LINKING REMOTE SENSING AND INFRA-SITE ANALYSIS TO THE RECONSTRUCTION OF RURAL SETTLEMENT AND LANDSCAPE PATTERNS

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Abstract. A certain dissatisfaction with the results obtained through the use of traditional methods in our landscape project has led us in the last ten years to focus our interest on the need to test new instruments and new approaches to construction of the archaeological record. The peculiarities of the south Tuscan landscape (low level of visibility and heavy clay soils) have directed us towards those techniques of remote sensing that leave a wide choice to the archaeologist in the periods for carrying out data capture. In particular we have begun to work on Ikonos-2 and QuickBird-2 imagery, on a systematic program of aerial survey and on micro-digital terrain modelling using digital photogrammetry. On the ground our infra-site analysis has been improved by applying extensive magnetic survey, differential GPS and PDA computer with mobile GIS system. Along with the development of new technologies we have continued the study of historical aerial photographs and the use of field-walking survey, both of which constitute undeniably valuable sources for the archaeological study of settlement patterns.

The results that we have obtained are encouraging and show clearly the need to use integrated sources. Source-integration now represents the prime focus of our research. Without this approach we foresee little possibility of obtaining results which will have a real effect on our understanding of the diachronic development of the settlement patterns of the region.

Keywords. Remote sensing, desktop GIS, mobile GIS, infra site analysis, magnetic survey, field walking

1 Introduction

Graeme Barker, in a well-known paper on landscape archaeology, identifies as one of the main differences between British and Italian studies on archaeological landscapes the separation in Italy between settlement and environmental patterns. His thesis maintains that the close relationship between ideas about ancient society and the environmental background in Great Britain is mainly due to the early development of aerial survey. The aerial photographs widely used by British archaeologists strongly emphasise the background context within which archaeological site belong (BARKER 1986).

In the last few years there have been changes that have at last allowed Italian archaeologists to photograph the landscape from the air and so to have at least a theoretical possibility of reconnecting the diachronic development of the environmental background to observed settlement patterns (CAMPANA et alii 2004). Almost at the same time the availability of new technologies – especially spatial technologies such as GIS, remote sensing and satellite georeferencing – have provided innovative possibilities for the localisation, integrated analysis, management and monitoring of archaeological sites (CAMPANA, FORTE 2001).

Prior to 1999 the Department of Medieval Archaeology at the University of Siena based its work in archaeological cartography on three methods of investigation: systematic field-walking in sample areas aimed at representing 20-30% of the whole landscape; the analysis of historical vertical air photographs through stereo viewing and ground-truthing in the field; and detailed surveying aimed at providing high-quality understanding of particular monuments or archaeological areas (FRANCOVICH, VALENTI 2001).

In this paper we will discuss in particular our experience with the progressive introduction of new methodologies and the problems of integrating different survey techniques in the archaeological mapping of Tuscan landscapes, specifically in the administrative areas of Siena and Grosseto.
2 The complexity of Tuscan landscapes as the background to the research design

The need to test new instruments and new approaches to surveying derives from a certain dissatisfaction with the results obtained through traditional methods. Our past work has allowed us to identify a large number of new sites and to collect new data about known sites. Notwithstanding this we still feel that we have not answered our questions about understanding the complexity that characterizes ancient landscapes, ancient settlement patterns and their reciprocal relationships. In particular some specific chronological periods, such as the Early Middle Ages, or some specific historical questions, such as the change in the location of settlement from Roman villa to hillfort, remain particularly hard to confront (FRANCOVICH, HODGES 2003). We focus in this paper on two main problems, the first one largely qualitative, the second quantitative:

- In our previous strategy there was too large a difference between the nature of the information obtained from surface collection compared with that derived from stratigraphical excavation. We clearly needed to develop our capacity to recover more detailed information without recourse to large excavation.
- The requirement to work on the basis of a limited sample, combined with the opportunity to study our landscapes from the air only through vertical air photographs, represented a strategic error that resulted in a considerable loss of otherwise detectable of sites. It was clear to us that there was a need to improve our study of the ancient landscapes in both of these respects. We have therefore turned our interest firstly to remote sensing techniques, while remaining aware of the limitations that this methodology will encounter in a countryside like that of Tuscany and in particular of the Province of Siena. Sixty percent of Tuscany is covered in forests and other areas characterized by a low level of visibility, whether from the ground or from the air (Fig.1 and Fig.2a/b). The remaining forty percent consists in great part of agricultural cultivation on heavy clay soils that are known to constitute a particularly unfavourable surface for most remote sensing techniques (Fig.2c). A second limitation introduced by heavy clay soils is that the number of years when the meteorological conditions are likely to produce good archaeological traces are even smaller than on soils above substrata such as gravel or sand (JONES, EVANS 1975).

