15.1 Detection and destruction in Siria
Palimpsest of field systems seen on the CORONA imagery (background) and their present-day destruction (inset)
INTRODUCTION

The last decade has seen the declassification of high resolution (sub 2-3 m) panchromatic military imagery such as the American CORONA (http://edcwww.cr.usgs.gov/) and Russian KVR (http://www.spin-2.com/) missions. The data is relatively cheap, readily available and has a significant historical component which is of particular benefit to archaeology. Several reports have already indicated the value of de-classified imagery for the identification of archaeological features (COMFORT et alii 2000; FOWLER 1996; KENNEDY 1998). A recent account (PHILIP et alii 2002) has demonstrated how geo-corrected CORONA imagery can be employed for the identification and accurate ground location of archaeological features. It can provide valuable input to landscape studies, particularly in areas where the archaeological resource is poorly understood and/or documented, such as parts of the developing world, where there may be no systematic databases of archaeological remains, and where access to detailed topographic mapping and aerial-photography can be problematic (DONOGHUE et alii 2001).

In the present case-study, CORONA imagery was employed within a regional survey project, Settlement and Landscape Development in the Homs Region, Syria (SHR). In addition to archaeological research questions, the project has as one of its aims the creation and maintenance of a Geographical Information System (GIS) based Cultural Resource Management (CRM) tool. Using CORONA data as a prospection tool the project has identified approximately 550 sites of archaeological significance within an application area of some 630 km². A considerable proportion of these were previously unknown, and only a few were recorded. In some instances historical satellite imagery provides the only archaeological record. This is particularly the case for parts of the study area that have undergone extensive landscape modification in recent decades (Fig. 15.1).

As Fig. 15.1 illustrates, there is a wealth of archaeological information contained within CORONA imagery. Although this information can be usefully analysed in isolation, the incorporation of the imagery within a GIS environment will “add value” to any analysis by allowing the incorporation of other spatially referenced datasets. Unlike modern satellite data CORONA is purchased as either film (positive or negative) or print and thus needs to be digitised and geo-located before it can be overlaid with the other spatially referenced datasets. To complicate matters the CORONA missions were conducted for military reconnaissance and not for mapping purposes. Hence, the non-metric nature of the camera system makes the imagery difficult to geo-locate in order to determine metric measurements. Errors are not standard across the negative.

This study considers the specific question of how CORONA imagery can be geo-referenced accurately and cost-effectively. Accuracy in this context means accurate enough to find a site on the ground with a handheld Global Positioning System (GPS), although the more accurate the rectification the better. Although many archaeologists may be content with a Root Mean Square Error (RMSE: “the square root of the arithmetic mean of the squares of the deviation of observed values from their arithmetic mean”: (www.harcourt.com/dictionary) of many decimetres. But some projects now integrate multiple satellite data sources in their analyses, for instance for time-change analysis or to exploit the different spectral properties of different imagery. For these analyses to work the user must be confident that each overlying pixel from the different sources...
refers to the same or nearly the same point on the ground. Modern, high spatial resolution Ikonos satellite imagery (http://www.spaceimaging.com) and GPS are compared as registration tools. It seems likely that other military reconnaissance missions with different spatial, spectral or geometric characteristics will be declassified in the future, although the experience of CORONA suggests that image data may be released without full declassification of the technical characteristics of the data-collection system. Therefore, the geo-location of CORONA can be seen as a vital preparatory step for the effective use for archaeological purposes of such declassified military datasets that researchers might find useful in the years ahead.

**Rectification Techniques**

Rectification is the process of correcting systematic and random errors in imagery. Rectification procedures can either be spatial or non-spatial. Non-spatial rectification is commonly used to correct camera lens and scanning aberrations (or other errors in a collection device). Spatial rectification is used to locate imagery somewhere in space (normally to a specified projection) and will also account for collection distortions.

Spatial rectification relies on the ability to recognise areas within the imagery with known locations or the use of ephemeris data (satellite sensor and orbit characteristics, not discussed here as this information is not available for CORONA). Concurrent known points in both the referenced and un-referenced media are referred to as Ground Control Points (GCPs). Hard-detail (points that are unlikely to move over time and are normally man-made) tend to be used as GCPs. Corners of fields, walls or buildings and road intersections are common examples. Once these control points are established, the image is stretched so that the points align as closely as possible, normally using a polynomial algorithm.

However, rectification does not always result in perfectly matched control points. By adjusting the Polynomial Degree of the correction algorithm the accuracy of the transformed points can be increased. However, reducing the error can create a higher degree of warping in the image as it is transformed to match the control points. Therefore, the lowest possible polynomial degree that still gives an acceptable result should be used (AutoCAD 2000). Most rectification packages show the RMSE of every GCP for each polynomial degree. These error values detail how far a transformed (rectified) GCP is from its true value. Thus, outlier GCPs can be evaluated and removed from the rectification process. Outliers occur because either the GCP locations are inaccurate (the feature perhaps having changed) or the un-registered medium is distorted. As a general rule increasing the number of GCPs and spreading them evenly across the image increases accuracy in the final rectification. It is important to understand that, whatever rectification technique is used, it will only work if GCPs in the declassified imagery are still extant in the landscape.

