Mapping the City
Sustaining the Environment

A programme of 3D scanning, geophysical survey and geomorphological assessment at the World Heritage Site of Cyrene

CYRENE ARCHAEOLOGICAL PROJECT REPORT
2007

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1 EXECUTIVE SUMMARY

On September 10th, with The Cyrene Declaration the Libyan government will announce the establishment of the Green Mountain Conservation and Development Authority (GMCDA), an ambitious plan to create the world’s first large-scale conservation and sustainable development project. Foster and Partners, the world’s leading firm of sustainable planners and architects, has been engaged to develop the regional plan. Among other activities the GMCDA will establish:

1. A National Park—to protect an area of outstanding natural beauty and ecological diversity that encompasses a UNESCO World Heritage Site,
2. Archaeological Conservation Areas—international collaborations to preserve and further excavate some of the world’s greatest Graeco-Roman remains. In addition the GMCDA expects to exchange knowledge and understanding between young Libyans and other peoples of the world.

The management and development of the World Heritage Site at Cyrene therefore lies at the heart of this ambitious plan. The magnificent remains associated with this Graeco-Roman city, and its hinterland, provide the opportunity to develop sustainable tourism through the planned, ethical development of the site. However, much of the city remains unexplored and even the extent of the archaeological site remains uncertain. The development potential of the site can therefore only be achieved following a thorough assessment of the current condition of the site and its potential for future archaeological exploration and display. The Cyrene Archaeological Project, a joint venture between Oberlin College (USA) and the University of Birmingham (UK) has, following discussion with the Libyan Department of Antiquities, begun to create:

- A systematic, GIS-based mapping programme of the surface and sub-surface remains at Cyrene to support conservation and development planning.
- A comprehensive 3D scanning survey of the upstanding remains to provide highly accurate point and surface models of the upstanding structures for reconstruction and conservation
- An extensive geophysical survey to provide accurate plans of sub-surface remains to improve knowledge of the nature and extent of the World Heritage Site.
- An extensive GIS-based regional database incorporating available environmental and archaeological data for the site and hinterland to support regional and site planning policy
- An archaeological, geomorphological and palaeoenvironmental regional survey to support regional and site-based planning policy.

This report provides an overview of the results to date and detailed proposals for future work within the World Heritage Site and its hinterland.

2 SUMMARY OF RESULTS SURVEY IN THE URBAN AREA OF CYRENE, 2007

The work carried out at Cyrene in the June-July 2006 season, and the GIS-based mapping of the World Heritage area and its hinterland (including the incorporation of the 2006 topographic survey into the GIS database), provided the basis for the 2007 season. In 2007 a series of projects were undertaken: 3D laser scanning and panoramic photography took place at the Wadi Bel Gadir sanctuary, King Battus I street, the Odeum/Bouleterion west of the Caesareum/Roman Forum (following Goodchild this complex will henceforth be referred to solely as the Roman Forum; Goodchild 1993: 43), the Roman Forum and Basilica, and the University of Chieti tomb excavation at Ain Hofra. A magnetometry survey took place on the acropolis, areas to the north of the agora and Roman forum, an area north of the Temple of Zeus and in the vicinity of the Roman cisterns to the east of the city. A brief geoarchaeological survey of Cyrene and its wadis
and hinterland was also undertaken to assess the potential of the sediments to provide detailed information relating to Cyrene’s development.

3 ACKNOWLEDGEMENTS

CAP would like to thank Dr Giuma Anag, Chairman, Department of Antiquities, and Abdulkhader el Muzeine, Controller, Department of Antiquities, Cyrene, who have been extremely helpful and supportive during the project. CAP would also like to thank all of the members of the Department of Antiquity and the Department of Archaeology, University of Omer al-Mukhtar at el-Beida who took part in the 2006 and 2007 seasons.

The University of Birmingham team would also like to thank Professor Susan Kane for her continued support of the project; her experience and knowledge of the site has proved invaluable during the two field seasons.

Fig. 1: 3D scanning in the Wadi Bel Gadir

4 INTRODUCTION

The Cyrenaica Archaeological Project (CAP) is an international mission under the direction of Professor Susan Kane, Oberlin College, USA. The key partners of the project are Oberlin College and the Institute of Archaeology, University of Birmingham, UK. CAP is the successor to the American archaeological mission in Cyrene that excavated the Sanctuary of Demeter and Persephone in the Wadi Bel Gadir under the direction of Professor Donald White. Following the renewal of relations between the United States and Libya in 2004, Professors Susan Kane and Donald White met with the Libyan Department of Antiquities in July 2004 and CAP was granted a renewable license to resume work in Libya.

In June/July 2006 a small team of archaeologists from the University of Birmingham and the University of Alberta undertook a topographical survey of the CAP concession area in the Wadi Bel Gadir. The CAP team, working alongside staff of the Department of Antiquities and members
of the University of Omer al-Mukhtar at el-Beida, used a differential GPS to examine an area of 127,000m².¹ The results of the survey were incorporated into a GIS database created at the University of Birmingham in 2005-6.

