Airborne Remote Sensing and Ground Penetrating Radar survey Coll and Tiree

A report for Historic Scotland - March 2003

Tom Dawson and Sandy Winterbottom
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and
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Introduction

The Airborne Remote Sensing and Ground Penetrating Radar survey of Coll and Tiree is a collaborative project that brings together the Department of Environmental Sciences, University of Stirling; the AHRB Centre for Environmental History, University of St Andrews; and the Coastal Research Group, University of Glasgow. The project aim was to test the use of Airborne Remote Sensing to discover archaeological sites within mobile sand dune and machair areas. The study areas were the dune systems of the islands of Coll and Tiree. In addition to collecting and examining Airborne Remote Sensing data, field visits have been made and a survey using Ground Penetrating Radar was undertaken. Airborne Remote Sensing data was collected by the National Environment Research Council (NERC). NERC also provided the Ground Penetrating Radar equipment. All fieldwork was grant-aided by Historic Scotland.

Rationale

The uncovering of coastal archaeological sites in Scotland as a result of wind and wave erosion is common. Notable examples include the Neolithic village at Skara Brae, Orkney, revealed in about 1850 and further damaged by a storm in 1924 (Childe, 1931). The larger, multi-period site of Jarlshof, Shetland, was partially destroyed by a series of storms in the years up to 1897 (Hamilton, 1956). There is now widespread acknowledgement that changes in sediment budgets, sea level and storminess may all contribute to changing patterns of erosion of the coast and dunes. This will fundamentally affect archaeological survivability (Hansom, 1999, 2003; Hansom and Angus, 2001).

The problem posed to archaeological sites by erosion has been recognised by Historic Scotland, and between 1977 and 1992 they sponsored the excavation of 38 major sites in advance of marine and aeolian erosion (Ashmore, 1994). They have also commissioned a series of coastal zone assessment surveys, which collected information on archaeological sites together with data on geology, geomorphology and erosion class (Historic Scotland, 1996). The recent surveys have begun to quantify the problems facing coastal archaeological sites from erosion in specific areas. To date, approximately 20% of the Scottish coast has been surveyed (Ashmore, 2003). In every case, the surveys located far more sites than had been previously recorded, in some cases quadrupling the existing records (Moore & Wilson, 1998; Brady & Morris, 1998). In many cases, new sites were discovered because they were seen eroding from cliff edges or were exposed due to storm activity.

The surveys have highlighted the difficulties of planning for the protection or excavation of threatened coastal archaeological sites. In many cases, sites aren't known about until they have been revealed due to erosion. By this time, they have already started to become damaged. What is needed is a way of being able to identify hidden sites within dunes and other areas that are subject to change, and thus to assess the level of threat posed to archaeological remains in those areas. This project is testing the utility of using Airborne Remote Sensing data to locate previously unknown sites within such areas.

The Study Area

The study areas selected are parts of the dune systems on Coll and Tiree, Argyll and Bute, Scotland. The islands are in the Inner Hebrides of Scotland (fig 1) and are situated to the west of the Isle of Mull. They lie on the Skerryvore Bank and are part of the Lewisian complex, the name given to the oldest rocks in the UK (Fyfe *et al*, 1993).

The low-lying island of Coll is approximately 19 km long and 5 km wide. Data were collected from the western half of the island, which has belts of Lewisian gneiss running in a general N-S direction. The strongly-banded grey gneisses contain hornblende and biotite. They alternate with belts of highly metamorphosed pre-Lewisian sediments.

Tiree lies 3 km south-west of Coll and is approximately 17 km long and between 1-10 km wide. It is low-lying, excepting two hills in the west and south west. The highest of these hills is Beinn Hynish which is 138m above sea level. The geology is similar to Coll, comprising bands of Lewisian gneiss with intercalated strips of older, metamorphosed sediments.

Although bedrock outcrops in many places, it is the large sheets of blown sand that most characterise the islands. The sand is principally composed of the pounded shells of marine invertebrates and algae.

Mather *et al* (1975) have calculated that of the 77 sq. km of land surface that makes up Tiree, 25.8km (33.5 %) consists of dunes and machair, 41.5% consists of raised beach and 25% of bare rock, heath and open water.

The population of Tiree is larger than Coll, and 760 people live there today. The population reached a peak in the mid-nineteenth century with 4500 people. The current population of Coll is approximately 150, far down on its peak of 1841 when 1440 people were recorded as inhabiting the island.

The climate of Coll and Tiree is generally drier, sunnier and windier than other coastal areas in Scotland (Mather & Ritchie, 1977). Tiree is often recorded as being the sunniest place in Britain, especially in May.

Previous Archaeological Investigation

Both islands have evidence indicating continuous occupation from the Mesolithic onwards. There are numerous prehistoric remains, and both brochs and duns have been recorded. In addition, Tiree has close links with Iona, and many chapels were built on the island.

The antiquarian Erskine Beveridge made successive visits to the islands between 1896 and 1901, recording all archaeological sites that he encountered during his visits. He published his discoveries in his book '*Coll and Tiree: their prehistoric forts and ecclesiastical antiquities,*' published in 1903. He wrote chapters for each island, concentrating on the 'Ancient Forts'; 'Hut Circles'; 'Sandhill Dwellings'; 'Prehistoric Burial Sites'; and 'Pre-reformation Chapels and Burial Grounds'.

In the chapters on the 'Sandhill Dwellings' he noted that ancient hearths and kitchen middens occur in many large groups, especially where the sand has been blown. His impression was that although the sites were plentiful, many more must remain hidden below the '*...high, bent covered mounds of drifted sand, and it may be that only a small proportion are now to be traced, their exposure varying from year to year according to the wind which most prevails*' (Beveridge, 1903 p35).

This statement is undoubtedly true, and a good example of a site undergoing the process of being buried (figure 2) is the chapel at Kilkenneth (Grid ref. 9432 4477).

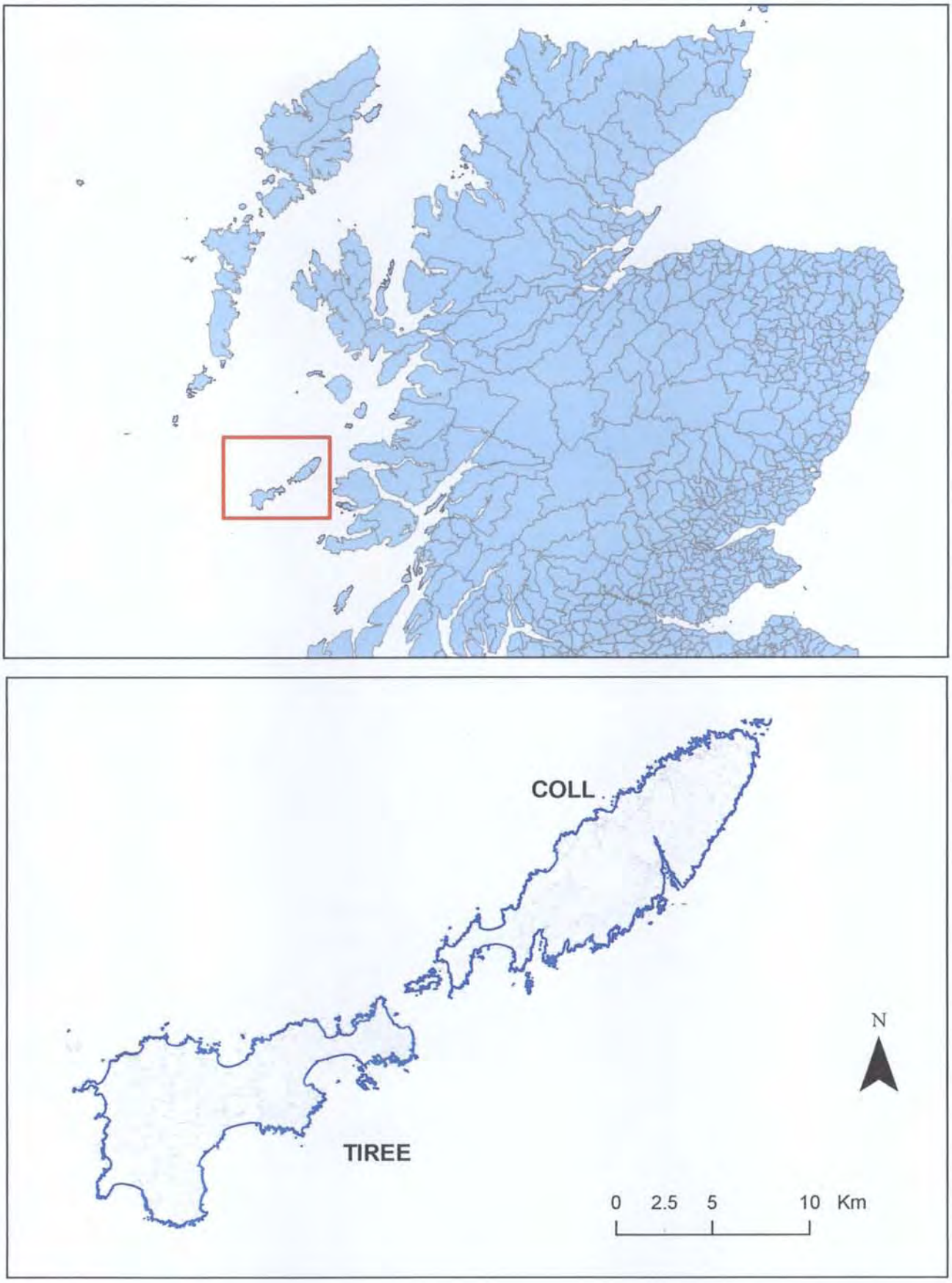


Figure 1 Location of the islands of Coll and Tiree, Scotland

Figure 2 Kilkenneth Chapel, partially buried by sand.

