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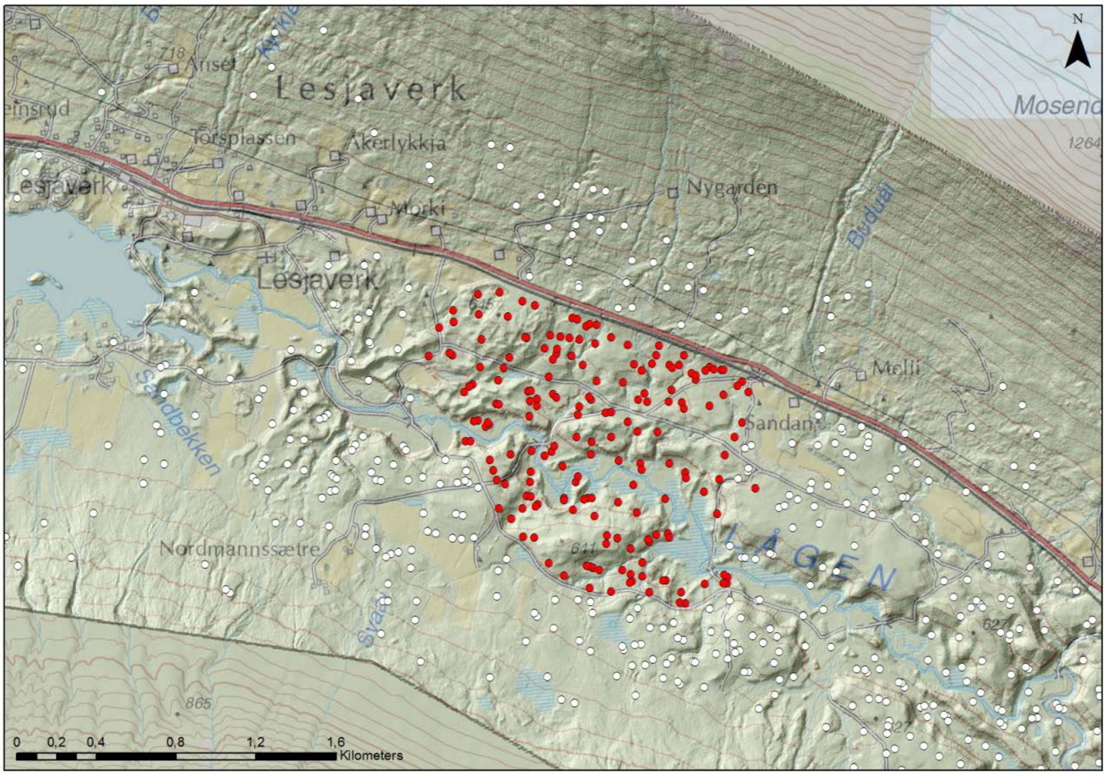
Note

Application of Remote Sensing in Cultural Heritage Management

Project report 2014



Note no. SAMBA/07/15

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Date 2 March 2015

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Abstract

This project was started in 2002 with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale. The project focuses on the development of automated pattern recognition methods for detecting and locating cultural heritage sites. The pattern recognition methods are included in a prototype software called *CultSearcher*. This software currently supports the following: (1) Search for crop marks and soil marks in optical satellite and aerial imagery; these marks could be levelled grave mounds. (2) Search for pits in airborne laser scanning (ALS) data; these pits could be pitfall traps or charcoal burning pits. (3) Search for heaps in ALS data; these heaps could be Iron Age or Bronze Age grave mounds.

This note describes the achievements of the project during 2014. The project is funded by the Norwegian Directorate for Cultural Heritage. In 2014, the semi-automatic method in *CultSearcher* for the detection of grave mounds was used in detailed mapping of grave mounds in the Iron Age grave field at Vang, Oppdal minicipality, Sør-Trøndelag County. The same method was used for detailed mapping of grave mounds in selected areas in Larvik municipality, Vestfold County. In Lesja municipality, Oppland County, a combination of automatic pit detection and automatic heap detection was used in the detailed mapping of charcoal kilns Results from the project was presented at the international CAA conference in Paris, April 2014 and at the national seminar CAA-Norge in Oslo, October 2014. The method for mound detection has been accepted for publication in *Journal of Archaeological Science: Reports* in 2015.

Keywords	Airborne laser scanning, lidar, grave mounds, charcoal kilns, iron works, Iron Age, semi-automatic detection
Target group	Archaeologists, remote sensing researchers
Availability	Open
Project number	220 663
Research field	Archaeology, Remote sensing
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1 Introduction

Several Norwegian municipalities are experiencing growing pressure on agricultural and forested land for development, being it new residential areas, new mountain cabins and hotels, new highways, or other purposes. The traditional mapping of cultural heritage, mainly based on chance discovery and with inaccurate positioning, has proven inadequate for land use planning. Therefore, the Norwegian Directorate for Cultural Heritage, in cooperation with some Norwegian counties and municipalities, are investing in the development of new methods, using new technology, for a more systematic mapping of cultural heritage.

A project was started in 2002 by the Norwegian Directorate for Cultural Heritage, aiming at developing cost-effective methods for surveying and monitoring cultural heritage on a regional and national scale. During the first years, the focus was on the automatic detection of crop marks and soil marks in cereal fields in satellite and aerial images (Aurdal et al., 2006; Trier et al., 2009). Several of these detections have been confirmed to be levelled grave mounds, dating to 1500-2500 years ago.

However, methods based on optical images are of limited value in forested areas, since the archaeology tends to be obscured by the tree canopies. However, by using airborne laser scanning (ALS) data, the forest vegetation can be removed from the data, which makes it possible to detect archaeology in a semi-automatic fashion, provided the archaeology manifests itself as details in the digital elevation model (DEM) of the ALS ground returns (Figure 1.1), and that these details may be described using some kind of pattern.

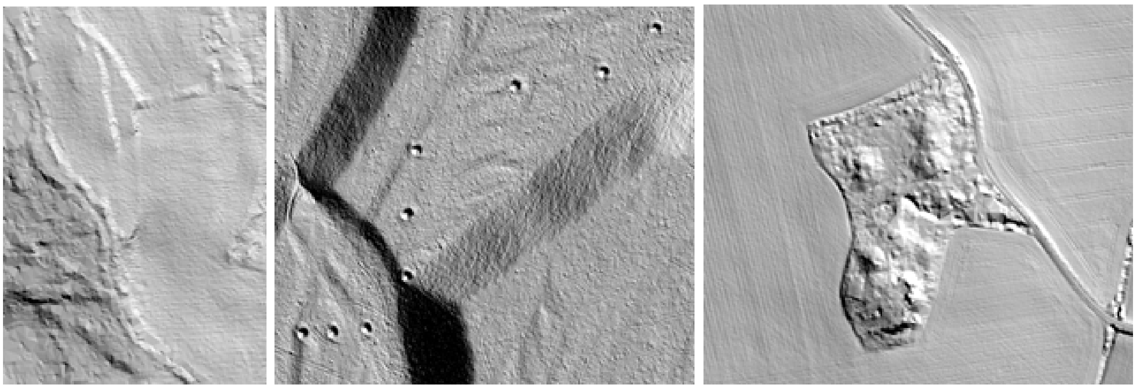


Figure 1.1. Airborne laser scanning (ALS) data from some Norwegian municipalities. Left: Kongsberg, with stone fences. Middle: Nord-Fron, with pitfall traps for moose hunting. Right: Larvik, with grave mounds.

In 2010, the project started the development of an automatic method for detecting pits in DEMs of ALS ground returns. The method was used to map hunting systems, iron extraction sites and charcoal burning pits (Trier and Pilø, 2012) in two ALS datasets: Olstappen (29 km^2, Nord-Fron municipality, Oppland County, 10 emitted pulses per m^2) and Øystre Slidre (400km^2, Øystre Slidre municipality, Oppland County, 5/m^2). In 2011, initial attempts were made at detecting heaps in ALS data. These heaps could be Iron Age or Bronze Age grave mounds. Preliminary experiments on ALS data from known grave mound sites in Larvik municipality, Vestfold County were promising.

The rest of the report is organized as follows. Section 2 describes detailed mapping of charcoal kilns in Lesja municipality, Oppland County. Sections 3 describes field work done in 2014 in Larvik municipality, for the on-going mapping of grave mounds in Vestfold County. Section 4 describes detailed mapping of Norway’s largest Iron Age grave field, located at Vang in Oppdal municipality, Sør-Trøndelag County. Section 5 contains a paper presented at the 42th Annual Conference on Computer Applications and Quantitative Methods in Archaeology (CAA 2014), Paris, 22-25 April 2014.

Many of the illustrations in this note are superimposed on base maps from the Norwegian Mapping Authority (Statens Kartverk).

2 Mapping of charcoal kilns in Lesja, Oppland County

By: Lars Holger Pilø (Oppland County Administration)

The 17th century saw the establishment of a number of iron works in Norway, based on the need of the Danish king for iron for ships, armaments and other military purposes. A typical feature of such iron works was the forced labour put on local farmers to supply wood and charcoal for the mines and the furnaces. This was normally done by establishing a circumference described in a royal letter of privilege, within which the local farmers had to supply set materials at a fixed price.

The iron works at Lesja (in Norwegian: Lesja Jernverk) was established 1660 in the wake of the discovery of iron ore locally. Royal privileges were given to the owners, including the forced supply of wood and charcoal within a circumference of 40 km. Since the iron works were placed in a forested valley with bare mountains to the north and south, this supply of wood and charcoal had to be collected from the valley extending to the southeast and northwest from the iron works. Since Lesja was a marginal agricultural settlement, the extra income from producing charcoal was welcomed by the local farmers. It is known from historical records that the local forests were cut down to such a degree already in the mid-18th century, that scarcity of charcoal put limits on the production of iron. After intermittent production of iron during the lifetime of the iron works, the production of iron at Lesja Jernverk ceased permanently in 1812.

The *bergmeister* for such iron works as a rule came from present-day Germany, where there was already a long tradition of mining iron ore and producing iron in blast furnaces. The Bergmeister brought with them a different tradition of producing charcoal – in kilns, instead of in pits, as had been the case in Norway in the Late Iron Age and the Medieval Period.

Surveys in connection with cultural heritage management work have pointed to the presence of large numbers of charcoal kilns in the area surrounding the Lesja Jernverk. It was not known, however, what the total number of preserved kilns was, if they showed sign of reuse, and how they were distributed throughout the circumference described in the royal letter of privilege.

In 2013 the entire forested valley in Lesja was mapped with lidar by TerraTec AS, using a Leica ALS70 airborne laser scanner. The quality of the data is five first returns per m^2. The initial visual interpretation of the lidar data, based on a single-light source hillshade and a spatially limited local relief model covering only the central area, yielded ca. thousand possible charcoal kilns. All were round, with a diameter between 10 and 20 m. However, the edge of the kilns had a varied topographical expression. Some kilns had a ditch surrounding them, some had pits, and some had a combination of the two. In addition some kilns had a low mound inside the ditch/pits or even pits inside the circumference.

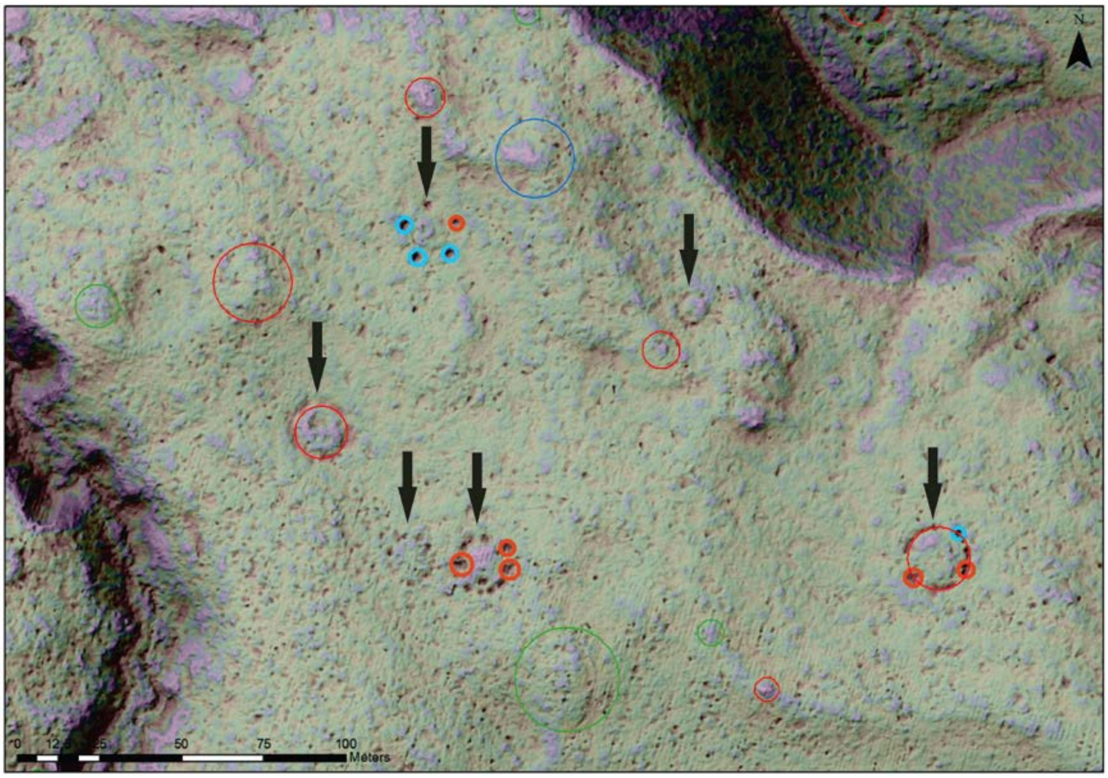


Figure 2.1. Charcoal kilns (marked with arrow), with automatic detections of pits (small circles in thick lines) and mounds (large circles in thin lines), of medium to high confidence. From the test run of automatic detection, prior to the field control.

The topographical expression of the charcoal kilns combining pits, round ditches and mounds made it likely that previous work on automatic detection (Trier and Pilø, 2012; Trier *et al*., 2015) would be applicable in the search for charcoal kilns in the data. This was confirmed by a test run of the detection of pits and mounds on the central part of the data set (Figure 2.1). The first step in developing an automatic detection method specifically for charcoal kilns was to collect field data for a training data set.

The fieldwork for the training set was conducted in early June 2014. Participants were Frank Røberg and Lars Pilø, Oppland County Council and Rolf Sørumgård, Lesja. The survey covered an area of 1.8 km^2, just east of the iron works. The area surveyed covered terrain on both sides of the Lågen River, and was mostly quite hilly. Nearly all recorded charcoal kilns were situated either on flat terraces or in depressions in the terrain. None were found on hilltops. This is most likely caused by purely functional reasons - transporting timber downhill to the kilns rather than uphill. Total area coverage was achieved inside the survey perimeter, not only a check of suspected kilns. A total of 183 kilns were recorded, including attribute data describing their topographical expression (Figure 2.2).

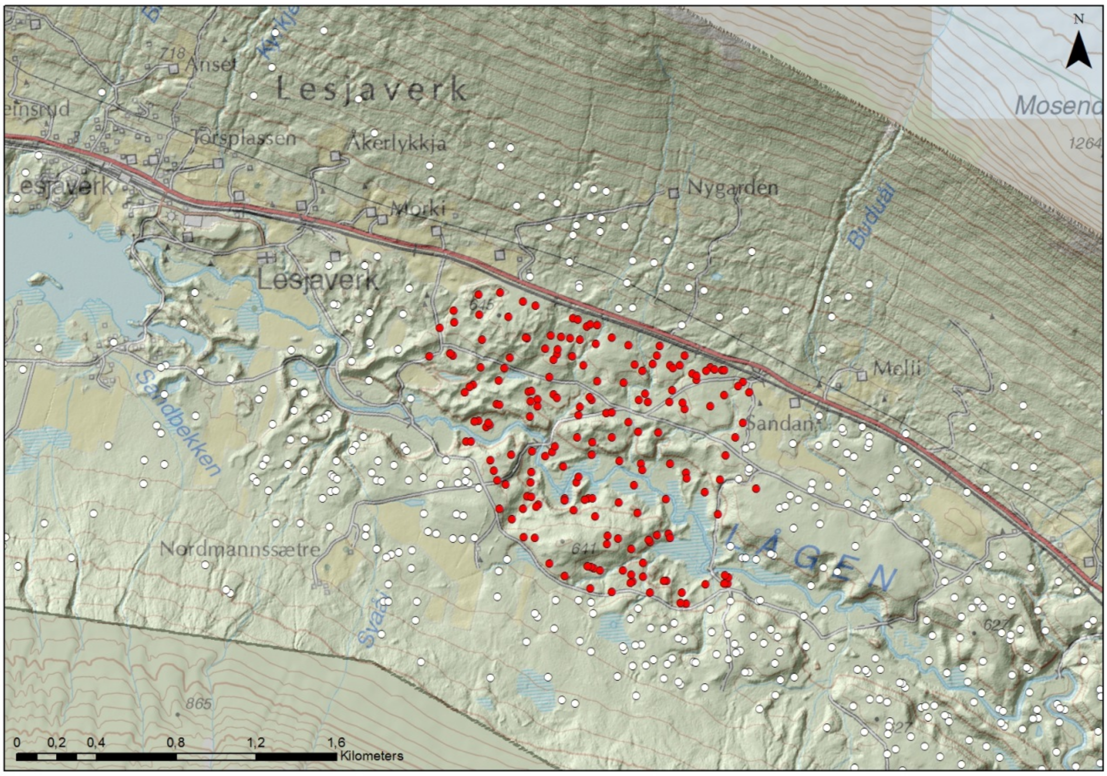


Figure 2.2. Charcoal kilns recorded in the field (red) and found during visual inspection of the data (white).

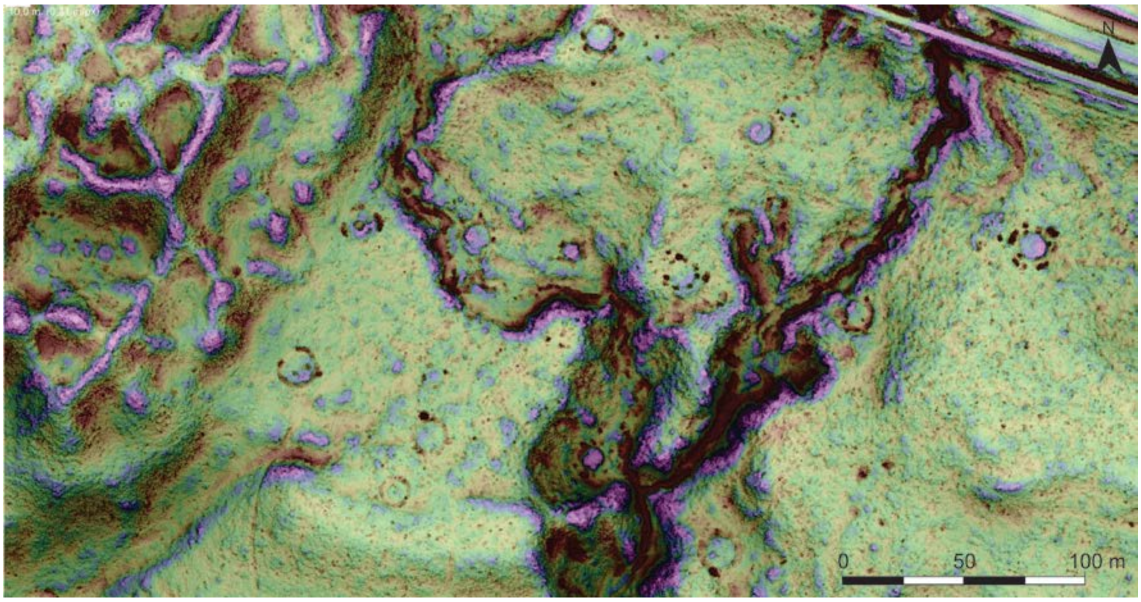


Figure 2.3. The new WMS-visualization showing the charcoal kilns clearly, using a combination of local relief model, sky-view factor and slope.

Based on the field control, a new visual inspection of the lidar data was undertaken. The quality of this re-interpretation was strengthened by the application of a new WMS-visualization developed by COWI and Oppland County Council (Figure 2.3). Using a combination of methods (Local Relief Model, Sky View Factor, Slope and MDOW hillshade, the parameters of which can be remotely controlled) it provides a better visualization of the lidar data, enhancing the quality of the visual interpretation.

The new interpretation yielded a total of 905 suspected charcoal kilns (not confirmed in the field), which may also be used for training purposes.