In June 2007 a six-person team from the University of Birmingham, helped by staff from the Department of Antiquities, undertook a series of surveys at Cyrene. The 2007 season took place between the 17th and 28th June and was aimed at building on the data acquired during the 2006 survey, which had provided a sound basis for further research. The team undertook 3D laser scanning and panoramic photography, using the latest Leica Cyrax HDS6000, at several sites in Cyrene in order to create 3D virtual models of the monuments. A geophysical survey using a Foerster magnetometer took place at several locations in the area of the Acropolis and the upper city, on the periphery of the Temple of Zeus and near the cisterns. Finally a preliminary geomorphological survey of visible sediments in the area of Cyrene, the Wadi Bel Gadir, Ain Hofra and in the hinterland of the city was carried out to assess the potential for environmental assessment of climatic and agricultural factors in the development of the city and its hinterland.

5 BACKGROUND

The American Archaeological Mission


The American excavation concentrated on the Upper, Middle and Lower Sanctuaries of the Sanctuary of Demeter and Persephone. They revealed a complex of shrines, walls, doorways, water installations and stairways and recovered numerous finds including votive deposits and statues. The American Mission also surveyed an area of 9,000m² including the excavated sanctuary, the wadi area and the line of the city’s defences. Archaeological work by an Italian team, under the direction of Professor Mario Luni, has subsequently revealed an archaic Doric temple (Luni 2001: 1533-1552) to the east of the ‘American’ Sanctuary area. The American and Italian excavations coupled with the work undertaken by CAP in 2006 (Cuttler et al. 2006: 9-10) suggests that the south bank of the Wadi Bel Gadir was, at least in part, a highly complex zone of religious and burial structures that demonstrates considerable evolution over time.

The 2006 Season

The 2006 season undertook work in the area of the valley of the Wadi Bel Gadir around the Sanctuary of Demeter and Persephone. The principle aim of the season was to assess the survival of archaeology within the study area. The further aims were: to fully define the concession area; link the topological survey with White’s site plan and section drawings; undertake a close resolution GPS-derived kinematic survey of the study area; map any standing remains and topographic features; train staff from the Department of Antiquities and the Department of Archaeology of Omer al-Mukhtar University in the use of GPS and GIS. Finally it was the project's aim to produce data that would allow an assessment of the archaeological resource

in order to ensure an effective and informed targeting of future work.

In order to fulfil these aims archaeological and historical information was assembled in order to produce a small-scale GIS project prior to the field season. This was used to provide the context for the study area and the rest of Cyrene. The material used for this project included:

- a low resolution DEM (Digital Elevation Model) for Cyrenaica from the Shuttle Radar Topography Mission;
- QuickBird satellite images; an original paper map showing the area which was scanned and then rectified to its proper coordinates by aligning the known points from the map to the QuickBird satellite image.
- Scanned aerial photographs from the Huntington survey. Those covering part of the concession area were also rectified using the satellite images.
- Scanned maps of Cyrene from the Istituto Geografico Militare and the surrounding region were also used. These maps from the 1920s illustrated the development of the urban area and the topography of the region.

Throughout the 2006 season data was collected using a Leica SR530 Differential GPS (base station and rover) to provide a close resolution topographic survey and to map visible features. All data that was collected was added to the GIS. Following the completion of the terrain model visible in situ features were mapped using the SR530 rover and added to the GIS project. This link between features and topography allowed the team to have an overview of both the complex and structures outside the concession area. As well as the main differential GPS survey, a handheld GPS unit was used to map the location of several rock-cut tombs in the side of the wadi.

**Post season: 2006-7**

The June-July 2006 mission assessed the potential and need for the application of remote sensing technologies at Cyrene (Cuttler et al. 2006: 12-27). Following the presentation of the interim report to the Department of Antiquities and an Access Grid meeting between CAP, Dr Giuma Anag, Chairman of the Department of Antiquity, and Dr Saleh Akab, Department of Archaeology University of Omer Mukhtar at el-Beida, in August 2006, the project decided to apply a range of techniques during the 2007 season. Accordingly CAP decided to take two state of the art pieces of equipment to Cyrene in June 2007; a Leica HDS6000 three-dimensional scanner to record standing buildings and a Foerster Multicat 4.850 magnetometer to explore the sub-surface remains. In addition the team also took a Leica SR530 Differential GPS (base station and rover) to link to the magnetometer.