The sites identified by Beveridge were subsequently revisited; by the Ordnance Survey in 1972 and by the Royal Commission on the Ancient and Historic Monuments of Scotland (RCAHMS) on several occasions in the 1970s (RCAHMS, 1980). Their field visits revealed that many of the sites recorded by Beveridge, especially those in the dune fields, were no longer visible.

A search of all sites recorded within the National Monuments Record of Scotland that lie within 1 km of the coast has shown that within the survey area, over 40 sites noted by Beveridge are now no longer visible. In some cases, the sites may have been lost to erosion, in others the stone robbed for building. However, the dynamic nature of the dune system must mean that many of these sites are no longer visible because they have been covered by sand.

Dune Systems of Coll and Tiree

The formation and current state of the beach and dune systems of Coll and Tiree is of great significance to the survival and stability of the archaeological remains. Mather and Ritchie (1977) state that *'any sand-beach system, which may include areas of beach, dunes, machair and other surfaces formed by wind blown deposits is normally, by definition, low and consolidated. Moreover, on various timescales, it is also mobile'*. It is this mobility that can have an impact on archaeological sites. Some sites will be revealed when the covering layer of sand is removed, others will become hidden. The concern is that sites covered by drifting sand can end up being damaged as a result of coastal erosion.

Formation of the system

The sand-beach system of Coll and Tiree is formed of shell sand, thought to be of ancient origin. During the post-glacial period, molluscs and crustacea were abundant in the seas surrounding the islands. The remains of the exoskeletons of these animals account for a significant proportion of the sand. These organic sands are rich in calcium carbonate, comprising up to 80%.

Large reservoirs of sand exist under the sea as offshore sediment banks. Some sand is transported to the intertidal beach by wave action. Most of this sand remains within the intertidal zone, where it moves

back and forth with the action of the tide and waves. Some of it gets pushed up beyond the intertidal zone, at times of exceptionally high tide or during storms, to form the backshore or upper beach. These storm coasts can have ramparts of sand raised over 10 metres.

If the sand is able to dry, it acts as a reservoir which is subject to wind movement. On-shore winds can move the sand inland to build up coastal dunes. The blown sand originally formed wedges with a steep seaward scarp, a crest and a long landward slope. Over time, sand movement, plant colonisation and human settlement have caused large-scale changes in the wedge-shaped profile. From the dunes, the wind can further carry the sand to build up the machair area.

Machair

The word machair is Gaelic, meaning an extensive, low lying, fertile plain (Dwelly, 1901). The word is now recognised as referring to a specific coastal feature, defined as a type of dune pasture (often calcareous) that is subject to local cultivation. The organic sand neutralises the acidity of peat and the poor gneiss soils and the machair has thus acted as a focus for settlement and exploitation for millennia.

Machair can be used both for grazing and for cultivation. In historical times, cultivation was on a rotational basis, helping to ensure that the most fragile areas were not cultivated, and that no part of the machair was ever permanently exposed or completely depleted of its organic matter. In many places, the soil was improved by the spreading of manure or seaweed.

The movement of sand

It is the wind that plays a crucial role within this mobile system. Vegetation will act as a barrier to sand movement, but in unvegetated areas, the wind can lead to the development of blowouts (erosion hollows) and corridors, areas where sand is excavated and carried by the wind. The blowouts at the western end of Coll (Crossapol) are up to 40 metres in depth (figure 3).

Usually, sand does not travel great distances, but occasionally, when exceptionally windy weather combines with a period of dryness, clouds of sand can be carried larger distances at higher levels. As noted above, Coll and Tiree are subject to sunny, windy weather.

Historical wind blows

The unstable nature of sand dune areas means that even without human interference, considerable and damaging sand blows can occur. The age of the dunefield at Crossapol, Coll, is unclear, but descriptions by Walker (1764, in MacKay, 1980) and Boswell and Johnson (1773) suggest that this area was once fertile, but that the land was overwhelmed by sand drift during the 17th and early 18th centuries. Walker (1764) mentions two farms near the dunefield that had to be moved at the beginning of the 18th century. There is a possibility that the great storm of 1697 may have played an important role in transporting and depositing this sand.

Human activity can accelerate rates of aeolian erosion. During phases of population pressure, over-exploitation of the resources provided by sand dune areas greatly increases the risk of serious sand blows (Dodgshon, 1998). Turnbull's survey of Tiree in 1768 listed some of the main contributory factors for sand blow, and included over-grazing and over-cultivation of the machair; pulling bent for ropes and baskets; and collecting plants for dye. These plants were pulled up roots and all and led to the recommendation of drastic punishments for those caught continuing the practice.

Figure 3 Large blowout at Crossapol, Coll. Note the human scale.

Turnbull's survey reported over 1624 acres of blown sand on Tiree, with the problem especially acute in the townships of Cladichchrosan, Badewilline, Keylepole, Quiyeish and Kelis. His map shows several townships on the north-west coast, west of Beinn Hough. All settlements in this area have today disappeared.

Another cause of sand blow may have been the growth of the kelp industry around the end of the eighteenth century. More people would have been attracted to the beaches, and damage done by the wheels of kelp carts may have caused the corrugation of the Balephuill machair, Tiree (Darling and Boyd, 1964). Additionally, the growth of a commercial outlet for kelp would have led to a decrease in the use of the seaweed as a manure.

Animals can also lead to the development of blowouts. Dr Johnson records a rabbit warren on Coll, owned by the Duke of Argyll. The burrowing of rabbits was soon seen by many to have a very detrimental effect on machair, and the islanders of Tiree have managed to keep the animals off their island.

Recent rates of change, Coll and Tiree

A detailed study of coastal change at selected beaches in Coll and Tiree over the last 120 years was undertaken in 1998 (Dawson 1999). Field survey data was compared with 1:10560 scale Ordnance Survey maps produced in 1878; aerial photographs from World War II and 1994; and detailed maps produced by Mather *et al* (1975).

Dawson was able to demonstrate that there has been significant erosion over the past 120 years. As an example, he estimated that at Traigh Thodhrasdail, Tiree, circa 100m of Shoreline retreat took place between 1878 and 1975, averaging 1 metre a year. It appears that this rate has been maintained, and possibly slightly exceeded during the time interval between 1975 and 1994. Dawson anticipates that the trend will continue.

He also demonstrated that dune movements can be rapid and was able to show that at certain places there has been significant vertical dune accretion. In extreme cases, examples of several metres of vertical dune accretion over the last several decades were noted, usually linked with progressive erosion of the dune toe. At Crossapol, Coll, a telegraph pole was recorded as being almost completely buried by wind-blown sand.

Implications to archaeological remains

It is the rapid rate of Shoreline retreat that is most worrying to archaeologists. Sites covered by sand within areas of stable dune may not be visible, but are not under immediate threat from aeolian erosion. However, the rapid rate of Shoreline retreat means that they may soon become threatened by encroaching coastal erosion. This project attempts to locate some of these sites before they are lost.

Aerial prospection

The use of aerial photography for archaeological prospection has become increasingly more common over the last century. It provides the ability to discover sites prior to large-scale infrastructure construction or destruction by natural erosion processes. Aerial photographs often allow the detection of buried archaeology through small-scale topographic changes or by discoloration of the overlying soils or vegetation (Wilson, 2000) and allow large areas to be surveyed within short time-scales.

Archaeological features may only be detectable using aerial photography under certain conditions and circumstances:

- Small-scale topographic variation is most usually observed when sun altitude is low and features can be picked out by the strong shadowing effects created under these conditions.
- Crop marks are dependent on buried features either enhancing or reducing the growth of overlying vegetation by increasing or reducing moisture availability. Deep, soil filled trenches often allow enhanced moisture retention and availability within soils, whilst buried stone usually causes a local increase in drainage efficiency thereby reducing moisture availability for crops. These subtle effects are often only evident in aerial photographs under extreme drought conditions when moisture availability is critical.
- Soil marks are where past activity has led to variations in the colour and character of the top-soil and are only evident when fields have just been ploughed.

The timing of aerial photography campaigns for archaeological prospection is therefore crucial and often, the optimal conditions for detection may not occur for many years.

Remote Sensing

The advances in remote sensor technology over the last 20 years have provided new opportunities for detecting buried archaeological remains that could not have been discovered using conventional aerial photography, or for features that are only evident under certain conditions. Remote sensing involves detecting electromagnetic energy which has been reflected from a ground surface. In passive remote sensing, the energy source in question is the sun and this energy is transmitted through the atmosphere until it interacts with the ground surface where it is either absorbed, transmitted or reflected. The degree to which the energy is absorbed or reflected over the wavelength range will be dependent on the physical and chemical characteristics of the ground surface. The reflected energy is then transmitted back through the atmosphere and is detected by the remote sensing instrument which records the

incoming signal electronically. The intensity of reflected energy is recorded as a digital number for each pixel, corresponding to a squared area on the ground. Multi-spectral sensors record the reflected energy for a number of sampled wavelength ranges - from the visible part of the electromagnetic spectrum, through near, short and middle infra-red to thermal infra-red.

The electromagnetic spectrum

The visible and in particular the infra-red parts of the electromagnetic spectrum are extremely sensitive to changes in vegetation type, vegetation moisture and nutrient status. The response of vegetation in the visible wavelengths (400 – 700nm) are determined by the compositions and concentration of chlorophylls a and b, caretenoids and xanthophylls (Tucker and Garrett, 1977) which will vary depending on vegetation type and nutrient status. The response in the near infra-red wavelengths (700 – 1300nm) are a function of the number and configuration of air spaces that form the internal leaf structure (Danson, 1995) and the moisture content of the plant tissue. The wavelengths between 1350 and 2500nm are also affected by internal leaf structure but more importantly are strongly affected by water concentration in the plant tissue. The thermal infra-red part of the electromagnetic spectrum is more sensitive to variations in soil/ground moisture (Davidson and Watson, 1995) as well as very small variations in topography which result in aspect related temperature variations.

