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Environment-man relationships in historical times: the balance between urban development and natural forces at Leptis Magna (Libya)

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Abstract

We analyze the relationships between human modification of the environment and natural events in the Roman city of Leptis Magna (UNESCO world heritage), western Libya. For the first time the history of Leptis Magna is tested against a high resolution geo-morphological and stratigraphical reconstruction and absolute radiocarbon dating.

Historical and archaeological sources indicate the occurrence of different natural events as the cause of the town decline: earthquakes, flooding, and tsunamis. Our data indicate that Leptis Magna was tightly linked to the nearby wadi. In fact, aware of the hazards related to violent flooding, the Romans were able to cope with the threat posed by the wadi by engineering defensive hydraulic works around the town. Once economic decay began and the society could no longer guarantee the ongoing maintenance of these structures, the decline of the settlement began and the occurrence of violent floods reclaimed the populated areas. The occurrence of large earthquakes, and the tsunami event that damaged the harbor have been discarded as playing a primary role in the decline of Leptis Magna.

Introduction

Since ancient times, socio-economic strategies of some civilizations have led to undertake severe environmental modifications, that in some cases may become so drastic as to require natural risk management. On the other hand, the rise and fall of great civilizations, wars and human achievements, thus human history in general has been tightly related to extreme natural disasters. Societies responded to natural disasters according to their socio-economic state: in some cases a society was resilient to perturbations and in others a society was so vulnerable to perturbations (generally for economic reasons) that it was unable to cope and collapsed, failed or migrated elsewhere. Historical disasters left permanent marks on the cultural development of entire regions. These are recognized not only in the study of civilizations, urbanization, migrations etc., but also in the geology and geomorphology of an area.

The sensitivity or vulnerability of landscapes and ecosystems to human activities were critical issues even during the Roman Empire. In this paper we analyze human modification on the natural environment and, *vice versa,* of the natural events on human history. We focus on the city of Leptis Magna, a magnificent Roman town in Tripolitania (western Libya) that reached its maximum expansion during the Empire of Septimius Severus (193-211 A.D.) and that started to decline during the late IV century.

Leptis Magna is located on the North-African coastline at the outlet of a major dry-land stream (also called wadi or oued) that served as a natural harbor. This natural harbor was progressively enlarged starting with the work of Nero and reached its maximum development during the time of Septimius Severus. Historical and archaeological sources suggest that the harbor basin became inefficient and was abandoned due to its complete infill, possibly related to: i) violent flooding following the collapse of a dam built to regulate the course of the wadi because of the large 365 A.D. earthquake (Salza Prina Ricotti, 1995; Di Vita, 1990); ii) lack of maintenance due to the decline of the settlement induced by severe damage after the 365 A.D. earthquake (Di Vita, 1990 and 1995), or other local seismic sources (Guidoboni *et al.*, 1994; Stiros, 2001); iii) inundation of a tsunami wave caused by the 365 A.D. earthquake that left a huge amount of debris and modified the local coastal morphology (Guidoboni *et al.*, 1994; Ambraseys *et al.*, 1994; Lorito *et al.*, 2007, Shaw *et al.*, 2008); iv) bad orientation and geometry of the harbor structures with respect to the local marine currents that were bringing debris inside (Salza Prina Ricotti, 1972-1973).

In this work we present geological data, supported by geomorphological analysis and radiocarbon dating, with the aim to: 1) verify the hypotheses concerning the harbor abandonment; 2) reconstruct the main events of the close human-environment interaction; 3) discover if there is a cause-effect relationship between natural disasters and the settlement decline; 4) integrate the archaeological knowledge at Leptis Magna by providing some independent chronological constraints.

Methodology

The methodology used here is based on a geological and geomorphological survey of the area in order to understand the depositional and erosional systems driven by the dynamics of the wadi. Drainage is certainly the most sensitive system to external modifications such as those induced by climate and human activity. As characteristic geomorphic markers of the wadi response to such modifications, we reconstructed and mapped the flights of inset terrace surfaces along the main channel of the Wadi Lebda. These terraces provide insights in to the degradational behavior of the wadi following alluvial phases. For this purpose, a topographical survey of the study site was performed by means of a differential GPS instrument (Leica Geosystems 1230), with profiles of 1.0 m horizontal resolution and 0.5 m maximum vertical standard deviation. Additionally, we investigate the alluvial phases along the main channel and at the wadi outlet by applying traditional stratigraphic analyses of outcrops and hand-made cores (up to 4.0 m deep) integrated with micropaleontological and paleoenvironmental analysis. Depositional characteristics were examined and correlated through the study area with the aim of recognizing changes to the wadi environment during historical times.

Because of the strict interaction of natural processes with human life, the stratigraphy included successive archaeological occupational layers. The stratigraphic position of archaeological artifacts (i.e. Roman villas and cisterns, Arabic fountains, etc.) and dating of ceramic artifacts were used as further constraints to complete this reconstruction.