**The 2007 season**

Work during 2007 followed discussion with, and advice from, Dr Abdulkhader el Muzeine, Controller, Department of Antiquities, Cyrene. A series of monuments, houses and streets in the upper town were scanned by CAP. The King Battus I street including the Xystos/Stoa of Hermes and Heracles (Fig. 2), the Roman Forum (Fig. 3), the Odeum/Ecclesiasterion opposite the Roman Forum (this was not comprehensively scanned but much of it was captured during the scan of King Battus I street; definition of theatre use from Sear 2006: 292), House of Jason Magnus and the Odeum/Bouleterion west of the Roman Forum were excavated at various stages during the twentieth century. The complex evolved over time with monumentalisation occurring in the Hellenistic period with elaboration, conversion (including the transformation of the Xystos into the Stoa of Hermes and Heracles; Goodchild 1993: 45) and new building taking place in the Roman period (including the two theatres Stucchi 1975: 289-293; Goodchild: 1993: 44; Sear 2006: 292). In the late Roman and Byzantine
period fortification, reuse and abandonment occurred complicating the standing remains still further (Goodchild 1993: 45).

The magnetometer survey took place at a series of sites in the upper town of Cyrene. The following areas were investigated: sections to the north of the agora and excavated portions of the upper town; the top and flanks of the acropolis; fields to the north of the Temple of Zeus; the football pitch east of the cisterns and inside the city wall. Traces of structures and roads have been previously located in these areas but the extent and nature of subsurface remains has never been clear. Survey was therefore concentrated on:
1. 3D scanning and panoramic photography in the Wadi Bel Gadir sanctuary of Demeter and Persephone and other sites within Cyrene (Vincent Gaffney, Helen Goodchild, Gareth Sears)

2. A magnetometer survey tied into a GPS within unexcavated areas of survey within the city (Richard Cuttler, Christopher Gaffney)

3. An assessment for palaeoenvironmental studies in and around Cyrene (Andrew Howard)

Specific aims of this work were to:

1. Use the 3D models to create detailed, extremely accurate, plans of individual monuments and the city as a whole.

2. Produce a map of the subsurface remains in unexcavated areas of the city using the magnetometry data.

3. Undertake a close resolution GPS-derived kinematic survey of the project area linked to the magnetometry data.

4. Incorporate the survey and scanning results into a GIS database.

5. Undertake interpretative analysis of the survey data to assess change at the city, the nature of occupation in unexcavated regions and the relationship between the unexcavated areas and the standing remains.

6. Create virtual models of key monuments with rendered real colour for educational, heritage management and research purposes.

7. Create panoramic/bubbleworlds of the scanned buildings for educational and heritage management purposes.

8. Carry out limited on-site processing of data and images from the survey assess the potential of the information gathered, problems of collection and to create ready models to demonstrate results to the Department of Antiquity

9. Train staff of the Department of Antiquities at Cyrene in the use of the Leica HDS6000 scanner and associated software applications.
6 DESCRIPTION OF THE SITE TOPOGRAPHY AND SURVEY CONDITIONS

The sites examined vary greatly in their topography. The site of the Sanctuary of Demeter and Persephone clings to the south slope of the Wadi Bel Gadir with the Upper, Middle and Lower terraces of the sanctuary being cut into the slope of the wadi (Fig. 4). From the sanctuary the wadi slope drops down to the bottom of the valley floor and then rises steeply on its north slope up to the cliffs that supported the Roman city wall. Professor Susan Kane had arranged for much of the vegetation on the site to be cut back as part of the recent restoration process, which facilitated the process of scanning and movement around the site.

The Upper Town and acropolis lie on a flat spur at the top of the steep escarpment that on the south plunges into the Wadi Bel Gadir, on the north-east slopes gently down into the Valley Street area and to the north and west of the acropolis descends steeply to the Wadi Bel Gadir, the Wadi Bu Turkia and the area of the Sanctuary of Apollo.

The flatness of the ground and the fact that King Battus I Street and its surrounding monuments are kept free of vegetation facilitated the process of scanning and photography. Away from the monuments, on the slopes of the spur and on the acropolis, the ground becomes progressively less flat towards the north and the ground is covered with dense thistles and low woody vegetation that impeded the magnetometry survey. CAP paid for a large area on the acropolis to be cleared and CAP staff and members of the Department of Antiquity cleared areas to the north of the Agora in advance of survey in order to mitigate against these problems. The fields to the north of the Temple of Zeus were newly ploughed and the land was flat. However, plough furrows provided further complications for survey. The football pitch next to the cisterns was, of course, flat and clear of vegetation facilitating the survey process.