Remote Sensing for archaeologists

The very subtle effects of buried archaeology on variations in ground surface vegetation, topsoil and topography are often not detectable using visible light alone. By using the infra-red part of the electromagnetic spectrum, our chances of detecting these subtle patterns are greatly enhanced. In addition, a combination of pre-dawn and mid-day thermal images can be used to determine variations in the thermal inertia of the ground surface (Tabbagh, 1976, 1979) which may be strongly affected by buried structures and/or moisture differences in the soil. Bewley *et al* (1999) highlight the considerable potential of thermal inertia mapping for detecting buried archaeology, although such studies have, so far, been limited.

A study by Powlesland *et al* (1997) compared single date multi-spectral imagery with data derived from a 10 year oblique aerial photography campaign. The study found that features which barely showed on vertical aerial photographs and were not present at all on oblique aerial photographs, were evident on the multi-spectral imagery. In addition, the ability to digitally enhance the multi-spectral data greatly improved the identification and interpretation of sites. They conclude that the usefulness of multi-spectral imagery for detecting sites invisible using conventional means is proven beyond doubt.

While the usefulness of multi-spectral imagery for detecting crop marks in agricultural land is undoubted, the range of conditions under which the technique has been tested is limited. One of the key objectives of this study was to test the usefulness of multi-spectral imagery in mobile biogenic dune sand as well as in biogenic sand-derived agricultural soils.

Data collection

The airborne data was acquired from specific coastal locations (figure 4) using the NERC ARSF (Airborne Remote Sensing Facility) Dornier 228-101 research aircraft flying at a height of 750m.

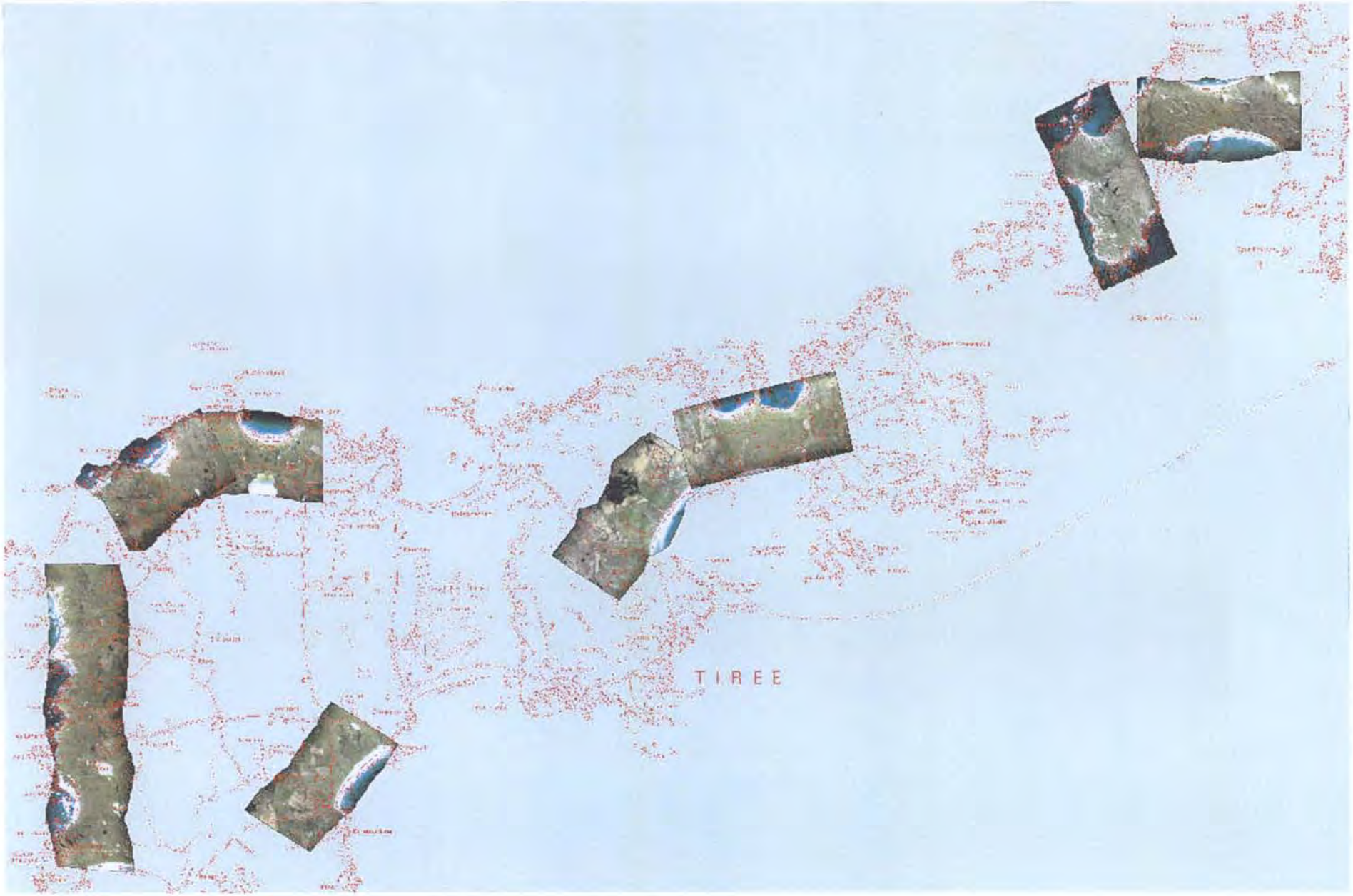


Figure 4 Airborne Remote Sensing images superimposed upon a map of Coll and Tiree.

Daedalus Airborne Thematic Mapper (ATM) data was collected on 6th of April 2002 at around solar noon and again pre-dawn. Both the daytime and night-time images had a spatial resolution of approximately 2m per pixel. The weather during data collection was near-perfect, with cloud-free and low-haze conditions. The resulting images are of excellent quality.

The ATM data-set samples reflectance in 11 spectral bands. Table 1 shows the spectral wavelength bands collected by the ATM.

Band Number	**Spectral wavelengths (μm)**	**Description**
1	0.435 – 0.45	Blue
2	0.45 – 0.52	Blue – green
3	0.52 – 0.605	Green
4	0.605 – 0.625	Red
5	0.63 – 0.69	Red
6	0.695 – 0.75	Near infra-red
7	0.76 – 0.9	Near infra-red
8	0.91 – 1.05	Near infra-red
9	1.55 – 1.75	Short wave infra-red
10	2.08 – 2.35	Short wave infra-red
11	8.5 - 13	Thermal infra-red

Table 1 Spectral bands and corresponding wavelengths for ATM data

Typically, band 1 is noisy and so not used as part of the data analysis. Bands 2, 3, 4 and 5 sample the visible blue, green and red parts of the spectrum respectively. Bands 6 to 10 sample in the near and short wave infra-red parts of the spectrum and are particularly sensitive to changes in vegetation type, moisture content and nutrient status. Band 11 samples in the thermal part of the spectrum and is directly related to ground surface temperature.

The night-time ATM data-set will only record data in the thermal part of the electromagnetic spectrum as this is the only band that doesn't rely on incoming solar radiation. Much of the night-time thermal image collected for this project was badly affected by image striping (figure 5). This has limited the usefulness of the images and ways of rectifying the striping are being sought.

Real-time GPS data was collected simultaneously with the image data. This allowed post flight image correction for geo-referencing purposes and to correct for the pitch and roll of the aircraft motion.

Coincident ground temperature measurements were taken for both the daytime and night-time flights. Ground temperature was measured at a depth of 2cm using an electronic temperature probe. The temperature was recorded at 11 different locations on Coll.

Data processing

The raw ATM data were received from the NERC ARSF unit in June 2002. The real-time GPS data was provided along with the raw data. The data was geo-corrected using AZGCORR program

(Azimuth Systems, 1998). A 50m Ordnance Survey Landform Panorama DTM (Digital Terrain Model) was also input so that topographic differences could be accounted for. The geo-corrected data was re-sampled to a 1m resolution using the nearest neighbour method.

Figure 5 Imaging striping on night-time thermal image

The geo-corrected output images from AZGCORR had a high Root Mean Square Error (RMSE) (a measure of the spatial difference between image locations and true locations). The high error is thought to be a result of the large distance between the GPS transmitting base station and the aircraft whilst flying over Coll and Tiree (ARSF, pers. comm). As a result, further geo-correction was undertaken using ERDAS Imagine software. The image data were corrected using ground control points taken directly from the Ordnance Survey Landline data. The resulting geo-corrected images had RMSE's of 3.2 and 2.7m for x and y respectively. For study areas where specific features of interest were located, further geocorrections were carried out on small image extracts to improve the geometric accuracy to +/- 1 pixel.

The output data is 8 bit for bands 1 to 10, which gives a grey-scale range from 0 to 255 and provides a relative scale of reflectance. Band 11 is output as 16 bit and is directly correlated with ground temperature. The night-time temperature images were subtracted from the day-time temperature images to give a crude measurement of thermal inertia.

The primary software used for image processing was Erdas Imagine version 8.2. The ATM images were enhanced using a histogram equalise stretch to improve contrast for visual interpretation. A number of different false colour composite images were created to determine the best band combinations for interpreting the images and highlighting differences in vegetation. A true colour composite was created by using bands 4, 3 and 2 in the red, green and blue display guns respectively. Bands 9, 7 and 3 were displayed in the red, green and blue guns respectively to create a false colour composite which maximised differences resulting from variations in vegetation type, structure moisture content and nutrient status. Band 11 was used on its own to create thermal infra-red images. This was

done for both the daytime and night-time data. In addition, a principal components analysis (PCA) was carried out to compress the 11 bands of data into 4 bands which contained 99.9% of the image variation. A colour composite of PCA bands 1, 2, and 4, as well as a grey-scale single PCA band 4 image were also used for interpretation.