Areas with a higher level of visibility consist mainly of the alluvial plains of substantial rivers, in particular the Arno, Ombrone, Serchio, Chiana and Orcia (Fig.2d). In some of these areas, however, other problems arise from the great thickness of the layer of alluvium and from the impact of modern industry and residential development (AGNOLETTI 2002). All these circumstances, as is already well known, have a direct influence on the results of researches based on the use of the methods and instruments of remote and proximal sensing (WILSON 2000; CLARK 1997).

This situation has directed us towards an integrated and interrelated use of those research techniques that leave a wide choice to the archaeologist in the periods for carrying out data capture, and in particular towards the study of parts of the electromagnetic spectrum not visible to the human eye (DONEUS et alii 2002; DONOGHUE 2001):

- Multispectral high-resolution satellite imagery (HSRI)

Fig.1 – Geological map and land use map of Tuscany
• Exploratory aerial survey and oblique air photography
• Digital photogrammetry
• Geophysics

Along with the development of these new approaches to the study of past landscapes we have of course continued our study of historical aerial photographs and the use of field-walking survey, which remains an undeniably valuable source for the archaeological study of settlement patterns (GUAITOLI 2003).

Riccardo Francovich

3 Remotely sensed research methods

As previously demonstrated, our Department manages regional and sub-regional landscape projects. Whatever the scale, the study area is always based on the local administrative units, which in Tuscany range in size between 40 and 450 sqkm with an average of 150 sqkm (FRANCOVICH, VALENTI 2001). In order to obtain a total coverage of areas of these dimension at relatively low cost we began in 2000 a project using multispectral imagery captured with the Ikonos satellite. The results have been encouraging, within the limits of the geometric and spectral resolution of the data. At the end of the first phase of this work we have recorded 84 features, of which 39 were new sites, in two sample areas of about 470 sqkm in total. In fourteen cases where anomalies had been identified previously through vertical or oblique air photography it was possible to add new data to the existing information. We should perhaps note two peculiarities of Ikonos-2 imagery (CAMPANA 2002a). Firstly, through Ikonos-2 we can recognise many features that were visible in early air photographs but which are no longer identifiable in those taken between 1976 and 1996. This situation perhaps derives from the inappropriate time of year in which the later photographs were taken, or alternatively from the higher sensitivity and computer enhancement capabilities of the Ikonos-2 data. If confirmed, however, this trend will indicate HRSI as an important tool for monitoring and exploring the archaeological heritage (Fig.3).

Secondly, we believe that most of the results obtained from analysis of the Ikonos-2 imagery depend heavily on the multispectral properties of the sensor. Above all the near-infrared represents the most powerful band. This band is particularly sensitive to plant health and can often detect water stress in vegetation before it can be seen by the naked eye (DONOGHUE 2001)

The following example highlights this possibility. The site in this case is in the district of Montalcino (Siena), in a zone in which, according to documentary sources, there stood from the middle of VIIth century the medieval monastery of San Pietro ad Asso. Before our research the
monastery was identified with the farm of San Pietro, which contains the still visible remains of a Romanesque building: a small church tower and several pieces of decorative stonework. All of the documentary sources, from the second half of the XIIIth century onwards, refer to a village that must have been present in the same area (CAMPANA 2004). The identification of the monastery was determined through historical photographs analysed by stereo viewing. This permitted the recognition of an abnormal hill form only 200 m from the abandoned farm of San Pietro. The ground survey produced clear evidence for shaping of the hill’s profile, with terracing along the slopes as well as round the crest of the hill. In particular, on the topmost part on the northern side there is a considerable spread of walling, perhaps attributable to fortification works.