7 3D LASER SCANNING AND PANORAMIC PHOTOGRAPHY

Scanner Methodology

The Institute of Archaeology and Antiquity at the University of Birmingham has considerable expertise in the application of 3D laser scanning for research and heritage management purposes within the UK and Europe. The HP VISTA Centre (www.iaa.bham.ac.uk/Computing/HP_VISTA/HPindex.htm) within the IAA is a world-leading facility for the application of 3D visualisation technologies to archaeology. The team, consisting of Vincent Gaffney, Helen Goodchild and Gareth Sears, used a Leica HDS6000 3D laser scanner to digitally scan the entirety of the Wadi Bel Gadir sanctuary (Fig. 5). This state-of-the-art system has produced excellent results in the June 2007 season. In particular it coped well with the unseasonably high temperatures whilst its relatively light weight, and battery capacity, facilitated ease of movement around the site (particularly important at the complicated Wadi Bel Gadir site and in the Odeum/Bouleterion west of the Roman Forum). The scanner was used at the settings Highest and High Power producing a point cloud with an accuracy to 0.8 mm. Each scan took c. 6 minutes and close supervision of the instrument was required to identify potential machine errors. Some 150Gb of point data representing many millions of individual scan points were collected over the survey period. This represents a major spatial database with considerable CRM and educational value.
For each monument the team plotted the best locations to maximise scan coverage in advance. The location of each scan-station was noted on a plan of the monument and control targets were set out and noted on the plan. The control targets were later used to tie the scans together in the creation of the 3D digital model (see below). The team used four mobile control targets and, where necessary, fixed paper targets. The mobile targets were gradually moved in tandem with the movement of the scan stations so that there were at least three control points in common between a scan-station and its predecessor. Scan stations were generally no more, and usually considerably less, than ten metres apart to ensure coverage of the buildings and clear views of control points in common with previous scans. Thirty-two scans were undertaken on the Sanctuary of Demeter and Persephone. The team started on the lower terrace and worked their way up the monument in order to capture as much of the monument as possible. It was not possible to comprehensively scan some rooms in the upper terrace. This was due to large holes or vegetation blocking the view of the scanner, or making it too precarious to site the scanner to effectively cover the entire floor of these rooms. The vast majority of the site was, however, covered by the scans and the remaining details can be modelled from the rest of the data gathered.

The team experienced fewer problems in the upper town because of the nature of the terrain. Sixty scans were taken in the Roman Forum area, twenty-five scans were done along King Battus I street and in the entrance area of the House of Jason Magnus and seventeen scans were done in and around the Odeum/Bouleterion west of the Roman Forum. The team were also invited to scan the tomb being excavated by the University of Chieti under the direction of Dr Oliva Mennozi at Ain Hofra. A further six scans were carried out at the tomb. CAP is liaising with Dr Mennozi to help the Chieti mission use the data.

In order to place the scans for each monument into their real position within the GIS database control points were plotted using a Leica SR530 Differential GPS base station and rover. The base station (Leica SR530 receiver) logged data from the GPS satellite constellation in order to provide a relative positional accuracy of ± 0.02m. To tie the scans into the GIS it was necessary to log three control points that appeared in more than one scan. This process was carried out in the Sanctuary of Demeter and Persephone, King Battus I Street, the Odeum/Bouleterion west of the Roman Forum and the Roman Forum.
Panoramic Photography Methodology and Processing

At each scan station, following the completion of the scan, a set of seven photos were taken to form a 360° spherical panorama (Fig. 6). The panoramas were then stitched together using the PTGui software. Once the panoramas had been created, Pano2QTVRGui was used to convert these images into 3D cubes (Fig. 7). Cubes are used in both applying the photographs to the scan data (see below) and creating QuickTime movies (Fig. 8). The QuickTime movies allow users to view the buildings and terrain through 360° by zooming and panning in any direction from the scan location. These movies are usable on any computer locally and easily shared through a web environment. These panoramas and movies have educational, heritage management and research value as they allow people who cannot travel to Cyrene to view the monuments and study facets of them remotely. This work will also facilitate the preservation of the remains of the city and record the site in case of damage by the environment or human agency.

The cubes will also be important in the process of rendering real colour on to the 3D scans. Control points visible on the images will be aligned with control points on the scans producing 3D models of the monuments on a 1:1 scale with recorded colour, texture, vegetation etc. Again this combination of the two imaging technologies will aid understanding of the monuments on the levels of research, education and heritage management.

A series of panoramas and 3D cubes of the Wadi Bel Gadir Sanctuary of Demeter and Persephone and King Battus I Street have now been created and will be linked together to create a clickable set of images on a website in addition to their incorporation into the 3D scanning process. The processing of the photography was undertaken during the field season to enable the team to check the data and to note areas where further photography might be undertaken to improve the results.

![Fig. 6: King Battus I Street, Station 02, 20-06-07, panorama](image-url)
Processing of scanner data

More than 150 gigabytes of point data were collected during the 2007 season. This has significant implications for both the storage but also, more importantly, the manipulation of the data. In order to facilitate the scanning process as much processing as possible was done whilst the team were in Shahat to inform methodology (e.g. the placing of targets). Processing of the 3D laser scanning data involves a number of stages:

- Importing a subset of the points into Leica Cyclone software,
- Tying multiple scans together using the captured target points,
- Rendering colour by tying the photographic cubes to the scanned points,
- Creating animated fly-throughs of monuments,
- Capturing 2D ‘slices’ of data in order to create accurate plans of the upper city and sanctuary.