An absolute chronological reference was provided by radiocarbon dating. We dated a total of 7 small fragments of charcoal sampled in selected layers at the Poznań Radiocarbon Laboratory (Poland). The samples were pre-treated with the acid-alkali-acid method and dated by decay counting through accelerator mass spectrometry (AMS) according to Goslar *et al*. (2004). The measured ages were dendrochronologically corrected for 12C/14C variations in the atmosphere through the radiocarbon calibration program Calib Rev 5.0.211 (Stuiver and Reimer, 1993) (Table I). The calibrated ages are calculated for the probability density function at the 95.4% (2σ) and at 68.3% (1σ) confidence limits. For the Roman Dam dating, seriating data were statistically treated through both combination and sequence models of Oxford Research Lab calibration program Oxcal 4.0. Because the dated samples are small fragments of charcoal, they could have experienced some reworking before deposition in hosting the sediment. Therefore, the possibility that the age of the sample could be older than the actual age of the sediment should be considered and represents an uncertainty.

The micropaleontological analysis consisted of quantitative and qualitative studies of the benthic foraminifera assemblages. Samples containing well preserved and abundant benthic foraminifera were counted (at least 100 specimens) and identified in the size fraction < 125 µm.

Further investigations on some selected samples were carried out through a cross sectional scanning electron microscopy (FESEM) analysis in order to discriminate the mineralogical content and to elucidate the possible relationships between different samples.

The Town

Since Phoenician times, the location of Leptis Magna was favorable to settlement because it offered both the availability of fresh water and a natural harbor that was strategically important for Mediterranean trade routes. After the Second Punic War, in the II c. B.C., the control of Leptis shifted from Carthage to Rome (Sallust, 40 B.C.). The city obtained the status of Municipium in the Flavian age (74-77 A.D.) and became a Colony during the Empire of Trajan (109 A.D.). This magnificent town continued to be enriched with monumental buildings between the I and the II c. A.D. Since it was his birthplace, the Emperor Septimius Severus led the town through its flourishing period, as testified by the proliferation of public monuments (the enlargement of the harbor, a great *nymphaeum*, a new *forum* with a magnificent basilica, etc.) and its general expansion, housing at its peak up to tens of thousands of citizens. The decline of the Roman town, commencing between the end of the IV and the beginning of the V c. A.D., was followed by a progressive contraction of the settlement during the Vandal (439-533 A.D.), Byzantine (533-644 A.D.) and Arabic times (following the conquest in 644 A.D.).

With the aim of understanding the depositional environment and the timing of depositional events, we studied five stratigraphic sections of the deposits that overlie the town. The section near the Septimius Severus Arch (S1, Fig. 1), along the *Cardo* (the main street), exposes a 4 m-thick, clear sequence of flooding events (Fig. 2a). Detailed analysis shows the lower 0.8 m of the alluvial deposit to be formed by a multilayer consisting of planar, parallel and laminated bedding of fine to coarse sand in a residual silty matrix. Local horizons of imbricated anthropic detritus (stones and pottery) cover the base of the ruins. Conversely, the upper part is characterized by massive deposits of a homogeneous, loose, fine to medium, mature quartzitic sand within a residual silty red matrix containing a few badly preserved (likely reworked) benthonic foraminifera. Towards the top, bioturbation occurs that conceals the original stratigraphy. Soil cover is absent or very thin indicating young sediments and unfavorable conditions for pedogenesis, perhpas due to frequent events of deposition/erosion. These deposits are equivalent to those observed in the wadi channels and derive from the reworking of the Red Sand and Marine Quaternary formations outcropping in the hinterland (Floridia,1939; Lipparini, 1940; Capitanio, 1999). The characteristics of these polycyclic deposits, the gentle (ca. 0.5°) seaward dip of bedding (Fig. 2b), along with the slightly convex surface morphology of the alluvium, suggests that Leptis Magna is located on an alluvial plain built up mainly from the nearby Wadi Lebda; thus, in an area prone to inundation. When the town was excavated at the beginning of the 19th's, all its magnificence was revealed by removal of alluvial deposits and sand derived from the active sand dunes that locally overlie the alluvium. Even today it is possible to draw a flat surface across the ruins that represents the last alluvial surface predating the archaeological excavations (Fig. 2c).

This confirms that the main role in the town-environment interaction is played by the local drainage network and its major dry-land stream, the Wadi Lebda. In semiarid Mediterranean environments rock and soil erosion constitutes a major aspect of landscape degradation. In fact, wadis discharge through quick, violent events (Schick, 1977; Reid and Laronne, 1995; Serrat *et al.*, 2001). Their suspended sediment yield is highly variable because precipitation and runoff are themselves highly variable, with high sediment transport efficiency according to intermittent flow regimes (Reid and Laronne, 1995). This highly erosive power has major repercussions both in the eroded zone and in the receiving zone (inundations, silting up of channels, reservoirs and harbors).

Despite the possibility of the occurrence of large flooding events, both the Greeks and Romans continued their occupation of the site because of its strategic location. Urban expansion during Roman times occurred closer and closer to the outlet of the Wadi Lebda and was adjusted following specific risk management plans. This flourishing society developed important hydraulic and engineering works, not only to provide water to the town and its numerous baths or to enlarge its trade capability, but especially to protect the town and its infrastructures from large and damaging floods.

