The future appears bright for the landscape archaeologist as we are entering into a period that will see enormous advances in our understanding of archaeological landscapes. New technologies, some still in their toddler state, if not infancy, will increasingly provide landscape archaeologists with currently unimagined levels of detail regarding human exploitation of landscapes over time. Some survey and mapping techniques such as earthwork surveys and oblique aerial photography, mainstays of archaeology in the 20th century, while still contributing, will take their rightful role as complementary elements in what is becoming GIS-based research spaces dominated and underpinned by geophysical, geochemical, and laser altimetry and hyperspectral imagery data, the last two collected from varying altitudes and platforms. This chapter tries to assess what these technologies are currently contributing to landscape archaeology, as well as their future potential.

What is clear at the outset is that what has been done to date will increasingly be seen to be paltry in comparison with what will come. For example, all the archaeological geophysical surveys ever undertaken in the United States up to the year 2000 amounted to less than the number undertaken in just one year in the United Kingdom (Kvamme 2003), where it still continues at similar rates. And it is not just that more geophysical surveys will be undertaken in the future as prices of specialist equipment drop in real terms and become more widely available; it is, rather, that year after year increasingly larger contiguous areas are being covered, and so for the first time total coverage of individual landscapes, at least by magnetometry, has become a viable proposition (cf. Gaffney, Gaffney, and Corney 1998; Gater 2005).

This great increase in detailed coverage is due to improved survey technology employing multiple sensors for increased resolution and/or coverage and multiple sensor-type platforms allowing, for example, ground-penetrating radar (GPR) and earth resistivity to be undertaken simultaneously (e.g., Leckebusch 2003). When such extensive geophysical surveys are combined with the high coverage rates and ease of repeatability of multispectral airborne/satellite techniques, we will be in a position to have the consistent and broad spatial and temporal coverage required to enhance major programs of landscape analysis that decades of conventional approaches have struggled to provide (Donohue 2005:558). Despite this potential, the failure to incorporate multispectral imagery survey in the techniques section of the recently published research agenda of a World Heritage site (Downes, Foster, and Wickham-Jones 2005) seems rather out of step with current knowledge, with only conventional film aerial photography being
Chapter 55: Noninvasive Subsurface Mapping Techniques

included (Brophy 2005), so awareness may be an issue. Therefore, one major aim of this chapter is to raise awareness of the complementary nature of these technologies and so promote a more integrated approach to their use.

The landscape archaeologist has always been able to obtain information from surface scatters, shovel and test pits, standing earthworks and structures. However, much information is now obscured from immediate view either by virtue of being buried or simply because the scale is such that remnants of features and structures surviving within the modern landscape can be identified and mapped effectively only from an elevated viewpoint. Therefore, this chapter also reviews the potential of these techniques, which allow landscape archaeologists efficient access to information that cannot otherwise be obtained without recourse to extensive excavation combined with extensive and highly intensive surface surveys. It cannot, and does not, intend to provide an introduction or manual for the practical use of the individual techniques, and the reader should follow up the sources cited and where possible collaborate with experienced practitioners when employing any in a landscape project.

**Development**

For present purposes only, a condensed history is required to contextualize the different strands. The reader is directed to Gaffney and Gater (2003), Heron (2001), and Giardino and Hayley (2006) for recent concise histories of geophysical survey, geochemical prospection, and airborne/satellite remote sensing, respectively, which are the sources for the following material in this section.

The archaeological survey utility of geophysical phenomena was recognized in the late 19th century when "bosing" (an acoustic prospecting technique involving hammering the ground) was successfully used to detect unseen ditches on chalk downland in southern Britain. However, it was half a century later, in the 1940s, before technology was harnessed to create the first successful electrical surveys of archaeological sites, followed a decade later by the first magnetic surveys. Electromagnetic (EM) techniques were also added to the armory of archaeological geophysics at the same time, although the specific EM variant that is ground penetrating radar was not employed for archaeological work until the 1970s. Despite this early work, the frequent and widespread use of geophysical survey had to wait until the 1990s, when more efficient systems became available, equipment to process the data became widely available. Current advances that are affecting data collection methodologies are the use of global position systems (GPS), mechanized rapid coverage systems, and multisensor platforms.

Aerial photography, despite being early 20th century and so later in origin, developed rather more quickly but only began to make a significant contribution after the Second World War, with the increased availability of suitable aircraft, camera equipment, pilots and resources dedicated to the technique in the United Kingdom. Initially utilizing visible spectrum black-and-white panchromatic film, both color and false-color near-infrared film were increasingly used, followed by aircraft becoming platforms for a range of multispectral digital sensor systems together with radar and laser altimetry. Satellite imagery had to wait until the Space Race of the 1960s and 1970s, and although data from early systems such as LANDSAT were applied to archaeological applications, it was really the turn of the new century that saw the release of higher resolution declassified intelligence imagery and the introduction of a new generation of high-resolution multi- and hyperspectral systems that have much greater potential for archaeological applications.

**The Techniques as a Group**

As stated above, this short chapter cannot even begin to cover each technique from a technical stance in the depth required to become competent to employ these in practice. That said, it is not an approach the author would wish to take anyway, because a rather more overarching discussion reviewing these techniques together in terms of what they can and, in practice, do contribute to landscape archaeology in combination is what is missing from the current literature. This chapter thus provides an opportunity to address this deficiency, filling a gap in the landscape archaeologist's essential knowledge base.