To date work on the data has focussed on importing the point subsets into the
software and tying the scans together. This has allowed the production of 3D models of the Wadi Bel Gadir site, King Battus I street between the eastern end of the Roman forum and the House of Jason Magnus, the Odeum/Bouleterion west of the Roman Forum (Fig. 9), the Roman Forum and the tomb being excavated by the University of Chieti. Rendered colour has also been applied to some of the 3D models (Fig. 10) It has already been possible to produce some plans of monuments in the upper city for instance the theatre Fig. 11). Work has also begun on the creation of animations, which will aid future research projects as well as the heritage management of the standing buildings.

Fig. 9: Screen Grab of a 3D model of the Odeum/Bouleterion to the west of the Roman Forum

Fig. 10: Screen Grab of a rendered model of King Battus I street
Results of the Scanning and Photography

The process of scanning and modelling has created a series of 3D models of some of the key features of the upper city of Cyrene as well as the American excavations in the Wadi Bel Gadir. It will also furnish the University of Chieti team with a virtual model of their excavation; this is of particular importance to CAP given the potential of collaborative projects between institutions and the Department of Antiquities to enable better understanding of the city and its hinterland in a way that cannot be achieved through isolated projects. The 3D laser scanning and panoramic photography have also illustrated the potential for future work using these technologies within Cyrene and its environs. The production of 3D virtual models at extremely high resolution is a powerful tool in the understanding of surviving standing remains in the city, their relationship to each other and to the topography of the site and to the buried remains being investigated via geophysics (see below). The 3D models also provide recording of standing remains, and the restoration processes that have been applied to these remains, to a resolution that cannot be achieved through conventional archaeological drawing. Given that the scanner has a maximum accuracy of ± 0.002m the plans that can be produced of the buildings and the topography using slices of the models goes significantly beyond what could be achieved in normal archaeological planning. Quite apart from the research uses to which this can be put the 3D models are a vital digital library to enable future conservation work and, if the structures were damaged or destroyed by natural or man-made processes, they would form an irreplaceable resource for the understanding of Cyrene and other Graeco-Roman cities.

8 GEOPHYSICS AND GPS

Geophysics and GPS methodology

One of the main objectives in the 2007 field season was to undertake a pilot geophysical survey within the town. The geophysical technique that was chosen for the study was based on Fluxgate Magnetometer (FM) technology. A team comprising Richard Cuttler, Chris Gaffney and members of the Department of Antiquities undertook a highly significant geophysical survey of several areas within Cyrene. A Foerster Multicat 4.850 magnetometer (Fig. 12) was
used to examine un-excavated areas within the known limits of the city. This was the first time that such a system had been employed in North Africa.

There are a number of reasons why this technique was chosen. Ancient towns tend to produce significantly enhanced magnetic soils due to the process of living and working in the environment; in turn this creates contrasts between archaeological features and the surrounding material that result in magnetic deviations (anomalies) in the Earth’s magnetic field. If sufficiently strong these anomalies can be measured at the ground surface using a magnetometer.

By collecting a grid of measurements over a predefined area a map of the deviations from the Earth’s field can be created; after visualisation an interpretation is made relating the map to the buried landscape.

There are many types of magnetometers, but among the most used for archaeological purposes are based on Fluxgate sensors. Many large area surveys have been undertaken using FM instruments. In particular some Roman towns have been mapped in their spatial entirety using these sensors. See, for example, Gaffney et al 2000 and Gaffney et al 2004.

A GPS Enabled Fluxgate Magnetometer System

In all of the published examples of survey within ancient towns the measurements have been undertaken on a regular grid, normally 2 or 4 samples/m and collected along traverses that are set at 1m apart. As a result of observations during the 2006 field season at Cyrene it was decided that a different approach was required. While the area is largely open, the terrain is highly variable with steep slopes, difficult terrain and much upstanding archaeology. As a result it is not easy to layout a conventional geophysical grid which has regular sides of 20m length. In the town of Cyrene this is a limiting factor for conventional magnetometer survey. It was decided that a system would be used that requires no grid surveyed in advance.

During the winter of 2006 tests were carried out at Roman City of Wroxeter to evaluate the Foerster Ferrex Fluxgate Sensor System. This site was chosen because similar magnetic responses are likely to be found at both sites and a considerable number of previous magnetic surveys have been undertaken at the site. The results from the Ferrex at Wroxeter were compatible with the earlier magnetic surveys and it was decided to proceed with this system at Cyrene. The important
differences from conventional magnetometer surveys are:

- The sensors are ‘factory-set’ i.e. they do not require time consuming set-up procedures that all other FMs require.
- The position of the sensors is located using real time GPS. In theory this means that the data will require less processing and that a higher level of confidence can be ascribed to the interpretation.
- Three sensors are mounted on a non-magnetic cart, allowing a swathe 1.5m in width to be investigated in each pass of the instrument i.e. the sensors are separated by 0.5m.

