafloor. The main advantage of a side scan sonar system is its ability to provide high-resolution images of the seafloor, which can help in identifying various geological features and potential archaeological sites. The images captured by the side scan sonar system are processed using various algorithms to enhance the contrast and clarity of the features on the seafloor.
scan sonar system is the ability to survey wide seafloor areas at a greater “over the ground” speed. The side scan sonar system consists of:

- A dual frequency (100 and 500 kHz) towfish 272TD (Fig. 5.1.1.a)
- kevlar cables 50, 150 and 200 m.
- digital recording unit Edgetech 4100P topside (Fig. 5.1.1.b).

Over 40 side scan sonar lines having a length of 150 km and covering a total area of about 8 km², were surveyed offshore Byblos at water depths between 10 and 150m (Fig. 5.1.2.). The side scan sonar lines were running: (i) parallel to shoreline up to 150m water depth (Fig. 5.1.2.), (ii) in a NE-SW direction (Fig. 5.1.2) and (iii) almost perpendicular to the shoreline (Fig. 5.1.2). The range of side scan sonar lanes was 50m and 100m for each side and the operational frequency was 100 and 500kHz thus achieving the higher resolution. The line spacing was such that the seafloor area covered between two lines was overlapped by 50%.

Side scan sonar system managed also to collect data inside small bays and coves which are formed at the coastline of Byblos area (Fig. 5.1.3.).
Fig. 5.1.2. Map of the survey area showing the total tracklines conducted by the side scan sonar system.

Fig. 5.1.3. Map of the survey area showing the tracklines of the side scan sonar system at the shallow waters (0-10m).
5.2 SUBBOTTOM PROFILING SURVEY

The subbottom profiling survey at Byblos offshore area was carried out using a 3.5 kHz high resolution Geopulse sub-bottom profiler. The sub-bottom profiler system emits medium to high frequency (mainly at 3.5 kHz) acoustic pulse in the form of acoustic conical beams providing a geological profile of the sub-bottom beneath the path over which the system is towed. A shallow-penetration, high-resolution sub-bottom profiling system permits the evaluation of the seismic stratigraphy of the seafloor, the detection and mapping of shorelines and/or other markers indicative of ancient shorelines which are now submerged on the seafloor or buried under loose sediments and the detection and mapping of submerged archaeological sites and buried targets of archaeological interest.

The 3.5 kHz system used in the present study consists of:
- A Model 5430A GeoPulse Transmitter (Fig. 5.2.1),
- A Model 5210A GeoPulse Receiver (Fig. 5.2.1),
- A Triton Imaging Inc® digital recording unit (Fig. 5.2.1; 5.2.3)
- An O.R.E. Model 132A/132B over-the-side Transducer Mounting (Fig. 5.2.2).

Fig.5.2.1. Photo showing the units of the 3.5kHz system used in the present study: GeoPulse Transmitter (1) and Receiver (2) and the Triton Imaging Inc® digital recording unit (3).
Over 46 3.5 kHz profiling lines having a total length of 166 km were insonified (Fig. 5.2.4.). In order to meet the objectives of the survey a large number of profiling lines conducted at shallow waters (0-10m; Fig. 5.2.5.). Additionally, for the reconstruction of the palaeogeography and the detection of submerged morphological features related to palaeshorelines, subbottom profiler lines were acquired in a NE-SW direction and almost perpendicular to the shoreline (Fig. 5.2.4.).

A Time Base (T.B.) of 0.10 sec and a 0.1-ms pulse were used for the subbottom profiling survey of the area. The vertical resolution of the system was higher than 0.3 m.
5.3 THE BATHYMETRIC SURVEY

Bathymetric data collected simultaneously with the profiling and side scan sonar data using the digital single-beam hydrographic echosounder Elac Nautic Hydrostat 4300 with accuracy of less than 5cm in shallow water environments (Fig. 5.3.1).

Fig. 5.2.5. Map of the survey area showing the tracklines of the subbottom profiler at the shallow waters (0-10m).

Fig. 5.3.1. The digital recording unit (a) and the transducer (b) of the echosounder Elac Nautic Hydrostat 4300 used in the present study.
Offshore Byblos area and in particular at the shallow waters, bathymetric survey was carried out, in a very dense grid (Fig. 2.3.2., 2.3.3.), since the construction of a detailed bathymetric map in conjunction with the geomorphological map was considered fundamental for the evaluation of coastal palaeogeography.

![Map of the survey area showing the tracklines of the echo sounder.](image1)

**Fig. 5.3.2.** Map of the survey area showing the tracklines of the echo sounder.

![Map of the survey area showing the tracklines of the echo sounder at the shallow waters (0-10m).](image2)

**Fig. 5.3.3.** Map of the survey area showing the tracklines of the echo sounder at the shallow waters (0-10m).
6. GEOPHYSICAL DATA PROCESSING

During the field work geo-referenced subbottom profiles, sonographs and bathymetric data were collected. Figure 6.1 shows the data acquisition methodological scheme.

The bathymetric data was processed using ArcGIS.

For the processing of subbotom profiling data the SB-Interpreter (Triton Imaging Inc) was used. For the side scan sonar mosaic, Isis and TritonMap (Trion Imaging Inc) softwares were used.

