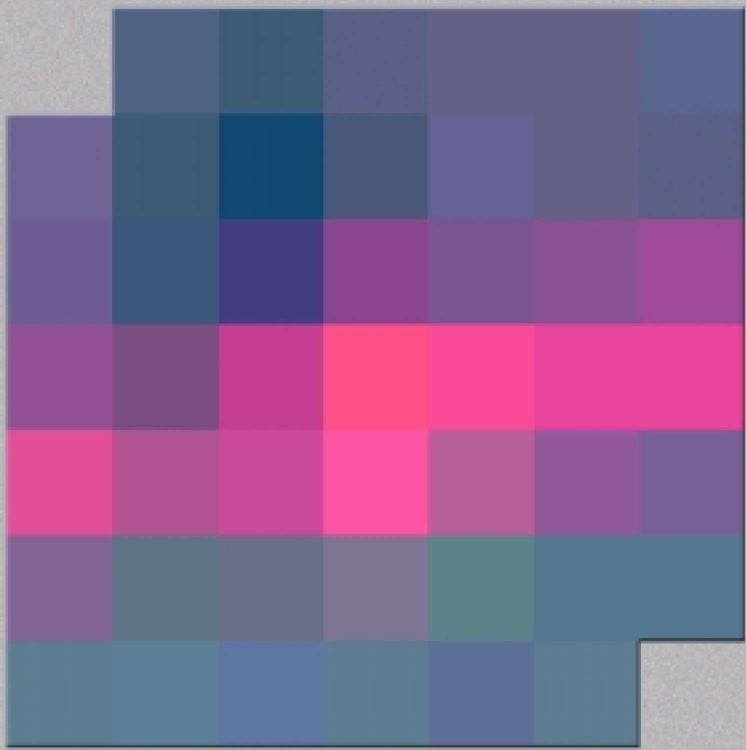
Development of methods for satellite monitoring of cultural heritage sites

Ole Grøn & Anke Loska



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Development of methods for satellite monitoring of cultural heritage sites

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1 Abstract: Development of methods for satellite monitoring of cultural heritage sites

The increasingly intensive use and modification of the landscape as a result of modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities) exerts growing pressure on areas and sites associated with our cultural heritage. The use of modern support technologies is imperative if such rapid changes are to be balanced against the sustainable management of this resource.

At present, cultural heritage legislation and management is based on expensive and old-fashioned methods of field survey which underpin regional and national registers of cultural heritage sites. These registers are flawed and contain not only a biased sample of sites in respect to period and region, but also include only a tiny fraction of the total population of cultural heritage sites which should be included in management strategies. This lack of reliable data not only influences realistic forecasting, but also causes costly delays and introduces unnecessary conflicts.

This pilot project directly addresses these issues by initiating the development of a basis for a sustainable, up-to-date and cost-efficient decision-support methodology which relies upon satellite remote-sensing, mapping and monitoring of cultural heritage sites. A central methodological element is the development of high-resolution empirical ground data, which facilitate fast and cost-efficient identification of potential cultural heritage anomalies identified in the multispectral data.

2 Introduction

2.a The problem in focus

It is generally recognised that the increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities) exerts growing pressure on cultural heritage in the landscape.

In order to match the political intentions of updated and sustainable cultural heritage management, a necessary first step is to create a representative picture of the resource that has to be managed. In Norway, where extensive white areas are still to be found on cultural heritage maps; where the registered cultural heritage sites display an unrepresentative concentration in areas with high human activity; and where the registered positions of the sites can easily be 30-40 metres from their true location, it is obvious that something has to be done in order to achieve even this basic goal.

In recognition that a) it will never be realistic to obtain funding for thorough survey and monitoring of the enormous tracts in question using traditional field-survey methods, and b) there is a demand for access to representative and comprehensive cultural heritage data to create a basis for the development of a flexible and up-to-date cultural heritage management, the Norwegian Space Centre (NRS) and the Norwegian Directorate for Cultural Heritage (RA) decided to support a pilot project designed to prepare the ground for the development of survey and monitoring methodology involving multispectral satellite data.

The project's aim is to develop a cost-effective method for surveying and monitoring cultural heritage sites. The costs of systematically surveying areas of the scale involved here by means of conventional fieldwork provides the incentive for the development of alternatives. Depending on which field methods are employed, and the type of landscape surveyed, costs for conventional fieldwork will normally be around 250,000 Norwegian Crowns (NOK) per square kilometre. In comparison, high-resolution satellite data cost less than NOK 1,000 per square kilometre, a fraction of conventional fieldwork costs.

Even though the costs connected with the processing of the satellite data will not be insignificant, and fieldwork can probably never be entirely replaced by high-technological methods, it seems plausible that an essentially cheaper, and possibly even qualitatively better, method for the surveying and monitoring of cultural heritage sites can be developed by using multispectral satellite data to target the fieldwork to a degree not possible today.

It must be anticipated that certain types of cultural heritage sites will be discriminated against by a method based on satellite data, although probably not to the extent to which current systematic fieldwork seems to overlook some categories, such as settlements, for instance. For example, in large areas, burial mounds comprise the predominant registered type of monument to such a degree that one wonders where the people buried in them lived. A systematic and standardised method for analysis of the satellite images should make it possible to make statistical corrections for such bias in the data.

Because the multispectral satellite images are normally delivered geo-corrected and related to a positioning system, the data contains a built-in registration of positions that is superior to that which can be obtained with a GPS in the field.

The ability of high-resolution multispectral satellite images (previously the term high-resolution was applied to the Landsat images; it now seems logical to restrict it to IKONOS and Quickbird images) to distinguish minor variations in the vegetation and in the soil is superior to what is possible using aerial photos. Furthermore, the development of multispectral techniques in the direction of more bands and finer resolution suggests that the potential of these techniques will increase considerably in coming years.

The most exciting aspect of multispectral techniques is to see how far they can be developed in the direction of distinguishing cultural heritage sites that have no visible physical manifestations preserved above ground level. This is the central critical issue for cultural heritage management at present, as demonstrated in the case of cultivated land by this report.

Accessibility is essential for the development and application of sustainable, up-to-date, and cost-effective decision-support methodologies based on high-resolution satellite data. Further development of the recently formed Satellite Data Archive within the framework of the Norwegian Mapping Authority is an important means of making the relevant types of satellite data accessible for the various sectors which can benefit from them.

2.b Aims

The aims of this pilot project are:

- To clarify what the current state-of-the-art is in terms of the location and monitoring of cultural heritage by satellite data.
- To evaluate the practical potential of multispectral satellite data with different resolutions.
- To look for relationships between anomalies visible in multispectral satellite data and ground features that can be distinguished by soil chemistry, ground spectrometry, and vegetation analysis.
- To suggest a strategy for further national initiatives in this field.

The project has produced a variety of results and experiences, which will be presented here. In order to pass on the experiences which have been gained, it has been decided to let this presentation of the project reflect its character as a process of development, to be continued in the form of a national project running from 2003-2007.

2.c Project organisation and funding

The pilot project is funded by The Norwegian Space Centre, NRS http://www.spacecentre.no/, and also by contributions from the Norwegian Directorate for Cultural Heritage (RA) http://www.riksantikvaren.no/, and (NIKU) http://www.ninaniku.no/.

The project leader is Ole Grøn, NIKU. The Steering Committee consists of Guro Dahle-Strøm, NRS, Anna Lena Eriksson, Anke Loska, Joel Boaz, RA, and Ole Grøn, NIKU.

The project's participants are Ole Grøn, NIKU, May-Britt Håbjørg & Joel Boaz, RA, Hans Tømmervik & Lars Erikstad, NINA (Norwegian Institute for Nature Research), Rune Solberg & Hans Koren, NR (Norwegian Computing Centre), Finn Christensen, GK (GeoKem), and Nancy Child UKM (University Museum of Cultural Heritage).

Apart from the officially-defined project elements, an important factor in the fieldwork has been the collaboration and helpfulness of the local landowners, Rygge municipal administration, as well as the Cultural Heritage department in Østfold County Council.

2.d The study area

The chosen study area was defined by the borders of the IKONOS image of Rygge Municipality, Østfold County, August 2001, made accessible to the project by NRS and the Satellite Data Archive of the Norwegian Mapping Authority. In WGS-84 UTM co-ordinates this is 592626-603618 E, 6575139-6586131 N (system 32) – an area of 10,992 km E-W and 10,992 km N-S. The image used is geo-corrected. A check against digital ØK maps (1:5000) proved it to be accurate to within ±2m.

The study area is a typical, intensively exploited, agricultural production area with a quite moderate topography in Norwegian terms (Fig.2). With the exception of a few protruding ridges and rocks, the landscape is flat

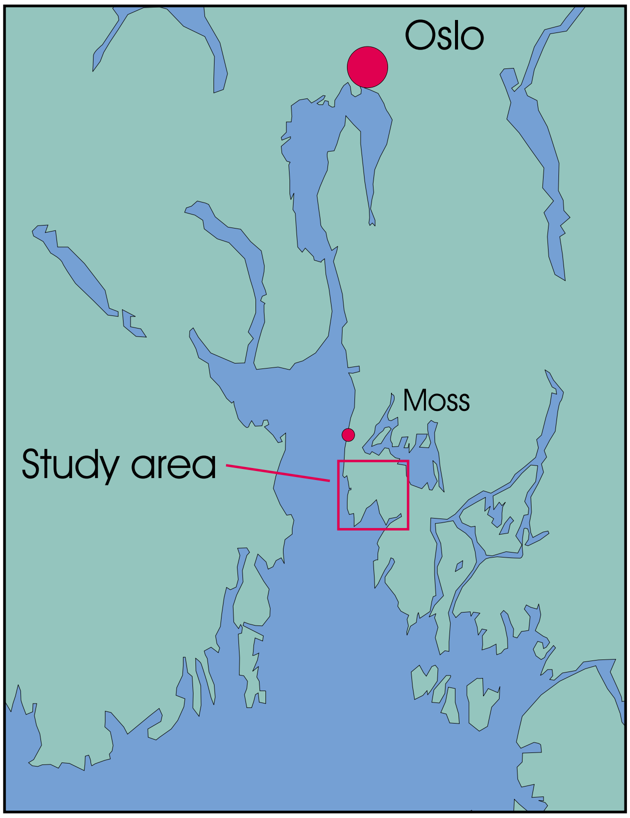


Fig.1 The study area is approximately 11 by 11 kilometres in area and covers a part of Rygge municipality, Østfold County.

and hilly. Areas not occupied by fields and not covered by forests form an extremely limited proportion of the area.

The presence of an airport at Rygge has resulted in the availability of a larger amount of local aerial photos than would normally be the case. A number of these are accessible on the internet (http://www.of.fylkesbibl.no/flyfoto/rygge/liste.html). These photos are an important source of information for determining the character of some of the anomalies visible in the multispectral satellite data (Fig.2, Fig.3).

A special group of anomalies consists of traces of facilities and bombing from World War 2, when Rygge airport served as a German military airport. Fortunately, the head of the department for planning and environment in Rygge municipal administration, Erik Vieth Pedersen, has been involved in systematic data collection connected with this, and has kindly allowed the project to benefit from this.

