# Chapter 14
# Integrated Remote Sensing Approach in Cahuachi (Peru): Studies and Results of the ITACA Mission (2007–2010)

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**Abstract** ITACA (Italian heritage Conservation and Archaeo-geophysics) is an international mission of the Italian CNR which applies different scientific methodologies, strongly based on the use of Earth Observation, to contribute to the study of the precolombine archaeology and the cultural heritage conservation and management in Peru and Bolivia. From 2007 up to today the research activity of the ITACA, funded by the Italian Foreign Ministry Affairs, has been focused on the Nasca Ceremonial Centre of Cahuachi, the Nasca geoglyphs (both of them in Southern Peru), the Ceremonial center of Tiwanaku (Bolivia) and the archaeological sites of Arenal and Ventarron in the Lambayeque region (Northern of Peru). Most of the scientific investigations have been carried out in Cahuachi and in the drainage basin of the Rio Nasca, with the aim of supporting archaeological studies and excavations of the *Centro de Estudios Arqueológicos Precolombinos* directed by Giuseppe Orefici. The main activity has been the archaeo-geophysics based on the integration of ground, aerial and satellite remote sensing methods, thus allowing the archaeologists to find buried walls, tombs and ceremonial offerings in Cahuachi and to discover a large buried settlement in the Nasca riverbed.

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## 14.1 Introduction: Study Area, State of Art and Motivation of Itaca Mission Investigations in Cahuachi

Cahuachi has many reasons to be considered one of the most important cultural resources of South America, such as: (i) to be the largest adobe ceremonial center built in the world, (ii) the monumentality of its architecture and the complexity of its urban fabric, (iii) to have been the cultural, religious and administrative core of the Pampa region of Peru during the Nasca age, in particular from the first to the fourth century AD.

The Nasca civilization is well-known for its refined and colourful pottery, characterized by a rich iconographic repertory, and, above all, for the huge geoglyphs drawn on the arid plateaus of the Rio Grande de Nasca Basin, characterized by different patterns and shapes from geometrical to biomorphic ones.

The mystery which has been surrounding the Nasca geoglyphs, since its discovery in the 1920s, has favoured the postulation of several different hypotheses on their cultural meaning and function and the way to have been drawn.

Among them (by omitting the imaginative theories related to landing sites for aliens !), for sake of brevity we cite only the studies of Paul Kosok and Maria Reiche (Kosok and Reiche 1949) who proposed an astronomical meaning to the lines, that is a sort of astronomy book which possibly enabled the Nasca to predict when to plant and harvest their crops, the hypotheses by Aveni which found a similarity of some lines with the Incas *ceque* system (Aveni 1986), the theories of Johan Reinhard (1996), according to which the lines were “sacred pathways to a place from which the people worshiped the mountains as the source of water, and invoked the mountain gods”, and finally other studies which point out the function of the lines as signal or maps of subterranean aqueducts and wells.

Whichever hypothesis increases the interest for the Nasca civilization and so, for Cahuachi which was the theocratic capital of the Nasca region, up to its abandonment due to natural disasters (flooding and earthquakes) in the fifth century AD. The pyramids of Cahuachi and the geoglyphs are linked to each other by a common vision of the religion, the nature and the relationship between the human beings and Gods, by means of ritual activity, thus generating an extensive zone of ideological influence, not only on the coastal areas but also in the upper valleys and in the Andean vicinity (Orefici 2009b, c).

### *14.1.1 Geographical and Historical Setting of the Drainage Basin of Nasca: Brief Notes*

The archaeological evidence of Cahuachi mainly spread out on a Pre-Montane desert formation on the left of the Nasca River, at an elevation of 365 m a.s.l.

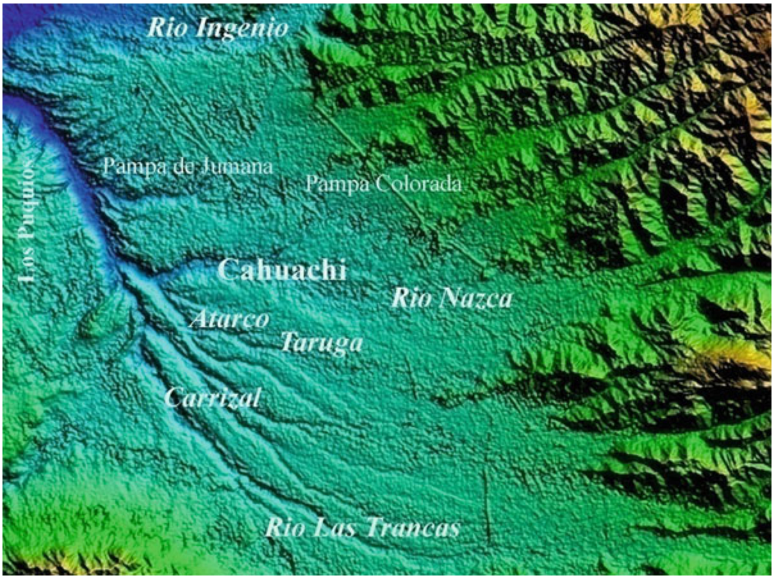


**Fig. 14.1** DEM derived from ASTER data: detail of the hydrographical basin of *Rio Grande* with *Rio Ingenio*, *Rio Nasca* and its tributaries. The digital map puts in evidence some linear geoglyphs of *Pampa de Jumana* and *Pampa Colorada* at North of Cahuachi

In particular, they are around 40 tells (earthen mounds), some of which have been completely excavated, located on Quaternary sedimentary rock formations (that are riverine and riverine alluvial) of a tectonic depression (Ica-Nasca Depression). A few kilometres away are the Andean foothills, composed of Jurassic and Cretaceo formations (Montoya et al. 1994).

With regard to the climate, it is hot and arid as well as it is characterized by very little measurable rainfall recorded each year, due to the confluence of a cold ocean current (the Humboldt Current) along with other climatic factors (Schreiber and Lancho Rojas 2009).

Nevertheless, the ecosystem of the valley of the Nasca River and its main tributaries (see Fig. 14.1) has been essential in forming the first complex societies, since about 5000 BC.

This territory has been characterized by a long and intense human activity since the Formative Period (2000–800 BC), to the Early Horizon period (800–200 BC, characterized by Paracas Culture), to the Early Intermediate Period (200 BC–500 AD) when the region flourished under the Nasca Culture and Cahuachi was founded and developed. In particular, at the end of the Early Horizon Period, several regional centers with a religious function developed. Cahuachi stood out among the other centers due to the unity of the religious creed, the control of water sources and the formation of an incipient autonomous social organization.

As time passed, the area of Cahuachi and its adobe pyramids and platforms were continually growing until reaching 24 km$^2$, probably also including the riverbed and the hills on the right bank of the river.

### *14.1.2 The Ceremonial Center of Cahuachi from the Archaeological Record*

The first studies in Cahuachi date back to the 1950s of the twentieth century. Between 1952 and 1953 W.D. Strong investigated an early village occupation. From the archaeological record, Strong credited Cahuachi a housing function—although limited to some periods of its development (from a report of W.D. Strong cited by Orefici 2009b). John H. Rowe supposed a transition process of Cahuachi: from a sacred place to a city (Rowe 1963).

More data have been provided by the studies and excavations of Silvermann and Orefici since the 1980s, which allowed us to identify a prevailing ceremonial functional of Cahuachi (Silverman 1993; Orefici 1993). In particular, systematic excavations, carried out on more than 150 sectors by Orefici, in two zones named A (0.16 km2) and B (0.10 km2), unearthed five historical building phases from the fourth century BC to the fifth century AD (see Fig. 14.2a, b). Such historical phases (400–100 BC; 100 BC–100 AD; 100–350 AD.; 350–400 AD; 400–450 AD), respond to climatic and environmental anomalies, as well as they reflect the functional and cultural evolution of the site (Orefici and Drusini 2003).

At the beginning (400–100 BC), it was a sanctuary or *huaca*. The architecture was composed of two step platforms and walls of *quincha*, cane or *guarango* tree branches interwoven by ropes of vegetal fiber, covered in mud and plaster, which supported a straw or mat roof.

In the second phase, (8100 BC–100 AD) Cahuachi becomes a ceremonial centre. The urban landscape is the expression of the functional change of the site. The architecture built with conic shaped adobes becomes more monumental and wider than in the past. The new platforms were composed of more than two steps and pre-existing structures were transformed into large storehouses. Moreover, the distribution of spaces is more complex, thus reflecting the hierarchic structure of the society, dominated by a religious elite. The new adobe architecture is also the result of works of remodelling and filling with material brought from other constructions that included remains of votive ceramics used in ritual sacrifices.

The third phase (100–400 AD) coincides with the apogee of the ceremonial center. The zone A is the monumental core of Cahuachi. It is composed of three big pyramids known as, *Gran Piramide*, *Grande Templo* and *Piramide Naranja* (see A1, A2, and A3 in Fig. 14.2; see also Fig. 14.3) surrounded by several minor temples that are connected through plazas, enclosures, stairs, passages and intermediate spaces enclosed by big walls. These buildings are examples of both the opulence that the Nasca society enjoyed during this period and the maximum specialization reached by artisans.

The building system, that used bread-shaped adobes, follows the same evolution: the interior structures were transformed into platforms filled with materials used in the rituals; while large perimeter walls hid the temples and the interior buildings friezes (Orefici 2009b).

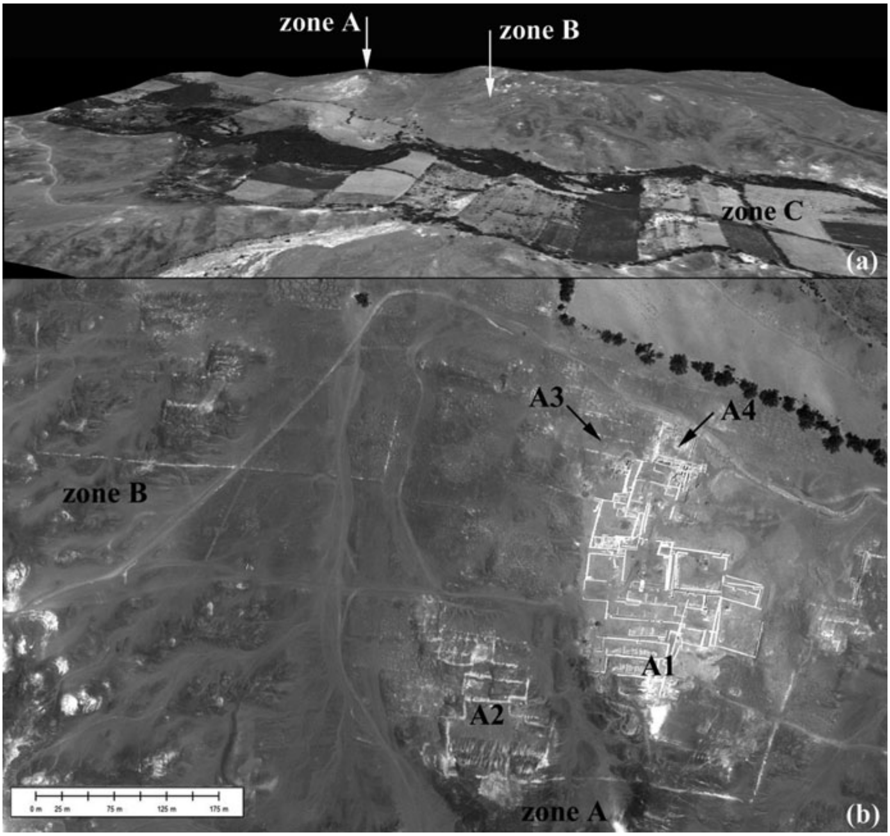


**Fig. 14.2** GeoEye panchromatic image acquired in March 2011. (**a**) 3d visualization of the Nasca River and the monumental complex of Cahuachi composed of the two zones A and B; (**b**) 2D image: *A1*, *A2*, *A3* and *A4*, indicate *Gran Piramide*, *Grande Templo*, *Piramide Naranja* and *Grande Templo*, respectively


**Fig. 14.3** Cahuachi landscape view from the Nasca River

Possibly during this phase, the excessive use of wood to fire pottery, to build, and to perform other activities, the intensive exploitation of agriculture and environmental resources cause an ecological change, partially faced by the construction of irrigation canals for the distribution of water. Some temples were used as storehouses thus proving the overproduction of food to feed the multitude of artisans and the specialists working in the transformation of Cahuachi.

