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# Evaluation of Corona and Ikonos high resolution satellite imagery for archaeological prospection in western Syria

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*Satellite surveys in Syria have made use of imagery recorded some 30 years apart. By comparing the earlier pictures (Corona) with the later (Ikonos), sites captured on the former can be accurately located by the latter. The comparison also reveals the stark implications for archaeology as large parts of west Asian landscape change from a state of 'benign neglect' to active redevelopment. Based on their experience in the Homs survey, the authors have important advice to offer in the design and costing of surveys using satellite imagery.*

*Keywords:* satellite survey, western Asia, Near East, Corona, Ikonos, tell settlements, field systems, archaeological resource management

## Introduction

An increasing number of archaeological researchers are routinely employing satellite imagery, particularly those working in western Asia (Ur 2003; Philip *et al.* 2002a; Kouchoukos 2001). The spatial, spectral, radiometric and even temporal resolutions of satellite imagery have developed to such an extent that they now share several of the physical characteristics of aerial imagery (see Tables 1 and 2). The value of satellite imagery is most obvious in those parts of the world, developing countries in particular, for which cartographic data is limited, aerial photography difficult to access, and archaeological inventories underdeveloped. The cost of satellite imagery can be low in comparison to that of a programme of dedicated aerial reconnaissance (*contra* Schmidt 2004). Competition between the main commercial vendors of fine resolution satellite data has prompted a marked reduction in cost, while the growing range of archive datasets should offer archaeologists access to a range of affordable digital data resources. In our view, satellite imagery will become ever more important for both research and heritage management particularly with the emergence of Google Earth

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**Table 1. Definition of spatial, spectral, radiometric and temporal resolution**

Axis of resolution	Definition
Spatial	The size of a pixel on the ground (normally notated in metres)
Spectral	The number, location and breadth of electromagnetic wavelength bands
Radiometric	The accuracy with which a spectral band is recorded (normally notated in to the power of 2 or bits)
Temporal	The time between revisits of the same area (normally notated in days)

and World Wind portals (Beck 2006). With this in mind, it seems appropriate to ask how effectively the capabilities of current datasets are being exploited and if synergies can be gained by employing data with different spatial, spectral, radiometric and temporal characteristics. It is important that archaeologists are fully aware of the benefits, limitations and methodological implications of using satellite imagery, as its misapplication may prove costly.

## **The research context**

The archaeology of western Syria is particularly under-researched, with many areas providing minimal information on the nature, distribution and structure of settlement evidence in even the broadest sense. The project *Settlement and Landscape Development in the Homs Region, Syria* (SHR) was designed to address this problem by investigating long-term human-landscape interaction in three adjacent but contrasting environmental zones, located in the upper Orontes Valley near the present-day city of Homs. Each zone is typical of a larger area, and initial study suggested that they differed substantially in both their settlement histories and in the nature of their archaeological records.

The project area consists of two study areas (Figure 1): the Northern Study Area (NSA) is located north-west of Homs and the Southern Study Area (SSA) to the south-west of Homs. The present discussion refers to the two most extensive landscape types, the marl landscape which constitutes by far the bulk of the 370km<sup>2</sup> SSA, and the 120 km<sup>2</sup> of basaltic terrain which characterises that part of the NSA located west of the Orontes River. For the wider aims of the project and detailed discussion of the study areas and current agricultural regimes the reader should refer to Philip *et al.* (2002b: 1-6) although a summary of the residue types in each zone is outlined here.

In the marl zone the majority of the archaeological residues takes the form of tells and low relief soil mark sites. We believe that these soil marks represent the decayed and thoroughly ploughed remains of abandoned settlements originally composed of mudbrick structures. In the basalt zone the archaeological residues take the form of cairns, field walls and concentrations of rubble which constitute the remains of abandoned structures (for an initial morphological classification of such structures see Philip *et al.* 2005: 36-8, Figure 6). The smallest of these features are stone alignments with a width of less than 1m, which in some cases, may project only a few tens of centimetres above the present ground surface.