2.e Methodological choices and limitations

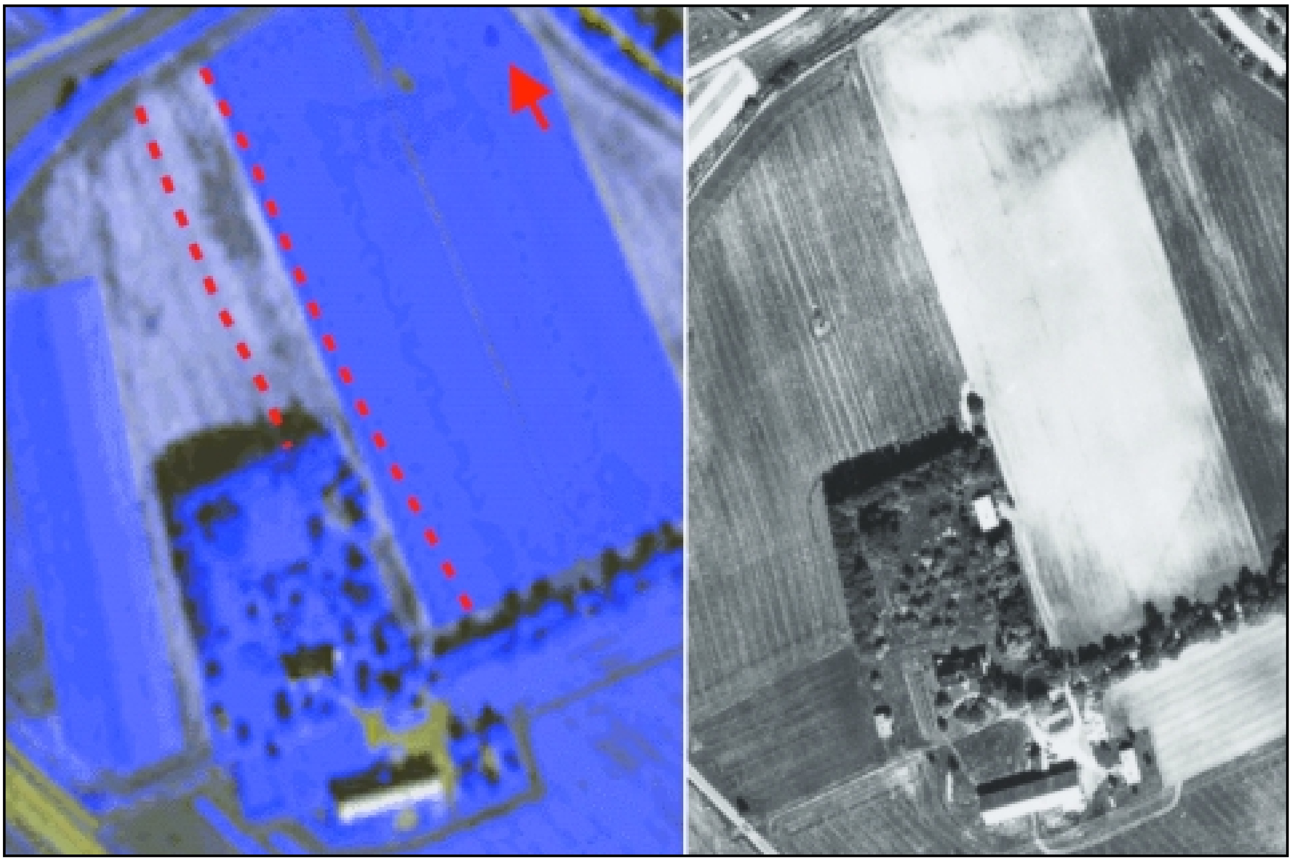
It was decided to postpone the application of radar to a later phase of development because the multispectral technique seems to be the most promising in terms of cultural heritage site localisation and monitoring, and has already shown its usefulness (Grøn et al. 1999; Holm-Olsen et al. 1999; Shennan & Donoghue D. 1991). In addition, the satellite-borne radar system's ability to distinguish minor topographical features would be of restricted value in relatively flat areas like that formed by the pilot project's study area.

The available IKONOS image was taken during the harvest period - a period when dynamics in the vegetation are small. Because many of the crops have been harvested, it gives access to more direct ground reflection than an image with a full vegetation cover would have done. The acquisition of a Quickbird scene from the spring with maximal dynamics in the vegetation in the central part of the study area is expected to be an important supplement to the already available multispectral data.

Forest areas represent a problem for cultural heritage remote sensing that will obviously not be solved immediately. It was seen as important to gain some experience with forested areas, and that is why they were not excluded from the study area.

Fig.2 *Aerial photo of Gibsund farm from 1956 (Østfold fylkes billedarkiv, ØFB. 1995-396) (http://www.of.fylkesbibl.no/flyfoto/rygge/liste.html). The dirt road marked with a red dotted line does not exist today.*

Fig.3 *Comparison with the aerial photo Fig.2 reveals that the linear feature between the two broken red lines in the multispectral IKONOS image (left – copyright: Space Imaging) with the mix of layers 2 (green), 2 (green), 4 (near infrared) is a reflection of the former dirt road. The red arrow marks an anomaly interpreted as a totally ploughed-out burial mound. Both features clearly stand out in the multispectral image but are not visible in the conventional aerial photo to the right taken in the autumn of 1980 (Vertical photo 6360 B7 - Copyright: Fjellanger Widerø AS).*



3 Technological aspects

3.a Multispectral scanning

In principle, multispectral scanning is digital photography, where the values recorded reflect the energy received from a specific interval of the electromagnetic radiation received. One value is stored for each pixel (Fig.4). One picture (or 'layer') may represent the green, the red, the infrared or another part of the spectrum. Analysing the data of the separate layers, or combinations of them, from one scene by means of algorithms provides analytic possibilities superior to those provided by conventional and infrared photography.

Already from 1972, when multispectral Landsat TM data was made available to archaeology, a series of attempts were made to use this information as a necessary supplement to/replacement for aerial photography, which in itself had never become the useful method for systematic survey which some had imagined it would. The limitations caused by the system's coarse resolution (10 m for the panchromatic and 30 m for the multispectral data) were soon recognised as restricting the field of application to large-scale features (Hamlin 1977; McHugh et al. 1988; Shazly 1983).

Shennan & Donoghue addressed the resolution problem most consistently by carrying out complementary surveys with a high-resolution airborne multispectral scanner (NERC ATM) with resolution down to 2 m and band specifications comparable to those of the Landsat TM's 7 bands. The study area was Morton Fen, an area consisting of marine and freshwater sediments. It was demonstrated that spatial resolution is crucial for multispectral archaeological survey, and that the system with a resolution of about 2 m produced very useful results (Shennan & Donoghue 1991).

As an apparent consequence of the present pricing policy for such high-resolution satellite data (IKONOS - available since 2001, Quickbird since 2002), research and development activity in this important area seems to have declined lately. This means that one must expect a delay in the ability to benefit from such sources in the cultural heritage sector until a realistic price level is created by competition between the new satellites and those in production today.

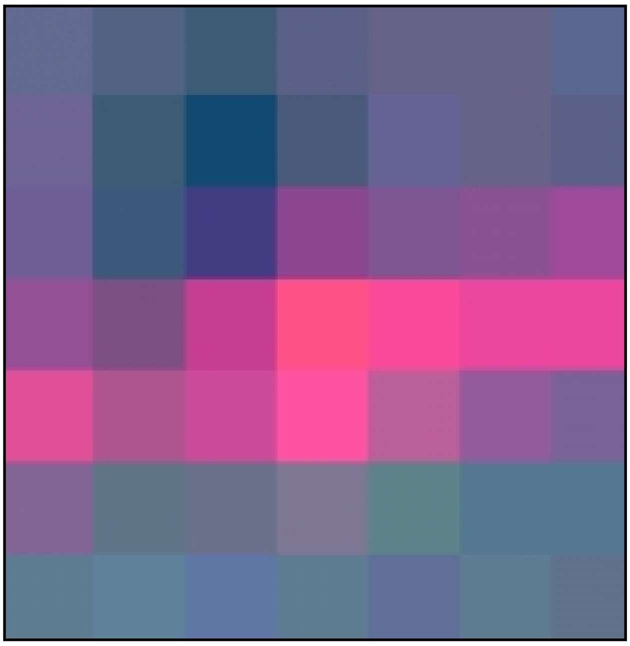


Fig.4 *A large tree in a hedge seen as 4 by 4 metre large pixels with one average value represented in each pixel – data from the multispectral part of the IKONOS recording (copyright: Space Imaging).*

3.b Radar

Different SAR systems (synthetic aperture radar) which can be operated from satellites, facilitate registration of small-scale topographical features (penetrating vegetation), variation in ground moisture, and the occurrence of stones. Used by itself, the data from such systems will only be useful in relation to a restricted number of types of cultural heritage sites in a flat area such as that represented by the present study area. Representing as it does a facility useful for distinguishing minor variations in ground moisture with quite high horizontal resolution, radar is expected to serve as an important supplement to the multispectral satellite data in a later stage of development.

3.c Analysis of the data and pattern recognition

From the earliest experimental application of multispectral satellite data to cultural heritage survey and monitoring, it has been obvious that it was necessary to develop automated procedures for data analysis in order to be able to deal with the large amounts of complex data it made available (Hamlin 1977).

There is a statistical problem involved in the use of data with increasingly finer resolution. Due to the ‘large’ size of the Landsat data (10 m for their panchromatic part, 30 m for their multispectral part) they represent rather representative average values for ‘larger’ areas. When the pixel size gets close to the size of trees, bushes, large stones etc. (as in the case of the IKONOS and Quickbird data), the pixel values will to a greater degree represent the reflection of single features and therefore display a much greater variation. This is an advantage in that it allows smaller anomalies to be reflected in the images, but it also constitutes a problem for the significant statistical distinction of small-scale structures.

In the present project, experiments were carried out with a large number of algorithms (formulas) for the manipulation of values from the single layers in the multispectral record, as well as from combinations of its layers, in order to see if it was possible to develop a method of positive discrimination of anomalies representing cultural heritage features. The conclusion is that no algorithm has so far shown the ability to ‘improve’ the data generally.

The best results were obtained by visual inspection of different ‘mixes’ of the values from the multispectral layers, thus using the pattern recognition capabilities built into human visual perception. This points towards automated pattern recognition as the way forward in reducing costs and the use of trained operators to a minimum.

4 The character of anomalies reflecting cultural heritage sites

A number of processes related to the formation of cultural heritage sites leave long-lasting traces. Digging and the construction of earthen structures tend to create detectable disturbances in the local geology. Mounds are often composed of material that differs from the subsoil on which they are placed (e.g. turf, larger stones etc. – Fig.5), and their construction may involve the creation of significant below-ground features, which will often be preserved even if they are removed to the level of the surface of the surrounding terrain.

Compression of the subsoil due to the building of structures above ground level (ramparts, mounds etc.) or transport facilities (paths, roads etc.) is a factor that may change the drainage locally and be reflected as local variations in ground moisture and vegetation. Pits, ditches and other dug features, as well as heavily-used tracks which are cut deeply into the ground, will, when no longer in use, often refill with material that differs from the surrounding substratum, and consequently appear as detectable anomalies.