The collected bathymetric, subbottom profiling and morphological (side scan sonar) data synthesized in ArcView GIS environment, in order to construct bathymetric, sediment isopach, acoustic echo types and geomorphological (seafloor) maps of the survey area.
For the interpretation and the analysis of the geophysical data a variety of sophisticated commercial (SB-Interpreter, Isis Sonar and TritonMap of Triton Imaging Inc®) and newly developed (by the Laboratory of Marine Geology and Physical Oceanography) softwares used.

The examination of the subbottom profiles were based on the definitions for echo types proposed by Damuth (1975).

The interpretation of side scan sonar data and mosaics were based on morphological and back scattering characteristics. The detection of potentially interesting targets which may represent man-made objects, based on: (i) their reflectivity in relation to the surrounding seafloor, and (ii) their shape and size (certain geometrical patterns). The Figure 6.2. shows a simplified flow diagram of the data processing and analysis.

Moreover for the classification of the targets on the basis of their archaeological importance two new softwares (SonarClass and TargAn) designed and proposed by the Laboratory of Marine Geology and Physical Oceanography were used for the processing

**SonarClass** is based on a methodology that concerns extraction and analysis of local textural and reverberational characteristics of the side scan sonar data and consists of five main steps: (a) manual selection of a limited number of small characteristic regions from each desired sea-bottom class (training samples), (b) extraction of a large number of first (tonal) and second (textural) order statistical parameters from each training sample, (c) automatic selection of the combination of parameters that provide the highest discrimination between the acoustic types, (d) extraction of these parameters from sub regions throughout the whole side scan sonar image and (e) supervised classification of the image. Second order (or textural) statistical parameters of the side scan sonar data are derived from the Grey Level Co-occurrence Matrices (GLCMs) and the two-dimensional Fourier spectrum. The originality of the method lays on the fact that: (i) it applies automatic selection of the best combination of parameters, through an iterative optimization process and (ii) it performs calibration of the offset (d) and theta parameters that control the GLCM efficiency. The main objective of the SonarClass is to ensure that the researcher has maximum supervision over the classification process and generalized classification rules can be straightforward realized. The SonarClass toolbox's has been successfully used for a variety of case studies.

**TargAn** is a new MATLAB graphical user interface that is used to extract descriptive statistical and geometrical features from distinct targets in side scan sonar records. The side scan sonar targets, whose boundaries were marked out either manually or via segmentation techniques, were analyzed for more than thirty-five features. The adopted and developed methodologies led to the extraction of: (a) textural (GLCMs and 2D FFT) and reverberational statistics estimated from both the inner target and from a peripheral region (buffer), (b) shape descriptives of the boundary itself and (c) regional statistics of possibly included objects in the target area (on user's demand by means of automatic segmentation). A friendly graphical user interface helps the user to have control over the processes involved and build a compact database that except for the extracted features can also include spatial information (such as the extent and the direction of each target) and georeferenced imagery for the visualization of the results. The TargAn toolbox has proved to be extremely helpful when large amounts of side scan sonar image targets need to be objectively clustered or classified and has been demonstrated through case studies of archaeological, geological and biological interest.
7. **MAP RESULTS**

7.1 **BATHYMETRY**

7.1.1 **DEEP OFFSHORE AREA**

The most remarkable features obtained from the deep bathymetric data of the surveyed area are three shallow plateaus; A, B and C (Fig. 7.1.1.1., 7.1.1.2.) located in distance of 1350m, 2100m and 2750m, respectively from the coastline with minimum water depths of 25m, 28m and 31m, respectively. The three plateaus are forming a chain running almost perpendicular to the Byblos coast. Just after the most distant plateau (C) the seafloor deepens rapidly reaching a water depth of 150m in a distance of 500m. Between 10 to 20m water depth the seafloor presents gently slopes.

![Bathymetric map offshore Byblos showing the general bathymetry and the three bathymetric shallow plateaus (A, B and C).](image)

*Fig. 7.1.1.1. Bathymetric map offshore Byblos showing the general bathymetry and the three bathymetric shallow plateaus (A, B and C).*
7.1.2 Nearshore area

The bathymetry of the coastal zone of Byblos (0-10m) is affected by the existence of coastal plateaus and small bays and coves (Fig. 7.1.2.1). Two isolated small deep areas were detected in the coastal zone very close to the coastline. The deepest is located at the entrance of the modern (and medieval) harbour of Byblos and the other at the northern side of the Jasmine islet (Fig. 7.1.2.1).

Fig. 7.1.2.1. Bathymetric map of the nearshore area of Byblos. The red arrows indicate the two isolated deep areas at the coastal zone. (Star: rockfill).
7.1.3 Jasmine Bay

The most striking finding in the detailed bathymetric map of the Jasmine islet surveyed area is a small (30x40m) area which is located very close to the northern coast of the Jasmine islet (Fig. 7.1.3.1.). This area shows a higher water depth (7.5m) compared to the surrounding seafloor (5m) (Fig. 7.1.3.1.).