A sample collected at the base of section S1, thus dating the oldest flood deposit, was radiocarbon dated at 320-440 A.D. (Table I). This age range indicates the beginning of exceptional alluviation episodes affecting the urban area. Because these deposits were not removed, as expected if there was systematic maintenance of the town, this suggests the beginning of the decline of Leptis, when men gave up against natural hazards.

The *agger* and the dam

In order to protect Leptis Magna and its agricultural suburbs from potential aggressors, and to keep away hazards of flooding, especially due to the presence of urban buildings along the wadi, the Romans erected a barrier of dirt, earth and soil (*agger*), up to 5.0 m high, with a ditch at its base. According to Rinaldi Tufi (2000), this *agger* was built initially in 69 A.D. between the town and the hinterland. Stratigraphical analysis of the *agger* confirms its man-made nature: chaotic arrangement of the alluvial deposits (i.e. loose, fine to medium sand and silt, with reworked benthonic foraminifera, within residual silty red matrix) derived from excavation of the ditch, mixed with artifacts and accumulation of skeletonized human bones. The abundance of well preserved charcoal in the *agger* allowed its construction to be dated between 0 and 140 A.D. (S2, Fig. 1 and Table I).

The *agger* surrounds the town for several kilometers and connects with a stonework dam where it crosses the Wadi Lebda. The dam served not only as a water reservoir but also as a strategic structure to regiment and deviate the flow of the Wadi Lebda along the *agger* into a secondary wadi (er-Rsaf) to the west (Fig. 1). The age of construction of the dam is not known, but most authors suggest that it was built during the Empire of Septimius Severus to allow the construction and functioning of the monumental harbor (Di Vita, 1990). The dam is 220 m long and 6 m high, the central part of which is made of thick walls with 4 ramparts. The dam body is still standing and does not show any evidence of damage related to shaking induced by earthquakes. Nowadays, the Wadi Lebda flows where the eastern shoulder of the dam was located, down-cutting and under-excavating the artifact and further endangering its stability. The whole basinward part of the dam is buried by a depositional terrace for its entire height (Fig. 3a). Geomorphological analysis allowed us to recognize this terrace as formed by the reservoir siltation process, since no correlative natural terraces along the wadi Lebda were identified (wadi terrace III, Fig. 1). In fact, the earliest wadi bed predating the construction of the dam is still visible below the dam and coincides with the central part of the construction (Fig. 3b). Nearby the dam shoulder, analysis of a stratigraphical sequence (S3, Fig. 1) also showed pre-dam wadi deposits composed of laminated silt and fine sand and interbedded poorly-developed paleosoils. The sequence shows well-stratified concave bedding of a channel base, lying below the 4.5 m-thick sediments filling the reservoir, characterized by homogeneous, compact silt and fine sand bodies, alternating with loose fine to medium sand, within abundant residual silty red matrix (Fig. 3c). The channel base deposits were radiocarbon dated at 40 B.C.-90 A.D. (Table I), indicating that during this period the dam was not yet built. Once the Leptitans built the dam, the siltation was induced by the aggradational behavior of the Wadi Lebda, as a result of the modification of the natural longitudinal profile of the wadi (Schumm, 1973). This body of sediments originating by the siltation mechanism may have been deposited relatively quickly (maximum a century), considering sediment transport delivery rates of the wadi (~8500 m^3/yr) (Achite and Ouillon, 2007) and the calculated reservoir volume of the dammed area (~$7.5*10^5$ m^3). Maintenance and sweeping of the basin could certainly have delayed this process.

The lower wadi

Construction of the dam drastically reduced the runoff along the lower reach of the wadi, which then became almost dry. We recognized a terrace that can be correlated only with the one that pre-dates the construction of the dam (wadi terrace II, Fig. 1). Above these terraces two Roman water cisterns were built, that should have supplied water to the town and probably to the Hadrianic Baths (in construction in 123 A.D.) and, later, to the Severian Great *Nymphaeum* (Fig. 1). These cisterns are located on the right bank of the wadi, fed by an aqueduct built by Q. Servilius Candidus in 119-120 from Wadi Caam (20 km East), characterized by a more regular flow and ensuring a water supply by connecting natural springs (i.e. connection aqueduct-Hadrianic Baths) (Romanelli, 1925; Bartoccini, 1929; Cifani and Munzi, 2003). Stratigraphical analysis in proximity of the upper cistern (S4, Fig. 1) and on the left bank on top of the pre-dam terrace shows a deposit containing Roman pottery and plaster fragments in a slightly compact silt. One piece of charcoal collected in this layer yields a corrected age of 80-230 A.D. (Table I), implying that the construction of the dam was completed before this time. Today the cisterns are partly covered by deposits derived from siltation body as the wadi crosscut the dam infill and successively re-incised to reach a new equilibrium.

The stratigraphy and morphology of Wadi Lebda provides evidence for subsequent phases of extreme overflooding events on to the terraces and fan surfaces, followed by a return of the flow inside the stream bed and formation of erosional terrace risers. Since the nearby Libyan coastline can be considered tectonically stable (Floridia,1939; Lipparini, 1940; Capitanio, 1999; personal observation of the Tyrrhenian (125ka) paleoshoreline), the discharge regimes, or liberation of sediments, are likely not related to sea level changes. Consequently, the net stream longitudinal profile adjustment produces only a limited downcutting that slightly deepens the channel floor.