Analysis of the same area, carried out on panchromatic aerial photographs from 1954, 1976, 1994 and 1996, revealed numerous features while oblique photographs taken during exploratory aerial survey in 2001 confirmed the presence of many anomalies. A magnetometer survey of the hilltop provided us with the possibility of mapping other archaeological features. The Ikonos-2 imagery uncovered further evidence of linear anomalies in farmland adjacent to the site, notably rectangular features and an anomaly on the top of a hill about a kilometre from the monastery.

Some particular anomalies look very interesting. These lie near the farm of San Pietro in the area where the data from surface surveying inclines us to identify the documented late medieval village of San Pietro. In this area the air photographs do not show the danger of the missing. It is very interesting to see that only the near-infrared band of Ikonos-2 imagery permits the identification of two square features that ground survey allowed us to associate with buildings of the medieval village. Bands blue, green and red in this case are entirely unproductive (Fig.4).

Despite these promising early results the true potential of this type of imagery is still not fully clear and needs to be further evaluated to test its effectiveness under a broad range of environmental conditions.

A real limitation of the Ikonos products turned out to be the great difficulty of achieving with precision the desired capture time. The commercial strategy of the Space Imaging Corporation is to make the priority ordering of images at the particular time required by the consumer extremely expensive. Since we did not have sufficient money to pay for the priority option the images ordered for the last week of May or the first week of June were not actually captured until the middle of July, a month which in our latitude corresponds to a very poor period of the year for the recording of archaeological traces.

In spring 2002 we started testing three samples of Quickbird-2 imagery, two for the province of Siena and one near the coast in the province of Grosseto, to a total extent of about 200 km² (Fig.5). On the basis of our experience with Ikonos-2 we focused our attention on two main problems: geometric resolution and best capture time.

Even though it has been possible to distinguish some small features through Ikonos-2 and to identify a first range of detectable site size we feel it necessary to stress that there is still a risk of misinterpretation. When we captured Quickbird-2 imagery we acquired both the multispectral and the panchromatic data. Pan-sharpening of the four multispectral bands using 0.7 m panchromatic image was then carried out to improve the spatial resolution. In this context it should be noted that a pixel of Ikonos-2 multispectral imagery corresponds to 32.65 pixels of Quickbird-2 pan-sharpened data (Fig.6). Our first impression, looking at the Quickbird-2 imagery, is that most features of the landscape can be easily and unambiguously recognized in this source of data.

In relationship to the second problem, the Ikonos-2 imagery was captured in July, though we would have preferred the end of May. The QuickBird-2 imagery was
captured after a delay of “only” 15 days from our preferred time, though this was probably enough to result in some significant loss of sites. There were two extenuating circumstances. Firstly, we did not consider the possibility of submitting a priority order (at a 50% increase in price) which would have given image capture within a maximum of five days from the specified date. The second was a typical problem of satellite imagery – though one not so significant in the Mediterranean region – that of poor weather conditions.

Our study of the Quickbird-2 imagery is still in progress and we do not yet feel able to present a fully considered report. However, our impression at this stage is that many of the limitations that we found in using Ikonos-2 imagery will be overcome with Quickbird-2 and that with the priority option of QuickBird it will at last be possible to achieve the right capture time for archaeological needs (CAMPANA 2002b).

As we anticipated, the analysis of satellite imagery does not entirely remove complexity from the study of ancient landscapes and in particular of complex territories like Tuscany. For instance many of the archaeological discoveries that we made during field survey or in examining vertical air photographs are not visible on the satellite imagery.

For these reasons we started in 2000 a programme of aerial survey averaging 35 hours of flight per year (Fig.7), focused on the end of May and the beginning of June (CAMPANA 2001). The use of exploratory aerial survey in Italy has only become possible in recent years following legislative changes, but in many other countries of northern Europe it is a method with a long tradition of application.

In ideal conditions this technique offers an extraordinary contribution to the search for new sites and for the continuous monitoring of the cultural heritage (Fig.8). From our short experience of the technique we can point to the flexibility of the method in allowing us to respond to the development of archaeological traces with extreme rapidity and therefore to be in a position to observe the landscape and document the archaeological information at the most appropriate time for each individual year and
each geographical area. In the air the archaeologist is free to choose conditions of lighting that range from soon after dawn to almost sunset (CAMPANA et alii 2004).