![Bathymetric map of the nearshore area at Jasmine islet showing the small deep area (red star) at the southern part of the Jasmine bay.](image)

7.2 SEISMIC STRATIGRAPHY

Nine acoustic types (ACT I, ACT II, ACT III, ACT IV, ACT V, ACT VI, ACT VII, ACT VIII and ACT IX) detected in the subbottom profiles selected from the study area. The acoustic types were defined based on the criteria proposed by Damuth (1975). The basic characteristics of the acoustic types summarised in table 4.2.1. and their distribution is given on the map of Fig. 4.2.1.

In general the seismic stratigraphy of the surveyed area presents an upper sedimentary unit overlaying the acoustic basement. The acoustic basement was considered the reflector beneath which no further penetration was detected. The acoustic signal of this
reflector was not the same on the acquired profiles probably suggesting differentials in the geological stratigraphy among the sites. Similarly the upper unit presents variability in thickness, in the number of recognized sedimentary layers and in the texture (i.e. grain size) of the deposits suggesting differentials in the recent sedimentology of the surveyed areas.

More specifically, three acoustic types (ACT I, II and III) have the major extend in the area. ACT I represents seafloor with one upper sequence that overlies the acoustic basement (Fig. 4.2.2.). The upper sequence represents a unit of loose sediments with variation in thickness and it is distinguished in 5 subdivisions (ACT Ia, b, c, d, e) based on the acoustic homogeneity (number of seismic reflections within the upper sequence) and the texture (grain size) of the sediments. ACT Ia is obtained almost all over the surveyed area but ACTIb-e are almost limited at the western and shallow part of the area. ACT II represents rock sub-cropping under a very thin layer (<0.5m) of sandy sediments and ACT III rock outcrops. ACT III is detected at the areas of the three plateaus and within the coastal zone and ACT II is almost always obtained around the areas where ACT III has been detected.

ACT IV is an acoustic type of a transition between ACTI and ACT III. It has been obtained within the coastal zone and usually seawards ACT III. ACT V is very similar to ACT I but presents an undulated morphology in the upper sequence (similar to that of ACT I) forming two linear mounts. ACT V has a local presence. ACT VI represents a coastal erosional surface and it has a limited extent located offshore the present-day harbour of Byblos. ACT VII is also located outside the present-day harbour of Byblos representing the rockfills of the harbour’s peer. ACT VIII was observed in the most distal and deeper part of the study area, westwards of the reef C, and it may be attributed to debris detached from the shallow plateau C and the surrounding seafloor. ACT IX was observed close to Jasmine islet. It is similar to ACT I, but it presents within the upper sedimentary unit a horizontal subbottom reflector 15 m long of unknown origin (Fig 7.2.4).
### Table 7.2.1. Basic characteristics of subbottom profiler acoustic types (ACT)

<table>
<thead>
<tr>
<th>ACT</th>
<th>Description of acoustic character</th>
<th>Interpretation</th>
<th>Seismic profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>Semi-prolonged continuous bottom reflector with intermittent subbottom reflector representing the acoustic basement</td>
<td>An upper unit of homogenized loose sediments</td>
<td><img src="image1" alt="Seismic profile Ia" /></td>
</tr>
<tr>
<td>Ib</td>
<td>Semi-prolonged continuous bottom reflector with intermittent subbottom reflector representing the acoustic basement. Two weak conformable subbottom reflectors close to each other are also observed.</td>
<td>An upper unit of stratified medium size grained sediments</td>
<td><img src="image2" alt="Seismic profile Ib" /></td>
</tr>
<tr>
<td>Ic</td>
<td>Prolonged, continuous and broad bottom reflector with intermittent subbottom reflector representing the acoustic basement. Few discontinuous and locally chaotic reflectors are observed.</td>
<td>An upper unit of loose coarse-grained sediments</td>
<td><img src="image3" alt="Seismic profile Ic" /></td>
</tr>
<tr>
<td>Id</td>
<td>Prolonged, continuous and broad bottom echo with discontinuous conformable and parallel subbottom reflectors. The deepest reflector is semi-continuous and semi-prolonged.</td>
<td>A thick unit (10-15m) of stratified sediments overlies the basement.</td>
<td><img src="image4" alt="Seismic profile Id" /></td>
</tr>
<tr>
<td>ACT</td>
<td>Description of acoustic character</td>
<td>Interpretation</td>
<td>Seismic profile</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Ie</td>
<td>Semi-prolonged, continuous and broad bottom reflector without subbottom reflectors or locally very weak reflector.</td>
<td>An upper unit of sandy (compacted?) sediments</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>II</td>
<td>Prolonged, continuous bottom echo locally with overlapping hyperbolae, without subbottom reflectors.</td>
<td>Bedrock subcroping the seafloor covered by a thin layer of sand (Interpretation in conjunction to side scan sonar data)</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>III</td>
<td>Very prolonged, continuous and overlapping hyperbolae without subbottom reflectors.</td>
<td>Bedrock outcropping the seafloor</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>IV</td>
<td>Semi-prolonged, continuous bottom reflector with subbottom reflectors. An inclined semi-continuous reflector with small width and extent is also observed.</td>
<td>The continuation of the rocky coastal plateaus underneath the loose sediments.</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>V</td>
<td>Prolonged, continuous undulated bottom echoes with intermittent subbottom reflector representing the acoustic basement.</td>
<td>The distinction from the other acoustic characters is the two continuous mounts with N.W. direction.</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>VI</td>
<td>Prolonged, continuous bottom echo with gentle hyperbolae tangent to seabed without subbottom reflectors</td>
<td>Coastal erosion or an older excavation in front of the harbour’s entrance.</td>
<td><img src="image" alt="Seismic profile" /></td>
</tr>
<tr>
<td>ACT</td>
<td>Description of acoustic character</td>
<td>Interpretation</td>
<td>Seismic profile</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>VII</td>
<td>Intense, sharp hyperbolaee echoes without subbottom reflector.</td>
<td>Artificial rockfills of the present day Byblos harbour.</td>
<td><img src="image" alt="Seismic profile VII" /></td>
</tr>
<tr>
<td>VIII</td>
<td>Faint hyperbolic echoes without subbottom reflectors</td>
<td>Probably gravity controlled mass movements originated from the shallow platform C and the surrounding seafloor</td>
<td><img src="image" alt="Seismic profile VIII" /></td>
</tr>
<tr>
<td>IX</td>
<td>Semi-Prolonged continuous and broad bottom echo with a horizontal 15 m long, semi-prolonged and narrow width subbottom reflector.</td>
<td>The strong subbottom reflector is of unknown origin</td>
<td><img src="image" alt="Seismic profile IX" /></td>
</tr>
</tbody>
</table>