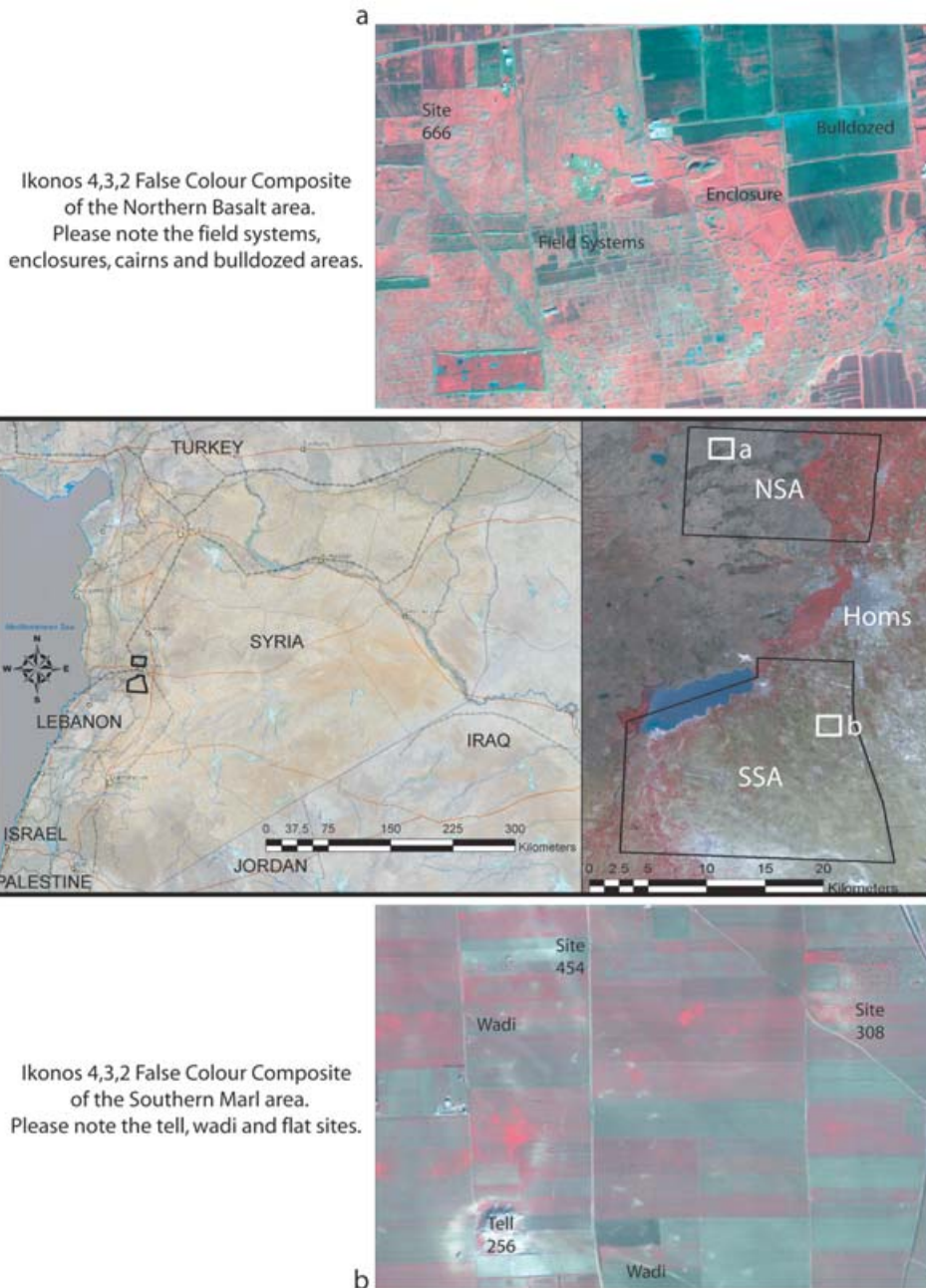


Figure 1. The basalt and marl area of the SHR project.

## Corona imagery and its limitations

It is important to summarise the use of Corona imagery so that the benefits of the more recent Ikonos imagery can be fully appreciated. Philip *et al.* (2002a) first discussed the

application of Corona imagery in the study area in this journal five years ago. Since then a number of methodological improvements have been made. While tell sites are generally easy to identify in the flat marl landscape of the SSA, Corona KH4B photography, collected in the late 1960s and early 1970s, has proved invaluable for the detection of low-relief archaeological sites which are characterised by an area of distinctive light coloured soil, and an associated surface artefact scatter. Most of these fall in the size range 0.5-4.0ha, and date to the Graeco-Roman or Islamic periods. As Corona photography was collected using a non-metric panoramic camera mounted on a satellite with a decaying orbit, the geometric rectification of the image is not a simple matter unless a good range of accurate ground control points is available (Galiatsatos *et al.* forthcoming). In this area, the degree of landscape modification since Corona was acquired in the late 1960s is such that it is often difficult to find points which are both readily identifiable on Corona and can be located with certainty in the present-day landscape. Despite these constraints, Corona proved perfectly adequate for the location of ploughed-out artefact scatters in the SSA. Survey teams were able to navigate to within 50-100m of a likely site, and then proceed to identify the exact location by fieldwalking.