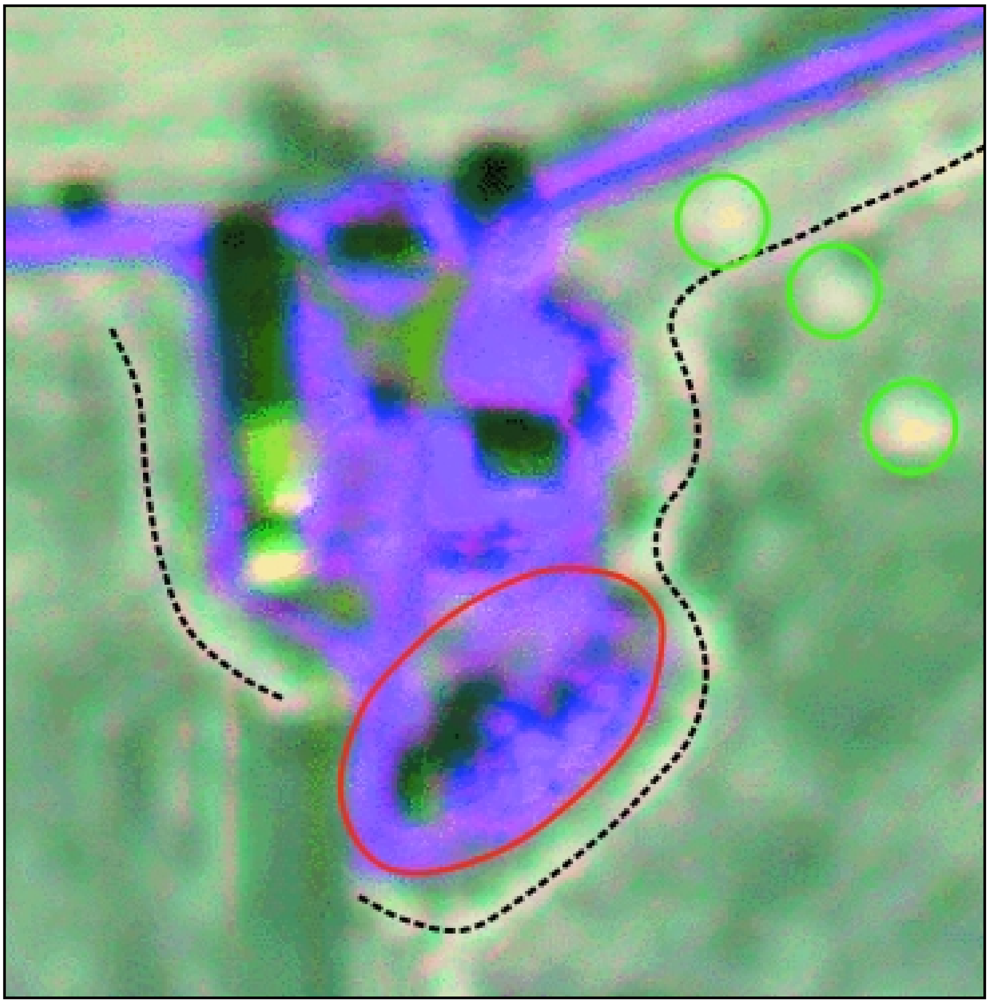


Fig.5 *A concentration of registered mounds, marked red. A linear feature created by field-cultivation methods is shown as a broken black line (see Fig.11). Three anomalies reflecting significant local changes in the soil and interpreted as the remains of mounds with no structural remains preserved above the surface are marked with green circles (IKONOS - copyright: Space Imaging).*

As centres for the exploitation of their surrounding areas, old settlements will often contain unnaturally high concentrations of trace elements. In agricultural and herding societies, these are mainly brought in from the surrounding areas with animals and deposited in the settlements together with their dung and urine. In hunting-gathering societies a similar effect can be observed, even though it is seldom associated with concentrations on the same scale (Grøn & Sørensen 1996, Jørgensen & Pedersen 1996) (Fig.6).

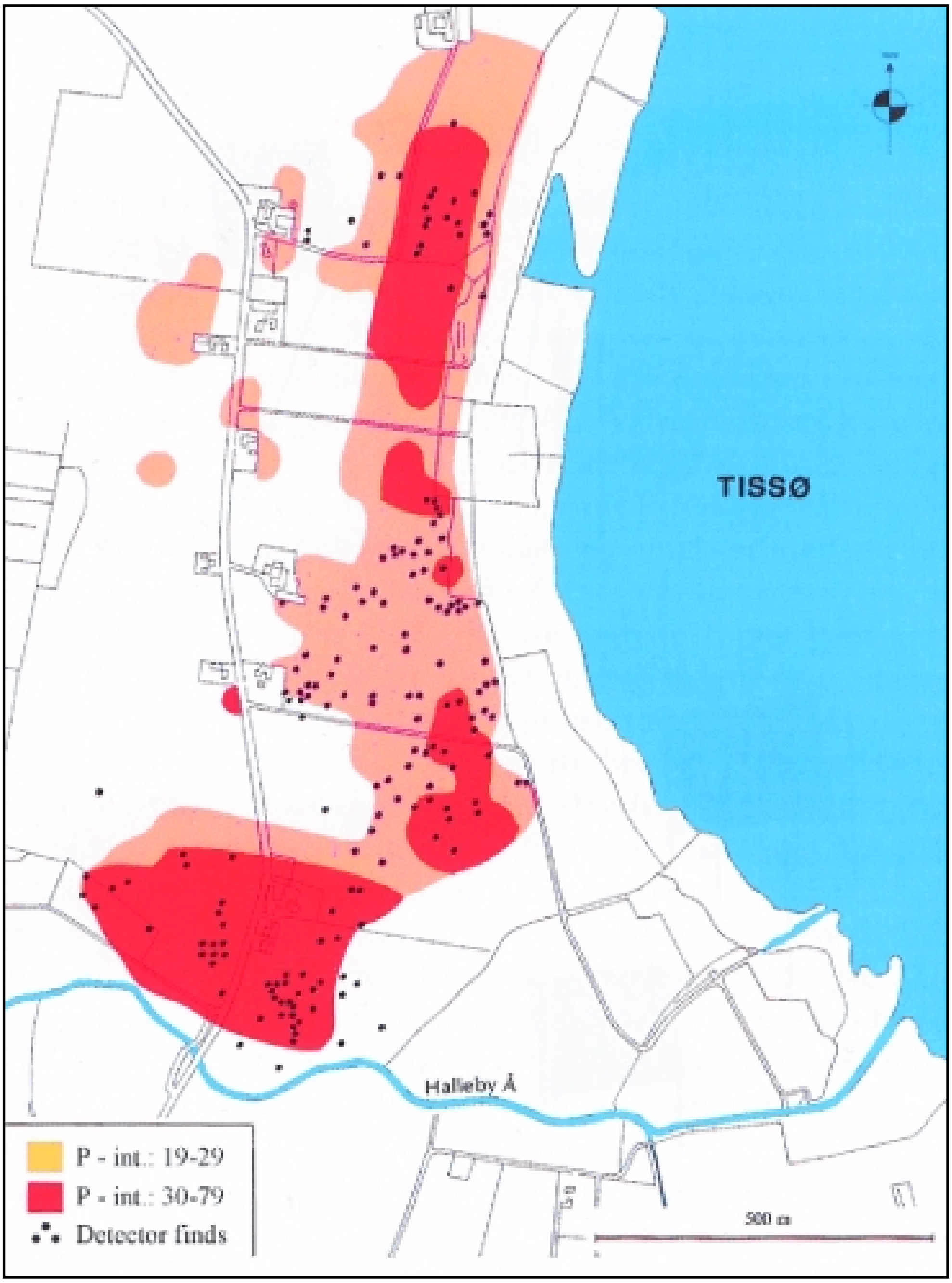


Fig.6 *Phosphate concentrations and locations of detector finds from the late Iron Age and Viking Age in a settlement at Tissø, Zealand, Denmark, where farm buildings from the period have been documented by excavation. Some of the smaller phosphate concentrations are related to modern farms (Jørgensen & Pedersen 1996).*

Phosphate and heavy metals are of interest as indicators of human habitation. Large phosphate concentrations seem to be capable of changing the character of vegetation locally (Grøn 1999, Holm-Olsen et al. 1999). Heavy metals seem to appear as an indicator of human habitation from the Bronze Age on (Aston et al. 1998).

A factor which is both surprising and helpful is the ability of vegetation to 'lift' some trace elements, such as for instance heavy metals, up to the surface from a depth of about 1.5 metres. Due to the effects of such compounds, many cultural heritage sites can be expected to be observable through small variations in the colour of vegetation even though they are covered by subsequently deposited sediments (Bjørlykke et al. 1973; Bølviken & Låg 1977; Shaw 1990).