Fig. 7.2.1. Map showing the aerial distribution of the Acoustic Types (ACT) offshore Byblos as these obtained from the seismic profiles.
Fig. 7.2.2. Subbottom profile showing the upper unit and the acoustic basement of Acoustic Types Ia and Ib.

Fig. 7.2.3. Subbottom profile showing: (i) the upper unit and the acoustic basement of Acoustic Type Ia, (ii) the Acoustic type III where the acoustic basement reaches the seafloor and (iii) the transition between them (Acoustic Type IV).

Fig. 7.2.4. Subbottom profile showing: (i) the upper unit and the acoustic basement of Acoustic Type Ib, (ii) the Acoustic type IV and (iii) the Acoustic Type IX where a semi-prolonged horizontal reflector (red color) appears within the upper unit.


7.2.1 THICKNESS OF RECENT SEDIMENTS

The variability in the upper sedimentary unit, as this obtained between the acoustic types in the collected seismic profiles maybe attributed to local changes in the geological lithostratigraphy or to erosional and environmental (and thus sedimentological) changes. In any case, the thickness of the sedimentary deposits was estimated and maps showing the distribution of the thickness were constructed, as an approach to evaluate the coastal palaeogeography.

The thickness of recent sediments and the depth of the acoustic background from the present-day sea level are presented below in detail maps designed in three different scales: general maps of the whole area (Fig. 7.2.2.1.1, 7.2.2.1.2), maps of the coastal zone (nearshore area) (Fig. 7.2.2.2.1, 7.2.2.2.2) and maps of the Jasmin Bay (Fig. 7.2.2.3.1, 7.2.2.3.2).

7.2.1.1 OFFSHORE AREA

The three shallow plateaus (A, B and C) and the coastal zone of the Byblos area are located within the almost zero-thickness isopach suggesting the subcropping of the geological background (Fig. 4.2.2.1.1.). Furthermore the distribution of the depth (from the present sea level) of the acoustic basement configures a large area which begins from the coastline and develops seawards including the three plateaus (Fig. 4.2.2.1.2.). The comparison of the above maps and the bathymetric map point out that this area probably corresponds to a former coast during the early Holocene period.
Fig. 7.2.1.1.1. Isopach (sediment thickness) map offshore Byblos.

Fig. 7.2.1.1.2. Bathymetric map of the acoustic basement offshore Byblos.
7.2.1.2 NEARSHORE AREA

Similarly, plateaus of small extent without any coverings of sedimentary deposits (sedimentary isopachs close to 0m) were obtained at the near-shore area (Fig. 7.2.2.2.1). The distribution of the depth of the acoustic basement (which almost coincides with the water depth in the bathymetric data) point out to ancient shorelines of more recent age (in comparison to the previous ones related to three plateaus) (Fig. 7.2.2.2.2.).

Fig. 7.2.2.2.1. Isopach (sediment thickness) map of the nearshore area of Byblos.
7.2.1.3 JASMINE BAY

The almost zero-thickness area at the Jasmine bay is running parallel to the present-day shoreline with an exception of a W-E trending rocky ridge (R) (Fig. 7.2.2.3.1.). This rocky ridge has a length of about 50m, is located at the southern part of the Jasmine bay and is not connected to the Jasmine islet (Fig. 7.2.2.3.1.).
Fig. 7.2.3.1. Isopach (sediment thickness) map of the Jasmine bay (Rocky ridge: R).

