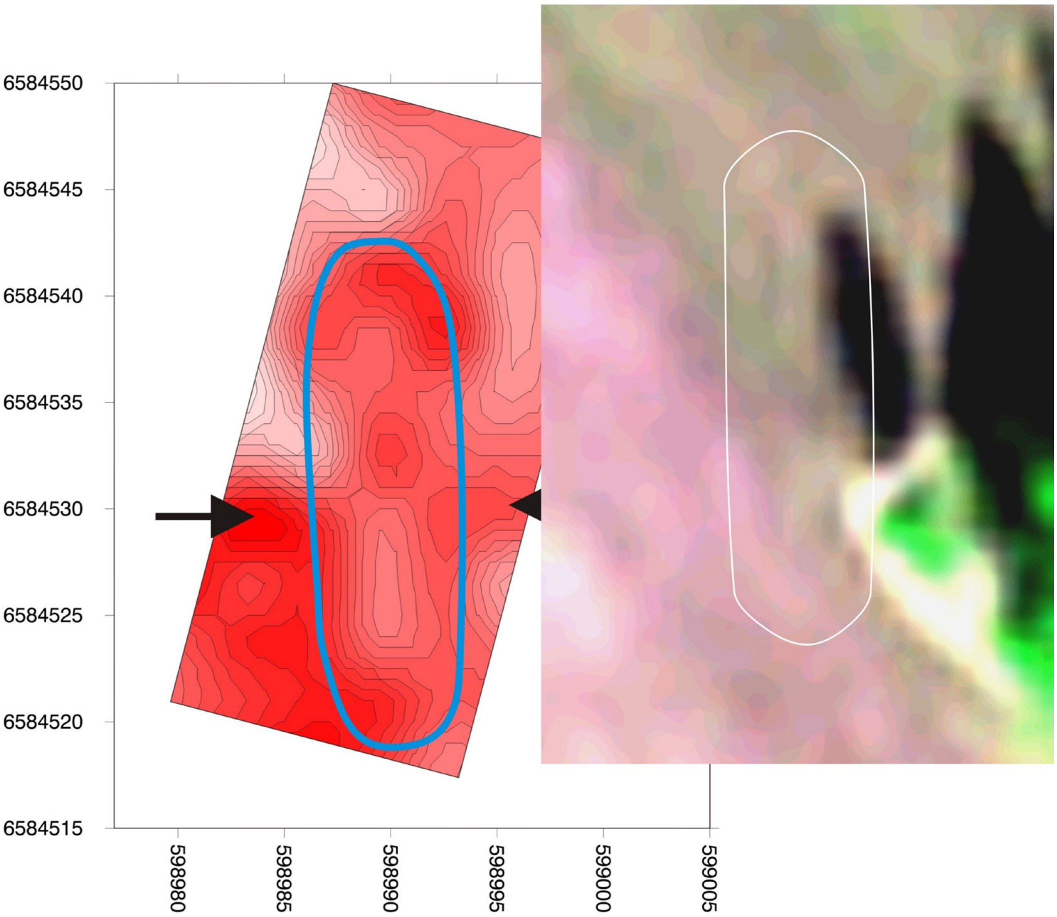
Locating invisible cultural heritage sites in agricultural fields

Development of methods for satellite monitoring of cultural heritage sites – report 2004



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1. Abstract

The increasingly intensive use and modification of the landscape as a result of modern demands for efficient infrastructure and land use (agriculture, 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 to a wide extent based on the results of expensive and technologically conservative methods of field observation, which underpin regional and national registers of cultural heritage sites. The content of these registers is therefore a non-representative sample of sites in respect to period and region, which includes only a fraction of the total of all those sites which should be included in management strategies. This lack of reliable data not only makes realistic forecasting a problem, but also causes costly delays and introduces unnecessary conflicts.

This project directly addresses these issues by initiating the development of a basis for a sustainable, up-to-date and cost-efficient decision-support methodology that relies upon satellite remote sensing for mapping and monitoring of cultural heritage sites. A central methodological element is the development of high-resolution geo-chemical ground data, which facilitate fast and cost-efficient verification of potential cultural heritage anomalies identified in the multispectral satellite data. Partial automatisation of the distinction of cultural heritage anomalies is attempted through the experimental application of pattern-recognition to the satellite data.

2. Introduction

2.a. Aims

The aims of the 2004 test project were:

- to look for relationships between anomalies visi ble in multispectral satellite data and ground fea tures that can be distinguished by soil chemistry,
- to evaluate the practical potential pattern recogni tion for locating cultural heritage sites,
- to obtain and interpret a new high-resolution sa tellite image (Quickbird) from the study area,
- to suggest a strategy for further national initiati ves in this field.

An additional point is:

- collaboration with and communication of the results to the local population, administration, and relevant cultural heritage societies and insti tutions in the study area.

As a cost-efficient support technology for the cultural heritage administration which can provide reliable information about the representative distribution of the different types of cultural heritage sites down to the small-scale level, the method under development should facilitate a significantly more efficient and flexible as well as cheaper planning process in relation to, for example, development projects than is possible today. An additional development of methods for monitoring the preservation status of the cultural heritage sites will add a further important facet to the administrative facilities.

2.b. The study area

The study area is an 11 by 11 km large square in Rygge Municipality, Østfold Fylke. In WGS-84 UTM coordinates this is 592626-603618 E, 6575139-6586131 N (system 32). It is a typical, intensively exploited, agricultural production area with a quite moderate topography in Norwegian terms. With the exception of a few salient ridges and rocks, the landscape is flat and hilly. Areas not occupied by fields and not covered by forests form an extremely limited proportion of the area.

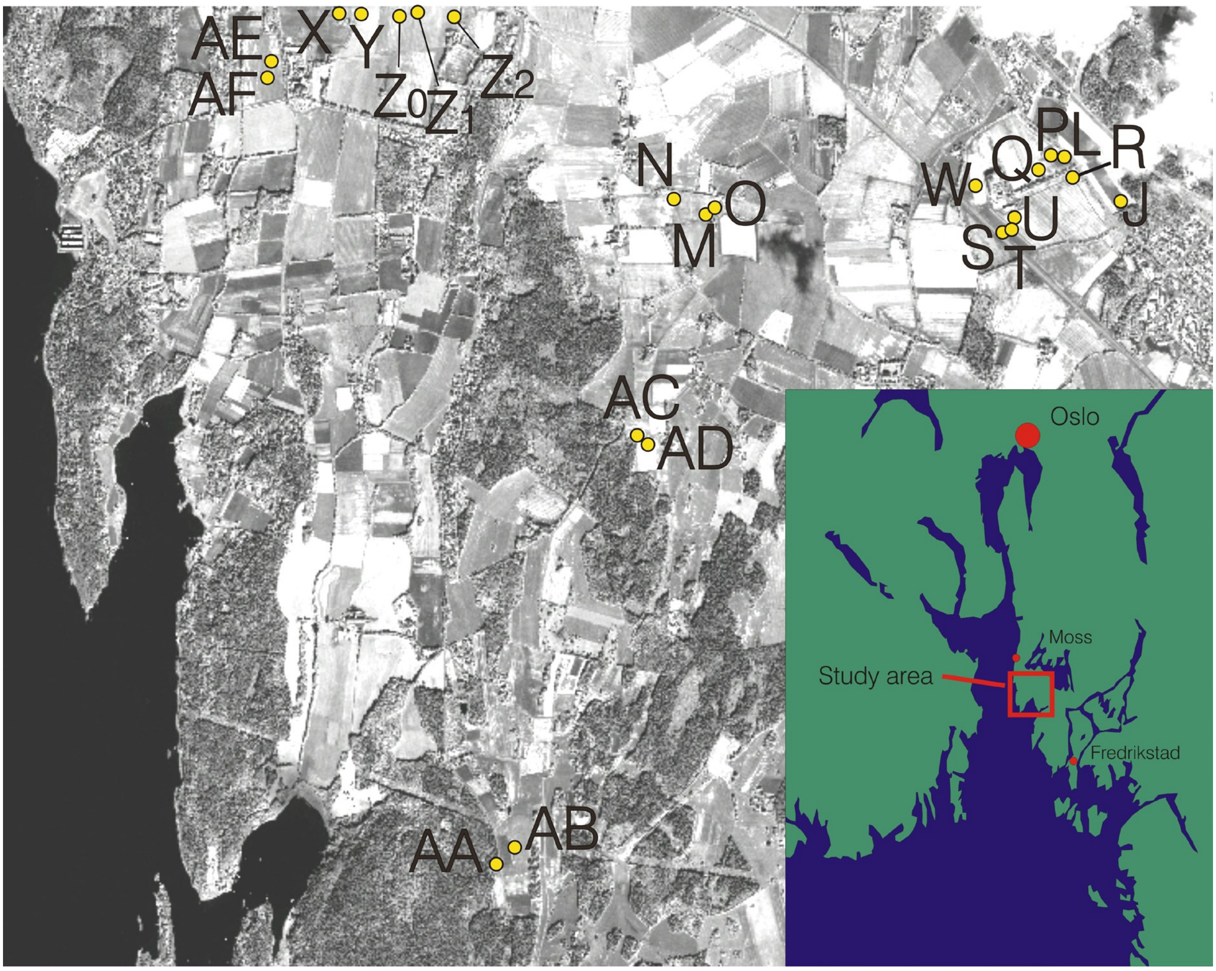


Fig. 1 The study area is approximately 11 by 11 km in size and covers a part of Rygge Municipality, Østfold County. The locations of the sites analysed are shown in the satellite image (IKONOS - copyright: Space Imaging and the Satellite Data Archive of the Norwegian Mapping Authority).

2.c. General background and introduction

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.

The most urgent problem in today's cultural heritage management is the unregistered 'invisible' cultural heritage sites located in the agricultural fields with no directly visible physical features preserved above ground. This group seems in the study area in Rygge to consist of at least twice the number of registered sites and most likely contains a large number of prehistoric houses/settlements, but also remains of earth-built burial mounds that have been systematically removed, roads, graves, different types of pits, etc. (Grøn and Loska 2002:15). In spite of their lacking visibility on the surface, such cultural heritage sites can have significant features preserved underground and represent an important potential for improvement of the understanding of the prehistoric cultural landscapes.

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 system, the Norwegian Directorate for Cultural Heritage (RA) and the Norwegian Space Centre (NRS) decided on the basis of a series of test projects (2001-2004) to prepare the ground for the development of a survey and monitoring methodology involving multispectral satellite data (Grøn and Loska 2002).

The project's aim is to develop a cost-effective method for locating/mapping and monitoring 'invisible' cultural heritage sites. The costs of systematically surveying areas of the scale involved here by means of conventional fieldwork provide 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 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.

Experiments conducted in the 2001-2002 campaigns indicated the existence of a significant correlation between cultural heritage sites and the variation in the chemical elements preserved in the soil. Ongoing development of the sampling strategy and the processing of the data indicate that it can be possible to distinguish a significant correspondence between observed anomalies representing the different types of cultural heritage sites and high-resolution geo-chemical ground data (chemical signatures). This opens for efficient and fast verification. The geo-chemical work has so far been focussed on burial mounds which form the predominant part of the register entries, but interesting results have also been obtained from anomalies supposed to represent prehistoric houses and old roads. A continued systematic investigation is planned of features such as fences, graves without mounds/cemeteries, pit-houses, wells, settlements without distinguishable structural elements (houses, wells, fences, …), etc.

The results suggest that high-resolution chemical sampling is a promising field for development of cultural heritage indicators. While geophysical methods such as GPRs (ground-penetrating radars) and magnetometers will give high resolution data relating to only one factor (reflection of radar signals or variations in magnetism, respectively), it is unlikely that they can be applied to all the relevant anomalies in the area. The geo-chemical survey applied to anomalies can provide data about the spatial variation of a number of different chemical factors in addition to basic information about the character of the sediments below the plough soil.

A second aim is to develop a partly automatised system for handling possible cultural heritage sites in multispectral satellite data. A crucial question in this connection is 1) to what degree pattern recognition can simplify and rationalise the manual/visual classification of cultural heritage sites, geological anomalies, and modern artificial anomalies and 2) how such a system can deal with cultural heritage sites that do not follow standardised patterns.

2.d. Project organisation and funding

The 2004-project was funded by The Norwegian Directorate for Cultural Heritage (RA)
http://www.riksantikvaren.no/
and The Norwegian Space Centre (NRS)
http://www.spacecentre.no/
and had additional project funding from the Institute of Archaeology, University College London (IoA UCL)
http://www.ucl.ac.uk/archaeology/
and the Norwegian Computing Centre (NR)
http://www.nr.no
UCL supplies the project with a chemical analysis capacity worth 2.7 mill NOK (Norwegian Crowns) per year.

Scientific project leader is Ole Grøn, IoA UCL. Administrative project leader is Anke Loska, RA. The steering committee consists of Guro Dahle-Strøm, NRS, and Anna Lena Eriksson, RA, (until Jan.1.2005) and Iver Schonhowd , RA, (from Jan.1.2005). The scientific project leaders act as counsellors for the steering committee.

The project participants are Ole Grøn, IoA UCL, Anke Loska, RA, Lars Aurdal, NR (Norwegian Computing Centre), and Finn Christensen, GK (GeoKem).

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.

3. Visual inspection, geochemical fieldwork and analysis

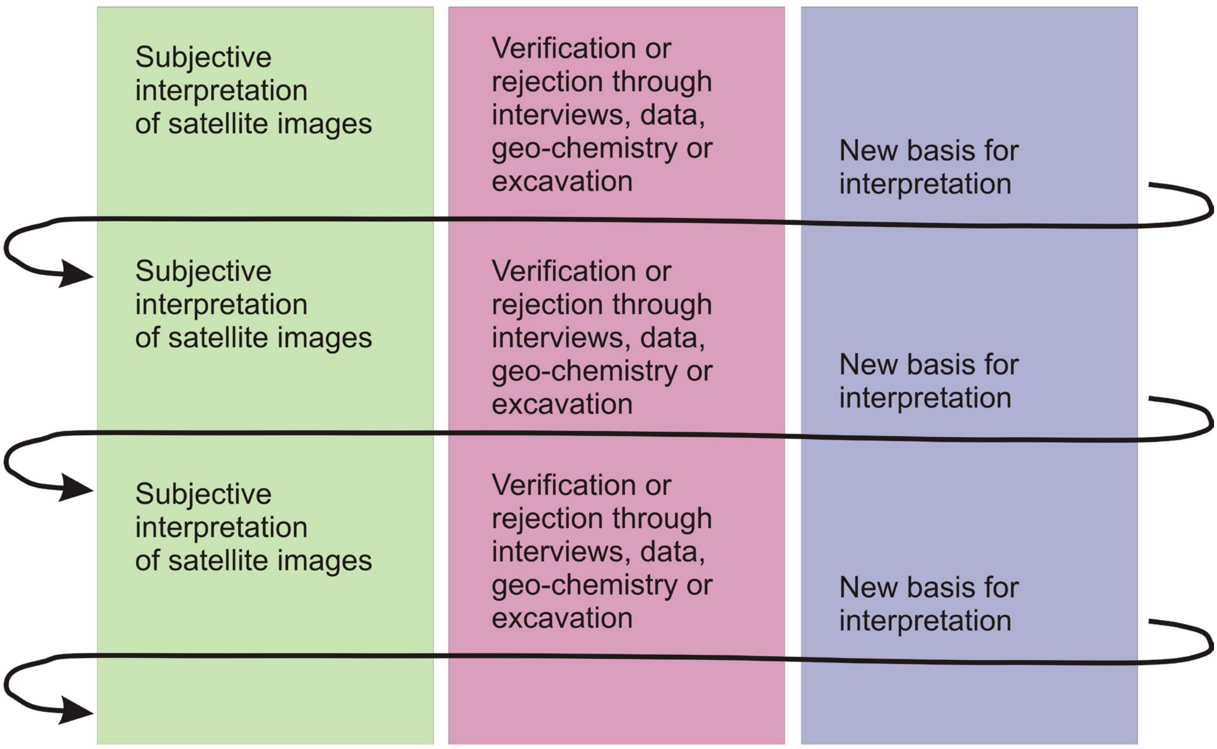
Ole Grøn, Finn Christensen, Richard MacPhail

This part of the project deals with what it is possible to extract of information about cultural heritage in the study area from multispectral satellite images by visual inspection. It addresses basic issues such as: what do cultural heritage sites of the different categories look like in multispectral high-resolution satellite images, in different seasons, in different types of vegetation/ no vegetation, etc., and how is it possible to carry out cheap and fast verification on the ground. Because application of high-resolution multispectral satellite-images to the mapping and monitoring of small-scale cultural heritage sites is a new field (Grøn et al. 2004b), it is necessary to take a basic approach in which the development of visual inspection can provide test-data for the development of the pattern recognition.

3.a. Development of the visual inspection

The acquisition of a new 64 square kilometre Quickbird scene of the study area with no clouds and very little vegetation in the fields (4.4.2004) demonstrated the importance of direct ground-reflection in the distinction of cultural heritage sites. Compared to the IKONOS scene from August 2000 and the Quickbird scene from June 2003 - both having large areas with dense vegetation cover - the latest scene apparently facilitates observation of much fainter anomalies in the fields.

Fig. 2 The interactive process used in the project to develop an increasingly 'objective' categorisation of the different types of cultural heritage anomalies, geological anomalies and anomalies reflecting modern activities observed in the satellite images on the basis of phases of subjective interpretation and verification.

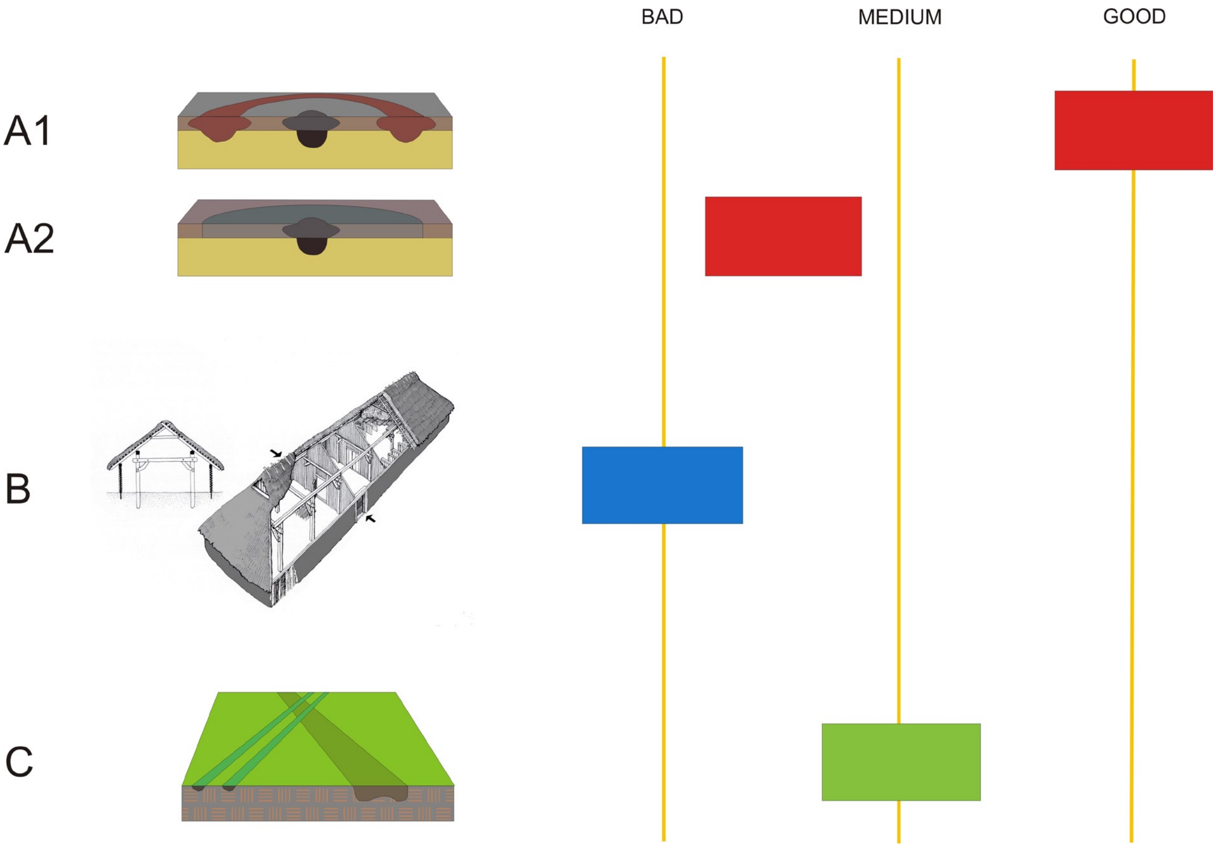


Even though the vegetation plays a role in lifting phosphates and heavy metals to the surface (Shaw 1990), the possibilities for observation of faint anomalies reflecting cultural heritage sites seem to increase with increasing direct ground-reflection and to decrease with increasing vegetation density in the fields.