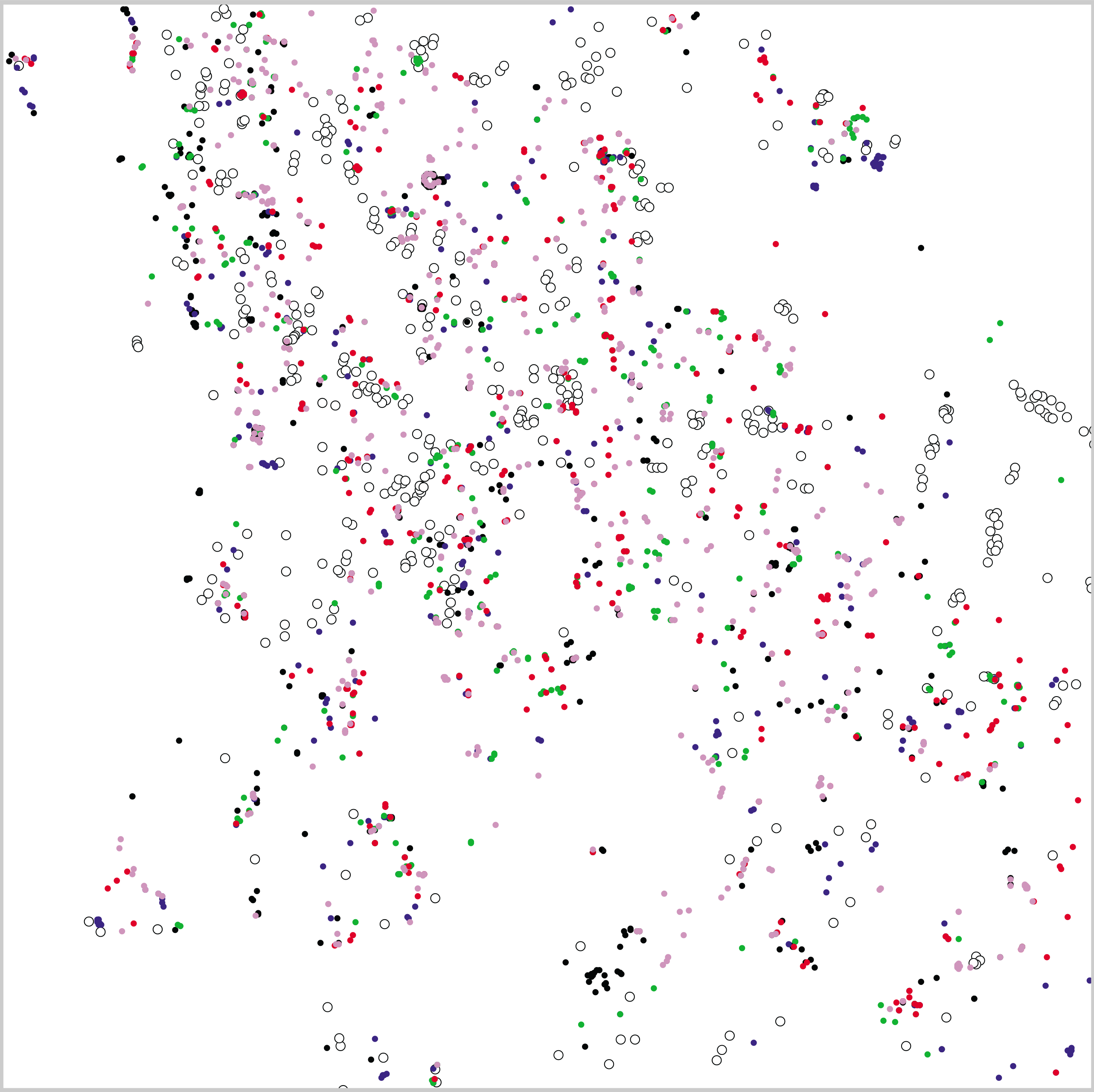
5 Visual inspection of the IKONOS data

5.a Visual inspection

The investigation's first step was to visually inspect the IKONOS image for anomalies that might represent cultural heritage features. The five layers – pan (panchromatic), blue, green, red, and NIR (near infrared) - were dealt with separately and in a series of different combinations. A surprising lack of correlation was observed between the registered cultural heritage sites and the observed anomalies and, to a lesser degree, between the anomalies observed in the different layers of the IKONOS image (Fig.7 & Tab.1).

Even though the data values in table 1 cannot be regarded as exact, due to errors in the registration of the cultural heritage sites of up to about ±50 m and difficulties in determining the limits of sites and observed anomalies, the data strongly suggests that we are dealing with two populations of features with only limited overlap: the registered cultural heritage sites and the anomalies observed in the IKONOS data.

Fig.7 *The distribution of registered cultural heritage sites (empty circles), and the locations of anomalies observed in the PAN (black dots), blue (blue dots), green (green dots), red (red dots) and NIR (lilac dots) layers.*



***Tab.1** – The relationship between the registered cultural heritage sites and the anomalies registered in the different layers. Because a) the error in the registered locations of the cultural heritage sites may be in the order of ±50 m and b) the limits of cultural heritage sites are difficult to determine, the information presented in this table is not exact. However, the trends it shows are valid.*

Type of feature	Number registered	Anomalies correlating with registered cultural heritage sites	Correlating with anomalies from other layers
Registered cultural heritage sites	458		
NIR – anomalies	568	37	261
RED – anomalies	437	30	219
GREEN – anomalies	466	37	240
BLUE – anomalies	422	31	242
PAN – anomalies	568	24	184

Some of the cultural heritage sites correlating with the observed anomalies were easy to identify in the IKONOS images because they were visible as small patches of uncultivated vegetation in the fields. Because those sites that are covered by small groves are often shown on the 1:5000 maps (Økonomisk Kartverk), precise registration of their positions has not been a problem. For the cultural heritage sites under cultivation, a correlation between the registered locations and the anomalies observed was only established in ***two cases*** (the mounds R 005885 and R 005870). In both cases, the imprecise positioning of the cultural heritage sites meant that the anomalies that were apparently registered at some distance from them proved on closer examination to be the registered features themselves.

That there is no systematic overlap between the anomalies in the five different layers of the IKONOS data shows that the visibility of the anomalies is different in each layer.

That the cultural heritage sites registered in open fields, and the anomalies distinguished in the IKONOS data, seem to form more or less complementary populations is a phenomenon that calls for a closer attention. It leaves us with two possible conclusions: that the IKONOS data are unsuited to the location of cultural heritage features, and/or that the present registration of cultural heritage features in open cultivated fields is far from adequate.

5.b An analysis - the impact of agriculture… or?

Two rectangular test zones were chosen at random within the study area. ‘A’ covers 592625-598961 E-W and 6584016-6586128 N-S (13.4 square kilometres), and ‘B’ covers 594817-601221 E-W and 6580444-6582292 N-S (11.8 square kilometres) in UTM WGS-84 co-ordinates, zone 32.

The land within these test zones was classified into two categories: land with tree-cover (including hedges and groves) and land without tree-cover. Because of the intensive nature of local agriculture, cultivated fields are totally dominant in the second category.

The numbers and densities of registered cultural heritage sites were calculated within the two land categories in the test zone (Table 2). A significant result is that the density of cultural heritage sites in the land category with no tree-cover is less than 2% of that in the land category with tree-over. Factors other than the destruction of cultural heritage sites may explain some of this difference between the two area categories.

The field systems were originally organised so that their boundaries coincided as far as possible with physical obstacles, in order to facilitate cultivation. Consequently, one should expect mounds, for example, to be over-represented in the hedge zones at their boundaries. However, the development of larger and larger fields today should have reduced this effect to a minimum. The satellite image in Fig.12 shows, for instance, traces of boundaries between fields which have been removed since 1956 (Fig.13).

Tab.2 *The numbers and densities of registered cultural heritage sites within the two land categories in the test zone.*

Area	Area in square kilometres	Number of registered cultural heritage sites	Registered cultural heritage sites per square kilometre
Area A – tree-cover	4,49	108	24,05
Area A – no tree-cover	8,89	4	0,45
Area B – tree-cover	4,53	74	16,34
Area B – no tree-cover	6,36	2	0,31
Tree-cover – A+B	9,02	182	20,18
No tree-cover – A+B	15,25	6	0,39

Zones with physical obstacles which could not be fitted into the system of field boundaries, and which were difficult to clear away (e.g. mounds with a base consisting of protruding bedrock), were often left as small isolated groves in the fields. A number of these still exist, but it is obvious that there has been significant clearance of such features with the aid of dynamite and modern machinery during the last century.

In the study area, there is a tendency towards burial mounds being located in the more elevated parts of the landscape, which are also more frequently covered by forest than the lower areas. However, since both mounds and forest are found in all parts of the landscape, which with its relatively moderate and hilly topography does not support a significant topographical polarisation between high and low areas, this can only be regarded as a rather weak tendency. It is unclear whether this reflects an original characteristic in the distribution of the mounds, or has been created by more intensive agriculture in the lower-lying areas.

Even though the carrying-out of a precise estimate of the importance of the factors discussed here lies outside the framework of this project, it can be firmly concluded that they only account for a moderate proportion of the cultural heritage sites which seem to be absent in the areas without tree-cover.

Extrapolating the density of registered monuments in the areas with tree-cover into the study area's approximately 50 square kilometres with no tree-cover results in an estimated shortfall of registered cultural heritage sites there in the order of 1000 locations. This indicates that a number of the anomalies listed in Table 1 may actually represent unregistered cultural heritage sites, and that an interesting relationship between agricultural areas and areas which significantly lack registered cultural heritage sites seems to exist.

In the Oslo area, recent observations have been made during excavation of what appear to be mounds which have only their ground-level structures preserved: Missing, Råde, Østfold (g/bnr. 83/7, 84/1), Hærland, Eidsberg, Østfold (the remains of R 007033), Gislevold, Ullensaker, Akershus (R 010281) (L. H. Vikshåland, and E. Berg, pers. comm.).

Data exist which demonstrate that, in a number of documented cases, ploughing of mounds and other cultural heritage sites has produced an annual average rate of 'wear' in the order of 0,3-1,0 cm per year (Hinchcliffe & Schadla-Hall 1980, Jørgensen & Jørgensen 1997:14). Due to the use of increasingly powerful machines in agriculture, this wear can be expected to increase.

Another effect may, however, be equally important. Several large mounds are known to have disappeared as early as the 18th century, in some cases probably because they contained easily accessible material used for levelling-out building sites and other constructional purposes (Brendalsmo 2001:128).

It should be noted that mounds – a highly visible cultural heritage category - dominate the registered cultural heritage in the study area. That only a few settlements are registered is most likely a reflection of difficulties in distinguishing them by means of traditional archaeological field-survey methods. Their moderate numbers, however, again indicates that the information in our registers currently only seems to represent the top of the iceberg.

6 Field inspection

6.a Field inspection

A field inspection, including interviews with landowners and other informants, was carried out in order to obtain a preliminary clarification of the character of a series of the anomalies observed in the IKONOS data.

6.b Mounds with a base consisting of bedrock and mounds built of large stones

A geological feature typical of the region consists of small portions of low, rounded bedrock that protrude from the subsoil (Figs.8 & 9). A thin layer of soil originally covered many of these natural 'mounds', but weathering and ploughing have exposed smaller or larger sections of bedrock in many cases. A number of these have been registered as prehistoric burial mounds. In some cases, preserved structural features prove this interpretation to be correct (Fig.8), in others their function is less obvious. This may either be due to wear or to the fact that, in spite of their close resemblance to them, they never served as burial mounds. In addition, many of these features, which are currently unregistered, may well contain burials.

Fig.8 *A geological feature used as a burial mound. Part of the bedrock that forms its foundation is exposed. A ring of kerbstones indicates that the feature served as a burial mound. Photo Ole Grøn.*

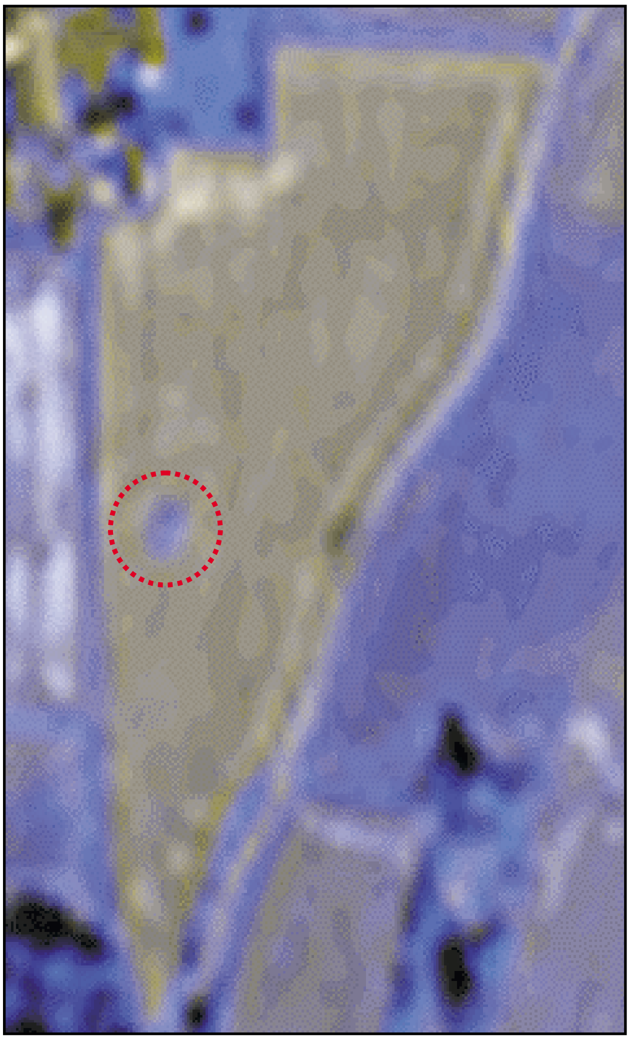


Fig.9 *From the multispectral IKONOS data: A low grass-covered portion of protruding bedrock registered as a prehistoric burial mound (nr.005885). It is in fact located 45 metres to the south-west of the position at which it is registered (IKONOS - copyright: Space Imaging).*

Another type of mound represented in the study area is built of large stones, the so-called 'røys'. These mounds are highly visible and therefore of restricted interest in terms of the present investigation. Furthermore, they are difficult to deal with, because large amounts of stones cleared from the fields have often been added to them. Some of these field-clearance cairns have a purely modern origin.