Image interpretation

The broad range of possible archaeological sites that can be detected using multi-spectral imagery means that there is no possibility of using an automated extraction procedure from the imagery for their identification. Sites may vary from small-scale features to large scale crop-markings. Indeed, Powlesland *et al* (1997) also noted that '*any idea that the archaeological component could be quickly extracted through a classification scheme had to be quickly discounted*'. The extraction of potential features is only achievable through an interactive and iterative process. There is still no better, nor more sophisticated image interpreter than the human eye.

For interpretation of the images, a 4, 3, 2 band true colour composite of the overall area to be examined was displayed in a large window. Small extract windows were then linked to this, in order to display 'zoomed-in' areas for: the 9, 7, 3 band colour composite; the daytime thermal image; the night-time thermal images; the PCA bands 4, 2, 1 image; and the PCA band 4 image. Images were then systematically scanned by two operators (one a specialist in remote sensing and the other an archaeologist) working independently. Potential features were entered into a Microsoft Access database with feature co-ordinates, description, priority for field visit and image extracts for the feature (figure 6).

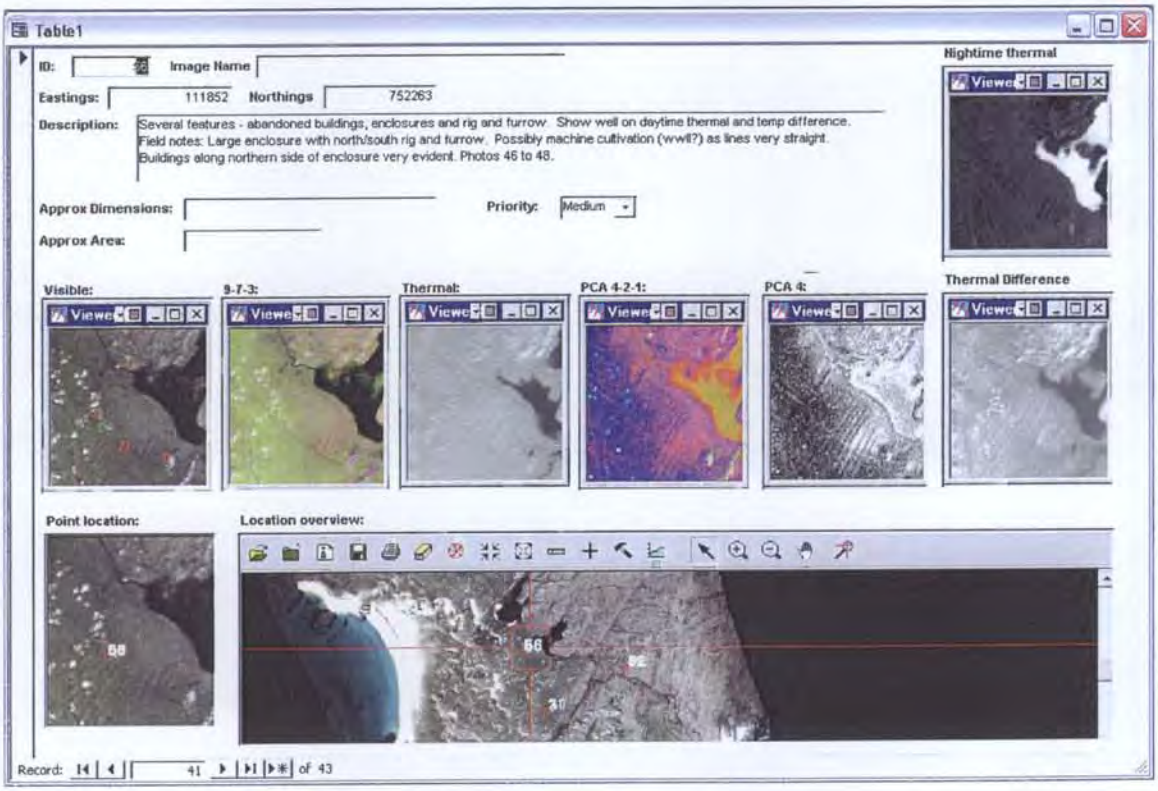


Figure 6 Example entry in the feature database derived from image interpretation

Table 2 lists the main land cover types found in Coll and Tiree and their corresponding appearance for the two colour composite and thermal images, along with small image extract examples. It should be noted that the differences in daytime and night-time temperatures are relative rather than absolute. For example, during the day-time, water is relatively colder than the land surface whereas at night, water is relatively warmer in comparison to the land surface.

Land cover type	Bands 4, 3, 2 true colour composite	Bands 9, 7, 3 false colour composite	Daytime thermal	Night-time thermal
Shallow Water	Blue/grey	Blue	Black (cold)	Light grey (warm)
Deep water or peaty water	Black	Black	Black (cold)	Light grey (warm)
Wet sand	White	Light blue	Medium grey	Light grey (warm)
Dry sand	White	Light pink	Light grey (warm)	Dark grey (cold)
Bare soil	Light brown	Dark pink/purple	Light grey (warm)	Dark grey (cold)
Sparse vegetation	Light green/brown	Light pink/purple	Light grey (warm)	Dark grey (cold)
Improved/lush vegetation	Dark green	Bright green	Light grey (warm)	Dark grey (cold)
Areas of peaty soil	Light brown	Bright pink/peach	Light grey (warm)	Dark grey (cold)
Occupied Buildings	White	Dark blue	White (hot)	Light grey (warm)
Unoccupied buildings	Grey	Dark blue	Medium grey (cool)	Medium to dark grey (cool)
Bare rock	Grey/light brown	Bright pink/purple	Dark grey (cold)	Light grey (warm)

Table 2 Land cover types and their interpretation

Field surveys

After the images had been scanned, two visits were made to the islands in order to check the interpretation for features identified in the images. The Access database was used to prioritise those sites that needed to be visited. Printouts from the database were made of the selected sites, and these were used in the field. Co-ordinates were taken from the database and entered as waypoints onto a handheld Garmin GPS (Global Positioning System). The GPS was used to navigate to the sites and was found to be very accurate. The site visits were undertaken by the two authors and by Dr. Richard Tipping of the University of Stirling. Field notes were made regarding the sites, and these notes helped with future sessions spent analysing the image data.

With experience, the ability to distinguish between possible archaeological sites and natural features was greatly enhanced. The first images to be analysed, and the first sites to be checked in the field, were those of Coll. Numerous anomalies on the images had been identified as potential archaeological sites. The field visits showed that other factors had caused some of the anomalies. Most frequently, it was outcrops of bedrock or small topographic features which had led to the misinterpretation. With experience, it was possible to identify features of this type by comparing images of various band combinations. It was noted, however, that the collection of LIDAR data at the same time as the other Remote Sensing data would have avoided many of the misinterpretations.

Examples of images

In order to give an idea of the resolution of the images, the following pages illustrate complete runs of data. This is followed by 'zoomed in' images illustrating particular site types. It should be noted that the quality of the printed images is not as good as when viewing the images on the screen. Loss of quality has been caused by converting the data into JPEG format, and by the process of printing. However, the printed examples display the range of information and site types detectable through this technique.

Figures 7 - 9 show examples of different band combination of data collected for the western end of Coll. The band combinations illustrated are 4, 3, 2 true colour composite (figure 7); 9, 7, 3 false colour composite (figure 8); and daytime thermal image (figure 9).

Figures 10 – 13 show examples of different band combinations of the data collected for the western coast of Tiree. The band combinations illustrated are 4, 3, 2 true colour composite (figure 10); 9, 7, 3 false colour composite (figure 11); daytime thermal image (figure 12); and night-time thermal image (figure 13).

Examples of sites located through Airborne Remote Sensing

Figures 14 – 23 show examples of site types identified during the analysis. This is not a complete list of the sites, but is intended to highlight the potential of the technique. Further interpretation of the images is given in the Discussion section, below. The examples demonstrate that by examining several images, it is possible to build up a more accurate idea of the type and nature of the sites located.