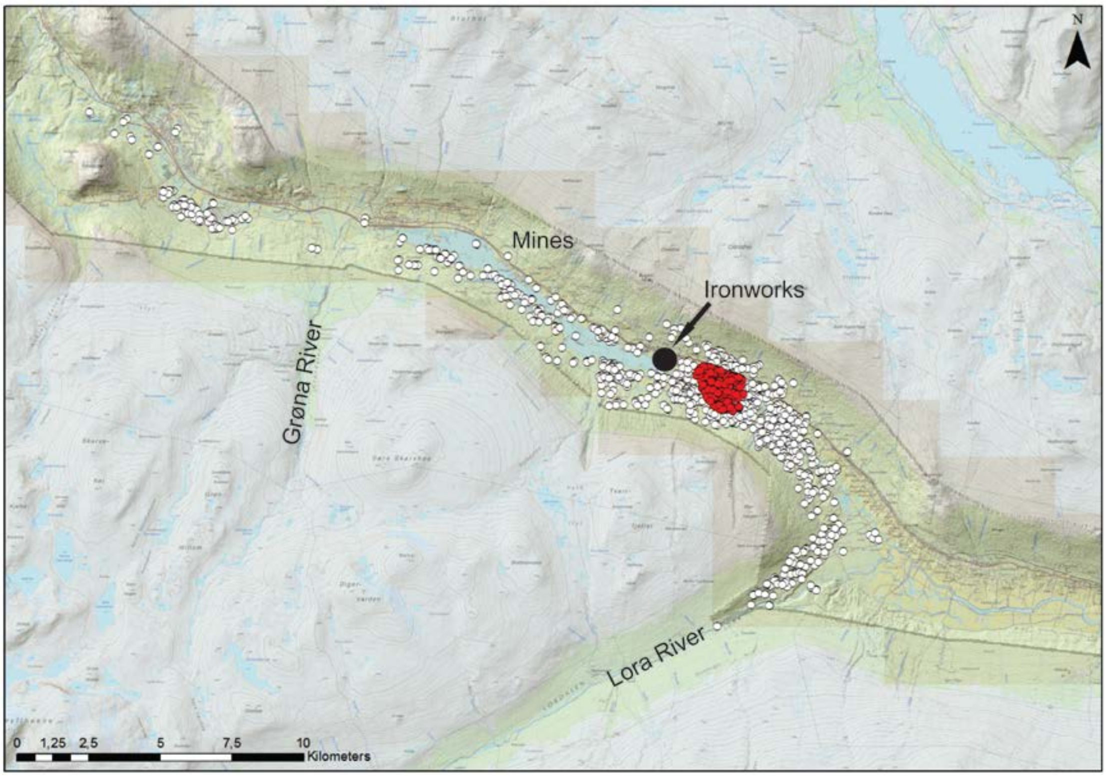


Figure 2.4. Overall map of the distribution of charcoal kilns surrounding Lesja Jernverk (ironworks). Field controlled kilns in red, visual inspection in white.

The overall map of the distribution of charcoal kilns (Figure 2.4) shows some interesting features, which may or may not be an expression of the real distribution of the charcoal kilns. Most of the charcoal kilns have been found on old flood plains or glacial washout deposits. Today these plains are covered by open pine forest. This gives excellent conditions for lidar, and could imply that kilns in such topographical situations are over-represented on the map. That this could be the case is supported by the fact that it was only discovered quite late during the first round of visual inspection, that charcoal kilns were also present in the hillside north of the iron works. They have a different topographical expression, being dug into the hillside on one side, and having a terrace on the other side – to provide a platform for the kiln. They can be hard to spot, even using the new WMS-visualization.

There is also the question of the lack of kilns in certain areas. That kilns are only present in limited numbers in the mining area northwest of the iron works is understandable, since the timber here would have been used for fire-setting in the mines. The lack of kilns in the old settlement area to the east of the Lora River could be caused by lack of forests in this area at the time of the iron works, since the timber here would already have been used for buildings, fences and other agricultural purposes. Lack of kilns at the mouth of the Grøna River in the north-western part of the circumference is puzzling, but may be caused by extensive flooding in the area, following the 1789 flooding catastrophe that struck much of the region.

Planned work on the charcoal kilns in Lesja will include further development of automatic detection of charcoal kilns based on the 2014 training data set, performed on the entire lidar data set from Lesja. Based on this improved detection method, targeted fieldwork will address the problems of the representativity of the distribution map described above.

Scheider *et al*. (2015) recently attempted automatic detection of charcoal kilns in a large kiln field near Cottbus, Germany. These kilns have a somewhat different topographical expression than the kilns from Lesja, but many of the challenges in applying automatic detection are similar, e.g., the number of false detections.

3 Mapping of grave mounds in Larvik municipality

By: Christer Tonning (Vestfold Country Administration) and Steinar Kristensen (the Museum of Cultural History at the University of Oslo)

The field season 2014 in Vestfold County was originally planned for the Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment (http://www.vfk.no/Tema-og-tjenester/Kulturarv/Vestfoldhistorie-artikkel/Regionalt-viktige-kulturmiljo/Jaberg-Istrehagan-Marumdalen-Haugen-og-Vestad/). This area is located in Sandefjord and Larvik municipalities, and is identified by the County Council as one of 37 national and regional important Cultural Heritage environments in Vestfold County (RPBA). The northern part of the area is in Sandefjord municipality, while the larger southern part is in Larvik municipality (Figure 3.1). The whole landscape of the area is marked by extensive use and cultivation, manifested by the many Cultural heritage sites, historical road systems and old place names. The most famous sites here are probably the Istrehågan Iron age ship-shaped stone settings and grave fields, and the Bronze Age rock carvings at Haugen. But also a significant number of grave mounds and grave fields are located in forest patches surrounding the modern farmsteads and fields.

Figure 3.1. Overview map. Purple outline: the Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment in Larvik and Sandefjord municipalities.

Figure 3.2. Aerial photography taken in the mid-1990s showing the farmsteads Istre Nordre and Søndre to the right in the photo, and Jåberggrenda to the left in the photo. The Istrehågan monument is situated in the forested area just south of Jåberggrenda. (Photo taken towards a southern direction. Photo: Isa Trøim).

Vestfold County Council conducted a field control survey of all known cultural heritage sites in Sandefjord in the period 2007-2009 (Jantsch 2009 : 4). That project demonstrated that cultural heritage sites in Sandefjord municipality were previously mapped with inaccurate positions. This is believed to be true for old mapping of cultural heritage sites in Norway in general. The inaccuracies may now be corrected due to technological advances during the past 15 years. While archaeologists previously used printed aerial photos and maps to position sites, archaeologists now routinely uses differential GPS systems with decimetre precision, even in forested areas. Also, the use of airborne laser scanning (ALS) data enables detailed mapping of cultural heritage remains, if they manifest themselves as features in a digital terrain model of the ALS data. These technological advances may be used to correct all old mapping of cultural heritage in Norway. However, in Sandefjord municipality, all old mapping of cultural heritage has been corrected in the Norwegian national cultural heritage database *Askeladden*. This could have meant that the collection of currently known grave mounds in Sandefjord municipality could be used as a training data set for improvement of the semi-automatic detection method in the *CultSearcher* software. However, the ALS data for Sandefjord has a quite low point density, so the potential of this data set is limited.

The 2007-2009 control project in Sandefjord municipality was intended to be continued in Larvik municipality. However, funding for the project ended in 2012 and only parts of Larvik municipality has been controlled.

3.1 Data and method

All municipalities in Vestfold County have been covered by ALS data during the past seven years, organized through a collaborative board of interested parties (named ‘Geovekst’) lead by the Norwegian Mapping Authority (Statens Kartverk), and including all municipalities in Vestfold County and Telemark County, the National Road Authorities (Statens Vegvesen), Skagerak electrical power company, and the Norwegian Water Resources and Energy Directorate (NVE).

ALS data covering all of Sandefjord, Tønsberg, Re and Stokke municipalities was collected by TerraTec AS in 2008 with an average point density of 2.1/m². The ALS data for Sandefjord was collected on 20 April 2008, using a Leica ALS 50-II laser scanner.

ALS data for Larvik municipality was collected in 2010 by Blom Geomatics in two parts; for the southern part (south of the E-18 highway), an average of 22 points/m² were collected, while for the northern part, 2.1 points/m². The southern part was collected by helicopter on 3-7 June 2010, with leaves on deciduous trees fully developed, thus, in effect, blocking the ground beneath these trees from being captured in sufficient detail for archaeological mapping (Trier *et al.*, 2013:23).

In the Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment area, we had the opportunity to test the method of semi-automatic detection of grave mounds in ALS data in two neighbouring data sets acquired with different qualities and with different techniques.

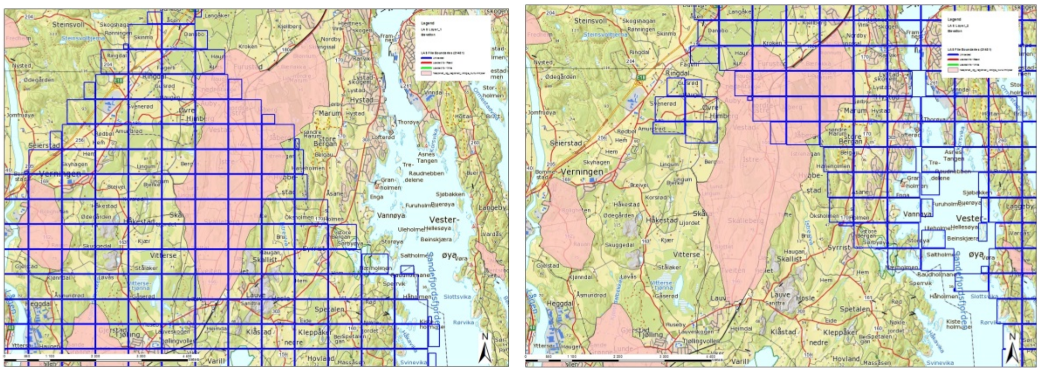


Figure 3.3.Left: ALS coverage for Larvik municipality from 2010. Right: ALS coverage for Sandefjord municipality from 2008.

The data quality of the Sandefjord data turned out to be poor for semi-automatic detection of grave mounds using *CultSearcher.* The data had artefacts in the form of stripe patterns, resulting in almost no automatic detections with high or medium high confidence (levels 5 and 4), but a very high number of false detections with medium and low confidence (levels 3 and 2). Several attempts were made by the Norwegian Computing Center to resolve the problems, but in conclusion the dataset is of too poor quality to be used with *CultSearcher*.

Thus, it was not possible to compare the detection rates obtained by *CultSearcher* in the two different datasets. Instead, we focused on the Larvik 22 points/m² data of 2010.

3.2 Selection of field verification sites

The Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment area covers more than 12 km², which was too large for complete field survey within the project's budget. Therefore, a selection of areas for fieldwork was necessary. The exclusion of the Sandefjord data due to poor data quality reduces the area by 4.5 km², down to 7.5 km². To further close in on clusters of grave mounds and grave fields a hotspot map was created (Figure 3.4), where detections of confidence level 4 and 5 within a 50 meter radius of known graves and grave fields were used as seed points.

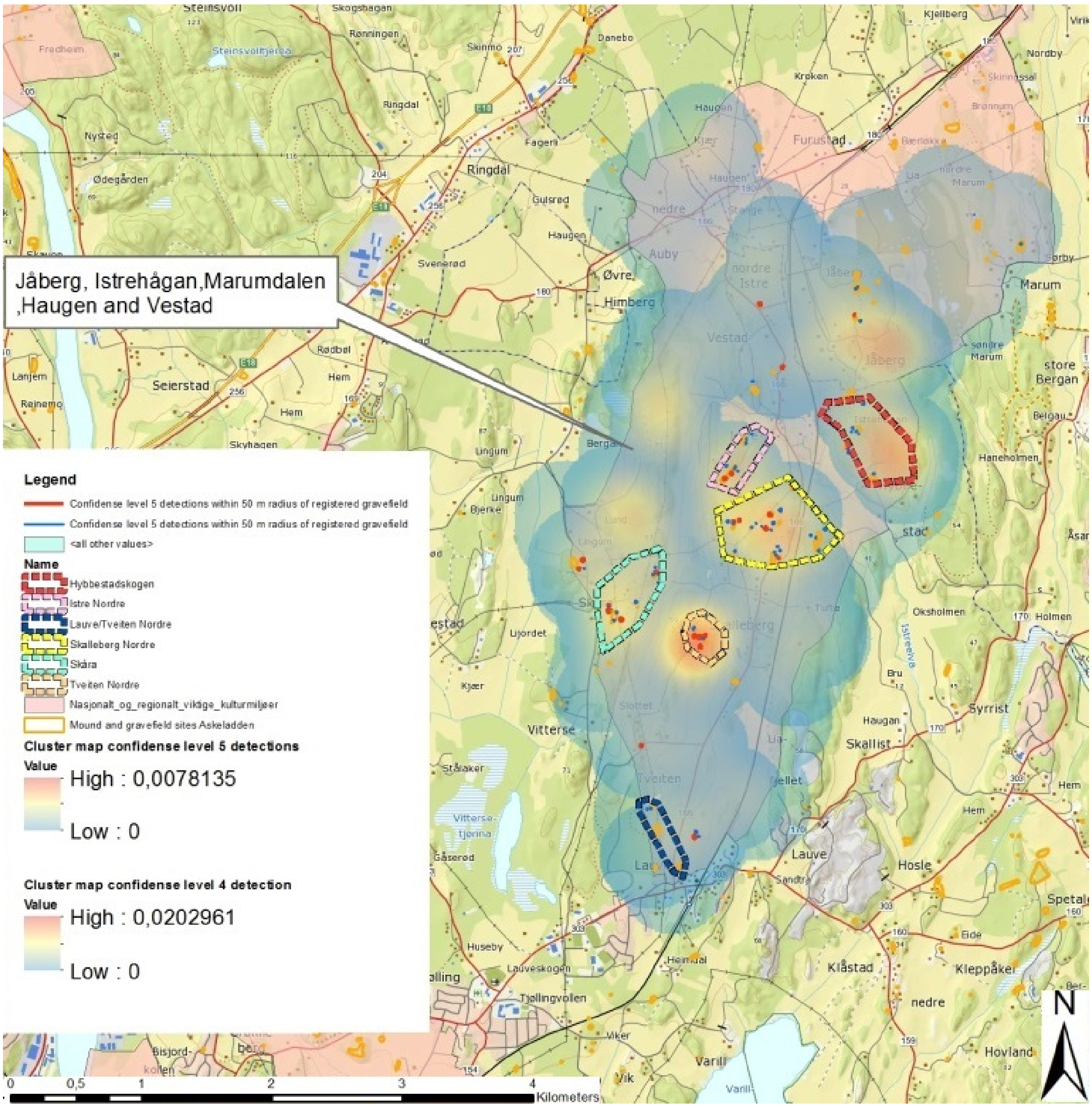


Figure 3.4. Hotspot map showing the clustering of known grave mounds and gravefields in the Larvik part of the RPBA area Jåberg, Istrehågan, Marumdalen, Haugen and Vestad.

Based on this map, the area for field inspection was reduced to 1.21 km², containing 25 known sites, which include 65 known grave mounds or grave cairns.

3.3 General fieldwork procedure

This subsection describes how Vestfold County Administration is currently conducting its archaeological field work and how the automatic detections from *CultSearcher* fit into this procedure.

Vestfold County Administration is conducting regular archaeological surveys in connection with zoning plans and in the early stages of construction work, whenever these may be in conflict with cultural heritage. The field work may involve test trenching with excavator, field walking in arable land, digging of test pits in forested areas, and/or general surface surveying. A rugged tablet computer connected to a precision GPS instrument is used to document the surveying and track coordinates. The archaeologist records the coordinates of all test trenches, test pits, cultural heritage sites, track logs, and more. The positional accuracy of the GPS instrument is a few centimeters. ESRI ArcPad 10 GIS software is used on the tablet computer.

Usually, prior to the field work, one creates a small GIS project which includes the area relevant for the survey. Backdrop map layers may be downloaded from web map services published by the Norwegian Mapping Authority (In Norwegian: Statens Kartverk) or other providers. A geo-referenced raster hill-shade visualization of the ALS data is used as a backdrop layer. The automatic detections by *CultSearcher* are used as vector layers, one layer for each confidence level, so that one may view, say, only detections of medium high confidence or better. Also, the current status of the *Askeladden* Norwegian national cultural heritage database is used as a layer. After the survey, the *Askeladden* database is updated with new detected monuments and corrected outlines of existing monuments.

The original ALS data has 10 cm accuracy, and was converted to a digital terrain model (DTM) with 20 cm resolution as part of the automatic heap detection. The GPS instrument has a few centimetres accuracy, so when walking in the terrain with a visualization of the DTM as a backdrop and the automatic detections of, say, medium high confidence or better, very little time was wasted on navigation; one could simply walk from one detection to the next and document the archaeological interpretation (mainly assessing whether the detection was false or not). In some cases, the diameter of the automatic detection did not match the actual size of the grave mound. Then, the archaeologist could walk along the circumference of the grave mound to digitize its extent rather quickly. Also, grave mounds missed by the automatic detection, whether spotted by visual inspection of the DTM visualisation, or spotted in the field, could be digitized in the same way.

Alternative visualisation of the ALS data was generated using the RVT software developed at ZRCSAZU in Slovenia (Zakšek *et al.*, 2011; Kokalj *et al.*, 2011).

3.4 The survey areas

Within the survey area, there are many small cultural heritage sites with one or several previously mapped monuments, e.g., grave mounds and/or cairns. The cultural heritage sites are in the following presented as 6 main survey areas with a total of 25 sites (Table 3.1). These areas are situated within a radius of approximately 1500 m. with a total of 65 previously known grave mounds and cairns. There are also a number of other previously known cultural heritage monuments in the area, in the form of hollow ways and standing rocks. Including these, the total number of recorded monuments is 73. The hollow ways and standing rocks were not subject to semi-automatic detection by the *CultSearcher* software, as no method for such structures has been developed yet. In the following, the numbers of monuments refer to grave mounds and cairns only, if not otherwise stated.

The survey team was to inspect *CultSearcher* detections of high confidence and medium high confidence (levels 5 and 4). The numbers of detections in the lower confidence levels are too many for complete field verification (see discussions in the project’s previous annual reports, e.g., Trier *et al*., 2013; Trier *et al*., 2014). If not mentioned otherwise, the surveys were carried out by archaeologists Christer Tonning (Vestfold County) and Steinar Kristensen (Museum of cultural history).

Table 3.1. Survey areas and Askeladden sites

Survey area	Askeladden IDs	#sites	#recorded monuments	#mounds/ cairns
Skalleberg	9316, 9317, 9319, 29165, 29166, 29167, 48740, 68451, 76922, 76926	10	23	19
Hybbestadskogen	38724, 38729, 76925, 107199	4	8	8
Tveiten Nordre	29155, 48741, 59345	3	3	3
Istre Nordre	59348, 68450	2	17	17
Skåra Vestre	9312, 29157, 59347	3	11	10
Lauve	9310, 68445, 136586	3	11	8
Total		25	73	65

3.4.1 Skalleberg

The Skalleberg survey area consists of three bedrock structures rising up to 25 m above the surrounding arable landscape, with large fields in between. The landscape is a mix of dense forest, areas covered with low vegetation and open areas with bare bedrock. The tree vegetation is mostly spruce, pine and juniper. In some areas the spruce forest was so dense that it was nearly impossible to penetrate by walking. There are some farms and settlements in the survey area. The survey area covered approximately 40 hectares. According to the national heritage database, *Askeladden*, there were 10 previously known cultural heritage sites with a total of 19 monuments well distributed in the survey area. The Skalleberg area was surveyed on 1-2 December 2014.

3.4.2 Hybbestadskogen

Hybbestadskogen also contains bedrock, in this case rising 30 - 40 m from the surrounding terrain. Located east of the rail road, the area is situated just south of the famous Istrehågan monument; a large ship-shaped stone monument. The area mostly consist spruce and pine but also low vegetation of younger trees in recent clear cuts. There are no settlement in the survey area, and just a few forest roads.

Before the survey there were four known sites with cultural heritage monuments and the numbers of monuments were eight, all mounds and cairns. The area of about 27 hectares was surveyed on 2 and 9 December 2014.

3.4.3 Tveiten Nordre

The Tveiten Nordre area is the eastern part of a larger ridge of bedrock covered mostly with spruce plantation. Some parts in east were more open than the plantation areas. The topography reaches not more than 15 m above the surrounding fields. With the exception of an old storage building, there are no settlements in the area. An old road, told to be the main road before the Second World War, runs through the area, connecting the farms together. The *Askeladden* database lists three sites in the survey area with a total of only three monuments. The area of about approximately 8 hectares was surveyed by on 9 December 2014.

3.4.4 Skåra

The Skåra survey area is parts of two larger ridges of bedrock north and south of the Skåra farm. They are rising 15 - 20 meters above the valley floor. The vegetation, as for most of the areas in this survey, was consisting spruce and pine, and low vegetation like juniper, both in dense and more open areas. Except from the farm in between, there are no settlements in the survey area. In the northern part there are remains of a quarry. From the debris observed in the quarry it has probably been in use until the 1970/80s(?). The area of about 23 hectares was surveyed in two days; on the 25th on November 2014 by archaeologist, Vibeke Lia and Christer Tonning (Vestfold County), project leader Øivind Due Trier (Norwegian Computing Centre), and the archaeologist Ole Risbøl (Norwegian Institute for Cultural Heritage Research) and Steinar Kristensen (Museum of cultural history). The rest of the survey was done on the 9. of December 2014 by Tonning and Kristensen.

Three sites with a total amount of ten grave mounds were recorded in the Askeladden heritage database. In the same area is also a hollow way recorded (not target for the CS).

3.4.5 Istre Nordre

The area at Istre Nordre consists of two Cultural Heritage sites ID 68450 and ID 59348. ID 68450 was logged after the laser acquisition in 2010. The forest is most dense in the southern and northern part and consisting of large coniferous trees, and especially in the north, dense ground vegetation. This forest stretches all the way up to site ID 59348 to the north-east.

The area Istre Nordre is about 11 hectares in size, and ground verification of the detections were conducted over two days on the 25th on November 2014 by archaeologist Christer Tonning (Vestfold County), Vibeke Lia (Vestfold county), project leader Øivind Due Trier (Norwegian Computing Centre), Ole Risbøl (Norwegian Institute for Cultural Heritage Research) and Steinar Kristensen (Museum of cultural history) and on 27 November 2014 by Lia and Tonning.

3.4.6 Lauve

The selected area called Lauve consists of three registered sites; ID 38715, ID 136586 and ID 68445. ID 136586 is a grave monument but consists of stone settings and no further detections were done here, this site will not be further mentioned in the text below. The grave field ID 38715 to the south is situated directly on a rock formation with mostly coniferous trees (pine) but also with some lower vegetation.

ID 68445 is a grave field situated in dense coniferous forest, mostly spruce and very little low vegetation. The selected area Lauve is about 9 hectares, laying in the southernmost part of the Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment area. The

Lauve area contains, in the southern part, a small non-arable stone ridge; in the middle, a small patch of arable land; and in the northern part, dense coniferous forest.