Probably in this phase Cahuachi reached the maximum urban expansion, with two monumental complexes with U-shaped courtyards (the so-called zone A and B, see Fig. 14.2b), oriented along the southeast-northwest direction, characterized by temples facing North, towards the Rio and the geoglyphs of *Pampa de Jumana* and *Pampa Colorada* (see Fig. 14.1).

The Fourth Phase (350–400 AD) was rich in cultural expressions but also was a time of profound and quick changes that underline a crisis determined by a series of mudslides and a very destructive earthquake. The access entries to the temples were changed and several of the most important buildings lost their monumental functions. The large enclosures were filled so that new embankments could be built and a big part of the terraces with columns and decorated ceilings were demolished in order to make room for the large platforms. During this period, the *Grande Templo* was completely uncovered due to the elimination of several rows of columns, after a ritual in which thousands of antara pipe flutes were destroyed and placed under a new clay floor. The archaeological records evidence a series of mudslides that left profound marks in the structures as well as in the layers of natural clay, due to a strong water flowing.

The fifth phase (400–450 AD) was the moment when the site was effectively abandoned. As in the previous phase, the ceremonial enclosures were filled after an intense series of big collective sacrifices of animals, ceremonial objects and human beings. The offering holes, intensely used during the Fourth Phase, were emptied; the tops of the temples were covered by layers of earthy materials and sealed with clay. The structures of Cahuachi were altered into big platforms and a large necropolis. The sacred character of the ceremonial center was maintained but its primary functions were modified as it was transformed into a large cemetery that was used until the Late Intermediate Period. The collapse of Ceremonial Centre was also due to the loss of power by the sacerdotal class after the mudslides and the earthquake that struck in the previous phase. The theocratic regime of the Nasca culture was lost in the last 50 years of its time, which gave place to the fragmentation of power among local lords (*curacas*), whose political system ruled the urban centers then spread in the valleys, right where the ideology of a central government developed in a homogeneous manner before (Orefici 2009b).

After the abandonment of the temples, the ritual activities moved to Estaquería, at 3.5 km NW from *Gran Piramide*. Estaqueria was occupied during the hegemony of Cahuachi and perhaps it functioned as a small temple. Its importance and its cultural influence on the surrounding territory had been strongly increasing after the collapse of Cahuachi, thus contributing to transmit the Nasca ideology, towards west, in the lower valley.

**Fig. 14.4** Northern side of *Gran Piramide*

### *14.1.3 Archaeological and Research Issues Addressed into ITACA Mission*

After more than the 25 years of investigations, excavation trials and systematic excavations focused prevailingly on the sector A, just one pyramid has been unearthed and restored (the so called *Gran Piramide*, see Fig. 14.4), other two temples are almost completely excavated and the restoration are in progress (*Piramide Naranja* and *Templo del Escalonado*). The archaeological findings allowed us to reconstruct the historical outline of Cahuachi from the Paracas period to its abandonment.

Still many issues need to be resolved regarding: (i) the extension of Cahuachi (Did it include also the riverbed and the hills on the right bank of the *Rio Nasca*?); (ii) the continuity of the ceremonial activity after the abandonment of Cahuachi (Did it move to Estaqueria? Why in that place? Is it possible that other settlements have been built to the west of Cahuachi as Estaqueria?); (iii) the function and the meaning of *Piramide Naranja* (Did the last ceremonies and sacrifices take place there?).

Since 2007 ITACA mission has been requested to support the archaeological investigations with the use of Earth Observation (EO) methods (satellite remote sensing and geophysics) in order to provide additional information on the history of Cahuachi and its surrounding territory.

In particular, the issues to be addressed have been the following:

(1) the detection of buried structures and ritual offerings in the *Piramide Naranja* and near *Templo del Escalonado*, which mainly conserve witnesses dating back to the decadence of Cahuachi (end of the III and IV phase);

(2) the survey of settlements to the west side of Cahuachi, where likely ceremonial activity moved as the archaeological records in Estaqueria proved (Sánchez Borjas 2009).

For both tasks 1 and 2 integrated remote sensing techniques have been applied. A complementary activity has been the evaluation of spectral capability and of the most reliable process methods of satellite images both for the vegetated and non-vegetated areas (see Sect. 14.3.1).

Moreover, before performing the geophysical investigations, the different technologies to be employed have been applied to test sites where the archaeological excavations were in progress, and so, the results would have been available after short time. This allowed us to provide information useful for the interpretation of geophysical outputs in presence of buried walls, tombs and ritual offerings.

## 14.2 Archaeogeophysics Rational Basis

### *14.2.1 Satellite Dataset*

A multitemporal and multiscale satellite dataset has been used both to archaeological purposes and for the study of the environmental setting. In particular, we used: (i) 90 and 30 m Digital Elevation Models (see Fig. 14.1) maps derived from SRTM (http://srtm.csi.cgiar.org) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), respectively; (ii) multispectral ASTER images to study land cover and the hydrographic pattern of the Rio Grande drainage basin. For the first results of these studies, the reader is referred to Chap. 12, in this book.

For the detection of archaeological features, we used Very high resolution (VHR) satellite commercially available imagery acquired from: (i) QuickBird2 (QB2), (ii) WorldView-1 (WV1), (iii) WorldView-2 (WV2), (iv) GeoEye-1 (GE1) sensors.

QB2 has panchromatic and multispectral sensors with resolutions of 61–72 cm and 2.44–2.88 m, respectively, depending upon the off-nadir viewing angle (0–25°). The panchromatic sensor provides images in a bandwidth ranging from 450 to 900 nm. The multispectral sensor acquires data in four spectral bands from blue to near infrared (NIR) (http://www.satimaging corp.com/satellite-sensors/quickbird.html).

WV1 provides panchromatic imagery with a ground sample distance (GSD) varying from 50 to 59 cm, depending on the off-nadir viewing angle. Additional details can be found at http://www.satimagingcorp.com/satellite-sensors/worldview-1.html.

WV2 acquires panchromatic imagery with 50 cm GSD, and eight-band multispectral imagery with 1.8 m resolution (http://www.ulalaunch.com/launch/WorldView-2/WV-2_MOB.pdf)

GE1 collects images with a GSD of 0.41-m or 16 inches in the panchromatic and multispectral imagery at 1.65-m resolution. The available GeoEye panchromatic images are re-sampled at 0.5 m (see http://launch.geoeye.com/LaunchSite/about/).

The VHR data used for this study have been:

(i) QB2 scene acquired on the 16th September 2002 at 15:17 with an off-nadir of 7.90, 61.90 cm and 2.48 GSD at panchromatic and multispectral, respectively;
(ii) QB2 scene acquired on the 25th March 2005 at 15:29 with an off-nadir view angle of 11.9°, 63.40 cm and 2.54 m GSD at panchromatic and multispectral, respectively;
(iii) WV1 image acquired on 31th July 2008 at 15.26 with an off-nadir view angle of 23.9° and 58.10 cm GSD;
(iv) WV2 image provided on 11th September 2010, at 15.30, with an off-nadir view angle of 2.7°, 50 cm and 2.0 m GSD at panchromatic and multispectral, respectively;
(v) GE1 image provided on 28th February 2011 at 15.09, 50 cm and 2.0 m GSD at panchromatic and multispectral, respectively

## *14.2.2 Satellite Image Processing Approach*

The image processing approach used for exploiting VHR satellite data has been aimed at improving the potential of imagery both in the spatial and in the spectral domain, by means of algorithms of image fusion (pan-sharpening), enhancement and edge detection.

### 14.2.2.1 Feature Enhancement Based on Pan-Sharpening Techniques

The first step of data processing has been the pan-sharpening, which provides a spatial enhancement of the lower resolution multi-spectral (MS) data (i.e. the four bands of QB2, WV2 and GE1). Equivalently, we can observe that pan-sharpening increases the spectral resolution of the panchromatic (Pan) image having a higher spatial resolution, but a lower spectral resolution bearing no spectral information.

The general protocol employed, can be summarised in two steps: (1) extraction of high-resolution geometrical information from the panchromatic image; (2) injection of such spatial details to the interpolated low-resolution MS bands through proper models.

According to this protocol, the pan-sharpening techniques can be divided into two main classes: (i) component substitution (CS) techniques, which are based on a spectral transformation of the MS data followed by the substitution of the first transformed component with the Pan image and reverse transformation to yield back the sharpened MS bands (the most widely used CS-based methods are Intensity-Hue-Saturation (IHS), Principal Components Analysis (PCA) and the

Gram-Schmidt (GS) orthogonalisation procedure (Laben and Brower 2000)); (ii) techniques that employ multi-resolution analysis (MRA) such as wavelets and Laplacian pyramids. These methods extract from the Pan image the geometrical information that will be added to the MS bands.

Due to the variety of surface covers in Cahuachi (bare-ground surface in the archaeological area, vegetated in the Nasca riverbed), and archaeological features (crop-marks, microrelief, surface archaeological structures), more algorithms, such as GS, enhanced GS (Aiazzi et al. 2007) with context adaptivity (GSA) and generalised Laplacian pyramid (GLP) with context adaptivity (Aiazzi et al. 2006), were used.

The comparative analysis performed in a qualitative way put in evidence that the methods based on CS technique (GS and GSA) provide fused images with higher geometrical quality with some spectral impairments, whereas the GLP is spectrally accurate, but is unsatisfactory in terms of spatial enhancement, as already experienced in other archaeological test sites (Aiazzi et al. 2008).

#### 14.2.2.2 Feature Enhancement Based on Linear Combinations of Spectral Bands

The spectral indices are generally computed by a linear combination of different spectral bands in order to obtain quantitative measures of surface properties. Spectral indices, attempt to quantify surface properties such as brightness, moisture, biomass cover, or vegetative vigour. The widely used index is the Normalized Difference Vegetation index (NDVI) obtained by using formula 14.1:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \tag{14.1}$$

The NDVI operates by contrasting intense chlorophyll pigment absorption in the red against the high reflectance of leaf mesophyll in the NIR. On the basis of the vegetation spectral properties, the NDVI provides a quantitative measure, suitable to assess biomass, vegetation type and vigour. NDVI is indicative of plant photosynthetic activity and it has been found to be related to the green leaf area index and to the fraction of photosynthetically active radiation absorbed by vegetation. High values of the vegetation index identify pixels covered by substantial proportions of healthy vegetation, whilst disease or stressed vegetation exhibits lower NDVI values.

PCA is a linear transformation which decorrelates multivariate data by translating and/or rotating the axes of the original feature space (Richards and Xiuping 2006). In this way, the data can be represented without correlation in a new component space. In order to do this, the process firstly computes the covariance (Unstandardized PCA) or the correlation matrix (standardized PCA) among all input spectral channels. Then eigenvalues and eigenvectors are calculated in order to obtain the new feature components. So, the PCA transforms the input multispectral bands in new components whose number is equal (or less) to the number of the input channels. In detail, the first component contains the major portion of the variance and provides a sort of average of all the input channels. Each successive component contains less of the total dataset variance and may represent information for a small area or essentially noise; in this case, it must be disregarded. The PCA should be able to make the identification of distinct features and surface type easier. This is a direct result of different facts: (i) only the meaningful low correlated data can be considered, (ii) the effect of noise can be easily identified and strongly reduced because it is in the later components. Moreover, the PCA can be used to obtain a new color enhancement technique, "Decorrelation Stretching", based on the following steps: (i) PCA transformation, (ii) each PCA component is contrast stretched, (iii) stretched components are rotated back using the inverse PCA transformation (iv) finally, the resulting components are generally shown using RGB compositions.

Finally, in order to better identify spectral signature anomalies on both bare ground and vegetated areas, Minimum Noise Fraction (MNF) transformation has been applied. By examining the images and eigenvalues, MNF allowed to determine which bands contain the coherent images, thus segregating and removing noise from the pansharpened multispectral channels (see Boardman and Kruse 1994). By using a routine of ENVI, based on MNF transformation modified by Green et al. (1988), the procedure is two cascaded Principal Component transformations.