Data Collection

Data was collected at seven broad locations across the city. The areas were chosen firstly on archaeological grounds and secondly on suitability for survey. Although the main factor in the latter was the low-lying vegetation, another that had to be taken into consideration was the potential obscuring of satellites for the GPS. In practice this means that areas with many trees must be avoided.

Data collection with the Ferrex system requires a notional rectangle that is defined by a baseline, the ends of which are located in the field. As a result the ‘best’ location for each survey block can be determined; in practice each area is made up of several different survey blocks, often on different orientations.

Each data block was sampled with traverses 0.5m apart and readings captured at c. 0.1m intervals. Two strings of information were used from the GPS; one was used to guide the cart along the centre of the notional 1.5m swathe, while the second located the actual position of the cart and, hence, the sensors. Of course the two locations differ due to obstacles on the surface and tiredness of the operator.

Data Processing and Display

As noted above one of main reasons for using real time GPS as an onboard navigation solution is that location accuracy is high for each reading. Processing is, therefore kept to a minimum. In the data analysis undertaken so far only de-striping (to equalise each sensor for minor height variation and direction of walk) has been undertaken.

The data is currently been analysed by block, although the data will be fully integrated into the project GIS.

Fig. 13: QuickBird satellite image of the city showing magnetometry grids (QuickBird Satellite image © DigitalGlobe)
Summary Results

A total of seven areas were chosen for magnetometer survey during the 2007 field season.
- Acropolis (Area 1 on location diagram)
- Terrace North of Acropolis (Area 2)
- Terrace North East of Acropolis (Area 3)
- West of Agora (Area 4)
  Area 4 part processed data and primary features
- North of Agora (Area 5)
- North of Temple of Zeus (Area 6)
- Eastern Gate (Area 7)

Sample data

Fig. 14: Area 4 Acropolis: Archaeological detail is present here despite considerable modern disturbance in this area

Fig. 15: Area 5 Although there is considerable noise in this dataset a large building (Agora?) can be identified
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Fig. 16: Area 6 North of Temple of Zeus: a clearly defined street and associated structures have been found in this zone

Fig. 17: General survey results from the central area of the temple of Zeus, overlain on a DEM. Streets and unexcavated buildings can be seen clearly in the foreground

Quite apart from the advantages in rate of data collection, the link between a GPS and the magnetometer also created a close resolution topographic survey over the same terrain as the magnetometry survey. In order to undertake the survey a GPS base station was established on high ground away from tall vegetation to log data from the GPS satellite array and to broadcast real time corrections to the SR530 rover. A range of un-excavated areas within the city of Cyrene were examined using the magnetometer array.

The first target of the work was spaces in the upper town and in particular to the north of the agora and on and around the acropolis (see Fig. 13). Additional surveys were then undertaken to the north of the Temple of Zeus and on the site of the current football pitch near the cisterns (see Fig. 13).
Processing of the Geophysics and Topographical survey data

As with the panoramic photography and 3D scanning much of the processing of the geophysics and topographical survey data was undertaken in Shahat on a daily basis. This was particularly important for the geophysics as it was necessary to download the data every night to check on the exact position of the day’s work and any gaps in the coverage, and therefore data, that might have occurred. Where this had happened, because of the terrain or the vegetation, it was possible to go back on subsequent days to fill in such holes.

9 ENVIRONMENTAL ASSESSMENT AND PALAEOENVIRONMENTAL POTENTIAL OF THE CYRENE HINTERLAND

Context of the Environmental Assessment

Considerable research into the arid and semi-arid landscapes of the Mediterranean has demonstrated the potential of both the sediments and geomorphology, particularly preserved in valley floors (Vita-Finzi, 1969; Lewin et al., 1995; Pope et al., 2003) and cave systems (Bailey, 1997; Woodward and Goldberg, 2001) to provide detailed information regarding climate, land-use and human activity.

A preliminary field season by staff from the Institute of Archaeology and Antiquity at the University of Birmingham in 2006 identified sediments burying archaeological remains in the Wadi Bel Gadir. Therefore, as part of the 2007 field season, a full geoarchaeological assessment of the area was undertaken. The aims of this evaluation were to:

- Assess the environmental potential of the excavated city.
- Assess the environmental potential of the sediments in the Wadi Bel Gadir and adjacent wadi systems.
- Assess the environmental potential of the hinterland of Cyrene including any other areas where information may be preserved (e.g. cave systems).
- Consider how the geological and geomorphological history of Cyrene may provide evidence pertaining to the cultural history of both Greek and Roman civilisations.