Ground verification of the detections were conducted during two days; on 25 November 2014 by archaeologists Christer Tonning (Vestfold County), Vibeke Lia (Vestfold county), Ole Risbøl (Norwegian Institute for Cultural Heritage Research) and Steinar Kristensen (Museum of cultural history) , and project leader Øivind Due Trier (Norwegian Computing Centre); and on 27 November 2014 by Lia and Tonning.

3.5 Results

The automatic method in *CultSearcher* is able to detect 18 of 66 grave mounds (27%) with high or medium high confidence (Table 3.2). Of these, four detections were new, i.e., not previously known according to the *Askeladden* database. From visual inspection, 10 new monuments were detected. The field survey was not able to recover 13 previously mapped monuments. All in all, the total number of known mounds and cairns is updated from 65 to 66, with 13 deletions and 14 additions. Detailed results for each survey area are described in Sections 3.5.1-3.5.6 below.

Table 3.2. Result of detailed mapping.

Observations/Survey Area	Skalle-berg	Hybbestad-skogen	Tveiten nordre	Skåra	Istre nordre	Lauve	Total
Numbers of Askeladden sites	10	4	3	3	2	3	25
Previously known monuments (mounds/cairns)	19	8	3	10	17	8	65
High confidence detection	8	6	8	8	2	0	32
Medium high confidence detection	34	29	8	12	13	3	99
Positive high confidence detections	3	0	0	1	2	0	6
Positive medium high confidence detections	5	1	1	2	3	0	12
Positive high and medium high confidence detections	8	1	1	3	5	0	18
Negative high confidence detections	5	6	8	7	0	0	26
Negative medium high confidence detections	29	28	7	11	10	3	88
Previously known monuments detected with high confidence	3	0	0	1	2	0	6
Previously known monuments detected with medium high confidence	2	1	1	1	3	0	8
New positive detections by CultSearcher	3	0	0	1	0	0	4
Visually new detections (not by CultSearcher)	4	1	1	4	0	0	10
Previously known monuments not recovered	0	3	1	0	7	2	13
Monuments not subject to automatic detection (hollow way, monoliths)	4	0	0	1	0	3	8
Total numbers of automatic detections (all confidence levels)	908	816	275	327	275	220	2821
Area (hectares)	42	27	8.4	2,3	11	8.7	80
Updated number of mounds/cairns in the Area	26	6	3	15	10	6	66

3.5.1 Skalleberg

At Skalleberg, CultSearcher was able to make three new positive detections, i.e., monuments that were previously not known according to the *Askeladden* database. In addition, four new positive detections were made by visual inspection of the ALS data. Out of an updated total of 26 heaps, only 8 (31%) were detected by *CultSearcher*. The relatively low level of true detections could in several cases be explained by natural causes. Three of the undetected mounds were totally covered with juniper, hardly penetrable for man (ID9316). Some other reasons for undetected mounds in the survey area were mounds cut by forest road or that the mound in other way was damaged and for that reason had a deviant shape (A111). In some other cases the mounds had vague boundaries against the bedrock. Almost all negative detections were natural heaps in the bedrock. One mound (A108) was detected with low confidence (level 2); and another (A1000) with very low confidence (level 1).

In addition to the 26 mounds and cairns, the Skalleberg area contains three hollow ways and one monolith (in Norwegian: bautastein). These are of a shape that the automatic methods in *CultSearcher* are not designed to detect.

3.5.2 Hybbestadskogen

CultSearcher made 6 detections of high confidence (level 5) and 29 detections of medium high confidence (level 4) within the area. Out of these 35 detections only one was positive; a medium high confidence (level 4) detection. The updated total number of mounds and cairns after the field survey was six, which gives a true detections rate at 17 %.

The only positive detection was one previously known mound (ID 38724). The detection was nearly spot-on the measured mound (A1211). The mound was about 11 m in diameter and 1.5 m high. The mound has damages from the south side and towards the centre, probably due to potato storage. All of the negative detections in this survey area were due to natural heap-shaped bedrock formations. There were also two charcoal kilns (A1021, A1022) in the centre of the survey area that were not detected by *CultSearcher*, one of them rather clear in shape. Several of the not detected mounds were rather clear in shape and size. At one site none of the three clear mounds were detected (ID38729). Two of them had damages from heavy machines due to recently logging (A1207, A1208). This may indicate the reason for no detection - that they at the time of the ALS (2010) were covered with dense spruce forest, while they at the time of verification appeared clear and highly visible.

3.5.3 Tveiten Nordre

CultSearcher made 8 high confidence detections and eight medium high confidence detections (level 4). Of these, one medium high confidence detection was true. With three mounds/cairns in total, the true detection rate is 33%.

One previously known mound (ID48741) could not be recovered, since the site was covered with a heap of large rocks, wood, etc., and therefore difficult to inspect. The site had a medium high confidence detection (level 4), but whether the detection was of a true mound before the deposit, or the detection is of the deposit itself is unclear.

An interesting situation which can illustrate how *CultSearcher* works for the archaeologist in the field occurred when the team tried to verify the site ID29155. According to the records, a mound, with some damage, and including monoliths, was located east of the forest road. The team did find a damaged mound, but could not make the visual verification quite fit the description (A1213). However, as descriptions may sometimes be vague, it could still be the correct one. Incidentally, it was not detected by *CultSearcher*. In the south there had been an outtake for soil/sand, and larger rock were seen in the damaged area as described in the *Askeladden* records. The mound had been mapped by the county in 2010, with the same lack of confidence as the verification team now had. However, *CultSearcher* did detect a mound in this area, but on the other side of the gravel road, with medium high confidence (level 4) and in dense spruce planation (A1214). When inspecting this detection (under the dense spruce), a grave mound appeared. The description from 1984 was all correct - except the fact that it should have been west of and not east of the road. *CultSearcher* made the team look at that side as well. If it wasn't for the automatic detection on the west side of the road, the now newly recorded mound could have been regarded as the originally recorded mound.

A third mound further to the south east was recorded as a long barrow. The middle part was detected with low confidence (ID59345).

In the Tveiten Nordre survey area, all of the false detections were bedrock shaped as smooth heaps.

3.5.4 Skåra

At Skåra, three out of 15 grave mounds (20%) were detected by *CultSearcher* with high or medium high confidence. Of these, one was not previously known according to *Askeladden*. In addition, four previously unknown grave mounds were detected by visual inspection of the ALS data.

The remaining seven automatic detections with high confidence (level 5) and 11 detections with medium high confidence (level 4) were all false.

Two true detections were in the southern site in the area; ID59347. One was a medium high confidence detection almost spot on a clearly defined mound, about 16 m in diameter and 0.5 - 1 m high (A712). The other was a high confidence detection of a previously unknown mound, about 25 m. north of the recorded sites boundary (A701). The size of the detection was almost twice the size of the mound situated there, and it turns out that it was two previously unknown adjacent mounds. The mounds were situated on a lower bedrock formation and were about 0,5 - 1,2 m high. Three of the other six true mounds in this site had automatic detections of low and very low confidence (levels 2 and 1). The site was partly covered with spruce and deciduous trees including oak. Next to the quarry in the northern part of this survey area three mounds were known and now visually controlled (ID9312). *CultSearcher* failed to detect any of them with high or medium high confidence (levels 5 and 4). A false detection with medium high confidence (level 4) north of the westernmost mound (A1245) turned out to be heaps from the quarry and the western boundary ditch of A1245. One of the three mounds was detected with very low confidence (level 1). One isolated mound was detected with zero confidence (level 0) (A1246/ID29157). This mound showed traces of holes from metal detection activity.

The false detections in this area were mainly heap shaped bedrock formations, but also included a dumping area for quarry stone.

3.5.5 Istre Nordre

The two sites has a total of 17 previously known mounds, of which 13 are round barrows, and seven of these were detected by *CultSearcher*. The remaining four mounds are long barrows, which *CultSearcher* is not designed to detect. In addition, CultSearcher made 10 false detections at medium high confidence.

In site ID 68450, two true detections of high confidence (A 503 and A504) and one true detection of medium high confidence (A 507) were made. In site ID 59348, two true detections of medium high confidence (A601 and A603) were made. Furthermore each site had one automatic detection with low confidence (A 502 in site ID 68450 and A602 in site ID 59348).

However during the fieldwork and of the sites, 7 of the original 17 mounds were not recovered in the field. On the site ID 59348 only three of original eight mounds were discovered, and on the site ID 68450, six of the original mounds were detected. At the site ID 59348 it seems that the original prospection could be wrong, there is little physically done here which could have destroyed the mounds, in the archives at Vestfold County (TopArk) no supplementary information could be found on this farm concerning the site. The other possibility is of course that 5 grave mounds have been completely removed and the tracks and evidence of this have been covered up by vegetation for the last 35 years. Concerning the site 68450, seven of the original nine mounds were re-discovered during fieldwork, and four of these were detected by *CultSearcher*. Three of the mounds were previously mapped as long barrows and six as round barrows in the original mapping from 1980. Only one of the long barrows was re-discovered (ID 506). At the time of the fieldwork, there was a lot of debris from logging, especially in the central part of the site (close to A505), which could of course be covering some of the mounds.

Both sites had poor precision on the original geometry, ID 68450 was almost 20 meters dislocated to the north, and ID 59348 the geometry was close to 20 meters dislocated to the east and not covering the mounds at all.

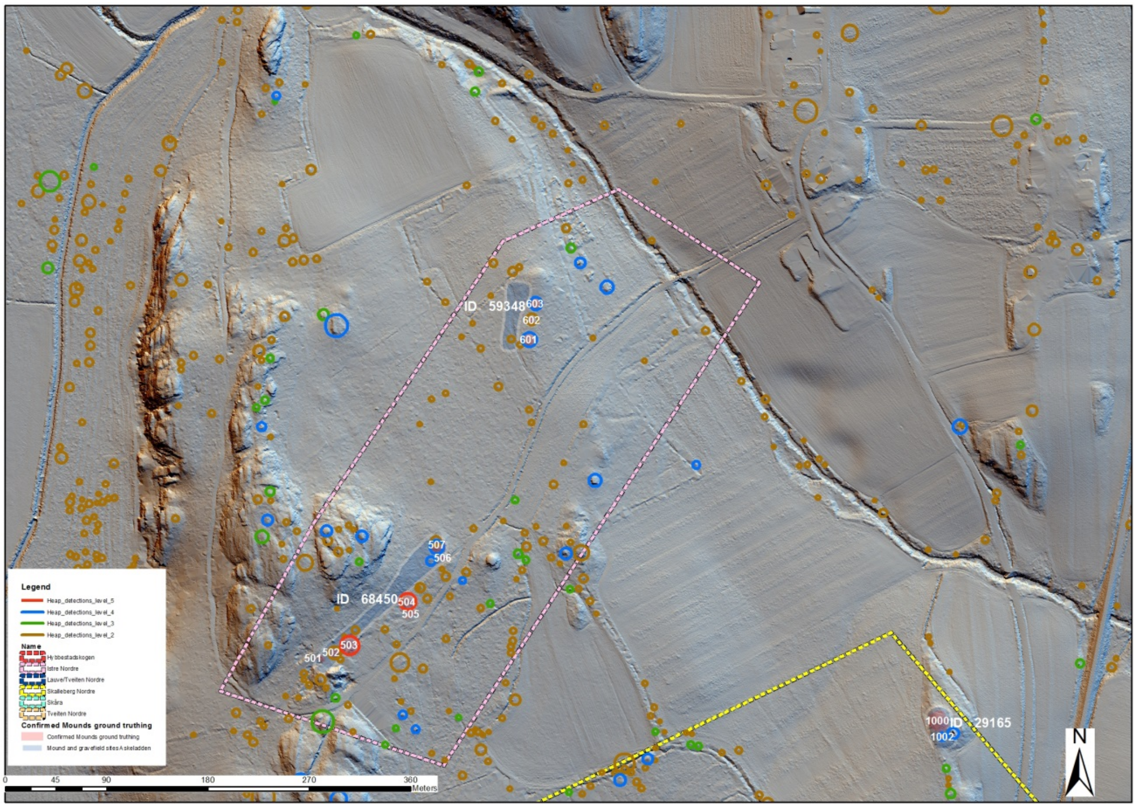


Figure 3.5. The selected area of Istre Nordre showing the two sites ID 68450 to the south and ID 59348 to the north.

3.5.6 Lauve

Two sites were checked out during the fieldwork; ID 38715 and ID 68445, a total of 8 grave mounds were known from this area from earlier prospections here. Of these, seven were round grave mounds and one was a long barrow (ID 68445).

No high confidence detections (level 5) were done inside the area, but three medium high confidence detections (level 4) were made. However, none of these were positive. On the site ID 9310 two of the three grave mounds were detected by *CultSearcher* (A801 and 803), but with low confidence (level 2).

At the site 68445 three of the originally registered mounds were re-discovered during the fieldwork, all of the mounds were detected by *CultSearcher*, two with medium confidence (level 3) (A901 and A902) and one with very low confidence (level 1) (A902). The low confidence of the detections is probably due to a dense cover of coniferous forest (spruce). A904 was originally thought to be a large long barrow in the original survey, and was also detected with medium high confidence (level 4) by *CultSearcher*. However this turned out to be a large, boat-shaped bedrock covered with just a few centimetre of moss. Also, one hollow way (non-detectable by *CultSearcher*) was mapped manually.

At the site 9310 no high confidence or medium high confidence detections were made. Two of the three previously known mounds were detected with low confidence (level 2) by *CultSearcher*. One of these detections (A801) is not a completely true hit by *CultSearcher*. This mound is situated close to a steep stone ridge to the south. One mound A802 was not detected by *CultSearcher*, the shape of the mound (slightly eroded to the south-east, where the small ridge slides downwards). Also this mound was quite low (20-30 cm), and located between two large pine trees, one to the north-east and one to the south-west.

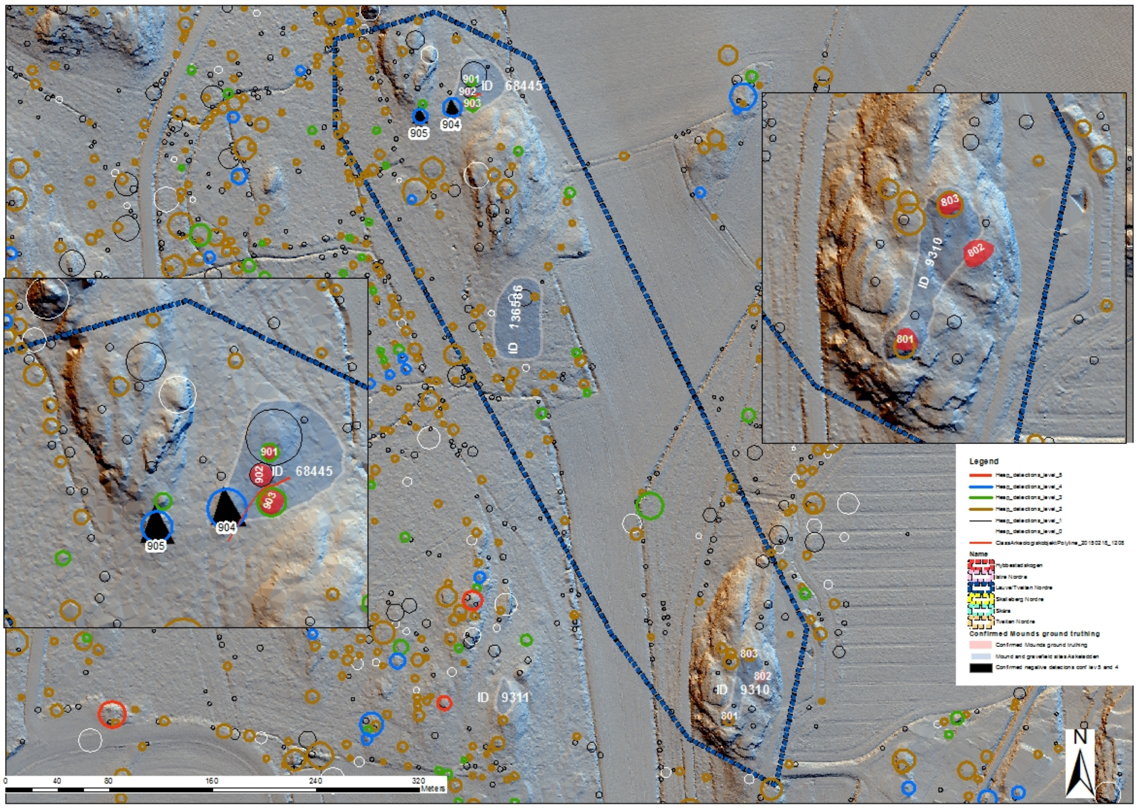


Figure 3.6. An overview map of the Lauve area. Inset maps show the two sites in more details.

As a result of the survey, 66 mounds/cairns have been confirmed. Two charcoal kiln were also observed; of these, one was detected by *CultSearcher* with low confidence (level 2). These charcoal kilns are not recognized as protected heritage monuments.

3.6 Discussion and Conclusions

In all of the six confidence levels (5-0) there were 2662 detections. Of these 32 were true mounds/cairns; this gives a user accuracy of 1.2 %. With 66 confirmed grave mounds and cairns in total, the 32 true detections give a producer's accuracy of 48%. 18 of these true detections were made with high or medium high confidence, giving 27% producer's accuracy if only the detections with these confidence levels are used. In that case, 132 detections are made in total, resulting in 14% user accuracy.

Incidentally, none of the 124 detections with medium confidence are true detections. However, we believe that this is only a coincidence and not an indication that medium confidence detections may be discarded.

As a result of the survey, 66 mounds/cairns have been confirmed. Two charcoal kiln were also observed; of these, one was detected by *CultSearcher* with low confidence (level 2). These charcoal kilns are not recognized as protected heritage monuments.

As stated above, 18 *CultSearcher* detections turned out to be true cultural heritage monuments out of the 132 detections verified in the two controlled confidence levels (5/4). This gives a true-detection-rate of 14 %. As a comparison, the burial field at Berg in Tønsberg was surveyed in 2013 and had a true-detection rate of 34 %, which is 2.4 times higher rate.

However, the lower true detection rate in the Jåberg, Istrehågan, Marumdalen, Haugen and Vestad cultural heritage environment area is not surprising. The most noteable difference between this area and the areas surveyed by the project in 2012 and 2013 is the rather complex and undulating terrain with ridges of bedrock in this area, which seems to trigger *CultSearcher* detections. Further, the monuments on the sites are quite small in both height and diameter. Nevertheless the *CultSearcher* tool is able to draw our attention to areas which have a great potential and although we would wish to have more of the mounds detected with a higher confidence level we are now convinced that *CultSearcher* is a useful tool for locating areas which has the potential to have grave mounds.

In conclusion, we encourage the development of a portal solution for *CultSearcher* to enable more archaeologists in Norway to use automatic detection methods as a tool in detailed cultural heritage mapping.

4 Semi-automatic mapping of the Viking grave field at Vang, Oppdal

By: Øivind Due Trier (Norsk Regnesentral), Hans Marius Johansen (Sør-Trøndelag County Authority)

Presented at CAA-Norge, 13-14 October 2014, Oslo, Norway.

4.1 Introduction

The grave field at Vang, Oppdal municipality, Sør-Trøndelag County, is the largest Viking grave field in Norway. It is located about 2 km west of Oppdal town centre, south of highway 70 (Figure 4.1). The grave field is maintained as a cultural heritage park.

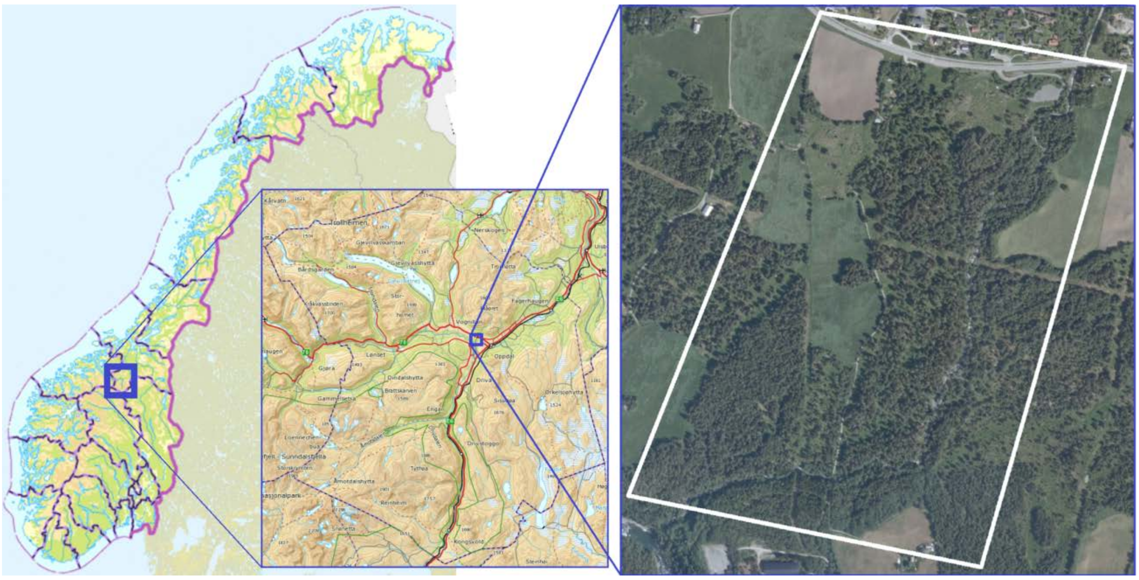


Figure 4.1. The location of the lidar data. Left: map of Norway, with county boundaries. Middle: map of Oppdal municipality in Sør-trøndelag County. Right: orthophoto of a small part of Oppdal municipality, with the extent of the lidar data superimposed as a white polygon.

The existing mapping of the grave field (Figure 4.2) is inaccurate and has some mistakes. The individual grave mounds need to be mapped accurately and entered into the Norwegian national cultural heritage database Askeladden. Also, the existing information signs (Figure 4.3) are to be replaced with new signs based on the new mapping.

