The application of high-resolution satellite imagery for the detection of ancient Minoan features on Crete

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Abstract: Archaeological features, such as ancient settlements, roads or other indications of human activity on the ground during ancient times can sometimes be detected with remote sensing techniques. Two modes of above-ground remote detection, aerial photography and satellite sensed imagery, have been used in the field of archaeology. 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 imagery in archaeology has been used in the recent past with varying degrees of success. Multi-spectral satellite imaging has the benefit of allowing the archaeologist to view parts of the electromagnetic 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 the satellite Ikonos-2, *offers new possibilities for imaging archaeological features to a ground resolution of 1-metre in panchromatic mode and 4-metres in four multi-spectral bands.*

This paper describes an investigation in which high-resolution Ikonos-2 *satellite imagery is employed as an archaeological tool to discover, locate and map ancient Minoan roads and other archaeological features, using the Greek Island of Crete as a study area.*

Key words: remote sensing, high-resolution satellite imagery, visual interpretation, field verification, multi-spectral analyses, image classification.

Introduction

Archaeological features whether they are situated sub-surface or on the surface of the earth can be potentially detected with remote sensing techniques. Airborne or spaceborne remote sensing offers a manner of discovering remnants from our human past on the ground from a high viewpoint. Viewing archaeological remains from ground level does not clearly identify the spatial significance of those remains or their relationship to surrounding archaeological sites. In some instances archaeological sites are not apparent from ground level but become obvious once viewed from above.

Two types of overhead remote sensing used for archaeological feature detection are aerial photography and satellite imaging. Aerial photography has the advantage of offering high spatial resolution enabling detailed visualisation of archaeological structures. Satellites produce imagery with a lower resolution but cover both the visible and non-visible parts of the electromagnetic (EM) spectrum, which is useful for multispectral analyses.

With the deployment of the *Ikonos-2* satellite in September 1999, the combination of high-resolution and multispectral imagery is available from one sensor. *Ikonos-2* is capable of producing high-resolution satellite imagery (HRSI) with a 1-metre spatial resolution in panchromatic mode and 4-metre resolution in the multispectral.

Archaeological investigations utilising the recent technological advancements in satellite imagery are in their infancy. The aim of this investigation is to explore the use of HRSI for archaeological feature detection, mapping and classification using *Ikonos-2* imagery of eastern Crete.

This paper is divided into two parts. Part I deals with the necessary background information regarding remote sensing issues and the satellite imaging system of *Ikonos-2*. While Part II focuses on the actual investigation encompassing the project characteristics, the methodology to achieve the aim, the results and conclusions.

Part I – Background

Remote Sensing in Archaeology

From about the turn of the twentieth century aerial photographs have been used to aid archaeological research. One of the first archaeological aerial photos was taken of Stone Henge, England from a hot-air balloon [Doneus, 1999 #28]. In the 1920s, OGS Crawford, one of the pioneers of aerial archaeology formulated a set of site classifications for determining archaeological features using aerial photographs. Table 1 lists the different types of classifications along with their descriptions.

These classifications are quite useful for both aerial photographs and satellite images providing that the spatial resolution of the satellite image is high enough for the interpreter to discern what is revealed within the image. Although not all archaeological features that are large enough to be detected from the air are immediately apparent in imagery. The site classifications in Table 1 are reliant on the visible patterns created by the archaeological remains. In some cases it is beneficial to investigate imagery within the non-visible part of the spectrum for archaeological features. The use of the infrared (IR) region of the electromagnetic (EM) spectrum provides additional information about the growth patterns of vegetation. Buried remains can cause changes in vegetation growth, as in the crop marked sites of Table 1, but sometimes these changes may be too subtle to be seen with the naked eye. With IR imaging these growth variations are enhanced allowing the interpreter to investigate vegetational changes within the non-visible spectrum.