Forming such an overarching view can be difficult to achieve given that non-invasive subsurface mapping, aerial imagery, and satellite imagery are so distinct in terms of the skill and knowledge base required to use each effectively, and more importantly, the differing types of evidence—and so the contribution to landscape archaeology that each makes (or potentially could make). The result of this situation is perhaps inevitable, in that it is hard to find general texts that integrate these specialist techniques effectively. For example, Bowden (1999) primarily focuses
include a short chapter on aerial photography together with an even shorter chapter that covers geophysical survey and surface collection, grouped together as “other” survey techniques, but it does not consider satellite and airborne multispectral imagery. Similarly, one of the latest texts to be published—entitled Remote Sensing in Archaeology: An explicitly North American Perspective (Johnson 2006)—is almost exclusively a study of ground-based geophysical survey methods, with only one chapter to cover all airborne and satellite remote sensing (see also David 2006 for a recent broad survey that also covers underwater techniques). Although this source should be praised for integrating all these techniques together in one volume, as with Bowden’s (1999) volume focusing on earthwork survey, the book’s purpose, and so outcome, cannot be considered a balanced worldview of the techniques covered taking the amount of literature on airborne and satellite techniques now available. In fact, considering that any grouping of techniques in relative isolation of other techniques is counterproductive; full integration of all the relevant data must be the aim. Remote sensing results that are not combined with data from alluvial, colluvial, and aeolian overburden surveys may well be flawed to an unknown extent (e.g., Powlesland et al. 2006).

Unfortunately, it is not simply that the literature fragments all of these specialist areas, and in the process fails to assist in bringing them together in the service of landscape archaeology. Archaeological organizations need to ensure that the full range of disparate landscape survey techniques and approaches are consistently and effectively integrated into major landscape investigation projects.1

**Choice of Technique and Survey Methodology**

The selection of survey techniques and survey methodologies to meet the aims of a particular landscape project can be problematic. The approach of providing tables or simplistic guidelines for the application of these techniques may lead to inappropriate techniques being employed; at the same time, adhering to rigid standard operating procedures (SOPs) inevitably stifles innovative approaches. While such an approach has been taken in the past for geophysical survey in a commercial archaeological assessment context (David 1995), Schmidt (2002) stresses that although there are scholarly sources and published guidelines, be employed at all stages, particularly since any of the techniques covered in this chapter will be but one element in a much wider program of work. Schmidt then lists the most important variables that determine the choice of geophysical survey technique (Schmidt 2002: 9). To encompass all the techniques covered in this chapter, an adaptation of this list of variables that should be considered is suggested to be

- the survey objectives;
- archaeological questions;
- previous remotely sensed evidence and results;
- current land-use;
- former land-use;
- underlying solid and drift geology;
- other local geomorphological and topographic factors;
- degree of access to the land;
- time, money, personnel, and equipment available for the survey.

In many situations, such desktop evaluations need to be followed by pilot studies or other methods of assessment based on field results. Powlesland and associates (2006) describe the use of “reference fields” where crop marks form on a regular basis and so provide a check on crop-mark responses obtained using conventional oblique aerial photography. The approach highlighted gaps in otherwise extensive and contiguous crop-mark complexes that required investigation using multispectral imagery and geophysical techniques.

For the discussion of the individual techniques, they have been grouped into the ground-based noninvasive subsurface mapping techniques followed by the remotely sensed imagery techniques that use airborne and satellite platforms.

**Ground-Based Noninvasive Subsurface Mapping Techniques**

Ground-based noninvasive subsurface mapping techniques can be divided into geophysical and geochemical techniques.

**Geophysical Survey**

The most important techniques for landscape survey are, in order of importance, geomagnetic (magnetometry and topsoil magnetic susceptibility), geoelectrical (earth resistivity and electrical conductivity), and topsoil magnetic susceptibility (magnetometry and topsoil magnetic susceptibility), geoelectrical (earth resistivity and electrical conductivity), and topsoil magnetic susceptibility (magnetometry and topsoil magnetic susceptibility).
imaging), and electromagnetic, which includes georadar (ground penetrating radar). The techniques are described in a broad survey of the specific methods and their archaeological applications in Gaffney and Gater (2003), with further detail in Clark (1996), Scollar (1990), and Becker and Fassbinder (2001) for magnetometry specifically; and, for ground penetrating radar, Conyers (2004). The quarterly journal *Archaeological Prospection* is now the main source for more detailed technical research into archaeological geophysical survey, although this journal also includes papers on airborne/satellite imagery and geochemical survey. Geochemical survey, usually considered separately as it is here, has a very close association with geophysical survey, especially regarding magnetic geophysical effects resulting from the variations in iron oxides that arise from inorganic and organic chemical processes. There is also a close affinity between those geophysical methods that exploit differences in moisture content (for example, earth resistivity) and crop-mark/parch-mark aerial photography, which also exploit such moisture differentials.

