High Resolution Satellite Imagery for Archaeological Application

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Abstract

For many millennia humans have been leaving their mark on the earth in various forms, analogous to clues left behind for modern people to discover, collect, record and decode the mysteries from our past. Disciplines ranging from the human, social and earth sciences have been applied to uncover and decipher vestiges from our human past, and archaeology is one such discipline which relies on interdisciplinary knowledge. For instance, anthropology provides insight into how ancient people lived their lives, environmental science assists with reconstructing ancient environments, while geology helps interpret how ancient people used and transformed their landscape. Although these disciplines are traditionally associated with archaeological investigations, archaeology also readily embraces new technologies for the discovery, collection and analysis of evidence from our past.

Satellite remote sensing is a recent addition to the range of disciplines that can assist with the detection, mapping and analysis of archaeological matter, providing that the satellite sensor is spectrally sensitive enough and has high spatial resolution capabilities enabling it to detect structural archaeological features. One such earth observation satellite is *Ikonos-2,* which is equipped with a high-resolution sensor and represents a technological advance for the commercial remote sensing industry. The article covers research conducted at the University of Melbourne, Department of Geomatics, in 2000 and 2001 for a Masters' thesis, supervised by Professor Clive Fraser and Mr Cliff Ogleby, investigating *Ikonos-2* satellite imagery and how it can be implemented to discover, locate and map archaeological features.

INTRODUCTION

Archaeology is a recent application area of satellite remote sensing and features such as ancient settlements, roads or any indication of human activity on the ground during ancient times can be detected with remote sensing procedures, providing that the spatial resolution of the sensor is adequate enough to detect the features.

Two modes of over-head remote detection used in the general field of archaeology are aerial photography and satellite sensed imagery. Aerial photography has to date been employed more often due to both the superior ground resolution traditionally available from photography, and the fact that aerial imaging is a well established technology. The use of satellite technology in archaeology in the recent past has met with varying degrees of success. Multispectral satellite imaging has the benefit of allowing the archaeologist to view parts of the spectrum not visible to the naked eye and also not detectable with photographic techniques. The development of commercial high-resolution satellite imaging, as exemplified by the deployment of *Ikonos-2* in September 1999, offers possibilities for imaging archaeological features to a ground resolution of 1m in panchromatic (pan) mode and 4m in four multispectral bands.

Thus the aim of the research conducted in 2000 and 2001, was to explore the use of remote sensing in the form of high-resolution satellite imagery (HRSI) for archaeological application. This was fulfilled by firstly exploring the background information dealing with remote sensing issues within archaeology, and then with a thorough investigation into the application of remote sensing techniques for the detection, classification and mapping of archaeological features.

BACKGROUND

REMOTE SENSING IN ARCHAEOLOGY

"Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information". (CCRS, 1998)

In relation to archaeology, remote sensing offers a manner of discovering remnants from our human past on the ground from a high view point. Archaeological features whether they are situated sub-surface or on the surface of the earth can be potentially detected with remote sensing techniques. Also, viewing structural remains from ground level generally do not clearly identify the spatial significance of those remains or the relationship of those remains to surrounding archaeological sites, and in some cases ancient sites are not apparent from ground level but become obvious from above. This is why the overhead view is of benefit to archaeological investigations.

Two types of over-head remote sensing used in archaeology include aerial photography and satellite imaging. Both have their advantages and limitations. Aerial photography offers high spatial resolution, enabling detailed visualisation and interpretation of archaeological structures, while satellites traditionally produce low resolution imagery, but cover both the visible and non-visible parts of the electromagnetic (EM) spectrum, useful for multispectral analyses. The EM is the extensive range of all types of radiation beginning from the largest wavelength, radio waves, to the smallest, gamma-rays. Somewhere in between is the visible spectrum (from 450nm to 700nm).

Aerial Photography

Since the development of aerial photography, remote sensing has been used as a tool for the acquisition of archaeological information. At the turn of the twentieth century, archaeologists realised that valuable archaeological data could be extracted from aerial photos (Doneus, 1999), thus it developed into a systematic discipline known as aerial archaeology. Even after the emergence of satellite technology in the 1960s aerial photographs were still preferred by archaeologists due to their higher resolution.

In the 1920s, OGS Crawford, one of the pioneers of aerial archaeology, formulated a set of site classifications for determining archaeological features in aerial photographs, listed below.

1. *Shadow marked sites* – are those sites where the remains are partly above the ground's surface and are visible due to the shadows they cast.
2. *Moisture marked sites* – the natural physical order of soil is disturbed due to past constructions so the sub-surface remains become visible from colour variations or tonal differences in soil.
3. *Crop marked sites* – the growth rate of plants varies depending on the contents of the soil. Sub-surface features become visible from differences in plant height and colour.

The limitations of the site classifications are that they rely on the *visible* patterns of the archaeological remains. In most cases, it is also useful to investigate imagery for archaeological features within the non-visible part of the spectrum, which can reveal more information about a site. For instance, the use of the infrared (IR) region in aerial archaeology provides additional information about vegetation growth patterns. Buried remains can cause changes in vegetation growth, but sometimes these changes may be too subtle to be seen with the naked eye. IR imaging enhances these variations and allows the image interpreter to investigate vegetation changes within the non-visible spectrum. The standard film used in aerial archaeology is sensitive to the visible part of the EM spectrum; however imagery within the non-visible spectrum can be achieved with either IR photographic film or the use of filters.