**Projection**

Prior to any rectification or data-collection procedure a projection system needs to be determined. In most areas that have institutionalised cultural resource management bodies the regional or national projection system is easily accessible. It is advisable (and in some instances mandatory) that this projection mechanism is used. This will ensure that any results will integrate seamlessly with the national CRM data and other datasets, enabling subsequent data re-use and integration (BEWLEY et alii 1999). Where such a system does not exist then it is advisable to use one of the standard worldwide referencing systems such as Universal Transverse Mercator projection (UTM) or Lat/Long and an appropriate datum (if in doubt use World Geodetic System, WGS 84)

Furthermore, all systems must support the projection used: i.e. the CRM institution, the primary registration medium (Ikonos or its equivalent) and the GPS system. Pre-registered satellite imagery will normally come in a worldwide referencing system. If the registration imagery needs re-projection, by one of the many available algorithms, then some data loss is inevitable. It should also be ascertained if the GPS supports the regional system as an internal or user-defined system.

In the case under discussion it was decided to use UTM as this projection is more instinctive for in-field work than Lat/Long (working in metres rather than seconds of arc), is widely supported (for example by Landsat, Ikonos and most GPS systems) and is already in use in Cultural Resource Management (CRM) databases elsewhere in the region (PALUMBO 1992).

**Geo-correction using other datasets**

The available mapping for our application area is at 1:50,000, of unknown quality and date and is located in the Syrian Grid. For security purposes the precise parameters of the Syrian Grid are not publicised. With GPS data collected from the 2000 season we were able to rectify the mapping to UTM, although the accuracy was deemed too poor to correct the satellite imagery. Therefore, we needed to find some other mechanism with which to locate our spatial data.

We had acquired a 6 x 7 km portion of the Ikonos Geo product. The Ikonos imagery comes pre-reg-
istered in UTM with 1-m ground resolution and a stated RMSE accuracy of 25 m.

During the interim fieldwork season, conducted between April and May 2001, raw co-ordinates from the Garmin GPS12XL were overlaid with the Ikonos data to determine the spatial compatibility of the two media (Fig 15. 2). The removal of selective availability theoretically allows the collection of co-ordinates to ±5 m with a handheld GPS.

The correlation between the two datasets was good. This encouraged additional research to compare the effectiveness in terms of cost, practicability and accuracy of the two spatial referencing techniques as means for geo-correcting CORONA imagery.

**METHODOLOGY**

The methodology described here outlines the procedure to rectify spatially un-referenced raster satellite imagery to such a degree of accuracy that GPS measurements can accurately overly the imagery, or accurate measurements can be taken directly from the geo-located imagery. GPS measurements and Ikonos imagery are used to collect ground control points. Rectification and evaluation occurred in AutoCAD Overlay 2000, ArcInfo and ArcView GIS.

**By GPS**

A Garmin 12XL GPS was used to collect GCPs in both the northern and southern application areas. Sample lines of roads, tracks and their intersections were collected as polylines using the GPS. More time was spent at junctions to improve accuracy. This data was downloaded using the Mapsource software supplied by Garmin and exported as a text file. This text file was imported into ArcView by using AV Garmin, an extension written by the California Department of Fish and Game to create point, polyline or polygon files (available from http://maphost.dfg.ca.gov/outgoing). This file was also imported into AutoCAD.

The most important factor to bear in mind when conducting this type of survey, in tracking mode, is to set an appropriate time interval for recording. When travelling on tarmac roads with speeds ranging between 30-60 km per hour one reading every 5 seconds gave adequate results, but when defining a site extent by foot one reading every 10-15 seconds was more appropriate. However, these are only rules of thumb and each individual survey will have unique requirements.

In some cases the accuracy of the vehicle-based GPS measurements were a cause for concern. At certain locations the variability between successive GPS readings could be as large as 70 m. These areas were re-recorded. This problem could probably be reduced by the use of an aerial mounted on the vehicle. Nine intersections were identified and used to provide GCPs for the rectification. Due to a lack of contextual information in the GPS road map it was necessary to rectify coarsely a copy of the imagery in order to resolve road intersections that were difficult to determine. A second-order polynomial gave the best result, with an average RMS error of seven pixel units (the image has a pixel resolution of 2.38 m). The resulting image was generally a good fit. However, the inadequacy of the road map did not facilitate an even distribution of GCPs. It is important to understand that apparently mundane, essentially practical, issues of this sort may have an important influence on the cost and effort involved in the GPS-based geo-correction of CORONA imagery.
By Ikonos

When Ikonos imagery was used as a substitute for a base map it allowed rectification to occur in a traditional manner. If anything, there was so much information provided in the CORONA and Ikonos imagery that some effort on the part of the analyst was required to select the most appropriate points. Seventeen GCPs were identified that were spread relatively evenly around the image. A second-order polynomial gave the best result with an average RMS error of 5 pixel units.