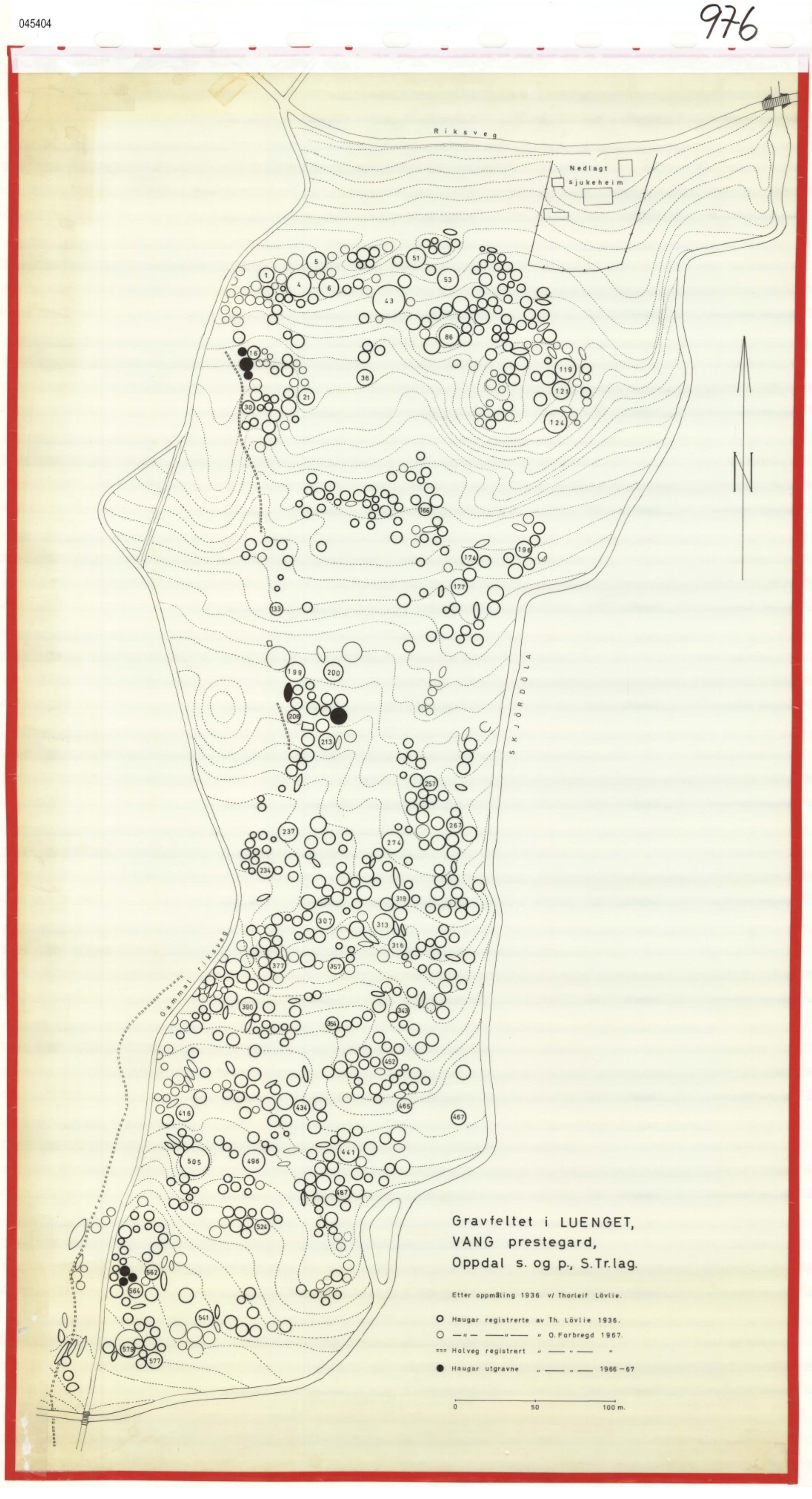


Figure 4.2. Existing map of the grave field. © NTNU Vitenskapsmuseet.

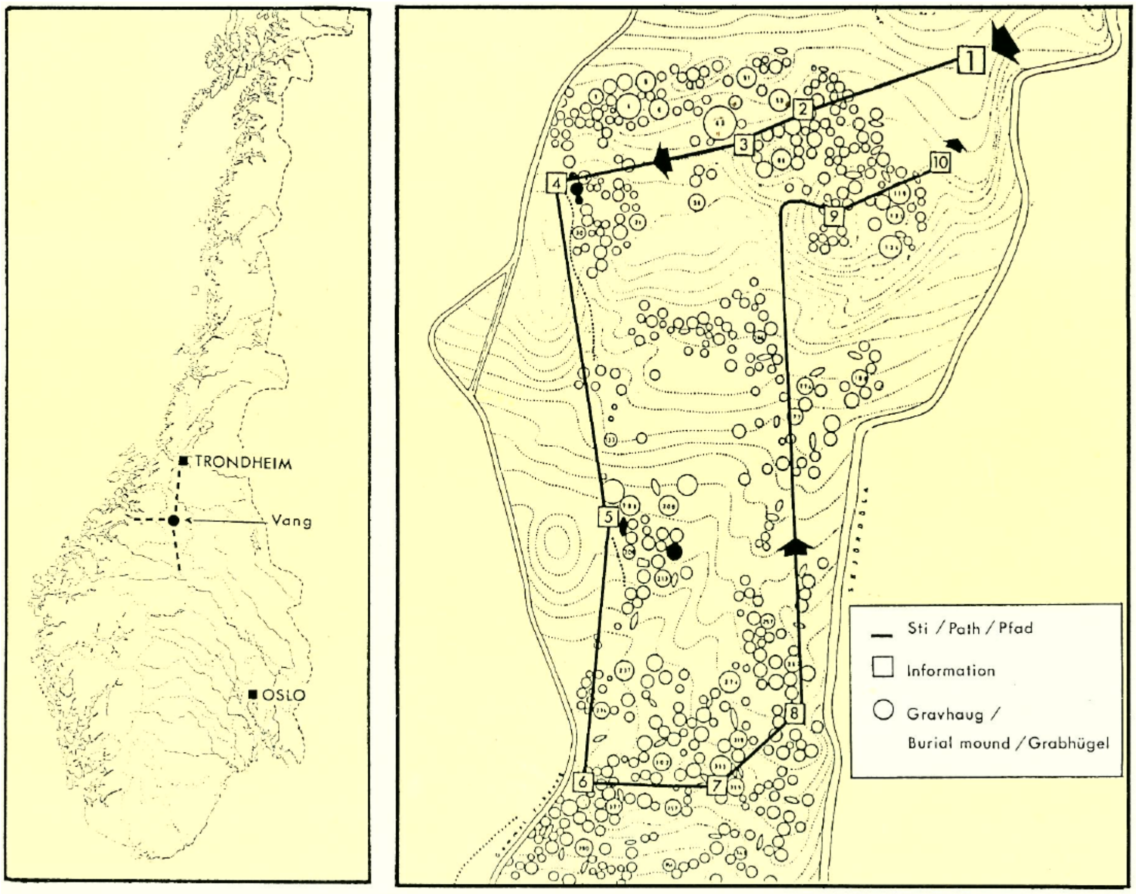


Figure 4.3. Existing information sign.

4.2 Data

The existing archaeological map (Figure 4.2) was surveyed in 1936 and updated in 1967.

Airborne laser scanning (ALS) data was collected for a 0.63 km^2 area, covering the known grave field at Vang, Oppdal municipality, Sør-Trøndelag County, Norway (Figure 4.1). Data was collected on 12 September 2012 by the commercial provider TerraTec AS, Norway, using a Leica ALS70 laser scanner mounted on an air craft flying at 150 knots and 589 m maximum elevation above the terrain. The specified point density was 12/m^2. Each pulse may result in up to four discrete returns. Each recorded return was stored with the return number (1-4), intensity, (x,y,z) position, and a class label (Table 4.1).

Table 4.1. Class labels for ALS data.

class	description
1	unclassified
2	ground
7	noise
9	water
10	bridge

For the purpose of method development, the ALS data has been divided into a training data set and a test data set (Figure 4.4).

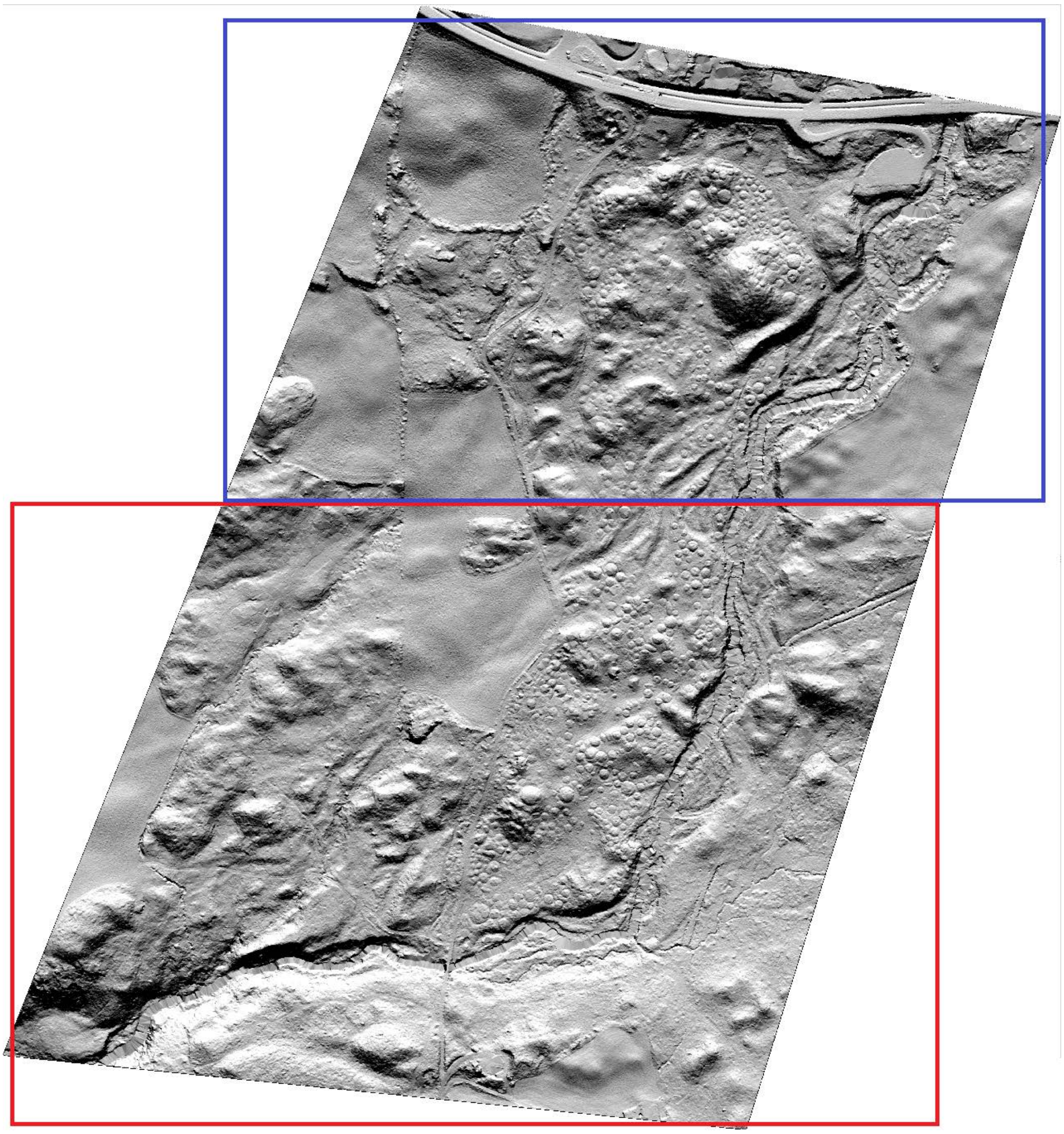


Figure 4.4. Division of ALS data into training data (blue) and test data (red).

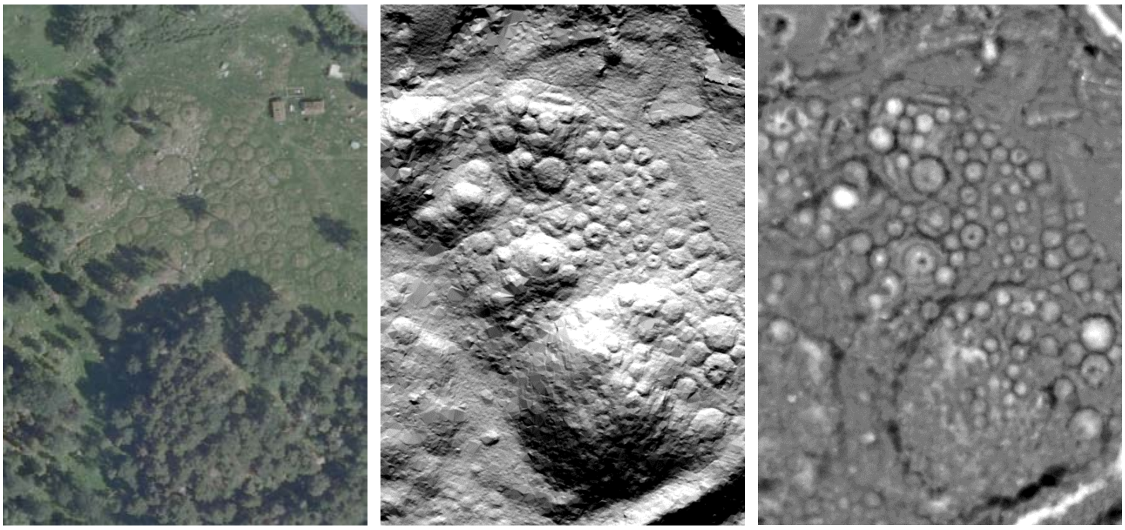
4.3 Methods

4.3.1 Detailed mapping of grave mounds

Detailed mapping of each grave mound was done by digitizing a circle or ellipse, with the following information as backdrop that could be switched on and off (Figure 4.5-Figure 4.6):

1. Aerial orthophoto (only useful in open terrain without trees and tree shadows)
2. Hill-shaded terrain, generated from ALS ground points
3. Local relief model (Hesse, 2010), also generated from ALS ground points
4. Automatic detections, with one separate layer for each confidence level 1-6.

In addition, the existing archaeological map (Figure 4.2) was used as reference.



(a) (b) (c)

Figure 4.5. Detail of a part of the grave field. Left: aerial orthophoto. Middle: hill-shaded relief of DTM. Right: local relief model.

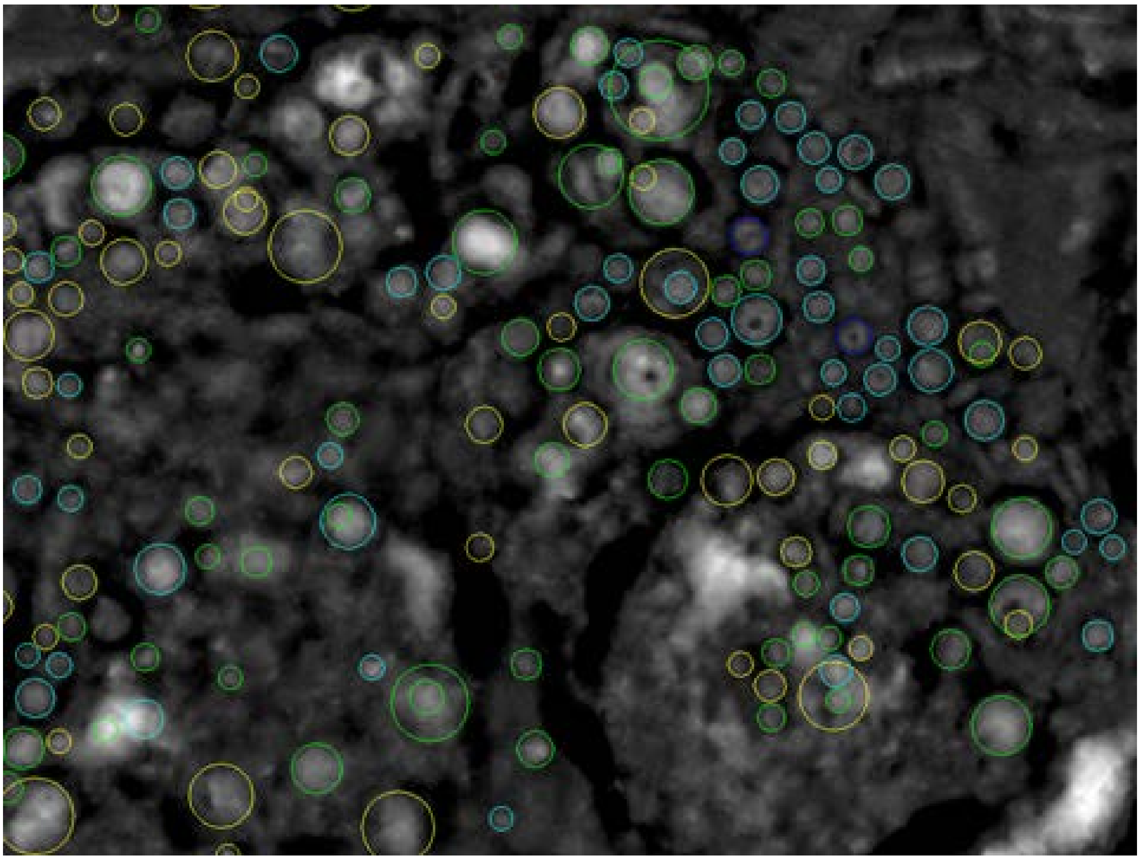


Figure 4.6. Automatic detections superimposed on local relief model.

4.3.2 Automatic mapping of mound structures

We have previously developed methods for the semi-automatic detection of archaeological pits (Trier and Pilø, 2012) and grave mounds (Trier *et al*., 2015). For the grave field at Vang, we observed that many grave mounds were located on hillsides, i.e., on slopes. However, the grave mound templates are developed for grave mounds in flat terrain. The local relief model

(Hesse, 2010) is removing the general shape of the terrain, thus emphasizing local terrain variations caused by grave mounds and other terrain features of the same scale.

The automatic mound structure method has the following steps:

1. Preprocessing: convert ALS point data to a digital elevation model (DEM) of the terrain surface (without vegetation).

2. Template matching using mound templates of varying sizes

3. Merging overlapping detections

4. Measuring various deviations from an ideal grave mound shape

5. Estimation of a confidence score for each mound detection

A number of visualisation techniques have been proposed for DEMs. The default visualisation is to use a hill shaded relief (Figure 4.5(b)), which is very intuitive, but has a number of drawbacks. First, the use of a directional light source precludes detail parallel to this direction from being visible. Second, details may be hidden in shadows, and third, this visualisation method is not suitable as input to automatic detection. Alternative visualisation methods include:

- Gradient image

- Local relief model (Hesse, 2010)

- Sky-view factor (Kokalj *et al*., 2011)

- Openness (Doneus, 2013)

Local relief model results in visualisations that are intuitive (Figure 4.5(c)), and at the same time suitable for subsequent automatic processing.

We have constructed mound templates from the grave mounds in the training data (Figure 4.4). For each mound, the centre position and radius was measured manually in the local relief model. Then, for each mound, a square sub-image was constructed, with side length equal to 4 × radius. Each sub-image was scaled to the same size, 100×100 pixels, which is 20 m × 20 m at 0.2 m pixel size. This results in 5 m radius. Since each mound was labelled as either 'intact' or 'with pit', average mounds for each of the two types were constructed, in addition to an average of all mounds.

By comparing the average mounds obtained from the DEM with the ones obtained from the local relief model (Figure 4.7), each of them seem to be fine inside the perimeter, but they are somewhat uneven outside the perimeters. To construct rotationally symmetric templates, grave mound profiles were constructed by using the average height for all pixels having the same distance to the template centre (Figure 4.8).

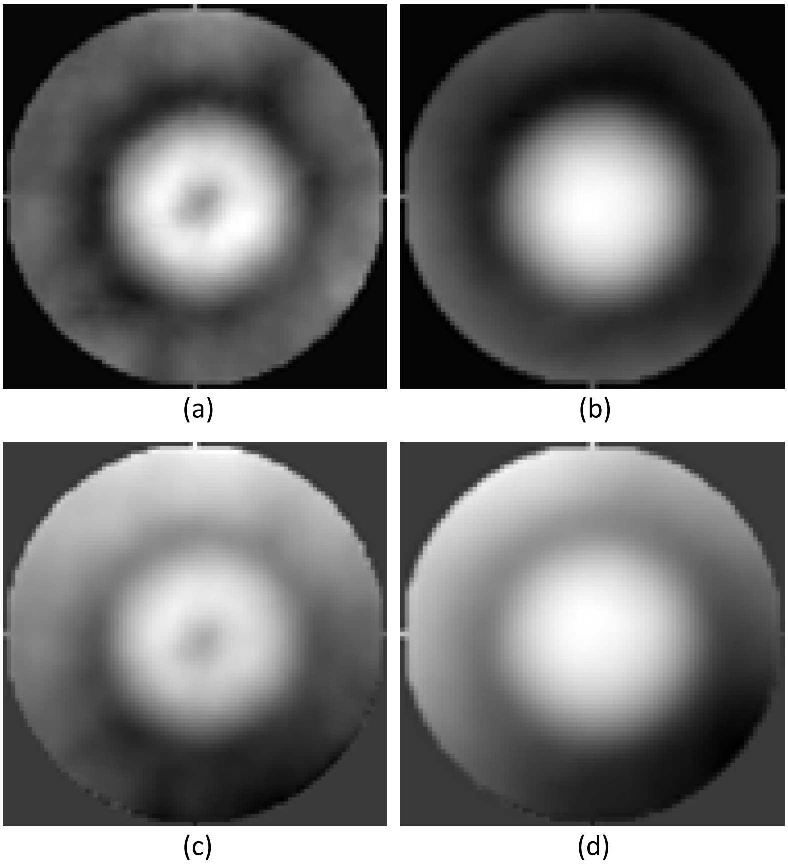


Figure 4.7. Average mound shapes extracted from training data. (a) Grave mound with pit, from DEM. (b) Intact grave mound, from DEM. (c) Grave mound with pit, from local relief model. (d) Intact grave mound, from local relief model.