The first transformation, based on an estimated noise covariance matrix, decorrelates and rescales noise in the data. This first step results in transformed data in which noise has unit variance and no band-to-band correlations. The second step is a standard Principal Component transformation of the noise-whitened data. For the purposes of further spectral processing, the inherent dimensionality of the data is determined by examination of the final eigenvalues and the associated images. The data space can be divided into two parts: one part associated with large eigenvalues and coherent eigen images, and a complementary part with near-unity eigenvalues and noise-dominated images. By using only the coherent portions, noise is separated from the data, thus improving spectral processing results (ENVI user's guide 1999).

#### 14.2.2.3 Feature Enhancement Based on Spatial Filtering

Once pan-sharpening and spectral combinations computed, in order to further improve the edges of objects (surface archaeological structures) and marks (possibly related to archaeological deposits), some convolution filters, including high pass, low pass, Laplacian, directional, Gaussian High Pass, Gaussian Low Pass, median, Sobel and Robert filters, have been used (for additional information on spatial filtering see Chap. 2, Sect. 2.4.5).

The best results in terms of edge enhancement of the edges have been obtained by using "High pass filtering" which removes the low frequency components of the

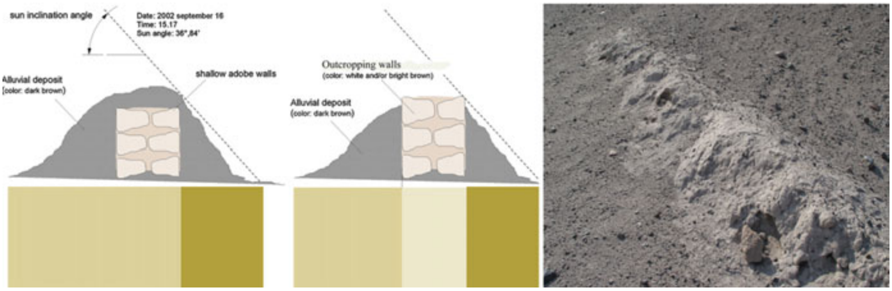


**Fig. 14.5** (*Left* and *medium*) Shallow and surface walls visible from remote by means of the shadow and the reflectance of the clay of adobe walls

images, thus retaining the high frequencies (local variations in the presence of surface archaeological structures). The filter has been applied by adopting a $3 \times 3$ kernel with a value of 8 for the center pixel and values of $-1$ for the exterior pixels.

In case of rectilinear features (i.e. we refer to the edges of terraced platforms of some mounds), good results have been observed by employing a directional filter, which is a first derivative edge enhancement filter that selectively enhances image features having specific direction components (gradients).

The above-said image processing routines have been applied to different test areas in order to select those to be systematically adopted in the areas to be investigated (see Sects. 14.3.1 and 14.3.3).

Unfortunately, the identification of buried and/or shallow remains (i.e. walls) in the desolate area of Cahuachi by using optical imagery is a very complex challenge, due to the building material, which is adobe, whose composition (sun-dried earth) is quite similar to the soil which covers the archaeological remains. This has been confirmed by a multitemporal observation of aerial and satellite images which allowed us to compare some areas before and after the excavations (Masini et al. 2008, 2009a, b).

The comparison put in evidence that: (i) buried adobe structures are generally not visible from an aerial and/or satellite view; (ii) surface wall remains were more easily identified due to the high contrast in brightness between the clay of the surface adobe walls and the surrounding alluvial deposits which cover a large part of the mound; (iii) microrelief related to shallow walls are enough detectable thanks to the small shadow produced on the ground (see Fig. 14.5).

To face the challenge of the detection of archaeological features, once selected and used the most suited pan-sharpening and filtering algorithms, further processing methods have been applied to some test sites shown in Sect. 14.3.1 which put in evidence a good performance of the PCA for the bare-ground sites and vegetation indices for the vegetated and damp areas of the Nasca riverbed.

### *14.2.3 Geophysical Approach*

The variety of archaeological features in the subsoil (buried structures, tombs, and ritual offerings), the low geophysical contrast between some archaeological features (adobe walls) and the soil, the complex stratigraphies unearthed by archaeologists made necessary the employ of different geophysical methods.

In some cases more methods have been used in order to integrate the information content, in other cases only one method has been employed due to logistic problems related to the application of all geophysical techniques or for the great extension and the complex morphology which suggest to perform only the least time consuming one, such as the geomagnetic one. In the following subsections, each geophysical method will be briefly described.

#### 14.2.3.1 Georadar Method

The GPR is an electromagnetic (EM) method used for several kinds of applications and with different investigation depths (Fig. 14.6). The archaeological targets are generally investigated by using medium frequency antennas. The EM-wave frequencies along with the electrical characteristics of the subsoil (permittivity and electrical conductivity) determine the investigation depth. The GPR radiates short EM pulses into the ground and detects the signals reflected from subsurface structures. The reflected signal is generated in the presence of a dielectric contrast between potential targets and surrounding soil.

This has been the crucial topic in Cahuachi because the adobe (made from sand, clay, fibrous material and water) have characteristics similar to the alluvial soil, in terms of resistivity and dielectric constant.

GPR measurements were performed by using the Subsurface Interface Radar (SIR) 3000 manufactured by GSSI: SIR 3000. It consists of a digital control unit with a keypad, VGA video screen, connector panel and is powered by a 12-V DC battery. The system is connected by fibre-optic cables at a monostatic type antenna (400 MHz) manufactured by Geophysical Survey Systems.

Due to the incoherent sand of soil surfaces the survey was acquired without a ‘wheel accessory’, so that a speed variation could occur. To reduce uncertainties on the antenna position, a reference metre rule was located along each profile and marked at each metre. In order to estimate the average electromagnetic wave velocity, a wall of known thickness fitted with a metallic plate was used to gain a maximum reflection of EM waves. A velocity of about 0.1 m/ns has been estimated observing the half two-travel time of the corresponding metallic plate reflection. The radar scans have been acquired in continuous mode with a 2-way time range of 40 ns. An interval band-pass filter of 100–800 MHz was used to reduce electronic, antenna-to-ground coupling noise as well as other low- and high-frequency noise.

The Reflex W software was used to process the data. The high quality of the traces only required standard analysis techniques for data processing and for

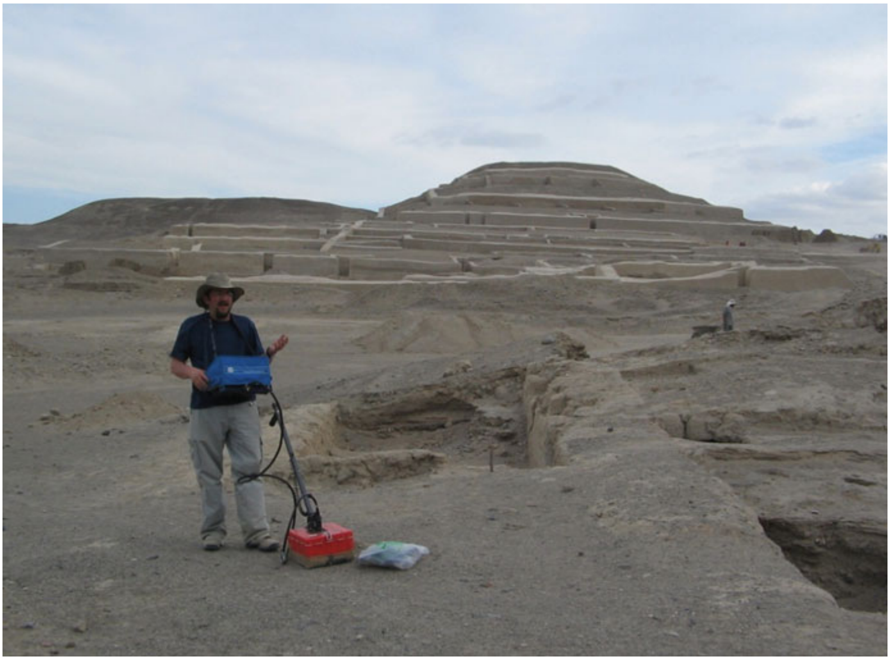

**Fig. 14.6** Georadar system

reducing background noise, linked to trace editing, normalization, acquisition gain removal, zero time correction and a background removal filter. High-frequency noise was attenuated by means of a 2D average filter. An interactive velocity adoption, based on EM reflection waves, was used to estimate the average EM-wave velocity of the geological material that covers the archaeological deposits.

#### 14.2.3.2 Geomagnetic Prospections

In Cahuachi geomagnetic method with a gradiometric configuration has been applied. The measurements were performed using an optical pumping magnetometer G-858 (by Geometrics) in gradiometric configuration, with two magnetic probes set in a vertical direction at a distance of around 1 m each other (Fig. 14.7). Such a configuration allowed the automatic removal of the diurnal variations of the natural magnetic field. Before defining the acquisition modalities, it was necessary to set up the proper orientation of the two magnetic sensors of the Caesium Magnetometer. Such an orientation depends on the survey direction and site location in the world. To do this CSAZ software (by Geometrics) has been used. It provides information about the Earth's magnetic field parameters including total field, inclination and declination anywhere in the world, using the IGRF (International Geo-Magnetic Reference Field). After entering latitude and longitude of the archaeological site and indicating the

**Fig. 14.7** Geomagnetic prospections

survey direction, the software provides the orientated caesium sensor to have the maximum signal and best performance. Therefore, the instrument was set with a tilt angle of 45° and the survey was defined along parallel profile in N-S direction.

Data were acquired along parallel profiles 0.5 m apart with a sampling rate of 10 Hz, obtaining a mean spatial resolution of 0.5 m × 0.125 m. The surveyed areas were geocoded through GPS differential measurements. All the acquired data were processed and interpolated to create regular grids. Afterwards, the final matrixes were mosaicked. In some cases, where the area to be investigated was very large (i.e. in the Nasca riverbed, see Sect. 14.3.3) or characterized by steep slopes, magnetic prospections have been performed by means of GPS.

The rough magnetic data have been visualized as 8 bit raster images, after having created regular grids using a Kriging interpolator with a linear variogram. Then, the rough magnetic data have been filtered to increase the signal/noise ratio by using MagMap software which provides pass-band filter, spikes elimination and destripe.

Finally, the filtered have been visualized as a shaded relief image, in order to highlight the main magnetic anomalies.

#### 14.2.3.3 Georesistivity

The third method employed has been the georesistivity, by using the RM-15 Resistance Meter (by Geoscan). It is a technique that measures the resistance encountered by an electrical current in passing through the subsoil between four probes. One pair of probes is fixed far from the investigated area, while the second one is mounted on a frame and inserted into the ground at regular distance. In the investigated area the interval distance was 1 m along parallel lines with a regular distance of 1 m. Each reading is a measure of the amount of the resistance encountered by the current as it passes through the soil.

In presence of adobe walls in the subsoil, low resistivity values are expected. On the contrary, electrical current should encounter greater resistance in tombs and ritual offering, due to the presence of voids and high content of pores.

## 14.3 Experimental Section: Test Sites, Archaeo-Geophysical Investigations, Results

### *14.3.1 VHR Satellite Image Processing Approach: Preliminary Tests*

Before the first systematic archaeo-geophysical campaign in 2008, some preliminary investigations have been carried out in 2007 on some test sites (TS) into the archaeological area and in its surrounding, which allowed to develop the most suited image processing approach for different archaeological features and land cover.

In this chapter we show the results obtained on four tests sites (see Fig. 14.8) which are: (i) the zone B located at West of zone A (named TS1); (ii) some lineal geoglyphs sited at South of *Gran Piramide*, at North of *Atarco* (TS2); (iii) a vegetated area north the Nasca River (TS3). The satellite images used for the preliminary investigations have been the 2002 QB data (see additional information of the image in Sect. 14.2.1).

The test site TS1 includes mounds which likely conserve pyramids, terraced platforms, a square and a U-shaped enclosure. The U-shaped courtyard is an urban scheme which typically characterizes the ceremonial town since Early Horizon period (Gavazzi 2009, 2010). In Cahuachi the U-shaped courtyard of sector B, faces North, in direction of the geoglyphs of the Pampa. The mounds and the platforms compose a chessboard shaped layout with some offset which allowed to look to east in direction of the sacred mountain of *Cerro Blanco*.

All these archaeological features in zone B are enough visible from the panchromatic image (Fig. 14.9a), however the shadow produced by the micro-relief (terraces, platforms, walls), the circular looted area and the presence of surface chaotic material, residues of adobe structures make difficult their identification and survey. So, TS1 has been visualized and interpreted by using not only the data input (panchromatic and pan-sharpened bands, but also the results of the post processing approach described in Sect. 14.2.2).