RESULTS

Fig. 15.3 demonstrates the effectiveness of the rectification procedures. Rectification using Ikonos as a basemap gave the better results, with near-perfect rectification at site 191. However, the GPS rectification is still more than acceptable with a 10 m offset to the NE. The coarse rectification had an offset of approximately 100 m. At such accuracy more time would need to be spent on the ground-location of small features observed in the imagery. If the survey programme includes the purchase of Ikonos data (or a future equivalent) for the entire application area this will provide by far the most accurate mechanism for the rectification of CORONA. Furthermore, the errors associated with the GPS can be a cause for concern. While differential GPS may allow more accurate geo-correction, this is unlikely to be a realistic option, in the foreseeable future, for archaeologists working in the more sensitive parts of the world.

DISCUSSION

Because of the problematic characteristics of CORONA imagery (see above), the number of GCPs required will, in part, depend upon the relative location of a specific application area within a negative. Furthermore, in the three decades that have passed since the collection of CORONA imagery, there has been extensive modification, at least in the study areas considered here, of the landscape and road networks. This can make it difficult to correlate an individual
feature as it appears in CORONA with its appearance on other data sources. Major roads and road-junctions may have been added, widened, or moved since the late 1960s, while other prominent landmarks may also have changed in the last thirty years. It is in this aspect of geo-correction that Ikonos imagery has a major advantage over GPS collection. Although the GPS and Ikonos may have approximately the same degree of accuracy in terms of their ability to position surface features in terms of a specific co-ordinate system, Ikonos imagery provides a range of additional background detail that can significantly increase confidence in GCP identification. This allows greater flexibility in the rectification process when compared to the constraints imposed by GPS collection. However, Ikonos data can be purchased at different levels of geometric and orthographic rectification, and increased rectification results in a more expensive product. Fortuitously, the application area has relatively little topography and so the Ikonos Geo product is quite accurate. In areas of uneven terrain a higher-accuracy product would be more appropriate to compensate for errors introduced by the terrain. This could substantially increase the cost of using Ikonos. However, as competitors such as Quickbird (http://www.digitalglobe.com) enter the high-resolution marketplace the price of such imagery is expected to fall.

COST OF DATA COLLECTION

As ever in archaeology, cost is an overarching consideration, with the cost of data collection normally constituting the single most expensive component of a project. Although the cost of collecting of GPS data may appear low when compared to that of purchasing high-resolution satellite imagery, the ‘hidden’ costs of field data-collection can be substantial. In the case of the work in Syria, a team of at least two was required to conform to UK Health and Safety legislation, and it cost approximately $600 (at 2001 prices) for a return flight from the UK to Syria. Furthermore, one must include the cost of GPS equipment, vehicle hire, accommodation and subsistence expenses, and salaries. There was also a significant input of staff resources by the Syrian Directorate General of Antiquities and Museums. On the other hand, the Ikonos imagery was relatively expensive. It was at the time of this study (in 2001) priced at $29 per km² or $18 per km² for archived imagery (late-2004 equivalents $27.50 and $21). At 2001 prices this equated to $18,270 to cover the whole application area (still less than the annual cost of many archaeological field seasons). However, it would not be essential to have the Ikonos imagery covering the entire application area in order to geo-correct the much cheaper CORONA data. If the initial CORONA imagery could be coarsely rectified, then appropriately distributed sub-sets of Ikonos imagery, amounting to some 5% or 10% of the total application area, could be identified and purchased, giving the potential to substantially reduce the cost of imagery (an approach successfully tested in subsequent studies using both systematic and random selection criteria).

Processing costs should not be forgotten. For the purposes of this study rectification was undertaken using AutoCAD Overlay 2000. A dedicated image processing system, such as PCI or ENVI can be brought into use for future rectification. However, these systems tend to be expensive, and the costs (purchase, maintenance and training) of such dedicated systems is likely to discourage most archaeological organisation from using them in the short to medium term. However, there are some processing packages that can be purchased with significant educational discount (AutoCAD or Idrisi) or which are available free (GRASS). Although they may not be as effective as the more ‘professional’ packages (and still do not overcome the maintenance and training costs) they are affordable packages for archaeologists.

CONCLUSIONS

Both Ikonos and GPS collection techniques have demonstrated their effectiveness for providing locational information to rectify a small sample area of CORONA imagery to a high degree of accuracy. Subsequent studies have suggested that this technique will work over the whole application area of 630 km² providing an effective mechanism to co-register the Ikonos, CORONA and Landsat imagery. Once co-registered it becomes possible to exploit the different spatial, spectral and temporal characteristics of the imagery so as to improve landscape identification and analysis. Furthermore, the integration of Ikonos in this way could produce a major change in the way in which survey projects are conducted. It is appropriate that the preliminary phase of an archaeological survey project should now include a significant Desk Based Assessment (DBA) of the available satellite resources, linked to an initial “reconnaissance” phase of fieldwork. This DBA should provide the basis of a GIS in the appropriate projection for the region. Potential sites can be identified from the imagery, and landscape themes (soil type, crop cover etc) can be extrapolated from multi-spectral imagery. The provision of this type of data will produce a higher level of contextual information. This, in turn, will encourage field teams to focus and reflect on the academic, theoretical and methodological aims during the all-important early stages of the project.