However, in the rubble strewn basalt landscape of the NSA, the limitations of Corona became apparent. These were imposed by a combination of the following:

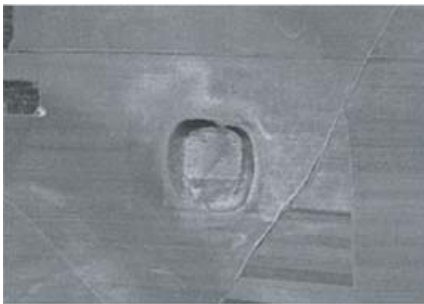
1. The inherent inaccuracy of the geocorrection process, which has a nominal positional accuracy of 50m.
2. The unobtrusiveness of many walls, which, while interpretable on Corona, were frequently hard to identify on the ground. The situation was exacerbated by the masking of anthropogenic features by the density of natural boulder cover and scrub and the fact that Corona photography is panchromatic.
3. The high density of features - several walls and cairns were often located within 10 or 20m of each other.
4. The degree of landscape modification since the 1960s, by settlement expansion and agricultural bulldozing, which made some areas almost unrecognisable.

The result was that even using hand-held GPS and a print-out of Corona imagery for the basalt landscape, surveyors found it nearly impossible to establish a one-to-one correspondence between the majority of features appearing on the imagery and those visible on the ground. Thus, while Corona offered a useful means of mapping the landscape as a whole, its value was constrained for more localised survey because of the difficulty of feature identification. Ikonos imagery is already geo-referenced and it was envisaged that Ikonos could transcend some of the limitations, or add value to, the Corona imagery.

The project has principally employed a combination of Corona, Ikonos and Landsat imagery (see Table 2 and Figure 2). All of these datasets are well documented (Day *et al.* 1998; Campbell 2002). The imagery spans every decade from the late 1960s and covers a number of different seasons. A small sample of 1950s Russian aerial photography was also acquired for the basalt landscape and was used to test a number of hypotheses on landscape development and the effect of spatial resolution on image interpretation (discussed later).

Table 2. Description of the satellite imagery used in this research.

Sensor	Resolution		
	Spatial (m)	Spectral (bands)	Acquisition dates
Corona KH-4B	2	1	17/12/1969, 28/05/1970, 31/06/1970
Ikonos Pan	1	1	06/09/2000 and 26/01/2002-03/02/2002
Ikonos MS	4	4	26/01/2002-03/02/2002
Ikonos Pan-sharpened	1	4	26/01/2002-03/02/2002
Landsat TM	30, 120	7	1980s and 1990s
Landsat ETM+	15, 30, 60	9	1999 onwards



Corona KH-4B photography (1967 - 1972)

1.83 - 2.5 m panchromatic

Photogrammetrically scanned to 8 bit raster imagery



Ikonos 11 bit digital imagery (1999 - present)

1 m panchromatic 0.45-0.9  $\mu\text{m}$   
 4 m Multispectral: 0.45-0.52  $\mu\text{m}$  Blue  
 0.52-0.60  $\mu\text{m}$  Green  
 0.63-0.69  $\mu\text{m}$  Red  
 0.76-0.90  $\mu\text{m}$  Near IR



Landsat 8 bit 7 band TM (and ETM+) digital imagery (1974 - present)

0.45-0.52  $\mu\text{m}$ , 30 m Blue  
 0.52-0.60  $\mu\text{m}$ , 30 m Green  
 0.63-0.69  $\mu\text{m}$ , 30 m Red  
 0.76-0.90  $\mu\text{m}$ , 30 m Near IR  
 1.55-1.75  $\mu\text{m}$ , 30 m Mid IR  
 10.40-12.50  $\mu\text{m}$ , 120  $\mu\text{m}$  Far (thermal) IR  
 2.08-2.35  $\mu\text{m}$ , 30 m Mid IR  
 15 m panchromatic ETM+ only

Figure 2. The satellite sensors discussed in this paper.

**Table 3. Sensor effectiveness in each environmental zone**

Sensor	Resolution		Zone		
	Spatial (m)	Spectral (bands)	Basalt	Marl	Alluvium
Corona	2	1	Medium-Good	Good-Excellent	Medium-Poor
Ikonos Pan	1	1	Good	Good	Poor-Medium
Ikonos MS	4	4	Medium-Poor	Good-Excellent	Poor-Medium
Ikonos Pan-sharpened	1	4	Excellent	Good-Excellent	Poor-Medium
Landsat TM	30	7	N/A	Poor	Poor
Landsat ETM+	15	9	N/A	Poor-Medium	Poor

While a number of archaeological users have taken advantage of the declassification of high-resolution (sub 2-3m) panchromatic military photography, such as the American Corona and Russian KVR missions (e.g. Kennedy 1998), the last five years have also witnessed the appearance of new commercial fine resolution imagery. In particular Ikonos and its competitor Quickbird provide geo-referenced panchromatic imagery at 1 and 0.7m and multispectral imagery at 4 and 2.44m spatial resolutions respectively. The present project has used Ikonos imagery acquired in February 2002 as part of a NERC-funded studentship designed to evaluate different image datasets for archaeological purposes.