The visual inspection of the satellite images is run as an interactive feed-back process with repeated interpretations based on visual inspections and manual processing of the satellite images, verification or rejection of distinguished anomalies through collection of new field data and the development and organisation of new experience as a basis for new interpretations (fig. 2).

Some types of anomalies are more visible than others. For instance mounds with a circular ditch around them are highly visible on a relative scale. Mounds with no circular ditch are generally relatively difficult to distinguish from, for example small-scale geological anomalies. Houses are generally very difficult to distinguish. Roads and tracks present medium difficulty (fig. 3). A further series of cultural heritage anomalies are under initial observation: graves without mounds, settlements without distinguishable features such as houses, old fences, wells, etc.

Fig. 3 The different visibilties in satellite images of some cultural heritage categories such as - A1: mounds with a circular ditch around them, A2: mounds with no circular ditch around them, B: houses and C: roads and tracks.



The field data consist of:

- Geo-chemical data from analysis of samples obtained from the anomalies investigated. The access to massive chemical analysis provides a unique platform for the development of reference areas with large numbers of known and verified invisible cultural heritage sites with well-mapped spatio-chemical features in Norway. For a future when the use of satellite-based hyper-spectral sensors able to distinguish minor changes in the chemical content of the surface may be anticipated, such areas will serve as an important basis for further development.

- Visual observations from the top of the sediments below the plough soil. During the sampling of the upper 2-3 cm of the sediments below the plough soil the character and colour of this material is registered. Variations can yield important information about the anomalies investigated. For instance, the appearance of a circular ditch filled with material with a high charcoal-content conjoining the observed outline of the anomaly will be a strong indication that it represents the remains of a burial mound (figs. 6,7).

- Observations of the relation between the landscape and the appearance of the different types of anomalies observed. These are observations done during the fieldwork of topographical and geological features, or observations from maps, archives and interviews with local informants about features that can be confused with cultural heritage anomalies.

Catalogue of features

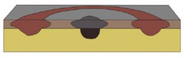
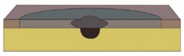
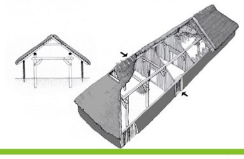
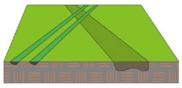
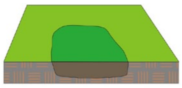
Type of sites	Reflectance, geometries, etc.	Chemical characteristics	Geology, landscape	Etc.
				
				
				
				
				
Etc.				

Fig. 4 The development of a 'catalogue' of the general features for each of the main types of cultural heritage sites is a precondition for what in the long perspective can develop into a partly automatised classification system.

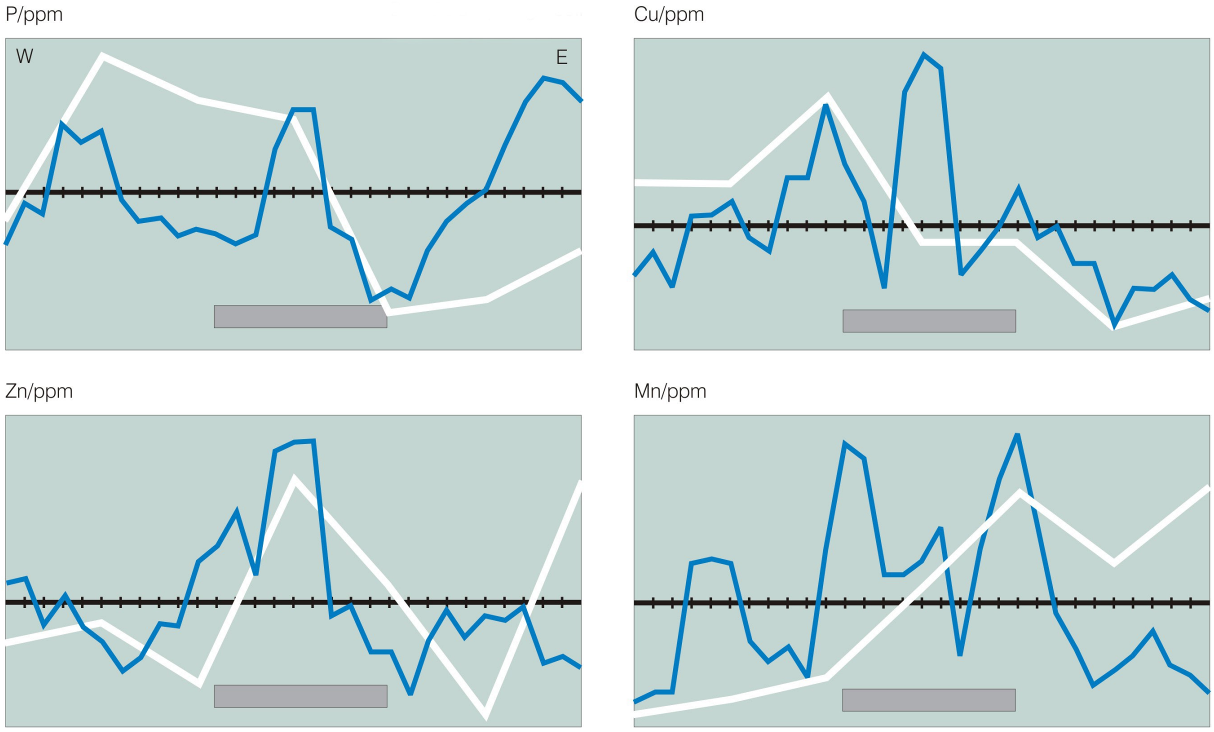
The results of the geochemical analysis are used as an increasingly important factor in the development of an ability to distinguish and correctly categorise faint anomalies that are difficult to observe. The distinction of a new type of cultural heritage site in the multispectral images can change a nd improve the visual inspection considerably. The results of the project's preliminary focus on faint anomalies seem promising with regard to localisation of the types of cultural heritage sites that seem to be lacking in the landscape on a common-sense estimate (houses, wells, infrastructure, etc.). It is important to obtain a realistic picture of these features as well, if one wishes to grasp the character of the original cultural landscape.

The development of a 'catalogue' of the general features for each of the main types of cultural heritage sites is a precondition for what in the long perspective can develop into a partly automatised classification system that can compete with the visual inspection of the images by a trained observer.

3.b. Geo-chemistry and sampling strategy

At an early stage of the development it became evident that a key factor was the geo-chemical sampling strategy. Several earlier attempts to distinguish a significant relation between archaeological sites and variations in the chemical composition of the soil had produced only meagre results, because the degree of variation at the small-scale level appears to have been underestimated. Even with samples taken at one-metre intervals in the sections a certain random variation around local averages can be observed. In the development of the graphical representations of the results, the application of a slight statistical standard-smoothing to the data has proved systematically to create images with a more consistent and significant relation to the anomalies in question (fig. 5). The value shown at each point represents the average of the value found at that particular point and of those found at the two neighbouring points; at the ends of a section the value represents the average of the value in the sampling point shown and the value from the neighbouring sampling point.

Fig. 5 Two different presentations of a section cutting an old road/track (Fig. 14, section J1, below the plough soil). The position of the road is shown as a dark grey rectangle in the lower part of the graphs. The white graphs show the relative variation around the average value (black horizontal line) if samples are taken for every fifth metre for Phosphates (u.l), Copper (u.r.), Zinc (l.l.) and Manganese (l.r.). The blue graphs show the relative variation around the average value if samples are taken for every metre. In spite of a slight statistical smoothing in the latter case it, is obvious that the blue graphs give a much better impression of the character of the significant local maxima related to the road and that the presentations by the white graphs are insufficient for a closer determination of the chemical features related to old roads.



For grid sampling a spacing of 2 m between the sampling points seems to provide a sufficiently precise picture of the spatial configuration of the chemical compounds analysed for in most cases (fig.12). Experiments are carried out with use of 1 m grids in what is regarded as especially important parts of larger 2 m grids to see if such a compromise can be used to improve significantly the spatio-chemical information obtained.

In the application of grid-sampling it is important to obtain a contrast area around the spatio-chemical features in focus. Because of the restricted analysis capacity and the delayed results in relation to the fieldwork it can be difficult to attain the optimal balance between minimising the number of samples and securing an adequate surrounding contrast zone. Fig. 12 shows an example of a 12 by 22 m grid that ought to have been extended both to the north and the south (it was not possible to extend it to the west). What was interpreted as one possible house-pit seems, according to the results of the analysis, to consist of two partly overlapping pits.

For each sampling point a material is taken for analysis from the plough soil and from the upper 2-4 cm of the upper part of the sediment below the plough soil. Especially in a development project it is important not only to know the chemical variation in the plough soil which is the basis for the reflection of the light recorded by the satellite scanners, but also to gain information about how the distribution of chemical components is affected by the ploughing, and how the signal looks from anomalies that are preserved solely in the plough soil in relation to anomalies with large chemical reservoirs preserved below the plough soil.

Observation of the sediment below the plough soil can in some cases contribute directly to the classification of the anomalies. In relation to three anomalies sampled with cross-profiles in 2004, the observations of circular ditches containing sediments with high charcoal content verified to a very high probability level their interpretation as mounds that had been removed. In two cases from 2004 the appearance of regular culture layer below the plough soil verified to a high level of probability the interpretation of two structures as dugout houses. In one case in 2003 (site H, Gipsund farm) the appearance of a regular culture layer below the plough soil indicated the presence of a dwelling pit at this Stone Age settlement (Grøn et al. 2004:23-26). At Værne Kloster (assumed mound AF) the appearance of modern remains reflected with a high degree of probability the former presence of the central heating facility for a series of large greenhouses located in the field in the last half of the 20th century.

The strategy for chemical sampling has been developed to consist of a first stage in which one or two profiles are used to distinguish the basic geo-chemical characteristics of a number of selected anomalies. In a second stage further samples are taken from promising anomalies in supplementary sections or in a grid that can elucidate spatial features.

Chemical sampling has some advantages in relation to other verification methods. Where GPRs have problems with penetration of clay and magnetometers have problems with certain types of subsoil, geo-chemistry can be applied under all circumstances where a covering sediment layer is present. Furthermore, the results provide information about the spatial appearance of a series of factors: the chemical components analysed for as well as the character of the sediment below the plough soil.

An important perspective in archaeological geochemistry is that hyperspectral satellite images (multispectral images with several hundreds of bands) in the future can be used for detailed analysis of the chemical composition of the top soil. With such systems calibrated in reference areas where the spatio-chemical features of a large number of cultural heritage sites have already been registered, such systems can furnish wide possibilities for cultural heritage management.

3.c The different types of monments

The number of types of cultural heritage sites dealt with in the project is slowly growing as the number of anomalies that are recognised in the available satellite images increases. It is considered important to develop the method so that it that can compensate for the skewed data in the existing registers, where mounds play a much too dominant role. The houses and settlements where people lived in prehistory, as well as the roads they travelled along, are important for the understanding of how the cultural landscape was organised. Still other types that can provide us with further detail about prehistoric behaviour are important to learn to distinguish and categorise.

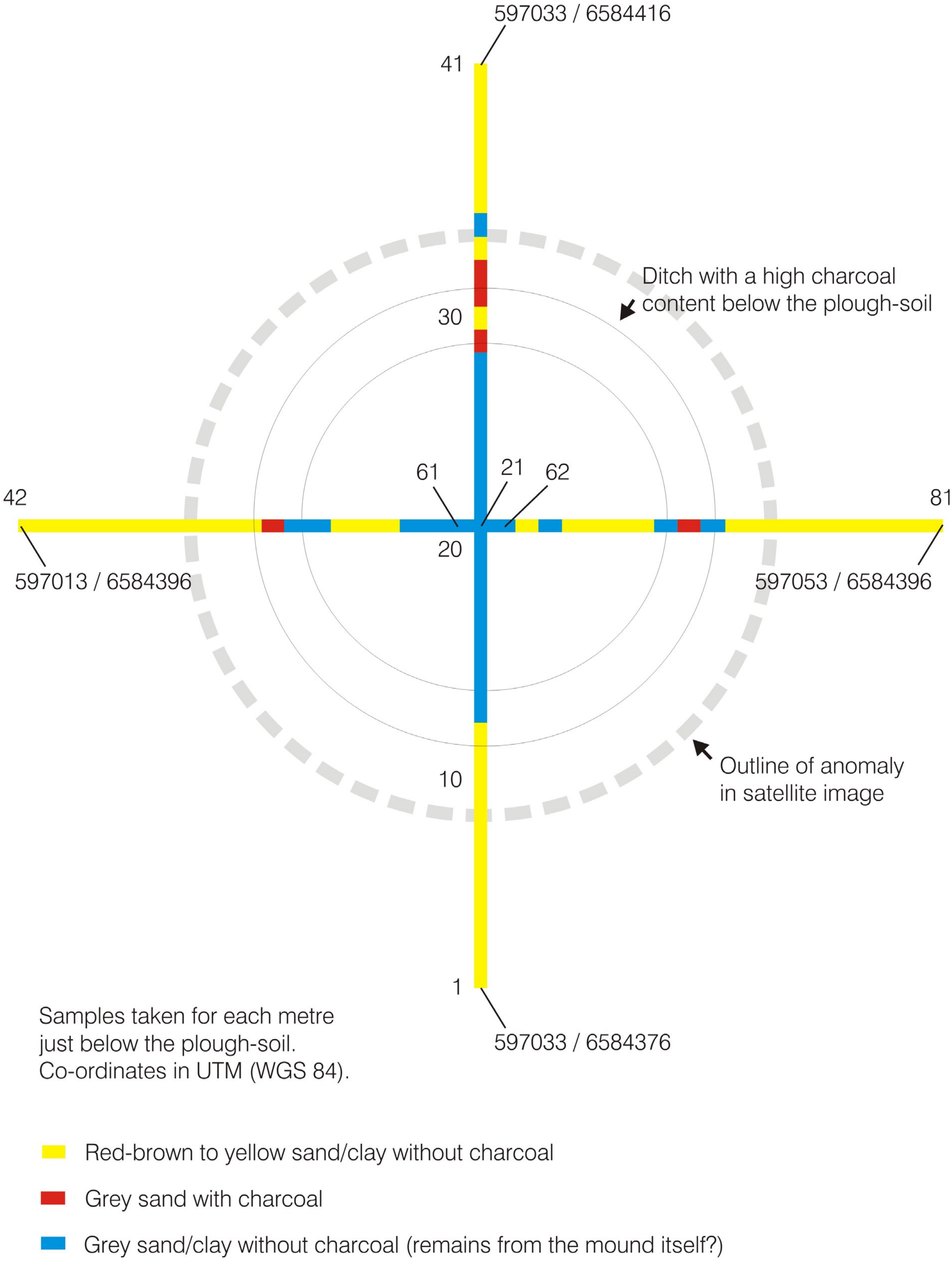
3.c.1. Mounds

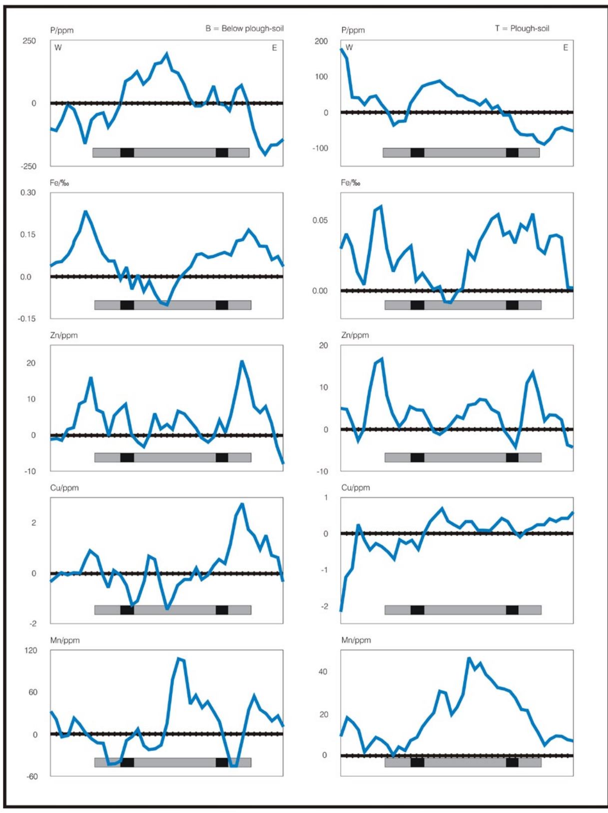
The tendency observed is that the central part of features supposed to be burial mounds has a relatively high content of phosphates in relation to their nearest surroundings (figs. 7,8). In 2004 seven anomalies (M, O, Z2, AC, AD, AE, AF) supposed to represent mounds were targeted. Observations of changes in the sediments below the plough soil made during the sampling verified with close to 100% probability three of them (M, O, AC) as mounds (e.g. figs. 6, 7). The single sections through AD and Z2 (fig. 8, left) look like what one would expect from mounds. The latter is interesting because its relatively low location in the landscape is atypical for the way mounds are thought to be located.

The N-S section through anomaly AE matches the outline of the suggested mound but shows no local phosphate maximum in its central parts (fig. 8, right), whereas the E-W section does not look like a mound at all. If AE represents a mound at all it must be heavily disturbed by the 100 m long greenhouses that stood in this field in the latter half of the 20th century. AF is most likely a modern anomaly: the central heating unit for the greenhouses in the same field as AE or a dump related to it.

Out of seven anomalies thought to represent mounds, three have been verified with close to 100% certainty as mounds with surrounding circular ditches and two as almost certain mounds without circular ditches. A further two are regarded as unlikely as a mound and as a modern feature, respectively. In future investigations it will be important to gather further data from mounds without surrounding circular ditches.

Fig. 6 Plan of the relation between the anomaly 'O' interpreted as a mound and the observations of the samples from below the plough soil in the two sections that demonstrate the presence of a surrounding circular ditch ploughed away in the southernmost part.