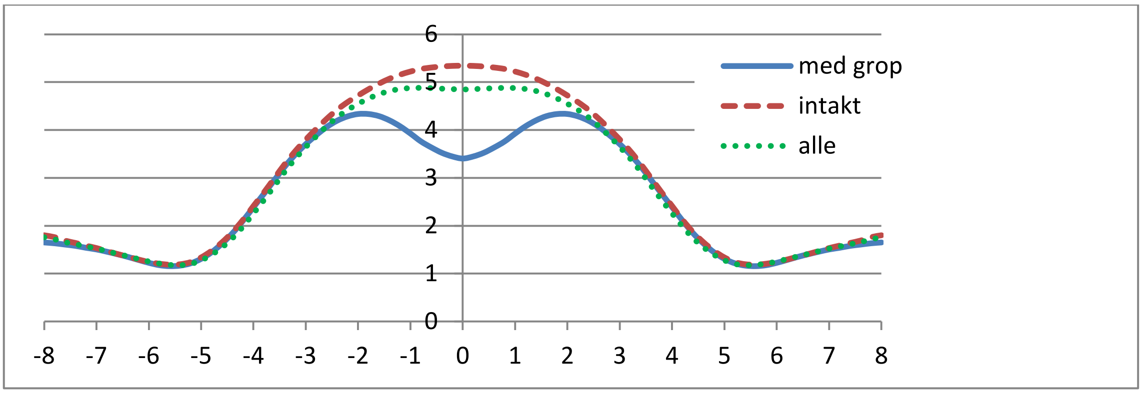


Figure 4.8. Profile of average grave mound shapes, from DEM of training data.

By comparing the mound template profiles for intact mounds obtained from the DEM (Figure 4.9) with the profile for intact mounds obtained from the local relief model, we observe that the standard deviation is smaller with the local relief model. The same observation is made when comparing the mounds with pits (Figure 4.11and Figure 4.12). Therefore, we will use the local relief model as input to the automatic detection method.

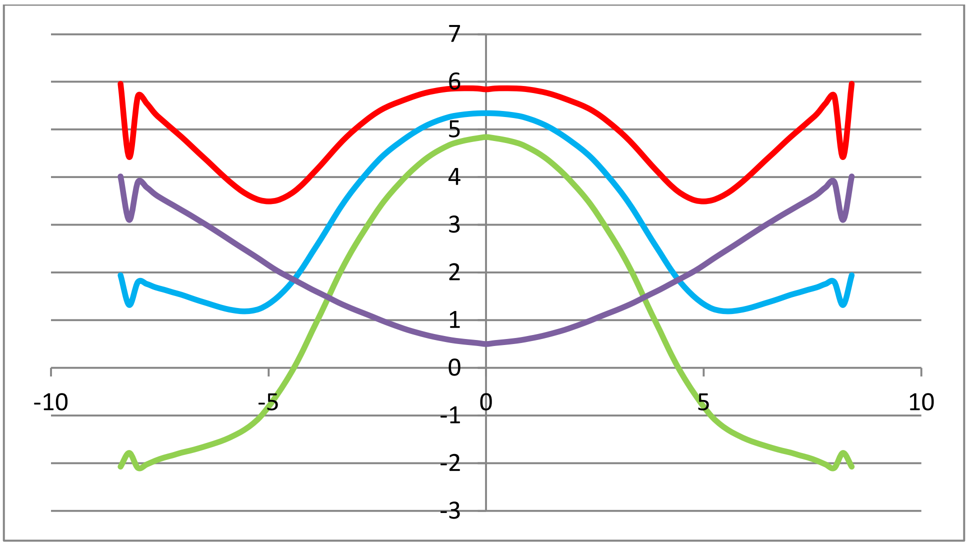


Figure 4.9. Average and standard deviation of profiles of intact grave mounds, from DEM of training data. Blue: average. Purple: standard deviation. Green: average minus standard deviation. Red: average plus standard deviation.

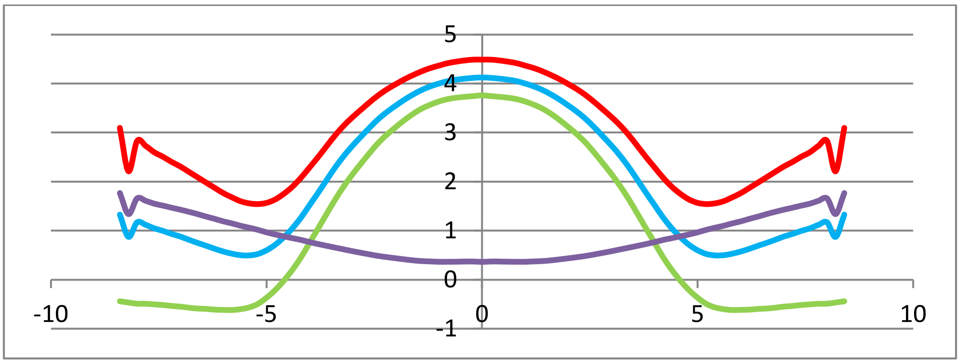


Figure 4.10. Average and standard deviation of profiles of intact grave mounds, from local relief model. Same legend as in Figure 4.9.

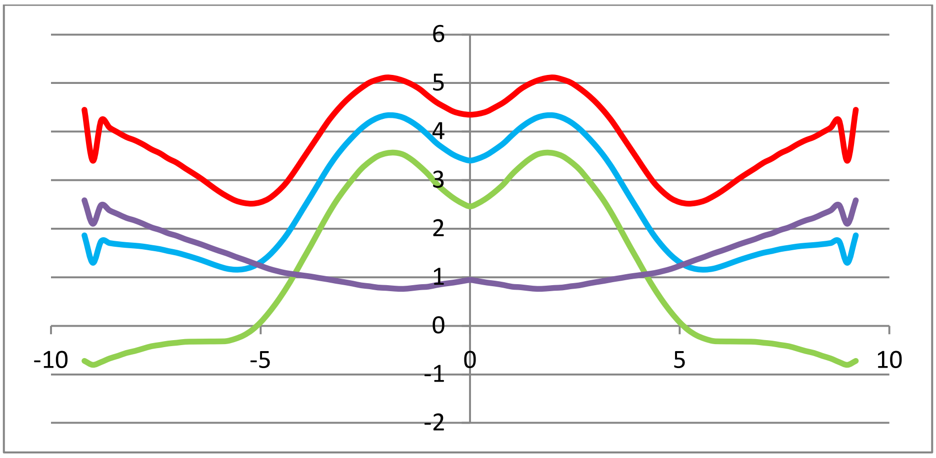


Figure 4.11. Average and standard deviation of profiles of grave mounds with pits, from DEM of training data. Same legend as in Figure 4.9.

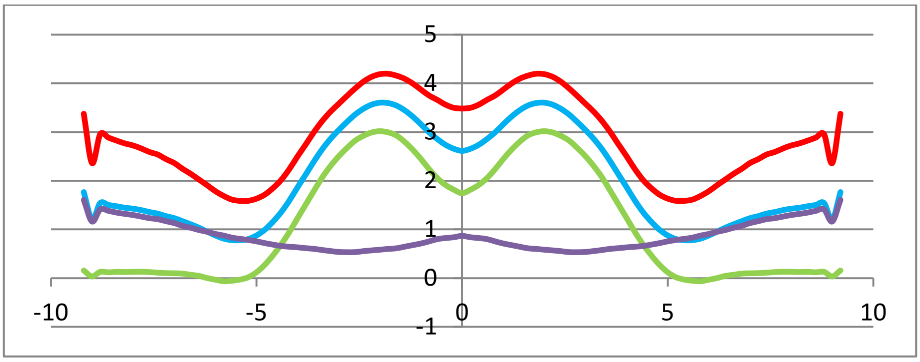


Figure 4.12. Average and standard deviation of profiles of grave mounds with pits, from local relief model of training data. Same legend as in Figure 4.9

4.4 Results

The method was used on the entire lidar data set in order to provide automatic detections as backdrops for manual verification and field inspection. However, using all automatic detections is not very helpful, as the number of false positives is too high (Figure 4.13). Rather, one should start with the automatic detections with confidence high and very high (Figure 4.14). By zooming in (Figure 4.15), one observes that the majority of these detections are true grave mounds. However, many grave mounds are also missing. By including detections with medium high and medium confidence, more grave mounds are detected (Figure 4.16). However, the number of false detection increases. One may continue to include detections with low and very low confidence (Figure 4.17). However, this further increases the number of false detections.

Visual inspection was done by using the existing archaeological map (Figure 4.2) as a backdrop in addition to the local relief model and the hill-shaded relief. By cycling through the different backdrops, each grave mound detection was evaluated as being one of:

1. Grave mound, well preserved
2. Grave mound
3. Grave mound, elongated
4. Possible grave mound (not in the existing archaeological map, but clearly visible in the local relief model and/or the hill-shaded relief)

In addition, missing grave mounds were recorded, each being one of:

5. Missing grave mound (present in existing archaeological map but not detected by automatic method)
6. Missing elongated grave mound (as above, but elongated)
7. Missing possible grave mound (not in existing archaeological map, not detected by automatic method, but clearly visible in the local relief model and/or hill-shaded relief).
8. Missing possible elongated grave mound (as above, but elongated)

Visual inspection of the automatic detections reveals that the automatic method is able to detect the majority of grave mounds (Figure 4.18). However, the exact size and shape of each grave mound has not been corrected at this stage. Of the 295 grave mounds in the training data, corresponding to the northern part of the existing archaeological map, the automatic method is able to detect 238 (81%), but misses 57 (19%). In addition 15 possible grave mounds are detected, and 10 possible grave mounds are missed (Table 4.2). Of the 469 grave mounds in the test set, the automatic method detects 304 (65%) and misses 165 (35%). In addition, 10 possible grave mounds are detected, while 11 possible grave mounds are missed.

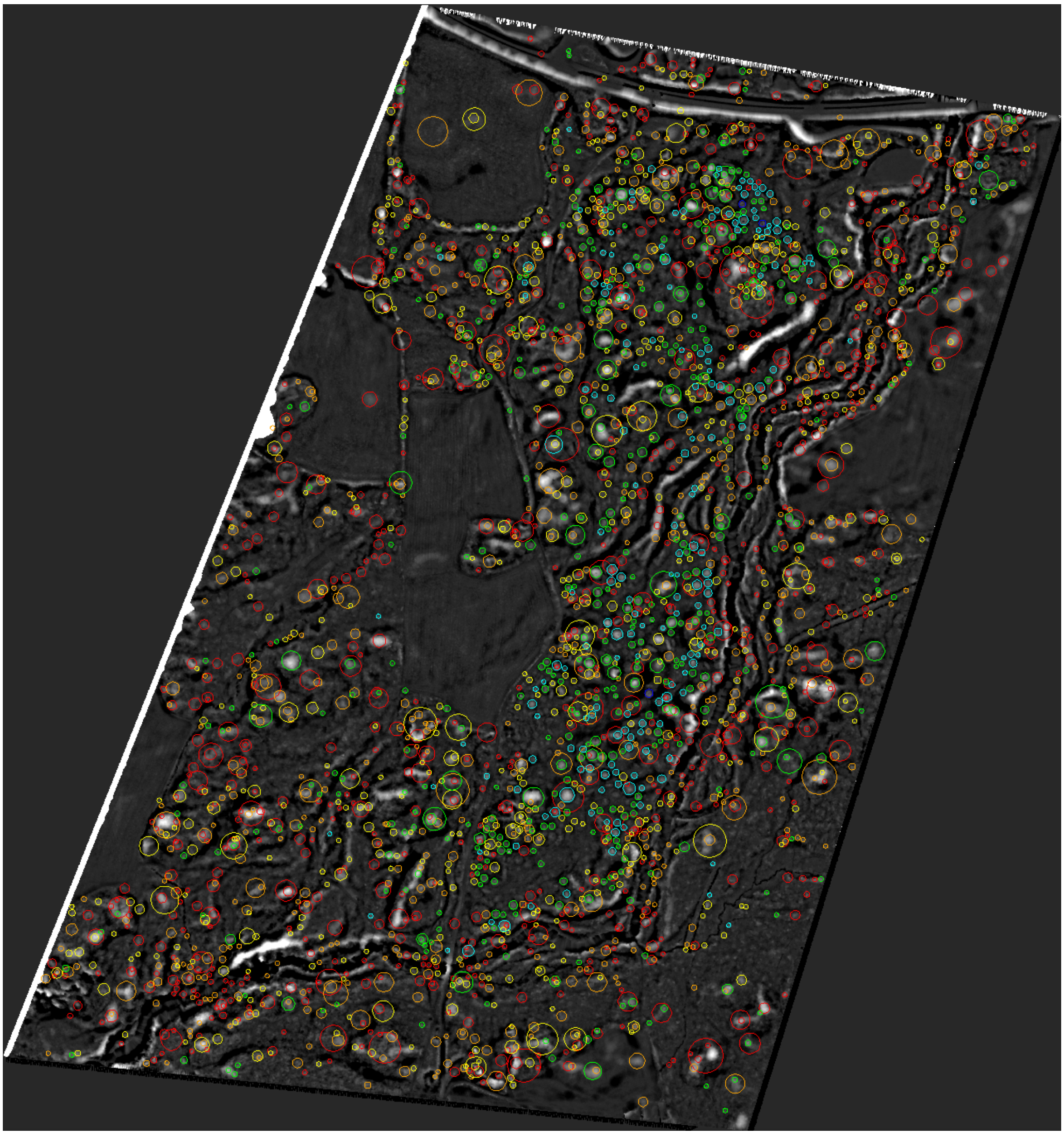


Figure 4.13. All automatic detections, superimposed on local relief model of the ALS data.

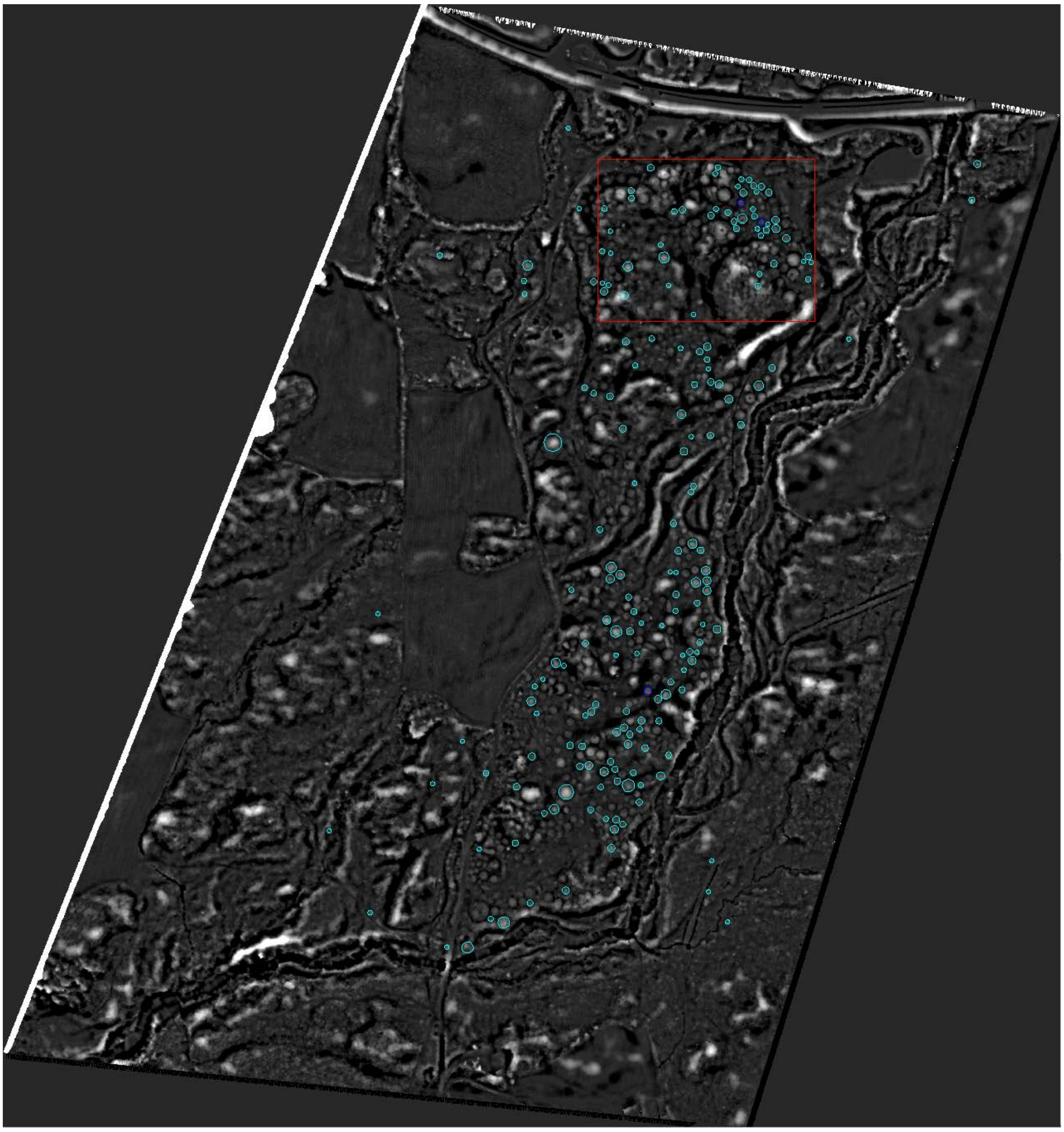


Figure 4.14. Automatic detections with high (cyan) and very high (dark blue) confidence. The red rectangle indicates the enlargement in Figure 4.15.

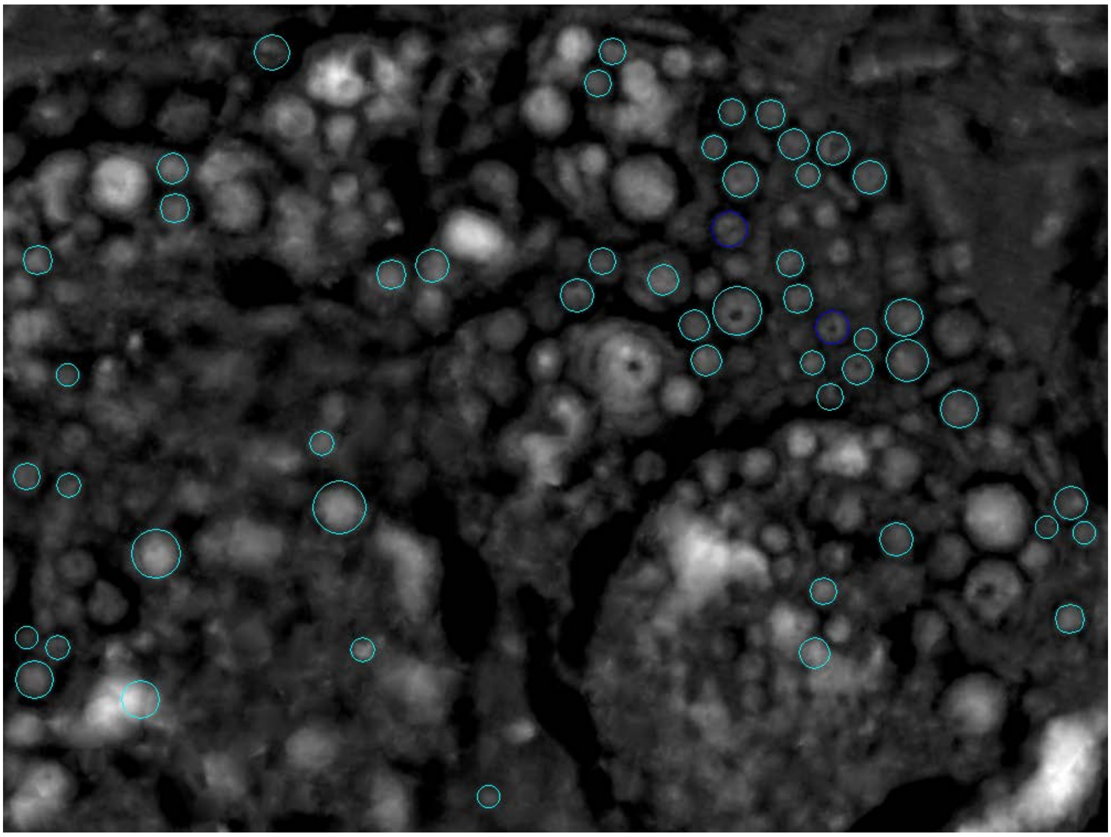


Figure 4.15. Enlargement of a part of Figure 4.14. Automatic detections with very high (dark blue) confidence and high (cyan) confidence.