Unfortunately, the take up of geophysical methods and their application is quite variable across the profession when considered globally (see Kvamme 2003: 436, and cf. Cheetham 2005). This inevitably results from both a combination of the differing starting points and pace of development, and so expertise and directions in different countries, but also the actual relationship between geophysicists and archaeologists. This can vary from a very high level of integration with highly experienced professional archaeogeophysicists—in the United Kingdom both have been working as one since the 1950s (Clark 1996: 16–20)—or with science-trained archaeologists leading projects, to more of a service situation with aerial and satellite imagery, and the one where all traces of former landscape features have been erased that geophysical survey results in situ-focused approach may still predominate. This is often simply because of the effort required to conduct large-scale geophysical surveys, and the starting point is inevitably an identifiable site of some nature. However, there have been some quite amazing feats of manual survey that have broken the tyranny of site focused survey: 1,000 hectares have now been surveyed during work in the Vale of Pickering in the United Kingdom (Lyall 2006), and the “landscapes” of entire ancient towns and cities are now almost routinely being revealed to us by geophysics (e.g., Gaffney et al. 2000). These large area geophysical surveys allow the challenging of basic ideas about the density and the character of activity that could not be addressed previously (e.g., Powlesland et al. 2006).

What is peculiar about geophysical survey (and also with respect to some phenomena detectable with aerial and satellite imagery), and the one reason archaeologists so enthusiastically use it, is that it can discover archaeological traces where there are no visible surface indications because the archaeology has essentially been erased from the landscape. This may seem obvious, but it can be considered from a slightly different perspective. Although geophysical survey can be used in situations where standing remains exist, it is in situations where all traces of former landscape features have been erased that geophysical survey results raise interesting questions about past landscapes. For example, during large-area magnetic surveys to investigate the landscape around the multiperiod site at Billown (Isle of Man; Cheetham and Stocks 2004; Cheetham et al. 2000), a large and currently largely featureless pasture field produced evidence for a number of periods of landscape use (Figure 55.1). What is striking is that this is not seen to be the adaptation over time of one system but appears to be the total erasure of one system replaced by another. Although modern destruction and organization can be put down to the practicalities of modern, mechanized intensive cultivation, this would seem not to be the case in the past. What would possess a past occupier of this area to fill in hundreds of meters of ditches and replace them with an equal length of new ditches on a slightly different alignment? Something required a change on a vast scale that must be related to how people studied the wider landscape. From a landscape archaeological perspective, little has been written specifically about the peculiar nature of geophysical evidence; and, as with many archaeological prospection and detailed investigation techniques, although there has been a recognition that off-site survey is desirable (Gaffney and Tingle 1984), a site-focused approach may still predominate. This inevitably results from both a combination of
Figure 55.1  Ballahot, Isle of Man. This magnetometry (fluxgate gradiometry) survey of the largest field on the Island reveals an unexpectedly dense palimpsest of archaeological landscapes from the prehistoric to recent past. Of note is that the extensive ditched systems running NW to SE in the center NW of the plot seem to have been replaced by a similarly extensive system on a slightly different alignment. As it was in this case, sometimes only geophysical survey can reveal and document effectively such long-erased and large-scale events in the exploitation of past landscapes. The field has not produced any evidence from other forms of survey that would suggest such a complex landscape history (courtesy of the Billown Neolithic Landscape Project, Bournemouth University).
they inhabited. That this happened a number of times is the most compelling evidence of the effort that people will go to acculturate the landscape to their satisfaction. No other approach demonstrates this as effectively and consistently in its results as geophysical survey does, time after time. In contrast, surveys of just the surviving earthwork may provide a very distorted and partial picture of past landscapes and be particularly poor at evidencing landscape change where that change has obliterated any upstanding evidence, if it ever existed.

**Magnetometry**

The technique of magnetometry (Becker and Fassbinder 2001) is the technique of choice for large-scale landscape survey. In the context of the use of lightweight fluxgate gradiometers, it was regarded as “the workhorse—and racehorse—of British archaeological prospecting” (Clark 1996: 69). Today large multiple sensor platforms, the latest of which is the vehicle-towed superconducting quantum interference device (SQUID) sensor systems (Schultze et al. 2005 and Figures 55.2 and 55.3), are providing rates of coverage at spatial resolutions and sensor sensitivities unimagined a decade ago (Merali 2006). The great strength of magnetometry is not, however, just the rate of coverage attainable (multi-antenna GPR can also provide high rates of coverage at high traverse resolutions—e.g., Finzi, Francese, and Morelli 2005) but the wide range of types of archaeological features and deposits that the technique responds to in the context of landscape archaeology. So effective is it as an archaeological prospection technique it has been described by one practitioner as “Nature’s gift to archaeology” (Kvamme 2003).