The harbor

Nowadays, the 10^5 m^2 harbor basin is completely infilled by a depositional sequence that is entrenched by the present wadi bed that here branches out into two channels. The infill surface morphology gently deepens toward the sea, where it connects with the beach and the active sand dunes located between the two dock tips (Fig. 4a). We studied the upper 4 meter of stratigraphy by coring the sediments (S5, Fig. 1). Through sedimentological and micropaleontological analysis, we recognized the occurrence of deposits from three different paleoenvironments that we describe below from the bottom (~1.6 m below sea level) to the top (~2.2 m a.s.l.) of the sampled core (E1, E2, E3, Fig. 4b):

E1) Gray sand with well-rounded quartz and a few small volcanic clasts, characterized by an association of recent smoothed and well-preserved shallow water benthic foraminifera (e.g. *Ammonia parkinsoniana, Peneroplis planatus, P. pertusus, Planorbulina mediterranensis, Sorites orbicularis, Quinqueloculina* spp.). This indicates a marginal marine embayment, as expected in an area such as the harbor before 210-400 A.D.;

E2) Gray fine sand with a strong decrease in well-preserved shallow water benthic foraminifera (few specimens often smoothed). This indicates a protected paleoenvironment probably not connected with the sea (the base of this layer date 210-400 A.D.; S5-2, Table I);

E3) Dark hazel fine sand and silt, upward graded, with weathered, well-rounded clasts and a few smoothed benthic foraminifera, indicating major fluvial sediment transport (the base of this layer date 560-660 A.D.; S5-1, Table I). The lower part of this latter deposit is anomalously interrupted by a well-sorted quartzitic sand layer that could suggest the occurrence of an energetic phase that affected the harbor. Toward the upper part, the deposit turns into reddish and orange sand and fine sand, locally with small pebbles and bioturbations testifying to an alluvial and well-defined continental environment.

Previous authors have suggested that the harbor was never used because it was shortly filled with sediments (Salza Prina Ricotti, 1972-1973). However, our data suggest that the harbor basin hosted marine water (at least before 210-400 A.D.) and thus we suggest that the harbor built by Septimius Severus was functional. Then, its marine sedimentation progressively changed and the leading depositional process became that related to alluviation episodes due to sediment delivery from the Wadi Lebda. The coring location, close to the eastern docks, is the part of the harbor most prone to infilling and thus has the highest probability for sediment preservation. In the western part of the harbor, where the wadi flows nowadays, the alluvial infill was limited. Consequently, this part of the harbor basin was probably used for a longer time. This hypothesis is also supported by the fact that a productive/residential settlement was sited at the beginning of the V century between the western docks and the western beach and survived for all the Byzantine period. During Arabic times the settlement also expanded on to the alluvial deposits within the harbor basin (Laronde, 1988), suggesting a landscape very comparable with that of today and at the end of harbor use.

Conclusions

Figure 5 shows how we correlated the data of the different sites of investigation in order to reconstruct the wadi evolution/response in time.

Wadi Lebda was responsible during the Holocene for the formation of an alluvial plain upon which Leptis Magna was built (A, Fig. 6). Still, it plays a dominant role in the production, transport and deposition of detritus into both the town and the harbor as sedimentary basins by flash floods.

In order to mitigate the severe flooding risk that was threatening the settlement, the Romans constructed the dam and excavated the ditch along the *agger*. Both the dam and the *agger* acted to control the Wadi Lebda and protect the town and harbor from possible overfloodings by decreasing the energy and draining out the intermittent flow from the wadi (B, Fig. 6).

Construction of the dam modified the behavior of the wadi, inducing longitudinal profile adjustment with sediment overloading and consequent aggradation and siltation in the artificial reservoir. Conversely, the lower reach of the wadi began to have a degradational behavior, preventing the excess of sediment delivery into the harbor basin and favoring marine deposition, as promoted by: (1) late sediment-deficient alluvial discharge; (2) predominant canalized runoff. According to statistical analysis of the sequence of ages of the analyzed deposits (S3<S2<S4, i.e. pre-dam deposits younger than the agger/dam construction, in turn younger than post-dam deposits), the agger/dam system was built between 32-131 A.D. (considering the 95.4 % of probability) (Table I). This is in agreement with historical and archaeological literature that identify two events related to the agger/dam system: the defensive need in 69 A.D. against the Garamantes

(Tacitus, 100 A. D.; Goodchild and Ward Perkins, 1949) and the building of the hydraulic network in 119-123 (aqueduct from Wadi Caam and Hadrianic Baths) occupying part of the dried wadi bed (C, Fig. 6).

After a period in which the agger/dam system was fully functional, extending at least up to the period of construction and use of the monumental harbor (beginning of III century), the maintenance of the system was stopped and siltation quickly filled the reservoir. When siltation reached the top of the dam the wadi was free to flow on this upper surface and, spilling out from the dam, by-passed the construction and started flowing again into the lower wadi reach, producing limited alluviation episodes in the abandoned wadi bed and at the harbor (D, Fig. 6). Because the reservoir is expected to completely fill within 100 yrs maximum, most likely before the beginning of the harbor alluviation (210-400 A.D. from the stratigraphy of the cores, Fig. 5), maintenance of the agger/dam system was probably stopped at some point between the III and beginning of IV cent.