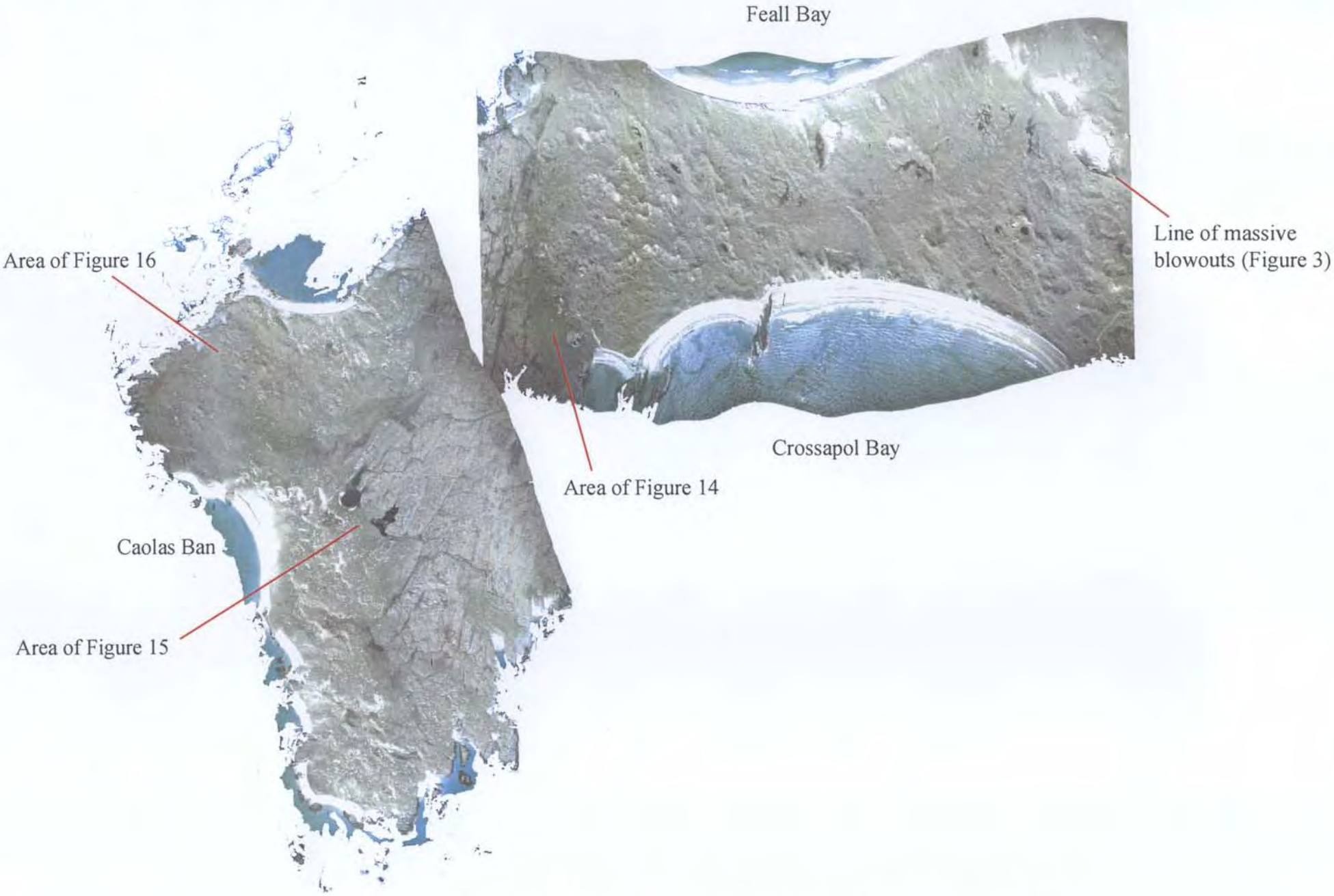


Figure 7 Bands 4, 3, 2 true colour composite image of the western end of Coll

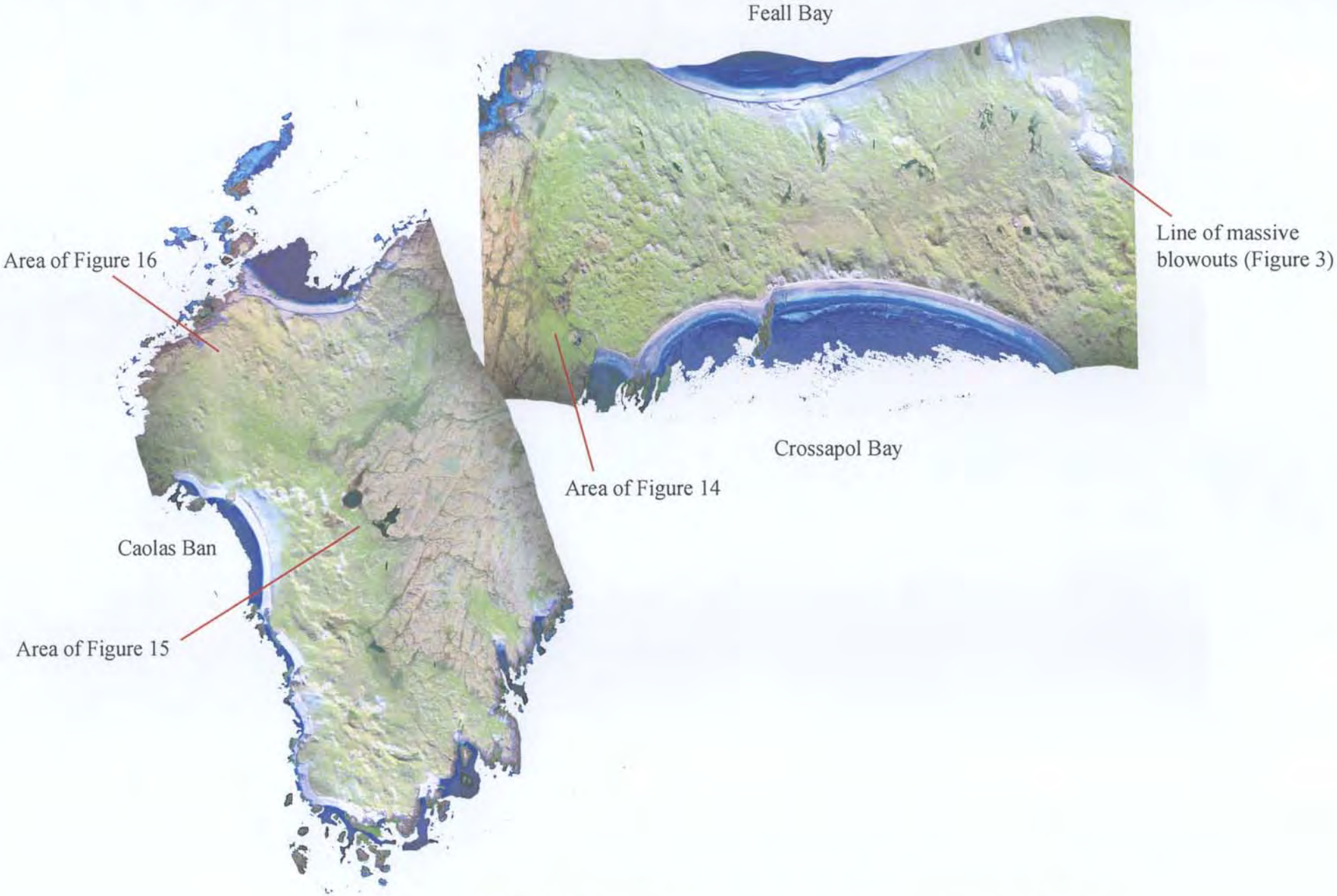


Figure 8 Bands 9, 7, 3 false colour composite image of the western end of Coll

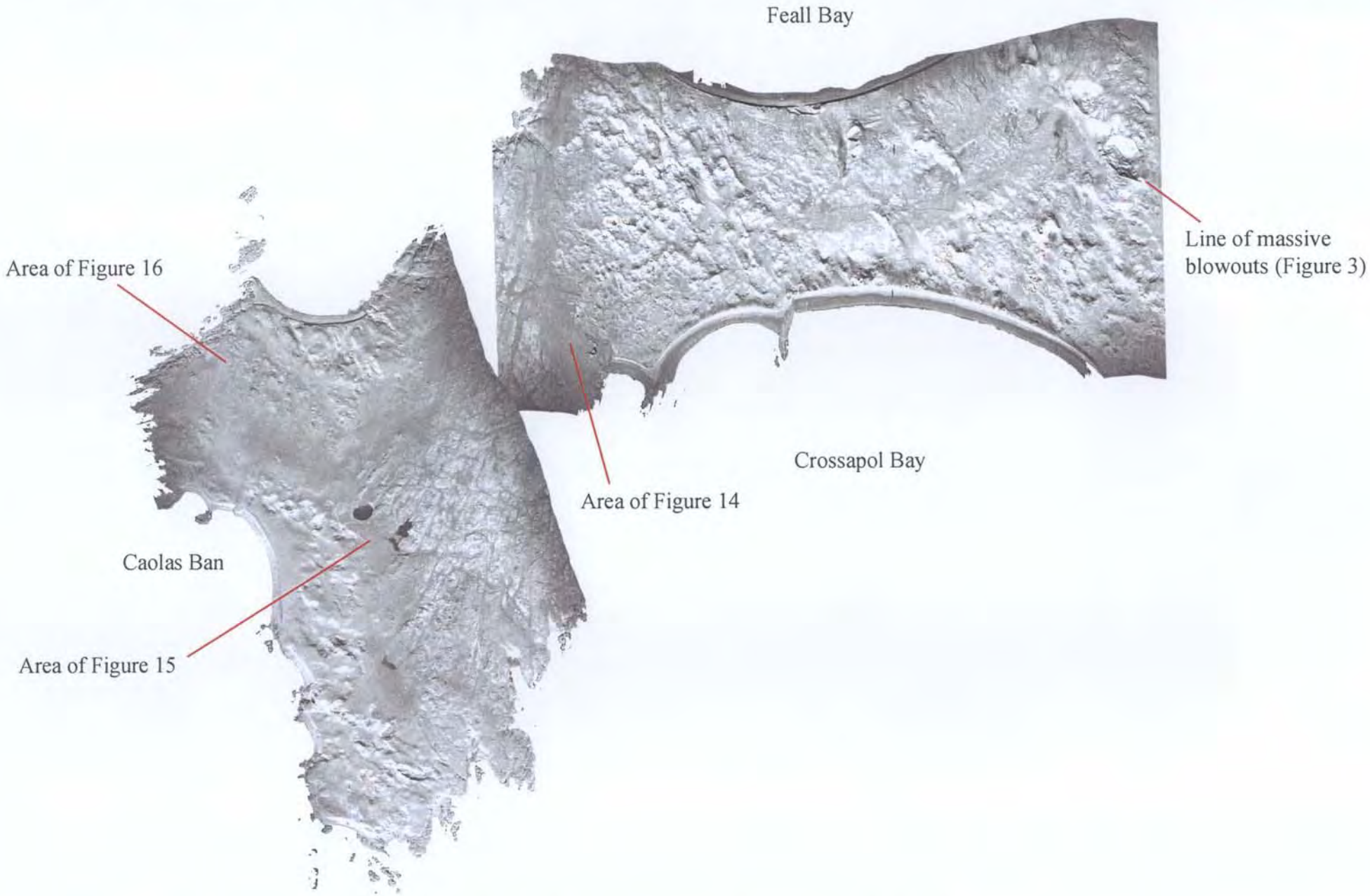