Because a) there is no problem locating both types of mounds, and b) they are difficult to deal with interpretatively, they have been omitted from the current investigation. It lies outside the scope of the present study to attempt to solve such general and complicated problems of culture-historical identification.

6.c Power-lines

The foundations of the masts for power-lines appear as small distinct anomalies in the landscape, which may easily, at the present stage of method development, be taken for potential cultural heritage sites. A useful feature which can be used for distinguishing them, is that they appear in lines with more or less standardised intervals between them (Fig.10). Where possible, they are located on boundaries between fields. This may be a useful feature for pattern recognition.

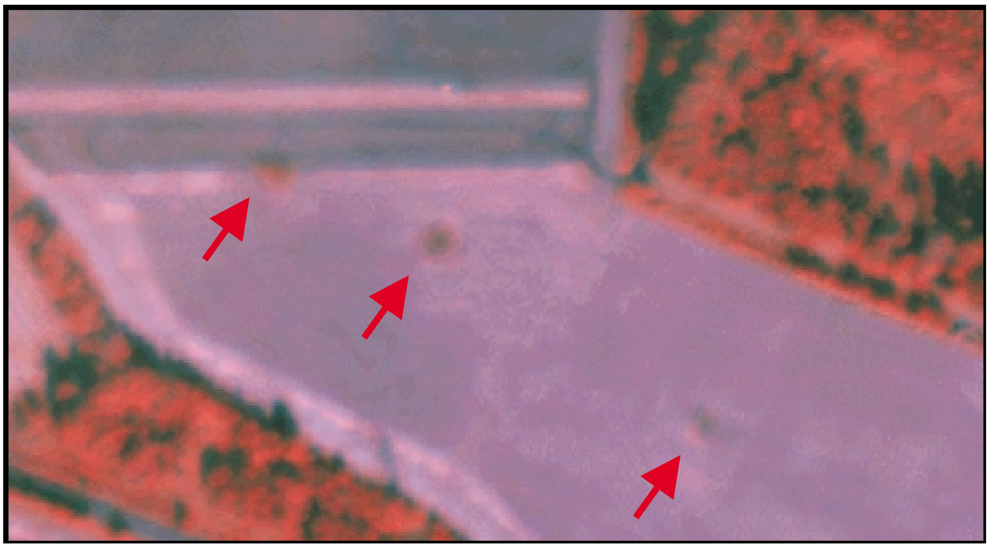


Fig.10 *Three anomalies representing the foundations of power-line masts (IKONOS - copyright: Space Imaging).*

6.d Symmetrical linear features created by field cultivation

In a number of cases, symmetrical linear features were observed in the fields. These features form patterns, which reflect the ways in which the fields are cultivated. When the tractor turns, the depth of the plough/harrow varies a bit and the working direction changes. In some circumstances this may cause the development of linear features in the soil. Similar features can be created along the edges of the fields, where the tractor drives parallel with the field boundaries. Such patterns can easily be misinterpreted when they are less obvious than those shown in Fig.11. Due to their symmetrical character, it should be possible to achieve an easy correction for such features using a pattern recognition system.

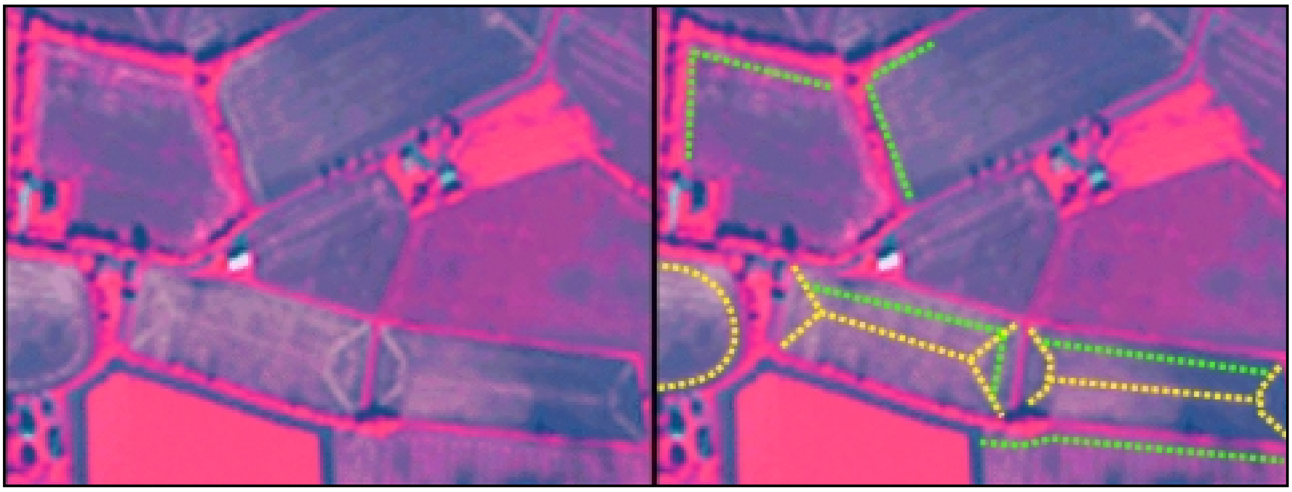


Fig.11 *Fields with symmetrical features caused by cultivation methods (left). To the right the features are represented by broken lines (IKONOS - copyright: Space Imaging).*

6.e Results – and strategy

The results of the field inspection show that, with the exception of a large number of registered mounds with bases composed of bedrock and some registered stone-built mounds, there are no registered prehistoric cultural heritage sites in the area which lacks tree-cover, the project's natural focus area.

That large amounts of cultural heritage sites (according to the analysis in Chapter 5) must have disappeared from the areas which lack tree-cover, strongly suggests that we are seeing what one might call 'the ruins of a cultural landscape'. A logical consequence of this conclusion was to focus the investigation on the unregistered anomalies in the agricultural fields, in order to, as far as was possible, begin the registration of what has been lost.

From a strategic point of view this had two consequences:

- In its initial phase the project could not benefit from data collected from a number of suitable and well-defined cultural heritage sites.

- Because the damaged mounds in the open fields appear to have been so efficiently levelled or removed, to the extent that no surface-level structural remains can be observed, and because settlements can be expected to be just as difficult to observe at this level, the development of an efficient, fast, and cheap methodology for identifying cultural heritage sites among the anomalies observed in the satellite data became more urgent than originally anticipated.

As a result of this, the chosen strategy for the initial development phase is to deal in detail with a restricted number of small-scale areas containing concentrations of promising anomalies, while at the same time pursuing a more extensive survey in order to identify new suitable small-scale areas.

Consequently, the fieldwork was focused on two locations where observable anomalies formed concentrations of features interpreted as potential cultural heritage sites.

7 Identification and verification of observed anomalies

7.a 'Lyby Mellom' farm

Relatively large amounts of surface finds dating from the Stone Age have been registered in the vicinity of the Lyby farms. East of the farm 'Lyby Mellom', 4 round/circular anomalies were observed with diameters ranging from 10 to 30 metres. In addition, our attention was caught by a large circular anomaly with a diameter of 140 metres. To the south of the three easternmost anomalies, a dark area was visible where the field was relatively high and dry and where no topographical features gave any meaningful explanation for the discoloration (Fig.12).

A series of parallel linear features running north-south, and a single linear feature running ESE-WNW were interpreted as the borders of previous smaller fields now amalgamated into a larger unit (Fig.12). This is documented by the aerial photo (Fig.13), which shows the situation in 1956 before the field boundaries were removed.

Several attempts were made to determine the character of the large feature, until in the autumn of 2002 a couple of informants remembered that the field had earlier been used for car racing by a group of locals.

Work in 2003 will focus on clarifying and documenting the character of the circular features in the eastern part of the area, which relate spatially to the dark area, as well as determining the character of the westernmost anomaly. During damp weather, water may accumulate to the north of the field boundary, which lies to the south of the westernmost anomaly, but this only accounts for the condition of its southernmost couple of metres. It is therefore assumed that the anomaly, which, apart from the aforementioned portion, seems fairly dry, is not a reflection of moisture.

Fig.12 *Four circular anomalies to the east of the farm 'Lyby Mellom' with diameters ranging from 10 to 30 metres interpreted as mounds (red arrows), and a large circular feature with a diameter of 140 metres (blue arrows). The white arrow marks a large stone in the field, which does not seem to be connected with the nearby circular anomaly. The black lines mark linear features that represent former field boundaries, which can be seen in the aerial photo from 1956 in Fig.13, taken in the direction indicated by the yellow arrow (IKONOS - copyright: Space Imaging).*

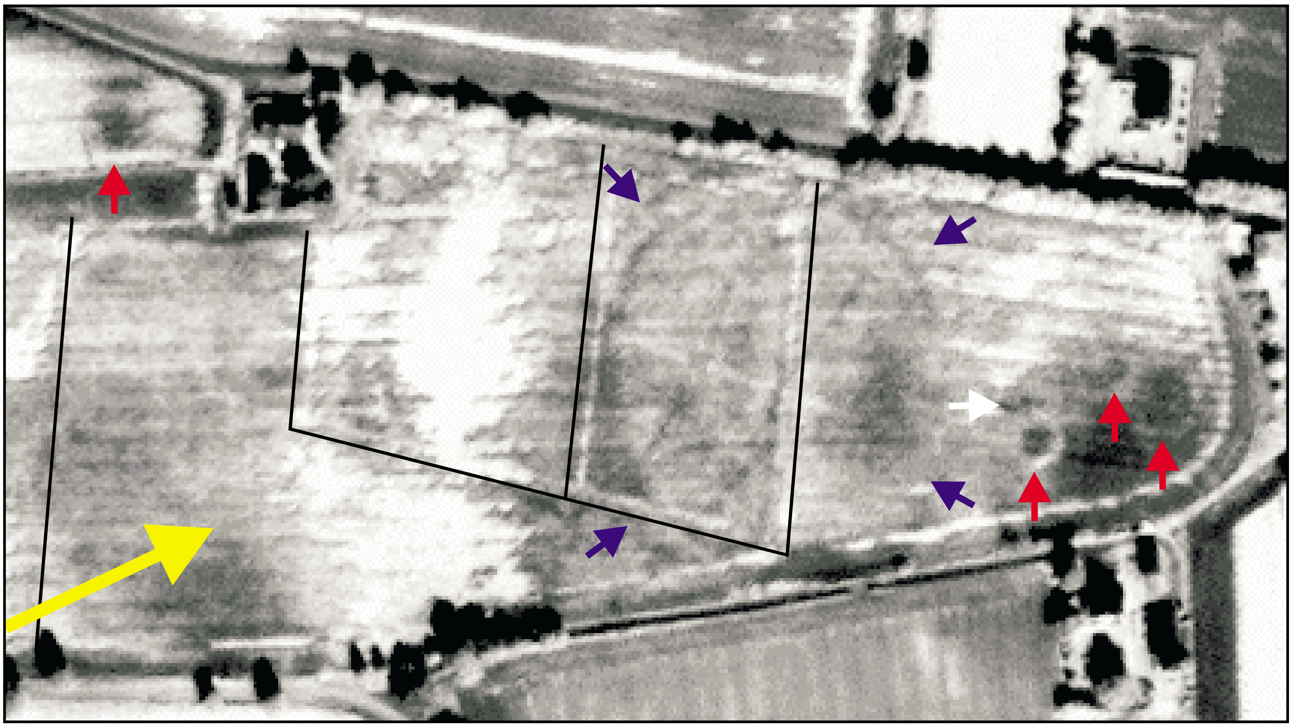


Fig.13 *Aerial photo from 1956 (Østfold fylkes billedarkiv, ØFB. 1995-310) (http://www.of.fylkesbibl.no /flyfoto/rygge/liste.html) showing the fields with five circular anomalies (Fig.12).*

7.b Gibsund farm

Gibsund farm is well known for the large number of important finds it has yielded which date from most of the prehistoric periods. What caught our attention in the IKONOS image was a series of dark discolourations in an area, which, according to the owners, had not been disturbed, at least as far back as they could remember. A dark feature in the northern part of the field seems to be associated with an area where marl was previously extracted. The circular anomaly in the northern corner of the field is interpreted as the remains of a mound (Fig.3, Fig.14).