Water spilling out of the dam likely favored erosion at the base of the dam itself by affecting the stability of its right shoulder, resulting in complete collapse. At this point the wadi gained again its freedom to erode and flood wide areas originally reclaimed by the Lepticians. In fact, rupture of the dam produced a double effect on the wadi longitudinal profile adjustment: erosion of the siltation deposits and strong remobilization of sediments, with sediment overloading from the dam point source resulting in channel-bed aggradation (i.e. the downfilling (Schumm, 1993; Sugai, 1993)) and consequent harbor infill (E, Fig. 6). The Town was buried under alluvial deposits by consecutive flooding events after 320-440 A.D., thus, the dam rupture did not occur later than the IV- beginning of V cent. (Fig. 5).

The structure of the dam does not show any type of damage that could have been caused by a local earthquake or by the occurrence of a destructive earthquake that hit a large part of the eastern Mediterranean, such as the 365 A.D. Creta earthquake. Moreover, the fact that the dam basin is filled by siltation sediments supports the hypothesis that the cause of the damage is related to lack of maintenance and not to an unexpected event such as an earthquake. The latter would have hit the dam in functioning conditions.

Lack of maintenance and rupture of the dam signaled the beginning of the decline of the harbor. In fact, as deduced by the core stratigraphy and dating, the harbor basin started first to be infilled by limited alluvial deposits between 210 and 400 A.D. (D,Fig. 6), then it turned into a purely continental environment before 560-660 A.D. (E, Fig. 6).

No evidence for a clear event of tsunami inundation hitting the harbor, or for an important change in the wadi-sea level balance during the past couple of millennia (F, Fig. 6) were found (the present bottom of the wadi in the harbor area is only a few centimeters below the one pre-dating the dam construction).

The change in the balance between natural disasters and the vulnerability of society, according to its socio-economic state, make the correct siting of settlements and infrastructures time-dependent. Until the Romans had the economic possibility to face the siltation troubles within the dam reservoir, by ensuring the maintenance of the hydraulic system, the town was protected. But, as the resources to counteract natural processes become less efficient and less widely available, nature once again began to dominate. A society that today appears to be resilient to natural perturbations can often prove unable to cope in the future. On this note, as “deciphering the past is a key to the future” (Charles, 1873), we must be aware that since we have urbanized areas that are known to be vulnerable to repeated and extreme natural events, we need to shield them, regardless of the economic fluctuations that tend to change societal priorities.

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Captions

Table I.

Radiocarbon ages and associated chronological data for sediments from the Leptis Magna area. The calibrated ages are calculated for the probability density function at the 95.4% (2σ) and at 68.2% (1σ) confidence limits. *Statistical analysis of sequential dates by means of: OxCal v4.1 © by Bronk Ramsey (2009); IntCal04 atmospheric curve (Reimer *et al*, 2004).

Figure 1. Geological and geomorphological map. The correlated wuadi terraces (I-III) and the stratigraphic sections (S1-S5) are reported. The inset shows the location of the study area.

Figure 2. Alluvial deposits of the town. a) the oldest polycyclic deposits that buried the roman buildings; b) alluvial deposits dip; c) view of the alluvial fan surface overlaid by sand dunes.

Figure 3. The Roman Dam. a) frontal view of the dam. On the left is visible the pre-dam wadi bed; b) view of the terrace formed by the dam's reservoir siltation; c) Stratigraphic section of the reservoir infill. Both deposits, laminated for the wadi flow and massive for siltation of the reservoir, in the lower and upper parts, respectively, are evident.

Figure 4. The harbor. a) view of the infilled harbor basin. b) Stratigraphic column of the cored deposits. Location of samples for ^{14}C (white square), micropaleontological and mineralogical (gray square) analyses is reported along with photos of ceramics and FESEM view of sand and some selected benthic foraminifera. The FESEM picture 1 shows not well sorted sand with dominant, smoothed quartz. The FESEM pictures of some benthic foraminifera (scale bar represents 100 µm) show: 2) *Ammonia parkinsoniana* and 3) *Peneroplis planatus*.

Figure 5. Correlation of the results of the study sites. The overlap between consecutive period of events is related only to 2σ confidence limits.

Figure 6. Conceptual sketch of the evolution of the Wadi Lebda longitudinal profile and its depositional history.