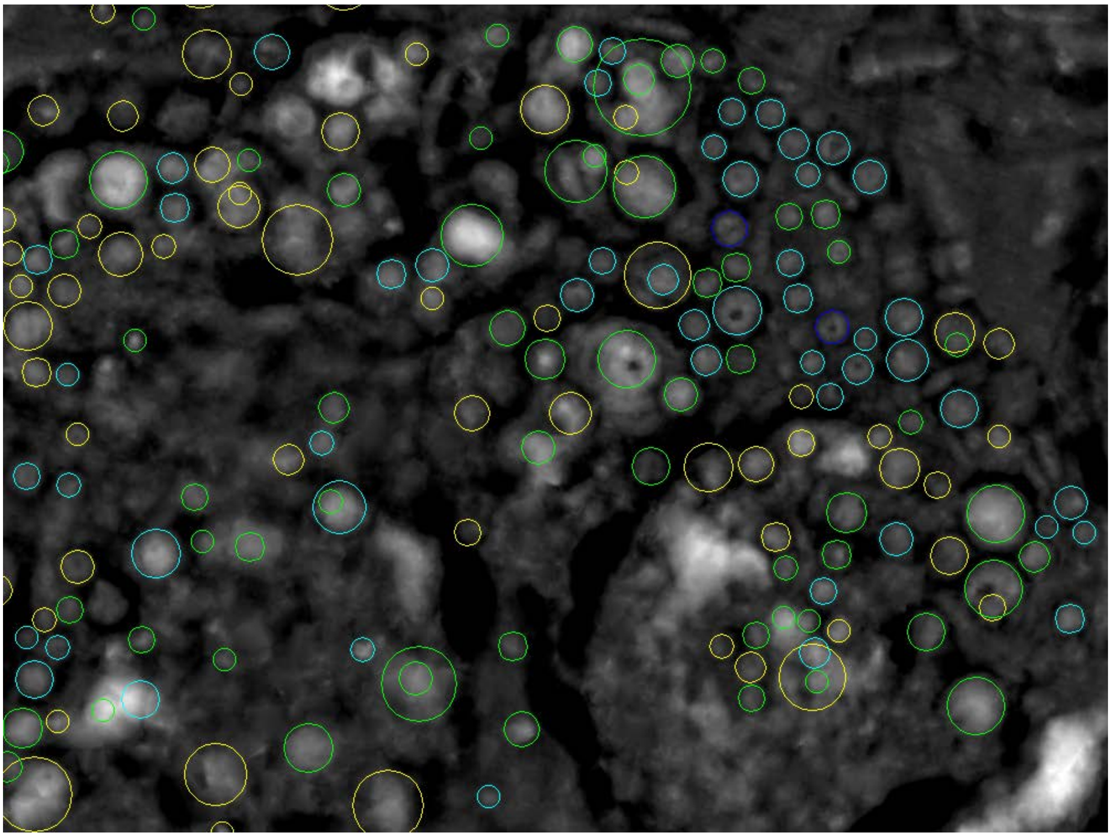


Figure 4.16. Automatic detections, with confidence levels: very high (blue), high (cyan), medium high (green), medium (yellow).

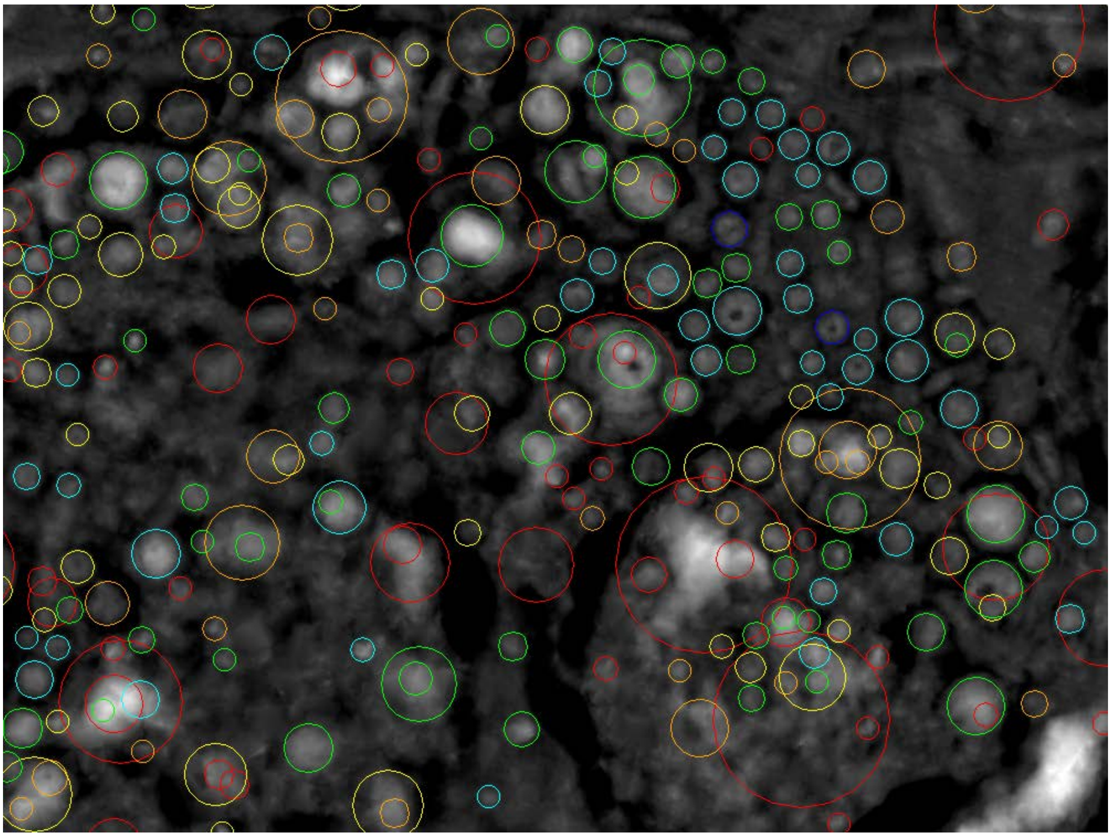


Figure 4.17. All automatic detections. Same legend as in Figure 4.16, plus: low (orange) confidence, and very low(red) confidence.

Table 4.2. Automatic detection results in the training data (northern part of grave field) and test data (southern part of grave field), evaluated by visual inspection and compared with existing archaeological map.

Type of grave mound	training		test		total	
Grave mound, well preserved	82		105		187	
Grave mound	156		197		353	
Elongated grave mound	0		2		2	
Sum detected grave mounds	238	81%	304	65%	542	71%
Missing elongated grave mound	14		52		66	
Missing grave mound	43		113		156	
Sum missing grave mounds	57	19%	165	35%	222	29%
Sum grave mounds in existing archaeological map	295		469		764	
Possible grave mound	15		10		25	
Missing possible elongated grave mound	1		0		1	
Missing possible grave mound	9		11		20	
Sum grave mounds and possible grave mounds	320		490		810	

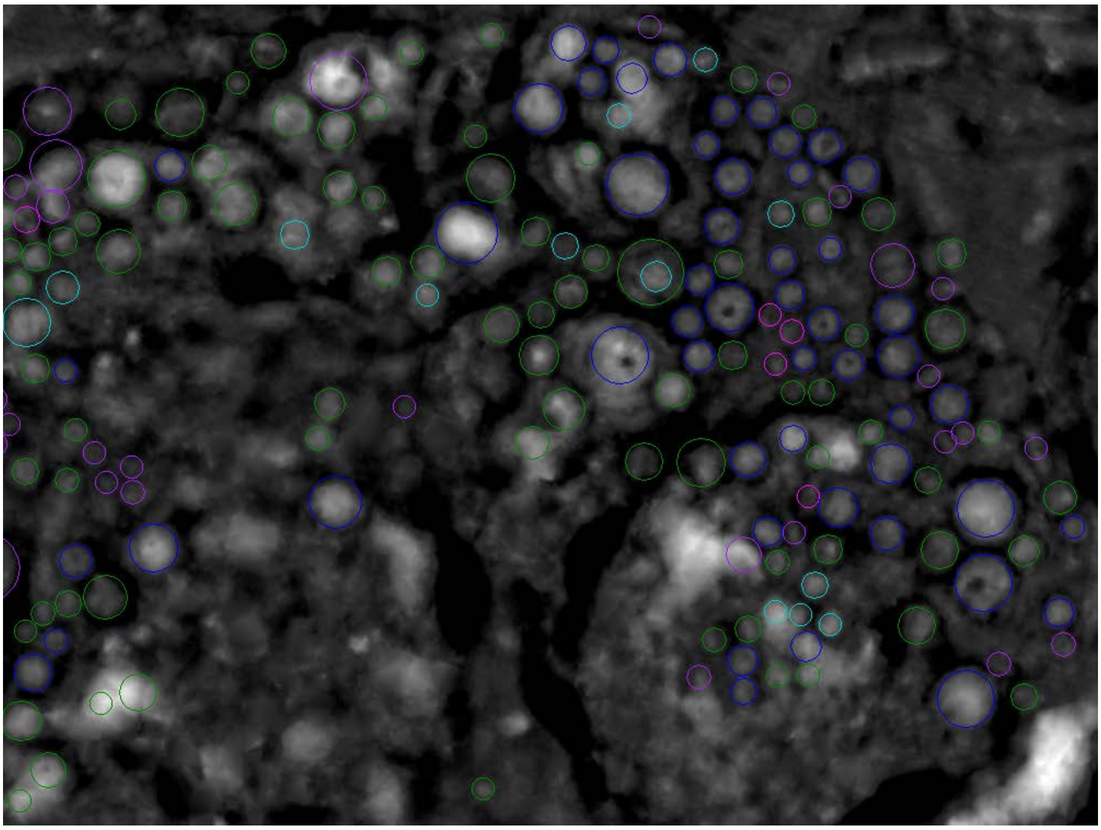


Figure 4.18. Result of visual inspection. Blue: well preserved grave mound. Green: grave mound. Cyan: possible grave mound. Purple: missing grave mound. Pink: missing possible grave mound. Here, 'possible' means that the location is not marked as grave mound on the existing archaeological map, but that the visual inspection has concluded that it may be a grave mound.

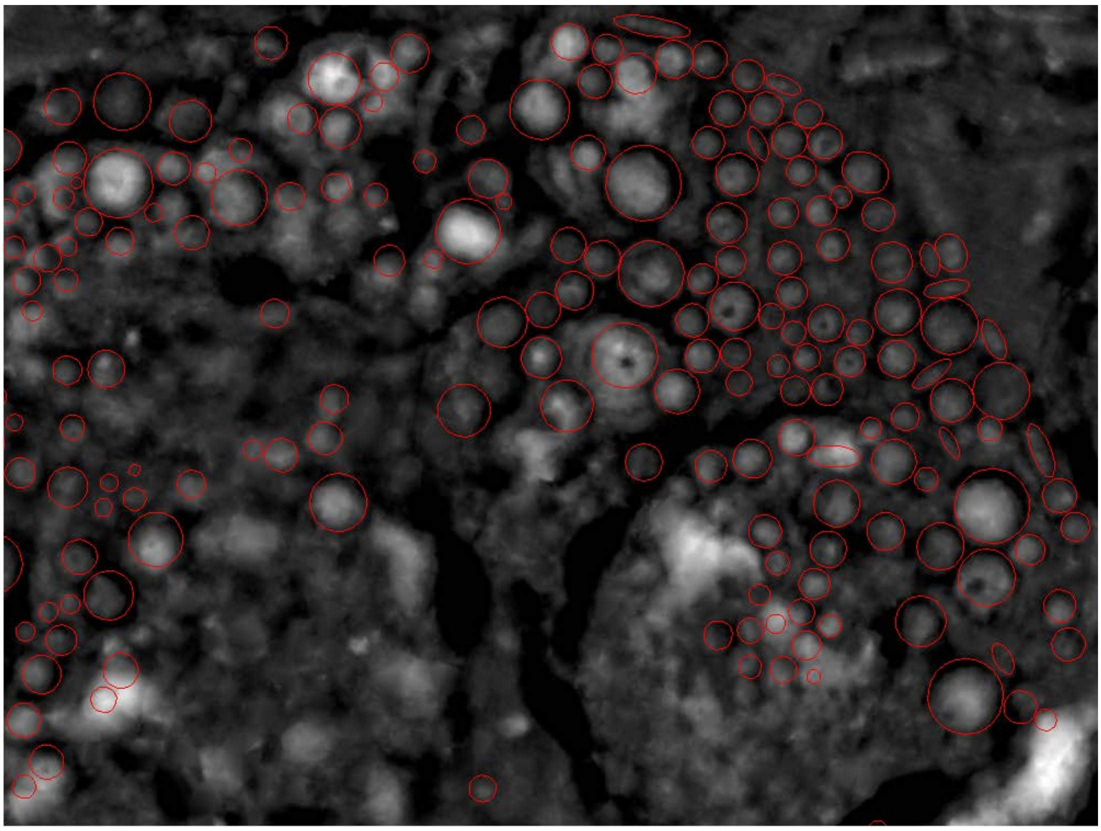


Figure 4.19. Preliminary result of on-going detailed re-mapping.

The automatic detections were used as input to the ongoing, detailed re-mapping of the grave field. A preliminary mapping exists, after partial field survey in the northern part. Field survey will continue in 2015. By comparing the preliminary re-mapping (Figure 4.19) with the automatic mapping after visual inspection (Figure 4.18), a number of differences may be observed. Some mound structures that were believed to be grave mounds after visual inspection, were not believed to be grave mounds by the preliminary re-mapping, and vice versa. Also, the exact size and shape may vary for the grave mounds that appear in both mapping results.

By overlaying the preliminary re-mapping on the existing archaeological map, the inaccuracies of the latter become evident (Figure 4.20). This has been done for the entire existing map (Figure 4.21-Figure 4.23).

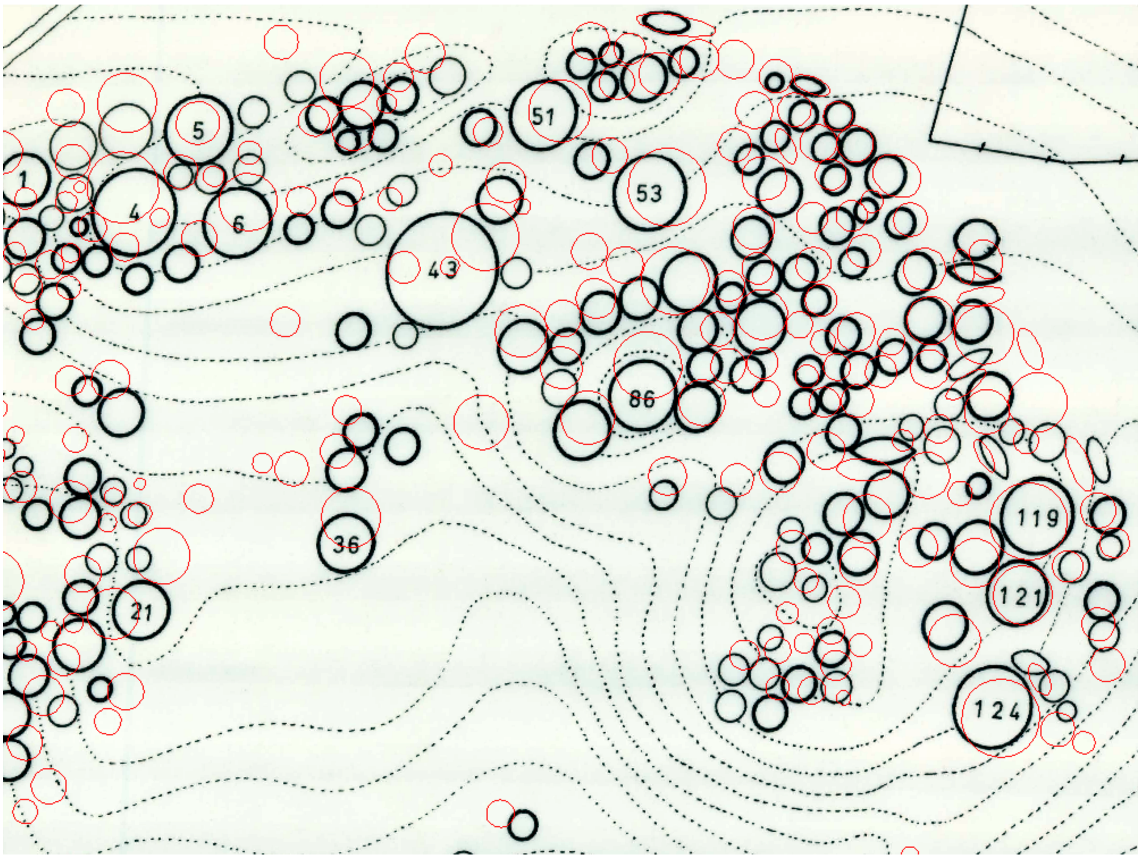


Figure 4.20. Comparison between existing archaeological map (black) and new mapping of grave mounds (red).

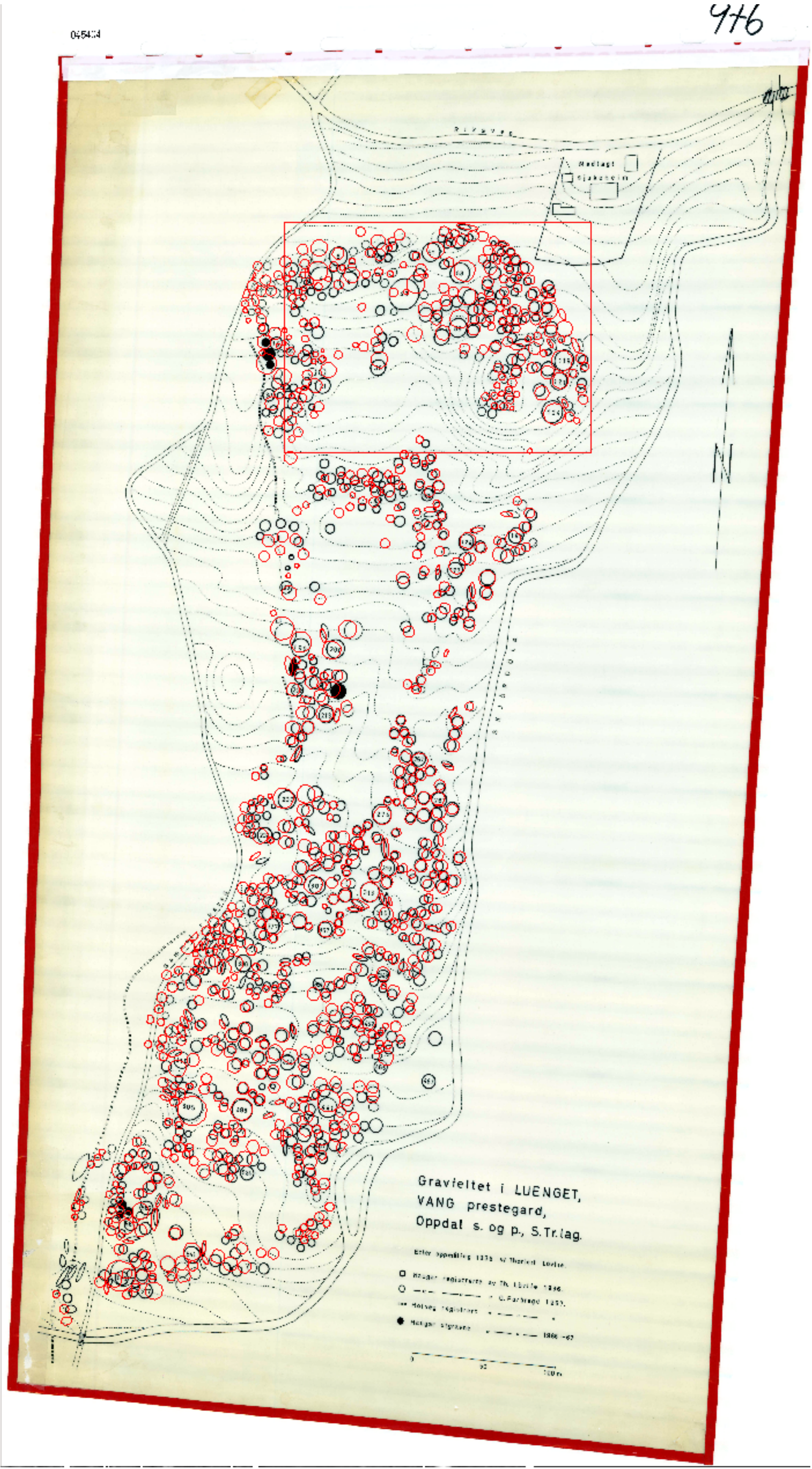


Figure 4.21. Comparison between existing archaeological map (black) and new mapping of grave mounds (red).

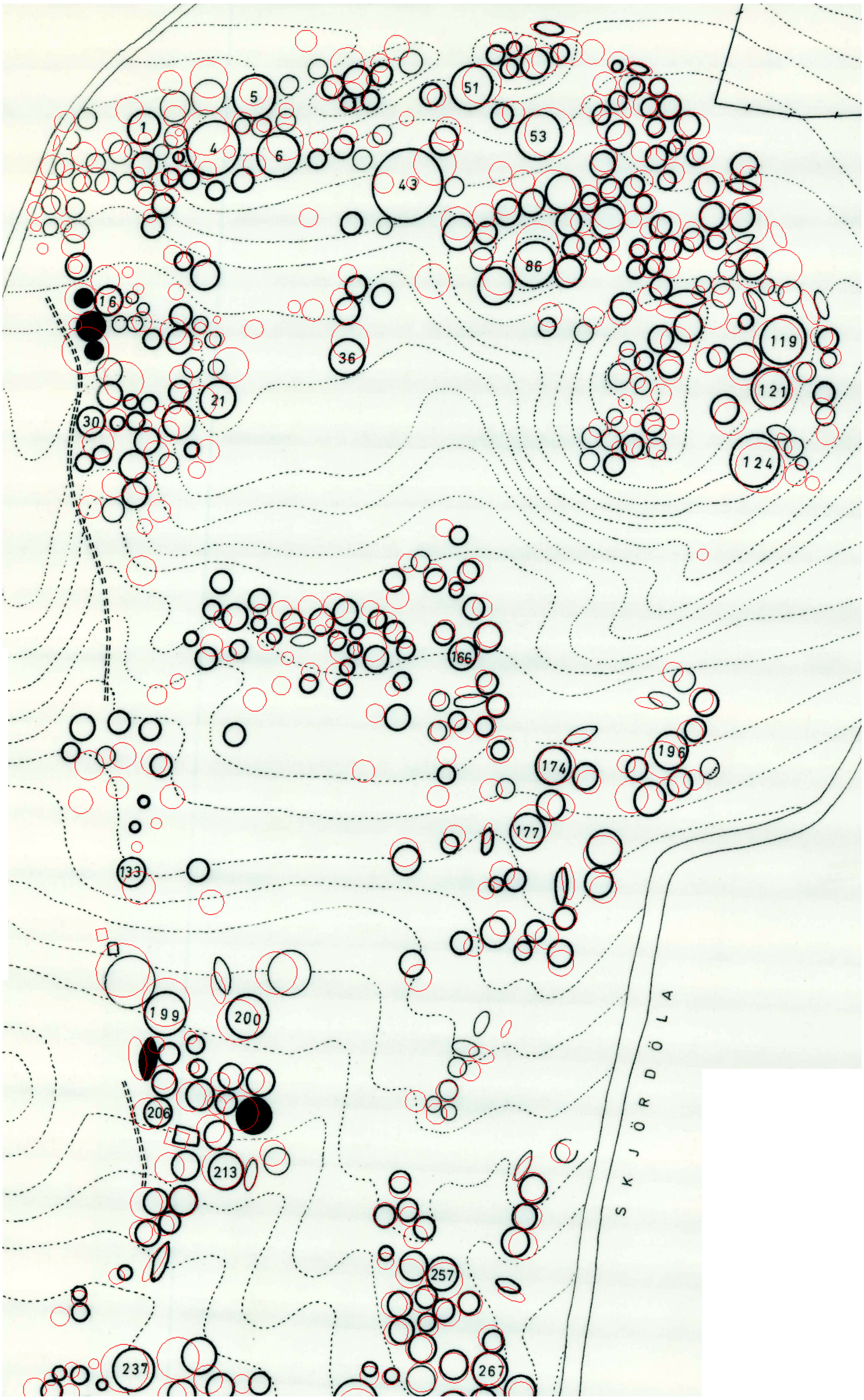


Figure 4.22. Comparison between existing archaeological map (black) and new mapping of grave mounds (red), part 1 of 2.