**Figure 55.2** Magnetometry, which has always been the most rapid ground-based archaeological geophysical survey technique, can now be undertaken at speeds of up to 30 km/h. The sensors employed here are superconducting quantum interference devices (SQUIDs) configured as a pair of gradiometers on a cart system that can be either manually or mechanically propelled (note the space for a third gradiometer not yet fitted owing to the high cost of these sensors). The tiny sensors are mounted in flasks that hold the liquid helium required to achieve the low temperature needed for the SQUID sensors to operate (courtesy of the Department of Quantum Electronics, IPHT Jena, Germany).
Magnetometry is a passive technique that measures anomalies in the Earth’s magnetic field caused by archaeological features having differing magnetic properties to the natural background. The causes of these magnetic differences are varied but often result from burning, whereas the instruments that can be used to detect and map them are also varied in cost, sensitivity, and ease of use. Vertical gradiometers (two sensor instruments) with sensor separations of 1 m or less filter out deeper geological and larger geomorphological features (but have problems mapping thin shallow deposits—see below) and so focus on shallow substantive remains that result from the processes of magnetic enhancement (both natural and anthropogenic) and the redistribution or \textit{in situ} formation of magnetically enhanced deposits that are or become the fills of pits, ditches, gullies, post holes. Burning, such an aspect of many domestic, ritual, and technological practices and processes in preindustrial societies, contributes greatly to this magnetic enhancement and extends the range of detectable substantive features to hearths, ovens, kilns, furnaces, and the locations of bonfires, pyres, and structures destroyed by fire. In terms of landscape archaeology, magnetic survey can show where agriculture was undertaken by mapping field systems and can detect the grain pits and silos that food was stored in and the hearths and ovens where food was cooked, within the buildings in which it was consumed. It can also help to identify (for example, salt production, ceramic production, and metallurgy, the latter an agent for more widespread landscape change owing to deforestation resulting from charcoal production).

**Topsoil Magnetic Susceptibility**

Where activity in the landscape does not involve the construction of structures, it may still result in the anthropogenic magnetic enhancement of the immediate topsoil over areas of occupation. Topsoil magnetic susceptibility survey, although subject to many limitations, can provide a rapid coverage of large areas in order to target more intensive surveys either by using specialized instruments or the in-phase mode of electromagnetic conductivity meters. Figure 55.4 demonstrates how a 10-m sampling interval field coil surface topsoil magnetic susceptibility survey has delimited an area of strong enhancement that magnetometry and earth resistivity have been able to resolve into detailed archaeological features of a Roman villa and its surrounding enclosures.

Despite its successes, magnetic survey does have substantial limitations. Magnetic susceptibility enhancement requires longer periods of intense occupation to develop, and so short-lived or non-settlement sites (for example, ritual structures such as mortuary enclosures) may not show up unless there is a strong natural topsoil subsoil magnetic contrast. An excellent example of the limitations
Figure 55.4 Pillerton Priors, U.K. Geophysical techniques, like many other landscape prospection techniques, are often found to be complementary, but some have higher rates of coverage and so are more appropriate for initial assessment with less rapid techniques being employed selectively to target specific classes of evidence. In this example, topsoil magnetic susceptibility surveys at 10m reading intervals (A) have located an area of magnetic enhancement that has been further investigated with magnetic gradiometry (B) and finally earth resistivity (C) to locate and map enclosure systems and stone buildings respectively (reproduced with the permission of David Sabin and Kerry Donaldson).
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(2003: 127, fig. 60), where the magnetic response of ditches falls off rapidly to invisibility from the focus of “habitation,” the ditches presumably forming a contemporary field system of the settlement, the full extent of which cannot be mapped by magnetic methods.

**Earth Resistivity**

As evident in Figure 55.4, earth resistivity survey is most effective over stone structures. It works by passing an electric current through the ground and mapping areas of high electrical resistance or low electrical resistance compared with background levels. Dense dry features such as stone will resist the electric current, whereas porous wet features such as ditches will conduct the electric current more readily. Until now, earth resistivity has not been used to provide areal coverage approaching anything like that of magnetic susceptibility or magnetometry. However, it has gained a new lease of life with the introduction of hand- or vehicle-powered rapid survey versions exploiting the square array (Aspinall and Saunders 2005), making large-area survey feasible, if at a somewhat lower resolution (Figures 55.5 and 55.6). Additionally, it can become the essential technique when either the archaeology or the environment does not produce the magnetic contrast that the two previously discussed techniques require to function. It can also be used to provide three-dimensional survey in situations that do not favor ground penetrating radar and, importantly, depth profiles that allow the geomorphological history of areas of the landscape to be understood (e.g., Challis and Howard 2006). However, such three-dimensional imaging comes at the expense of areal coverage because of the time taken to take multiple readings at each reading station to provide data at different depths.

**Figure 55.5** Employment of the square array has allowed mechanized systems to greatly increase the rates of coverage for earth resistivity surveys. The automatic resistivity profiler (ARP) system shown utilizes three differently sized square arrays and so also provides three different depths of survey simultaneously. At a traverse interval of 1 m and taking readings every 20 cm along the traverse, it can survey up to 10 hectares per day (reproduced with the permission of Michel Dabas, Geocarta).
Figure 55.6 A 50-hectare area surveyed by the ARP system shown in Figure 55.5 undertaken in 10 days. In this survey (high resistivity shown in black, low in white) the large scale sinuous dark anomalies represent evidence of palaeochannels. At this scale, many smaller archaeological features that are present are not evident in the plot, but traces of earlier field systems are visible in the south east. The ability to cover such large areas economically at high resolution and at multiple depths allows both small and large scale natural, as well as anthropogenic, features to be identified, which can then be incorporated into the archaeological analysis of the landscape (survey plot courtesy of Geocarta and Prologis-GSE).
**Electromagnetic Systems**