ID	Radiocarbon age (yr BP)	% area enclosed	Cal. A.D. age ranges (yr A.D.)	Rel. area under prob. distrib. [Reimer et al., 2004]	Applied age ranges (yr A.D.)
S1	1655 ±35	68.3 (1σ)	344-427	1.000	340-430
		95.4 (2σ)	259-285	0.056	320-440
			288-292	0.005	
			322-443	0.826	
			448-463	0.017	
			483-532	0.096	
S2	1920 ± 35	68.3 (1σ)	54-126	1.000	50-130
		95.4 (2σ)	1-143	0.954	0-140
			146-173	0.027	
			193-210	0.019	
S3	1960± 30	68.3 (1σ)	5-12	0.091	20-70
			16-72	0.909	
		95.4 (2σ)	39 B.C.-87 A.D.	0.961	40 B.C.-90 A.D.
			104-121	0.039	
S4	1865± 30	68.3 (1σ)	86- 107	0.222	120-180
			120-175	0.579	
			191-211	0.199	
		95.4 (2σ)	77-228	1.000	80-230
S5	1435± 35	68.3 (1σ)	601-648	1.000	600-650
		95.4 (2σ)	564-658	1.000	560-660
	1745±35	68.3 (1σ)	244-337	1.000	240-340
		95.4 (2σ)	181-185	0.003	210-400
			214-401	0.997	
S3>S2>S4*	1920 ± 35	68.3 (1σ)	59-96	0.846	30-130
			104-115	0.154	
		95.4 (2σ)	32-131	1.000	

Table I.
Radiocarbon ages and associated chronological data for sediments from the Leptis Magna area. The calibrated ages are calculated for the probability density function at the 95.4% (2σ) and at 68.2% (1σ) confidence limits. *Statistical analysis of sequential dates by means of: OxCal v4.1 © by Bronk Ramsey (2009); IntCal04 atmospheric curve (Reimer *et al*, 2004).

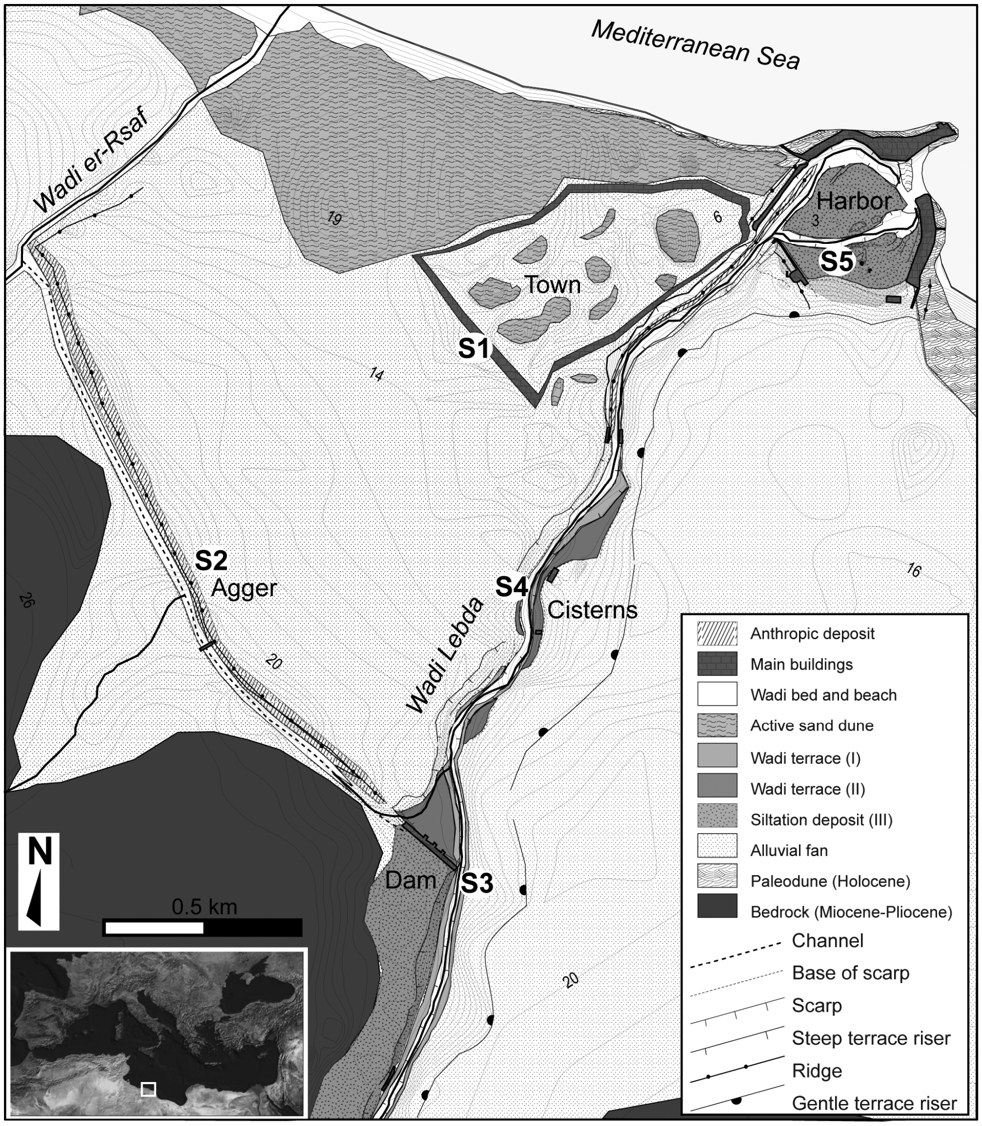

Fig. 1

169x208mm (300 x 300 DPI)