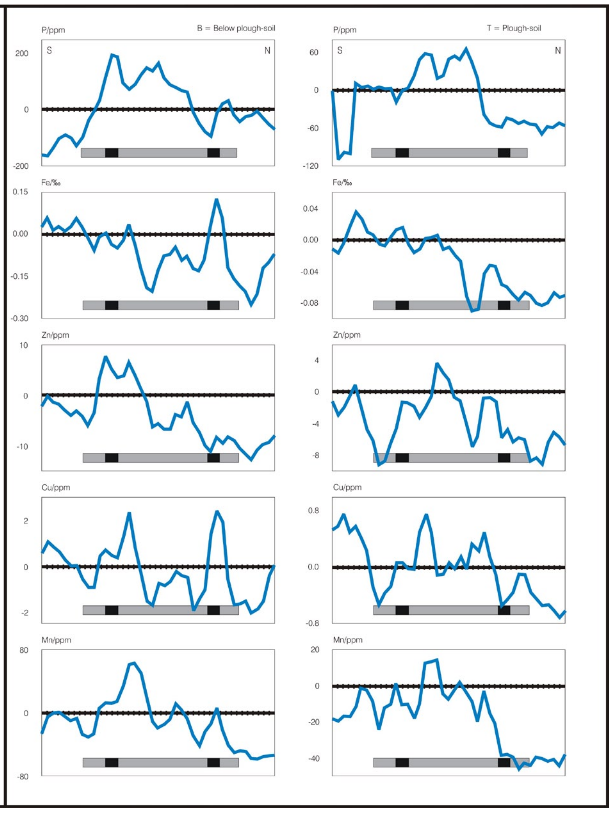
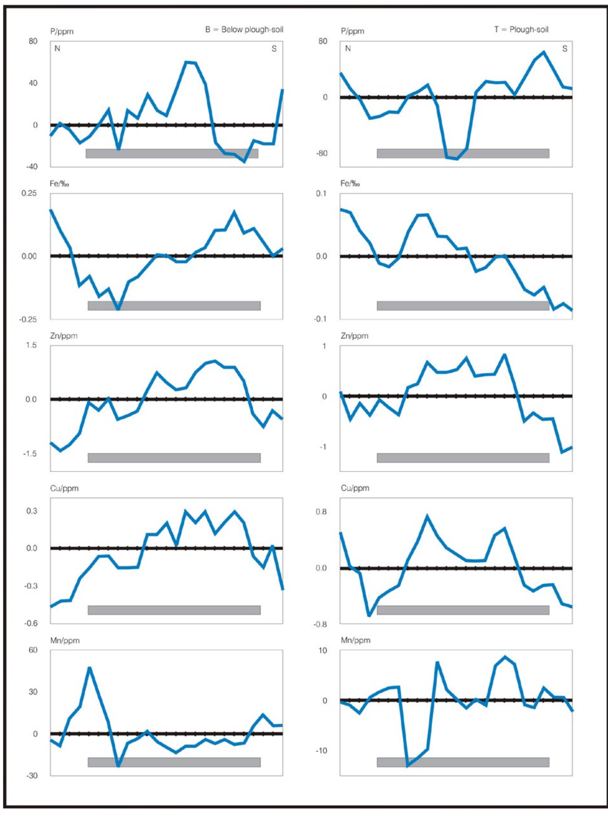


Fig. 7 The spatio-chemical features of anomaly O. In the left table the values from the E-W section and in the right the values from the N-S section. The values from the plough soil are to the right and those from below it to the left in both tables. The grey rectangle shows the extent of the mound as it was determined in the satellite images. The dark rectangles show the location of the circular ditch. The values are shown as variation around the average for the site.

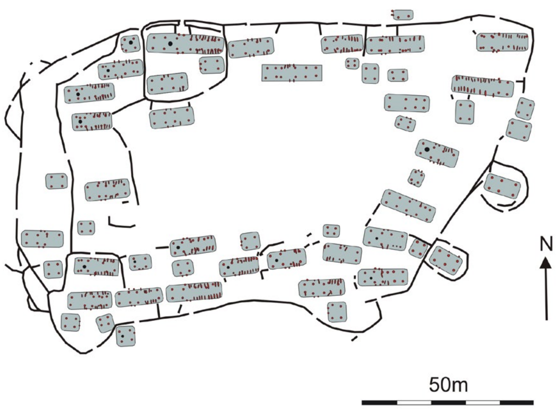
Fig. 8 In the left table the spatio-chemical features from the single N-S section through anomaly Z2. In the right table the features from the N-S section through anomaly AE that is likely to represent modern activities (greenhouses). The values from the plough soil are to the right and those from below it to the left in both tables. The grey rectangle shows the extent of the mound as it was determined in the satellite images. The values are shown as variation around the average for the site.



3.c.2. Houses

Parallel to the work on isolation of useful criteria for distinction of the dominant mound types, initial efforts have been directed at developing criteria for the distinction of prehistoric houses and old roads. Forming one of Norway's most fertile agricultural areas and with a large number of burial mounds, it is obvious that large numbers of people must have lived in the study area. With the dimensions of the prehistoric house types relatively well known (fig. 9) and with the wagons drawn by horses or oxen appearing in Scandinavia in the later part of the Stone Age (Neolithic), the reason for the lack of observed houses and roads is likely to be that they are difficult to distinguish in the images (e.g. figs.10,12,14). Therefore a search was launched for such faint anomalies.

A combined used of maximum zooming and screen modes showing the images as interpolated intensity levels on the basis of their pixel values instead of as square pixels (fig.10) led to the observation of a number of very faint features that on a preliminary basis were interpreted as very dubious houses. In several cases these features merged with the furrows from ploughing or the traces of other agricultural activities. Walls constructed of clay (wattle and daub) (fig. 9) or turf should be expected to appear as narrow zones outlining the houses with a mineral content differing from that in the immediate surroundings.



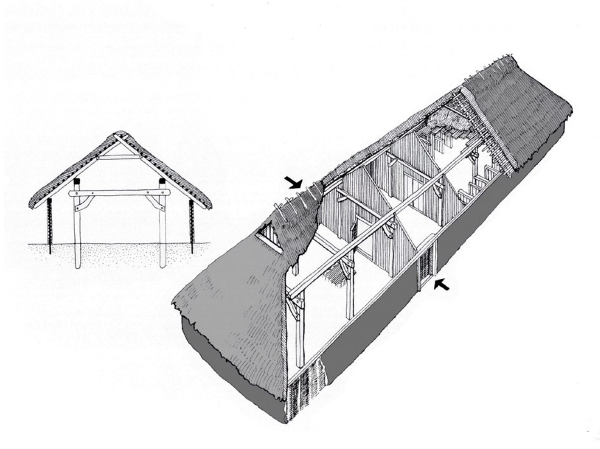


Fig. 9 One phase of the Danish Iron Age village Hodde (left) and the construction of an Iron Age house with wattle and daub walls (right).

Geo-chemical sections through the majority of the faint features tentatively interpreted as houses displayed characteristic similarities with the pattern observed at the features interpreted as two house pits at Børsebakke (houses AA)(fig.12) and as a house (house A) from Gipsund (fig.11). The concentration of phosphates was low inside these features but high outside them – a phenomenon thought to reflect that waste with high phosphate content was cleared out from the inside and dumped outside in good accordance with observations from excavated prehistoric houses as well as ethnographic observations of how such houses are used in living cultures.

Fig. 10 Four faint anomalies assumed to represent prehistoric houses shown with a screen setup using square pixels (left) and one employing interpolation between the pixel values (right). (Quickbird - copyright: Digital Globe and the Satellite Data Archive of the Norwegian Mapping Authority).

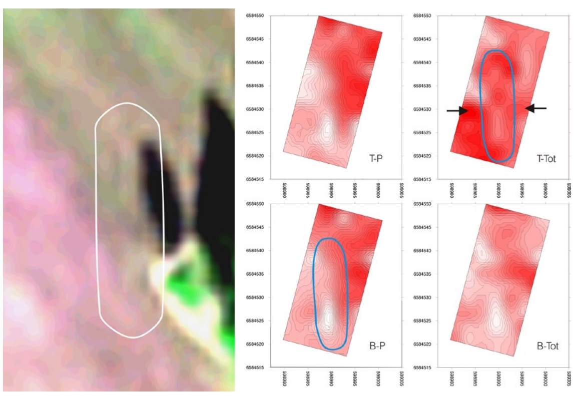


Fig. 11 Feature A, Gipsund Farm, interpreted as a house. Left: seen as a faint anomaly in the Quickbird image from 4.4.2004. Right: the feature was in 2003 grid-sampled. The distribution of phosphates to the left, and to the right the sum of the five chemical components equally weighted (upper – plough soil, lower - underground). The house appears as a significant local minimum with regard to phosphates and with a possible dumping area to the east. In the total, two concentrations may reflect the position of two entrances located as was common in many prehistoric houses. The supposed eastern dump starts at the suggested eastern door (fig. 9). The orientation of the house has been adjusted a bit in relation to the one given in a former report (Grøn et al. 2004: 8-11).). (Quickbird - copyright: Digital Globe and the Satellite Data Archive of the Norwegian Mapping Authority).

The concentration of prehistoric houses is found to be impressive in the parts of Northern Europe where systematic large-scale investigations have been carried out. The Danish Iron Age village Hodde is one of many well-known examples (fig. 9). On the basis of such observations it would be surprising if the fertile study area does not contain similar densities of houses (fig.10).

The promising results from house A, Gipsund Farm (fig.11), led to a further eight features interpreted as possible houses being tested with sections (L, P,Q, R,U, W1, W2, Z0, Z1), and one being grid-sampled (AA) in the 2004 campaign. The results are that four out of the section-sampled anomalies (L, P, R, Z0) are regarded as probably representing houses, three are regarded as doubtful (W1, W2, Z1), and one was because of an earlier erroneous interpretation placed between two anomalies that are at present interpreted as houses.

Taken into consideration how difficult these anomalies are to distinguish with present experience, such a result is promising. Two supposed houses (P, U) are planned to be grid-sampled in the 2005 campaign. Further activities along these lines are planned in 2006.

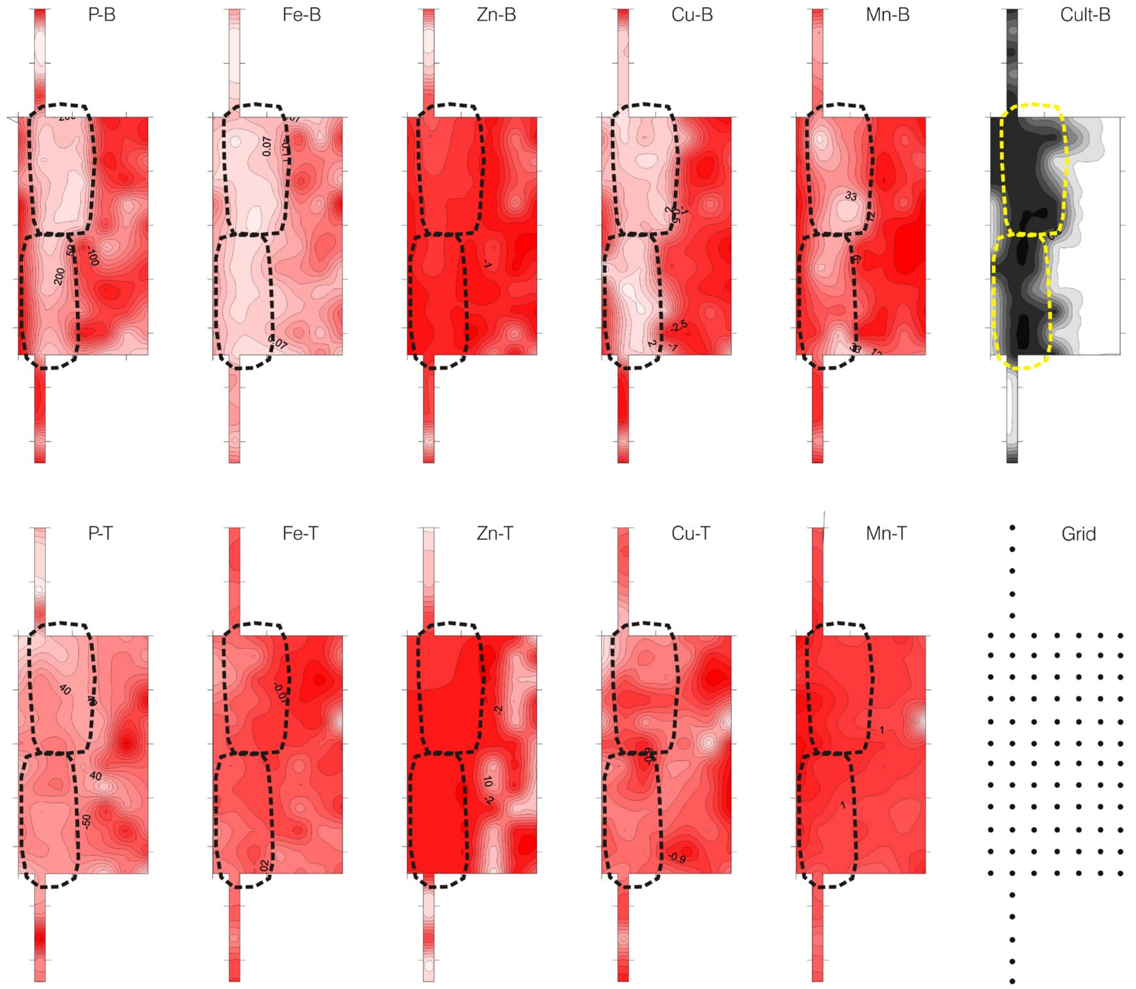


Fig. 12 Spatio-chemical features from an anomaly interpreted as two house-pits (houses AA, Børsebakke Farm) sampled with a 12x22m grid. The suggested outline of the houses is shown with a broken black line. The upper series of distributions is from the centimetres just below the plough soil the lower series from the plough soil (P = Phosphates, Fe = Iron, Zn = Zinc, Cu = Copper, Mn = Manganese). The black distribution upper right shows where dark culture layer could be observed in the upper 2-3 cm below the plough soil, during the sampling. Below it is a plan of the sampling points (the grid).

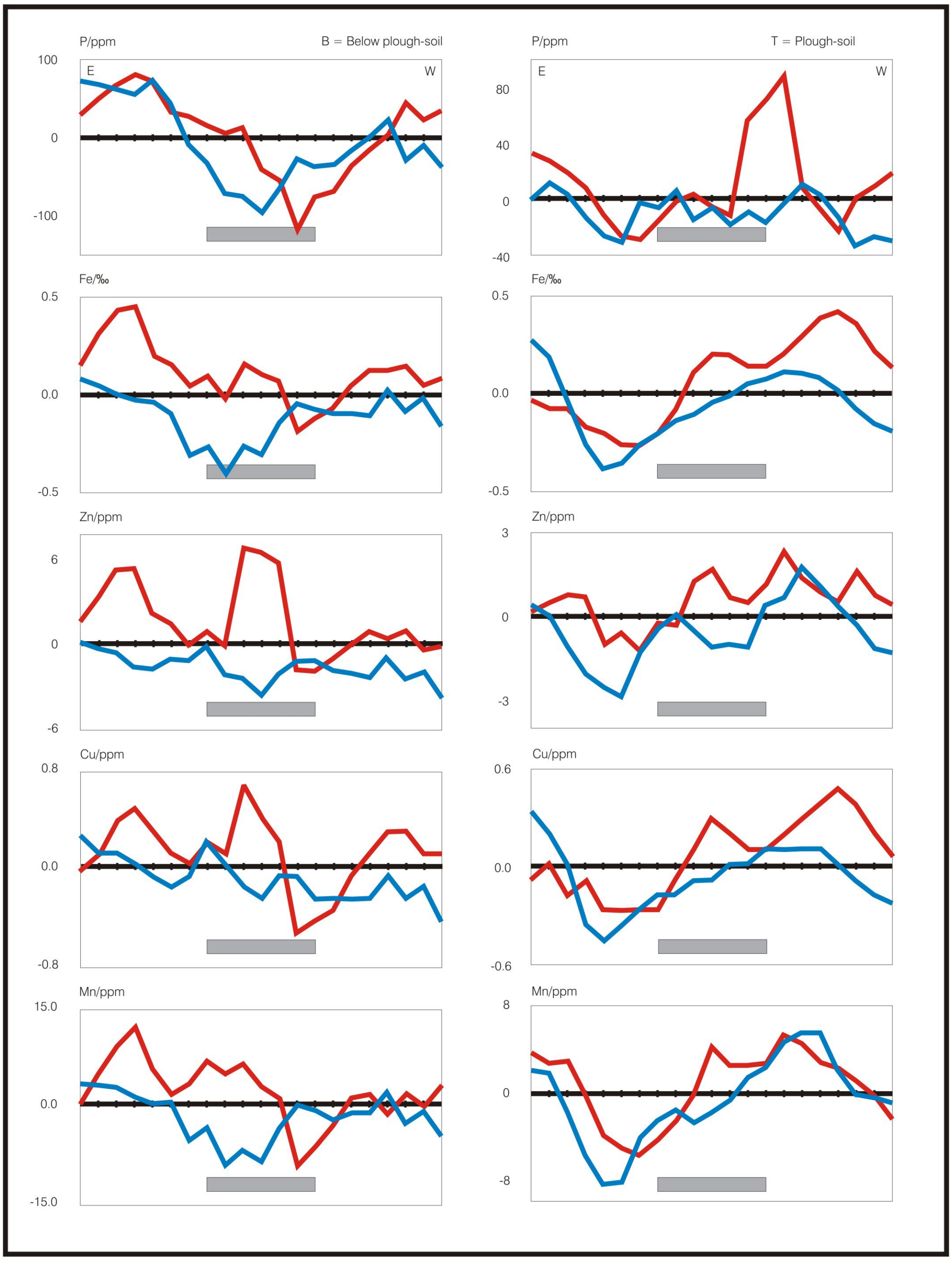


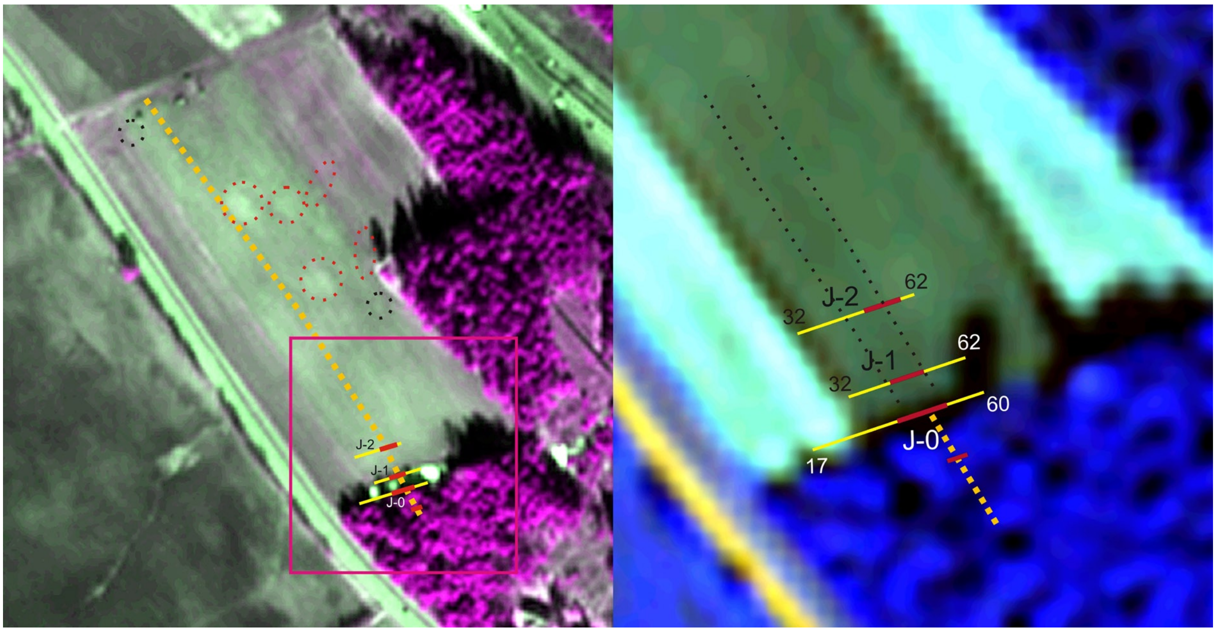
Fig. 13 The spatio-chemical features of the supposed house P. Two parallel E-W-sections through the feature. The values from the plough soil are to the right and those from below it to the left in both tables. The grey rectangle shows the extent of the suggested house as it was distinguished in the satellite images. The values are shown as variation around the average for the site.