Compared to aerial photography not as many archaeological investigations have been conducted using satellite imagery, mainly due to the ground resolution constraints and cost and availability. However the spectral range of satellite imagery is greater than that of aerial photography due to the capabilities of multi-spectral sensors, allowing for a more comprehensive analysis. Satellite images exhibit greater spectral sensitivity and contrast in ground reflectance, in comparison to aerial photographs [Fowler, 1996 #36]. Most satellite sensors have the ability to capture data within the visible and non-visible parts of the EM spectrum encompassing a portion of the ultraviolet region, the visible and the near IR (NIR). Other remote sensors are capable of capturing the thermal IR region, such as the sensor in the satellite LANDSAT TM [Kruckman, 1987 #10].

IKONOS-2 Capabilities

The satellite *Ikonos-2* orbits the earth at an altitude of 680 kilometres and travels at a ground speed of 7km per second. It captures 1-metre panchromatic digital images and 4-metre multi-spectral images covering the blue, green, red and NIR bands. The two data sets are captured simultaneously over an 11km swath [SpaceImaging, 1999 #32]. The satellite has the ability to acquire stereo images for the creation of 3-D data. It has a nominal 26° angle of convergence for stereo scenes and can collect data of the same scene three times for stereo applications by first tilting the sensor forward by 26°, then at nadir and again when the sensor is tilted back 26°. The size of a single *Ikonos* scene is normally 11km by 11 km.

Space Imaging, the company that owns the *Ikonos-2* satellite, produces a number of image products for commercial use. For instance the *Geo* product is geometrically corrected and georeferenced to a user-specified ellipsoid and map projection. The absolute positional accuracy of the image is ±25m (RMS, 1-sigma) [SIE, 2000 #88]. The user has the option of ordering the image as a 1-metre pan-sharpened product, which is effectively a colour image with a 1-metre resolution. The image of eastern Crete used in this investigation is from the *Geo* range, being georeferenced to WGS84 with a UTM projection and ordered as 1-metre panchromatic and the 4-band multispectral.

When thinking about satellite imagery for archaeological application two main features are necessary: 1) high spatial resolution, and 2) multi-spectral bands for quanitative pixel analyses. *Ikonos-2* possesses both of these important features offering high-resolution capabilities and basic multispectral content.

Part II – The investigation

Project Characteristics

The Area of Study

The area of study is situated in eastern Crete, Greece. Crete is a topographically diverse island where the ancient people, known as the Minoans (as they were named at the turn of the 20th century) flourished during the Bronze Age from approximately 3000 to 1100 BC [Hood, 1971 #17].

The *Ikonos-2* image of the study area was captured on March 9, 2000 at the requested time of 8:30 in the morning to highlight any shadow marked sites. The image covers an area of 9km by 11km and includes the ancient Minoan palace site at Kato Zakros. Figure 1 shows a true-colour composite image of the area of study.

Like most of the island, eastern Crete is a rocky and barren region with very few natural springs. The mountains are mostly composed of grey limestone and earlier deposits of brown, grey and greenish schists, quartzites and shales. Around the coastal areas are homogeneous marls – a soft marly limestone also known as *kouskouras* [Gifford, 1992 #15]. The schists were used by the Minoans for paving while limestone materials and mud-bricks were used for buildings.

Ancient Minoan Archaeological Features

The Minoans had developed external trade relations with the Aegean islands, Egypt and the Near East. Their harbours were important for commercial reasons so major settlements were built at these locations. There is evidence in the form of traded goods to suggest that there was contact between these major sites [Tzedakis, 1990 #40]. The topography of the island played a major role in moulding Minoan society with respect to the location of settlements and the routes of internal interaction between settlements.

From the work carried out in eastern Crete by a team of archaeologists led by Yiannis Tzedakis and Stella Chryssoulaki we know the location of some Minoan sites and roads. Investigations led the researchers to the discovery of ancient Minoan roads and other sites that were verified through excavations and were subsequently mapped [Tzedakis, 1989 #3; Tzedakis, 1990 #40; Tzedakis, 1990 #41]. Table 2 sets out Minoan archaeological features and their characteristics compiled from the extensive research of the area by Tzedakis and colleagues.