Geology, Geomorphology and Geoarchaeology of the Wider Landscape

From the Mediterranean coastline southwards to the city of Cyrene and beyond, the landscape can be divided into three distinct geological terrains dominated by a series of south-west to north-east trending fault scarps, each 200-300m high. The underlying solid geology is relatively simple comprising limestone and associated calcareous rocks of shallow marine origin, reflecting episodes of subsidence, uplift and marine transgression.

Approximately 200m back from the modern coastline, steeply rising ground and cliffs mark the edge of the modern coastal plain (Fig. 18). It is in these cliffs a few kilometres beyond Apollonia where the Hauf Fteah Cave is located; this rock-shelter has yielded Middle to Late Palaeolithic human remains including two Neanderthal mandibles as well as a sequence of Quaternary deposits extending back to at least the last interglacial (approximately 125 ka BP). Initial excavations at this site were carried out between 1951 and 1955 by a team from the University of Cambridge led by Dr C.B.M. McBurney and it is now the focus of renewed excavation by a Cambridge team led by Professor Graeme Barker (McBurney 1960: 199-205). This cliff line is dissected by steep gorges carrying ephemeral rivers, which drain the hinterland. As these rivers exit their respective gorges, both their energy levels and hence capacity to carry...
sediment (usually coarse sands and gravels) are reduced, resulting in the deposition of alluvial fan landforms.

The area in front of the fossil cliff line and the Mediterranean Sea (Zone 1, the modern coastal plain) comprises a series of coalesced alluvial fans, which form a prograding wedge of sediment declining in altitude towards modern sea level. Immediately adjacent to the fossil cliff-line, exposures close to the road demonstrate that the fans comprise coarse grained gravels and boulders, with limited evidence of fine grained sedimentation. Radiometric dating of such fan and associated wadi deposits in the Wadi Zewana near Tolmeita using uranium-thorium disequilibria (U-Th), electron-spin resonance (ESR) and optically stimulated luminescence (OSL) techniques demonstrate that the sequences were aggraded over an extended time period from around 200,000 to 12,000 years ago (Rowan et al., 2000).

At the top of the fossil cliff line, Zone 2, an extensive bare limestone terrace surface extends southwards for approximately 8 km. This surface, which is initially of marine origin, is dissected by the narrow, deep gorges of the wadis draining to the coast. With the exception of a few small areas where scrub vegetation is recorded and agriculture is practised, Zone 2 and is notably devoid of any thick mantle of regolith (i.e. soil), which appears to have been largely eroded (stripped) from the landscape (Fig. 19).

The southern limit of Zone 2 is marked by a further steep escarpment upon the top of which sits the historic City of Cyrene and the modern town of Shahat. Away from the edge of the escarpment the land surface forms another relatively flat terrace, which rises gradually in altitude towards the south (Zone 3). Though this increasing elevation is barely visible on the ground, it is identifiable by a change from poorly developed scrub vegetation near Cyrene to thick scrubland around the modern city of Lamliouda (i.e., reflecting slightly cooler, moister conditions).
Within Zone 3, the wadi systems that dissect the region are relatively shallow and have low channel gradients, except in some cases where they are close to the edge of the escarpment. In the case of the Wadi Bel Gadir, within 1-2 km of the edge, its internal gradient increases significantly, which has caused rapid incision through the local limestone, forming a pronounced gorge, hanging above the escarpment. This lower, section therefore offers little opportunity for the preservation of sediment and below the Sanctuary of Demeter and Persephone bare limestone walls are evident (Fig. 20a). An Italian team from the University of Urbino, under the direction of Professor Mario Luni, has undertaken excavation in the central part of the Wadi Bel Gadir for several years revealing an archaic Doric temple (Luni 2001: 1533-1552); their excavations seem to indicate the potential for environmental examination of deposits within the Wadi Bel Gadir. Immediately downstream of Professor Luni’s excavations within the CAP concession, small exposures of natural sediment approximately 4m above the contemporary valley floor may provide evidence of earlier sedimentation (Fig. 20b and 20c). The material within this zone is coarse and contained little visible archaeology. A comparison between sediments within Professor Luni’s trenches and sediments lower down the valley might enable better understanding of changes in sediment supply through time and might be a useful area for collaborative research. Unlike the colluvial deposits in the Wadi Zewana, dated by Rowan et al. (2000) to the last glacial cycle the deposits near Cyrene are demonstrably of post-glacial origin.

Such changes in sedimentation are certainly recorded to the north-east of Cyrene, in the adjacent wadi at Ain Hofra. Unlike the Wadi Bel Gadir, the lower part of this valley is not incised, but has a gently undulating floor approximately 50-100 wide as far as the escarpment edge. The floor of the wadi contained approximately 1-2m of reddish brown stony colluvium with fragments of pottery. Approximately 4-5m above the valley floor, exposures of unconsolidated sediment in a road cutting revealed coarse, angular gravels set within a reddened
(rubified) clay matrix (Fig. 21a). The degree of reddening of these slope deposits is reminiscent of ‘terra rosa’, which suggests that they have undergone prolonged weathering and hence may be of considerable antiquity (i.e. Pleistocene age).