The supposed House AA, Børsebakken Farm, appears as an easily observable anomaly in the satellite images. During the grid-sampling it became clear that sediment looking like a regular culture layer appeared below the plough soil (fig.11, Cult-B). The spatial configuration of this culture layer and the intensities of the different chemical components analysed for indicate a bipartite structure that is interpreted as the remains of two dugout houses. The nearest area around the feature has large numbers of finds from Late Neolithic/Early Bronze Age

3.c.3. Roads

It is the impression that old roads seem to be present where concentrations of houses or graves are observed. The work with this group of anomalies is in an early phase. Due to their linear character, it will be necessary to gather data that can facilitate a distinction between this type and other linear anomalies such as old field boundaries, drainage systems, etc. Roads and tracks will be a key factor in the understanding of the organisation of the culture landscape. A number of features that most likely represent old roads have been distinguished in other parts of the study area. A systematic investigation of these is planned to start in 2006.

Fig. 14 The linear feature at Gipsund Farm interpreted as an old sunken road. Left: the whole field in the Quickbird recording from April 2004 with chemically verified mounds, houses and settlements shown with red broken outlines and unverified anomalies with black broken outlines. The suggested road is shown as a yellow broken line. Right: A section of the field and the forest from the IKONOS image from August 2000. The preserved sunken road in the forest is shown as a yellow broken line and its faint continuation into the field with a broken black outline. The latter coincides with the signatures interpreted as road-indicators (fig. 15). Earlier chemical results indicate that the road is part of a road system consisting of a number of parallel tracks between which the road used for traffic has meandered through time (Grøn and Loska 2002). (IKONOS - copyright: Space Imaging, Digital Globe and the Satellite Data Archive of the Norwegian Mapping Authority).



Studies of the continuation of an old sunken road at Gipsund Farm (fig.14) with several sections perpendicular to its supposed continuation from the forest to the south where it is found preserved have produced interesting chemical results (fig.15). The significant peaks in the heavy metals are according to Richard MacPhail the result of the accumulation of animal dung in the track that bonds and therefore better preserves heavy metals than is the case in the surrounding areas (Richard MacPhail, personal communication).

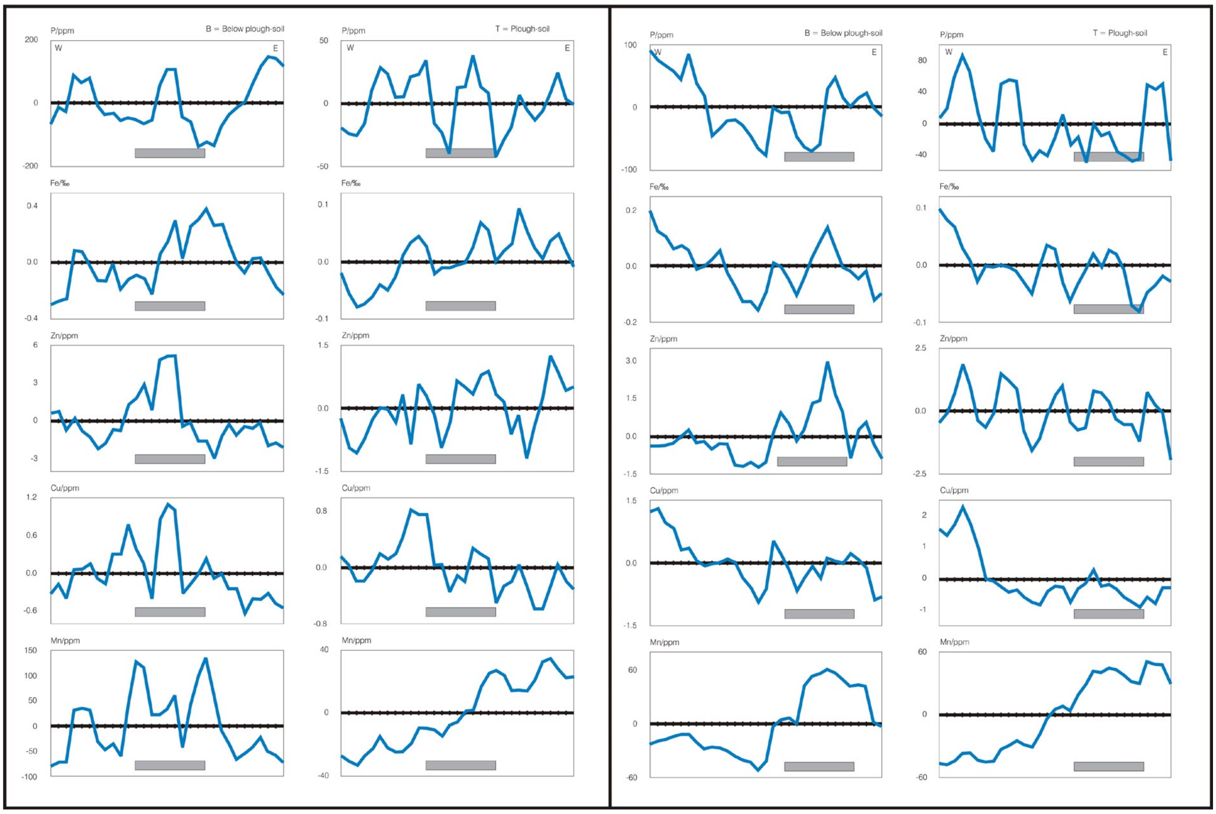


Fig. 15 The chemical results of the two 2004 sections (right: J1, left J2) cutting the anomaly interpreted as a continuation of a preserved piece of an old sunken road. The values from the plough soil are to the right and those from below it to the left in both tables. The grey rectangle shows the extent of the anomaly as determined in the satellite images. The values are shown as variation around the average for each location.

3.c.4. Settlements with no recognisable features

A group of anomalies that must be expected to be of high importance as well as difficult to categorise due to their similarity to geologically based anomalies and lack of observable standardised geometric elements comprise settlements with no recognisable features (houses, roads, fences, wells, etc.).

One such settlement dated to the Stone Age appeared in the satellite images as a blotch with no well-defined shape (site H, Gipsund Farm)(Grøn et al. 2004:23-27). Another – a Viking Age settlement – can be observed so-to-say post mortem in the IKONOS image from 2000. It was not recognised in advance of the construction of a new golf-course on the property of Evje Farm and was therefore destroyed with no systematic registration of the finds and preserved structures (fig.16).

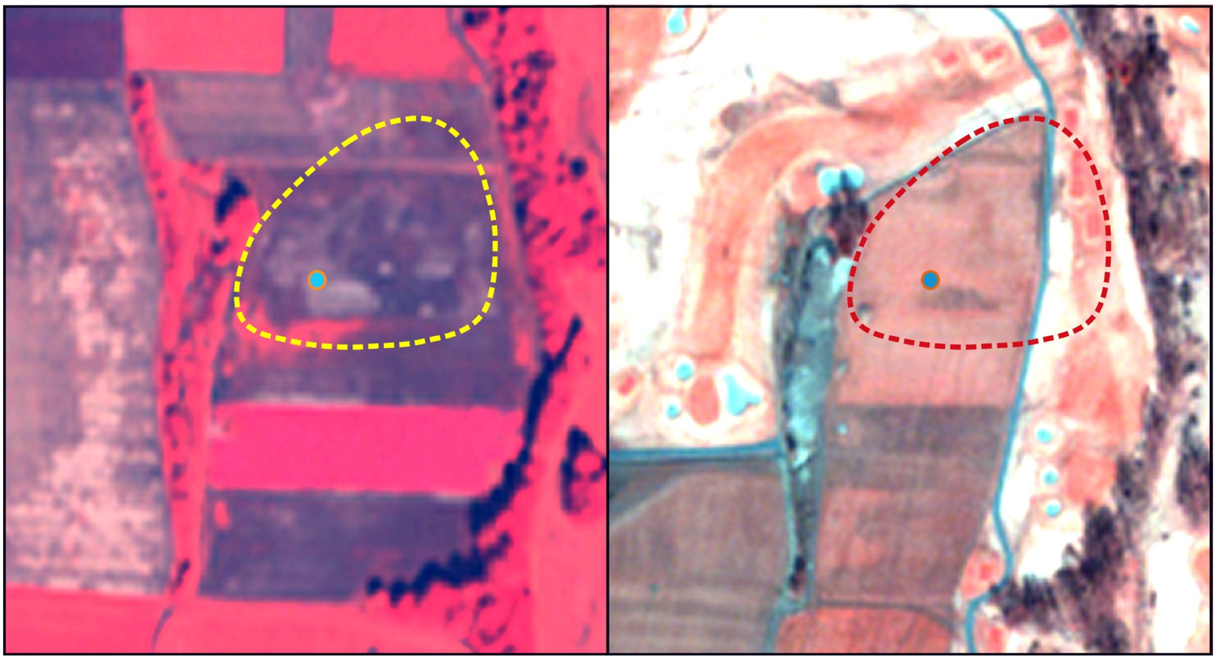


Fig. 16 Right: Anomaly representing a Viking Age settlement at Evje Farm as recorded in the IKONOS image from 2000. Left: The same location after construction of a golf-course and the destruction of the settlement. (IKONOS - copyright: Space Imaging and the Satellite Data Archive of the Norwegian Mapping Authority). AA

3.c.5. Pits, pit houses, graves wit hout mounds, fences, etc.

A number of important smaller archaeological features exist that are small or narrow in relation to the pixel size in the available multispectral images, such as pits, pit-houses, graves without mounds, fences, etc. To be able to improve the representativity of the information that can be extracted from the images, initial training in distinction of anomalies related to such small/narrow features has started with distinction of areas with known pits.

4. Computer-assisted cultural heritage detection and classification. System requirements and design

Lars Aurdal, Rune Solberg, Joachim Lous

Abbreviations:

CHDS	Cultural heritage detection software
GB	Gigabyte
GIS	Geographic information system
GUI	Graphical user interface
MOS	Minimal Operational Sub-system
NIKU	Norwegian Institute for Cultural Heritage Research
ROI	Region of interest
SWE	Software engineering
TBD	To be defined
UP	Unified software development process

4.1. The software development process

Development of successful, complex software systems to be applied by many users, often representing rather heterogeneous user requirements, is a challenging task. Decades of trials and error combined with scientific research on software development methodology have resulted in well-documented approaches that significantly increase the chances of developing successful systems.

The current project is rather small compared with most software development projects. However, there are elements of best practices for software development that should be taken into account here as well. The following sections give a brief introduction to the most important elements of iterative and incremental-software engineering.[1]

4.1.1. Users

Although there are many possible users of the CHDS, we will distinguish between two main types of users: the general archaeologist and the remote-sensing archaeologists.

4.1.1.1. General archaeologist

General archaeologist users will typically work in a local county administration. These users will normally have their basic education in the fields of archaeology and history. They will use the CHDS in a result-oriented fashion in which the main aim is to produce maps of possible cultural heritage sites. They have much local knowledge and are typically involved in the county's administration, protection and excavation of cultural heritage sites. These users are not necessarily very familiar with sophisticated GIS and remote-sensing software.

4.1.1.2. Remote-sensing archaeologist

Remote-sensing archaeologist users may work in a local county administration, in national administrative bodies such as the Directorate for Cultural Heritage or in universities or research institutes such as Norwegian Institute for Cultural Heritage Research. These users will also normally have their basic education in the fields of archaeology and history, but might have a technical background at least through their work experience. They are very familiar with GIS and have some knowledge about remote sensing. They will use the system much as does the general archaeologist, but will go to greater lengths in exploring each particular site not only from an archaeological point of view, but also from a remote-sensing viewpoint. These users will therefore need more analysis tools in order to analyse the underlying remote-sensing data.

4.1.2. Software engineering approaches

Software engineering (SWE) research has proposed many tools, methods, and techniques for improving the software-development process. It has long been recognised that the linear »waterfall« model of *requirements → design → implementation → testing → evaluation* simply does not work in practice for complex systems. The most successful models suggest an approach to closely incorporate the evaluators and developers by taking a more incremental approach. This incremental approach seeks to implement a scaled-down version of the system (its skeleton) as soon as possible and then

[1] We gratefully acknowledge the indirect contribution of Jason Baragry, former employee of NR, in writing this chapter.

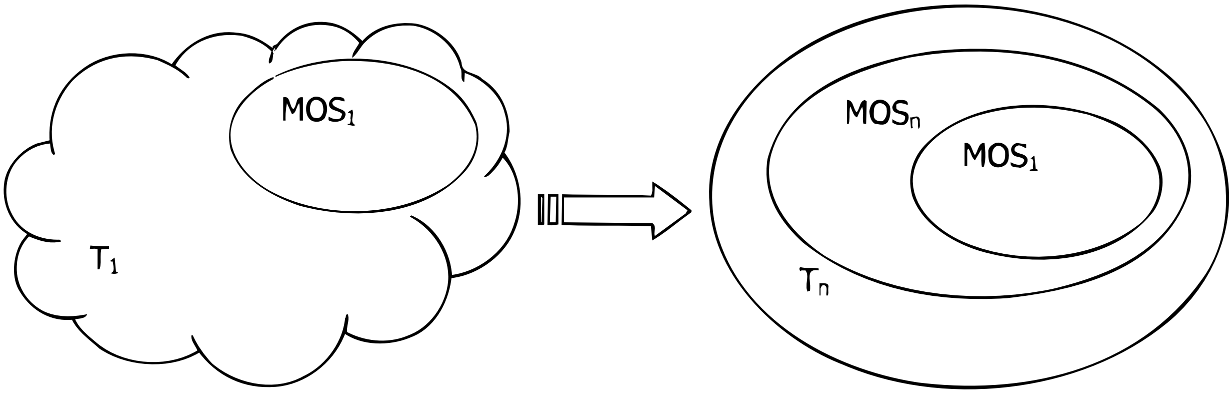
build the appropriate functionality in increments onto that skeleton. During each increment, the system is evaluated, and modifications can be implemented while the development proceeds rather than after final implementation. The result is the development of large-scale systems with greater user satisfaction, better working quality, and providing system managers with an improved ability to estimate production cost and delivery times.
A solution to the known problems of traditional large-scale software systems engineering is the Unified Software Development Process (UP) [3]. The UP approach concentrates on three areas:

Use-case driven
Focus on architecture
Iterative and incremental development

This process gives the system development much better 'visibility' to enable modifications and improvements based on user-driven evaluation. Furthermore, the UP improves the ability to specify important issues such as time-to-delivery and development costs. It also improves the ability to deal with changing requirements, which is a serious problem in large-scale development and research-based projects.

4.1.3. The iterative development process

Changing requirements is destructive to development even when change is inevitable, and no matter how well change is managed. Thus, an iterative process of gradual refinements to the requirements itself should be devised and implemented. One scenario is to specify the requirements for a well understood, minimal and operational sub-system (MOS_1) within the overall "vague" target system (T_1) and revisit/refine the requirements in iterations after designing and implementing the MOS at each iteration.



At each iteration, the MOS (the well-understood and specifiable sub-system) will build upon the previous MOS and will cover more of the target system, uncovering requirements and issues along the way, thus making it possible to specify the target system better and better.

At each requirements/design/implementation iteration, the requirements for the current MOS will then be possible to freeze against changes. Still, there will be changes in requirements for the target system, and (to a lesser degree) for the current MOS also. To avoid or reduce the impact of changes in ongoing work, a two-tier change management scheme should be devised and implemented. This implies that all change requests (to current MOS, the target system or other iterations) are logged and pre-evaluated by a separate team (typically by requirements engineering, project management and test management teams, often termed the Change Control Board (CCB)) regularly. Changes that do not concern the current MOS will be assigned to future iterations. Only changes that belong to the current MOS will involve development staff, who then evaluate the impact of these changes and help re-plan current activities (and hence the current project plan).

Projects involving many users, often also geographically spread, add an additional constraint of communicating unambiguously across the distributed virtual team members/sub-groups. This is a contradicting requirement, requiring a more linear (non-situated) planning and execution model.

A possible solution to this kind of complexity (and the need to reduce uncertainty in communication across borders and cultures) is sketched below:

- At each iteration, the MOS (the well-understood and specifiable sub-system) will build upon the previous MOS and will cover more of the target system, uncovering requirements and issues along the way, thus making it possible to specify the target system better and better.

- At each requirements/design/implementation iteration, the requirements for the current MOS will then be possible to freeze against changes. Still, there will be changes in requirements for the target system, and (to a lesser degree) for the current MOS also. To avoid or reduce the impact of changes in ongoing work, a two-tier change management scheme should be devised and implemented. This implies that all change requests (to current MOS, the target system or other iterations) are logged

4.2. Use scenarios

In order to define the user requirements for the system we will begin by describing use scenarios. The use scenarios will make it possible to see how the different users will use the CHDS in a larger setting. It also makes it possible to see how the CHDS can (and cannot) contribute in the users' work tasks. Based on the use scenarios, we will derive user requirements; these are detailed in the next chapter.

4.2.1. General archaeologist

Along the Lågen river in Vestfold County there are many known culture-historical sites in agricultural fields. Some of these have been known to archaeologists for a long time and are currently being excavated. This is done by field archaeologists associated with the Vestfold county administration. Although all excavation efforts are focused in one particular field, it is considered to be of interest to examine other fields for visible traces that could indicate the position of unknown cultural heritage sites.

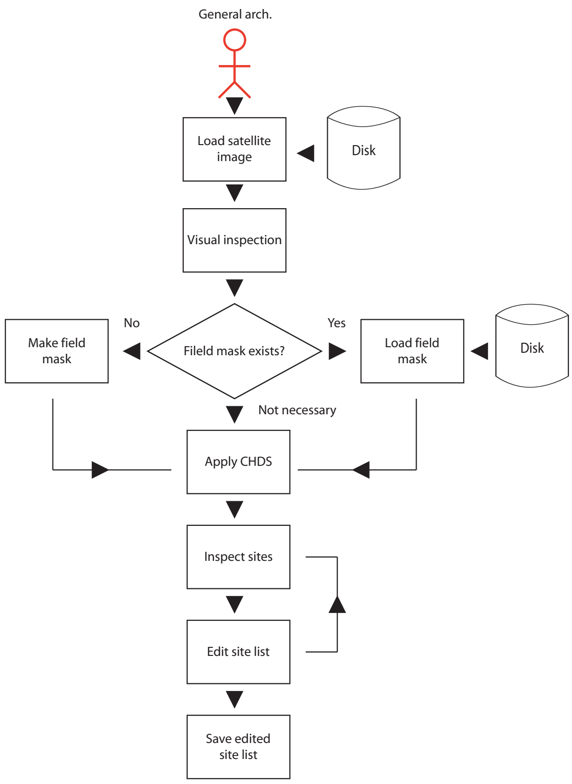
It is decided that an analysis is to be made of images of the interesting agricultural fields using local human and computer resources. The personnel assigned to the task are general archaeologists with detailed field knowledge of the study area. The local computer resources comprise ordinary desktop computers running Windows-based operating systems. In addition to ordinary office software, these computers have GIS systems such as ArcView installed. For this purpose a Quickbird Satellite image covering the study area of interest has been acquired. This image comprises a panchromatic image with a resolution of 0.6 metres and 4 spectral bands (red, green, blue and near infrared) with a resolution of 2.4 metres. The image is georeferenced to high precision.