The detail of the acquired information is remarkable and, despite the strong distortion of oblique images, the spatial information can be corrected using algorithms developed by Professor Irwin Scollar (Fig. 9), mapped and integrated into our archaeological GIS (HERZOG, SCOLLAR 1989; SCOLLAR 1998; DONEUS 2001). Currently at the University of Siena we have collected an archive of about 10,000 oblique air photographs, recording just under 1000 archaeological sites of widely varying types. We wish to emphasize here our view that oblique air photographs and satellite imagery are not in conflict with one another. Apart from the obviously varying degree of detail, the satellite images provide a total, continuing and objective view of the whole of the land surface within the chosen survey area. By contrast, every oblique aerial survey is dependent on the environmental conditions of the moment and is influenced by the experience of the individual archaeologist in choosing which parts of the landscape to document.

Along with the development of new methodologies we are of course continuing our study of historical aerial photographs, which have an importance which we think it unnecessary to emphasize here (PICCARRETA, CERAUDO 2000; GUAITOLI 2003). We are thinking particularly in this regard of the photographs of the Institute of Military Survey from the 1930s to the 1950s, along with the regional coverage of the 1970s. Our work has been concentrated on the mapping of the anomalies recorded in the last 20 years of activity and on repeated analysis of the images using traditional stereo viewing, digital image processing techniques and in recent months of a digital photogrammetric workstation. The availability of this last instrument has proved extremely useful for the precise mapping of vertical air photographs, as well as for the next research step, the collection of data useful for infra-site analysis through the medium of detailed micro-topographic maps and photogrammetric digital elevation terrain models (WHEATLEY, GILLINGS 2002).

The mapping of all the information recovered from satellite imagery and from vertical and oblique air photography represent the main result of this strategy (DONEUS et alii 2002). This operation allows us to create detailed georeferenced layers of the sub-soil features that, as we will see in the following section, greatly enrich the data at our disposal and consequently our reconstruction of the archaeological record (Fig. 10).

4 Mobile information technology, fieldwork research methods and problems

Before discussing our work in the field we should emphasise that from the second half of the 1990s, when in Siena as in the rest Italy we began to use Geographical
Information Systems for the management of archaeological data, we have felt a progressive disjunction between work in the laboratory and work in the field. While the availability of advanced technologies has continued to grow, activities in the field have continued to make use of instruments and methodologies developed in the 1970s. A first real improvement for us came with the introduction of GPS measurement in field survey and in last the two years with the testing of mobile GIS systems (RYAN et alii 1999; CRAIG 2000).

In 2002, during work on the archaeological map of Siena, we gained our first experience with the use of the PDA computer. We started from a Compaq iPAQ on which we had installed the corresponding versions of the software used in the laboratory: ArcPad 6 as graphical interface with the geographical data and FileMaker Mobile as Data Base. In order to be able to work with satisfactory
precision we used as our GPS device the Trimble Pathfinder Pocket with the appropriate GPS software to allow differential correction either in post-processing or in real time (via telephone links to the reference station in the Department at Siena). This system has allowed us to insert in the PDA all the data that we required and therefore to take into the field as much information as was formerly accessible to us only in the laboratory (Fig.11). Specifically the main application and the improvement of research in the field can be summarized as follow:

- real time access to a large selection of the information stored in the data base and GIS;
- capacity to integrate topographical, thematic and historical maps, aerial photography, satellite imagery and geophysical data;
- quick, easy and accurate navigation to any target whose coordinates are known;
- the opportunity to make direct and accurate real time comparisons between past survey data and the actual situation observed in the field, for instance in monitoring changes of land-use or the movement of artefact scatters, etc.;
- significant savings of time through the use of software for the downloading into the server of data collected in the field;
- the availability of a device that “connects” real landscapes (the material world as observed at a precise moment in time) with the digital representation of past and present countryside.

In our experience the integration between PDA and GPS represents for archaeologists (and more generally for earth scientists) an extremely powerful instrument able to transform the practice, quality and strength of our work in the field in the same way as happened more that 15 years ago with the arrival of desktop personal computers in the laboratory. The technological merging between PDA and GPS goes far beyond the level of increased fieldwork efficiency, in at last making possible the systematic application of strategies and methodologies developed in the past but applied only rarely before now because of excessive amount of time involved in their use (ORTON 2000). One may think here, for instance, of the georeferencing of every single object or the collection of artefacts organized into predefined grids, etc. (Fig.12).