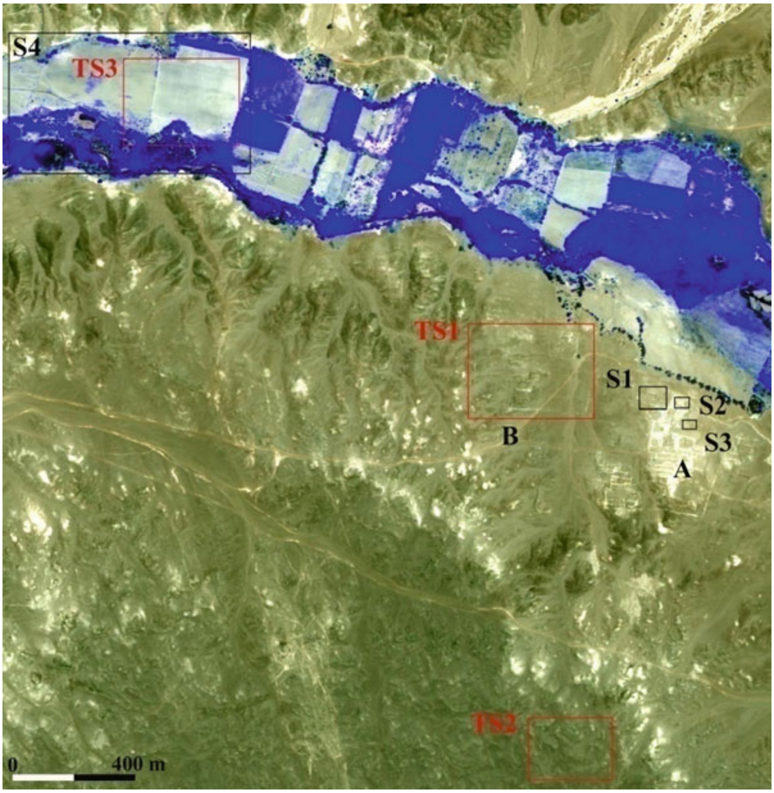


**Fig. 14.8** Location of test sites (TS1, TS2, TS3) and the investigates sites (S1, S2, S3 and S4)

The comparative observation of known archaeological features from the data input put in evidence a better performance of the panchromatic images respect to multispectral pan-sharpened data, including the RGB visualization. This has been found also in the other test site characterized by bare and arid soil surface (TS2). So, the post processing has been focused on the panchromatic data, showed in Fig. 14.9. The best results have been obtained by using PCA and MNF. For sake of brevity we show only the results of PCA (the percentage of the computed eigenvalues have been 79% for PC1, 16% for PC2, 5% for PC3 and PC4). In Fig. 14.9, related to the panchromatic image of the sector B, the result of PC1 has been overlaid in the lower left corner has, thus revealing a slight enhancement of some details in particular of the looted areas, characterized by circular holes.

A better discrimination of archaeological features has been obtained by PC2 (Fig. 14.9b). The latter makes the identification of edges related to mounds and platforms easier (see 3 and 7, in Fig. 14.9a, b), and some parts of the U-shaped enclosure (see 1, in Fig. 14.9a, b). This is in perfect accordance with the fact that the first PCA substantially provides an average of all the input spectral channels, e.g. a map very close to the brightness of the scene quite similar to the panchromatic image.

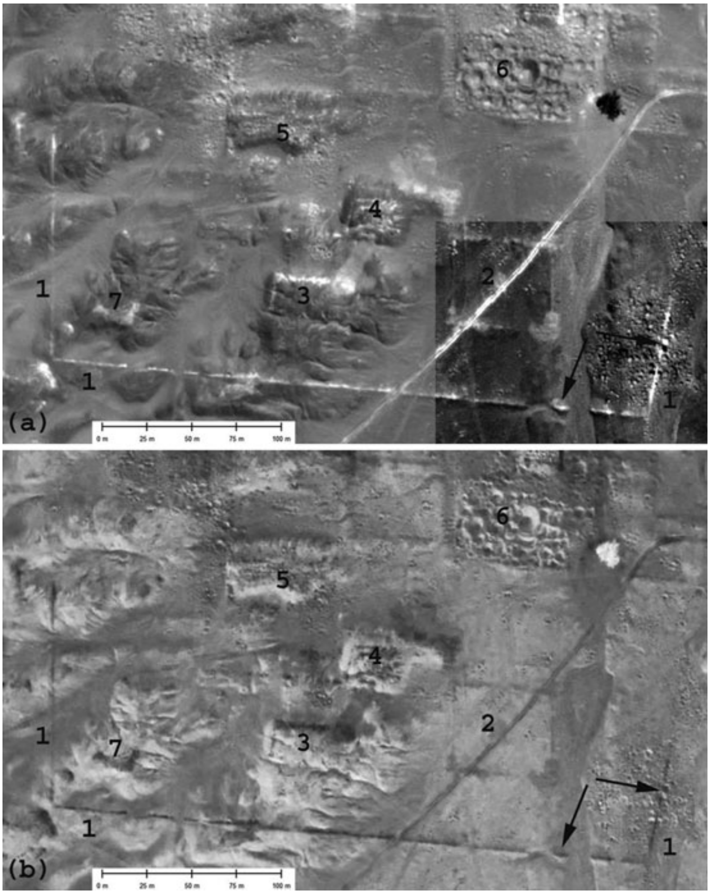


**Fig. 14.9** Test site TS1. (**a**) Panchromatic 2002 QB, in the corner lower right the PC1 result has been overlaid on the panchromatic scene; (**b**) PC2 result

Whereas the second component cannot be associated with a general meaning since it is obtained from the statistic computation and depends on the current dataset.

Still better results of PC2 could be observed in TS2 (see Fig. 14.10).TS2 is an area located between Cahuachi and *Atarco* River, about 1 km South of *Gran Piramide*, where several geoglyphs could be observed (Fig. 14.10a, c). They are geoglyphs less known and rich from the iconographical point of view respect to those of *Pampa Jumana* and *Pampa Colorado*. Here we do not find any biomorphic geoglyph. However they are important because they clearly seem to be part of a ritual complex closely related to Cahuachi. They are likely pathways used by pilgrims on their way to the Ceremonial Centre.

As in the Pampa this area could be another place of gatherings and ritual activities. Such geoglyphs have been produced removing stones from their original

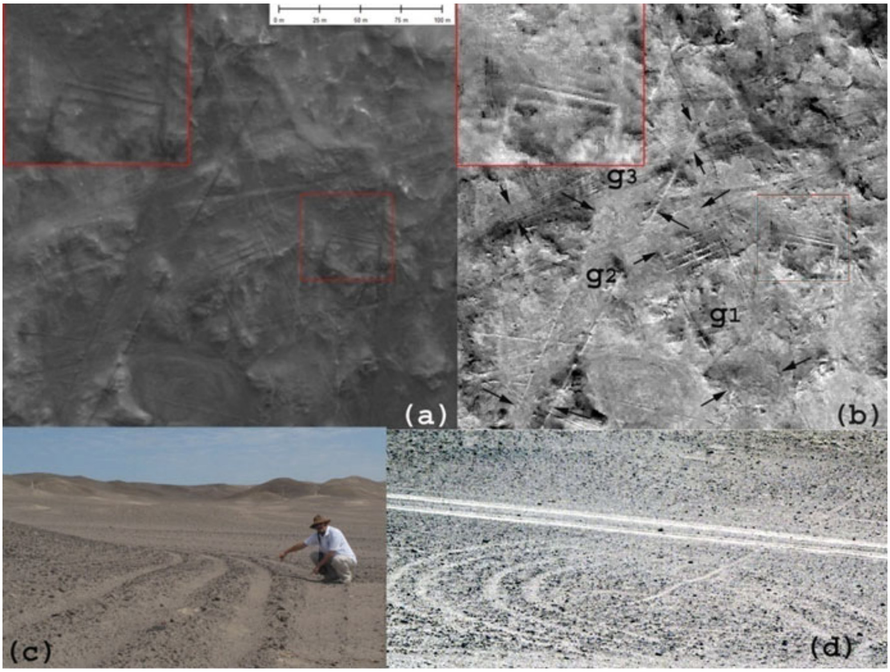


**Fig. 14.10** Test site 2: geoglyphs at south of Cahuachi (for their location see Fig. 8). (**a**) 2002 panchromatic image with a zoom in the corner upper *left*; (**b**) the visualization of PC2; (**c**–**d**) ground truth

place in order to create different motifs such as lineal (straight lines, U-shaped, meandering, zig-zag, spiral, areal trapezoidal and triangular), as showed in Fig. 14.10a–c. In some cases the contrast clear-dark had been obtained by removing darker stone material (pebble and gravel) and unearthing the clearer subsoil. The image processing of QB images has been aimed to improve the contrast of the lines. The test site has been selected because it is characterized by the superimposition of more geoglyphs. The convolution filters and PC2 allowed us to identify the temporal sequence of the drawn lines. The visualization of PC2 in Fig. 14.10b puts in evidence at least three different tracking phases (g1, g2 and g3). Such superimposition did not necessarily mean the destruction of a line (or pathway) and the creation of a new one. In some cases the overlapped geoglyphs created an intersection of active pathways to be walked.

The final test site herein described is a vegetated area at 1.8 NW from *Gran Piramide*, located on a cultivated strip on the right of the Nasca River. The river is close to the test site (around 200 m) and supplies enough water for the cultivations.

Some aerial images captured during in-flights on April 2007 had put in evidence some interesting crop marks. For this reason it is selected to test different image processing methods in order to exploit the spectral features of QuickBird images.

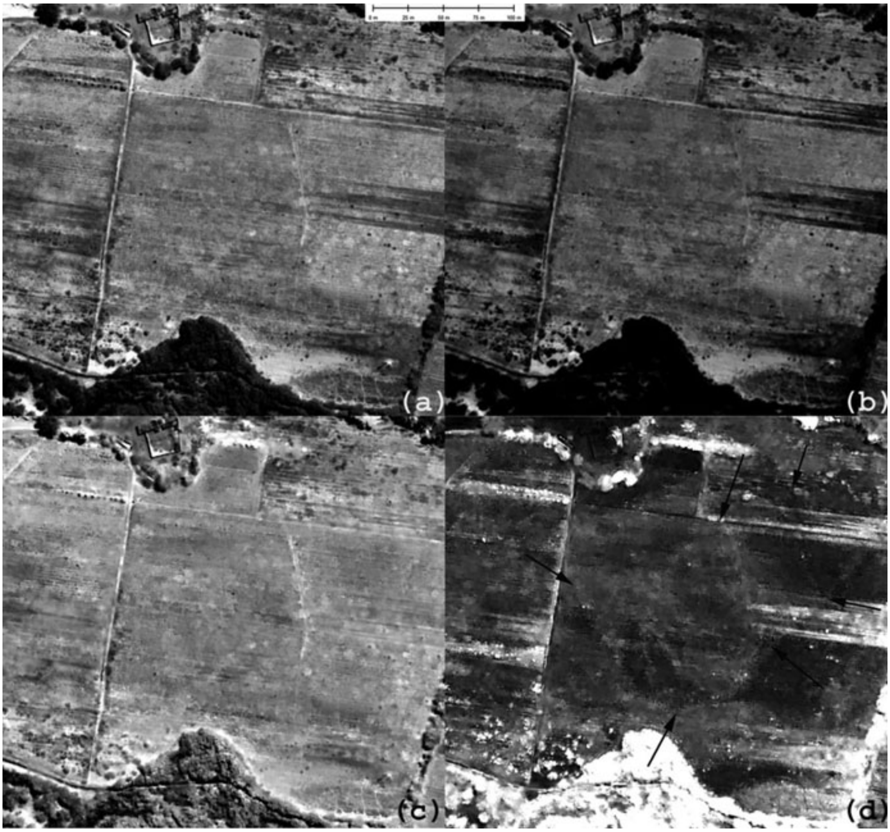


**Fig. 14.11** Test site TS3 selected in a vegetated area. (**a**) 2002 QB2 panchromatic image; (**b**) *red* pan-sharpened channel; (**c**) NIR pan-sharpened channel; (**d**) NDVI map. The latter put in evidence a quadrangular shape signal (indicate by *black arrows*)

Unfortunately the month of acquisition satellite data (September) was not ideal for crop marks. Panchromatic image and NIR channels do not show significant information (Fig. 14.11a–c).