It is important to have the background knowledge of the geological composition of the island to assist with the multi-spectral analysis and classification of the image. The summarized characteristics of Minoan features in Table 2 were compiled to assist with the spatial interpretation of the imagery.

Research Methodology

The methodology was developed by taking into consideration the existing remote sensing techniques, Crawford's classifications and the background knowledge regarding the island and the Minoan people. The different phases of the methodology are as follows:

A. Pan-sharpening
B. Ancient Feature Overlay
C. Visual Interpretation
D. Field Verification Survey
E. Remote Sensing Analyses

A. Pan-sharpening

The pan-sharpening of the 4 multispectral bands using the 1m panchromatic image was carried out to improve the spatial resolution of the multi-spectral images so as to assist in the visual interpretation. The pan-sharpening process consisted of converting the multispectral band combination from the three colour guns red, green and blue (RGB) into hue, saturation and intensity (HSI). The intensity layer was replaced by the panchromatic band and the HSI was then converted back into RGB [Carper, 1990 #73], resulting in the pan-sharpened multispectral image with a spatial resolution of 1 metre.

B. Ancient Feature Overlay

This process involved the tentative location of ancient Minoan features using the archaeological map created by Tzedakis and colleagues. This was done so that the interpreter could gain a better idea as to where to look for the ancient roads and sites in the image.

C. Visual Interpretation

This phase involved a visual search of the image for linear or geometric features with possible archaeological significance. It was accomplished by taking into account the spatial characteristics of ancient features as set out in Table 2, and using the ancient feature overlay as a guide. The whole image was systematically visually scanned to manually detect any of the characteristics. Once detected the features were digitized on the image into a vector layer with various symbols denoting different features, such as roads, palace and forts.

D. Field Verification Survey

The verification process involved a field trip to the area of study in eastern Crete to determine whether what was visible in the image corresponded with what is on the ground. The field survey incorporated a GPS survey to locate ground control points (GCPs) and the verified features.

E. Remote Sensing Analyses

A number of steps were implemented for the remote sensing analysis, once the image had undergone enhancement and re-georeferencing using the GCPs from the field survey.

- Band ratios and combinations to highlight certain ground cover types.
- Edge detection filters for enhancing linear and geometric features.
- Classification of the image to emphasize sites with the same spectral signature.

Software

The software packages used to carry out the various phases of the methodology were ERMapper v:6.1 and ERDAS Imagine 8.4, both being used on a Pentium platform under Windows.

ERMapper and ERDAS Imagine are both suites of software for remote sensing analysis. ERMapper was primarily employed for the pan-sharpening and the ancient road overlay, whereas ERDAS Imagine was preferred because it supported more rapid processing of large data volumes. Also, it is equipped to perform any type of GIS and image processing application, and it has the facility to execute photogrammetric processes.

Results

In Phase C of the methodology the visually detected features were mapped for verification in the study area. The field verification survey was conducted in conjunction with the Institute of Mediterranean Studies (IMS) at Rethymno, Crete, who supplied the high-accuracy GPS (Global Positioning System) equipment, namely 2 Ashtech Z-12 receivers. The 4 GCPs located in the GPS control survey were used to transform the image coordinates to accord with the coordinates of the GCPs, thus improving the absolute positional accuracy of the image to ±2m.

Not all detected features were searched for on the ground due to time constraints. A total of six days were allocated to perform both the field verification and the GPS control survey. In some cases the process of verifying at least one feature took a full day due to the rugged terrain and vehicle inaccessibility at most areas visited. Some of the detected features were verified whereas others were not. Figure 2 is a portion of the image showing a detected linear feature. The pink line is from the ancient feature overlay and represents a Minoan road, the distinctive curving white line is a dry creek bed and the faint linear feature that forks out is a detected linear feature, corresponding to the Minoan road overlay. When the survey team visited the area to verify the linear feature we could not find anything on the ground that resembled a road, path or track. A few placed stones were found parallel to each other at a distance of about 2 metres wide running for approximately 6 metres, but these were not representative of what is visible in the image. Possible explanations for this are the different seasons of image capture and field survey causing the feature to appear more emphasized in the image; and, the linear feature is better seen from an aerial view rather than from the ground.