Electromagnetic (EM) systems that use an electromagnetic field generated by one coil and detected by another can provide information similar to earth resistivity, topsoil magnetic susceptibility, and magnetometry, all from one instrument. This is possible by varying the instrument coil orientation and recording the in-phase (or real) and the 90° out-of-phase (quadrature) parts of the instrument's response simultaneously. The coil orientation determines the depth response characteristics, while these two phases can detect magnetic and conductive anomalies respectively. The interpretation of EM data can be difficult due to the complexity of the instrument's response, particularly regarding changes with depth, while magnetic and conductive effects can "stray" into the other's response phase and in some situations predominate. Again, mechanized systems with EM instruments mounted on multisensor platforms can provide coverage at rates allowing the mapping of larger-scale landscape features such as field systems, scoring over earth resistivity in situations where obtaining readings by inserting electrodes is not possible (for example, under very dry conditions), while simultaneously collecting magnetic data. Used for extensive surveys more frequently by North American than by European practitioners, the volume edited by Johnson (2006) is a good starting point for information about EM techniques together with example surveys. Despite the great potential of EM survey for landscape survey it remains a rather under-exploited technique with Jordan (2000) commenting on the lack of use of EM in Mediterranean landscape archaeology.

**Ground Penetrating Radar (GPR)**

Ground penetrating radar employs electromagnetic pulses directed down into the ground that reflect back from interfaces that represent changes in the electromagnetic properties of the subsurface. Most effective for mapping in three dimensions stone structures and voids, it can also detect ditches and pits if the conditions are favorable. Although GPR is currently not used frequently for larger-scale landscape surveys, it has proved its worth in some difficult landscape survey situations. Utsi (2004) demonstrates the effectiveness of GPR in wetland peat bogs that are generally not regarded as environments offering high potential using conventional archaeological electrical and magnetic survey methodologies owing to the waterlogged nature and depth of the deposits. Mechanized GPR survey systems are 2005; Leckebusch 2003), and so GPR's contribution to landscape archaeology is likely to increase greatly as these systems become more widely used.

**Impact on Landscape Archaeology**

The technological innovation in archaeological geophysical survey, and in particular magnetometry, has been such that very large area surveys are now frequently undertaken and total surveys of entire landscapes are not only proposed but also represent a viable aim. Gater (2005) puts a case for total coverage of the landscape that constitutes the Orkney World Heritage site, where initial geophysical surveys of the area around the Stones of Stenness produced important findings regarding this landscape: “we did not imagine how dramatic our results would be. Almost from the first day it became clear that the known sites represented only a tiny percentage of what was actually there” (Card 2005: 343). With over 100 hectares of magnetometry supplemented by targeted resistivity undertaken already, the aim of total geophysical survey coverage of such landscapes is clearly realistic. However, more importantly in this case, on the strength of the results obtained so far, such extensive coverage has transformed our view of areas previously considered and described to be "sterile" into a vision of landscape development representing almost every period from the Neolithic onward. The result is a staggering increase in our knowledge of, and the importance of, this World Heritage Site (Card 2005). Multisensor platforms (Figure 55.7) incorporating both magnetometry and resistivity can increase coverage rates making larger surveys more viable.

It is important that geophysical data is correlated and so interpreted with the topography of the area of the survey. Although geoelectrical imaging and GPR are routinely corrected for topography (e.g., Goodman et al. 2006; Similox-Tohon et al. 2004), this is less often done with large area surveys of resistivity and magnetometry, or done only at a coarse level when combined with topographical data surveyed for wide coverage purposes (that is, reading interval of 1 m or more). Both resistivity and magnetometry will record false anomalies as a result of relatively small but abrupt changes in topography encountered when one is surveying areas with upstanding earthworks or features such as revetted terraces in garden landscapes or arising from agricultural terracing. In such circumstances, a high-resolution topographical survey created by ground-based laser scanners integrated with the geophysical surveys within a GIS environment...
assists in the correct interpretation of geophysical anomalies that result from topographical effects or simply correlate with them.

**Geochemical Survey**

Geochemical survey in a landscape archaeological context has generally not been undertaken anywhere near as frequently or spatially as extensively as geophysical and airborne and satellite methods. Reviewed by Heron in 2001 and concluded to be the “Cinderella of archaeological prospecting,” this partially invasive technique has the potential to turn a landscape not to one that simply reveals its physical features but, directly, the use of that landscape in ways that the archaeologist is interested in (Entwistle, Dodgshon, and Abrahams 2000). As such, geochemical survey offers the prospect of moving beyond features and artifacts to the wider landscape and so the “environmental” setting of sites.

Phosphate surveys, the most established category of archaeological geochemical survey, are (2001) points out, establishing standardization of extraction and detection protocols while also facing up to the identified uncertainties in the method are both required to push this technique forward. The current brief review suggests this analysis is still valid in 2006. Multi-element survey has become more prevalent, but the “life cycles” of many of the elements are not understood, nor is how to interpret identified enhancements in terms of the anthropogenic activity that produced them. Phosphate is still regarded as the most easily identified and interpretable evidence of large inputs of organic matter, even if the exact form of the original organic matter is unknown, and although there is potential for lipid and amino acid survey to input into interpretation, this refinement of the technique is even less established in basic research (for example, establishing the difference between manured and simply grazed land) and in extensive application in landscape archaeological contexts. Although the method offers great potential, understanding what are anthropogenic geochemical
extremely problematic when we move to the landscape situation where the whole landscape becomes the "site". It has already been alluded to that some aspect of geophysical properties, particularly magnetic susceptibility, result from land-use and "industrial" processes, and so it is not surprising that geochemical surveys are often combined with magnetic susceptibility surveys, providing evidence for the distinct zonation of activities (e.g., Clark 1996: 113, fig. 88).