We are totally convinced about the iPAC system as information vehicle, although the fragility, bulkiness and physical complexity of the instrument greatly limits its use in the field. In our field survey during 2003 we changed to use of a Trimble GEO XT. Although this still has some hardware limitations it has turned out to be totally satisfactory in almost restoring the link between analysis of the data in the laboratory and similar activities in the field (Fig.11).
The activities of field-walking are aimed at the systematic investigation of areas determined through a combination of probabilistic and non-probabilistic sampling strategies (Campana 2001) and at the verification of the remotely sensed evidence (Fig. 13).

In the last 25 years of field-walking about 9000 sites have been detected in the provinces of Siena and Grosseto (Francovich, Valenti 2001; Carandini et alii 2002). Field survey constitutes therefore an extremely important source for the archaeological study of settlement patterns but the collected information often turns out to be incomplete, confused and difficult to interpret because of post-depositional processes in the field (Boismier 1997).

We should take account of the progressive degeneration of many of the surface finds due to more than half a century of ploughing, vineyard and olive cultivation. Many years ago Tim Potter wrote about this subject in his “The Changing Landscape of South Etruria” underling how from the beginning of the 1970s the ideal moment for this kind of studies has been finished (Potter 1979).

Our experience in Tuscany shows that progress in the development of interpretation methods for surface evidence has given us the possibility in the last 25 years to carry out successful programmes of field-walking with an acceptable degree of uncertainty (Valenti 1989; Fentress 2002). In the last survey the trend definitively show a changing in the relationship between surface and sub-surface archaeology. We realized that it is more and more rare to achieve to satisfactory interpretation of surface remains and in some cases the process of collection within carefully predefined grids is no longer sufficient (Fig. 12). This situation could arise, as already shown by authors in other study areas, from the total destruction of the once-present archaeological stratigraphy. In addition, there are at least two other scenarios which could produce on the surface a similar absence of findings.

Firstly there is the possibility that over last fifty years the plough has worked almost always at the same depth, so that most of the surface finds have been completely destroyed. Beneath this “usual dept” of ploughing, however, it may be possible to identify of other archaeological remains not corrupted by ploughing. A second hypothesis could be related to the trend towards a reduction in the depth of ploughing as promoted, from the 1990s onwards, by the European Community with the objective of the better conservation of soil fertility.
(AGENDA 1996). In both cases the presence of surface remains would be very poor. The key issue for us is represented by the difference between the complete destruction of archaeological stratigraphy and problems related to the depth of ploughing. If the archaeological record has been totally destroyed the archaeologist has no opportunity to make worthwhile observations. The second option, associated with the depth of the plough, reduces the applicability of field-walking methodology, directing research instead towards test excavation or remote and proximal sensing techniques for the analysis of the sub-surface remains.

5 The relationship between cropmarks and surface remains, and vice versa

After describing these phenomenon it will be more clear a recurrent problem we find in the field. Visible traces detected through the analysis of remote sensed data do not correspond to the presence of dense or well-defined scatters of archaeological material in the field (Fig.14). Due to other causes but equally frustrating is the inverse occurrence, when the satellite imagery and/or the vertical and oblique air photographs do not help us to supplement the information gained from the recording of extensive scatters of ceramics or other materials in the field (Fig.15). Considering that the minimum scale at which we operate is the local administrative area, with an average area of 150 sqkm and that the situations just described occur on average between ten and twenty times per administrative...

Fig 14 – Case where didn’t find relationship between remotely sensed data and surface collection

Fig 15 – Relationship between: surface collection and remotely sensed data, surface collection and magnetic survey data (in all the pictures the red areas delimited surface findings)
district we cannot hope to address the situation through systematic test excavations. Moreover we have to consider the bureaucratic difficulty of asking for permission for each excavation from the Italian Office of Heritage Conservation. In the last two years we have focused our attention on this topic in order to overcome or at least to reduce the consequences of this problem. The first attempt took the form of experiments with magnetic survey of a kind related to our particular requirements.