Remote Sensing Analyses

ERDAS Imagine was used to perform the remote sensing analysis, which included supervised classification, band ratioing and edge detection. The supervised classification involved the classification of the image into different ground cover types according to the interpreter's *a priori* knowledge of the area. Band ratios were implemented since they can highlight a particular surface type, while edge detection filters were used to enhance linear and geometric features through mathematical operators.

A **Supervised classification** is dependent on the analyst's familiarity with the various ground cover types within the image and relies on knowledge from field surveys, maps, aerial photographs or personal experience. In the software, the analyst defines a sample area on the image that is representative of a specific ground cover or information class. This is called a *training area.* Once the analyst trains all areas of interest to represent the known different ground cover types in the image the computer then classifies the remaining pixels according to the training areas. It does this by using the spectral signatures of the trained pixels to identify and categorize every remaining pixel in the image with similar spectral properties [ERDAS, 1999 #80].

Twenty ground cover types were 'trained' in the *Ikonos* image. They ranged from olive groves, bitumen roads, bare soil, gravel roads, the sea and crop fields. The image was then processed to classify all the pixels according to the 20 ground cover types. One of the chosen training samples was the archaeological site of the Minoan palace at Kato Zakros. The colour magenta was used to represent the archaeological class. As a result of the supervised classification the Minoan forts near Karoumes bay were classified in the archaeological group along with some other areas, like the linear feature running in an east to west direction in the upper part of figure 3. The reason why the Minoan palace at Zakros and forts at Karoumes have a common spectral signature is because they are excavated sites, revealing a common sub-surface layer with ruins made from similar building materials. The other areas that were also highlighted under the 'archaeological' class are areas that have experienced some erosion exposing a similar ground surface, such as the bottom of the gorge in figure 3, which undergoes weathering processes during the wet months.

The classification of ancient roads is rather difficult since the roads were constructed from local materials, which have the same spectral response as the surrounding environment. But in the regions where the natural surface has been disturbed there may be a different response. The other factor limiting the classification of the ancient roads or paths is that some roads are only 1 to 2 pixels wide, which is not enough for the software to reasonably select those pixels for classification into a class of their own. Instead these pixels are grouped into a class that resembles their spectral response the most [Gorte, 1999 #91].

Band Ratioing involves the manipulation of multi-spectral bands by dividing one band with the other. This is useful for enhancing subtle differences between rocks and soils [Jensen, 1996 #76]. As mentioned, limestone was used by the Minoans as a building material. The ratio of NIR to Blue was selected because the reflectance level of limestone is lower in the blue than it is in the NIR and by dividing the blue band values into the NIR, the limestone values increase causing higher reflectance and appearing as a bright colour. This ratio also highlights vegetation while bodies of water are shown as black as is evident in figure 4. The portion of the image in figure 4 shows the area of the Minoan palace at Zakros Bay. The result of the NIR/Blue ratio image was not as expected. The palace area is shown as dark but was expected to appear as a light grey since it is known that it was constructed with limestone blocks, mudbricks and sandstone for paving. The most likely explanation for this is a high soil-moisture content resulting from the water table being close to the surface.

Edge detection enables the spatial enhancement of geometric or linear features in an image. General filtering techniques or convolution operators are employed to detect edges or lines by changing the spatial frequency characteristics of the image [Richards, 1999 #74]. Convolution operators are designed to highlight or conceal specific features in an image, based on their spatial frequencies. A low-frequency area in an image is where there are minimal changes in brightness values of pixels. For high-frequency areas the opposite is true. Areas of high-frequency are those where maximum changes in brightness values occur over short distances [Jensen, 1996 #76].