Figure 9 daytime thermal image of the western end of Coll

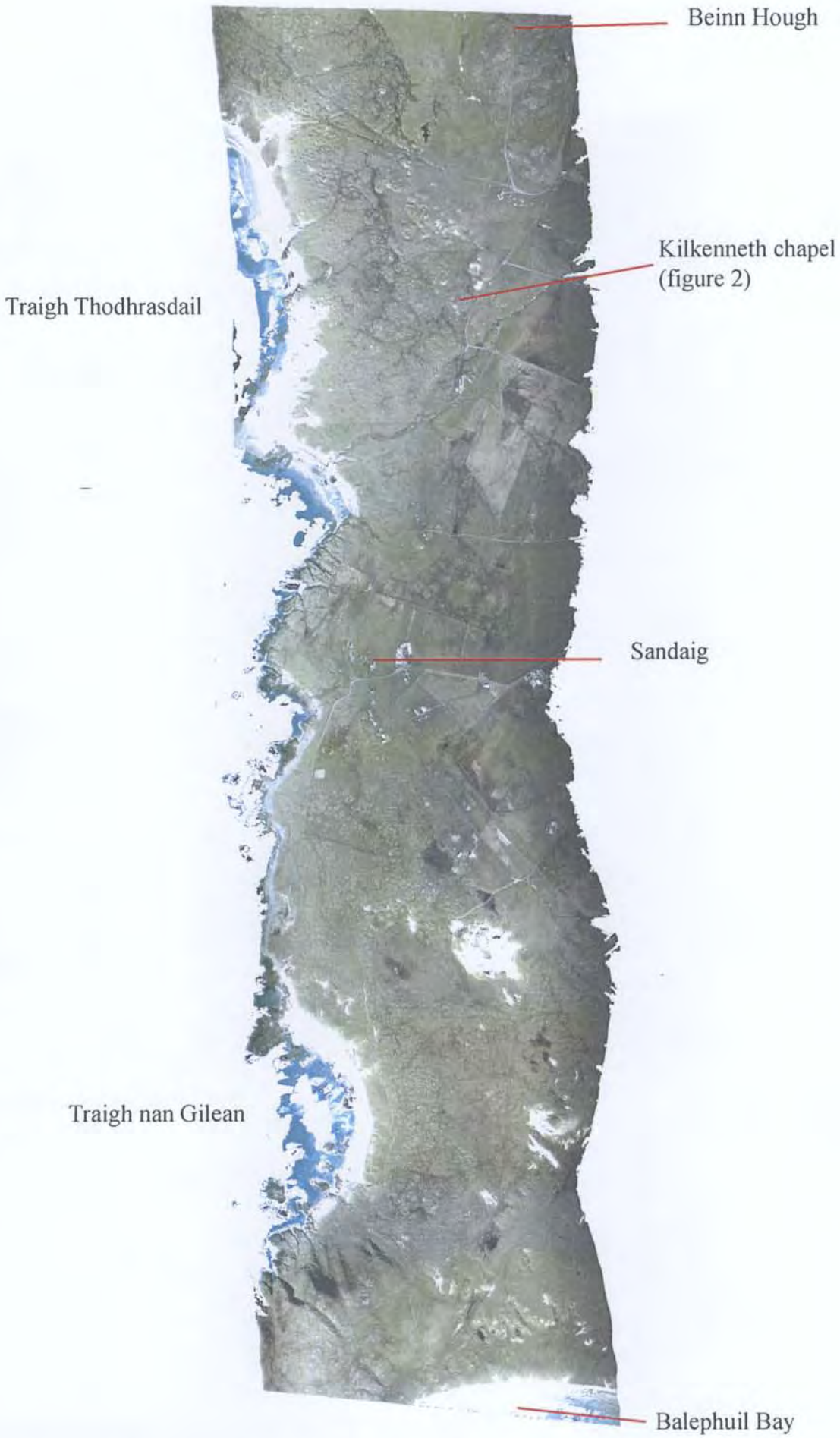


Figure 10 Bands 4, 3, 2 true colour composite image of the western coast of Tiree

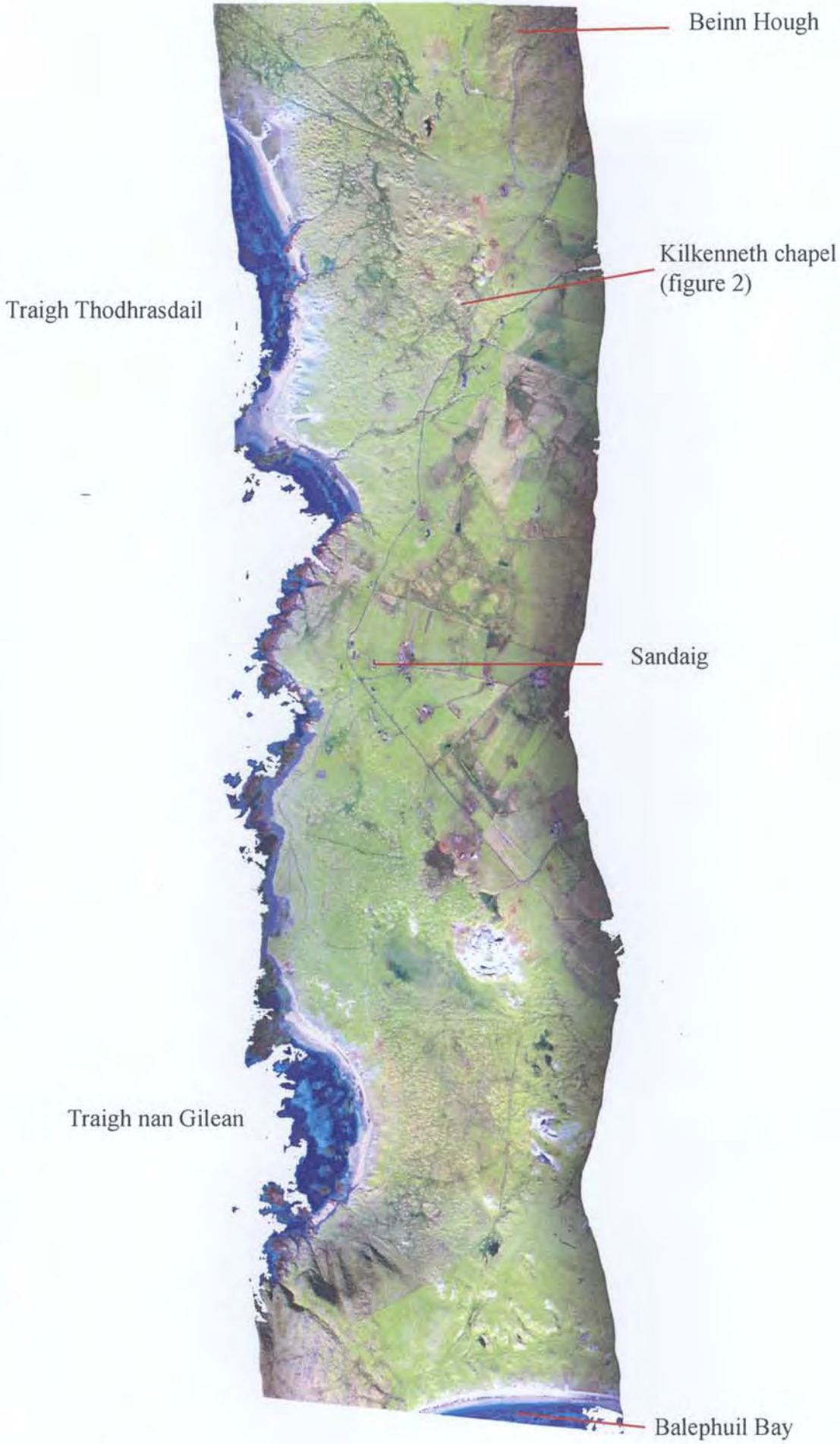


Figure 11 Bands 9, 7, 3 false colour composite image of the western coast of Tiree