The map of the distribution of the depth occurrence of the acoustic basement shows that the rocky ridge (R) separates the present small cove into two areas of deeper water depths and thus configures two approaching routes to the cove which are probably of palaeogeographic and archaeological importance. (Fig. 7.2.3.2, 7.2.3.3).
Fig. 7.2.2.3.2. Bathymetric map of the acoustic basement of the Jasmine bay.

Fig. 7.2.2.3.3. Bathymetric map of the acoustic basement of the Jasmine bay showing the rocky ridge and the related deeper approaches for the bay.
7.3 SEAFLOOR MORPHOLOGY AND BACKSCATTER PATTERN

The 100 and 500 kHz sidescan sonar mosaics of the surveyed seafloor present wide areas of high backscatter facies (light tone) with or without any acoustic shadows indicating the presence of sedimentary cover of coarse sediments and/or hard substrate (Fig. 7.3.1.). The high reflectivity area are found at the coastal zone of Byblos at shallow waters (0-4m) and unexpectedly at water depth between 30 and 50m and about 1km offshore the Byblos (Fig. 7.3.1., 7.3.2.). The latter area coincides well with the shallow plateaus (A, B and C). However, there is also an extended area of low (dark tone) and homogenous reflectivity which is attributed to soft seafloor covered by fine-grained sediments (Fig. 7.3.1., 7.3.2.). This low reflectivity area is located between 4 and 30m water depth separating the two previously mentioned high reflectivity areas (Fig. 7.3.1.). Areas of moderate reflectivity have been also observed lying at water depths deeper than 50m and surrounding the high reflectivity area of the shallow plateaus A, B and C (Fig. 7.3.1.).

Distinctive tonal patterns revealed on the sidescan-sonar mosaic (Fig. 7.3.1., 7.3.2.) include seven Acoustic Backscatter Patterns (ABP 1-7) which represent seven Seabed Types (Fig. 7.3.3.). The interpretation of the acoustic backscatter patterns was based on the reflectivity and the texture of the sonographs and the Acoustic Types and seismic stratigraphy of the 3.5 kHz profiles.

ABP1 includes areas of high reflectivity (Fig. 7.3.4., 7.3.6.). This backscatter pattern is detected (a) close and parallel to the coastline (0-4m) and is accompanied with acoustic shadow areas and (b) at the shallow plateaus (30-50m) showing a patchiness tonal character and linear acoustic shadows (Fig. 7.3.4., 7.3.6.). This backscatter pattern is attributed to a rocky seafloor which has a predominantly smooth surface and represents exposed plateaus in bedrock. ABP2 usually includes areas with dense high reflectivity spots accompanied by acoustic shadows. The boundary of the pattern is distinct and encircles the shallow plateaus A, B and C (Fig. 7.3.4., 7.3.5.). ABP2 is attributed to areas of densely distributed rock outcrops.

ABP3 characterizes wide areas of moderate backscatter (Fig. 7.3.5., 7.3.6.). This backscatter pattern usually shows a patchy character or includes areas with narrow striped alternations between light and dark tone (Fig. 7.3.5., 7.3.6.). This pattern encircles the ABP1 and ABP2 areas and is attributed to sand ripples and locally to very low relief outcrops.
ABP4 includes wide areas of very low and homogeneous backscatter (Fig. 7.3.7., 7.3.8.). This pattern detected in the central zone (4-30m) which separates the two high reflectivity areas and deeper than 50m (Fig. 7.3.3.). This pattern is attributed to fine-grained sediments (possibly muddy) covering an almost flat seafloor.

ABP5 characterize a small area of moderate backscatter which is located in the north of the A, B and C plateaus (Fig. 7.3.8.). The combined interpretation of side scan sonar and subbottom profiling data suggests that this pattern is probably attributed to disturbed sediments due to gravitational sediment movements. ABP6 represents mount-like features of unknown origin (Fig. 7.3.9.) and the ABP7 is attributed to rock fill construction (Fig. 7.3.8.).

Fig. 7.3.1. Side Scan Sonar mosaic offshore Byblos.
Fig. 7.3.2. Side Scan Sonar mosaic of the coastal area of Byblos.

Fig. 7.3.3. Seafloor map showing seven Acoustic Backscatter Patterns (ABP 1-7) which represent seven Seabed Types offshore Byblos.
Fig. 7.3.4. Side Scan Sonar sonograph showing ABP1 (bedrock exposure) and ABP2 (densely distributed rock outcrops).

Fig. 7.3.5. Side Scan Sonar sonograph showing ABP2 (densely distributed rock outcrops) and ABP3 (dense sediments locally with sand ripples).
Fig. 7.3.6. Side Scan Sonar sonorgraph showing ABP1 (bedrock exposure) and ABP3 (dense sediments locally with sand ripples).

Fig. 7.3.7. Side Scan Sonar sonorgraph showing ABP4 (fine-grained sediments) and ABP7 (rock-fill construction).
Fig. 7.3.8. Side Scan Sonar sonorgraph showing ABP4 (fine-grained sediments) and ABP5 (disturbed sediments).