A 9x9 high-pass filter was passed over the whole image to enhance edges. Figure 5 shows a portion of the colour infrared image with a soil marked site that underwent the 9x9 high-pass filter. The portion is part of the false colour image where areas of red represent vegetation and the greenish areas are bare soil. The high-pass filter enhanced the olive trees and the linear feature running south-west and forks out in the bare field, is more apparent.

Discussion of Results

The visual interpretation of the *Ikonos* image was moderately successful as confirmed by the field verification survey. Some of the detected features were verified on the ground demonstrating that HRSI is useful for visual interpretations. The supervised classification showed that it is suitable for detecting the known archaeological sites although it is not a totally automated approach, since other areas with similar spectral responses are highlighted also. Therefore, it is a matter of verifying on the ground all the areas classified with the archaeological site training region, to check whether they are archaeologically significant or not. For the classification of ancient roads, it is recommended that imagery with even higher spatial resolution be used to pick up the spectral signature of the road pixels.

The band ratio of NIR/Blue did not produce the expected outcome but it still managed to emphasize the palace and surrounding excavated settlement as a dark colour. However, this is not as useful as the supervised classification where the analyst has more command over the selection of sites to be highlighted or grouped. A greater range of the EM spectrum needs to be covered for the differences in rock types to be discernible with band ratioing. As mentioned, the NIR/Blue ratio also emphasized the vegetation within the image. If the area of study were more vegetated, the use of the ratioed NIR band would be useful for highlighting any crop marked site.

The edge detection filters are effective for enhancing existing lines or edges which may not be greatly apparent in the original image. In this way features can be 'detected' more easily after the image has undergone a high-pass filtering, as compared to their original state. It must be noted that edge detection cannot detect any lines or features that are not present in the original image.

Conclusion

Archaeological remote sensing is best served by technology which produces high-resolution, multispectral images since it is a large scale application and depends upon visual detection. The investigation for the detection of ancient ground features using *Ikonos-2* imagery over eastern Crete has shown that HRSI has practical potential for archaeological applications mainly in the areas of visual interpretation and the creation of archaeological maps.

HRSI is particularly useful when combined with a field verification survey to confirm the results of the visual interpretation of the image. This usefulness is further enhanced via a GPS control survey to satisfy accuracy needs for the creation of archaeological maps.

It is evident from the investigation that *Ikonos* imagery has further archaeological potential in areas of study where there is more vegetation, in order to take full advantage of the NIR channel.

Overall, the investigation so far has shown that HRSI is useful for qualitative archaeological image analyses, whereas the remote sensing analyses have not been as successful, although not all possible avenues of remote sensing techniques have been considered. Thus, the research is continuing with emphasis on the quantitative analysis of the image, by further examining its multispectral properties with the use of various techniques such as principal component analyses.

Tables

Table 1: Crawford's Site Classifications (Scollar et al., 1990)	
Shadow Marked Sites	Are those sites where the remains are partly above the ground's surface and are visible from the air in early morning or late afternoon sun, through shadows cast by the above ground irregularities. Visibility of features depends on the contrast they create in the photo.
Moisture or Soil Marked Sites	From past constructions the physical order of the soil is disturbed, due to the introduction of foreign materials into the local soil. Past features become visible from colour variations or tonal differences in the soil.
Crop Marked Sites	Plants grow differently depending on the contents of the soil. Sub-surface archaeological features become visible from differences in height and colour of the crop.
Frost Marked Sites	Timing and the appropriate season need to be chosen for this type of marking to appear. When air temperatures are around freezing point, thermal gradients become visible as differences in thawing and freezing of frost or light snow occur.