The entire IR region ranges from about 700nm to 300,000nm (Dorrell, 1989), whereas IR film is sensitive to a small portion of that range; from wavelengths 700nm to 900nm, also known as near infrared (NIR). This range of IR energy does not emit radiation from an object but reflects the infrared signal emanating from a light source, namely the sun in the case of aerial photography. Longer IR wavelengths, such as thermal IR, emit heat and film cannot be used to detect thermal IR energy since the touch of a human hand would expose it (Kodak, 1992). Overall aerial photography has a limited spectral range due to film emulsions, which are sensitive only in the visible region and the NIR region of the EM spectrum.

Satellite Imagery

In the recent past, archaeological applications have been conducted with the aid of satellite technology, but due to ground resolution constraints, these studies have not progressed to the extent of aerial archaeology.

Low resolution imagery can only detect the larger archaeological structures such as the Pyramids of Giza (Fowler, 1996) in Egypt. To further explain - a Landsat image has a 30m ground resolution allowing for the visualisation of structures with dimensions of 30 by 30 metres or more. However the possibility of detecting archaeological structures of 30 square metres or more is low, primarily because very few ancient ruins of this magnitude exist. The combination of low-resolution imagery with high-resolution imagery can yield favourable results, enabling the visualisation of moderately sized archaeological features.

An advantage satellite imagery has over aerial photography is greater spectral range, due to the capabilities of on-board sensors. Most satellite multi-spectral sensors have the ability to capture data within the visible and non-visible spectrum; encompassing a portion of the ultraviolet region, the visible, and the IR region, enabling a more comprehensive analysis. In the case of the Landsat TM sensor its range extends into the thermal IR region up to about 25,000nm (Kruckman, 1987).

Image Source for the Investigation

Both aerial photography and satellite imagery have advantages and limitations with regard to archaeological applications. While aerial photography offers high-resolution photographs, satellite sensors produce imagery which possess superior spectral content. A combination of the two is ideal for archaeological remote sensing applications. In view of this, the satellite image source used for the investigation was *Ikonos-2* since it produces multispectral images with a 4m resolution, covering the blue, green, red and near infrared bands, along with 1m resolution images in the panchromatic mode, comparable to that of aerial photography.

INVESTIGATION

AREA OF STUDY

The study area, located on the island of Crete, Greece, is situated within the Mediterranean Sea south of the Greek mainland, bounded by the Cretan Sea to the north and the Libyan Sea to the south. It was chosen on the basis that previous archaeological studies regarding ancient roads and sites had already been conducted by archaeologists, and therefore, some literature and maps of ancient features already existed for consultation to assist with the detection and verification of features within the satellite image. The background knowledge regarding the ancient Minoan people of Crete and how their activities affected the natural environment is important in order to gain an idea of their spatial organisation. Also information on what the island is composed of is useful to assist with the analysis of the imagery.

The bounding blue rectangle shown in the map of Figure 1 indicates the study area in eastern Crete.

Figure 1: Map of Crete showing modern towns in blue, archaeological sites in red, and study area enclosed by the blue rectangle.

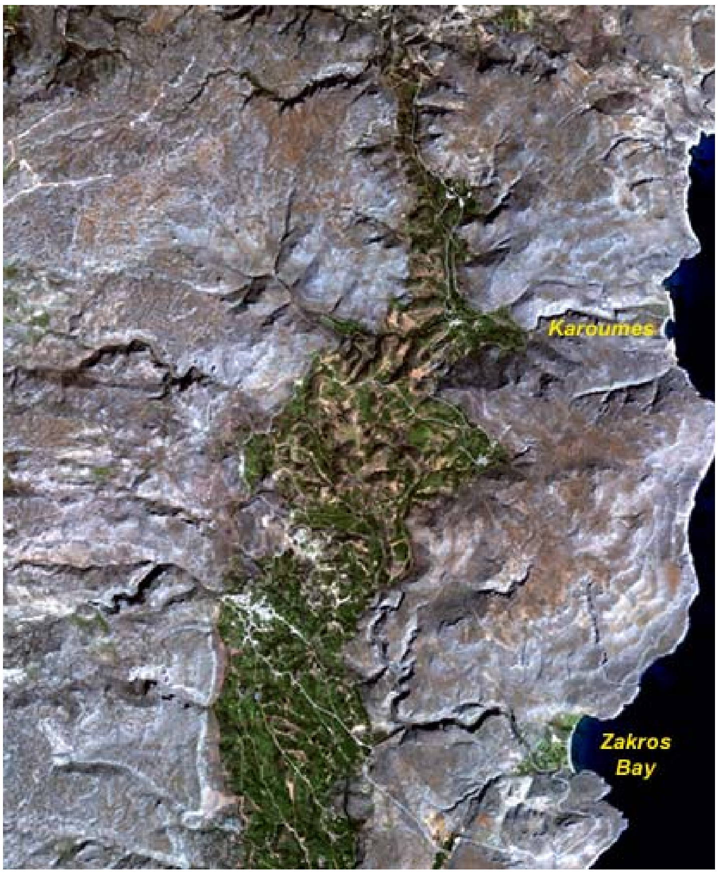

Figure 2: *Ikonos-2* true-colour image of eastern Crete

The *Ikonos-2* image of the study area is 9 km by 11 km, and was captured March 9, 2000 at the requested time of 8:30am, to highlight any shadow marked sites. Its coordinates are in WGS84 projected in UTM35.