As part of the local administrative GIS tools, the County owns the digital version of the economic (1: 5000) maps made by the Norwegian Mapping Authority. In particular the mask for agricultural fields is at the disposal of the project team.

Using the Cultural Heritage Detection Software the image is opened and displayed on screen. The screen display might appear as appendix: A.1. providing navigation and zoom capabilities. Using the navigation tools an initial visual inspection of the panchromatic image is performed revealing the presence of numerous interesting sites.

Analysing all the interesting fields in this fashion is a large and tiresome task. Using local GIS software, the agricultural field mask is loaded. A selection is made among all the fields and only those in reasonable proximity to Lågen are retained. The result is saved to file. Loading this modified agricultural field mask using the Cultural Heritage Software it becomes possible to do an automated scan for interesting sites located in the specified agricultural fields. After the field mask is loaded and displayed for inspection, the screen display might look as appendix: A.2.

Fig. 17: The work flow of the general-archaeologist user.



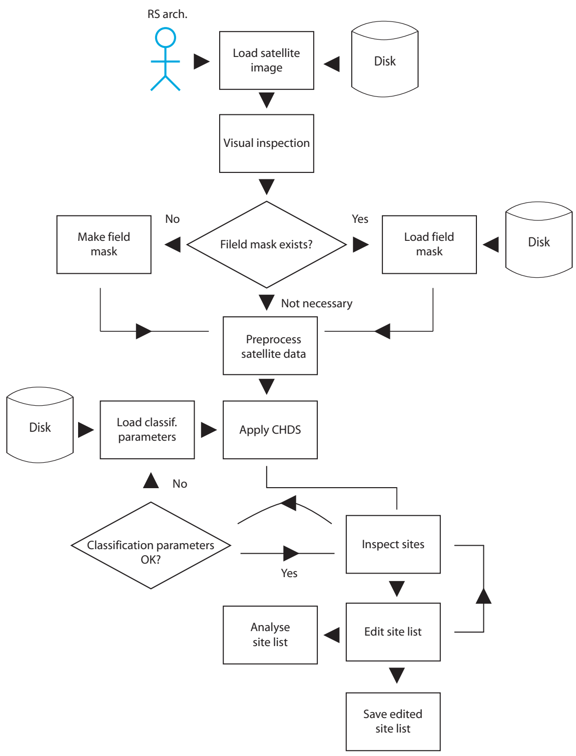
Having loaded the panchromatic satellite image along with the modified field mask, an automatic scan of the given fields is initiated. Upon termination of the scan the possible sites are displayed. The screen display might appear as in appendix: A.3. As before, the display provides navigation and zoom capabilities, in addition, a list of all the detections and a suggested interpretation (grave, house, etc.) is displayed. The detections will be local regions that have shapes and intensities that make it reasonable to assume that they may be representative of cultural heritage sites. The suggested interpretation will be based on each detection's size and other shape parameters. The system is designed in such a way that its threshold for including a region in the list of possible detections is low. This is done in order to reduce the risk of missing possibly interesting sites. For this reason the result must be scanned and sorted by the general archaeologists. Clicking on each detection in the list of detections takes the focus of the display to that site. Having decided whether a site should remain on the list or not, it can be deleted or, if necessary, modified as the operator pleases. If necessary the operator can add sites in a fully manual fashion if the system has omitted a possible site. After a manual deletion of detections the screen display might look as appendix: A.4.

When it has been decided what detections to keep, the result can be saved to file and eventually reloaded in order to continue the analysis at a later point. The result can also be saved to a file format compatible with local GIS software. This makes it possible to display the detections on top of the different layers composing the economic maps and to analyse possible sites in relation to terrain and infrastructure features.

4.2.2.Remote-sensing archaeologist

After the general archaeologists have found possible sites along Lågen, as described in section 3.1, a careful inspection of the sites is carried out. Some turn out to correspond to known and inventoried cultural heritage sites, most of the sites, however, are previously unknown. It is expected that many of the sites have nothing to do with the local cultural heritage. In an attempt to distinguish between truly interesting sites and those that can safely be ignored, an in-depth analysis of the available remote sensing data is performed.

Fig. 18: The work flow of the remote-sensing archaeologist user.



For this purpose an archaeologist specialising in remote sensing is engaged in the project. In a first attempt to distinguish between interesting and uninteresting sites, a spectral analysis of the detections is carried out. This consists of using the CHDS to analyse the values of the different spectral bands in order to look for patterns. The remote-sensing archaeologist also suggests using different pre-processing options (for instance noise and plough furrow removal) available in the CHDS, to see if this changes the detections. In an attempt to further narrow down the list of detections it is decided that the criteria the CHDS uses for including or excluding sites should be adapted to match local conditions better. In particular, remains of houses are found to have deviating forms in Vestfold County. Working in close co-operation with remote sensing experts, the CHDS is modified so as to work optimally under the local conditions in Vestfold County. This modification is done by editing the ground truth description used by CHDS. This consists of a list of shape and size criteria that recapitulate what is known about cultural heritage sites observed in satellite images. Having tried these approaches the list is narrowed down and consolidated.

4.3. User requirements

The following sections summarize the user-functional and system requirements. The user-functional requirements are the requirements imposed on the system by its final users concerning the functionality provided by the system. This is distinct from the user-system requirements which are the requirements imposed on the system by its final users concerning the hardware and software environment in which the system must be operational.

The user-functional requirements will be expressed in the user's terminology, thus making it possible for the end users of the system to fully comprehend all the imposed requirements. This makes it possible for the end users to verify that all user requirements are met, and furthermore it makes end-user interaction in the specification process possible.

The user system requirements summarize the requirements imposed on the system by its final users concerning the hardware and software environment in which the system must be operational.

As for the user-functional requirements, the user-system requirements will be expressed in the user's terminology, thus making it possible for the end users of the system to fully comprehend all the imposed requirements.

4.3.1. General archaeologists

4.3.1.1. File-input requirement

1. The CHDS must be able to read all satellite image formats that are relevant for the project. Currently, the relevant formats are Quickbird and Ikonos satellite image formats, but it is highly desirable that more formats can be read. The input satellite-image files must be georeferenced to a standard geographic reference system.
2. THE CHDS must be able to read field masks in the form of SHAPE files, the de facto standard format used by the ArcView GIS system. The input field-mask files must be georeferenced to a standard geographic reference system.
3. The CHDS must be able to load previous cultural heritage site detections in the form of SHAPE files.

4.3.1.2. Input-display requirements

1. The CHDS must be able to display a satellite image to screen.
2. The satellite image display must allow for navigation in large satellite images.
3. The satellite image display must allow for zooming in satellite images.
4. The satellite image display must allow for contrast and brightness modifications.
5. The CHDS must be able to display a field mask.
6. The field mask display must allow for navigation in large field masks.
7. The field mask display must allow for zooming in field masks.
8. The CHDS must be able to display a field mask on top of a displayed satellite image.
9. The CHDS must be able to display the geographic position of a selected point either in a satellite image or in a field mask.

4.3.1.3. Pre-processing requirements

None

4.3.1.4. Processing requirements

The CHDS must be able to perform the following processing operations:

1. Site detection. A site detection comprises a search for site candidates followed by a classification of these.

4.3.1.5. Detection-display requirements

1. The CHDS must be able to display a list of the detection results including the systems interpretation (e.g. grave, building, etc.) of the detection.
2. The CHDS must be able to display the detection results in a separate detection result window.
3. The CHDS must be able to display the detection results on top of a displayed satellite image.
4. The CHDS must be able to navigate to each detection result by displaying that part of a satellite image that resulted in the detection.

4.3.1.6. Detection-editing require ments

1. The CHDS must provide capabilities for adding detections to those found automatically.
2. The CHDS must provide capabilities for deleting detections from those found automatically.
3. The CHDS must provide capabilities for modifying the shape of a detection found automatically.

4.3.1.7. File-output requirements

1. The CHDS must be able to save the detections in the form of SHAPE files, the de facto standard format used by the ArcView GIS system.

4.3.1.8. Analysis requirements

The CHDS must be able to perform the following analysis operations:
1. Distance measurements (between specified points, units are pixels or metres).
2. Area measurements (of polygonal shapes; units are pixels or square metres).

4.3.1.9. System requirements

The system must be able to run on Windows (2000 and XP) computer systems.

4.3.2. Remote-sensing archaeologists

4.3.2.1. File-input requirements

See 4.3.1.1.

4.3.2.2. Input-display requirements

1. See 4.3.1.2.
2. The CHDS must be able to display the spectral values of a selected point either in a satellite image or in a field mask.

4.3.2.3. Pre-processing requirements

The CHDS must be able to perform the following pre-processing operations:
1. Noise removal.
2. Plough furrow removal.

4.3.2.4. Processing requirements

See 4.3.1.4.

4.3.2.5. Detection-display requirements

See 4.3.1.5.

4.3.2.6. Detection-editing require ments

See 4.3.1.6.

4.3.2.7. File-output requirements

See 4.3.1.7.

4.3.2.8. Analysis requirements

See 4.3.1.8. The CHDS must be able to perform the following analysis operations:
1. Calculate the statistics of the pixels included in a detection (min, max, mean, variance, band covariance).

4.3.2.9. System requirements

See 4.3.1.9. The system must be able to run on UNIX systems.

4.4. Use cases

After the needs of the different users through use scenarios and textual descriptions of user's requirements have been established, the requirements are here formalised as use cases. These are textual descriptions, in the form of tables, of the different uses of the system. Based on these use cases, the system design is developed. A use case is presented in the form of a table as shown below:

Use Case	Textual presentation of the use case, the use case ID.	
Description	Short description of the use case.	
User type	Which users are concerned in this use case	
Importance	We state the importance of the use case and distinguish between **High**, **Medium**, and **Low**. Importance is meant to express a combination of how important we consider it to be to provide the use case from an end user's point of view and how realistic it is to provide an implementation.	
Implementation phase	We state in what implementation phase this functionality should be added.	
Formulation of request / Prerequisites	What needs to be specified by the user? When the user enters this use case, what additional information will (s)he have to provide?	
Presentation of results / Post-requisites	How could the result be presented?	
Action Sequence	**Step**	**Action**
	1	How is the response produced, step by step?
	:	
	N	
Variations	**Step**	**Branching action**
	1	Small variations that can occur in the use case
	:	
	N	
Exceptions		**Branching action**
	2	What if data does not exist, or other exceptional situations occur, so that a proper response cannot be generated? What are the exceptional situations that can occur, and what should be done in each case?
	:	
	N	
Comments	Comments of any kind	
Open issues	Any open issues	

As we have already pointed out, the general archaeologist user will use the software in a highly result-oriented manner. This user's main focus will be to produce maps of possible cultural heritage sites as quickly and easily as possible with a minimum of user interaction and with a minimal exposure to the underlying system. The remote sensing archaeologist user uses the system in much the same way, but employs a large range of tools to analyse the intermediary and final results of the process. The following figures resume the users and their associated use cases. We point out that the use cases are written with the intention that the system be run and operated through a graphical user interface; this is therefore not specifically stated in any of the use cases. The following table recapitulates all the use cases and identifies their implementation phase.

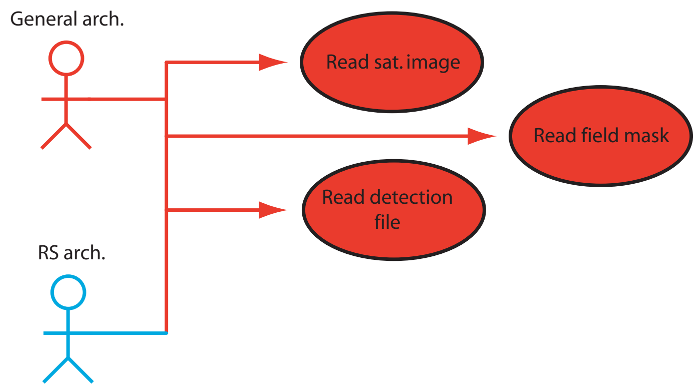


Fig. 19: The file-input use cases. Use cases marked in red are applicable to all users of the system.

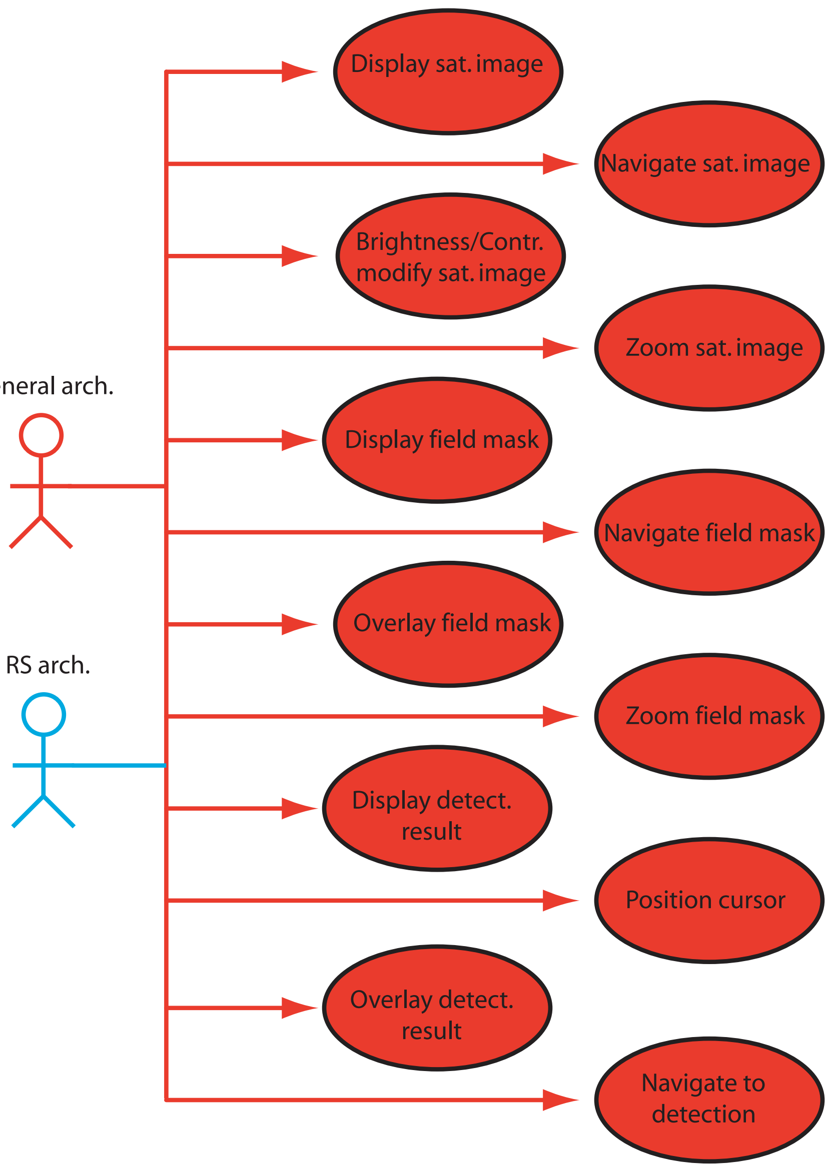
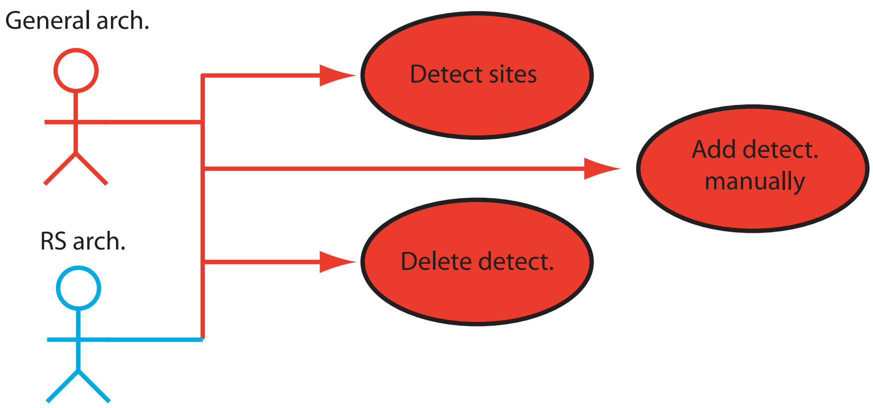


Fig. 20: The display use-cases. Use cases marked in red are applicable to all users of the system.

Fig. 21: The detection use-cases. Use cases marked in red are applicable to all users of the system.



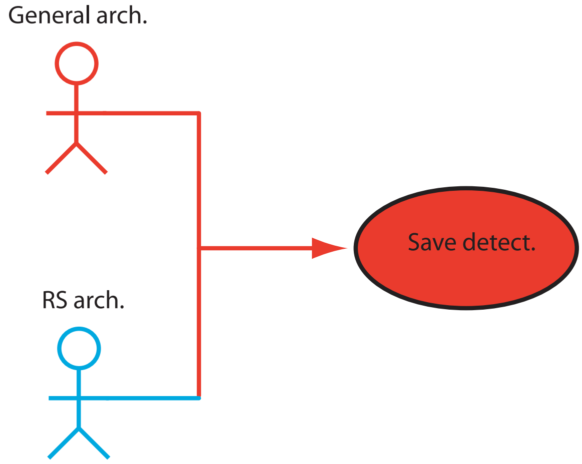
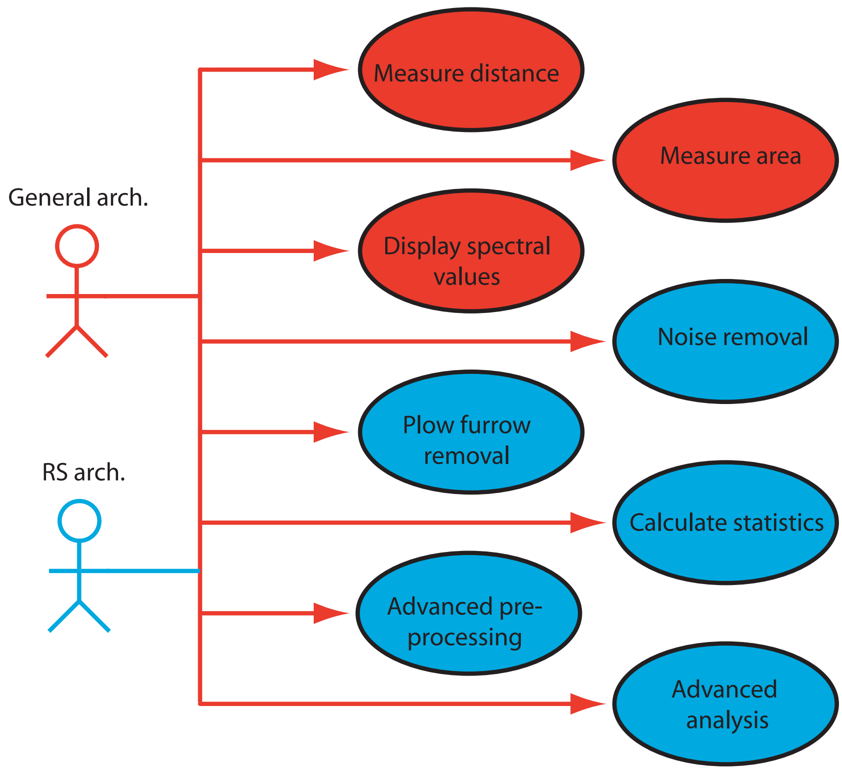


Fig. 22: The file-output use-cases. Use cases marked in red are applicable to all users of the system.

Fig. 23: The analysis use-cases. Use cases marked in red are applicable to all users of the system, use cases marked in blue are applicable only to the remote sensing archaeologist users of the system.