### **The rectification of Ikonos and Corona imagery**

If multiple datasets are to be combined effectively and readily integrated with other information such as national CRM records, a single projection system is essential (Bewley *et al.* 1999). The current project uses the WGS84 datum and the Universal Transverse Mercator (UTM) projection, both of which are widely supported by image datasets and GPS systems.

Features in the basalt zone are often separated by much less than the positional error of the imagery (for Ikonos Geo-product<sup>TM</sup> this is > 25m). Thus the error inherent in the Ikonos imagery is still too large to enable accurate desk-based mapping in this context (see Table 3). Fraser *et al.* (2002) had demonstrated that the accuracy of the Ikonos Geo-product<sup>TM</sup> could be increased to sub-metre levels by using Ground Control Points (GCPs) located using Differential GPS to enhance the positional accuracy of the imagery. This study noted in particular that the internal geometries of the Ikonos imagery were very accurate and hence that relatively few GCPs were required for the corrections. In the light of security issues, the current project has been reliant upon re-geocorrection of the Ikonos imagery using GCPs established using handheld GPS (c. 4-5m accuracy in this region for prolonged readings) providing an image with approximately 5-8m error. The Corona imagery was georeferenced to this re-corrected Ikonos imagery using a number of selected tie-points and retained approximately the same error. The result of this process was imagery that was accurately located to a level which desk-based mapping and subsequent field navigation could be undertaken with improved confidence. This simple technique has provided the project with the kind of spatial control that could only otherwise have been obtained using a Total Station survey, a technique which would have been vastly more time-consuming for an area of this size (see Table 3).

Of particular importance is the fact that without using the Ikonos imagery as a basemap, it would have been nearly impossible to rectify the older Corona data to an acceptable level of precision. Using Ikonos imagery, the rectification of Corona can become a desk-based, rather than a field procedure, which offers obvious economies. Thus, in addition to its inherent value as high quality imagery with fine spatial resolution, Ikonos can considerably increase the usability and value of older Corona data.

## **Detecting archaeological residues**

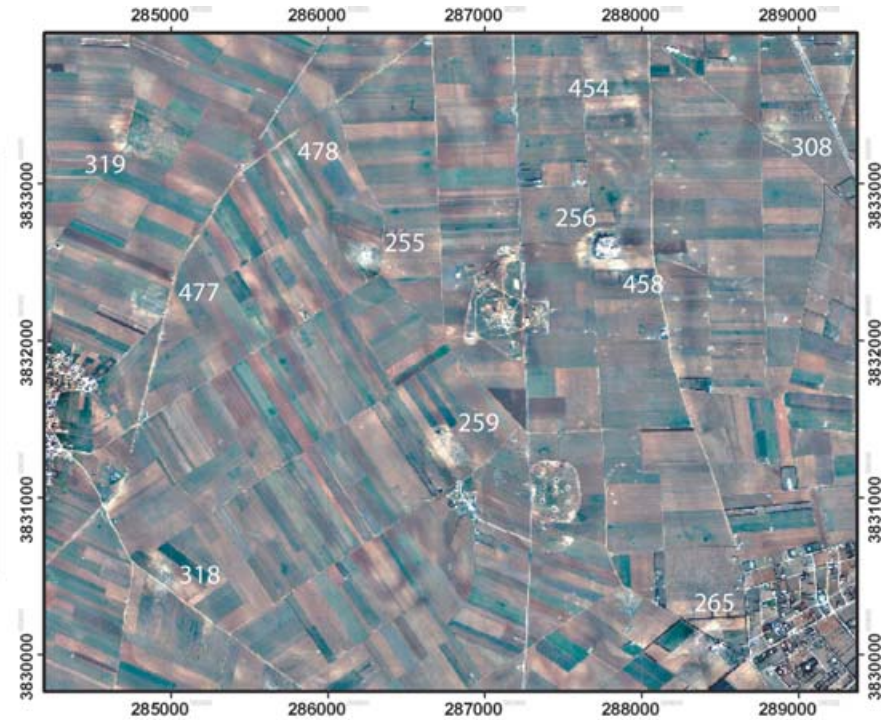
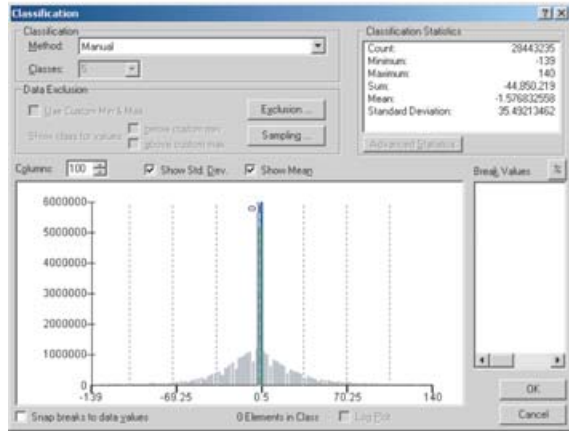
The nature of the archaeological residues and their relations with the immediate matrix (or context) determine how easily they can be identified. For example, it is relatively easy to identify a feature which has been cut into chalk and then back-filled with soil, whereas it can be much more difficult to identify a feature which has been cut into soil and immediately backfilled with the same soil. It is this very contrast between an archaeological feature and its surrounding matrix that one is hoping to identify.