On the contrary, red channel (Fig. 14.11b) put in evidence a signal apparently irregular at west of the field division. The NDVI (Fig. 14.11d) map has strongly enhanced this signal, thus revealing a quadrangular shape and some linear marks parallel to the sides of the areal anomaly. The geometric pattern suggests a possible anthropogenic cause to the signal observed from NDVI map. On site some ceramic fragments and bread-shaped adobe refer to a possible archaeological interest of the place. This test site was very useful in the perspective to perform an archaeo-geophysical investigation, based on the integration of geophysics and satellite remote sensing, carried out the following year (2008).

Section 14.3.3 shows the results of this research which lead to the discovery of a large buried settlement.

## 14.3.2 Archaeo-Geophysical Investigations and Results in the Sector A

### 14.3.2.1 Site S1. From Satellite to Geophysics: The Discoveries in *Piramide Naranja*

The study of *Piramide Naranja* has been the last as well as crucial investigation phase within the multi-year archaeological programme of the mission directed by Giuseppe Orefici. The first archaeological findings before ITACA investigations had clearly put in evidence the richness of tombs and ritual offerings and the presence of walls dating back to third and fourth phase.

For archaeologists, the expected results of excavations in the *Piramide Naranja* would have contributed in casting new light on the last historical phase of the Ceremonial Centre: its abandonment.

So, archaeo-geophysical investigations have been starting since 2008 with twofold aims: (1) the identification of surface and shallow archaeological features referable to walls in order to spatially characterize the trunk-pyramidal architecture; (2) the detection of buried archaeological deposits related to tombs and ritual offerings (the first results of geophysical investigations have been published in Lasaponara et al. 2011).

For the first aim three different approaches have been adopted. One is multitemporal, that is the observation of a time series of aerial and VHR satellite images (1955, 2003, 2005, 2007, and 2008). The second has been based on the analysis and processing of VHR satellite imagery. The third approach has been the integration of geomagnetic and georadar methods. The geomagnetic method has been employed to confirm the presence of shallow walls already visible by the optical data set as well as to add further information. The georadar has been used to obtain information on the depth of buried walls. This latter task has not been fully obtained, since the attenuation of radar signal capable to survey only shallow reflections referable to the upper part of buried walls.

Figure 14.12a–f show the 3d visualization of *Piramide Naranja* from the available aerial and satellite images, performed by using a DEM (a) derived from a topographical map (1:1.000 scale). The map has been done with photogrammetrical techniques on the base of the 1955 aerial images (one of which is showed in Fig. 14.12b) and a topographical survey carried out in 1988–1989.

*Piramide Naranja* has an asymmetric shape, as the other pyramids in Cahuachi. It faces to North as well as it is characterized by four terraced platforms. The multitemporal data set analysis put in evidence some changes of the site, such as the increasing of the looting activity from 1955 to 2003 (Fig. 14.12b, c) and the walls unearthed on the eastern slope which are visible since 2007 (Fig. 14.12e, f).

For the mapping of the edges of terraced platforms all the data set of Fig. 14.12 have been assessed in terms of discrimination of the mentioned archaeological features. From the comparative qualitative assessment the best results have been obtained by the 1955 aerial photo and 2002 QB panchromatic scene (see Figs. 14.12b, 14.13a, and 14.14a). So, the enhancement processing has been focused on the above said data.

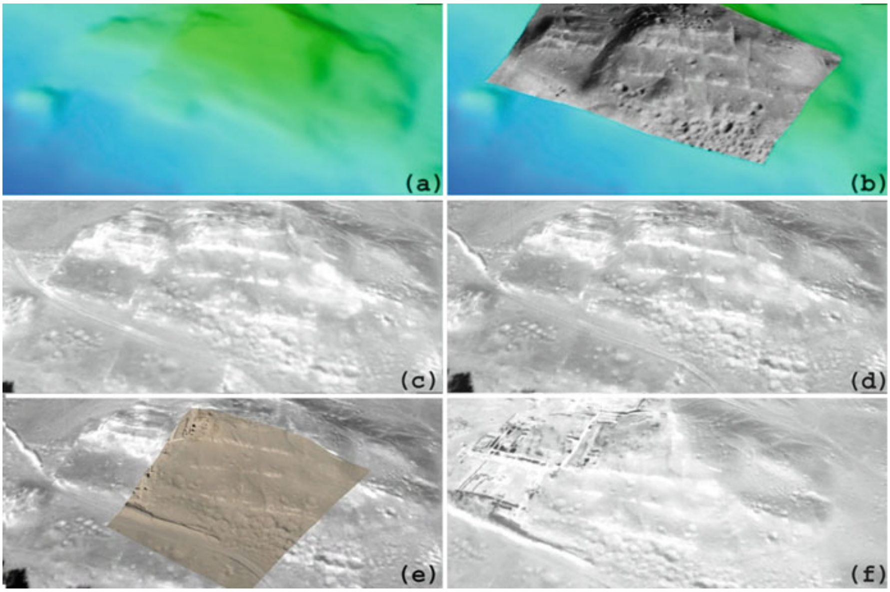


**Fig. 14.12** *Piramide Naranja*: 3d visualizations of aerial and satellite data set by using a DEM (**a**) derived from a topographical map performed for scale 1:1.000. The 3d visualizations are related to an aerial photo taken in 1955 (**b**), two QuickBird images acquired in 2002 and 2005 (**c**–**d**), an aerial photo captured in 2007 (**e**) and WorldView-1 image acquired in 2008 (**f**)

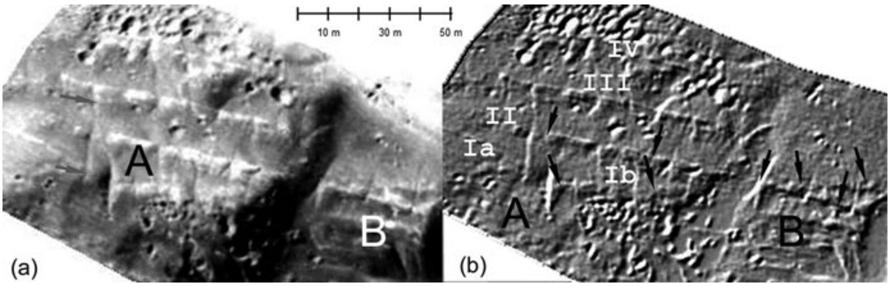


**Fig. 14.13** (**a**) Aerial image taken in 1995; (**b**) result of convolution filter. *A* and *B* denote respectively the *Piramide Naranja* and the *Templo del Escalonado*

The Fig. 14.13a shows the 1955 aerial photo orthorectified on the base of the available DEM (Fig. 14.12a). The scene includes *Piramide Naranja* (labelled with letter A), divided by a moat from an adjacent terraced structure on the east, known as *Templo del Escalonado* (labelled with letter B).

The historical photo has been filtered by directional convolution, computed by applying a direction filter angle of 90° and kernel size $= 3 \times 3$ (Fig. 14.13b), thus improving the contrast of the terraced platform edges *II*, *III* and *IV*. Moreover, it allows to identify the edge of the top platform I, characterized by a broken line

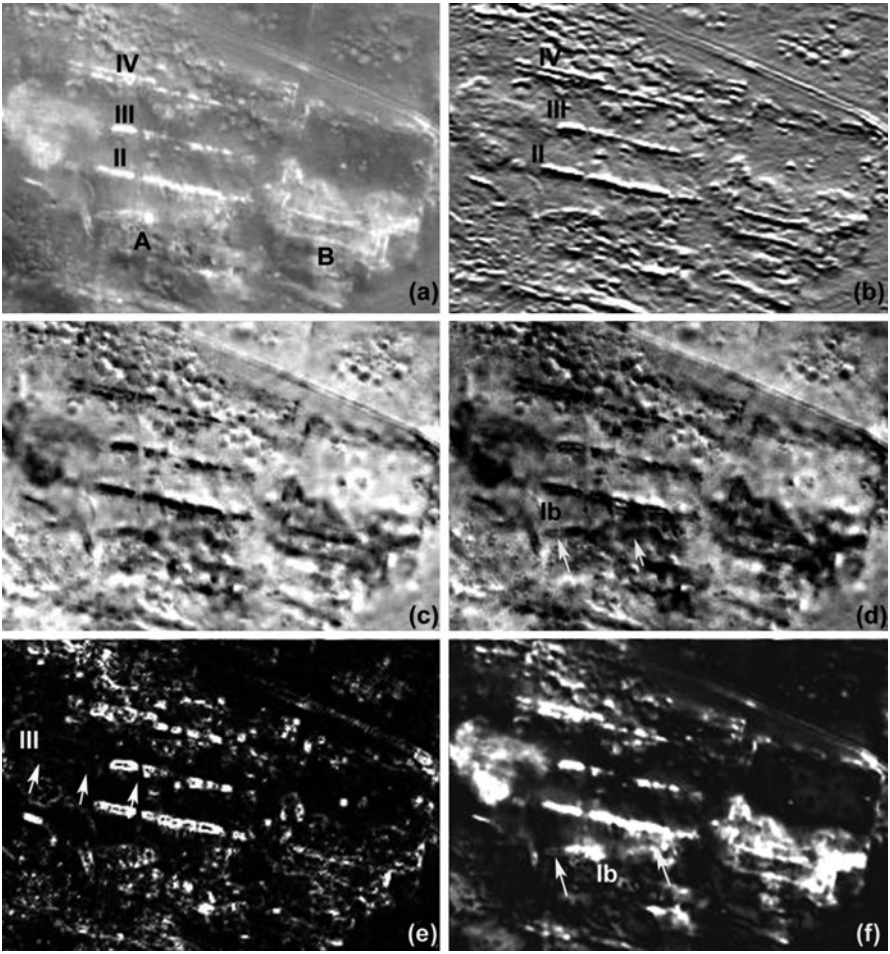


**Fig. 14.14** Detail of northern slope of *Piramide Naranja* from 2002 QB2 panchromatic image (**a**) and the results of some post processing applications such as: (**b**) directional convolution; (**c**) PC3; (**d**) standard deviation; (**e**) Geary's C index; (**f**) Moran's index

composed of a segment parallel (*Ia*) to *II-IV* and an oblique segment (*Ib*). The filtered image shows also the alignment of II and *Ib* with some edges of the adjacent *Templo del Escalonado*. Such alignments are less visible in the non processed aerial image (Fig. 14.13a) as well as non visible in the aerial and satellite dataset, since 2002, due to clandestine excavation activity.

Figure 14.14a shows the 2002 QB2 panchromatic scene. On the QB2 imagery (panchromatic and pan-sharpened bands) directional and high pass filter, PCA, Standard deviation and spatial autocorrelation statistics has been computed. The best discrimination of linear archaeological features has been obtained by the directional convolution (Fig. 14.14b), PC2 and the standard deviation. Respect to the

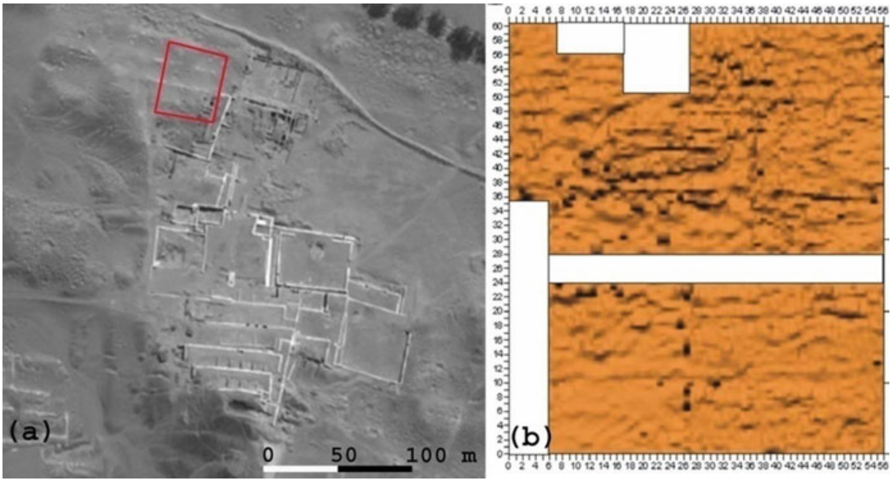


**Fig. 14.15** (**a**) Location of the area of *Piramide Naranja* investigated by geomagnetic method; (**b**) geomagnetic map

panchromatic image (Fig. 14.14a) the directional convolution (Fig. 14.14b) reduces the noise due to the high reflectance of the clay which the surface and shallow walls are composed of, thus allowing to thin the archaeological features. PC2, Standard deviation (Std) and the result of Geary's C index show the above mentioned oblique feature IB, whereas Moran's index allow to identify a subtle linear feature aligned (at west) with the feature III.