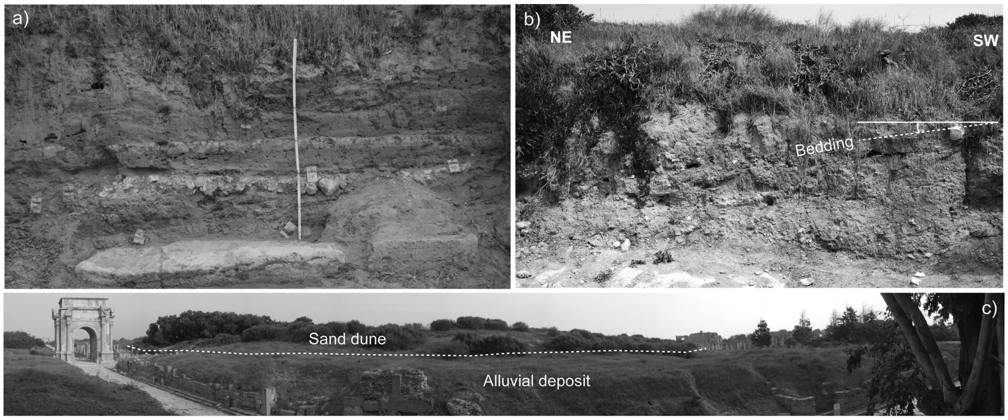

Fig. 2

263x119mm (300 x 300 DPI)

Fig. 3

229x138mm (300 x 300 DPI)