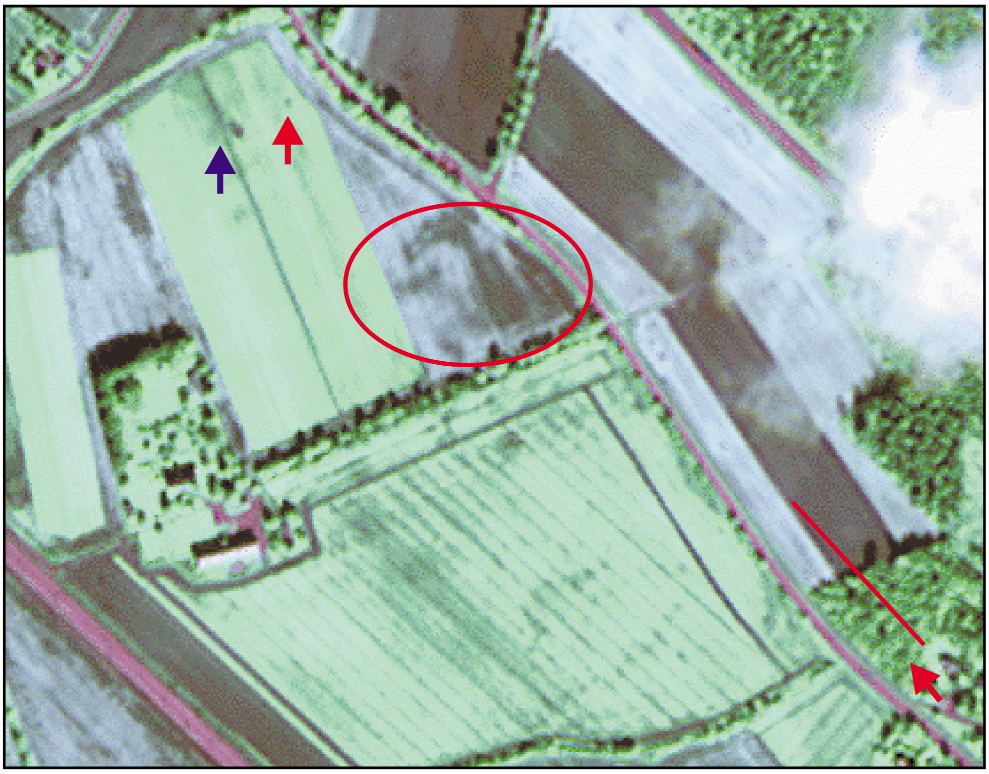


Fig.14 *Area with a series of dark discolourations, marked with red. The red arrow to the north marks an anomaly interpreted as a mound. The red arrow in the south-eastern corner shows the line of an old forest track, one phase of which seems observable as a dark line running to the west of, and parallel with, the red line. Another phase of this track seems to run along the boundary between two different crops in the same field and is therefore poorly visible. The blue arrow shows an anomaly related to an area probably disturbed by former marl extraction. A cloud covers the eastern part of the IKONOS picture (copyright: Space Imaging).*

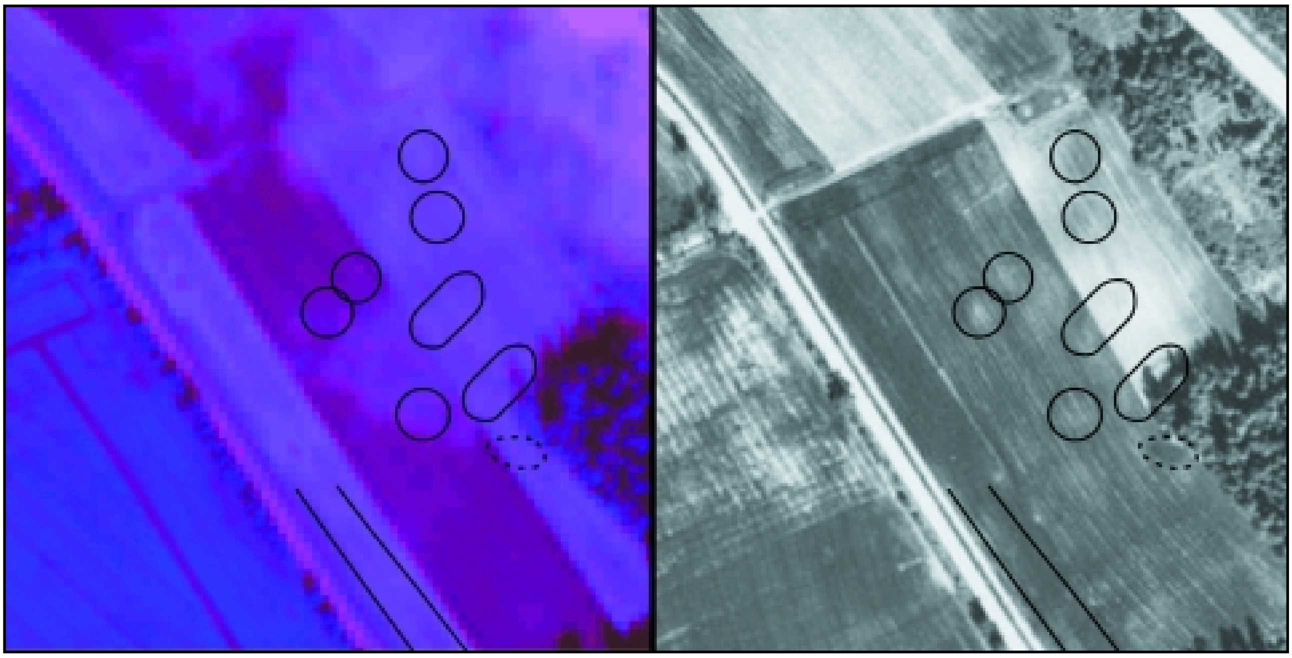


Fig.15 Comparison of the IKONOS image and the military aerial photo (Vertical photo 6360 B7 - Copyright: Fjellanger Widerø AS). None of the anomalies interpreted as mounds (circles) or houses (ovals) in the aerial photo can be distinguished in the part of the IKONOS image obscured by a cloud. Neither can the postulated Stone Age site (broken line oval). The linear feature interpreted as a phase of the old track outside the cloud-covered area is more visible in the IKONOS image (IKONOS - copyright: Space Imaging).

Several aerial photos have produced strong evidence for traces of a concentration of circular mounds, probably representing two houses or oblong mounds, in the area covered by a cloud in the available IKONOS image (Fig.15). Because of the concentration of anomalies and the variation displayed by them in this central area - factors making it an ideal laboratory for the development of identification methods- it was decided to focus on this area despite the fact that a cloud obscures an important part of it in the IKONOS image. Until better satellite data could be obtained it was decided to use the military aerial photo (6360 B7) as the basis for the investigation of the screened zone.

Chemical samples were taken in four profiles at intervals of 2 or 4 metres with a steel probe to see if there was any observable correspondence between the anomalies interpreted as cultural heritage sites and significant variations in mineral content of the soil. Special emphasis was placed on testing the suitability of phosphate and iron as indicators (Fig.16).

Profile 1.1 was positioned to cut through the possible settlement area, seen as a dark discolouration on the IKONOS image (Fig.16). A large concentration of phosphate coincides with the anomaly. One small maximum in the iron values coincided with its westernmost part and three with its easternmost part (Appendix - Profile 1.1).

Profile 1.2 cut the old track running NW-SE (Fig.16). A narrow zone with high phosphate values coincides with the proposed westernmost phase, whereas a broader and significant one coincides with the phase which apparently represents a direct continuation of the part of the deep track still preserved in the small forest immediately to the south of the field. An approximately 6-8 metre broad zone with significantly reduced iron values in the sediment below the plough soil (45 cm deep) may indicate a deep disturbance from a third, eastern phase (Appendix - Profile 1.2).

Profile 1.3 cuts through two anomalies thought respectively to be a mound and a house (Fig.16). Local maxima in the iron values coincide with both features but do not appear, in practical terms, outside their borders, apart from at the edge of the forest outside the field close to a small star-shaped cairn. Below the plough soil (45 cm), the phosphate values are low inside the postulated house, which may indicate that waste was cleared out from it, and that ploughing has blurred this feature in the overlying plough soil. The highest iron value inside this feature is also observed below the plough soil. Phosphate displays a significant local variation with several significant peaks in relation to the suggested mound (Appendix – Profile 1.3).