Table 2: Minoan archaeological features and characteristics

Archaeological Feature	Geometric Characteristics	Additional Characteristics
Ancient road	Linear, 1.5m to 3m wide	• Paved with limestone slabs (closer to settlements) • Follow natural course of terrain • Enlargement of naturally narrow curves
Guard post	Approx. 10m x 10m	• Situated at road junctions • Constructed from limestone megaliths
Palatial complex	Approx. 120m x 100m	• Contains central courtyard 30m x 12m, treasury, royal rooms, other adjoining rooms • Surrounded by Minoan urban settlement • Positioned near harbour
Peak sanctuary	No structure or dimensions	• Located on top of mountain peaks • Situated close to settlements

Figures

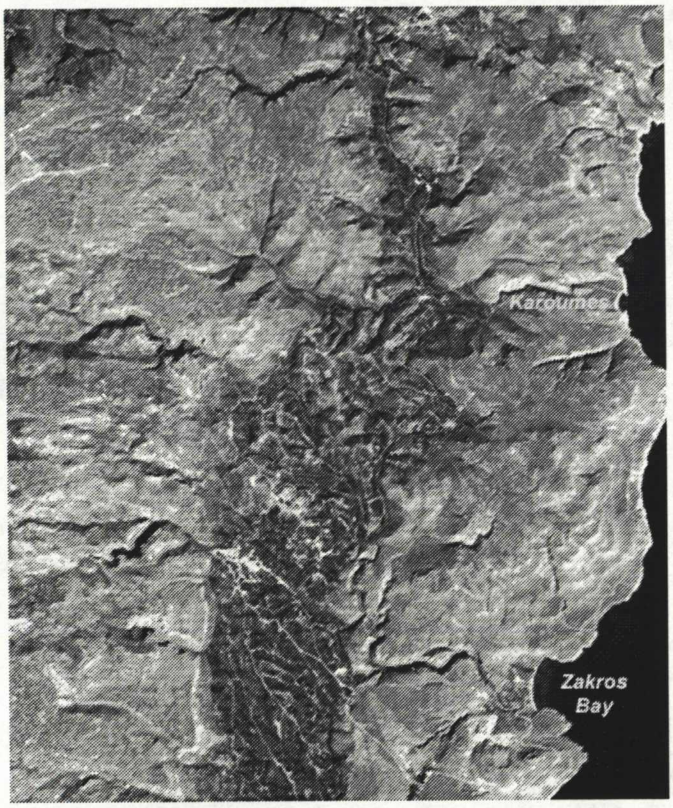

Figure 1. Ikanos-2 image of area of study (eastern Crete).

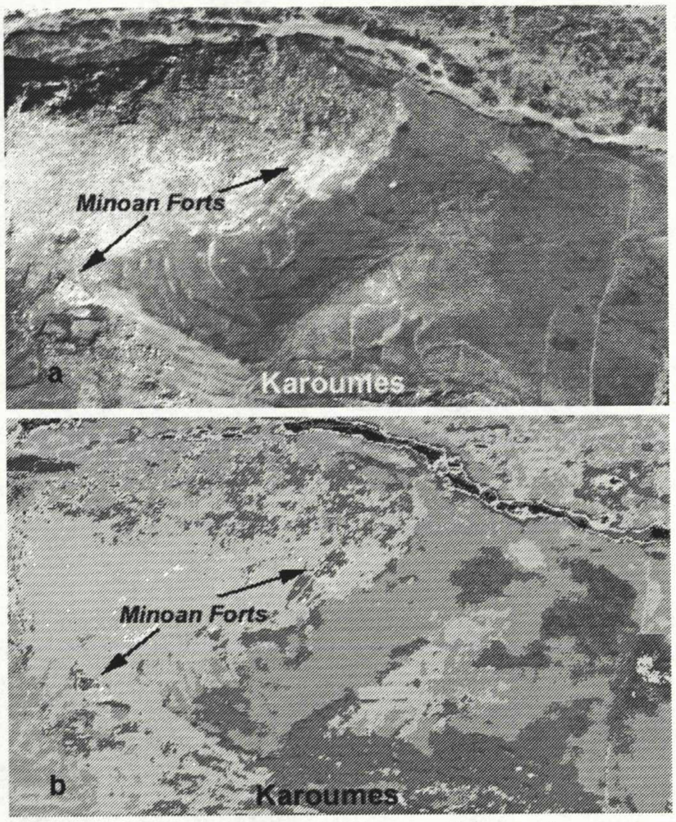

Figure 3. The supervised classification showing the two Minoan forts in magenta and the linear feature to the north.