Given the proximity of the calcareous bedrock to the ground surface, it is notable that no dolines or other types of solutional feature, which often form valuable sediment traps in limestone landscapes, have been noted during the rapid geoarchaeological survey of Zone 3. With the exception of Haua Fteah Cave (McBurney 1960: 199-205; McBurney 1967), the only other rock shelter identified during this rapid survey was the feature being excavated approximately 50m below the escarpment within the wadi of Ain Hofra by Dr Oliva Menozzi and her team from the University of Chieti (Fig. 21b). A slot trench approximately 4m deep within the shelter exposed cave sediments rich in molluscan remains.
Environmental Potential of the Wider Landscape

**Wadis**

Despite the high channel gradients and gorge like nature of the majority of wadi’s both close to the escarpment of Zone 3 and within Zone 2, Professor Luni’s excavations and the work of Rowan et al. (2000) demonstrate these valleys can contain sediments capable of providing proxy environmental data elucidating both land-use and climate.

- In the Wadi Bel Gadir, there is clearly the potential for the extension of excavations in the upper part of the valley near the Temple of Demeter to produce valuable environmental sequences.
- Detailed analysis of stratigraphy could date the timing of colluviation through the use of pottery typology and phasing as well as radiometric techniques such as Optical Stimulated Luminescence of appropriate sediments (e.g. Lang, 2003.).
- Whilst the sediments are clearly derived they contain significant quantities of animal bone, which if analysed systematically through the sampling of spits, could provide important information of palaeoeconomy.

**Cave Systems**

- Exposures of sediments interbedded with archaeological features in Haua Fteah Cave and the rock-shelter at Ain Hofra demonstrate the significant potential of such features to provide environmental records extending back well into the Palaeolithic period. Appropriate techniques to name but a few that could be applied to sequences include, pollen analysis, soil micromorphological study, palaeomagnetic analysis as well as radiometric dating techniques.

**Geoarchaeology of the Immediate City Environs**

The upper city is situated upon the crest of a north-south trending ridge of bedrock and ends abruptly at the northern end of the Acropolis at the escarpment edge. Numerous exposures around foundations indicate that there is a thin spread (around 0.5m thick) of locally derived colluvium containing abundant pottery across the area. Where this is banked against walls etc, it can be thicker (Fig. 22). However, in addition to this local material, exposures to the west of the Agora/Forum demonstrated the import of sediment to the site, presumably as building/levelling fill materials. Further excavation work through such fills might provide answers regarding the extent of this activity as well as the date of the process.
Environmental Potential of the City

As in the wider landscape, radiometric dating of the local colluvial deposits could provide information of the timing of sediment deposition. The complex sequence exposed in Professor Luni’s excavations demonstrate the great potential for environmental work. If similar sequences could be found elsewhere, it would be possible to:

- Study the loams using micromorphological techniques to study soil development and sub-aerial exposure; undertake geochemical analysis to provenance the materials; and undertake pollen analysis to determine vegetation patterns.
- Study the bone remains in detail to study aspects of palaeoeconomy and diet.

This section provides an overview of the environmental potential of Cyrene and its immediate hinterland. It demonstrates that there is considerable potential for further work, especially in the city, and environmental work needs to be integrated into any future large-scale archaeological project.

10 CONCLUSIONS

Future Work

The work by the CAP team has demonstrated that a programme of systematic mapping of existing structures, sub-surface features and environment can provide data that is essential to the provision of a management policy required by both UNESCO and the Green Mountain Conservation and Development Authority. Indeed without such a programme it is unlikely that the site can be developed in a rational, ethical or effective manner. The work by CAP, however, is only a beginning. The following mapping and associated programmes would be considered as part of a larger plan for Cyrene and the larger hinterland to support the work of the Department of Antiquities and the GMCDU.

Within Cyrene

- Extension of magnetometry and other technologies to the periphery of Cyrene – a poorly understood zone with significant research and display potential.
- Directed Radar survey on the large wooded hill to the south-east of the Caesareum and other selected deeply stratified sites
Extension of 3D scanning to encompass all surface structures.
Continued modelling of the 3D scan data to produce models or animations for heritage management purposes.
Targeted palaeoenvironmental studies to tie valley sediments and erosional histories with site specific data.
Creation of an urban GIS to manage the digital resource for planning purposes.

Regional Activities

Creation of regional GIS to manage cultural and environmental archive (see technical appendix)
Creation of an enhanced archaeological context through implementation of a large regional survey incorporating:
Analysis of available aerial photographic or air and satellite remote sensed data to locate features associated with settlement and land use
Targeted surface survey to locate, characterise and date the range of settlements within the hinterland
Targeted geophysical survey to ascertain structural characteristics of a range of sites or landscape features.

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