Crete is the largest of the Greek islands spanning about 250km in an east to west direction with varying north to south widths, ranging from 57km to 12km (Pendlebury, 1963). The study area, in eastern Crete, encompasses the ancient Minoan city of Kato Zakros in the lower right portion of the image, Figure 2. Kato Zakros is situated within the Zakros Bay surrounded by vast beaches. The narrow valley of Kato Zakros has a cultivable area but is confined by two rocky hills, one north-east of the valley the other south-west, upon which a Minoan settlement once prospered. In general, the land of Kato Zakros is not considered to be agriculturally prosperous as the soil is rocky and barren. In some instances, ruins of ancient buildings embedded within the soil, add to the difficulties with cultivation on these barely productive hills (Platon, 1971). Nikolaos Platon, the prime excavator of Kato Zakros, identified the structural remains in the plain at the foot of the hills as a Minoan palace.

Ancient Minoan Civilization of Crete

The ancient features in question are those left by the Minoan civilization, which flourished during the Bronze Age from approximately 3000 to 1100 BC (Hood, 1971).

Crete is a topographically diverse island as it was in antiquity, and it took the Minoans about 1000 years during the early stages of the Bronze Age to develop into a thriving civilisation, building grand palatial centres, religious focal points and establishing internal and external trading relations (Cadogan, 1992).

The topography of the island played a major role in moulding Minoan society, in the placement of settlements and in physically shaping the routes of internal interaction between settlements. The landscape and geology of the study area in eastern Crete are quite remarkable. Like most of the island, it is rocky and mountainous. During Minoan times it is highly likely that eastern Crete had forests and more vegetation, however deforestation and natural weathering processes rendered the land arid (Willetts, 1969). Today the soil is quite barren and therefore not many crops are successfully grown. The main produce of the area is the olive and olive trees are found sprawled all over the island as they are able to survive in such barren conditions. Similarly, in ancient times olive production was a significant source of sustenance and economic growth (Willetts, 1977).

Much of what is known about the ancient Minoans has come from information obtained from the plethora of archaeological sites excavated in Crete. Most people familiar with Homer's *Odyssey* associate the word 'Minoan' with the powerful king of Knossos, king Minos, who demanded from Athens an annual ransom of sacrificial victims to appease the Minotaur (half-man/half-bull). The mythical beast was subsequently slaughtered by the brave Theseus in the labyrinth. Sir Arthur Evans, prime excavator of Knossos, from the turn of the twentieth century till around 1940, coined the term 'Minoan' to refer to the period of civilisation on Crete (Hood, 1971). It was implied from ancient literary sources that the name Minos represented a dynastic succession of kings named Minos rather than just one ruler (Burrows, 1907).

The arrangement of Minoan settlements was such that the palaces were immediately surrounded by towns that were in turn surrounded by satellite settlements or villas and agricultural dwellings, sprawled throughout the countryside (Willetts, 1969). Since the palaces were supported by the rural sector, an understanding of this relationship is necessary to determine the networks of communication between them. However, it is still somewhat difficult to elaborate on the social and administrative organisation of the Minoan people, due to scant evidence (Willetts, 1977). What can be inferred, though, is that the palatial centres relied on the farming communities to sustain them, along with specialised craftspeople in the towns who provided the residents with various items, and also peak sanctuaries that were religious focal points located on tops of mountain peaks and near upland grazing areas. Through evidence of contemporaneous artefacts, peak sanctuaries were associated with major centres and villages.

Hood (1971) suggests that trade between the main settlements of Crete most likely occurred along routes for pack animals and wheeled vehicles around the less mountainous regions, and by sea along the coasts wherever passage through treacherous terrain was difficult. Evidence of trade and communication between settlements has been unearthed through various finds, such as items manufactured in one settlement and found in another.

Archaeological Features

Table 1 below is a compilation of Minoan archaeological features and their characteristics obtained from studies by Tzedakis and his fellow archaeologists (1989; 1990a; b), and was used to assist with the spatial interpretation of the imagery.

Table 1: Minoan archaeological features and characteristics

Archaeological feature	**Geometric Characteristics**	**Additional Characteristics**
ancient road	linear, 1.5 m to 2.5 m wide	paved with limestone slabs (near major site)
		followed natural course of terrain
		enlargement of naturally narrow curves
guard post	approx.10 m x 10 m	situated at road junctions
		constructed from limestone megaliths
palatial complex	approx. 120 m x 100 m	contains - central courtyard 30 x 12
		- treasury
		- 'royal' rooms
		- other rooms
		surrounded by Minoan urban houses
		positioned near harbour
		constructed from limestone and mudbrick
peak sanctuary	no structures	located on top of mountain peaks
		situated close to settlements

The Minoans did not put a lot of effort into ‘road’ construction. The roads/tracks mainly followed the natural course of the terrain and roads closer to settlements were paved with local limestone slabs, or otherwise they levelled off any obtrusive rocks along the road and also widened natural curves for easier passage (Tzedakis, 1989; 1990a; b).