After mapping the linear features related to the edges of terraced platforms geomagnetic investigations have been performed. The aim was to detect materials characterized by magnetic properties such as metals, ceramic and coal associated to possible tombs and ritual offerings.

Lower differences of magnetic field between the shallow walls and its surrounding were expected. The total map surveyed was around 56 $\times$ 60 m, thus covering three terraced platforms of northern slope of the pyramid.

As measurement acquisition modalities, we selected the mapped survey mode, which allows us to define and visualize the survey area as well as to move around within it in a non-continuous fashion by means of regular grids (for detail on data acquisition and processing, see Sect. 14.2.3.2).

In order to overcome logistic problems, due to the presence of excavation trials and old pits dug by grave looters, the investigated area was subdivided into ten sectors. The survey direction was always South-North. Figure 14.15a shows the location of the investigated area. On the right of the same figure (Fig. 14.15b) the geomagnetic map obtained from gradient data is showed.

The overlay on the satellite image (see Fig. 14.16) helped in interpreting the magnetic anomalies. In particular, lower but linear oriented anomalies (in E-W direction) correspond to the archaeological features, already visible from the optical dataset (see I, II and III in Figs. 14.14a and 14.16a, b), which have been thought to

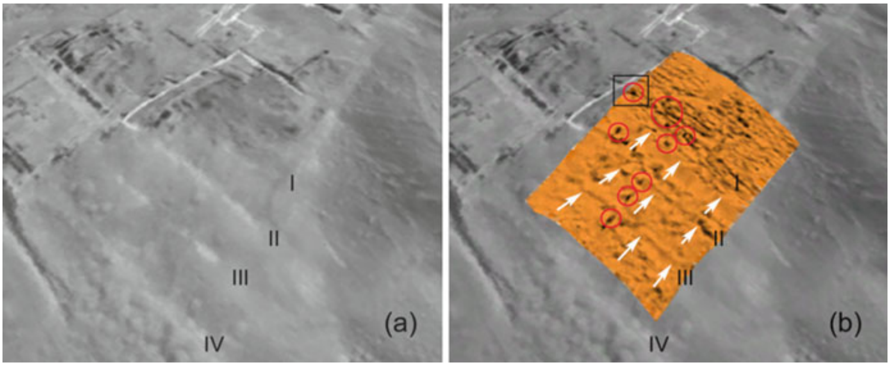


**Fig. 14.16** (**a**) 3d satellite image (2008 WV1) visualization of northern slope of *Piramide Naranja*, and (**b**) geomagnetic map overlaid on the satellite image. The *white arrows* denote linear magnetic signals, the *red circles* indicate more intense magnetic signals, the *black block* evidence the anomaly selected in collaboration with archaeologists to be firstly investigated by GPR and then excavated

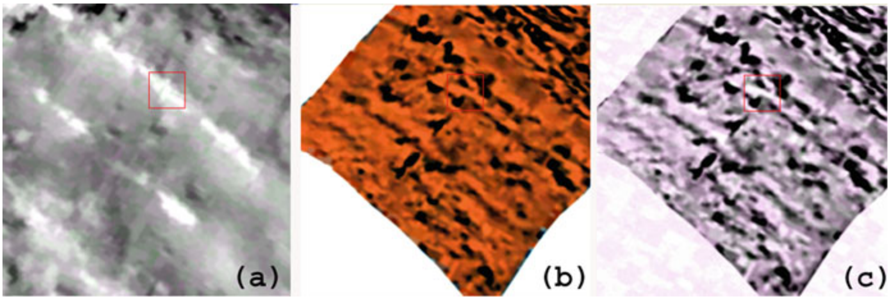


**Fig. 14.17** *Piramide Naranja*: data fusion between WW-1 panchromatic image and geomagnetic map

be surface and shallow walls which limit the external edges of the platforms. Other linear anomalies are oriented in N-S direction, thus suggesting the presence of walls related to ramps and corridors which connect the different levels of the pyramid.

The fusion between panchromatic image and geomagnetic map has been performed by using Grahm-Schmidt spectral sharpening, with nearest neighbour resampling (see Fig. 14.17a–c). The image fusion product confirms such correspondence as well as improves the quality of information content. Moreover, small circular and intense magnetic anomalies could be observed (Figs. 14.16b and 14.17b). Most of them are over pits partially dug by grave looters, with a greater density in the top of the pyramid. Some other strong anomalies are aligned along a line between the platforms II and III (Fig. 14.16b).

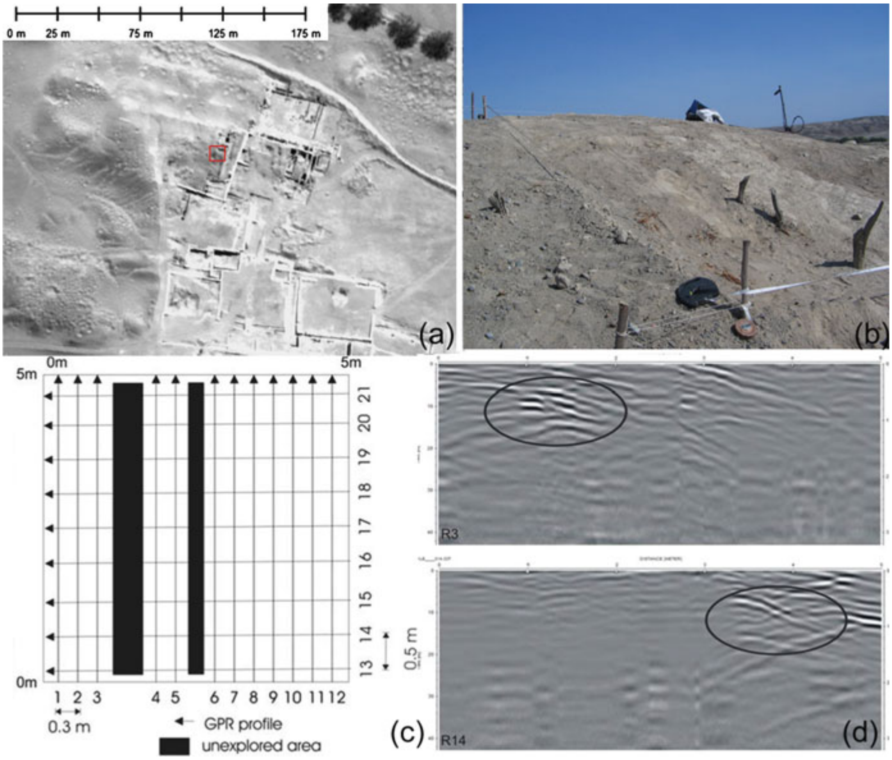


**Fig. 14.18** (**a**) Location of the area investigated by georadar method, indicated by a *red square box*; (**b**) detail of the investigated area; (**c**) georadar profiles performed on a 5 x 5 m area where geomagnetic technique provided high values of magnetic field; (**d**) migrated radargrams R3 and R14, where it is possible identify some superficial reflection hyperbolas (indicated by *black ellipses*)

All these circular anomalies have been thought to be linked to tombs. To prove this hypothesis, before proceeding with excavations, georadar prospections on a test area have been performed. The selected area was on the top of the eastern slope of the pyramid (see Fig. 14.16b and 14.18a, b). The soil was mostly characterized by sand, thus explaining the higher electromagnetic wave average velocity respect to other sites (estimated by hyperbola analysis) and equal to 0.15 m/ns. Therefore, by exploiting the estimated *Vem* for the 400 MHz antenna, the time range of 30 ns corresponds to a maximum investigated depth around to 2 m.

Several GPR profiles were carried in the area divided into several grids of 5 m $\times$ 5 m, selected according to the dimensions of each square excavated by the archaeologists (Fig. 14.18c). The square area was investigated by 21 profiles carried out along two directions (nn. 12 and 9 in E-W and N-S direction, respectively).

For sake of brevity, herein we focus on some profiles, representatives of the final results: profiles R3 and R14 (shown in Fig. 14.18d). The profiles are perpendicular each other and have an investigation depth around 2 m (with *Vem* = 0.15 m/ns).


**Fig. 14.19** (**a**) Archaeological layer at 50 cm depth: wood framework of a tomb is visible; (**b**) deeper archaeological layer which put in evidence a rich offering ritual material: (**c**) detail of some artefacts unearthed from the excavation: from *left* to *right*: a polychrome vessel, an antara and two painted pumpkins

The GPR profiles point out several reflections at depths ranging from 6 to 16 ns (0.45 and 1 m, respectively). In particular profiles R3 and R14 (Fig. 14.18d) show the presence of a strong reflector, ascribed to buried objects. The excavation of the first 50 cm unearthed remains of *huarango* trunks and branches, in agreement with the reflector of the radargrams (Fig. 14.19a). Such *huarango* elements belong to a wood framework, which typically covers a Nasca ceremonial offering and/or tomb.

The excavation of the subsequent layers revealed the existence of a rich ceremonial offering (Fig. 14.19b), which included 80 ceramics, painted textiles, precious metal objects and painted pumpkins of the Nasca Culture (see Fig. 14.19c). Finally, the archaeological deposit also revealed two human bodies belonging to a child and to an adult. Both of them were sacrificed and formed part of the ceremonial offering.

#### 14.3.2.2 Site S2: *Templo del Escalonado*

Between 1984 and 1988 the Italian archaeological mission unearthed a monumental structure belonging to a transitional period between the architectural phases II and III of Cahuachi, and characterized by precious incised friezes with stepped motif on the walls, which the name of *Templo del Escalonado* derives from (Orefici 1988).

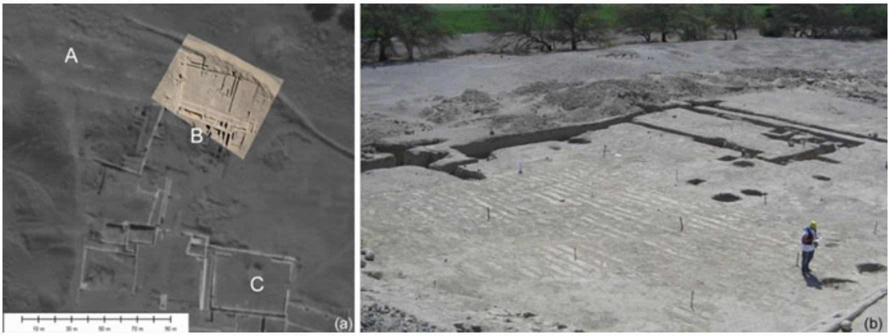


**Fig. 14.20** (**a**) Location of the investigated area near *Templo del Escalonado*: the image is given by an orthorectified aerial photo on WW-1 satellite panchromatic image. *A* denotes *Piramide Naranja*, *B* indicates *Templo del Escalonado*, *C* is a *plaza undida* of *Gran Piramide*. (**b**) View of the prospected area

Since 2001 the investigations were enlarged to a flat area below the *Templo del Escalonado*. Trial excavations unearthed some walls. Unfortunately, the archaeological records till now available do not allow us to understand the spatial and functional relationships between this area and the *Templo del Escalonado*. This made necessary to conduct additional investigations by using geophysical methods (Rizzo et al. 2010).

Geophysical prospections have been carried out in two different field trips using: (i) a Ground Penetrating Radar (GPR) in a three dimensional survey (April 2008) and (ii) a geomagnetic survey with a gradiometer configuration (November 2008).

Figure 14.20a, b show the investigated area and its location. Figure 14.21b shows the areas investigated by Geomagnetic and georadar methods, contoured by black continuous and dot lines, respectively.