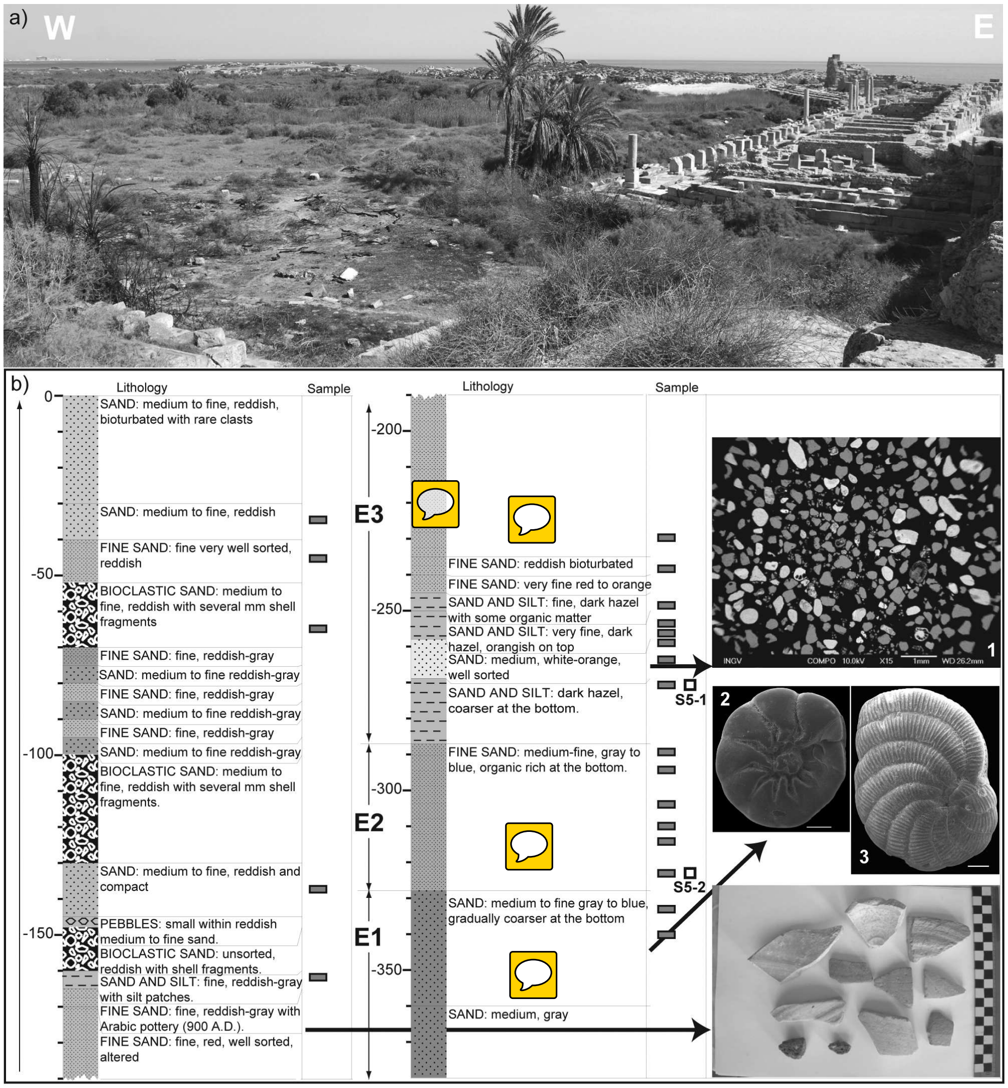

Fig. 4

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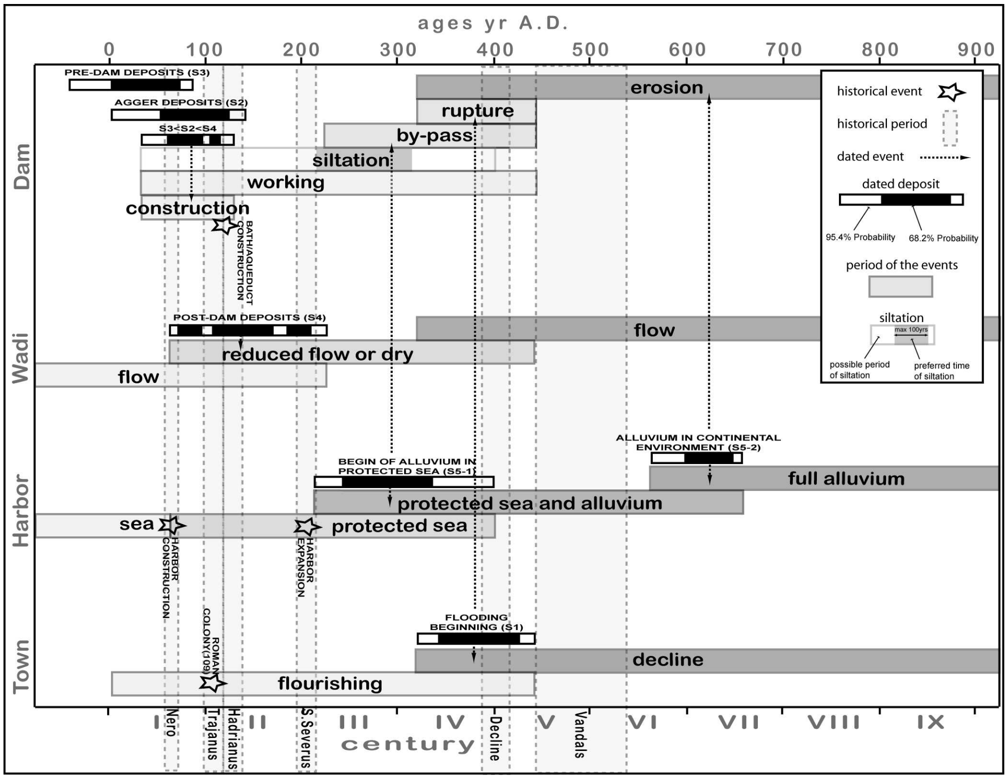

Fig.5

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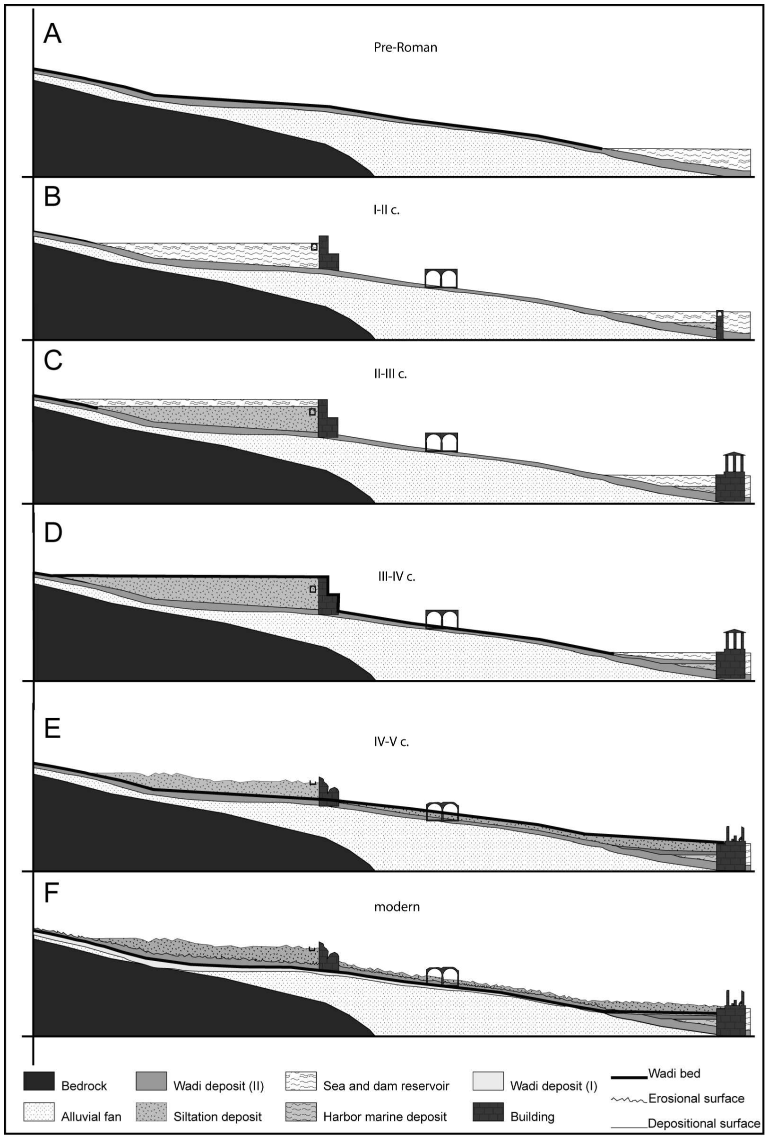

Fig.6

136x214mm (300 x 300 DPI)