It is conceivable that in some areas of Crete ancient Minoan roads are still buried, however, the east side of the island has experienced considerable erosion, so it is possible that some ancient roads have been revealed through these natural processes or even eroded away.

Composition of Eastern Crete

The mountains of eastern Crete are mainly composed of grey limestone, with earlier deposits that have been exposed from erosion processes consisting of brown, grey and greenish schists, quartzites and shales (Hood, 1971). Around coastal areas, are homogeneous marls - soft white marly limestone known as *kouskouras*, and soft gypsum (Gifford, 1992); (Willetts, 1977). It was this material, the soft gypsum stone, which the Minoans mainly exploited for building their palaces. Willetts (1977) notes that at least 165 gypsum quarries dating to Minoan times have been found in Crete. Within the Zakros palace complex though, gypsum was not used (Cadogan, 1976). Instead, limestone blocks and mud-bricks were used, which have survived today as ruins.

The surrounding mountains of Kato Zakros are bare, primarily composed of schist, which exhibit various colours such as violet, brown or light green depending on the texture of the layers of sedimentary schist (Platon, 1971). The remains of a Minoan town on the hill tops surrounding the valley at Kato Zakros must have overlooked the palace (Platon, 1992) during the Bronze Age.

Information on the island's composition and the building materials used by the Minoans was used to aid the spectral analysis and classification of the satellite image.

RESEARCH METHODOLOGY and RESULTS

The methodology incorporated the spatial attributes of the Minoan features documented in Table 1 along with various remote sensing techniques, and the following objectives which emerged from the background research:

Research Objectives

- Improve the spatial resolution in the multispectral image to assist in the visual interpretation of the imagery;
- Use of background literature and maps of archaeological features to ascertain search locations;
- Detection and mapping of any features that may be archaeologically significant;
- Verification of detected features on the ground;
- Implementation of image processing techniques for the purpose of highlighting and detecting archaeological features.

Figure 3 shows the various phases of the methodology used to address and fulfil the objectives.

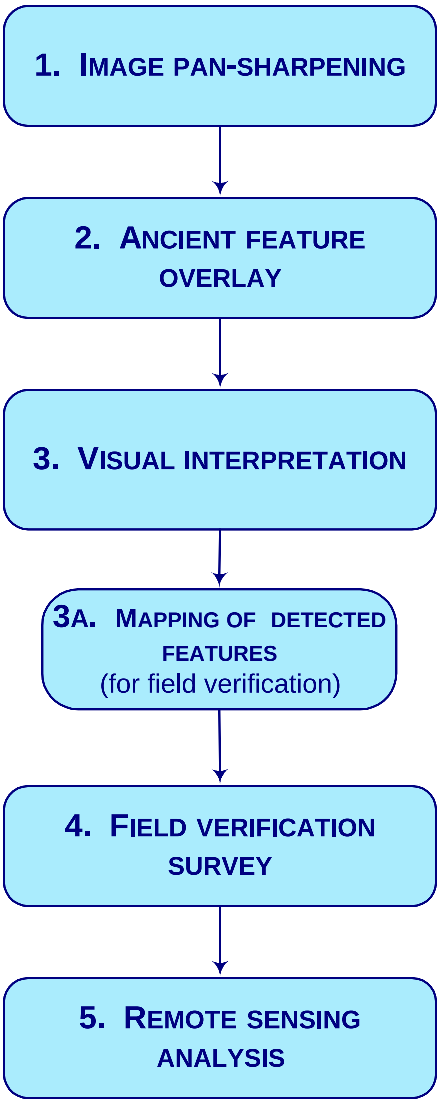

Figure 3: Methodology Phases

Phase 1: **Image Pan-sharpening**

- The 4 multispectral bands were pan-sharpened using the 1m resolution panchromatic image in order to improve the visual detail in the multispectral images.
- Pan-sharpening process - the multispectral band combination from the colour guns red, green and blue (RGB) was converted into hue, saturation and intensity (HSI). The intensity layer was replaced with the panchromatic band then the HSI was converted back into RGB (Carper et al., 1990), resulting in a multispectral image with a spatial resolution very close to 1m.

Figure 4: Comparison of enlarged 4m multispectral image (a) and 1m pan-sharpened multispectral image of the same area (b).

Phase 2: **Ancient Feature Overlay**

- The archaeological map of ancient Minoan features, produced by Tzedakis and colleagues (1989), was scanned then the features were digitized, and then a 2-D transformation using eight common points was used to transform the digital map into the coordinate system of the image (WGS84, UTM35) in ErMapper.

Phase 3: **Visual Interpretation**

- The third phase involved a visual search of the image for linear or geometric features that possibly had archaeological significance.
- It was accomplished by taking into account the spatial characteristics of ancient features as set out in Table 1, and using the ancient feature overlay as a guide. The visually detected features where then mapped.