The majority of the techniques used in this project rely on visual interpretation although a number of digital techniques can be used to enhance the contrast of archaeological residues. Spectral signatures have been used to accurately identify different vegetation and geological surface types with multispectral scanners. Many archaeologists believe that the same can be done for archaeological residues; however, it must be stated that as archaeological residues represent modifications of a pre-existing landscape one cannot create a suite of standardised archaeological spectral signatures that will work in any environment. If the idea of a spectral signature can be applied at all, it will only work within a consistent background environment (see for example Altaweel 2005). Rather, we hypothesised that the archaeological residues produced localised contrasts in the landscape matrix which could be enhanced, thus improving the likelihood of their detection. Although this statement sounds self evident, it requires an understanding of both the nature of the residues and the landscape matrix within which they exist.

In the marl environment the archaeological sites were associated with an increase in reflectance against the background soil. This change in reflectance is not consistent and so it is difficult to define a distinct archaeological spectral curve that will detect residues across the marl zones. In many instances the contrast of the archaeological residues could be enhanced by simple histogram manipulations (i.e. density slicing, contrast stretching or using false colour composites). However, subtracting an averaged background soil value from an on-site pixel value will generally produce a positive value. A 200m moving average kernel was applied to the imagery in order to evaluate whether residues were easier to locate in the resultant statistical surface. In theory, after processing, areas of unmodified soil should have a value approaching zero. Features that significantly deviate from these background values, such as archaeological residues, roads, buildings and crops, will exhibit positive or negative deviations from this mean. This kernel-based operation creates a statistical surface which approximates to a normal distribution with a mean value of zero. Figure 3 represents an example of such a surface in the marl; sites were much easier to identify in this image.

In the basalt environment the archaeology was represented as a series of walls, structures and cairns predominantly manufactured out of locally sourced basalt (i.e. they have a similar





*High resolution satellite imagery for archaeological prospection*

200m radius kernel average Ikonos MS (3,2,1 standard deviation stretch)  
and statistical distribution of values in the Red band

Figure 3. Ikonos near true colour composite image of the marl landscape enhanced using the 200m kernel filter to help identify sites from soil colour.

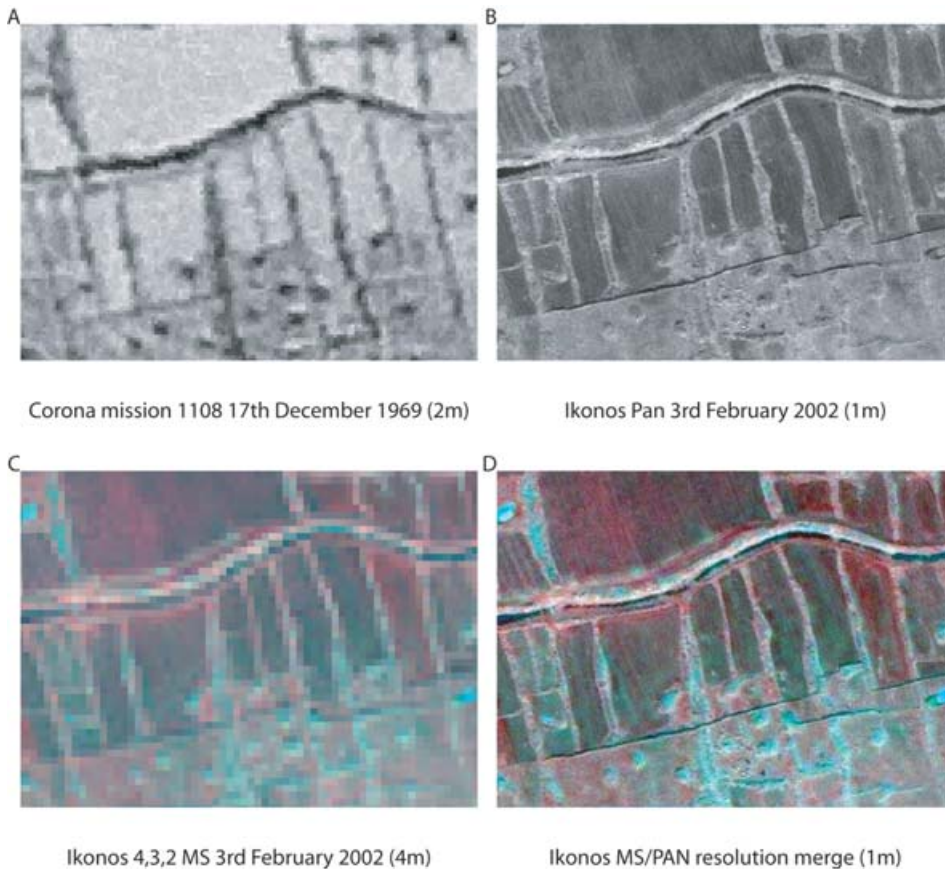


Figure 4. Comparison of different image types in the basalt environment.