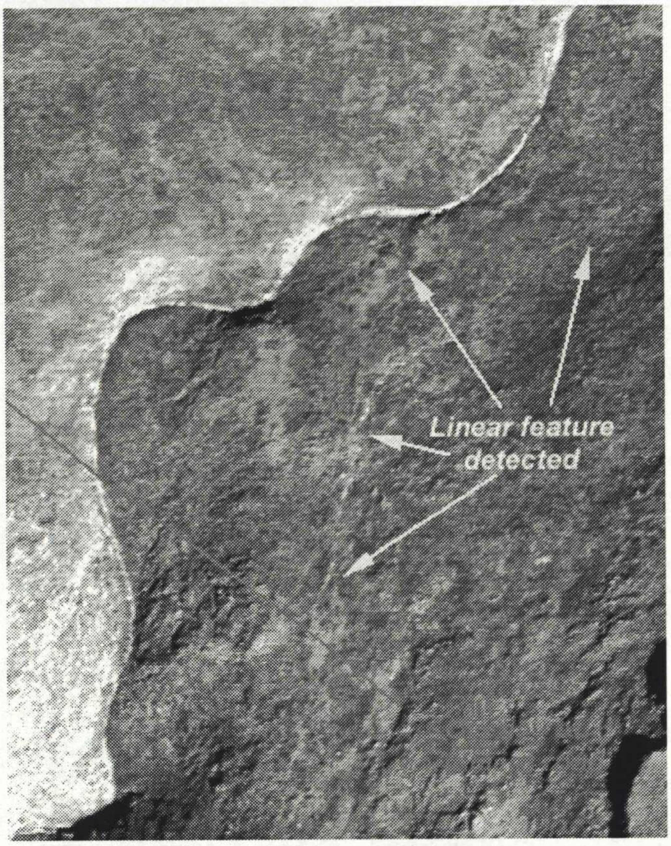

Figure 2. detected linear feature in Ikonos image.

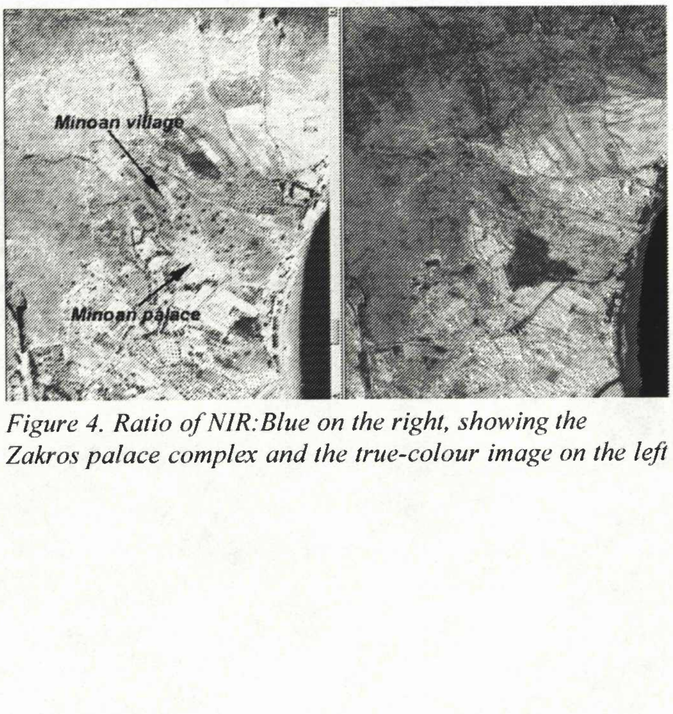

Figure 4. Ratio of NIR:Blue on the right, showing the Zakros palace complex and the true-colour image on the left

Figure 5. CIR portion of the image after high-pass filtering