Phase 3A: **Mapping of the detected features**

- Any features with the potential of being archaeologically significant were digitised into a vector layer with various symbols denoting different features, such as roads, the Zakros palace and fortresses then overlaid onto the image and hard copy maps were printed to take into the field.

Table 2 below outlines examples of the types of features detected the detection criteria and the reason why the feature was considered to be ancient.

Table 2: Examples of visually detected features		
Feature	**Detection Criteria**	**Reasoning**
Minoan palace	Shadow marked site Geometric characteristics from Table 1	Previously known archaeological site
Square and rectangular features near Karoumes	Geometric characteristic from Table 1 – guard posts	Near roads from overlay
Linear features near Kato Zakros	Linear characteristics from Table 1	Correspond to road overlay
Linear features near Karoumes	Linear characteristics from Table 1	Not natural linear features – man-made

The combination of the site classifications and image interpretation elements were applied to the image for archaeological feature detection and proved to be successful due to the 1m spatial resolution of the *Ikonos* image. This led to the development of a new list of archaeological attributes for visual detection of ancient features in high-resolution imagery, as presented in Table 3.

Table 3: Ikonos-2 - *Archaeological Visual Interpretation*	
Attributes	**Archaeological Description**
Tone	Tonal differences in soil may indicate buried structures
Texture	Different vegetation textures may indicate buried features
Shape	Foreknowledge of shapes of archaeological features can assist with determining whether a feature can be considered as archaeological or not
Size	The dimensions of the feature are also important in order to regard the feature as archaeologically significant or not
Spatial patterns	If the feature is of an extensive size, the spatial patterns within the feature could represent an ancient settlement
Orientation	Some archaeological features are consistently oriented in a certain direction
Shadows	Positive archaeological features appear in imagery through the shadows they cast
Spatial relationships	Some ruins which have been abandoned for hundreds or thousands of years are sometimes located in isolated areas. However, some excavated sites have modern roads leading to them for public access. Depending on the state of the ruins, they may still be associated with other nearby ancient features

Phase 4: **Field Verification Survey**

- The purpose of the survey was twofold:
    - To verify detected features,
    - And, to measure ground control points (GCPs) and coordinate features found with the GPS survey.
- Four GCPs were measured and used to improve the positional accuracy of the image from ±25m to ±2m.
- Most features detected in the image, as a result of the visual interpretation, were verified on the ground, although segments of a linear detected feature were not visible from ground level. A possible reason for this is the *albedo* effect: the lighting conditions at the time of image acquisition were such that the sun's rays coincided with the remains of the road at a particular angle whereby they were illuminated and clearly visible in the image. Whereas when the area was checked on the ground for the road the lighting conditions were inevitably different and thus the remains of the road were not discernible. Figure 5 shows the image portion of the detected linear feature that was not visible from the ground.

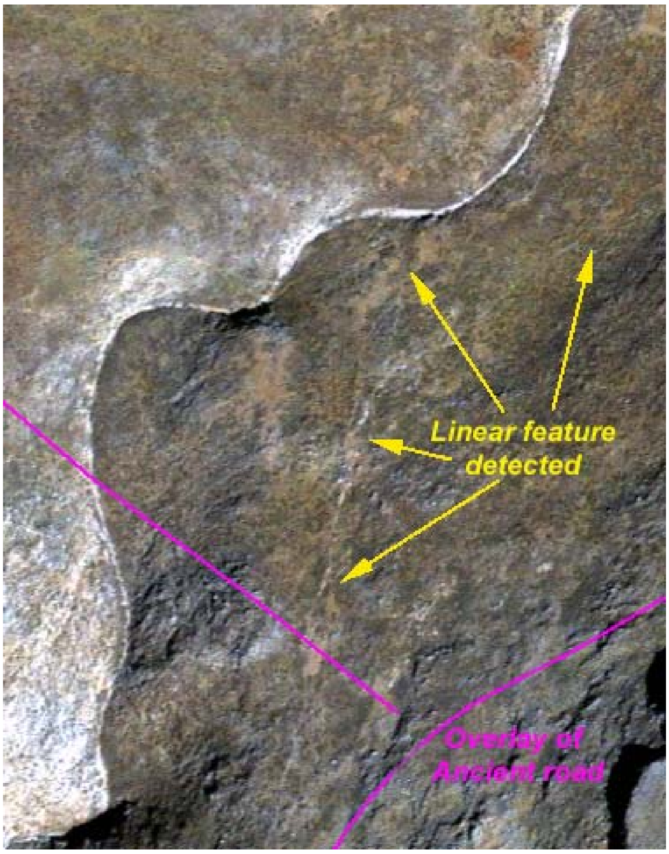

Figure 5: The visible linear feature in the *Ikonos-2* true-colour image with the overlay of the corresponding ancient road as found by Tzedakis and colleagues (1989).