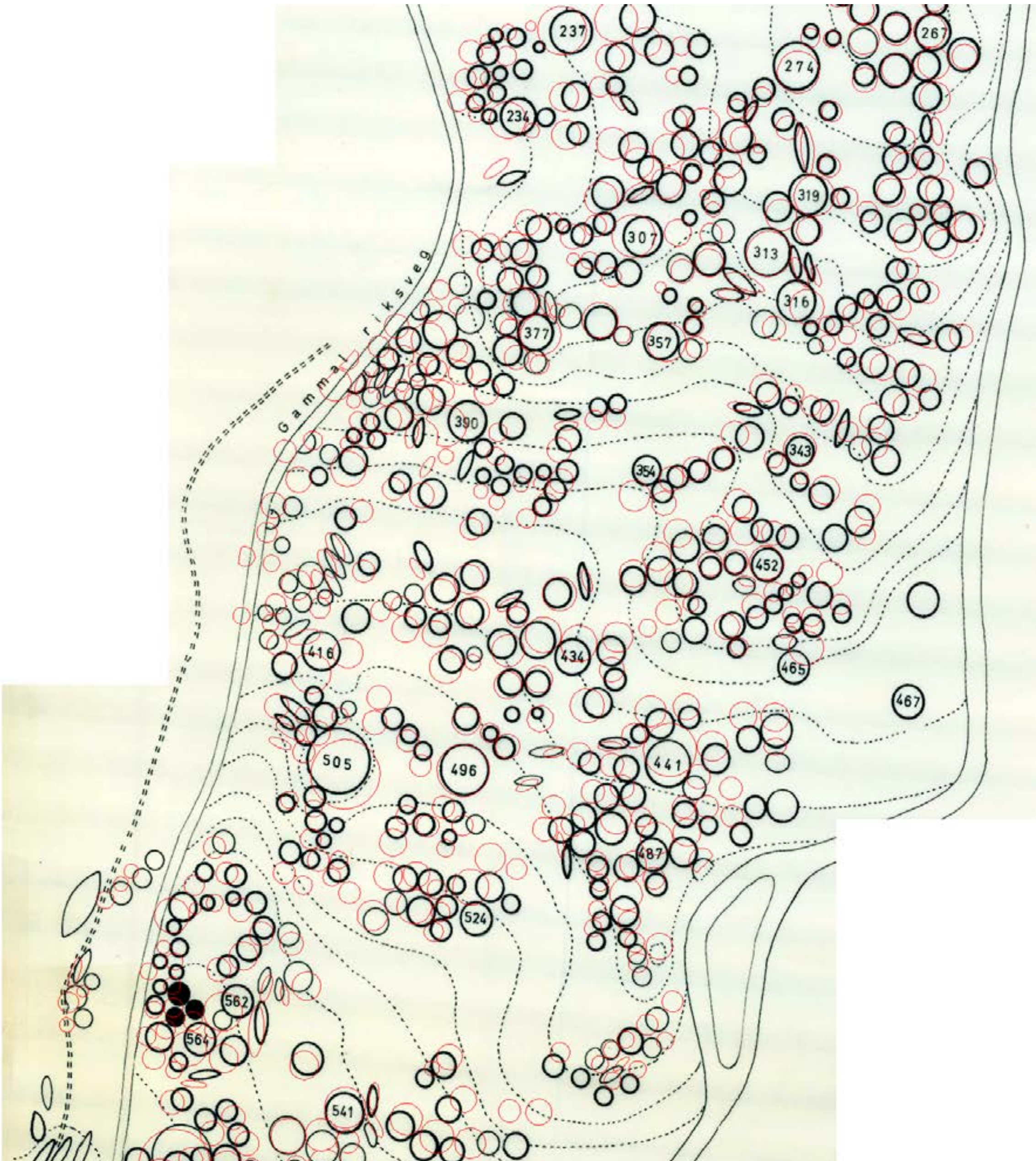


Figure 4.23. Comparison between existing archaeological map (black) and new mapping of grave mounds (red), part 2 of 2.

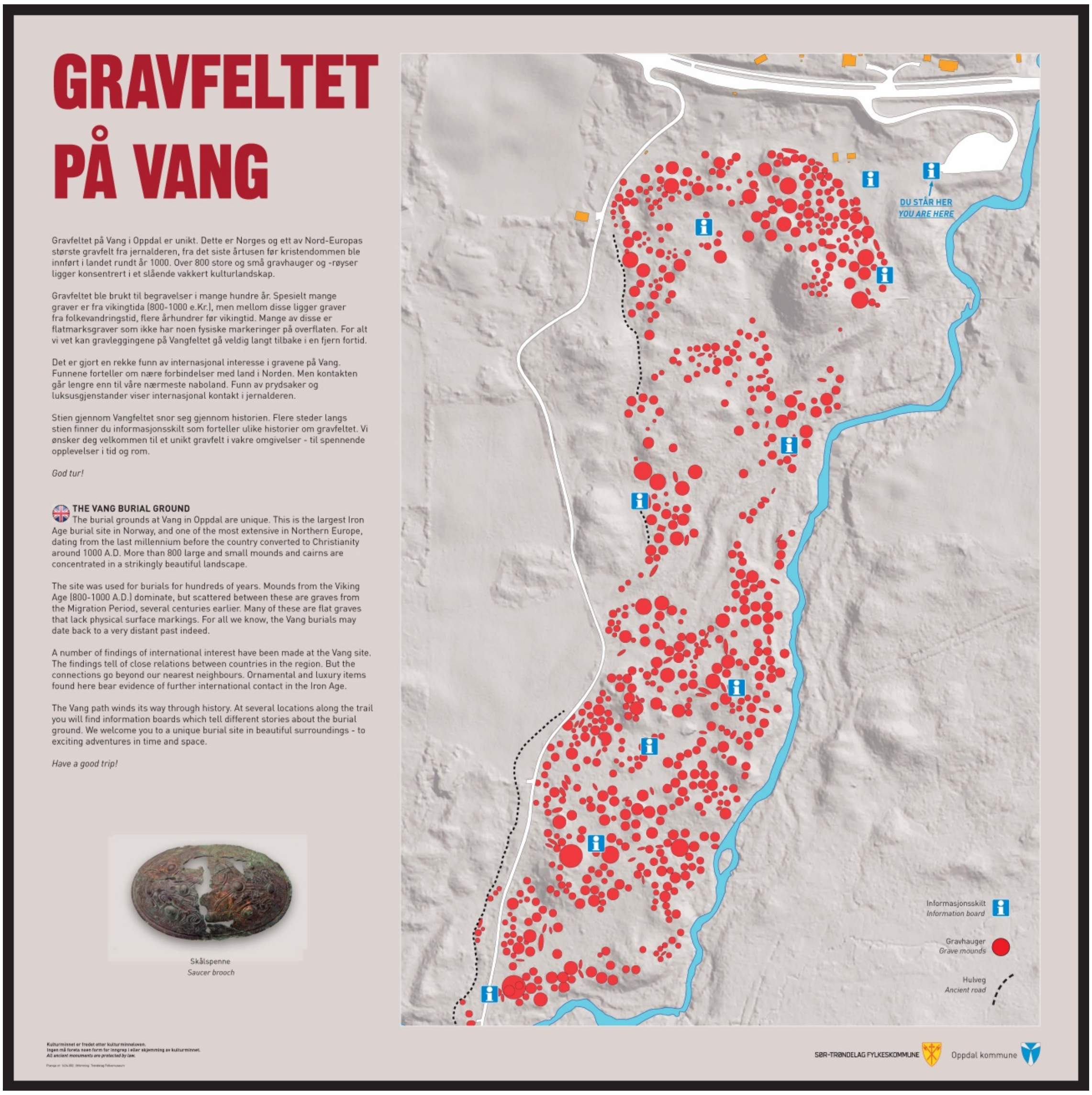


Figure 4.24. New information sign.

From the new mapping, new information signs have been made (Figure 4.24). The text reads:

"THE VANG BURIAL GROUND.

The burial grounds at Vang in Oppdal are unique. This is the largest Iron Age burial site in Norway, and one of the most extensive in Northern Europe, dating from the last millennium before the country converted to Christianity around 1000 A.D. More than 800 large and small mounds and cairns are concentrated in a strikingly beautiful landscape.

The site was used for burials for hundreds of years. Mounds from the Viking Age (800-1000 A.D.) dominate, but scattered between these are graves from the Migration Period, several centuries earlier. Many of these are flat graves that lack physical surface markings. For all we know, the Vang burials may date back to a very distant past indeed.

A number of findings of international interest have been made at the Vang site. The findings tell of close relations between countries in the region. But the connections go beyond our nearest neighbours. Ornamental and luxury items found here bear evidence of further international contact in the Iron Age.

The Vang path winds its way through history. At several locations along the trail you will find information boards which tell different stories about the burial ground. We welcome you to a unique burial site in beautiful surroundings to exciting adventures in time and space.

Have a good trip!"

5 Archaeological mapping of large forested areas, using semi-automatic detection and visual interpretation of high-resolution lidar data

By: Øivind Due Trier (Norsk Regnesentral) and Lars Holger Pilø (Oppland County Administration)

Paper presented at the 42th Annual Conference on Computer Applications and Quantitative Methods in Archaeology (CAA 2014), Paris, 22-25 April 2014.

5.1 Abstract

This paper presents results from the on-going mapping of cultural heritage in Oppland County, Norway, based on airborne lidar scanning of forested land.

Automatic detection is used in combination with manual inspection of visualizations of the ground surface, derived from the lidar data, and targeted field survey. In this manner, large forested areas in Oppland County, Norway have been mapped for ancient monuments, especially moose hunting systems and iron extraction sites.

Airborne lidar data is now being used extensively in the mapping of cultural heritage in forested areas in Oppland County, Norway. Fieldwork may be done in a much more targeted and limited way than traditionally. If the lidar point density is sufficiently high, prognosis mapping of archaeological pits may be done without fieldwork. Much larger areas may be mapped than before the introduction of airborne lidar scanning, at the same time providing a much more accurate and complete mapping.

5.2 Introduction

Oppland County, Norway, has several on-going and planned road construction projects, and some areas are being zoned for building of mountain cottages. Also, many areas have commercial timber production. To reduce conflicts between cultural heritage protection and modern land use development, Oppland County Council is conducting a much more accurate and complete mapping of cultural heritage than has been done previously.

Starting in 2010, the Cultural Heritage Department of Oppland County Council is currently conducting a large project, using high-density airborne laser scanning (ALS) to map ancient monuments. Approximately 4100 km^2 were mapped in 2013, mainly forested areas, bringing the total up to about 5700 km^2. Automatic pit detection has been used to support visual inspection of a digital terrain model (DTM) generated from the ALS data.

For visual inspection of a DTM, a number of visualization methods exist, including the standard hill-shading and slope images, which are available in many software packages like ENVI and ArcGIS; sky-view factor (Kokalj *et al*., 2011) and local relief models (Hesse, 2010). Several authors have mapped cultural heritage by visual inspection (e.g., see Bewley *et al*., 2005; Bollandsås *et al*., 2012). However, for automatic detection of pit structures, no suitable method existed to our knowledge, so we developed our own method (Trier and Pilø, 2012).

Oppland County Council undertook three separate ground-thruthings of objects in 2013, based on ALS data from 2012. The purpose was to investigate whether data collected during visual inspection of ALS data, supported by automatic detection, was of a sufficient quality to allow it to be entered into the national database of ancient monuments without a field control.

5.3 Data

Large forested areas in Oppland County, Norway, are known to contain ancient moose hunting systems and iron extraction sites. Today, these are manifested as pits in the ground. The iron production sites were used 1400–700 years ago, and consist of charcoal burning pits, often located in groups of three or more around a central oven. The hunting systems were used 2000–500 years ago, and consisted of concealed pitfall traps and wooden fences, located on moose trekking routes. The fences are gone, but the pits remain.

We have received ALS data in the form of LAS files, containing (x, y, z) points with the following information:

- x, y, z coordinates in UTM zone 32 and minimum 10 cm accuracy
- return number: 1-4 (each emitted lidar pulse may have up to four discrete returns)
- class label: 'ground' or 'other'
- intensity

The three areas chosen for fieldwork are situated in Nord-Fron and Sør-Fron municipalities in the central part of Oppland County. The ALS data was acquired in 2012 and has at least five emitted pulses per square meter, i.e. the number of first returns per m^2 is 5 points or better. The individual points have a precision of better than 10 cm. The ALS data for all the three areas belong to the same scanning-project. The laser-scanning instrument was a TopEye System, with a frequency of 200 000 Hz, mounted on a helicopter.

The density map of ground returns shows that nearly all the areas have more than 2 ground returns pr. m^2 (colour coding in Figure 5.1-Figure 5.3). Some parts have more than 5 ground returns, due to overlapping fields of view from neighbouring flight lines.

The three areas are Stølssletta, Venlisætra and Fagerlisætra. The Stølssletta area in Nord-Fron municipality is situated in a forested area adjacent to modern farm settlement in the Skåbu Valley at an altitude of 760-910 m.a.s.l. The checked area covered 2.5 km^2 (Figure 5.1). The hilly terrain is sloping towards the Northeast. The area contains single charcoal pits of a medieval date, and occasional pit fall traps, dating to the Iron Age and Medieval Period.

The Venlisætra area in Sør-Fron municipality is a summer farm area at an altitude of 720-960 m.a.s.l. It covers 1.6 km^2 in a Northeast-facing slope (Figure 5.2). It contains Medieval iron extraction sites with clusters of charcoal pits, single charcoal pits from the Medieval Period, pitfall traps from the Iron Age and Medieval Period, and occasional above ground charcoal kilns mainly dating to between the 17th and 19th century.

The Fagerlisætra test area in Nord-Fron municipality (Figure 5.3) is situated in a lightly forested area with summer farms. It covers 1.1 km^2 at an altitude of 870-930 m.a.s.l. The area contains medieval iron extraction sites with clusters of charcoal pits, single charcoal pits from the Medieval Period, and occasional above ground charcoal kilns mainly dating to between the 17th and 19th century.

5.4 Methods

A computer-based image analysis system is used in combination with manual inspection of visualizations of the ground surface, derived from the lidar data, and targeted field survey. In this manner, large forested areas in Oppland County, Norway have been mapped for ancient moose hunting systems and iron extraction sites.

5.4.1 Automatic pit detection

The automatic method of Trier and Pilø (2012) for the detection of pit structures in ALS data was used. We received airborne laser scanning data in the form of LAS files (described above). The (x, y, z) points labelled as 'ground' were used to form a triangular irregular network, which was then used to form a digital terrain model with 20 cm grid spacing. Then, template matching was used to locate candidate pit locations. A range of template sizes were used, covering the plausible pit sizes. Overlapping template matching detections were merged, keeping only the strongest one in each case. Next, a number of measurements were computed for each detection. The measurements were designed to quantify various deviations from the expected pit shape. Thresholds were used on the measurements to assign a confidence level (0-6) to each pit detection:

0 = not a pit, deleted

1 = pit with very low confidence

2 = pit with low confidence

3 = pit with medium confidence

4 = pit with medium high confidence

5 = pit with high confidence

6 = pit with very high confidence.

The pit detections of each confidence level (1-6) were exported to a separate GIS layer. For a more detailed description of the method, please see (Trier and Pilø, 2012).

5.4.2 Visual inspection

A highly detailed model was constructed from the ALS ground points, with a grid size of 0.25 m. The software used was Quick Terrain Modeller. An additional generalized model was constructed, with a 2 m grid size. The generalized model was then subtracted from the highly detailed model as a change analysis with an interval of 0.5 m. In this way a local contrast was produced, showing very local differences in height as differences in colour instead of as shadows, as in the case of hill-shade. In many ways this represents a local relief model (Hesse, 2010). However, the local relief model is more complicated, and time-consuming, to compute.

Visual inspection of the local contrast took place using one screen with an exported 2D-geotiff of the local contrast (azimuth 0, elevation 55) in ESRI ArcGIS and one screen with a 3D local contrast model in Quick Terrain Modeller. The visual inspection was supported by automatic pit detections marked in the ArcGIS-project. All automatic detections were visually checked on the screen. Some were interpreted to be ancient monuments or anomalies, while others were discarded during the inspection process. The automatic detection method produces a varying number of false detections depending on topography, data quality and modern activity. The main purpose of using automatic detections during the visual inspection is to achieve a consistent quality of archaeological data, cutting down on human error during inspection, i.e. missing objects.

Objects are marked in two different shape-files during visual inspection. Objects that are believed to be ancient monuments (based on experience) are geo-referenced with a point in the centre of the objects in an “Ancient monument” shape-file. Other objects that could possibly be ancient monuments, but where interpretation of the DTM is more uncertain, are marked in an “Anomaly” shape-file. The main reason for splitting the objects into two groups is that the “Ancient monument” shape-file is made available to area-planners and other interested parties through a public website (http://open.innlandsgis.no/), while the “Anomaly” shape-file contains too many false objects to be of use to planners.

5.4.3 Fieldwork

The purpose of the fieldwork is to assess to what extent data collected during visual inspection of ALS data, supported by automatic detection, is of a sufficient quality to allow it to be entered into the national database of ancient monuments without a field control.

In all three areas, a single archaeologist, using a handheld GPS with DPOS correction, undertook ground-truthing. The GPS contained a GIS-project, including the objects both from the “Ancient monument” and the “Anomaly” shape-file. To avoid visual clutter on the small GPS-screens the automatic detection data were not included.

Ground-truthing was undertaken by walking from “Ancient monument” point to point and checking each object. Anomalies were also checked, but to a varying degree in the different areas (see below). No systematic surface survey was undertaken, but the terrain was surveyed when walking between checked objects, yielding some impression as to the presence of visible objects, not found during the visual inspection of the ALS data.

5.5 Results

Fieldwork at Venlisætra and Fagerlisætra was undertaken by Lars Pilø, while the ground truthing at Stølssletta was undertaken by Anna McLoughlin.

Anomalies were systematically checked during the ground-truthing at Stølssletta (Table 5.1, Figure 5.1). No additional objects were found during fieldwork.

Table 5.1. Automatic detections versus field verification at Stølssletta.

Objects	True	False	Total	% True
Ancient monuments	100	5	105	95.2%
Anomalies	8	22	30	26.7%
Total	108	27	135	80.0%

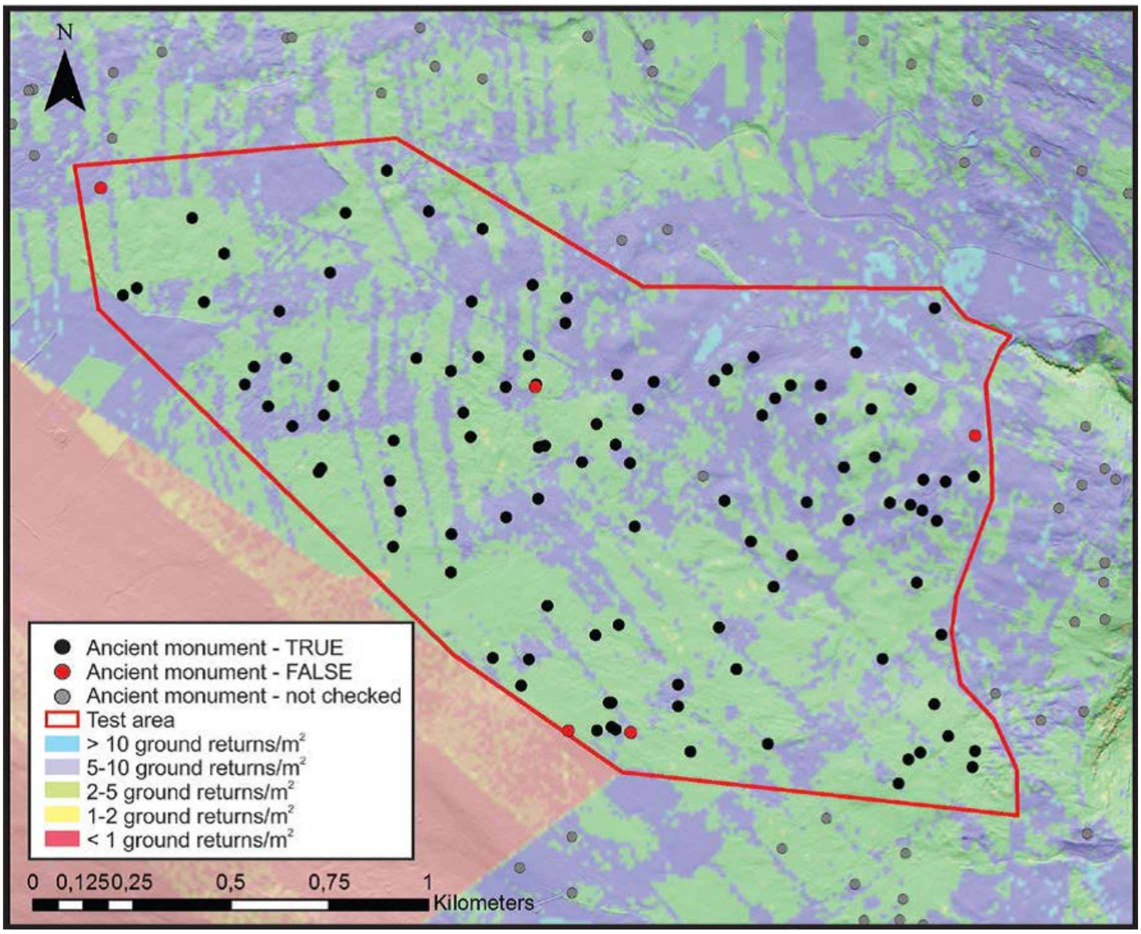


Figure 5.1. Result of field inspection at Stølssletta, Nord-Fron municipality.