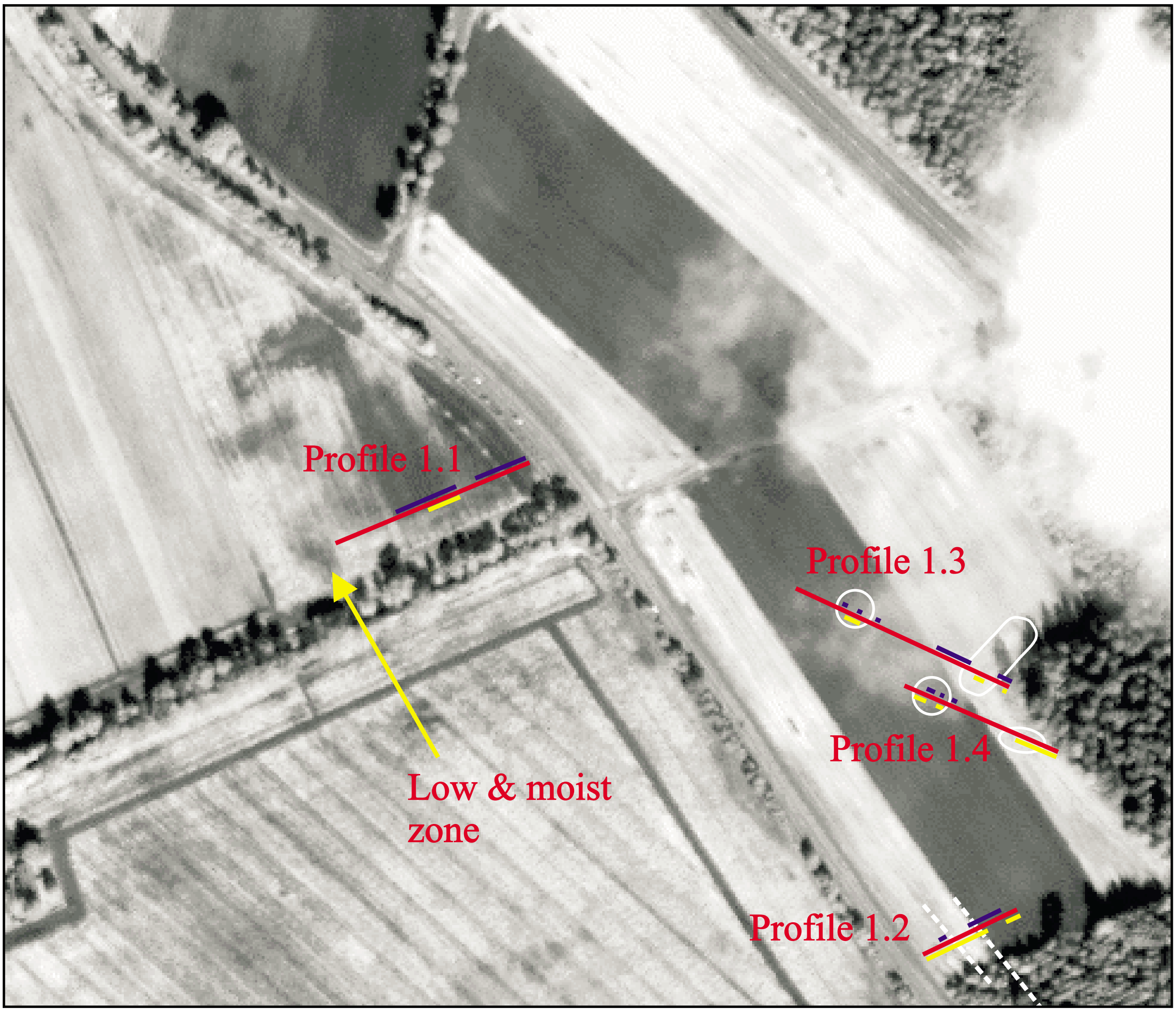


Fig.16 *The four chemical profiles from Gibsund, shown as red lines. Yellow shows local maxima in the concentration of iron (Fe3+) and blue shows local maxima in the concentration of phosphate (P). Anomalies interpreted as mounds are shown as white circles, a possible Stone Age site as a small white oval, two phases of a track as broken lines, and a possible house as a large white oval. Only the anomalies cut by the profiles are shown in this figure (see Fig.15) (IKONOS - copyright: Space Imaging).*

Profile 1.4 cuts through a proposed Stone Age site and another anomaly interpreted as a mound (Fig.16). The south-eastern end of the profile shows a relatively high value for iron just at the edge of the forest. High iron and phosphate values coincide with the central part of the possible Stone Age site. A pattern with several local maxima in the phosphate values and a central insignificant maximum in the iron values is again seen in relation to the anomaly interpreted as a mound. One local maximum in the phosphate values is found between these two features (Appendix – Profile 1.4).

A small concentration of worked flint was associated with the suggested mound in profile 1.4. Nothing was found around this, even though a careful survey was carried out. In the centre of the feature, in an area of a few square metres, there was humic soil to a depth of about 1 metre, whereas the natural clay lay at a depth of 50 cm outside the centre. This feature may reflect the existence of a central grave.

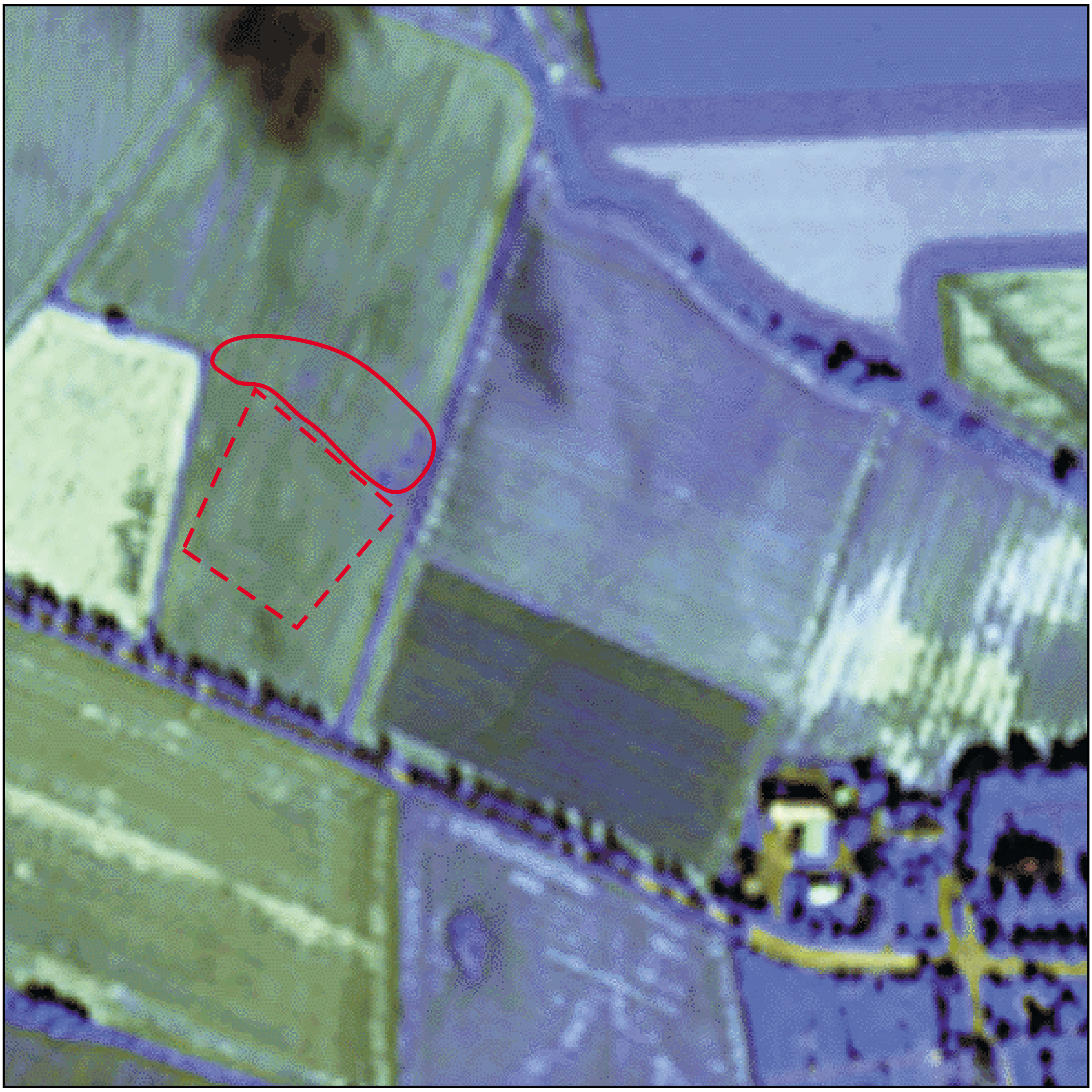
It is interesting that the two features interpreted as a house and a track respectively show the most significant variation in the chemical trace elements below the plough soil, whereas this is not the case with those interpreted as mounds. This may reflect that the former may have extensive structural features preserved below the plough soil, whereas this is not the case with the latter.

7.c Rygge church

An interesting area coming into focus is the zone immediately around the church at Rygge. The present building goes back to the twelfth century, but is unlikely to be the first to be built on the site. It is located on the highest hill in the nearby area. The second highest hill in the area lies a few hundred metres to the WNW of it. Small patches a few metres across, and a rhombic feature that may represent the borders of an old field or something else, were observed on its top (Fig.17). A check revealed that charcoal is being ploughed up on the top of the hill, and that a 'church-builder myth' is associated with this hill.

As there appears to be a concentration of small anomalies around the church, further investigation of this area is planned.

Fig.17 *Inside red line: small anomalies a few metres across. A rhombic feature – possibly an old field – marked with a broken red line. Rygge church is in the lower left-hand corner (IKONOS - copyright: Space Imaging).*



8 Conclusion

The pilot project period has been both exciting and frustrating. In such an early phase of complex methodological development, one often has to reconsider approaches and strategies. The main aim is to come up with results that demonstrate that further development along planned lines will pay off, both for investors and potential users.

The pilot period has demonstrated that the use of satellite data is not without its problems. Clouds may obscure important areas. This is particularly problematical when one has to rely on only one satellite image per study area. At present, it is difficult to envisage a situation where multiple coverage with high-resolution multispectral images (IKONOS and finer) is available for the entire country. However, in the not-too-distant future, the availability of easy and reasonably cheap access to satellite data for users/customers will be an important criterion for success in the sector that produces them – as we have seen with all other types of modern technology. The Satellite Data Archive of the Norwegian Mapping Authority has an important future role to play here.

A couple of important goals have been reached in the project period 2001-2002. Preliminary – but tenable – documentation has been produced, which demonstrates that the decimation of cultural heritage in the open agricultural landscape is an undeniable factor. Generally speaking, archaeologists have been aware that something was wrong. The observed scale of destruction, however, is both surprising and alarming. It will be interesting to see whether the observations at Rygge can be extrapolated directly to other areas, or whether this area that is so rich in cultural heritage is, at the same time, an especially disastrous case.

It is satisfying to have achieved a successful start for the development of a methodology for the identification of observed anomalies as cultural heritage features – but this was also a necessary step towards further development. It would be of little interest to be able to distinguish a large number of anomalies in a cheap and efficient way if there was no efficient way of figuring out what they represent. An extensive database of unidentified anomalies would be an administrative and political burden that might easily lead to ignorance of problems relating to cultural heritage.

A strategic aspect arising from the project's experiences is that one should not focus on areas that are too large in such an initial developmental phase, because one has to rely heavily on a network of local informants to attain an efficient first-phase sorting of the observed anomalies. For the development of future automated procedures, the collection of examples of anomalies which do not represent cultural heritage features, will probably be of high value.

Hopefully, this report has shown that the methodological development in question does not lead to the exclusion of either the use of aerial photos nor traditional fieldwork as valuable sources of information. The point is not to be exclusive, but to demonstrate the sense in adding a new and advantageous type of information to those which are already in widespread use. Apart from representing a step forward for the cultural heritage sector itself, the general usefulness of multispectral methodologies will undoubtedly motivate a general increase in interdisciplinary activities involving all the landscape-related disciplines.

Norway is not the only country that can benefit from high-resolution multispectral satellite images. Developing and perfecting a methodology that allows the cultural heritage sector to benefit from multispectral techniques is such a demanding task that a supra-national co-ordination of the various national initiatives in this field should be seen as a necessary and natural requirement.