Phase 5: **Remote Sensing Analysis**

- Firstly, the image was enhanced by transforming the image histogram to obtain sufficient contrast.
- A *Supervised Classification* of the image was performed to group the various ground cover types according to similar spectral signatures. Using the ERDAS Imagine remote sensing software a total of twenty ground cover types were 'trained' in the *Ikonos* image. They ranged from different vegetation types such as olive groves and shrubs, built-up areas (bitumen/gravel roads and villages), different types of rock surfaces, the sea and of course archaeological sites. The NIR, red and blue bands, were used for the classification as this combination is the least correlated. The Minoan palace at Kato Zakros was chosen as a training sample for the archaeological sites class and was trained such that it included a cross-section of the limestone and mud-brick building materials, and the excavated surface of the palace. The colour magenta was used to represent the archaeological class, (see Figure 5). The image was then processed to classify all the pixels according to the 20 training samples.

  As a result of the supervised classification, the Minoan forts near the Karoumes Bay were classified in the archaeological group along with some other areas, which run linearly in an east to west direction in the upper part of Figure 6(b).

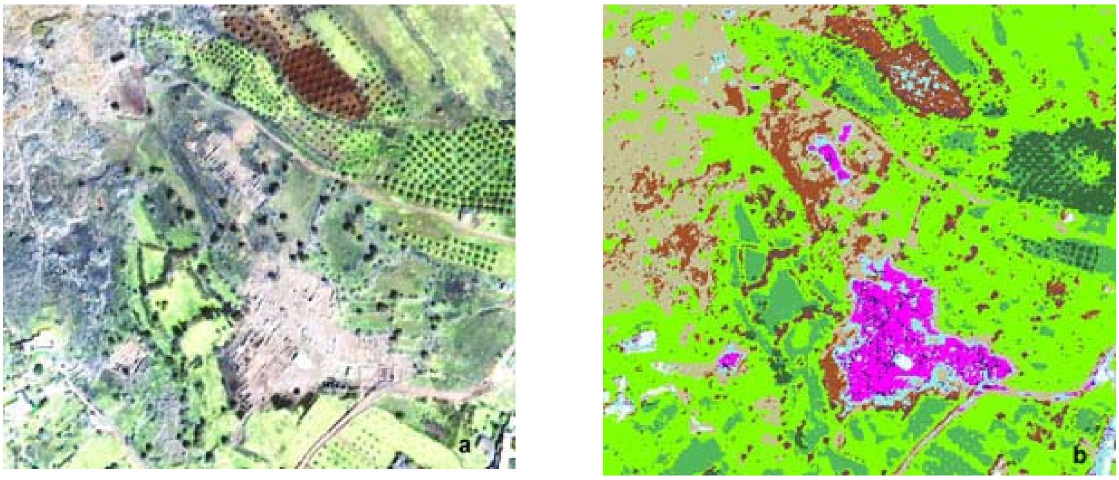

Figure 6: (a) Shows the excavated palace in the pan-sharpened image. (b) Shows the same area with the archaeological classification of the palace in magenta and the surrounding ancient settlement

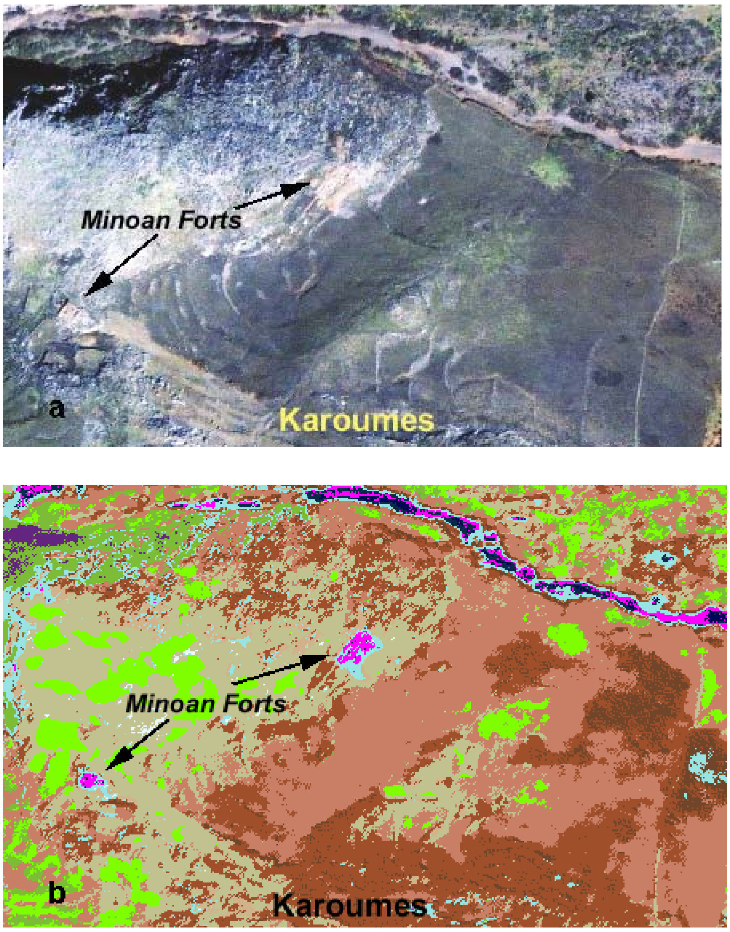

Figure 7: (a) Is a portion of the true-colour pan-sharpened image showing the Minoan forts. (b) Shows the classification of the two Minoan forts in the archaeological class.