Use case	User	Implemen-tation Phase	Importance
Read satellite image	Gen. Arch.	MOS1	High
Read field mask	Gen. Arch.	MOS1	High
Read detection file	Gen. Arch.	MOS2	Medium
Display satellite image	Gen. Arch.	MOS1	High
Navigate satellite image	Gen. Arch.	MOS1	High
Zoom satellite image	Gen. Arch.	MOS1	High
Brightness/contrast modify satellite	Gen. Arch.	MOS2	Medium
Display field mask	Gen. Arch.	MOS1	High
Navigate field mask	Gen. Arch.	MOS1	High
Zoom field mask	Gen. Arch.	MOS1	High
Overlay field mask	Gen. Arch.	MOS1	High
Position cursor	Gen. Arch.	MOS2	Medium
Detect sites	Gen. Arch.	MOS1	High
Display detection result	Gen. Arch.	MOS1	High
Overlay detection result	Gen. Arch.	MOS1	High
Navigate to detection	Gen. Arch.	MOS1	High
Add detection manually	Gen. Arch.	MOS3	Low
Delete detection	Gen. Arch.	MOS1	High
Save detection	Gen. Arch.	MOS1	High
Measure distance	Gen. Arch.	MOS2	Medium
Measure area	Gen. Arch.	MOS3	Low
Display spectral values	Rem. Sens. Arch.	MOS2	Medium
Noise removal	Rem. Sens. Arch.	MOS2	Medium
Plow furrow removal	Rem. Sens. Arch.	MOS2	Medium
Calculate statistics	Rem. Sens. Arch.	MOS3	Medium
Advanced preprocessing	Rem. Sens. Arch.	MOS3	Low
Advanced analysis	Rem. Sens. Arch.	MOS3	Low

Table 1: All use cases and their implementation phase. This table gives an overview of all the use cases, their associated users and the implementation phase. A use case to be implemented in MOS1 will thus belong to the initial Minimal Operating System.

4.4.1. General archaeologist use cases

Use case	Read satellite image	
Description	The user selects a satellite image to read. The image file is opened and the image is read into memory. A list of currently loaded images is updated	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The image file path and name. The prerequisites are: • The image must exist and be in a format that is readable by the system. • In order to avoid resampling of the images, the images should be georeferenced to a standard geographic reference system.	
Presentation of results / Post-requisites	The image file is opened and the image is read into memory. A list of currently loaded images is updated	
Action sequence	**Step**	**Action**
	1	Select image file path and name.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	The image does not exist. Warn the user about this.
	2	•
	3	•
Comments	It is possible that the loading of a satellite image should trigger the display of this image also, not only list it as an available image for display. Currently loading an image and displaying it are two different use cases.	
Open issues	None	

Use case	**Read field mask**	
Description	The user selects a field mask to read. The field-mask file is opened and the field mask is read into memory. A list of currently loaded field masks is updated	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The field-mask file path and name. The prerequisites are: • The field-mask file must exist and be on a format that is readable by the system. • In order to avoid resampling of the images the field mask should use a standard geographic reference system.	
Presentation of results / Post-requisites	The field-mask file is opened and the field mask is read into memory. A list of currently loaded field masks is updated	
Action Sequence	**Step**	**Action**
	1	Select field-mask file path and name.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	The field mask does not exist. Warn the user about this.
	2	•
	3	•
Comments	**I**t is possible that the loading of a field mask should trigger the display of **the field mask** also, not only list it as an available field mask for display. Currently loading a field mask and displaying it are two different use cases.	
Open issues	None	

Use case	Read detection file	
Description	The user selects a detection file to read. The detection file is opened and read into memory. A list of the loaded detections is displayed.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • The detection-file path and name. The prerequisites are: • The detection file must exist.	
Presentation of results / Post-requisites	The detection file is opened and is read into memory. A list of the loaded detections is displayed.	
Action sequence	**Step**	**Action**
	1	Select detection-file path and name.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	The detection file does not exist. Warn the user about this.
	2	•
	3	•
Comments	A detection file is a file containing a list of detections made by the CHDS containing the suggested interpretation of these along with the vectors that mark polygonal regions in the image corresponding to the detections. This file must be compatible with the SHAPE file format	
Open issues	None	

Use case	Display satellite image	
Description	The user selects a satellite image from the list of loaded satellite images. The selected image is displayed on screen. The display shows the satellite image along with a navigation window and a zoom window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The satellite image from the list of loaded satellite images. The prerequisites are: • The satellite image must be loaded.	
Presentation of results / Post-requisites	The selected image is displayed on screen. The display shows the satellite image along with a navigation window and a zoom window.	
Action sequence	**Step**	**Action**
	1	Select the desired satellite image from the list of loaded satellite images.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	It is possible that the loading of a satellite image should **trigger the display of this image** also, not only list it as an available image for display. Currently loading an image and displaying are two different use cases.	
Open issues	None	

Use case	**Navigate satellite image**	
Description	Using the navigation tool the user decides what part of the satellite image is to be displayed to screen.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The part of the satellite image that is to be displayed. The prerequisites are: • A satellite image must be displayed.	
Presentation of results / Post-requisites	The part of the satellite image specified by the user is displayed to screen.	
Action sequence	**Step**	**Action**
	1	Select the part of the satellite image to be displayed.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	If the satellite image is small enough to fit the screen, this option should not be available.
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	**Zoom satellite image**	
Description	Using the zoom tool the user decides the zoom factor used in displaying the satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The zoom factor to use. The prerequisites are: • A satellite image must be displayed.	
Presentation of results / Post-requisites	The satellite image display is zoomed to the desired scale.	
Action sequence	**Step**	**Action**
	1	Select zoom factor.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	How should the zooming be implemented? Should the zoom apply to the main display window (a la Photoshop) or should there be a separate zoom window (a la ENVI).	

Use case	Brightness/contrast modify satellite image	
Description	The user selects the brightness and contrast to be used in displaying the satellite image.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • The gain/offset to be used in modifying the display greylevel lookup table. The prerequisites are: • A satellite image must be displayed.	
Presentation of results / Post-requisites	The satellite image display is updated with a new greylevel lookup table.	
Action sequence	**Step**	**Action**
	1	Select gain.
	2	Select offset
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	Should only this type of linear LUT modification be allowed or do we need more sophisticated LUT management?	

Use case	Display field mask	
Description	The user selects a field mask from the list of loaded field masks. The selected field mask is displayed on screen. The display shows the field mask along with a navigation window and a zoom window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The field mask from the list of loaded field masks. The prerequisites are: • The field mask must be loaded.	
Presentation of results / Post-requisites	The selected field mask is displayed on screen. The display shows the field mask along with a navigation window and a zoom window.	
Action Sequence	**Step**	**Action**
	1	Select the desired field mask from the list of loaded field masks.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	It is possible that the loading of a field mask should t**rigger the display of the field mask** also, not only list it as an available field mask for display. Currently loading a field mask and displaying it are two different use cases.	
Open issues	None	

Use case	Navigate field mask	
Description	Using the navigation tool the user decides what part of the field mask is to be displayed on screen.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The part of the field mask that is to be displayed on screen. The prerequisites are: • A field mask must be displayed.	
Presentation of results / Post-requisites	The part of the field mask specified by the user is displayed on screen.	
Action sequence	Step	Action
	1	Select the part of the field mask to be displayed.
	2	•
	3	•
Variations	Step	Branching action
	1	If the field mask is small enough to fit the screen then this option should not be available.
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Zoom field mask	
Description	Using the zoom tool the user decides the zoom factor used in displaying the field mask.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The zoom factor to use. The prerequisites are: • A field mask must be displayed.	
Presentation of results / Post-requisites	The field mask display is zoomed to the desired scale.	
Action sequence	Step	Action
	1	Select zoom factor.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	• The image does not exist. Warn the user.
	2	•
	3	•
Comments	None	
Open issues	How should the zooming be implemented? Should the zoom apply to the main display window (a la Photoshop) or should there be a separate zoom window (a la ENVI).	

Use case	Overlay field mask	
Description	Having opened a display of a satellite image the user can select a field mask to be loaded and displayed on top of the satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The field mask to be loaded from the list of available field masks. The prerequisites are: • A satellite image must be displayed. • There must be at least partial overlap between the already displayed satellite image and the selected field mask.	
Presentation of results / Post-requisites	The field mask is displayed as an overlay over the already displayed satellite image.	
Action sequence	Step	Action
	1	Select field mask from list of available field masks.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	There is no overlap between the field mask and the displayed satellite image. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Position cursor	
Description	Whenever a satellite image or a field mask is displayed and the cursor is positioned in such a display, the image and geographic position of the cursor is continuously displayed.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • Nothing The prerequisites are: • A satellite image must be displayed	
Presentation of results / Post-requisites	Whenever the cursor is placed over a pixel in a displayed satellite image, the cursor pixel and geographic position is displayed.	
Action sequence	Step	Action
	1	Position cursor over displayed satellite image.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	**Detect sites**	
Description	Having loaded a satellite image to memory the user can launch a cultural heritage site detection. If a field mask is loaded, it can be used to mask the processing of the image to within the field mask.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • A satellite image from the list of available satellite images. • If field masking is desired, a field mask from the list of available field masks. The prerequisites are: • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded.	
Presentation of results / Post-requisites	The system analyses the satellite image (possibly within the selected field mask) and generates a list of possible cultural heritage sites. A list of detections is displayed.	
Action sequence	**Step**	**Action**
	1	Select satellite image to be processed.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	If field masking is desired, select field mask
	2	•
	3	•
Exceptions		**Branching action**
	1	There is no overlap between the field mask and the displayed satellite image. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	**Display detection result**	
Description	Having loaded a detection file or performed a site detection the user can display the detections in a separate display window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The user must select display of the detection result. The prerequisites are: • A detection file must have been loaded or a site detection must have been performed.	
Presentation of results / Post-requisites	The detection result is displayed on screen. The display shows the detections along with a navigation window and a zoom window.	
Action sequence	**Step**	**Action**
	1	Select display of detection result.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is possible that a site detection should open this display by default.	

Use case	**Overlay detection result**	
Description	Having loaded a detection file or performed a site detection the user can display the detections on top of an already displayed satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The user must select overlay of the detection result. The prerequisites are: • A detection file must have been loaded or a site detection must have been preformed. • A satellite image must be displayed.	
Presentation of results / Post-requisites	The detection result is displayed as an overlay over the already displayed satellite image.	
Action sequence	**Step**	**Action**
	1	Select overlay of the detection result.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	A satellite image is not displayed. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	This could also be a default output from the detection module.	

Use case	**Navigate to detection**	
Description	By indicating an element in the list of detections the user can navigate to a particular detection.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The part of the detection result that is to be displayed on screen. The prerequisites are: • A detection result must be displayed in a separate window or as an overlay to a satellite image.	
Presentation of results / Post-requisites	The part of the detection result specified by the user is displayed on screen.	
Action sequence	**Step**	**Action**
	1	Select the part of the detection result to be displayed.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	If the detection result is small enough to fit the screen, this option should not be available.
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Add detection manually	
Description	Having displayed a detection result or overlayed a detection result on an already loaded image the user can add a detection manually.	
User type	All	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	The user must specify: • The position and shape of the new detection by drawing it in the display window. The prerequisites are: • A detection result or a detection result overlayed on a satellite image must be displayed.	
Presentation of results / Post-requisites	The desired new detection is added to the list of detections. any displays are updated with this new detection.	
Action sequence	Step	Action
	1	Draw new detection in display window.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Delete detection	
Description	Having displayed a detection result or overlayed a detection result on an already loaded image the user can delete a detection manually.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The detection to be deleted in the list of detections. • The detection to be deleted in the detection-result display or the detection-result overlay display. The prerequisites are: • The detection list must be displayed. • The detection result or the detection-result overlay must be displayed.	
Presentation of results / Post-requisites	The selected detection is removed from the list of detections. All detection-result displays are updated.	
Action sequence	Step	Action
	1	Select the detection to be deleted from the list of detections or from a display of detection results or from an overlay of detection results on top of a satellite image.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is possible that a functionality allowing only for deletions from the list of detections is sufficient?	

Use case	Save detection	
Description	Having generated a detection result the user can save the result to file.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	The user must specify: • The detection-result file path and name. The prerequisites are: • A detection result must exist.	
Presentation of results / Post-requisites	The detection result is written to the specified file.	
Action sequence	**Step**	**Action**
	1	Select detection-result file path and name.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	• The detection-result file already exists. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Measure distance	
Description	In any image, field mask or result image display the user can measure distances in a set of specified units (pixels or metres) by indicating a from and to position.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • Two points in the display of interest. The prerequisites are: • A satellite image, field mask or detection-result display must be open.	
Presentation of results / Post-requisites	The distance in pixels and metres between the points is displayed.	
Action sequence	**Step**	**Action**
	1	Select from point in the display of interest.
	2	Select to point in the display of interest.
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Measure area	
Description	In any image, field mask or result-image display, the user can measure areas in a set of specified units (pixels or square metres) by indicating the polygon for which the area should be calculated.	
User type	All	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	The user must specify: • A polygon in the display of interest. The prerequisites are: • A satellite image, field mask or detection-result display must be open.	
Presentation of results / Post-requisites	The area in pixels and square metres of the given polygon is displayed.	
Action sequence	Step	Action
	1	Draw a polygon in the display of interest.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

4.4.2. Remote-sensing archaeologist use cases

Use case	Display spectral values	
Description	In any image, field mask or result-image display the user can display the spectral values of the underlying satellite-image data by indicating the position for which the spectral values are sought.	
User type	RS archaeologist.	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • The point in the image for which the spectral values should be displayed. The prerequisites are: • A satellite image, field mask or detection-result display must be open.	
Presentation of results / Post-requisites	A plot window is opened and the spectral values of the underlying satellite image data are plotted as a function of wavelength.	
Action sequence	Step	Action
	1	Select a point in the display of interest.
	2	•
	3	•
Variations	Step	Branching action
	1	None
	2	•
	3	•
Exceptions		Branching action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	Noise removal	
Description	Prior to site detection a noise removal can be performed on the satellite image to be processed.	
User type	RS archaeologist.	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • A satellite image from the list of available satellite images. • If field masking is desired, a field mask is sekected from the list of available field masks. • A noise removal method. The prerequisites are: • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded.	
Presentation of results / Post-requisites	The specified noise removal is performed on the given satellite image. If field masking is specified, the processing is limited to the field mask.	
Action sequence	**Step**	**Action**
	1	Select satellite image.
	2	Select field mask.
	3	Select noise removal algorithm.
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a masking of this operation.	

Use case	Plough furrow removal	
Description	Prior to site detection a plough furrow removal can be performed on the satellite image to be processed.	
User type	RS archaeologist.	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	The user must specify: • A satellite image from the list of available satellite images. • If field masking is desired, a field mask from the list of available field masks. The prerequisites are: • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded.	
Presentation of results / Post-requisites	Plough furrow removal is performed on the given satellite image. If field masking is specified, the processing is limited to the field mask.	
Action sequence	**Step**	**Action**
	1	Select satellite image.
	2	Select field mask.
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a masking of this operation.	

Use case	Calculate statistics	
Description	The user can specify a particular detection and calculate the statistics of the pixels belonging to this detection.	
User type	RS archaeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	The user must specify: • The detection for which to calculate statistics. The prerequisites are: • A satellite image must be loaded. • A detection result with at least a partial overlap with the satellite image must exist. • A detection-result list or a detection-result display or a detection result overlayed on a satellite image must be open.	
Presentation of results / Post-requisites	A window reporting certain statistics of the pixels belonging to a specified detection is opened.	
Action sequence	**Step**	**Action**
	1	Select the interesting detection from a detection-result list or a detection-result display or a detection result overlayed on a satellite image
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	None
	2	•
	3	•
Exceptions		**Branching action**
	1	No overlap between the detection result and the satellite image. Warn the user.
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a graphical selection of the interesting detection. It is possible that it suffices to allow for a selection of the detection from the list of detections.	

Use case	**Advanced pre-processing**	
Description	The RS archaeologist user will need a set of advanced preprocessing routines.	
User type	RS archaeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	Depending on the implementation of the system, it is doubtful whether this functionality should be included in the final system or not. If the final system is implemented as an extension to a library of image processing and GIS functionality, then this functionality might be an added benefit.	
Presentation of results / Post-requisites	Not applicable.	
Action sequence	**Step**	**Action**
	1	Not applicable.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	Not applicable.
	2	•
	3	•
Exceptions		**Branching action**
	1	Not applicable.
	2	•
	3	•
Comments	None	
Open issues	None	

Use case	**Advanced analysis**	
Description	The RS archaeologist user will need a set of advanced analysis routines.	
User type	RS archaeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	Depending on the implementation of the system, it is doubtful whether this functionality should be included in the final system or not. If the final system is implemented as an extension to a library of image processing and GIS functionality, then this functionality might be an added benefit.	
Presentation of results / Post-requisites	Not applicable.	
Action sequence	**Step**	**Action**
	1	Not applicable.
	2	•
	3	•
Variations	**Step**	**Branching action**
	1	Not applicable.
	2	•
	3	•
Exceptions		**Branching action**
	1	Not applicable.
	2	•
	3	•
Comments	None	
Open issues	None	

4.5. Conceptual design

4.5.1. Introduction

Having identified the user requirements and analysed them through use cases, we will now propose a system conceptual design of the CHDS. By conceptual design we mean design issues related to the system architecture and the overall operation of the system, such as the user's interaction with the system, the system main modules and their interaction, and finally a high-level description of the algorithms and methods that the system will employ in order to carry out its assigned tasks.

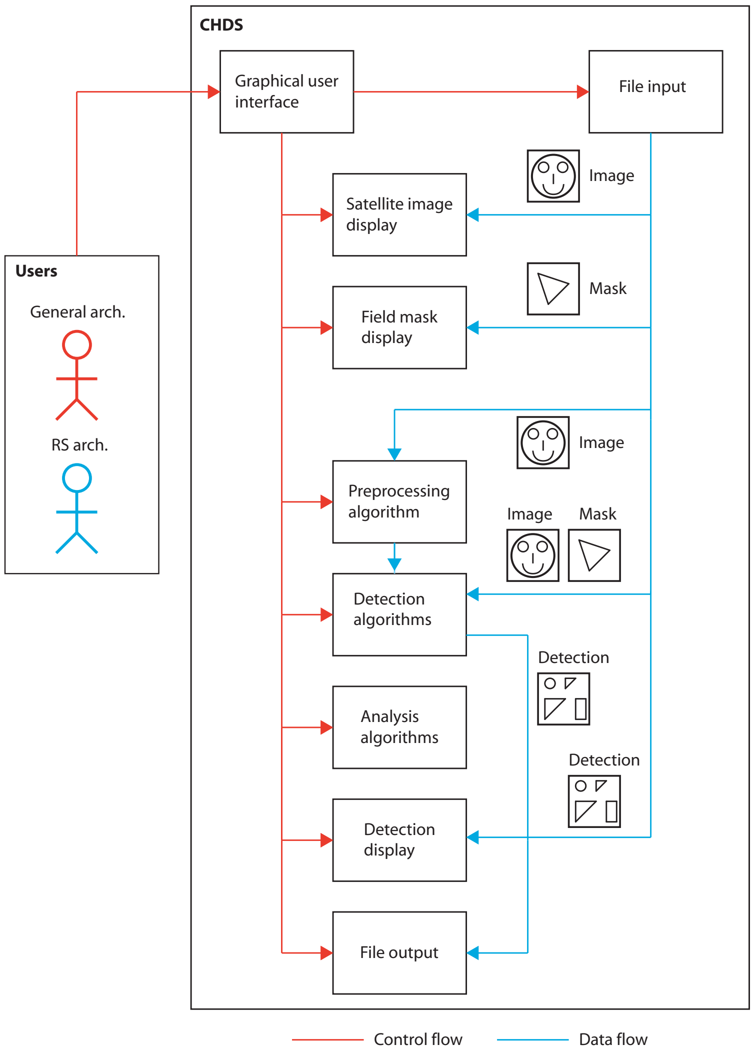
We will therefore not discuss issues related to the exact layout of the user interaction tools, the implementation language or specifics of any algorithms. Rather, we will try to identify the high-level functionality the system must provide in order to meet the user requirements.