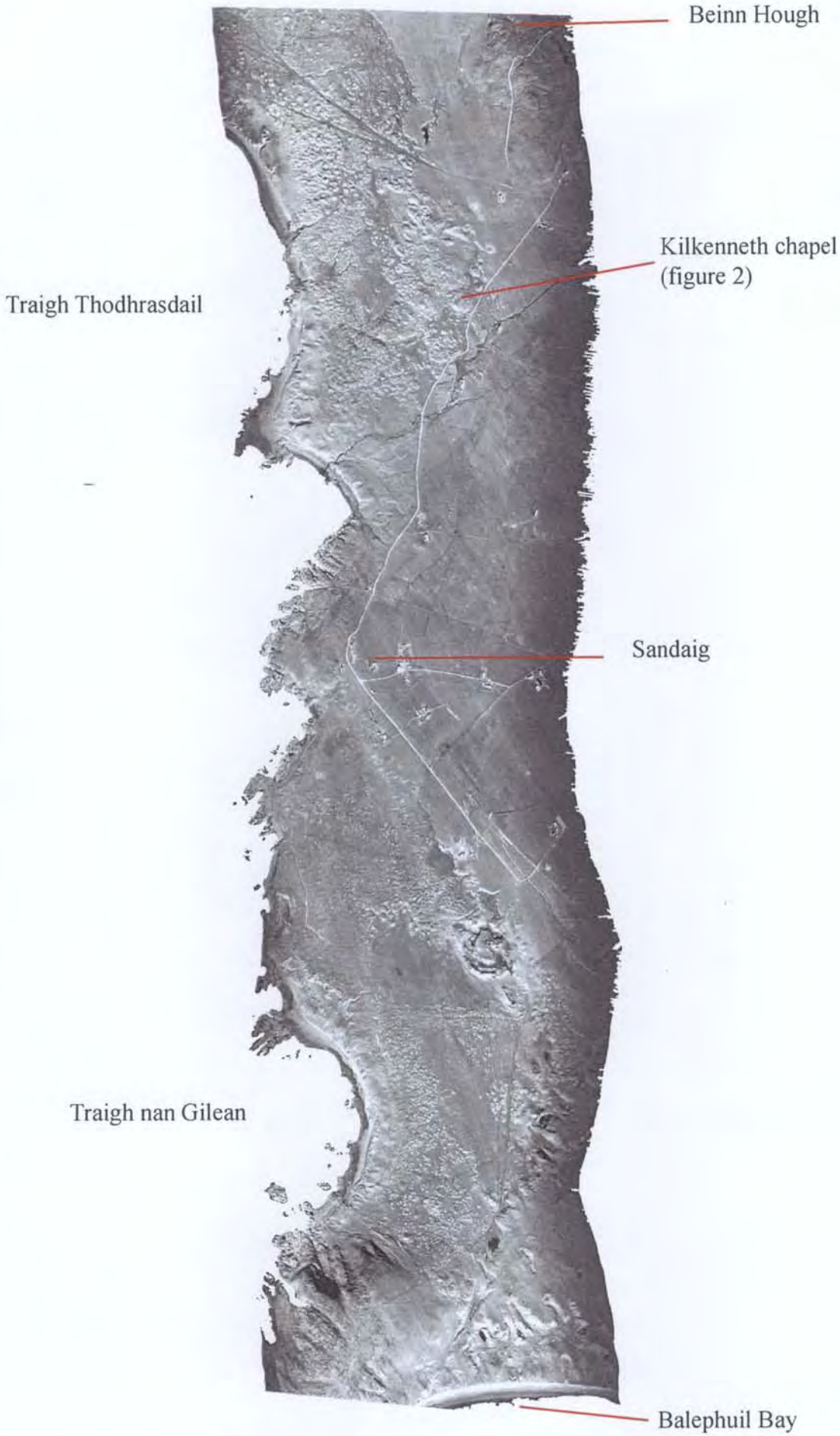


Figure 12 Daytime thermal image of the western coast of Tiree

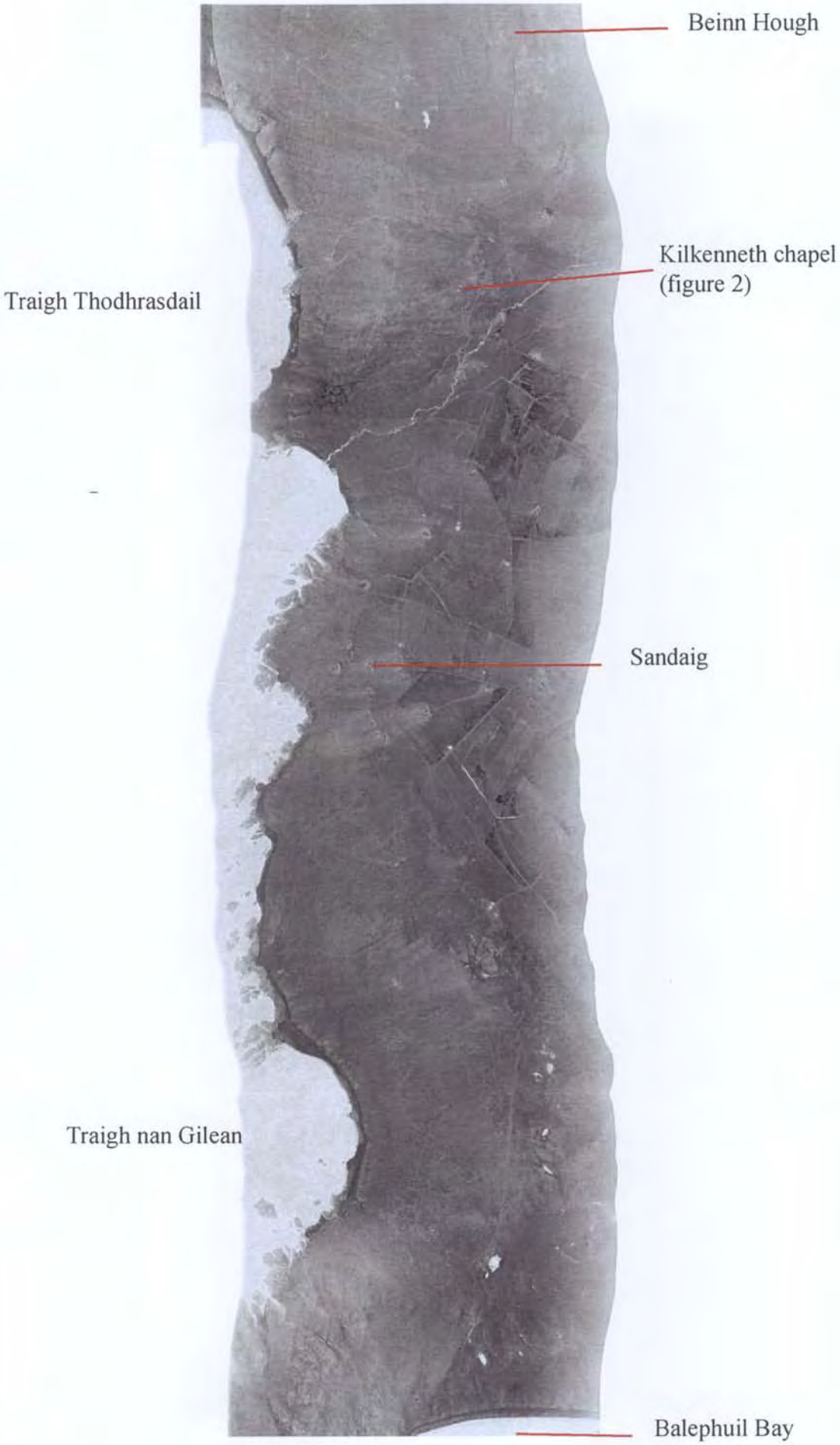
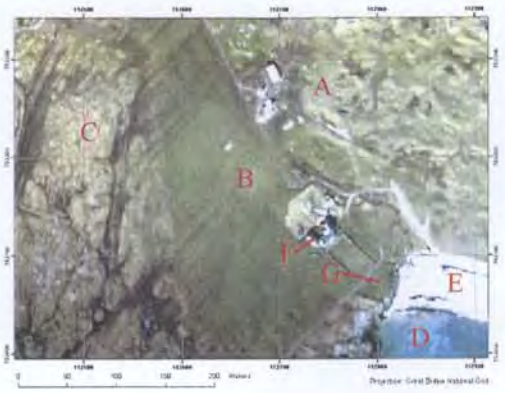
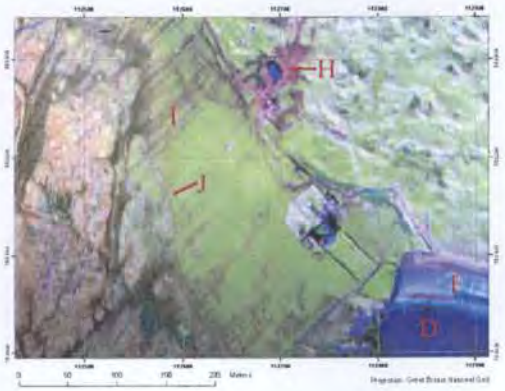


Figure 13 Night-time thermal image of the western coast of Tiree

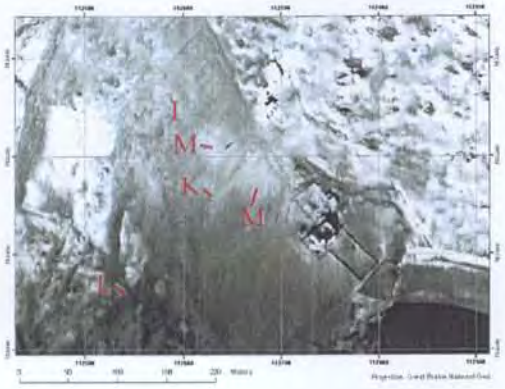
Figure 14
Possible chapel, Crossapol, Coll 112650, 753200



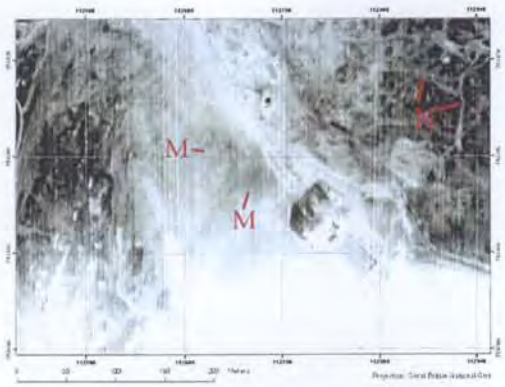
Bands 4, 3, 2 - true colour composite
The image shows an area of improved land (B) sandwiched between dunes (A) to the east and a boggy area (C) to the west. The sea (D) and a beach (E) can also be seen. The farmhouse (F) is called Crossapol, and there is a small graveyard (G) to the south of the house. A chapel is reported to have once existed within this locality.



Bands 9, 7, 3 - false colour composite
The distinction between the dunes, improved land and wetter area is clearly visible. Tracks and trampling (H) around some farm buildings are also evident. Cultivation or drainage lines (I) run across the improved field, and a wall (J) appears to run NW-SE across these. It is not easy to distinguish between the sea (D) and the beach (E) in this image.

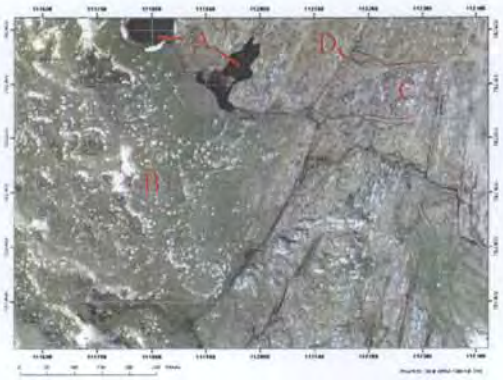


Daytime thermal
A buried wall, (K) can be seen running NE-SW across the area of improved land. It is orientated in the same direction as the cultivation or drainage lines (I). The wall appears to continue into the area of boggy ground (L). On either side of the wall are two patches of disturbed ground (M), showing up as warmer areas.