For useful results to be obtained, there is a need to sample sites carefully at appropriate points in the soil profile and establish natural variations by adopting appropriate sampling strategies. Physically collecting, recording, and bagging the individual soil samples and transporting them to a laboratory for pretreatment prior to actual analysis make geochemical surveys slow, complex, and expensive in comparison with other prospection techniques. Few extensive area surveys have been undertaken. Aston and associates (1998) is one such more extensive multi-element survey.

The recent availability of portable but expensive X-ray fluorescence (XRF) instruments that allow direct multi-element analysis of soils in the field may make a significant impact on geochemical survey. The utility of portable XRF instruments has been demonstrated in environmental soil analysis applications (Clark et al. 1999), and although these can be used to take direct readings on soil surfaces in situ, better results can be obtained if the samples are sieved before analysis. This is a balance between rapid survey against quality of individual determinations; however, for many archaeological applications less precise in situ measurement may well be adequate. A few protostudies have been undertaken, such as Wager and associates (1998), in which Bronze Age copper ore processing sites were identified and the instrument used deemed to be "highly effective" for this application, particularly if used in conjunction with topographical and geophysical surveys.

**Remotely Sensed Imagery from Airborne and Satellite Platforms**

This section includes traditional film aerial photography, laser altimetry, and airborne and satellite multispectral imaging.

**Aerial Photography**

Aerial photography is recognized as the most productive archaeological prospection technique, wide range of site types, landscape management, and environmental information and often provides the principal record and hence framework for the types of archaeology and spatial relationships within particular landscapes. However, its value to individual landscape archaeology projects needs to be questioned strongly. In comparison with geophysical survey, aerial photography is much more biased in terms of the sample of the past it provides owing to its coverage being dependent on many more variables, some of which are not possible for even the most diligent archaeologist and well-funded project to overcome. For example, woodland or desert sand will not produce crop marks, whereas they will often produce excellent geophysical survey results. Crop regimes, cultivation patterns, and restrictions on flying near sensitive military and civilian sites all hamper aerial photography’s providing a consistent sample of a landscape’s archaeology. The magnetic effects that make magnetometry the most successful geophysical survey technique is a phenomenon not accessible via aerial imaging, so whole swathes of archaeological landscapes can go undetected. This pattern contrasts with geoelectrical methods that will often produce results similar to those provided by crop and parch marks. What is often championed as the major advantage of aerial photography is probably its most problematic in terms of being able to understand how the landscape was perceived and exploited by those who peopled it in the past: this is that an aerial view makes it easier to make "sense" of things that when viewed at ground level would be extremely difficult for the archaeologist to identify and to categorize. If it is to be used simply as a tool for archaeological recording, then this aspect of aerial photography is not a problem. However, if this is extended to making the assumption that people in the past also had a comparable aerial overview concept of the landscape that in some way determined its organization and ritual activities, then we may run into serious problems when forming our interpretations.

It is not the role of this section to go into the detail of individual aerial photographic methods but to consider the contribution of the technique as a whole to landscape archaeology to date and to identify any emerging strengths and weaknesses. There is a large body of excellent general and more detailed sources, including Riley (1997) and Brophy and Cowley (2005), and with a Mediterranean perspective, Jones (2000). For keeping abreast of ongoing technical developments, the newsletter of the Aerial Archaeology Research Group is the most useful source.
It is very hard to balance the often-stunning clarity and sheer quantity of the archaeology that is frequently revealed by aerial photographic methods against the fundamental weaknesses of the method, in that the archaeologist has little or no control over the uniformity of the aerial archaeological data set over wide areas. Such uniformity of basic data is a fundamental requirement of landscape archaeological approaches. It was quite obvious to the author back in his undergraduate days, when looking at the aerial photography records of the North Yorkshire (United Kingdom) County Sites and Monuments Record, that although the Vale of Pickering had been flown to the point of near-exhaustion in terms of the ratio of new site to repeat sites photographed, less than 40 km to the west in the Vale of York there was a much higher proportion of new to repeat sites, because of the lack of an equivalent level of sustained and systematic survey (Cheetham 1985). The consequences for any useful comparisons of the settlement of these two areas based on the aerial photographic evidence are obvious. In the United Kingdom, such deficiencies in coverage are being addressed by English Heritage’s National Mapping Programme but will remain a factor in the historic coverage.

Featherstone and associates (1999) reported 1996 as the best year in the United Kingdom for recording new sites since the extreme drought year of 1976. That the 1996 campaign resulted in half of the sites photographed being new to the record may seem to be a triumph. In fact, if anything, this highlights the very poor recovery in almost a century of flying and pulls into sharp focus the lack of any control over the sample of archaeology that is recovered as crop-mark evidence. The consequences for landscape archaeology of relying on such randomly produced evidence are clearly demonstrated by the fact that during the 1996 campaign, a very major site, that of a Roman legionary fortress, was discovered in Norfolk. Again, a great triumph for aerial photography, but how valuable would be any study of the Roman period landscape of the area around this site without knowledge of the presence of such a major socioeconomic center, and one that may have remained unknown for another century if we relied solely on aerial photography? Any landscape analysis that relies on sites located by aerial photography is in danger of being rewritten ad nauseam as the unpredictability of oblique crop-mark survey introduces new sites into the equation at random. The debate between the effectiveness of selective oblique photography against the rather more objective vertical covering considered more recently by Mills (2005), both of whom suggest that a more systematic and so better overall landscape coverage is afforded by vertical surveys as long as they are undertaken at appropriate times of the year.