Fig. 23 on the page 31 gives a graphical view of the operation and interdependence of the different modules making up the CHDS.

4.5.2. System operation

The system operation is as described in the following figure. All users will operate the software through a graphical user interface (GUI). The GUI gives access to file input/output functionality as well as the different processing options.

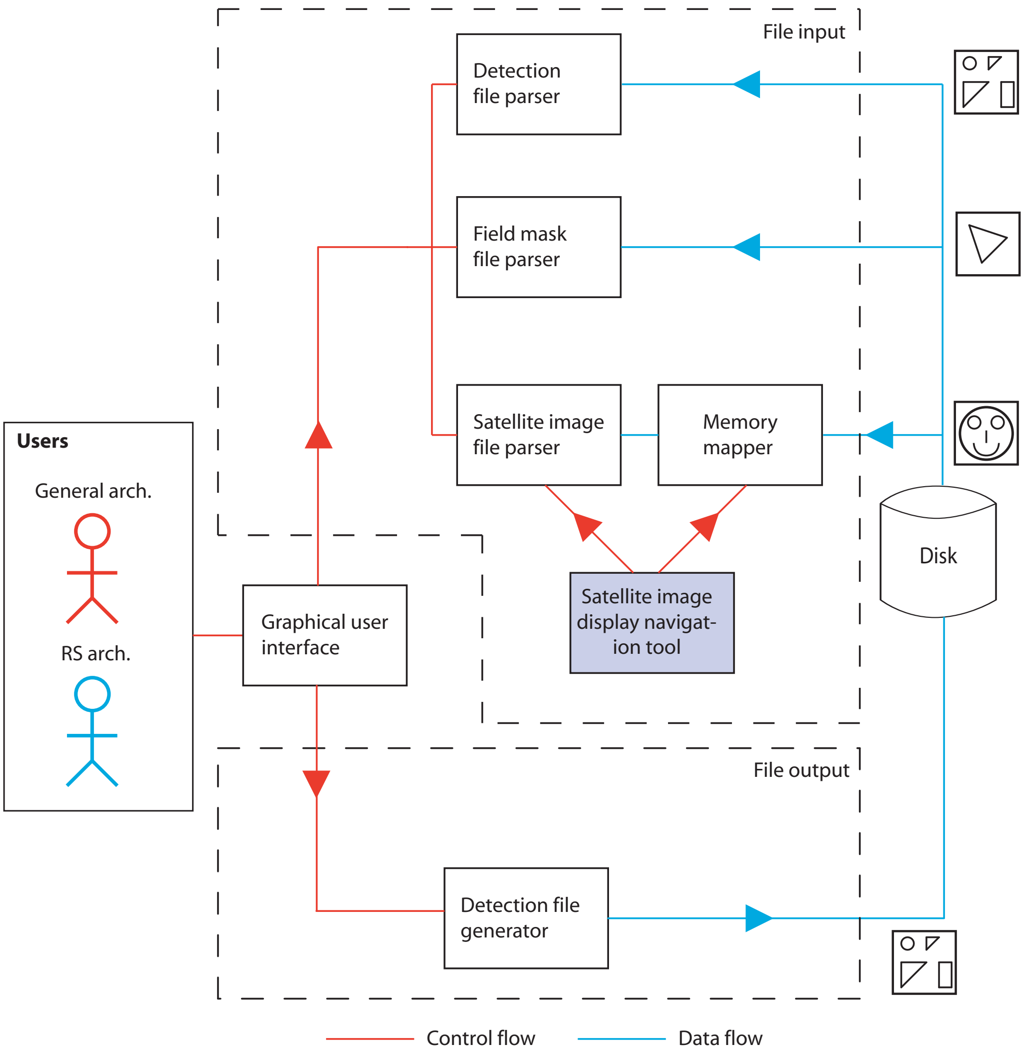
Fig. 24: Overall system operation and module interdependence. Through the graphical user interface both users operate all the functionality of the CHDS. The file input module provides the different data inputs as illustrated in the figure. The symbols indicate the type of objects that flow between the different modules.



4.5.3. File input/output

There are three types of file input to the CHDS system: satellite images, field masks and detection files. The only file output is the detection file. In this section we will discuss the handling of all of these file inputs and outputs. The following figure shows the interaction of the modules involved in the file I/O process. Notice that the navigation tool associated with the satellite-image display functionality must also have access to the satellite-image file input functionality. This is also illustrated in the figure.

Fig. 25: The file input and output functionality. Both users control this functionality through a user interface. Input files can be satellite images, field masks or detection files. Output files are only detection files. The handling of these three file types is described in the text.



4.5.3.1. Satellite file input

Satellite image files are normally binary files containing the satellite image data, possibly along with meta-information of various types. The satellite image data are typically multi- or hyperspectral. There are many possible types of meta-information, the most common are:

- Image size and number of spectral bands
- Spectral bandwidths
- Projection and georeferencing information
- Acquisition information (satellite type, date, time etc.)

Satellite image files have two particularities that require special handling. They are typically stored on a binary, proprietary format, and secondly they are often very large (~1GB). The specific file format obviously requires an adapted parser; their size makes it impossible to load them in their entirety into the memory of the computer used to process them. The parsing problem is typically resolved by including a library of satellite image file parsers; these are available both as freeware (e.g. GDAL) and as commercial libraries. The file size problem makes it necessary to dynamically load only the part of the file that is currently needed for display or processing. The standard way of doing this is by memory mapping the file.

4.5.3.2. Field mask input

The field masks that the CHDS will load will be represented in a vector format (the most common of these being the SHAPE-file format used in programs such as ArcView). These files are built up of the actual vector information along with meta-information. The vectors describe geometric primitives (typically lines) that are used to draw the desired features. The meta-information will typically contain the georeferencing information.

Typically smaller than the satellite image files, their contents can be read into memory directly. Most vector file formats (such as the SHAPE-file format) are proprietary binary formats whose parsing should be resolved by including an appropriate library.

4.5.3.3. Detection input

The detection files will be represented in a vector format just like the field mask, and the comments concerning the field masks also apply to the detection files. These files essentially contain polygons describing the shape and size of the detections along with meta-information, in particular meta-information describing what the CHDS considers to be the most likely interpretation of a detection.

These files will in all practical situations be small, and the entire contents can be loaded into memory.

4.5.3.4. Detection output

The only type of file output generated by the system is detection files. See the comments in section 6.3.3 concerning these files.

4.5.4. Satellite-image display

The display of satellite images will typically be closely linked to the satellite-image file input since it is normally impossible to load the entire satellite file into memory for display or processing. As stated previously, the display must comprise a navigation and a zoom tool as well as functionality for modifying the brightness/contrast of the satellite-image display (see the appendix for examples of this), and the navigation tool actually decides what part of the total file is displayed to screen. The functionality of this module is

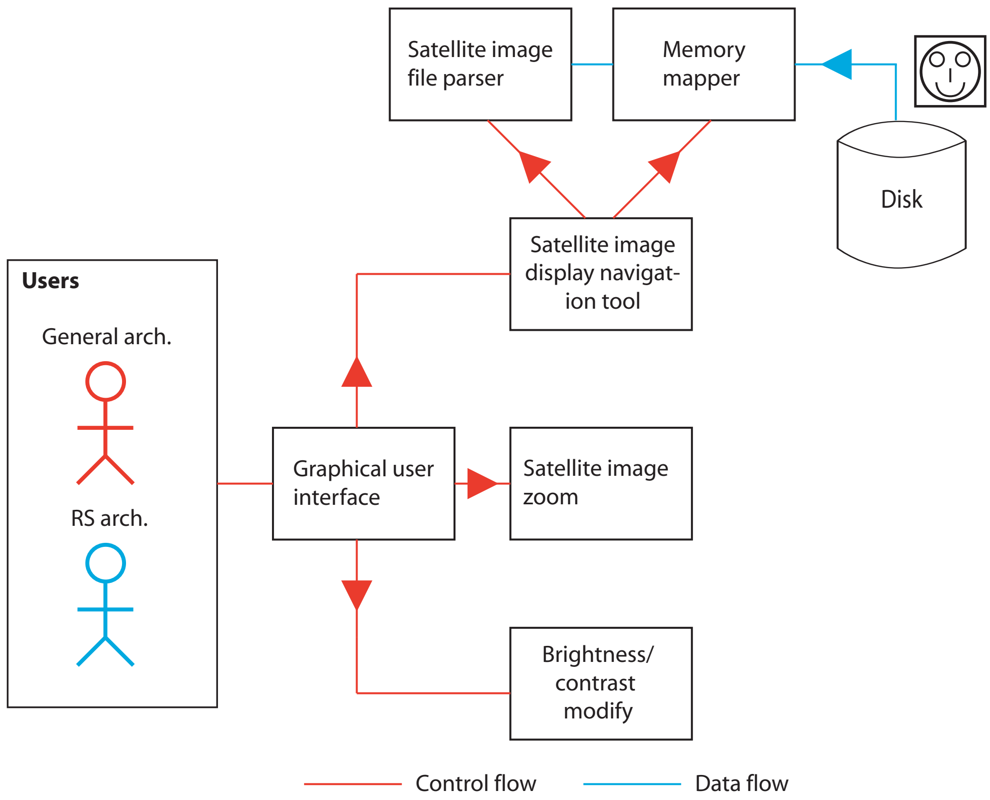


Fig. 26: The satellite-image display functionality. Both users control this functionality through a user interface. Input files are satellite images. Again, the complexity of displaying image data to screen makes use of imaging libraries the only viable alternative for this operation.

4.5.5. Field mask display

The display of field masks can be done either in specialised vector display windows or on top of satellite images. For both types of display a navigation and zoom tool must be available. See the appendix for an example of a field mask displayed on top of a satellite image.

As for the satellite images, the complexity of displaying such vector data on screen makes use of imaging libraries the only viable alternative for this operation.

4.5.6. Detection display

The display of detections can be done either in specialised vector-display windows or on top of satellite images. For both types of display a navigation and zoom tool must be available. See the appendix for an example of detections displayed on top of a satellite image.

As for the satellite images, the complexity of displaying such vector data on screen makes use of imaging libraries the only viable alternative for this operation.

4.5.7. Pre-processing algorithms

The pre-processing algorithms that should be available under the CHDS system are noise and plough furrow removal. The functionality of this module is described in the following figure:

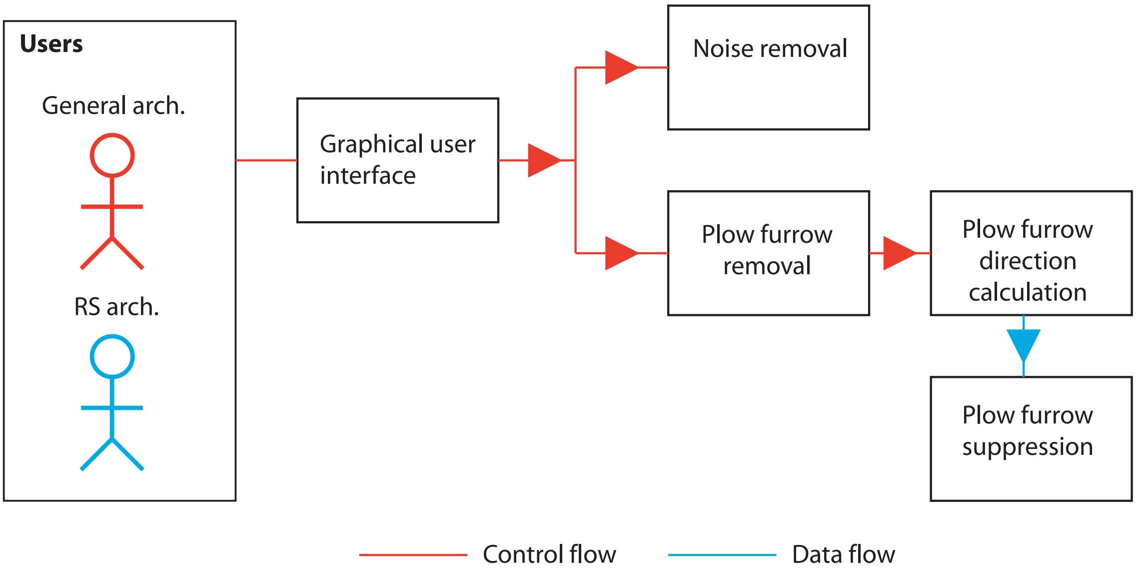


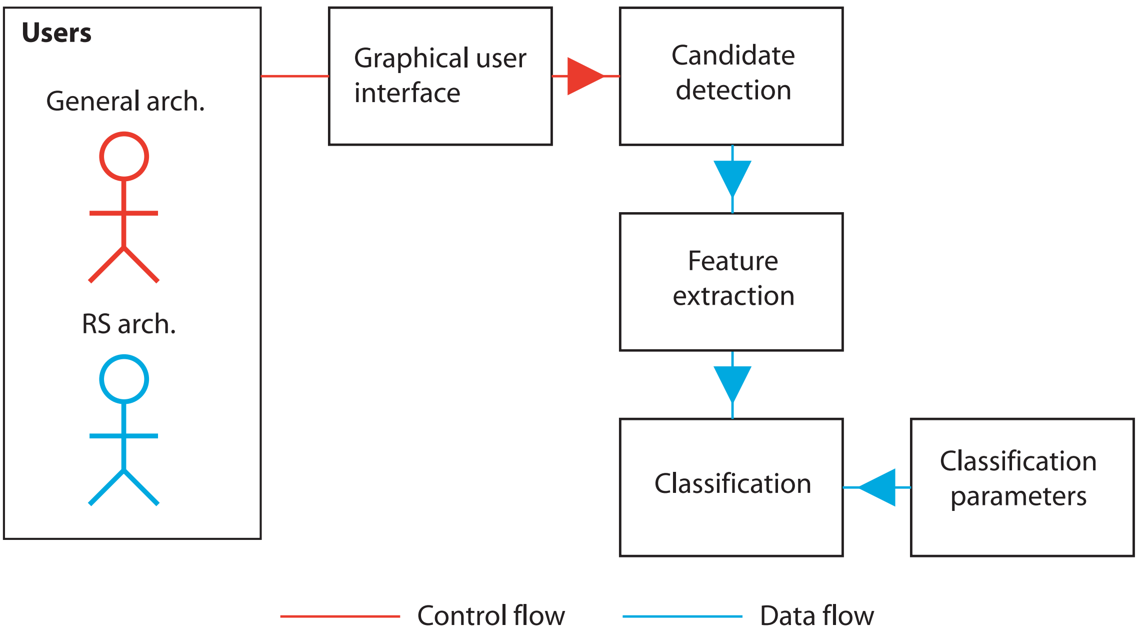
Fig. 27: The pre-processing functionality. Both users control this functionality through a user interface.

The noise-removal algorithms should allow for simple spatial-domain filtering. The plough-furrow removal depends on detecting the local plough-furrow direction followed by a filtering to suppress the furrows.

4.5.8. Detection algorithms

The detection algorithm is a two-step procedure (see [2]) consisting of detection of regions with deviating grey levels or spectral values in the image followed by a classification step that sorts and keeps/discards the initial detections according to size, shape and other criteria. The functionality of this module is as described in the following figure:

Fig. 28: The detection functionality. Both users control this functionality through a user interface.



The candidate detection module will extract regions from the image that have deviating spectral properties compared to their local background. This can either be done using locally adaptive thresholding algorithms or by using an unsupervised clustering of each field (as described in [2]). Once the candidate regions are found, features describing these regions must be extracted. As described in [2], these features can for instance be:

- Size
- Degree of rectangularity
- Compactness
- Aspect ratio
- Grouping (contextual information)
- Location in the terrain

The classification module will most likely be implemented using a trained classifier. Since the interesting classification parameters are likely to change (for instance as the CHDS is applied in different regions or as experience is gained in the project) it is probably necessary that the classification parameters be read from file to allow for simple updating.

The necessary algorithms for carrying out these steps are found in many image processing and pattern-recognition libraries.

4.5.9. Analysis algorithms

The analysis algorithms that should be available are algorithms for computing statistics, and for advanced pre-processing and analysis. It is impossible at the current time to determine what algorithms and tools should be made available to the user as part of the analysis algorithms. Most image processing and pattern-recognition libraries contain a wealth of such algorithms, and the use of such a library will make it simple to offer extensive functionality to the user.

5. Perspectives

2070 chemical samples were in 2004 taken from 27 different anomalies. The majority of the samplings consisted of sections to test out anomalies. Only one site was grid-sampled. This means that the activity was focussed on preliminary sampling with a high degree of mobility and relatively few samples in relation to the energy spent on negotiating permissions with the landowners and setting up measuring systems in new positions. In the coming campaigns it will be important with a larger number of grid samplings and accordingly a larger number of samples.

Geochemical analysis for a value of 2.7 mill. NOK was made available for the project in 2004. The aim is in a longer perspective to use the information extracted about the catalogued chemical signatures of the different types of cultural heritage sites to develop a cheap and fast chemical method for categorisation of the cultural heritage anomalies on the ground.

The investigation is to an increasing degree, and with apparent success, focussing on cultural heritage anomalies with a low visibility. This is a difficult but also crucial part of the method development to facilitate the necessary distinction of a reasonably representative picture of the cultural heritage situation in prehistory. The dominance displayed in the present registers by structurally preserved mounds is to a high degree a reflection of their high visibility in the landscape. It seems obvious that the methodology will underpin a radical change in the concepts related to the prehistoric cultural landscape. Increasingly precise small-scale data will allow for a considerable improvement of the medium- and large-scale approaches.

There has not yet been capacity to start up a systematic analysis of small-scale anomalies that reflect modern features and geology to improve the ability to distinguish this comprehensive group from the cultural heritage anomalies. Collection of this type of comparative data is a precondition for successful application of cost-efficient ground verification based on geochemical signatures.

The development of Norwegian reference areas with well-known cultural heritage sites and with well-documented geochemical signatures will create a platform for direct interaction with future hyperspectral satellite sensors facilitating detailed remote-analysis of the chemical components on the surface. The development of such reference areas will secure Norway a position in future developments in the cultural heritage remote-sensing field and probably also in related environmental fields.

Pattern recognition is on an experimental basis applied to the multispectral satellite images. The aim is to develop a partly automatised system for distinction and classification of possible cultural heritage anomalies. Reasonable success criteria for such a system will be 1) that it is able to distinguish the majority of the important cultural heritage anomalies in a given area without picking out large numbers of irrelevant anomalies and 2) that it can exclude significant search areas so that the manual search for relevant anomalies the system has not been able to pick up will not have to be applied to the full search area. This report contains the Norwegian Computing Centre's outline of a first-generation system for 'partly automatised computer-assisted detection and classification of possible cultural heritage sites.'

The primary aim of the present project is to develop an administrative decision-support system that with a minimal involvement of a trained human observer can classify cultural heritage sites on the basis of multi/hyper-spectral satellite images. For administrative purposes ground verification of the results will be necessary. A second aim is therefore to develop a non-destructive and cost-efficient geo-chemical verification method that can also provide a data-platform for methodological interfacing with hyperspectral satellite data in the future.

On the basis of the results of the approach assumed through the last years of development it does not seem unrealistic to expect that the methodology can support the development of significantly improved administrative routines in the cultural heritage sector and at the same time contribute to the introduction of a more realistic understanding of the prehistoric cultural landscapes than one based on the present content of the cultural heritage registers.