spectral signature). In this environment fine spatial resolution is necessary for the definition of shape and structure and improved identification comes from higher spectral resolution. In this case combining the spatial resolution of the Ikonos panchromatic with the spectral resolution of the Ikonos multispectral imagery would be most beneficial. This can be done by transparently overlaying the panchromatic with the multispectral imagery or by fusing the fine spatial resolution imagery with the multispectral imagery in a process known as pan-sharpening. Figure 4 compares a number of image representations in the basalt zone; image fusing the spectral and spatial components of the Ikonos imagery provides the best interpretative product.

## Finding sites

Work in the Southern Study Area (SSA) a typical 'lowland' zone, has increased the number of known ancient settlements to 101 (21 tells and 80 flat sites) an increase of 100 per cent over existing records (Philip *et al.* 2005: 30). Tell sites are generally easy to locate, both on the basis of their distinctive morphologies, and the casting of shadows (see Figure 1). However, these sites also demonstrate distinctive spectral characteristics. In fact, the environment of

the marl zone is ideally suited to site prospection using remote sensing because of localised differences between the soils associated with ancient settlement remains (confirmed by the presence of characteristic concentrations of surface artefacts), and that derived from the local geology. These differences are primarily manifested through soil colour (see Figure 1 and Figure 3). These equate directly with what aerial archaeologists refer to as soil marks (Wilson 2000).

Field measurement of soil colour using Munsell charts established that, when dry, archaeological residues were significantly lighter in colour (reflecting an increase in chroma) than the surrounding off-site soils; the two were indistinguishable by eye when wet. The inspection of imagery from different seasons revealed that the colour differences between sites and non-archaeological soils were most evident during peak aridity (September to November), although sites were also readily detectable during periods of drying-out following rainfall. This presumably reflects differences in the capacity of archaeological and non-archaeological soils to retain moisture.

This phenomenon proved highly effective in identifying sites in both the Corona and Ikonos imagery. The Ikonos multispectral and Corona were the most useful images in this role. For prospection purposes, the finer spatial resolution of Ikonos panchromatic imagery provided little additional information. Rather, sites are identified by recognising localised variations in reflectance in the different spectral bands. As most of the residues covered areas of at least several tens of metres in diameter, it may be that the key to the identification of such sites lies not in sensors with finer spatial resolution, but in those with improved spectral resolution. The point is that these sites are identified by their contrast to the background soils and vegetation and that information from different wavelengths may be more sensitive to these contrasts. This is an issue which requires further investigation, as more sensitive sensors become available. It should be noted that the statistical surface created by the moving average kernel made the visual identification of these residues much easier.

The Ikonos imagery exhibited a number of areas of high reflectance which appear to represent potential archaeological residues but which were not visible on the Corona imagery (see Figure 3, e.g. the unnumbered bright patches in the top left area of the image). Ground observation of a sample of these features has demonstrated that they have no archaeological significance, and appear to represent areas where quantities of broken marl bedrock have been brought to the surface as a result of recent deep ploughing in already shallow soils. However, where Ikonos data is used without the control provided by older Corona imagery, these 'false' signatures would present a significant amount of 'noise'. As the site identification process is based upon the recognition of a change in localised contrast in different spectral bands and not upon a particular spectral signature, there is no simple way to distinguish between the residues of ancient settlements and the 'false' signatures described above other than by morphology (no more than an approximate indicator) or ground observation.

It appears that the deformation of material associated with past settlements shows a tendency to alter the local soil structure which in turn changes the drainage and water retention characteristics of the soils resulting in increased reflectance in the visible and near infra-red component of the electromagnetic spectrum. For the generally well draining soils at archaeological sites the difference in soil moisture produces a localised discernibly brighter

reflectance which is most pronounced during peak aridity. This issue is discussed further by Wilkinson *et al.* (2006).

The small size of many residues in the basalt landscape means that sensors with fine spatial resolution are required in order to detect them (see Table 3). The 1m Ikonos panchromatic and 2m Corona proved by far the most effective datasets for this purpose. The Ikonos imagery provided a better interpretative product as it offered higher levels of detail than the lower resolution Corona imagery. The spatial resolution of the 4m Ikonos multispectral proved too coarse to allow the accurate mapping of these residues. Probably the most effective tool, in terms of facilitating the detection of both pattern and detail in the basalt was pan-sharpened Ikonos data. This addition of a colour component to the fine spatial resolution imagery proved especially suitable for the problems of the basalt landscape (Figure 4D).