Streamlining the management of oblique aerial photographic surveys has been focused on by Leckebusch (2005), who proposes a totally automated system that links high-resolution digital cameras with orientation sensor, GPS, and PC, so enabling the geographical coordinates of the frame to be automatically established, thereby allowing more time to be spent searching for, observing, and photographing rather than recording. This system would also allow the seamless porting of the resulting primary record into a GIS system and on to a digital archive for wide access and integration with other sources of data, the latter being a principal requirement of the landscape archaeologist (e.g., Campana and Francovich 2003) as the basis for well-supported interpretation (see also Conolly, this volume).

**Laser Altimetry**

One problem in aerial photography employing natural sunlight as the illuminating source is that, as is the case with many of aerial photography’s other parameters, it is difficult, if not impossible, to control shadow in any meaningful way other than being there at the right time when the sun’s angle reveals the targeted site, which may occur only for a few days or weeks in any year. One way out of this problem is the use of airborne laser altimetry, also known as LiDAR (Light Detection And Ranging), to provide a high-resolution digital terrain model that can be lit from any angle including directly from the north, a sun direction never available to aerial archaeologists (or the south, if they are working in the southern hemisphere). Such an approach led to the discovery that ramparts were standing as low earthworks at Newton Kyme (North Yorkshire, United Kingdom), despite the site being previously heavily photographed owing to its excellent crop-mark response (Bewley 2003).

Within landscape archaeology, airborne LiDAR sits somewhere between ground-based survey techniques of earthwork and high-resolution topographical surveys (both important field techniques for recording and understanding archaeological landscapes, particularly settlement layout and associated field systems) and true remote sensing techniques, the distinction being somewhat blurred by the increasing use of surface or tower-mounted.
Challis (2006) looks at landscape archaeological applications of LiDAR data that were originally collected by the United Kingdom Environment Agency for flood prediction and management, and concludes that even this relatively coarse data (2 m ground resolution; ground-based platform mounted LiDAR can be subdecimeter resolution over restricted areas) is particularly effective for mapping mature middle-reach flood plains in terms of providing the geomorphological context for understanding past cultural landscapes, defining areas of low or high potential for further study and cultural resource management, and so parameters for predictive modeling. Challis and Howard (2006) also note that the intensity of the reflected LiDAR pulse operating in the near-infrared can also be used and that this is currently being explored. Crutchley (2006) tried to assess low-ground resolution (2 m) height data for the definition of archaeological features and found limitations, whereas higher ground resolution (1 m) data used at Stonehenge exceeded expectations (Bewley, Crutchley, and Shell 2005).

### Airborne Multispectral Imagery

Despite the use of increasingly sophisticated satellite-based imagery systems and the use of declassified military imagery for evaluating landscape change in both environmental and Cultural Resource Management (CRM) temporal studies, multispectral imagery (MSS) sensing from lower altitude airborne platforms offers the greatest potential for archaeological applications. The increased ground resolution offered by airborne MSS compares favorably with conventional film aerial photography, and the detection of crop marks at wavelengths beyond the visible allows greater latitude in observing such effects than does the more restricted window of identification offered by just the visible and near-infrared wavelengths. This approach also has the advantage of providing a more uniform coverage requiring fewer repeat visits during optimal conditions for crop-mark formation. As discussed above, Powlesland and associates (1997) and Donoghue (2001) highlight these advantages of airborne multispectral imagery over conventional aerial photographic approaches when used in landscape projects. Barnes (2003) also demonstrates its combination with LiDAR data to provide information for managing entire archaeological landscapes, which underpins future archaeological analysis of such landscapes. Airborne thermography, although having potential for archaeological survey (e.g., Ben-Dor et al. 2001), has failed to make any significant impact, years. Until national and international agencies that are responsible for the archaeological resource undertake airborne multispectral scanning routinely to provide the appropriate data to underpin landscape archaeology, commissioning flights to obtain such data may, in practice, be beyond the resources of individual projects.