The main reason why the Minoan palace at Zakros and forts at Karoumes have a common spectral signature is because they are all excavated sites. Other areas that were also highlighted under the 'archaeological' class were areas that experienced some erosion exposing a similar ground surface to the excavated archaeological sites. For instance, the magenta linear feature to the north of the Karoumes forts in Figure 7(b) is the bottom of the gorge which undergoes weathering processes during the wet season.

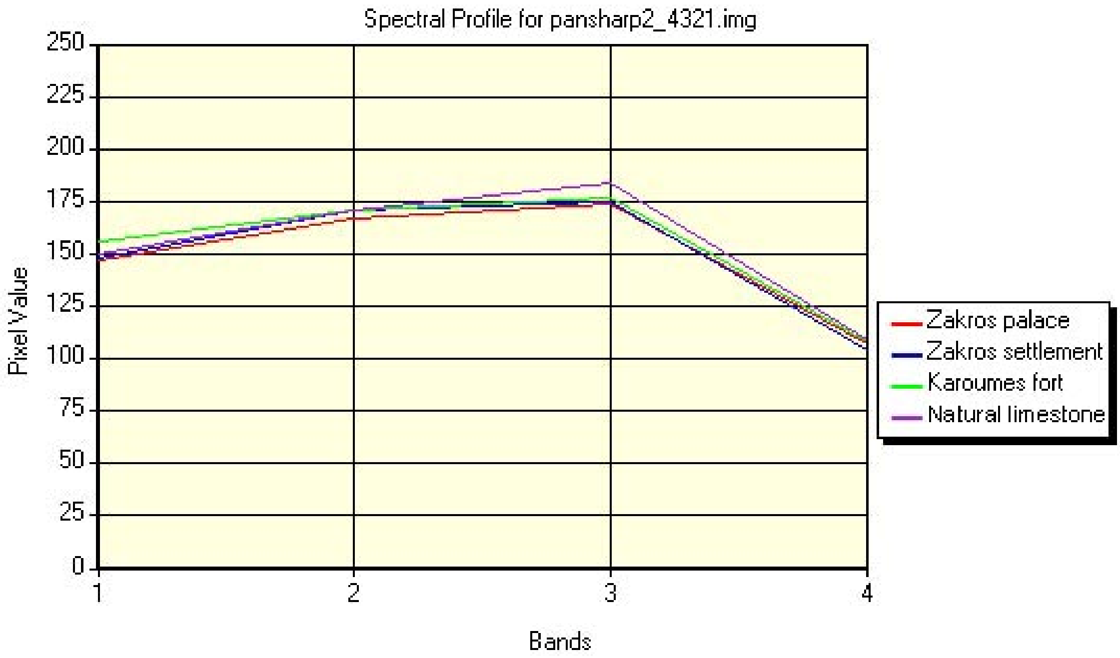

Figure 8: A spectral response curve of limestone from various archaeological sites and undisturbed limestone within the blue (band 1), green (band 2), red (band 3) and NIR (band 4) bands

The profiles in Figure 8 represent the response of a single pixel selected at each of the above archaeological sites. Each pixel is representative of the limestone construction materials used at each site. The profiles illustrate that the limestone materials at each archaeological site and the undisturbed site possess similar spectral signatures. This suggests that training only part of an archaeological site containing one particular surface material is not practical for classification purposes. Rather, training a cross-section of an archaeological site is more pragmatic, as was done for this classification to obtain a representative spectral signature of the site.

The supervised classification did not successfully detect any ancient roads via the Zakros palace cross-section sample, since the roads were constructed from local materials, which would have the same spectral response as the surrounding environment. But in the regions where the natural surface has been disturbed by human interference and compressed due to thousands of years of pedestrian and/or wheeled traffic there may be a different response. However, not enough of the spectrum is covered by the *Ikonos* sensor to pick up on the discrepancies between disturbed and undisturbed rock surfaces.

- *Band ratios* were used to highlight certain ground cover types. The ratio NIR/blue highlighted limestone as seen in Figure 9. The vegetation ratio, NDVI, was also tested and it was concluded it would have been more useful if there was more vegetation in the image.

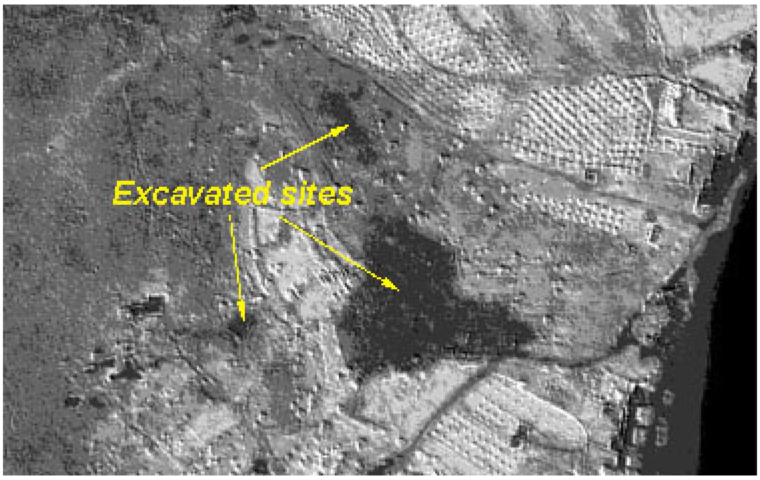

Figure 9: NIR/blue ratio highlighting the excavated areas around the Zakros region.