### Resource management issues

A gap of a little over 30 years separates the Corona (1969, 1970) and Ikonos (2002) datasets used by the project. Given the scale of recent landscape modifications, the temporal component of the imagery has been of profound significance for understanding the resource. It is particularly fortunate that the Corona imagery appears to have recorded the landscape as it existed prior to the recent modification of the archaeological residues as a result of the increasingly widespread use of bulldozers to reshape the agricultural landscape. That this is indeed the case has been confirmed both by discussions with local farmers and by comparing the Corona imagery with a sample of Russian aerial photography dating to the 1950s.

While the expansion of settlement and various infrastructural projects have impacted on archaeological residues to a degree, this has mainly been centred upon those ancient settlement locations which are under present-day occupation. Abandoned settlements had, until recently, escaped such extensive damage. This situation of benign neglect has been transformed as a result of changes in agricultural practices, in particular bulldozing in the basalt landscape which is designed to create large rectangular fields. The surface stone cover, of which archaeological features are a considerable component, is removed by this process. A comparison of Corona and Ikonos imagery revealed those areas where the archaeological record had been substantially modified up to 2002. Subsequent field observations have demonstrated that bulldozed areas are now much more extensive than was the case in 2002. Efforts are now being made by the Directorate General of Antiquities and Museums to control bulldozing in selected areas. In those areas which have undergone extensive modification, the Corona satellite imagery now provides the best available record of the original archaeology (see Figure 5). This development highlights the ability of local landscape management to shift rapidly from a situation of 'benign neglect' to large-scale destruction, and stresses the continuing importance of large-scale prospection.

Observation of the settlement distribution has revealed that many of those sites situated beyond the immediate vicinity of the Orontes River are located along one or other of a series of shallow, relict watercourses (Philip *et al.* 2002b: Figure 6). These can be readily detected on the Corona imagery where they are present as a series of meandering, linear, high reflectance features, presumably from the presence of a pebble lag deposit on the stream bed (Philip *et al.* 2005: 26-7, Figure 4). However, such has been the impact of recent agricultural practices

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EVIDENCE TYPE	EVIDENCE CHIP		EVIDENCE GROUND TRUTH	EVIDENCE DISCUSSION
	Ikonos pan sharpened	Corona		
Tell				Tell site 49. Even in the basalt zone tells display a reflectance increase. Note that topographic shadow is present and that the clouds are easy to see on Ikonos.
Wall 2				Wall type 2. Long straight walls enclosing narrow fields. These do not tend to show on the Corona.
Wall 3				Wall type 3. Moucha farming. Large fields subdivided into much smaller units. The outer field possibly relates to centuriation.
Road				Ancient Road Network. It can be very difficult to distinguish these from walls. However, the form of these features are more irregular.
Bulldozer Mask				Masking by bulldozer. The field systems evident in the Corona imagery have been bulldozed. It is possible to extrapolate the original field systems in Ikonos.

Figure 5. Segment of an image interpretation key (positive evidence in the basalt zone).

that extensive stretches of these channel beds are impossible to identify in the Ikonos imagery.

As Ikonos data can image only the present-day landscape, the value of Corona data in areas where recent change has removed or obscured archaeological evidence, is obvious. The conclusion is that in both the marl and basalt landscapes there are important, and bi-directional, synergies between Corona and Ikonos. In fact, given the scale of recent landscape modifying operations, the 30-year time difference between the Corona and Ikonos imagery offers a highly effective and complementary resource for interpretation.

## Survey design

In the course of this research the project has spent around £22 000 on satellite imagery, which, for a total survey area of approximately 650km<sup>2</sup>, equates to £34 per km<sup>2</sup>. Recognising that most projects would seek to reduce the cost of acquiring data, we would make the following recommendations for researchers wishing to use imagery in similar environments.

Prior to purchasing any imagery it is essential that the nature of the environmental zones and the archaeological residues are understood and that a desk-based assessment is undertaken. This information can be contextualised using one of the number of free satellite images available over the internet (for example Landsat imagery at the Global Land Cover Facility in Maryland: <http://glcf.umiacs.umd.edu/index.shtml>) or with one of the on-line



viewers (for example Google Maps: <http://maps.google.com/>). Preliminary field data is also required for the following environmental, archaeological and background information:

1. The type and extent of different environmental zones.
2. The nature of the surface cover in each zone (this helps to clarify what the imagery is showing).
3. The extent of agricultural seasons in each zone.
4. The extent of any irrigation systems.
5. The average monthly precipitation.
6. Atmospheric variations over the year (e.g. cloud cover, pollution and atmospheric particulates).
7. The nature and extent of known archaeological residues in each zone (so the visibility of known features on the imagery can be established).
8. GPS coordinates for a range of Ground Control Points that can be identified on the ground and, potentially, on both present-day and historic imagery.