For Venlisætra, anomalies were checked in the first part of the survey, but as the first 11 yielded no true objects, the checking of these objects was discontinued, to allow for a larger number of checked objects in the “Ancient monuments” group (Table 5.2, Figure 5.2). No additional objects were found during ground truthing.

Table 5.2. Automatic detections versus field verification at Venlisætra.

Objects	True	False	Total	% True
Ancient monuments	60	3	63	95.2%
Anomalies	0	11	11	0.0%
Total	60	14	74	81.1%

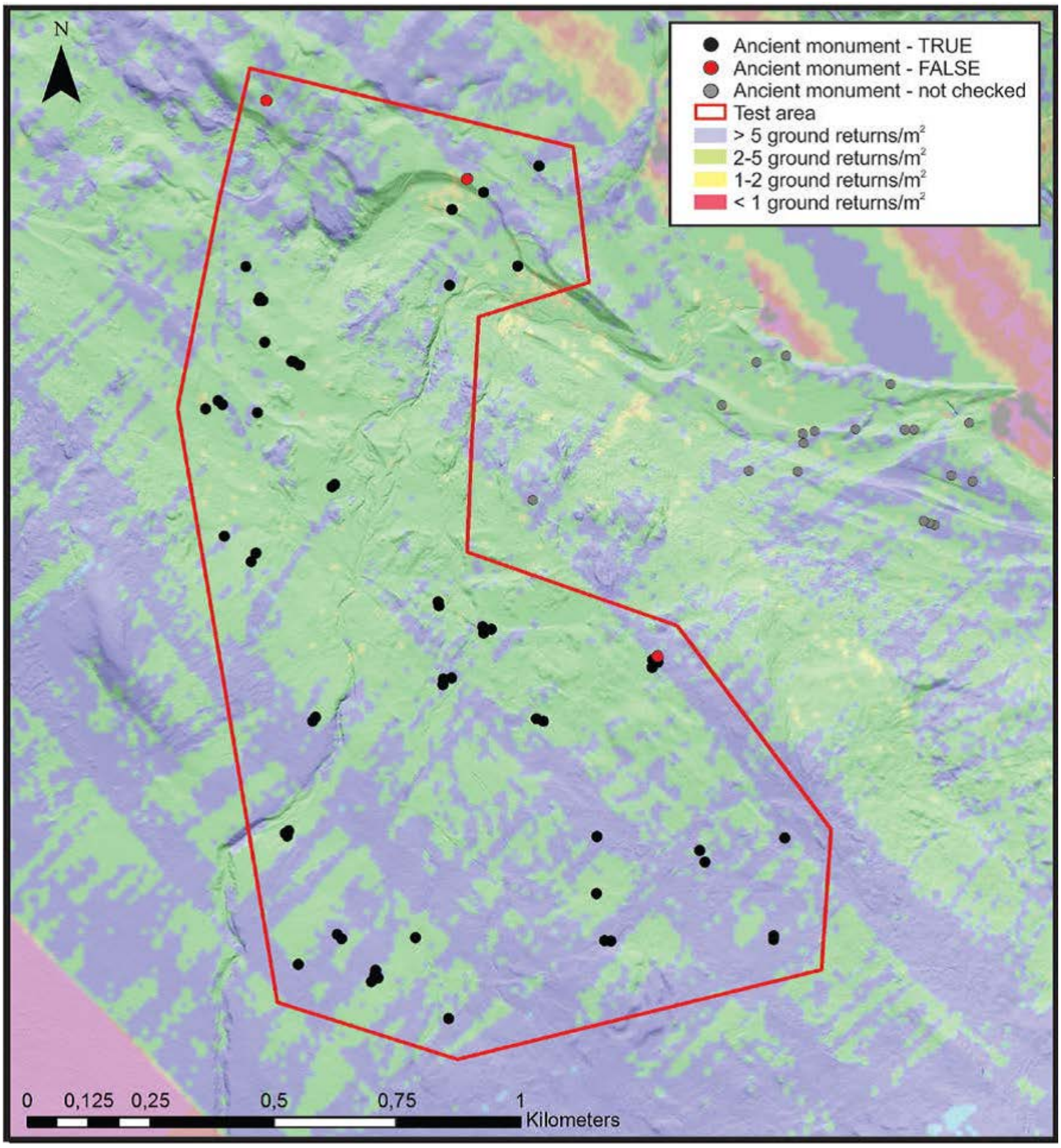


Figure 5.2. Result of field inspection at Venlisætra, Sør-Fron municipality.

Only two anomalies were checked in the Fagerlisætra area (Table 5.3, Figure 5.3). Both were small charcoal pits, adjoined to the same iron extraction site. Two additional objects were discovered during the ground-truthing. Both had been categorized as confidence level 2 (low confidence) by the automatic pit detection, but had been discarded during the visual inspection of the ALS data. As the automatic detections had not been included in the field GIS-project, it was only later discovered that they had in fact been targeted by the automatic detection.

Table 5.3. Automatic detections versus field verification at Fagerlisætra

Objects	True	False	Total	% True
Ancient monuments	37	0	37	100.0%
Anomalies	2	0	2	100.0%
Total	39	0	39	100.0%

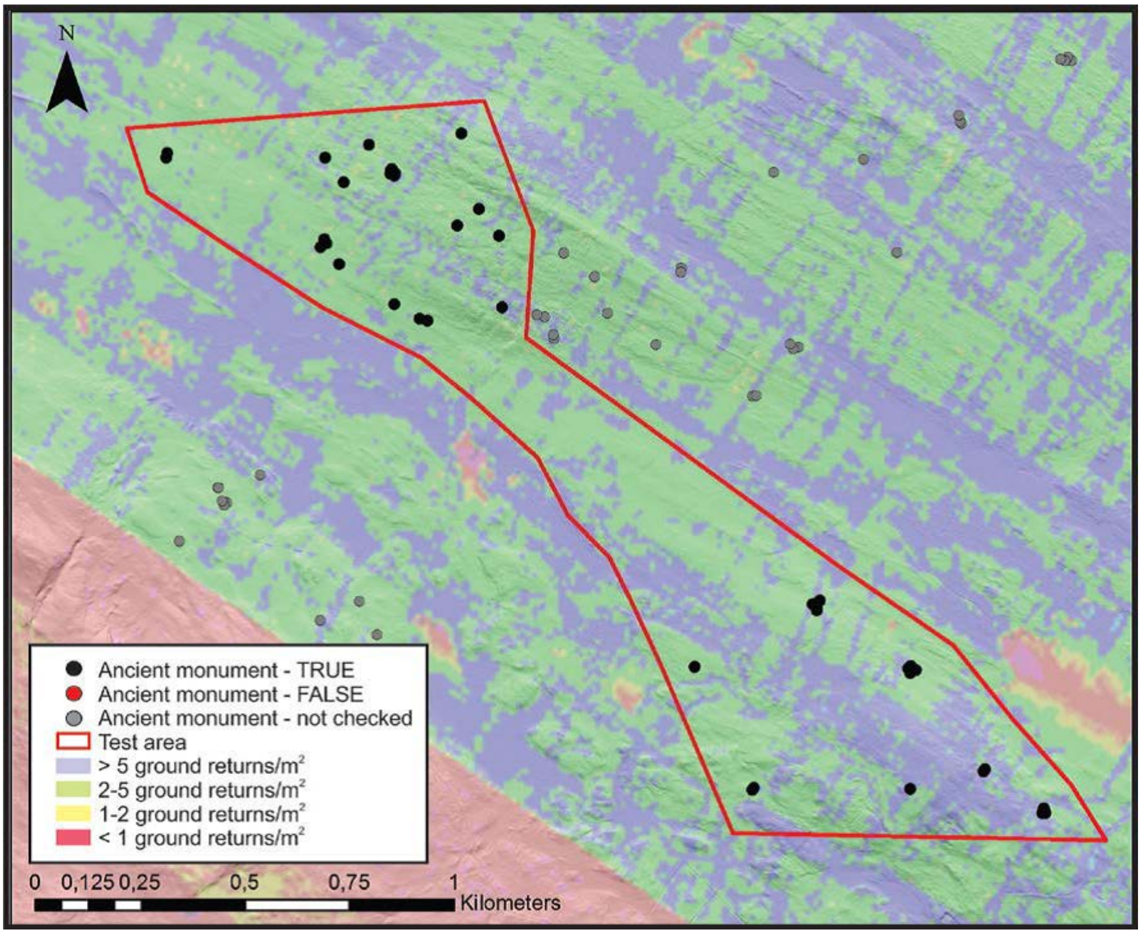


Figure 5.3. Result of field inspection at Fagerlisætra, Nord-Fron municipality.

To summarize, 197 of 205, or 96% of the objects that were interpreted as ancient monuments from visual inspection turned out to be true ancient monuments according to the field inspection (Table 5.4). In addition, some anomalies detected by visual inspection turned out to be true ancient monuments by field inspection.

Table 5.4. Summary of results for the three areas.

Test area	Visual inspection: objects interpreted as ancient monuments	Field inspection		
		True	False	% True
Stølssletta	105	100	5	95.2%
Venlisætra	63	60	3	95.2%
Fagerlisætra	37	37	0	100.0%
Total	205	197	8	96.1%

5.6 Discussion and conclusions

The three checked areas are relatively similar. They are situated at an altitude of above 700 m.a.s.l. Two areas (Stølssletta and Venlisætra) are situated in a Northeast-facing slope while Fagerlisætra has a slightly undulating topography. All three areas showed a remarkable consistency in producing 95% or better of true objects in the “Ancient monuments” category.

On the basis of the evidence it seems reasonable to conclude that typical outfield monuments like charcoal pits and pitfall traps can be accurately mapped using visual inspection of detailed DTM, supported by automatic detection, provided that the number of ground returns is sufficiently high (> 2 ground returns pr. m^2 (Trier and Pilø, 2012)). It should thus be possible to produce large-scale maps of these monument-types, provided that ALS data is available. This work is already on going in Oppland County.

This study does not give much information on the presence and number of visible ancient monuments not found during the visual inspection of the DTM. Based on the limited surveys conducted by walking in the terrain between the checked objects the number of additional objects in the test areas is believed to be low. However, information from previous ground-truthing in Gravfjellet in Øystre Slidre municipality provides more systematic information on this question. This area also contained medieval iron extraction sites with charcoal pits in clusters, single charcoal pits and some pitfall traps. A 70 km^2 ground-truthing in 2011, based on visual inspection of a one-light-source hill-shade (and with less experience in interpretation of ALS data than now), led to the discovery of 1650 visible ancient monuments. In 2012 plans were initiated to develop about 10 km^2 of this area for cottages and infrastructure. This provided an opportunity to do systematic surface survey of this limited area (Tveiten and Pettersson, 2013). An additional ca. 10 % of single charcoal pits were found during the systematic survey, which is a remarkable low number, considering the visual inspection was undertaken using hill-shade, which is not really a suitable visualization technique for this kind of work. The impression of the distribution of single charcoal pits did not change after adding the extra objects. The additional pits were typically small, hidden in dense spruce forest or damaged.

As of 2013, the new ALS-based mapping has covered 5700 km^2 of forested land. At Gravfjellet in Øystre Slidre municipality, a 70 km^2 area has been zoned for mountain cottages. A total of 1650 archaeological features, mostly charcoal pits belonging to iron extraction sites, have been mapped and ground-proofed. This enables the municipality to plan the location of individual cottages, local roads, etc., in order to minimize the destruction of cultural heritage. In Gausdal municipality, prognosis mapping (as yet without ground-proofing) of 290 km^2 revealed about 1800 cultural heritage objects. These figures illustrate the density of cultural heritage in some areas in Oppland County, and the need for detailed archaeological mapping.

The purpose of using ALS in the heritage management in Oppland is mainly as a tool to map outfield monuments. In this it succeeds brilliantly, providing inexpensive, good quality and above all systematic data, which is of great value for cultural heritage management. It is, however, not a substitute for proper fieldwork on the ground, when an area is scheduled for development, as not all visible monuments are found in the ALS data, detail on some objects is lacking, and of course not all sites are visible above ground. In the forested areas of Oppland, however, most monuments are clearly visible above ground, making the interpretation of ALS data a very valuable tool for cultural heritage management. Under such conditions, ALS data provides excellent mapping opportunities for large areas (Figure 5.4-Figure 5.5).

In conclusion, airborne lidar data is now being used extensively in the mapping of cultural heritage in forested areas in Oppland County, Norway. The results of combining semi-automatic detection and visual inspection are good. Fieldwork may be done in a much more targeted and limited way than traditionally. Provided that the quality of the lidar data is sufficiently high, that is, the digital elevation model derived from the lidar ground returns contains sufficient detail; prognosis mapping of archaeological pits may be done without fieldwork. Much larger areas may be mapped than before the introduction of airborne lidar scanning, at the same time providing a much more accurate and complete mapping of cultural heritage.

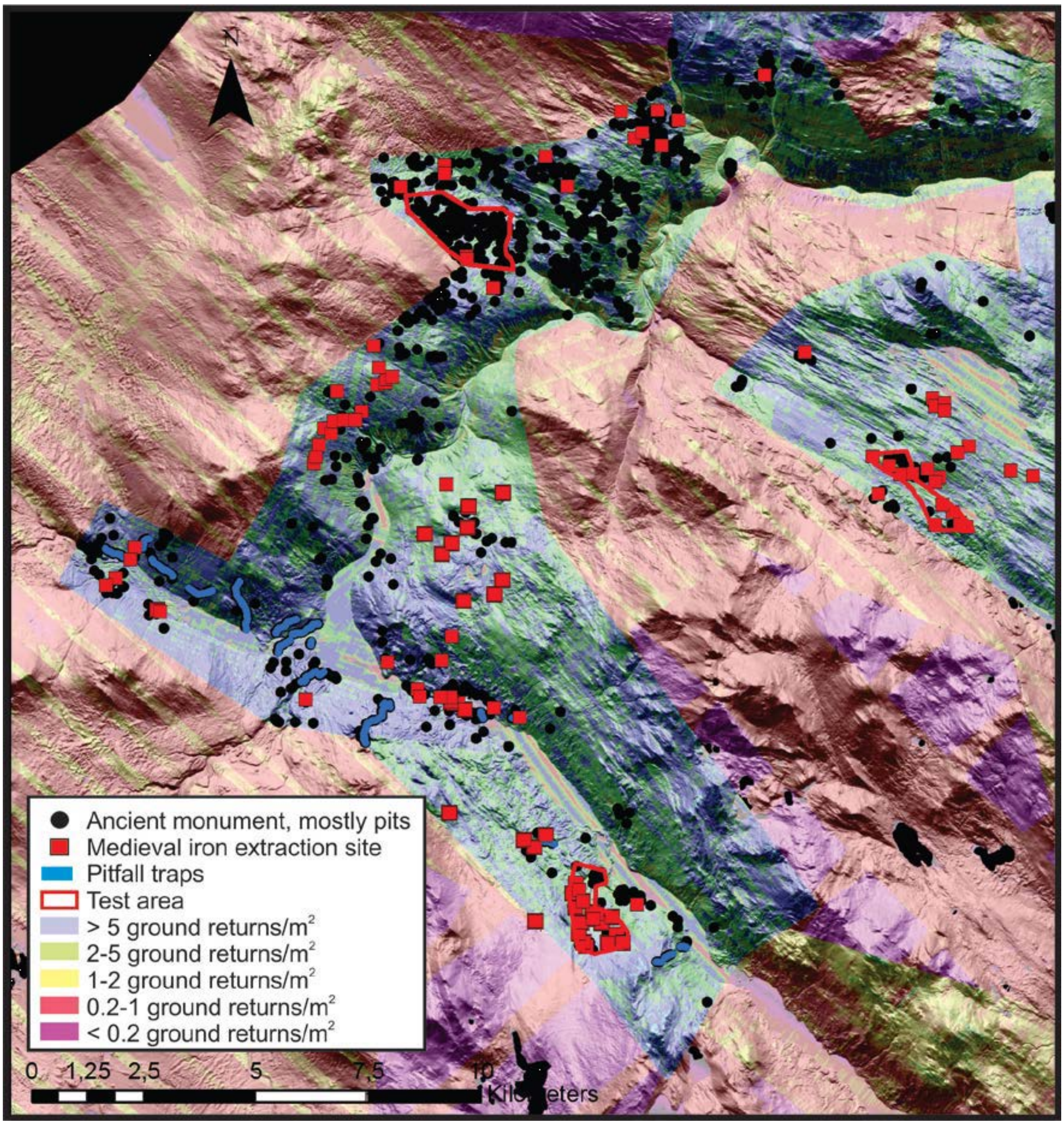


Figure 5.4. Overview of ancient monuments mapped from ALS data in Nord-Fron and Sør-Fron municipalities. The three field survey areas (test areas) are indicated with red polygons.

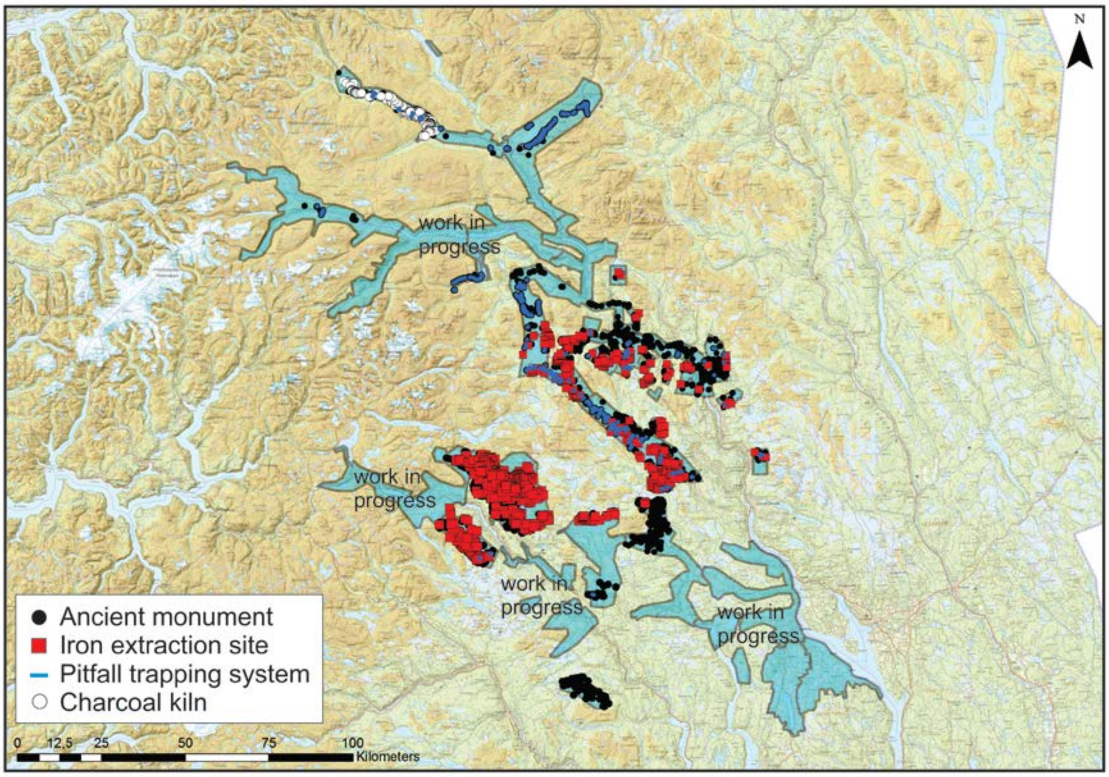


Figure 5.5. Overview of all ancient monuments mapped since 2010 based on ALS data.

5.7 Acknowledgements

This research was funded by the Directorate for Cultural Heritage in Norway (Riksantikvaren).

6 Discussion

In 2014, the automatic detection methods in *CultSearcher* were used for the mapping of cultural heritage from airborne laser scanning (ALS) data, in combination with visual inspection of the ALS data and field surveys. This included:

1. Mapping of charcoal kilns in Lesja municipality, Oppland County, by using a combination of automatic pit detection and automatic heap detection.

2. Mapping of grave mounds in the Iron Age grave field at Vang, Oppdal municipality, Sør-Trøndelag County.

3. Mapping of grave mounds in Larvik municipality, Vestfold County.

There is no specific detection method for charcoal kilns in *CultSearcher*. However, the shapes of charcoal kilns often include pits and/or heaps. With a few hundred charcoal kilns recently mapped in Lesja municipality, the project is ready to develop a tailored charcoal kiln detection method, on the condition that the project is continued in 2015.

A substantial effort was made to try to improve the semi-automatic grave mound detection method. However, the number of false detections still remains high, while the percentage of missed grave mounds is also quite high. We suspect that the problem is two-fold: (1) many grave mounds are quite subtle, and (2) the ALS acquisition was in the period with leaves fully developed on deciduous trees, preventing grave mounds under such trees from being well captured in the ALS data.

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