In addition to the well known diagnostic characteristics of magnetic survey methods (PIRO 2001) this technique satisfies one of our fundamental needs: the capacity to cover large areas in a limited time (POWLESLAND 2001). In a field survey carried out in Val d’Orcia during the last months of August and October 2003 we progressively tested a system of acquisition that allowed us to cover one hectare per day at a resolution 60 cm along traverses which were each set 1 metre apart.

The mapping of magnetic surveyed areas has been accelerated by recording the geographical coordinates of the corners of the grids through a sub-metric dGPS (PDA Trimble XT). So far we have acquired only 10 hectares of data but the general trend of the results seems to confirm that the degree of detail, although not very high, is sufficient to show with a good approximation the position of the main features, depending on the characteristics of the material to which the magnetometer is reacting. This pattern of acquisition will allow us to contemplate the future acquisition of approximately 20-40 hectares per year, an area perfectly compatible with our research requirements.

In several cases we were able to improve the resolution by means of a sampling interval of 25 cm along traverses set only 50 cm apart. We can take as an example the case of Pieve di Pava in the community of San Giovanni d’Asso (province of Siena) where we acquired 2 hectares of data at a resolution of 1 metre between traverses and then reduced the resolution to 50 cm in order to make a comparison (Fig.16).

While there is undoubtedly an enrichment of the data and an improvement in the definition of the shapes of features the way in which the archaeologist carries the equipment leads to lateral oscillations that at a resolution of 50 cm introduce significant elements of noise. At this stage of the work in progress we are testing two different solutions, a wheeled trolley to transport the sensor and the application of a specific algorithm in the post-processing of the data (HERBICH 2003).

The site of Pieve di Pava represents for us an important case study bearing in mind that between June and July of

Fig.16 – Mapping process of the whole archaeological record (a – the red areas delimited surface findings; d – magnetic anomalies) and example of increasing of the resolution of magnetic survey (b and c)
2004 we will be undertaking an archaeological excavation at this site. The excavation represents for us the first chance to verify and compare the gradiometric data with the observed stratigraphy. Obviously in the last month we intensify our activity on the site by testing a wide range of different parameters of the instrument and of the capture-resolution in order to collect a large amount of data. In the immediate future we need to make use more and more often of the practice of small test excavations on different site to improve our experience. As has already been established this approach is essential to reconcile, at least to some extent, the different kinds of information given by gradiometer survey and excavation evidence, allowing us to achieve a better overall understanding of our data.

6 Conclusions

A common risk in archaeological research on the use of technology in the study of the cultural heritage is the obsessive pursuit of the latest technological device or software. In this short review of our work and our experience during the past five years we have tried to show that the progressive integration of survey techniques directly matches the requirement to answer specific historical or archaeological questions. This approach has allowed us to define some research strategies for a better understanding of the past. In this context we must stress that we are not seeking to define standardised methodologies for site detection and data collection. We are aware of the risk of forcing data into predetermined descriptive frameworks that are generally for the most part unrelated to any particular historical question or concern (Boismier 1991). On the other hand we have needed to improve the range of methodologies and techniques at our disposal in order to apply each time different ways of meeting differing archaeological problems and different environmental backgrounds. Our challenge concern the application of techniques and instrument using different parameters and related combinations to answer differing archaeological questions. We insist that these efforts are inevitably conditioned by the physical context in which we operate and are always closely conditioned by the kind of historical and archaeological questions which we wish to answer in our investigation of the landscape.

On the basis of our present experience we are firmly convinced of the advantages of using integrated sources and technology. Even in favourable areas such the Tavoliere in southern Italy, or in lowland Britain or parts of central and eastern Europe such as Hungary and Poland, it has been demonstrated that there are significant advantages in the use of integrated techniques (Powlesland 2001; Grosman 2000; Doneus et alii 2002; Gojda 2002). This strategy become even more obvious in less favourable contexts such as Tuscany, and particularly in the Province of Siena and the hill-country of Grosseto (Campana 2002c). Without the integrated use of multi-sensor approaches we can rarely hope to achieve results which will have a real impact on the search for a better understanding of the development through time of of regional settlement patterns.

Stefano Campana

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