Regarding archaeological residues, it is particularly important to understand how their contrast changes against any 'background' readings during different environmental conditions. In the present case, residues in the marl zone exhibit greater contrast during periods of peak aridity. After rainfall, and when under crop, this contrast can be significantly reduced.

When deciding upon which types of sensor are appropriate for the study one should understand the nature of the residues to be encountered and the level of identification that one is hoping to achieve. Inevitably this will mean that a range of different sensors are appropriate for a survey: for example the following sensors could be employed in this study area:

- a) Coarse spatial (>100m) and high spectral resolution imagery for coarse landscape identification (particularly soils and geology).
- b) Medium spatial (10-60m) and medium spectral (>6 bands) resolution imagery for refined landscape identification, e.g. Landsat ETM+ or equivalent.
- c) Fine to medium spatial (2-15m) and low to medium spectral (>3 bands) resolution to detect larger features (ploughed out sites, tells etc.), e.g. Quickbird MS, Ikonos MS or SPOT 5.
- d) Fine spatial (<1m) and low spectral (pan) resolution imagery to detect very small features (walls, cairns, linear soil marks, pits, postholes etc.), e.g. Quickbird pan, Ikonos pan and/or Corona.

Wherever it exists, historic satellite imagery (e.g. Corona) should be purchased, even if it turns out to be of limited value. The purchase and evaluation costs can be minimal and it has the benefit, in many (though not all) areas, of having been collected prior to the adoption of deep ploughing, extensive irrigation schemes and other large-scale earth moving activity, each of which has had a profound impact on the present day landscape. Archive fine resolution commercial image sets should also be consulted.

Further, one can discriminate where imagery should be purchased. Significant economies can ensue from the targeted application of appropriate satellite sensors. For example, in the environments of this study area fine spatial resolution sensors are only required for the basalt zone as opposed to the medium spatial and spectral resolution sensors required for the marl zone. If this advice were followed then the aforementioned suite of satellite imagery would cost between £8000 and £10 000 at current prices. We would argue that at a cost of £12-5 per km<sup>2</sup> this represents an extremely good investment for any project which is entering a planning/reconnaissance stage of work in a hitherto poorly documented area.

When the imagery is interpreted, image interpretation keys (see Figure 5) should be created. These metadata resources are essential knowledge transfer tools that will aid future researchers and those in adjacent project areas. It should be remembered to record both positive and negative responses as these will help future interpreters determine which data resource is appropriate for their own research.

## **Conclusion**

Corona and Ikonos imagery have delivered considerable benefits to the SHR project in both the basaltic and the marl landscapes. Although these data have very different properties in terms of date of acquisition, spatial and spectral resolution, it turns out that the information they contain is complementary and has enhanced our understanding of the landscape. Without both the Corona and Ikonos satellite imagery this project would have a significantly reduced understanding of the archaeological record. The complementary application of satellite imagery to target ground survey has led to a number of cost benefits. Most significantly, the scale and immediacy of the threat to less obvious aspects of the archaeological record has resulted in a positive preservation strategy from the local authorities.

In terms of the archaeology of this particular project the main advantages of the data can be summarised as follows:

- Provision of a valuable map base, environmental dataset and navigation tool
- Ability to undertake extensive preparatory desk-based analysis allowing a focused and question-led approach to field-survey
- Comprehensive identification of the archaeological residues in the area, the scale and importance of which had hitherto been underappreciated by fieldworkers in the region (e.g. flat sites, cairns and field systems)
- Rapid identification of a large number of inconspicuous ploughed-out sites that represent the post-Iron Age settlement record in this part of Syria. While the Directorate General of Antiquities and Museums conservation strategies are focused upon tells, this will only protect the settlement evidence for the Bronze and Iron Ages. It is important to recognise the form taken by the 'lowland' component of Graeco-Roman and Islamic period sites.

Over a period of five years, the analysis of satellite imagery, in combination with a targeted programme of fieldwork, has facilitated the acquisition of a body of reliable information on the form and distribution of archaeological remains. It has also clarified the nature of soil cover, hydrology and recent agricultural practices, and through the comparison of imagery

of different dates, highlighted key recent trends in the anthropogenic modification of the local landscape (Philip *et al.* 2002b; 2005). The analysis of these data will provide the information necessary to develop an evidence-based sampling strategy for a second phase of more intensive investigations (see Alcock *et al.* 1994: 138). The project has also provided a heritage management tool which has been used by the Syrian Directorate General of Antiquities and Museums to identify parts of the archaeological resource which are under imminent threat from a current programme of large-scale agricultural bulldozing.

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