The GPR survey area of around 235 $m^2$ was investigated by 26 profiles 18 m long and with a line separation distance of 0.5 m. The two-way time acquisition range was of 40 ns, but after the processing the useful signals was only 20 ns, which corresponds to 1.5 m depth. In order to better interpret potential buried features, a 3D analysis has been planned using a developed GPR time slice, which required very closely spaced profiles (Goodman et al 1995; Conyers and Goodman 1997). Once the signal processes were applied to the radargrams, time slice analysis was defined. In this analysis, the recorded amplitudes of the reflections across the entire site are compared at different times to generate amplitude time slice maps.

Figure 14.21b, c show two GPR time slices where it is possible to detect two different kinds of potential archaeological features with circular (Fig. 14.21b) and linear (Fig. 14.21c) shapes, at around 15 and 30 cm depth, respectively.

The time slice of Fig. 14.21b shows two reflected zones, A1 and B1, with circular shape at high amplitude. The profile, which we do not show for sake of brevity, confirms the presence of several reflection hyperbolas due to some buried objects. In the time slice at around 0.3 m depth (Fig. 14.21c) several linear reflections are visible (see black arrows).

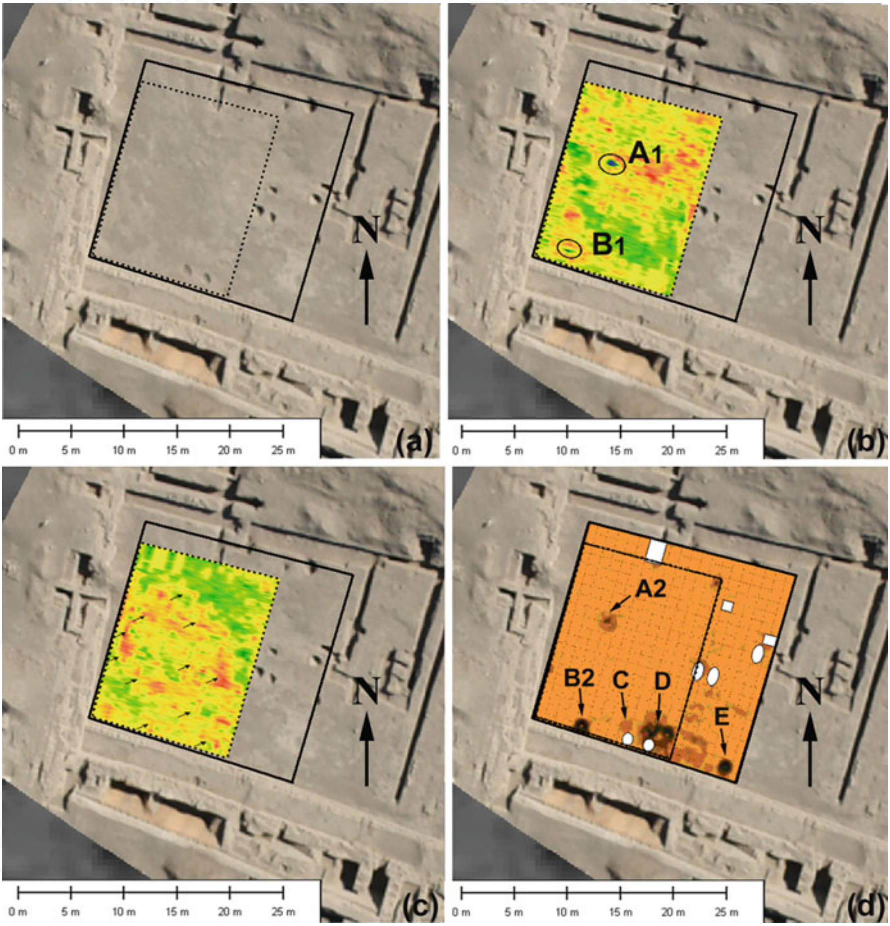


**Fig. 14.21** (**a**) The investigated area: the two rectangles with *dot and continuous line* indicate the areas investigated by georadar and geomagnetic method, respectively; (**b–c**) GPR time slices at 15 and 30 cm, respectively; (**d**) geomagnetic map

In the same area a geomagnetic map has been carried out with a gradiometric configuration. The investigated area was enlarged compared to that of the GPR survey (see Fig. 14.21a, d). The data have been acquired on a regular grid 20 m $\times$ 20 m by an interspaced line of 0.5 m and a sampling rate of 10 Hz.

The data filtered in order to obtain the best signal/noise ratio, further processed using a kringing interpolation and visualized as a shaded relief image highlighted four main geomagnetic anomalies.

Figure 14.21d shows the final geomagnetic map, where several anomalies are visible. Black arrows indicate the main magnetic anomalies and white circles and squares put in evidence pits excavated by looters. In particular the gradiometric map shows two anomalies A2 and B2, which could be correlated

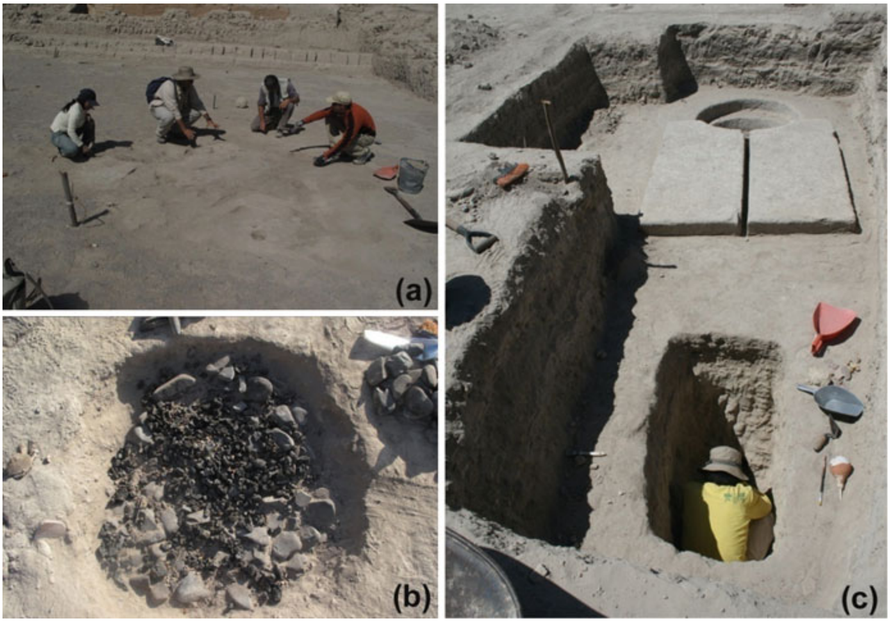


**Fig. 14.22** After the localization on site of the anomaly A detected by both georadar and geomagnetic method (**a**), archaeologists excavated thus unearthing a ritual fire (**b**). Then another excavation has been performed in correspondence of the anomaly D. The result (**c**) has been a ceremonial altar

with ones localized on the GPR time slice at 0.15 m depth, A1 and B1 of Fig. 14.21b, respectively.

Moreover, other two circular geomagnetic anomalies, C and D, are detected at X = 1.5 m and Y = 18.5 m and at X = 7 m and Y = 2.5 m, respectively. Finally, a large anomaly, E, with a regular shape is between X = 4 and 10 m and Y = 4 and 10 m.

So, two anomalies of possible archaeological interest have been detected by both geophysical methods ($A_1$, $A_2$, $B_1$, and $B_2$). Geomagnetic method shows further anomalies not surveyed by georadar (see *C* and *D* in Fig. 14.21d). Moreover, the enlargement of geomagnetic prospection allowed us to identify another anomaly, indicated as *E* in Fig. 14.21d.

On august 2009, a trial excavation was carried out in correspondence of anomaly *A* detected from both GPR and geomagnetic methods (see Fig. 14.22a). A ceremonial offering was unearthed. It was characterized by the presence of coal and remains of a ritual fire made by fluvial stones with lens shape (Fig. 14.22b). Inside several coals are well defined and covered by leaves of *pacae*.

From the archaeological perspective, this ceremonial offering was very significant, because the hearth was located below a floor dated back to the end of the phase IV (known as phase IVc) and, therefore, archaeologically associated to a platform built after the earthquake and the mudslides described in Sect. 14.1.2. The phase IV

(350–400 AD) of Cahuachi was characterized by several offerings and sacrifices, as consequence of a crisis determined by the above said devastating natural disasters which determined profound and quick changes. The discovery of this ritual fire and its archaeological implications oriented the archaeologists to conduct further analysis also in correspondence of the other anomalies indicated in Fig. 14.21d.

On the base of archaeo-geophysical results, after a month archaeologists started excavating again in this area. They focused on the zone characterized by geomagnetic anomaly D. The excavation unearthed a ceremonial altar (Fig. 14.22d) dated back to the phase IV and composed of two large platforms symmetric respect to a rectilinear groove. The latter was axial to a well characterized by a mouth composed of two eccentric circles. In the well archaeologists found four gold bars (which are likely the cause of the magnetic field change) arranged according a square shape whose centre is characterized by the presence of a shell. Additional offers, such as necklaces and animals (bird and cuy) sacrificed to the divinities were also found.

#### 14.3.2.3 Site S3

An 800 sqm plain area at North of the *Gran Piramide* was investigated by the georesistivity method (Fig. 14.23a). The survey was carried out with 1 m resolution using two different configurations of the probes which allow to provide georesistivity maps at the depths of 50 cm and 1 m. Figure 14.23b shows the geophysical system and the investigated site composed of four rectangular areas indicated with letters M1, M2, M3 and M4. Figure 14.23d shows the resistance map at 1 m depth, which visualizes low resistance values ($<300\ \Omega$) measured on a wide area, including most of M3 and M4 (at East of the map). The irregular shape does not help in identifying possible archaeological features. However the low resistivity is compatible with the presence of earthen buried walls and platforms. In the western part of the map (M1 and M2, in Fig. 14.23c, d), smaller areas with high resistivity values are evident. The latter could be related to tombs or ritual offerings.

### *14.3.3 Site S4. New Research Perspectives for the Study of Cahuachi: The Buried Settlement*

The investigations on Site S4 followed the preliminary study of test site TS3 performed by using 2002 QB2 imagery which put in evidence some features characterized by geometric shapes of possible archaeological interest (see Sect. 14.3.1). In particular the NDVI map showed more info than panchromatic and multispectral pan-sharpened images (see such features depicted in Fig. 14.11d).

This area, as well as other zones of the Nasca riverbed, were focused to study and map *puquios* (see Chap. 12) and palaeoriverbeds. Then, the aim was enlarged to the

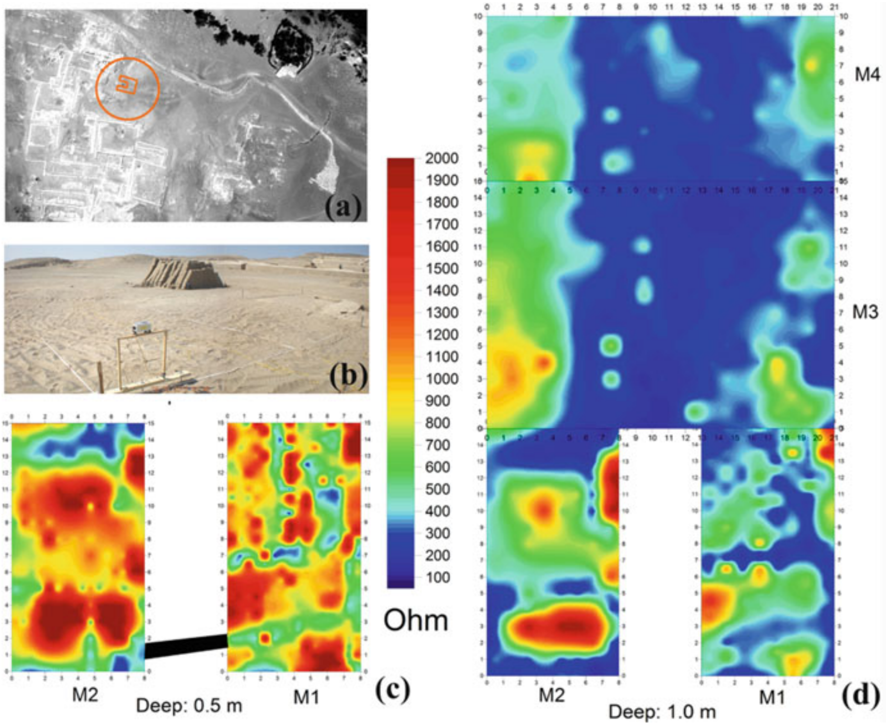


**Fig. 14.23** (**a**) Location of the study area; (**b**) the study area; (**c**) georesistivity map at 50 cm depth; (**d**) georesistivity map at 1 m depth

identification of buried settlements at the west of the pyramids of Cahuachi, in the direction of Estaqueria, where ceremonial activities moved after the abandonment of the ceremonial centre.