Fig. 7.3.9. Side Scan Sonar sonorgraph showing ABP6 (mount-like features).
7.4 TARGET DETECTION

The side scan sonar survey led to the detection of a large number of acoustic anomalies (targets) on the seafloor offshore Byblos. The detected acoustic anomalies were separated in two main categories; targets and area of interest (A.o.I) based on their aerial extent and their acoustic characteristics. Tables 7.4.1 and 7.4.2 present the coordinates and dimensions of the targets and the areas of interest (A.o.I) for the survey area offshore Byblos, respectively. Description, interpretation and sonograph images of each target/area of interest are given in the Table 7.4.1. Figures 7.4.1 and 7.4.2 show the location of targets and areas of interest referred in the Tables.

Fig. 7.4.1. The targets (T) and the areas of interest (A) on the side scan sonar mosaic offshore Byblos.
Fig. 7.4.2. The targets (T) and the areas of interest (A) on the side scan sonar mosaic nearshore Byblos.

<table>
<thead>
<tr>
<th>Area Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Dimensions (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1</td>
<td>35° 37' 15.46&quot; E</td>
<td>34° 7' 14.96&quot; N</td>
<td>250x3</td>
</tr>
<tr>
<td>A 2</td>
<td>35° 37' 26.94&quot; E</td>
<td>34° 7' 13.38&quot; N</td>
<td>250x4</td>
</tr>
<tr>
<td>A 3</td>
<td>35° 37' 18.71&quot; E</td>
<td>34° 6' 48.68&quot; N</td>
<td>300x3</td>
</tr>
<tr>
<td>A 4</td>
<td>35° 38' 2.92&quot; E</td>
<td>34° 7' 19.37&quot; N</td>
<td>70x2.5</td>
</tr>
<tr>
<td>A 5</td>
<td>35° 38' 10.29&quot; E</td>
<td>34° 7' 13.64&quot; N</td>
<td>300x15</td>
</tr>
</tbody>
</table>

Table 7.4.2. Coordinates and dimensions of the targets (T).