- A *principal components analysis* was performed whereby correlated bands were decorrelated allowing better interpretability, showing up surfaces rich in iron.

CONCLUSION

The scope of the research encompassed an investigation into the capabilities of HRSI for archaeological application and the development of remote sensing image processing techniques for the interpretation and analysis of HRSI.

Two principal requirements emerged for the successful implementation of satellite technology in archaeological applications, accordingly fulfilled by the *Ikonos* sensor:

i. High spatial resolution,

ii. Multispectral capabilities.

The investigation established that with the 1m-resolution capability of *Ikonos-2* imagery it is possible to detect visible archaeological structures with the aid of a visual interpretation approach. The development and use of the *archaeological visual interpretation* elements in Table 3, affirmed that archaeological features can be detected visually on the image.

The methodology designed from image processing techniques and known spatial data regarding archaeological features in eastern Crete resulted in an extensive analysis of the processed imagery as well as the development of techniques for archaeological remote sensing with HRSI. These techniques were:

- Archaeological visual interpretation (Table 3);
- Image processing procedures;
  - Supervised classification of archaeological features,
  - Band ratioing for the purpose of discriminating between archaeological sites and non-sites,

- Classification of archaeological features based on PCA.

The significance in the development of these techniques is that they can be implemented with any type of HRSI, although it must be noted that the success of archaeological feature detection and classification is dependent on:

- the radiometric quality of the image;
- the physical composition of the study area;
- and, whether the sensor has the required sensitivity to capture the spectral anomalies within the study area and distinguish between archaeological sites and non-sites.

REFERENCES

Cadogan, G., 1992. Ancient and Modern Crete. J.W. Myers, E.E. Myers and G. Cadogan (Editors), *The Aerial Atlas of Ancient Crete*. Thames and Hudson, London, 31-43.

Carper, W.J., Lillesand, T.M. and Kiefer, R.W., 1990. The Use of Intensity-Hue-Saturation Transformations for Merging SPOT Panchromatic and Multispectral Image Data. *Photogrammetric Engineering and Remote Sensing*, 56(No. 4): 459-467.

CCRS, 1998. *CCRS Remote Sensing Tutorial*. Canada Centre for Remote Sensing, 10-Oct-1999, http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/tutore.html

Doneus, M., 1999. *Aerial Archive*. University of Vienna, 4-Dec-1999, http://www.univie.ac.at/luftbildarchiv/

Dorrell, P.G., 1989. *Photography in Archaeology and Conservation*. Cambridge University Press, London.

Fowler, M.J.F., 1996. High-resolution Satellite Imagery in Archaeological Application: A Russian Satellite Photograph of the Stonehenge Region. *Antiquity*, 70: 667-671.

Hood, S., 1971. *The Minoans: The Story of Bronze Age Crete*. Praeger Publishers, New York.

Kodak, 1992. Basic Infrared Photography. *Information from Kodak*, AM-406.

Kruckman, L., 1987. The Role of Remote Sensing in Ethnohistorical Research. *Journal of Field Archaeology*, 14: 343-351.

Pendlebury, J.D.S., 1963. *The Archaeology of Crete: An Introduction*. Biblo and Tannen, New York.

Platon, N., 1966. *Crete*. Nagel Publishers, Geneva.

Platon, N., 1971. *Zakros: The Discovery of a Lost Palace of Ancient Crete*. Charles Scribner's Sons, New York.

Platon, N., 1992. Zakro. J.W. Myers, E.E. Myers and G. Cadogan (Editors), *The Aerial Atlas of Ancient Crete*. Thames and Hudson, London, 292-301.

Scollar, I., Tabbagh, A., Hesse, A. and Herzog, I., 1990. *Archaeological Prospecting and Remote Sensing.* G. Hunt and M. Rycroft (Series Editors), Topics in Remote Sensing. Cambridge University Press, Cambridge.

Tzedakis, Y. and Chryssoulaki, S., 1989. Les Routes Minoennes: Rapport Preliminaire Defense de la Circulation ou Circulation de la Defense. *Bulletin de Correspondence Hellenique*, 113: 43-75.

Tzedakis, Y., Chryssoulaki, S. and Kyriopoulou, L., 1990a. O Dromoς sth Minoikh Krht . *Cretological VI*, A'2: 403-414.

Tzedakis, Y., Chryssoulaki, S., Venieri, Y. and Avgouli, M., 1990b. Les Routes Minoennes: Le Poste de Coiromandres et le Controle des Communications. *Bulletin de Correspondence Hellenique*, 114: 43-65.

Willetts, R.F., 1969. *Everyday Life in Ancient Crete*. Jarrold and Sons Ltd, London and Norwich.

Willetts, R.F., 1977. *The Civilization of Ancient Crete*. University of California Press, Los Angeles.