The current project has demonstrated the usefulness of satellite images for up-to-date cultural heritage management. In order to provide a solid basis for a national strategy for mapping and monitoring cultural heritage sites, it is necessary to continue this pilot project, with particular emphasis on: a) continuing the detection of anomalies in the satellite images, b) further investigation of the use of geo-chemical trace elements in the identification of anomalies observed in satellite images, and c) starting the application of pattern recognition to the interpretation of these anomalies. In strategic terms, the continuation of work in the existing study area is seen as valuable, but it is also important to start including data from one or two areas with a more moderate impact from agriculture.

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Apendix –
Chemical data from profiles 1.1 – 1.4.

Profile 1.1

UTM-E: 59-	8757	8753	8750	8746	8742	8738	8735	8731	8727	8724	8720	8716	8712	8709	8705	8701	8697	8694	8690	8686	8683	8679	8675	8671	8668	8664
UTM-W: 658	4634	4633	4631	4630	4628	4627	4625	4624	4622	4621	4619	4618	4616	4615	4613	4612	4610	4609	4607	606	4605	4603	4601	4600	4598	4597
Distance (m)	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	100
P (ppm)																										
Point	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y	Z	Æ
5 cm	556	569	484	559	517	617	472	558	625	598	592	528	548	536	525	514	558	470	555	409	441	406	388	428	406	414
30 cm	445	436	498	472	538	505	509	452	444	472	494	433	447	450	463	388	433	431	406	388	309	356	348	378	381	375
45 cm	505	344	455	397	481	377	242	252	242	311	298	305	317	423	245	295	325	281	195	131	138	211	119	238	195	355
																	411		316							
Average	502	449	479	476	512	499	408	420	437	460	461	422	438	470	411	399	432	394	368	309	296	324	285	348	328	381
Fe^{3+} (‰)																										
Point	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y	Z	Æ
5 cm	0,43	0,41	0,39	0,33	0,38	0,41	0,36	0,39	0,41	0,45	0,40	0,41	0,41	0,42	0,40	0,38	0,39	0,29	0,32	0,25	0,26	0,21	0,26	0,30	0,41	0,40
30 cm	0,43	0,36	0,31	0,29	0,31	0,33	0,32	0,39	0,40	0,43	0,45	0,39	0,44	0,42	0,38	0,36	0,37	0,34	0,33	0,29	0,26	0,26	0,26	0,31	0,41	0,46
45 cm	0,61	0,28	0,26	0,26	0,35	0,27	0,32	0,29	0,36	0,43	0,26	0,25	1,00	0,45	0,29	0,33	0,33	0,23	0,12	0,12	0,15	0,18	0,12	0,53	0,19	0,25
																	0,77		0,26							
Average	0,49	0,35	0,32	0,29	0,35	0,33	0,33	0,35	0,39	0,43	0,37	0,35	0,62	0,43	0,36	0,36	0,47	0,29	0,26	0,22	0,22	0,21	0,21	0,38	0,34	0,37

Dark zone adjacent to road

Profile 1.2

UTM E: 59-	8954	8958	8961	8965	8969	8972	8976	8980	8984	8987	8991		8995	8998	9002
UTM N: 658-	4386	4388	4389	4391	4392	4394	4395	4397	4398	4400	4401		4403	4404	4406
Distance (m)	0	4	8	12	16	20	24	28	32	36	40	42	44	48	52
P (ppm)															
	A	B	C	D	E	F	G	H	I	J	K	K/L	L	M	N
5 cm	583	672	753	552	594	550	766	659	795	783	689	727	595	603	694
30 cm	363	617	517	517	475	581	527	639	539	547	466	552	625	577	648
45 cm	366	463	366	333	239	397	419	573	513	670	498	545	364	489	456
	445														
Average	439	584	545	467	436	509	570	624	616	667	551	608	528	556	599
Fe3+ (‰)															
	A	B	C	D	E	F	G	H	I	J	K	K/L	L	M	N
5 cm	0,48	0,49	0,49	0,47	0,52	0,44	0,50	0,45	0,45	0,44	0,39	0,47	0,45	0,47	0,47
30 cm	0,40	0,44	0,47	0,50	0,53	0,46	0,44	0,45	0,45	0,48	0,37	0,44	0,44	0,49	0,45
45 cm	0,48	0,49	0,45	0,50	0,52	0,50	0,41	0,43	0,48	0,27	0,32	0,38	0,40	0,50	0,46
	0,47														
Average	0,46	0,47	0,47	0,49	0,52	0,47	0,45	0,44	0,46	0,40	0,36	0,43	0,43	0,49	0,46
		Track ?								Track ?					

Profile 1.3

	A	A/B	B	B/C	C	C/D	D	D/E	E	E/F	F	G	H	I	J	K
UTM E: 59-	9002		8998		8995		8991		8988		8984	8980	8977	8973	8970	8966
UTM N: 658-	4519		4521		4523		4524		4526		4528	4530	4531	4533	4535	4537
Distance (m)	0	2	4	6	8	10	12	14	16	18	20	24	28	32	36	40
P (ppm)	A	A/B	B	B/C	C	C/D	D	D/E	E	E/F	F	G	H	I	J	K
5 cm	269	266	278	564	700	734	683	691	673	709	833	844	747	809	889	689
30 cm	389	127	216	545	539	588	561	623	650	577	630	617	702	663	672	683
45 cm		338	248	463	539	245	445	458	478	542	552	511	577	650	648	908
Average	329	243	247	524	593	522	563	591	601	609	671	657	675	707	736	760
Fe^{3+} (‰)	A	A/B	B	B/C	C	C/D	D	D/E	E	E/F	F	G	H	I	J	K
5 cm	0,79	0,38	0,36	0,46	0,47	0,48	0,45	0,48	0,46	0,45	0,43	0,46	0,45	0,43	0,39	0,44
30 cm	0,66	0,62	0,42	0,50	0,52	0,52	0,48	0,50	0,46	0,47	0,46	0,43	0,46	0,38	0,41	0,49
45 cm		0,99	0,76	0,49	0,44	0,55	0,79	0,49	0,44	0,36	0,45	0,31	0,42	0,42	0,46	0,44
Average	0,73	0,66	0,51	0,48	0,48	0,52	0,58	0,49	0,45	0,42	0,45	0,40	0,44	0,41	0,42	0,46

	P	R	S	T	T/U	U	U/V	V	V/X	X	X/Y	Y	Y/Z	Z	Z/Æ	Æ	Ø	Å	AC
UTM E: 59-	8948	8941	8937	8934		8930		8927		8923		8919		8916		8912	8909	8905	8894
UTM N: 658-	4545	4549	4551	4552		4554		4556		4558		4559		4561		4563	4564	4566	4568
Distance (m)	60	68	72	76	78	80	82	84	86	88	90	92	94	96	98	100	104	108	120
P (ppm)	P	R	S	T	T/U	U	U/V	V	V/X	X	X/Y	Y	Y/Z	Z	Z/Æ	Æ	Ø	Å	AC
5 cm	766	811	1044	963	848	706	747	752	878	866	727	867	788	780	903	798	830	822	847
30 cm	720	747	652	688	723	652	655	652	731	956	586	803	738	797	725	683	455	347	650
45 cm	611	589	623	561	566	633	464	358	573	738	656	673	661	541	586	609	694	516	720
Average	699	716	773	737	713	664	622	587	728	853	656	781	729	706	738	697	659	561	739
Fe^{3+} (‰)	P	R	S	T	T/U	U	U/V	V	V/X	X	X/Y	Y	Y/Z	Z	Z/Æ	Æ	Ø	Å	AC
5 cm	0,41	0,45	0,42	0,48	0,50	0,43	0,49	0,42	0,52	0,47	0,53	0,52	0,50	0,48	0,53	0,50	0,51	0,53	0,45
30 cm	0,52	0,44	0,43	0,45	0,50	0,44	0,47	0,51	0,55	0,55	0,49	0,52	0,41	0,49	0,49	0,49	0,44	0,28	0,44
45 cm	0,48	0,38	0,39	0,36	0,41	0,55	0,56	0,49	0,52	0,50	0,51	0,48	0,50	0,34	0,48	0,43	0,44	0,52	0,46
Average	0,47	0,42	0,41	0,43	0,47	0,47	0,51	0,47	0,53	0,50	0,51	0,51	0,47	0,44	0,50	0,47	0,47	0,44	0,45

Grass outside field | Anomaly - house ?

Approximate extension of anomaly interpreted as a mound

Profile 1.4

UTM E: 59-	9016	9013	9009	9006	9002	8998	8995	8991	8988	8984	8981	8179	
UTM N: 658-	4490	4492	4493	4495	4497	4499	4500	4502	4504	4506	4507	4508	
Distance (m)	0	4	8	12	16	20	24	28	32	36	40	44	46
P (ppm)	A	B	C	D	E	F	G	H	I	J	K	L	L/M
5 cm	570	617	769	783	780	848	839	903	984	814	775	795	755
30 cm	456	548	592	628	653	638	645	670	706	706	697	689	642
45 cm	366	423	441	605	830	764	464	438	667	538	491	481	438
Average	464	530	601	672	754	750	661	670	786	686	654	655	611
Fe3+ (‰)	A	B	C	D	E	F	G	H	I	J	K	L	L/M
5 cm	0,53	0,60	0,61	0,56	0,58	0,64	0,55	0,54	0,52	0,51	0,52	0,47	0,48
30 cm	0,54	0,59	0,52	0,53	0,55	0,53	0,51	0,57	0,49	0,50	0,52	0,47	0,48
45 cm	1,11	0,58	0,59	0,61	0,84	0,68	0,54	0,59	0,51	0,41	0,44	0,45	0,48
Average	0,73	0,59	0,57	0,57	0,65	0,62	0,53	0,57	0,51	0,47	0,49	0,46	0,48

UTM E: 59-	8975		8972		8968		8965		8961		8958	8954
UTM N: 658-	4510		4512		4513		4515		4517		4518	4519
Distance (m)	48	50	52	54	56	58	60	62	64	66	68	72
P (ppm)	M	M/N	N	N/O	O	O/P	P	P/Q	Q	Q/R	R	S
5 cm	836	811	805	1048	688	920	848	655	853	780	728	763
30 cm	616	723	736	606	638	606	570	663	581	570	577	536
45 cm	581	523	580	511	398	456	511	467	436	413	472	470
Average	678	686	707	722	574	661	643	595	623	588	592	590
Fe3+ (‰)	M	M/N	N	N/O	O	O/P	P	P/Q	Q	Q/R	R	S
5 cm	0,49	0,49	0,46	0,45	0,40	0,48	0,44	0,44	0,50	0,50	0,50	0,46
30 cm	0,44	0,44	0,43	0,36	0,46	0,43	0,47	0,49	0,43	0,52	0,42	0,40
45 cm	0,43	0,44	0,39	0,35	0,46	0,50	0,40	0,38	0,35	0,31	0,37	0,45
Average	0,45	0,46	0,43	0,39	0,44	0,47	0,43	0,44	0,43	0,44	0,43	0,44

Pit ?

Approximate extension of anomaly interpreted as a mound

Dark zone - Stone Age site?

Conc. of worked flint (few)

The report is available on the internet at: http://www.riksantikvaren.no/

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