<table>
<thead>
<tr>
<th>Target Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Dimensions (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T 1</td>
<td>35° 38' 4.14&quot; E</td>
<td>34° 7' 5.50&quot; N</td>
<td>55x21</td>
</tr>
<tr>
<td>T 2</td>
<td>35° 38' 0.96&quot; E</td>
<td>34° 6' 53.32&quot; N</td>
<td>6x1</td>
</tr>
<tr>
<td>T 3a, b</td>
<td>35° 38' 11.27&quot; E</td>
<td>34° 6' 57.62&quot; N</td>
<td>7.5x0.5, 2x2.3</td>
</tr>
<tr>
<td>T 4</td>
<td>35° 38' 5.61&quot; E</td>
<td>34° 6' 48.17&quot; N</td>
<td>4.3x1.5</td>
</tr>
<tr>
<td>T 5</td>
<td>35° 38' 6.45&quot; E</td>
<td>34° 7' 8.66&quot; N</td>
<td>8x6</td>
</tr>
<tr>
<td>T 6</td>
<td>35° 38' 6.48&quot; E</td>
<td>34° 7' 1.31&quot; N</td>
<td>50x20</td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>T 7a, b</td>
<td>Many linear scours on the surface of the seafloor. The length of these scours is up to 20m</td>
<td>Anchor scours from the vessels reaching the harbour of Byblos</td>
<td><img src="image" alt="Sonograph Image" /></td>
</tr>
<tr>
<td>T 8</td>
<td>35° 38' 25.44&quot; E, 34° 6' 54.56&quot; N</td>
<td>1.5x0.7</td>
<td></td>
</tr>
<tr>
<td>T 9a, b</td>
<td>35° 38' 28.15&quot; E, 34° 6' 51.84&quot; N</td>
<td>1.3x0.7, 1.2x0.6</td>
<td></td>
</tr>
<tr>
<td>T 10</td>
<td>35° 38' 8.29&quot; E, 34° 7' 30.18&quot; N</td>
<td>1.4x1</td>
<td></td>
</tr>
<tr>
<td>T 11a, b</td>
<td>35° 38' 8.71&quot; E, 34° 7' 28.36&quot; N</td>
<td>2.6x0.9, 1.2x1.2</td>
<td></td>
</tr>
<tr>
<td>T 12a, b</td>
<td>35° 38' 14.96&quot; E, 34° 7' 12.09&quot; N</td>
<td>1.4x0.7, 0.8x0.6</td>
<td></td>
</tr>
<tr>
<td>T 13</td>
<td>35° 38' 17.80&quot; E, 34° 7' 10.77&quot; N</td>
<td>1.5x0.9</td>
<td></td>
</tr>
<tr>
<td>T 14</td>
<td>35° 38' 27.42&quot; E, 34° 6' 46.54&quot; N</td>
<td>2.5x0.2 m</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.4.1. Description and interpretation of the targets and the areas of interest.
<table>
<thead>
<tr>
<th>Target ID</th>
<th>Description of backscatter pattern and shape characteristics</th>
<th>Interpretation</th>
<th>Sonograph image</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>A2 is the same as the A1, the only difference is that it consists of only one linear scour, with 326m</td>
<td>Possibly anchor scour</td>
<td><img src="image1" alt="Sonograph image of A2" /></td>
</tr>
<tr>
<td>A3</td>
<td>Linear target of higher reflectivity compared to the surrounding seafloor</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image2" alt="Sonograph image of A3" /></td>
</tr>
<tr>
<td>A4</td>
<td>Linear target with higher reflectivity compared to the surrounding seafloor. Subbottom profile crossing the linear target showed a</td>
<td>Possibly anchor scour</td>
<td><img src="image3" alt="Sonograph image of A4" /></td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>T1</td>
<td>strong hyperbolic echo.</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image1" alt="Sonograph image" /></td>
</tr>
<tr>
<td></td>
<td>Elongated area (55x 21 m) of scattered targets of high reflectivity and acoustic shadow</td>
<td></td>
<td><img src="image2" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T2</td>
<td>Linear target (6x1m) of higher reflectivity compared to the surrounding seafloor</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image3" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T3</td>
<td>2 targets area. One linear (7.5x0.5m) and one rounded (2x 2.3m). The rounded target show very high reflectivity</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image4" alt="Sonograph image" /></td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>T4</td>
<td>Linear target of higher reflectivity compared to the surrounding seafloor. Dimension: 4.3x1.5m</td>
<td>Unknown origin (ground-truthing)</td>
<td>![Sonograph image for T4]</td>
</tr>
<tr>
<td>T5</td>
<td>A wide target (8x6m, 39m²) with high reflectivity and high relief (acoustic shadows)</td>
<td>Unknown origin (ground-truthing) Possibly rock outcrop</td>
<td>![Sonograph image for T5]</td>
</tr>
<tr>
<td>T6</td>
<td>It consists of many scattered linear targets up to 0.5 m length each. (Dimension 50x20m Perimeter 148m Area 629 m²)</td>
<td>Unknown origin (ground-truthing) Possibly scattered rock outcrops</td>
<td>![Sonograph image for T6]</td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>T7</td>
<td>Two small linear targets of high reflectivity. The southern target (s.t) is bigger than the northern one (n.t). (s.t: 1.3x0.7 m, Perimeter: 3m, Area: 1m²) (n.t: 0.5x0.7m Perimeter: 2m Area: 0.4 m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image" alt="Sonograph Image" /></td>
</tr>
<tr>
<td>T8</td>
<td>Linear target of high reflectivity. (1.5x0.7m Perimeter: 3m Area: 0.7m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image" alt="Sonograph Image" /></td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>T9</td>
<td>Two small targets; one of positive (mound) and the other with negative morphology (depression)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image1.png" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T10</td>
<td>Almost circular target with rough relief. (1.4x1m, Perimeter: 5m, Area: 2 m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image2.png" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T11</td>
<td>Almost the same as the T10</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image3.png" alt="Sonograph image" /></td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
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<td>----------------</td>
</tr>
<tr>
<td>T12</td>
<td>Two visible small targets with the same reflectivity as the surrounding sediment (1.4x0.7/0.8x0.6m Perimeter: 4/3 m Area: 1/0.7 m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image1" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T13</td>
<td>A small depression (1.5x0.9m Perimeter: 4m Area: 1m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image2" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T14</td>
<td>Linear target, of high reflectivity, accompanied by acoustic shadow (2.5x0.2m Perimeter: 5m Area: 1m²)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image3" alt="Sonograph image" /></td>
</tr>
<tr>
<td>Target ID</td>
<td>Description of backscatter pattern and shape characteristics</td>
<td>Interpretation</td>
<td>Sonograph image</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
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</tr>
<tr>
<td>T15</td>
<td>Target of high reflectivity, accompanied by acoustic shadow (10x4m, Perimeter: 27m, Area: 37$m^2$)</td>
<td>Unknown origin (ground-truthing)</td>
<td><img src="image1" alt="Sonograph image" /></td>
</tr>
<tr>
<td>T16</td>
<td>High reflectivity almost linear targets (7x3m, Perimeter: 21m, Area: 12$m^2$)</td>
<td>Unknown origin (ground-truthing) possibly rock outcrops</td>
<td><img src="image2" alt="Sonograph image" /></td>
</tr>
</tbody>
</table>
8. DISCUSSION

Egyptians developed seafaring techniques and marine trade, in enormous rate, in need of raw materials, situation which forced them to look for new places like Byblos where cedar-wood was in abundance. Egyptians, apart from exchanging culture with raw materials, they used Byblos as a key region for overland trade expansion, to countries like Syria, Mesopotamia and even Afghanistan. In order to have a constant contact with their traders, the presence of a harbor with access from both, North and South should be necessary. Tombolo’s a spit of sand or shingle linking an island to the adjacent coast, were widely used in the eastern Mediterranean as excellent spots, using them as harbors. Tombolo develops in shallow areas behind island barriers, where sufficient sediment supply coupled with wave and wind actions are favorable to beach accretion. Tides swell and currents serve as the transporting media, interacting with the island to set up a complex pattern of wave refraction and diffraction on the lee of the obstacle. The inception of their prograding sediment wedges is dated to approximately 8000 to 6000 BP (Stanley and Warne, 1994).