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Appendix: Simulated screen snapshots

In order to provide a preliminary impression of what the screen output during the different stages of a typical use case will look like we provide the following illustrations. The illustrations are made using ENVI in conjunction with manual drawing to produce an impression of what a final result may look like.

A.1. Display of input satellite image

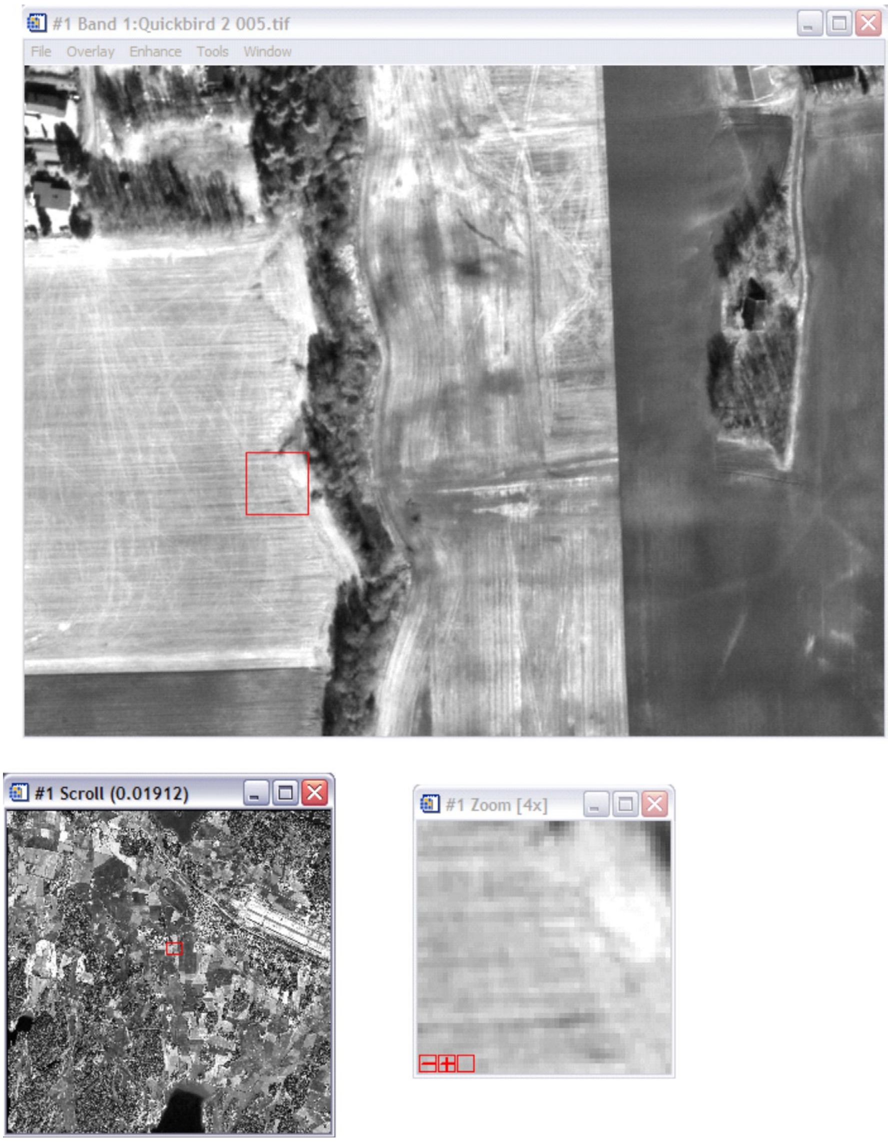

Figure 1: Conceptual satellite image display. The lower left window shows the navigation (scroll) window, displaying a sub-sampled version of the entire image. The upper window shows a part of the total scene (that marked by a red box in the navigation tool) in 1:1 scale (that is, one satellite image pixel is mapped to one screen pixel). The lower right image shows a 4:1 scale zoom of the part of the image marked by the red box in the 1:1 display.

A.2. Display of field polygons on top of satellite image

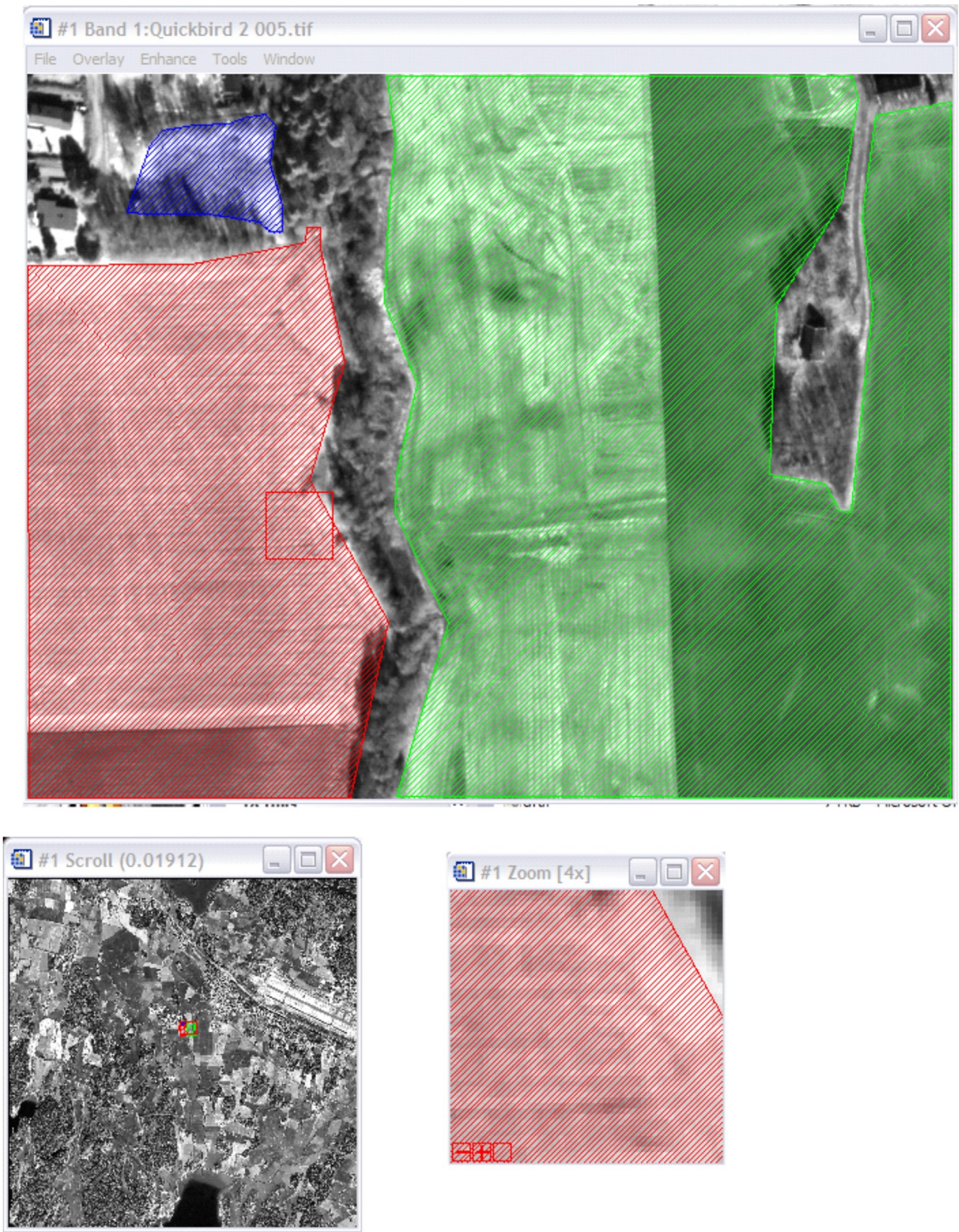

Figure 2: Conceptual display of field masks. Three field masks have been loaded and are displayed on top of the satellite image. As before, a navigation and zoom tool is available.

A.3. Classification output and list of detections

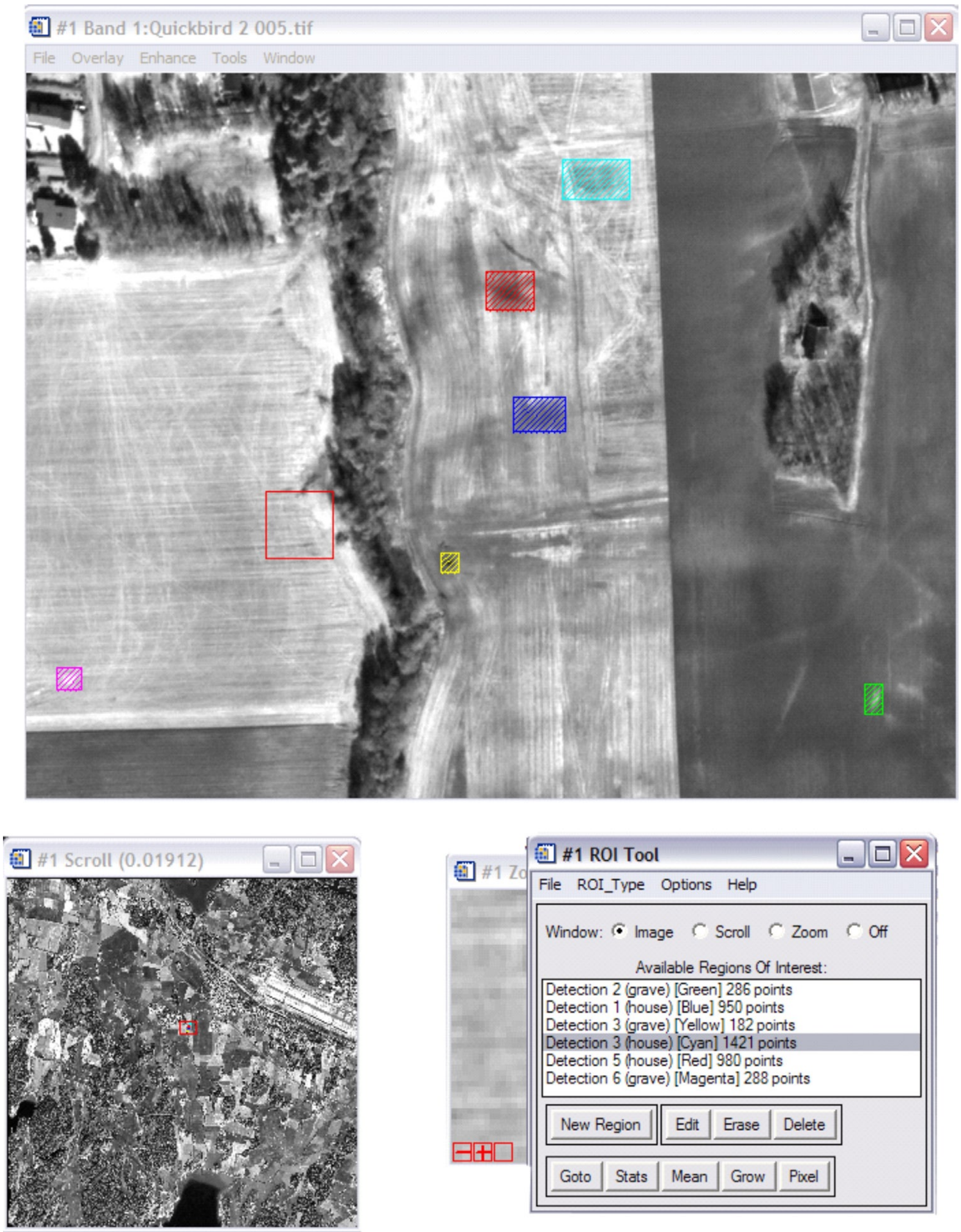

Figure 3: Conceptual display of detection result. Having run a cultural heritage site detection within the masks shown in the previous figure, these could be the detections returned. As before, a navigation and zoom tool are available. The window listing the detection also shows a (fictitious) interpretation of each site. By clicking on a particular detection in this list (detection 3 in the example) this detection is centered in the 1:1 display window.

A.4. Retained classifications

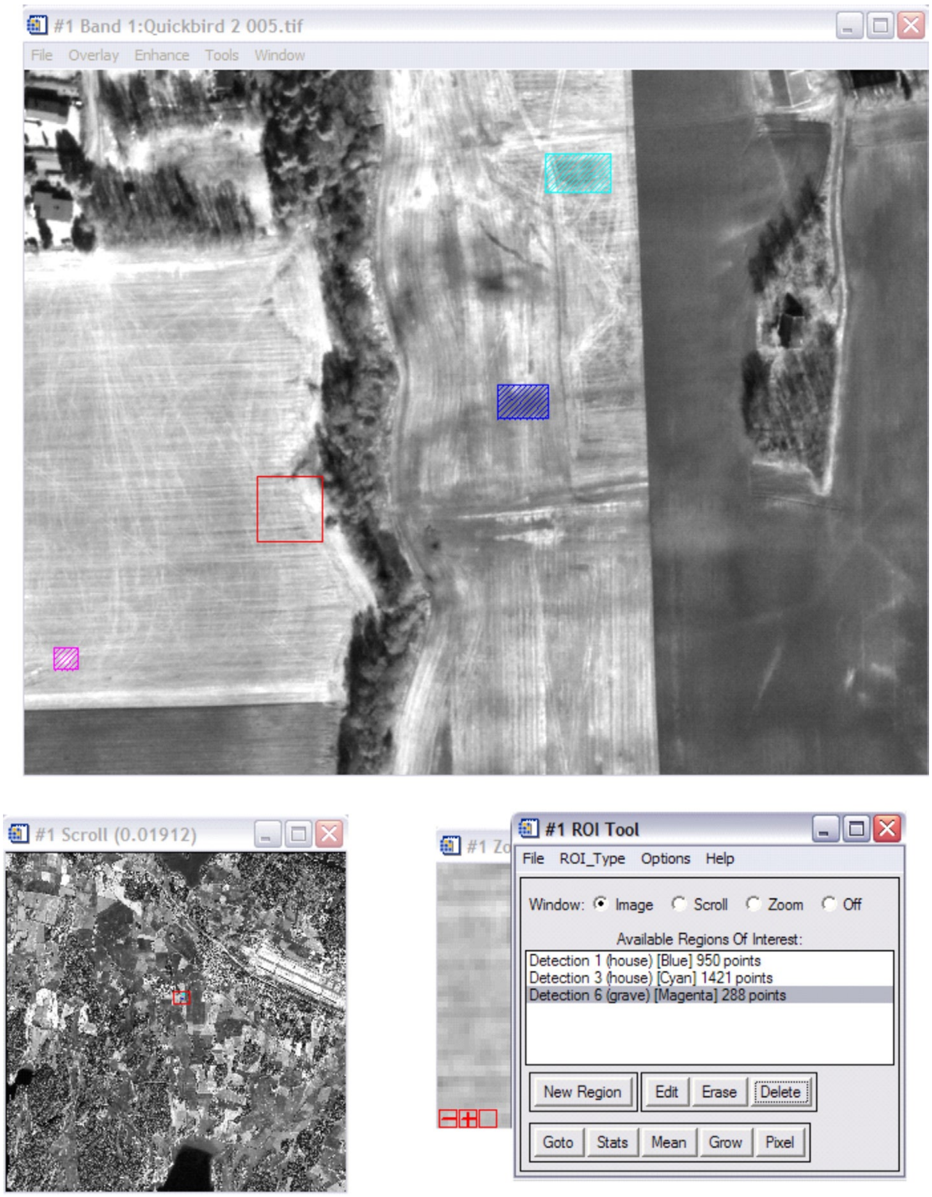

Figure 4: Conceptual display of edited detection result. Having run a cultural heritage site detection within the masks shown in figure 2, the user has deleted detection assumed to be of no interest. As before, a navigation and zoom tool are available.

A.5. Zoom and contrast enhancement of detection

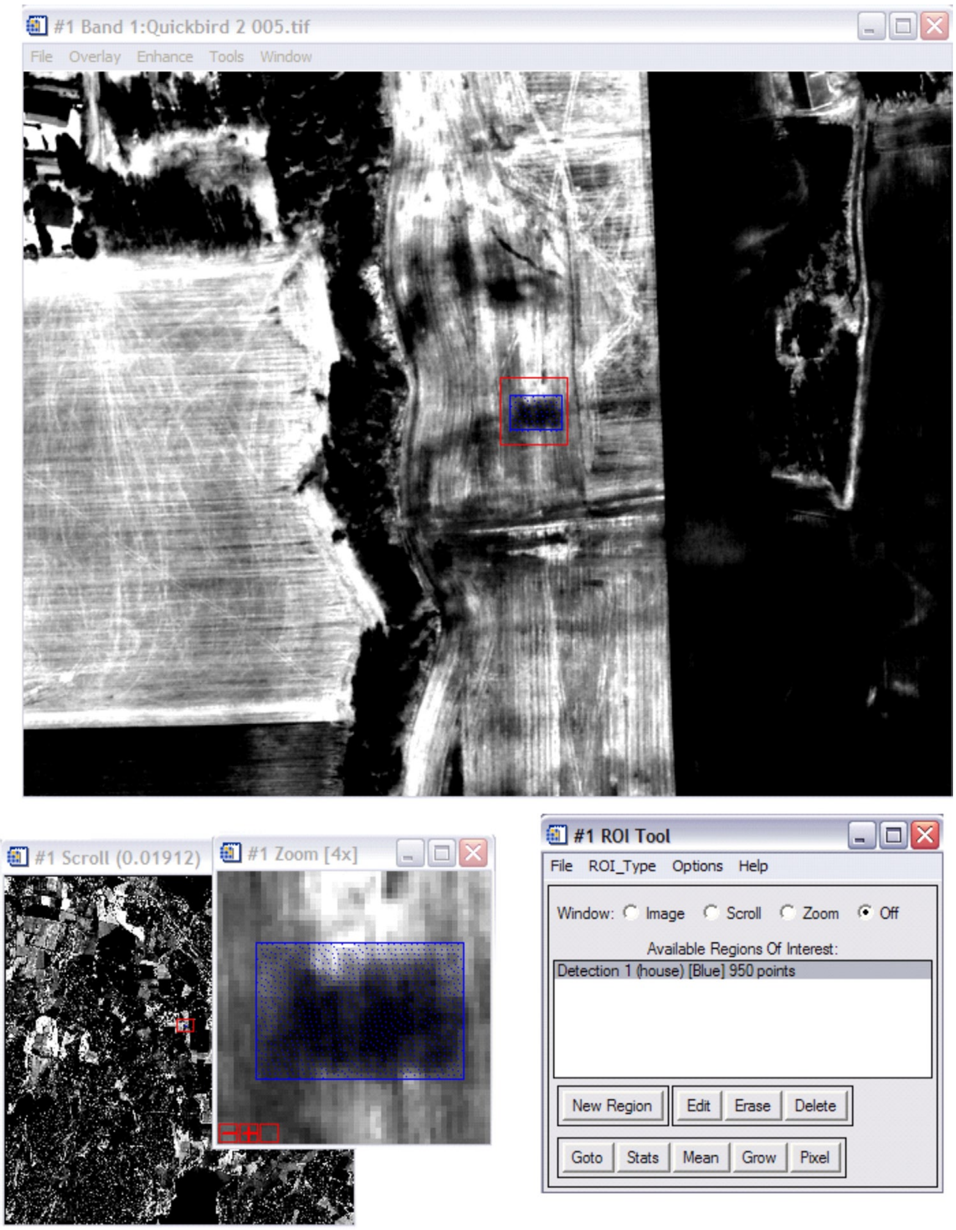

Figure 5: Conceptual display of detection result after modification of the brightness/contrast of the display.