Some aerial photos taken in April 2007 put in evidence the presence of several damp marks, some of them related to recent buried infrastructures, other referable to palaeoriverbeds and many other features not clearly referable to the above said features. In particular, our attention was focused on an area about 2 km NW of *Gran Piramide*. Herein ceramic fragments and adobes were found.

So, another QB2 image acquired on March 2005 was selected from the Digital Globe archive and purchased. The expected result was an improved visualization of the damp mark geometrical patterns, as it really was.

Panchromatic was very effective in highlighting several features, the typical crop-marks (see Lasaponara and Masini 2007), as the site was partially covered by grass and cotton plants at the time of satellite image acquisition. Moreover damp marks characterized the bare ground areas of the site.

So, particular attention was paid to enhance such features by applying different pan-sharpening algorithms which allowed us to exploit the higher spatial resolution of panchromatic image and the spectral content of the red and NIR bands.

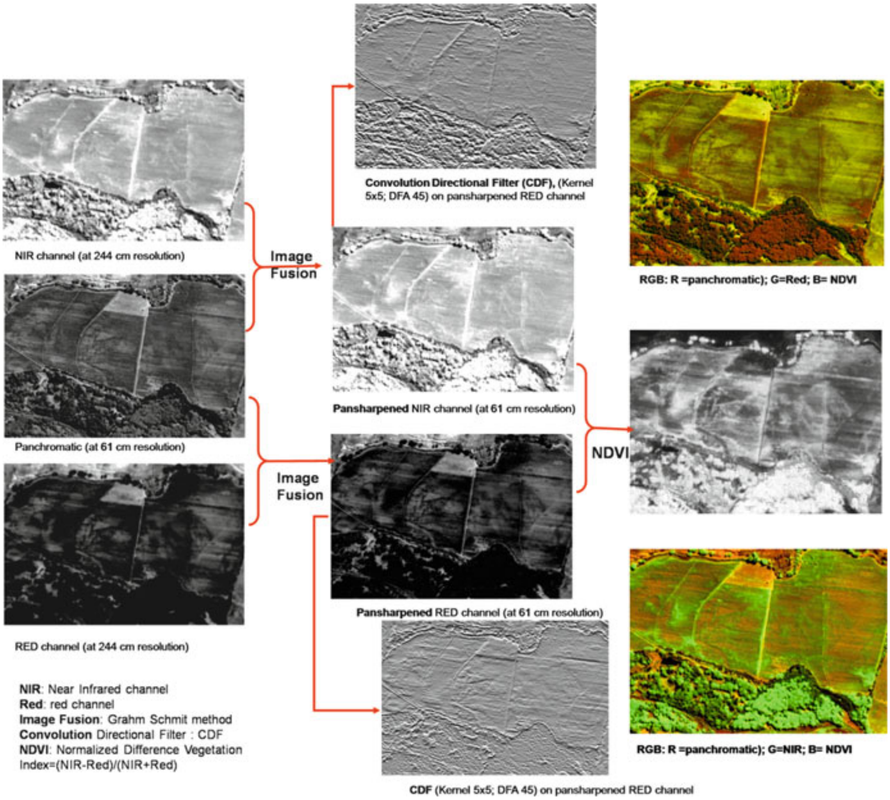


**Fig. 14.24** Site S4: satellite image processing approach adopted for the detection and reconnaissance of archaeological features

Graham Schmidt algorithm has been considered the most effective image fusion algorithm in terms of discrimination of marks, for the red and NIR band. The RED pan-sharpened channel provides the greater content of information. A further improvement has been achieved by computing NDVI, as in the case of test site TS3. Finally the edge thinning was performed by using directional filters (see Fig. 14.24).

The identification of marks reported on the RGB composition NDVI, Pan and Red, respectively (see Fig. 14.25a), put in evidence four different patterns of features named with letters A, B, C and D.

Pattern A has a rectangular shape with dimensions 100 × 90 m and an orientation of about 45° respect to the North. The shape and parallel segments inside the rectangle suggest to us that it is probably a complex of terraced platforms.

Pattern B is composed of several linear features suggesting the edges of platforms, which represent quadrangular shapes intersected by oblique lines, for a total area equal to 1 ha.

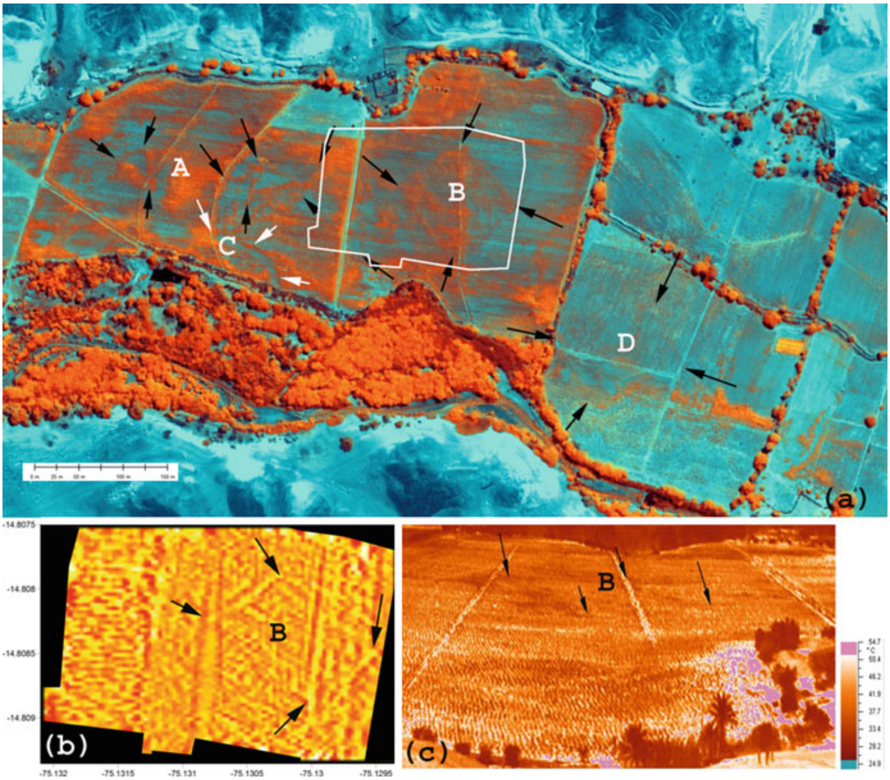


**Fig. 14.25** Site S4. (**a**) RGB satellite image composition: R = NDVI; G = pan; B = red. (**b**) Letters *A*, *B*, *C* and *D* indicate the patterns of anomalies identified. The features of pattern *B* were confirmed by geomagnetic method and (**c**) infrared thermography

Feature C is a typical palaeoriverbed which along with other similar features indicate changes of the river over time. Finally, subtle marks of pattern D, visible from RED and NDVI images, seem to reveal a quadrangular shape referable to similar buried structures to the above mentioned A.

The pattern B was investigated by geomagnetic method and infrared thermography (Fig. 14.25b, c). The magnetic prospections were carried out using GPS over an area of 2.2 ha, on 2009 August. Linear magnetic signals oriented in correspondence to the four sides of the quadrangular pattern were identified (Fig. 14.25b).

Finally, Infrared thermography (2008 November) provided thermal anomalies in agreement with the features surveyed by the processing of satellite data and geomagnetic map.

From the archaeological point of view the discovery of this buried settlement opened new perspectives of research (Orefici 2009a) and new questions regarding its function and its spatial and temporal relation with the near Ceremonial Centre of Cahuachi.

## 14.4 Conclusions

This chapter provides an overview of the results from the scientific investigations carried out by ITACA Mission in Cahuachi and in *Rio Nasca* from 2007 up to today.

The main scientific activity of ITACA focused on archaeo-geophysics based on the integration of ground, aerial and satellite remote sensing methods, thus allowing the archaeologists to find buried walls ceremonial offerings in Cahuachi and to discover a large buried settlement in the Nasca riverbed.

The importance of these investigations was to address an open issue which is the detection of buried earthen structures. Such issue is a strategic challenge as crucial as complex. It is crucial because earthen archaeological remains are widely present through the world (in South America, Asia, Africa) and it is complex due to the subtle physical contrast between earthen remains and the surrounding subsoil.

To address this challenge we investigated some test sites selected from within: (i) *Piramide Naranja*, (ii) *Templo del Escalonado*, (iii) a 800 sqm plain non vegetated area north of the *Gran Piramide*, and (iv) a vegetated area located on the opposite river bank from the known archaeological area.

These sites were investigated using integrated non destructive analyses based on VHR satellite imagery (2002, 2005, 2008), geomagnetic (November 2008, August 2009), GPR (April 2008) and georesistivity methods (August 2010).

In particular for *Piramide Naranja*, we investigated: (i) North East side, not yet excavated, using satellite data and magnetic method and (ii) eastern side, where GPR has been used to support the ongoing excavation activities. In the North East side, results from the analysis of satellite images, based on spatial autocorrelation statistics and image filtering techniques, allowed the identification of unknown shallow and outcropping adobe walls, related to terraced platforms which compose the trunk-pyramidal structure. Additional information on the presence of buried and shallow walls were provided by geomagnetic surveys. The gradiometric map enabled also the identification of magnetic anomalies linked to tombs and ceremonial offerings. In the eastern side of the *Piramide Naranjada*, GPR allowed the discovery of an unknown rich ceremonial offering, including ceramics, painted textiles, precious metal objects and painted pumpkins, which belong to the Nasca civilization.

For the *Templo dell'Escalonado*, integrated geophysical investigations (GPR and geomagnetic) performed in two different field trips captured spatial anomalies which were confirmed by archaeological excavations. In particular, a ceremonial offering and an altar were unearthed. The ceremonial offering was characterized by the presence of coal and remains of a ritual fire made by fluvial stones with a lens shape. Inside several coals were well defined and covered by leaves of *pacae*. From the archaeological perspective, this ceremonial offering was very significant, because the hearth was located below a floor dated back to the end of the phase IV (known as phase IVc) and this, according to archaeologists, indicates that the fire was the "last ritual offering" before abandoning the Pyramid.

Therefore, it was ignited a symbolic funeral ritual for the Pyramid to close the ceremonial centre.

The ceremonial altar, dated back to the phase IV, is composed of two large platforms which are symmetric in respect to a linear groove. Archaeologists found four gold bars and additional offering, such a snacklaces and animals (bird and cuy) sacrificed to the divinities.

Investigations conducted using the georesistivity method have been performed over a 800 sqm plain, at north of the Gran Piramide. The maps obtained at the depths of 50 cm and 1 m showed anomalies probably linked to the presence of earthen buried walls, and platforms and tombs or ritual offerings.

Out of the archaeological area investigations focused on the vegetated areas located on the opposite river bank to study and map puquios and palaeoriverbeds. Then, the aim was enlarged to the identification of buried settlements at the west of the ceremonial centre in the direction of Estaqueria, where ceremonial activities moved after the abandonment of Cahuachi. Some aerial photos taken in April 2007 had put in evidence the presence of several damp marks, some of them related to recent buried infrastructures, other referable to palaeoriverbeds and many other features. The processing of different VHR satellite images and magnetic maps allowed us to discover several anomalies of archaeological interest in an area about 2 km NW *of Gran Piramide*. The rectangular shape of one of the detected anomalies has been interpreted as a complex of terraced platforms. From the archaeological point of view the discovery of this buried settlement opened new perspectives of research (Orefici 2009a, b) and new questions regarding its function and its spatial and temporal relation with the near Ceremonial Centre of Cahuachi.

As a whole, our results pointed out that the use of different remote sensing technologies can open new perspectives for the detection and documentation of adobe archaeological remains, not only for the ancient Andean civilizations but also for the earthen archaeology in Middle East, Northern Africa and Asia. Earth Observation can significantly contribute to the monitoring of the fragile earthen archaeological heritage, whose conservation policies must also address looting activity.

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