<table>
<thead>
<tr>
<th>Years BP</th>
<th>Factors (m) Ice-volume equivalent &amp; Glacio-Hydro isostatic fluctuations (Lambeck,2005)</th>
<th>Vertical Tectonic Displacement (Sivan, 2010)</th>
<th>Relative sea level prediction for Byblos</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.000</td>
<td>-0.4</td>
<td>1.24</td>
<td>-0.84</td>
</tr>
<tr>
<td>6.000</td>
<td>-2(±1)</td>
<td>3.72</td>
<td>-1.72</td>
</tr>
<tr>
<td>10.000</td>
<td>-30(±2)</td>
<td>6.2</td>
<td>-24</td>
</tr>
<tr>
<td>12.000</td>
<td>-45(±3.5)</td>
<td>7.44</td>
<td>-34</td>
</tr>
</tbody>
</table>

Table 8.1 Combination of Lambeck et al., 2005 & Sivan et al., 2010 sea level fluctuations
First of all, at most situations the barrier can be a rocky mass suitable for marine biota as they can be protected from predators, so developing fishing methods, the supply of sea food could be plentiful. Secondly, a river is often responsible for the supply of sediment, which means that living close to a tombolo gives you the possibility to have fresh water to drink and for irrigation uses. The reef that works as a barrier has the ability to decrease the velocity and height of the waves, automatically there's constructed a really calm sandy area capable of creating a physical harbor, easy to approach and unload the cargo, in order to become a place for trade. Behind the tombolo the mainland gets also protected from the ocean currents so it can be developed too.

The Jasmine islet would be a perfect spot which could be used as a physical harbor. Having a look again at fig. 7.1.3.1, an anomaly in the bathymetry can be observed north of the Jasmine islet. With the aim of SB Interpreter, we were able to remove the upper unit of sediment and built a bathymetric impression of the acoustic bedrock (fig.2.2.3.2). After that with the information taken from Lambeck et al., 2005, concerning the sea level change affected by the ice-volume equivalent and glacio-hydro isostatic fluctuations combined to biological sea level (Sivan, 2010) giving us an uplift of 0.62mm/year for the last 2000 thousand years and consider the most reliable tectonic factor till today, resulted in the creation of Table 8.1. This table helped us make maps for 12ka, 10ka, 6ka, 2ka years BP. (Fig. 8.2, 8.3, 8.4, 8.5, and 8.6 respectively). In addition, Lambeck, 2001 curve helped us combine eustatic, glacio-hydro isoastasic and archaeological components, with results from our survey (Fig. 8.1).
Fig. 8.2 Bathymetric map of Byblos 12ka years BP

Fig. 8.3 Bathymetric map of Byblos 10 ka years BP
Fig. 8.4 Bathymetric map of Byblos shallow area 6ka years BP

Fig. 8.5 Bathymetric map of Jasmine islet 6ka years BP
Figure 8.4 showing the bathymetry 6ka years BP reveals a similar anomaly to that of the bathymetric map showed at figure 7.1.3.1. This unusual for the seabed regime, is observed only near to Jasmine islet. The reefs existing at the offshore area of Byblos, as it can be seen from the mosaic (fig. 7.3.1), have erosion zones around which might be old remnants of the reefs. Near Jasmine islet this erosion zones doesn’t exist and seems to be “shifted” to the north. Dredging was first observed in Marseilles’ ancient harbor from sedimentological and stratigraphic evidence (Hesnard, 1995, Morhange et al., 2003). Roman dredging boats continued to be a proof, in order to maintain a navigable depth of at least 1m (Morhange & Marriner, 2006). In Tyre there was an absence of 4ka year – 500 BC strata and also been observed in the northern harbor of Sidon (Morhange et al., 2005). A possible explanation for this anomaly might be the dredging activity.
Given that *Dendropoma* is an excellent biological sea level indicator, and observing the similarity of the plateaus with offshore elevated platforms (Fig. 8.7), the curve of sea level change could be enriched by a new finding of our survey. As it can be seen three main plateaus exist in offshore Byblos at a depth range of -35 to -30 m, which according to fig. 8.1 they were above sea level 12ka years before. This environment might be excellent for mesolithic-neolithic people, to live, farm and fish. Actually archaeological
findings shown that during the Neolithic people were buried in jars with grave goods and mostly fish hooks!

Finally a very interesting finding was located near the Jasmine islet. Having a look at table & fig. 7.2.1 a Semi-Prolonged continuous and broad bottom echo with a horizontal 15 m long, semi-prolonged and narrow width sub bottom reflector can be observed. This linear acoustic horizon possibly represents a submerged platform similar to those of fig. 8.7. If we use table 8.1 it can be dated to 8-7ka. (fig.8.8)

![Fig.8.8 Sub bottom 3.5 khz profile showing the platform next to Jasmine islet (solid orange line). Dated 8-7 ka years BP according to table 8.1](image)

In a second phase of the survey, it would be interesting to take a core from the tombolo wright behind the Jasmine islet in order to confirm the hypothesis about sea level changes and the anaplasis of the palaeoshore. Secondly because of the presence of the plateaus, it is highly proposed to ground truth targets found and a small core of a *Dendropoma petraeum* to be taken from one of the reefs, so that an exact chronology of the biological level could be afforded.
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