### Satellite Imagery

Ground-resolution, bandwidth, spatial-coverage, and image-processing techniques are constantly improving, and for information on these, the landscape archaeologist is directed to the latest sources, such as the *International Journal of Remote Sensing*, to keep abreast of developments in the more technical aspects of satellite imagery. Currently, ground resolutions of 0.61 m panchromatic and 2.44 m multispectral are reported for Digital Globe’s QuickBird system (Giardino and Haley 2006), making such systems now capable of comparing favorably with low-resolution, high-altitude airborne surveys. Although such higher-resolution imagery is always more useful, lower-resolution imagery can be used to provide landscape environmental information that gives wider coverage and so build on more limited coverage ground and airborne surveys. As is the case with aerial photography and airborne imagery, although satellite remote sensing can be used as a very effective prospection and landscape-assessment tool, it must be used very carefully for making interpretations about past landscape perception from such an artificial and large-scale generalizing viewpoint. That said, a number of projects employing remote sensing illustrate the effectiveness of this technique in parts of the earth that are not accessible to either extensive ground-based or lower-altitude aerial survey. Satellite imagery can also play an important part in providing information for areas of the world that lack detailed conventional topographical mapping, and as such provide a supporting role in archaeological surveys. It can also be the route into landscape work in countries that have restrictions on airborne and ground-based surveys owing to political and legal issues. For example, Altaweel (2005) demonstrates the utility of analyzing ASTER multispectral data from 2000 in conjunction with 1960s and 1970s CORONA imagery for studies of hollow route ways, canal systems, and tell sites in Iraq.

Satellite imagery is also useful for providing information in areas where ground survey is physically difficult to undertake, such as in wetlands and tropical forests, but has proved particularly
Chapter 55: Noninvasive Subsurface Mapping Techniques

One aspect that links all the techniques is their integration within geographical information systems (GIS) as the basis for moving on to higher levels and, arguably, more relevant interpretation at the landscape level than any individual geophysical survey, aerial photograph, or satellite image can hope to do. GIS, covered in this volume by Conolly, incorporates the relationship of GIS to remotely sensed data, the spatial technologies offered by GIS being useful in order to visualize and so to inspect the spatial relationships between landforms and archaeological data (see Conolly, this volume, Figure 55.2). It is, however, naïve to simply consider the integration of remotely sensed data without incorporating surface survey, excavation, and environmental, historical, and other relevant information, which is beyond the scope of this chapter. Powlesland and colleagues (2006) explore the relative effectiveness and complementary nature of aerial photography, airborne multispectral imagery, and magnetometry (Figure 55.8), but these are considered along with an almost 2,500 auger core survey of the aeolian deposits. Lock (2003) also contextualizes many of the survey and prospection techniques covered here together with other non-invasive survey techniques within the specialism of archaeological computing and its wide range of applications. This source reviews specific computer-based techniques, such as the rectification of oblique aerial photography and the presentation of geophysical data together with data integration, to create "digital landscapes" (Lock 2003: 164–82) that GIS can exploit. As with rectification, the conversion of conventional film airborne images into digital form is required to integrate and exploit effectively the information they hold. Forghani and Gaughwin (n.d.) used conventional color and black- and-white film aerial photography, which was scanned, rectified in a GIS, and followed by supervised image classification to identify and map an historic road network in a forested area of Tasmania (Australia). Schmidt (2004) provides a concise overview of informatics requirements of geophysical prospection and airborne and satellite remote sensing specifically for archaeological prospection. To integrate such diverse data sets requires the landscape archaeologist to be conversant with these informatics aspects increases and costs drop, while expertise in using such satellite imagery effectively to address more relevant archaeological questions will, we hope, also improve.

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Although the three are broadly comparable, each has revealed features of archaeological significance that the others have not. In this example, the only airborne multispectral survey has detected ring ditches in the southern part of the survey area, which appears less responsive to both conventional aerial photographic and magnetic techniques (reproduced with the permission of Dominic Powlesland, The Landscape Research Centre).
on to petabytes. The abstraction of archaeologically meaningful results from such large data sets without assistance from automated classification systems may well be beyond human interpretative abilities or time scales, and so it is in this area that major advances need to be made if we are to reap the benefits of the comprehensive subsurface, airborne, and satellite remote-sensing data that are increasingly becoming available to the landscape archaeologist.

Conclusions

Particularly in the areas of geophysics and airborne LiDAR and multispectral scanning, technical advances and the wider availability of these techniques are making their use not only viable but also arguably essential to getting the comprehensive and uniform levels of data recovery over large areas to underpin any serious landscape archaeology research project. Unfortunately, although individual techniques can be demonstrated to have significant impacts and potential yet to be fully exploited, the employment in any one project of anything like the full range of techniques that are available is still a rarity. As suggested in this chapter, this is in part due to the organization of these highly specialized techniques into individual and somewhat isolated centers resulting in a lack of coordination in their development and application, and so integration in the service of landscape archaeology. Without this coordination and integration, these highly effective tools of landscape archaeology will continue to be applied piecemeal with only the most well-resourced projects being able to benefit in full from the excellent development, knowledge base, and specialized expertise that is now available to the landscape archaeology community. Landscape archaeology must not accept second best in this area of the discipline, because all higher levels of analysis and interpretation should be based on the best data available; otherwise, the discovery of one missed important site could require the whole to be revised, or worse if important sites still unknown through lack of appropriate prospection efforts being lost forever to landscape archaeology by development, agriculture, or erosion.

2. A more useful example and source of integrated programs or survey and research can be found at the Laboratory of Geophysical-Satellite Remote Sensing and Archaeo-environment (www.imsf. forth.gr/lab_index.html) of the Institute for Mediterranean Studies (I.M.S.)/Foundation of Research and Technology (F.O.R.T.H.). Since 1996, this laboratory has combined and so integrated geophysical prospection, satellite remote sensing, and archaeo-environmental and geographical information systems (GIS) within one facility, which is clearly the way forward both from a research and application perspective.

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