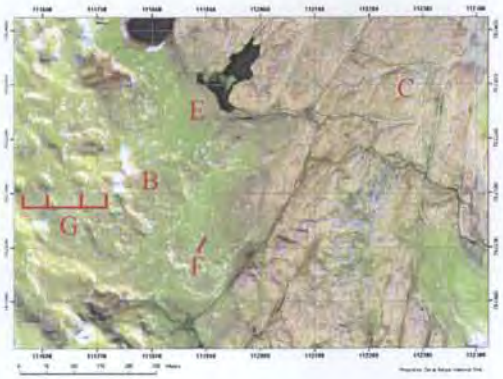


Night-time thermal
The two areas of disturbed ground (M) appear colder than the surrounding land. Some tracks (N), not visible in other images, are apparent in the night-time thermal image.

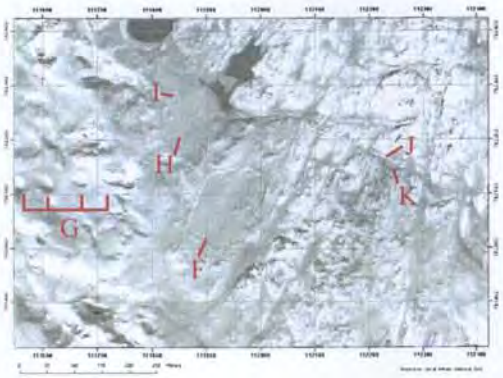
Figure 15
Enclosures, Caolas, Coll 111900, 752200



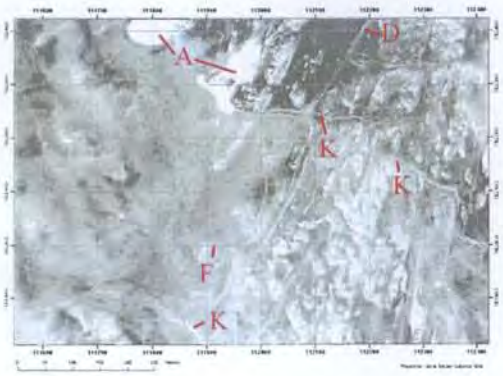
Bands 4, 3, 2 - true colour composite
This image shows a large area; each gridline is at 100m spacing. Two small lochs (A) are visible, with an extensive area of dunes in the west (B) and an area of wetter ground in the north and east (C). A drainage ditch is evident at D.



Bands 9, 7, 3 - false colour composite
The differentiation between the area of dunes (B) and the wetter ground (C) becomes clearer in the 9,7,3 image. Between them lies an area of improved grassland (E). An enclosure (F) is visible within this. Arable ridging is visible within this enclosure. A line of blowouts or craters (G) runs east-west at the western edge of the image.

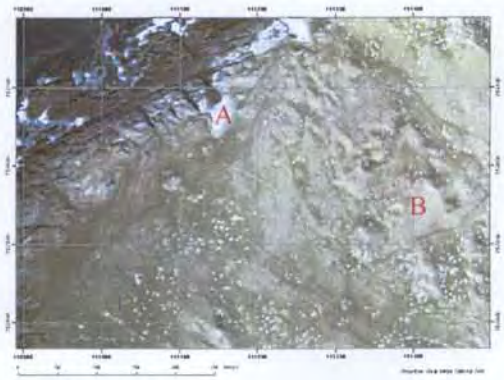


Daytime thermal
The large enclosure (F) is clearly visible in the daytime thermal image. A second enclosure (H) can be seen to the north east. Arable ridging is also visible within this enclosure. On the north-eastern side of the enclosure, a number of structures are visible. One structure (I) appears to be a dwelling. These structures are more apparent when the scale of the image is increased. The line of craters (G) are clearly visible. A buried wall (J) can be seen running to the north of a watercourse (K).

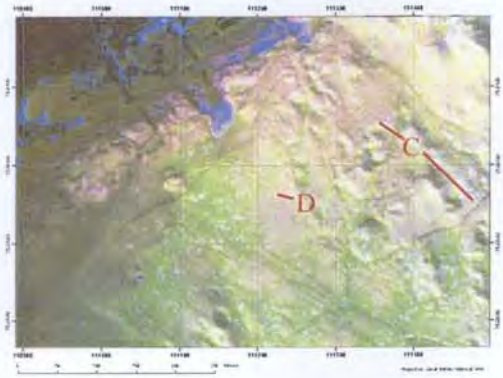


Night-time thermal
The night-time thermal image helps to determine the position of water, which appears warmer (whiter) than the surrounding features. The two small lochs (A) are easily visible, as is the main drainage channel (D). Other streams and ditches (K) are apparent, and the night-time thermal image helps to avoid confusion with tracks. The larger enclosure (F) is also visible on this image.

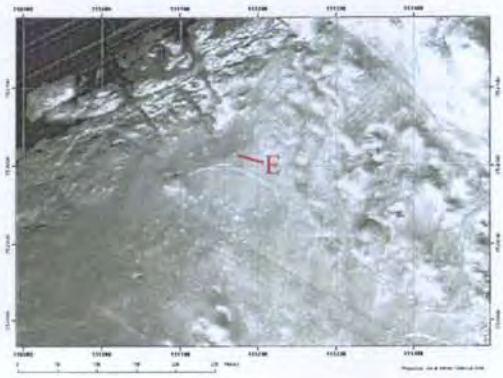
Figure 16
Cairns, Caolas, Coll 111180, 753000



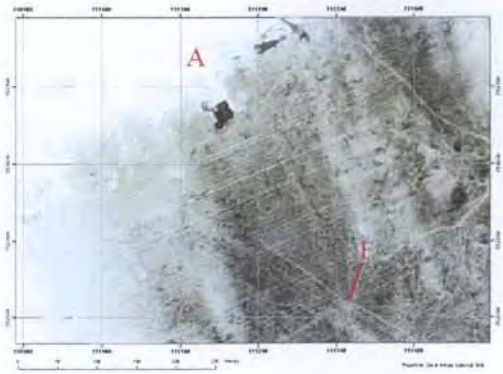
Bands 4, 3, 2 - true colour composite
The image shows a large area; the gridlines are spaced 100m apart. The rocky coastline (A) and an extensive area of dune (B) are visible. The entire image is peppered with white specks, indicating areas of bare sand showing up between areas of vegetation.



Bands 9, 7, 3 - false colour composite
A pattern of abandoned fields is clearly evident in the 9, 7, 3 image. Agricultural ridging is apparent at C, and a large enclosed field (D) is also visible. Further ridging can be seen around this enclosure. The image is from the edge of the data collected and the resolution is poor in the western area.



Daytime thermal
The daytime thermal image also indicates areas of cultivation. Due to the scale, the image does not show clearly a group of small cairns at E. These become apparent when the image is viewed at a larger scale.

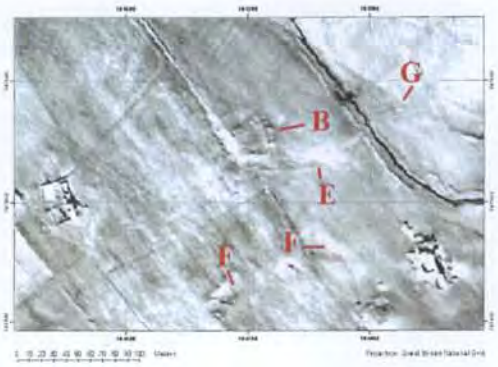


Night-time thermal
The night-time thermal image is badly affected by stripiness. It mainly shows the coast (A) and several tracks. The star shape at F is caused by the tracks and trails coming together at a gate.

Figure 17
Buried farmstead, Kirkapol, Tiree 104700, 747500

Bands 4, 3, 2 - true colour composite
The image shows an area of improved land and two farms (A). The First Edition Ordnance Survey map shows a ruined farmstead at B. The farmstead is visible as a vague outline on this image. Arable ridging can be seen at C, running parallel to the existing field boundary, and at D, where it does not respect the present boundaries.

Bands 9, 7, 3 - false colour composite
The false colour composite detects vegetational changes around the area of farmstead B and individual buildings can be seen. A track or road (E), also visible on the First Edition Ordnance survey map, can be seen to the south of the farmstead. To the west, this track passes close to the Kirkapol chapels (figure 19). Former deflation hollows (F) have recovered and are grassed over.



Daytime thermal
The deflation hollows (F) are clearly evident on the daytime thermal image, as is part of the former road (E). It is, however, the farmstead (B) that shows up most clearly. Individual buildings laid out around a yard can be seen. This layout corresponds exactly with the First Edition Ordnance Survey map. There appears to be a rectangular structure at G.

Night-time thermal
The image is badly affected by striping, and is thus difficult to interpret. The different vegetation in the two fields is very obvious at night, this difference was not apparent on the daytime thermal image. The track (E) is visible where it passes below the westerly of the two fields, showing up better than in any of the other images. Farmstead B is visible, but is not clear. Near it are two cold spots (H), which may represent buried stone.

Figure 18
Field boundary, Kirkapol, Tiree 104450, 747500

Bands 4, 3, 2 - true colour composite
The central field (A) had recently been ploughed when the image data were collected. To the east of the field there is grazing land, to the west, a deep ditch (B) separates the field from a boggy area cut by numerous drainage ditches.

Bands 9, 7, 3 - false colour composite
The difference in vegetation and soil type becomes clearer in this image. The recently ploughed area is purple, while the wetter and boggier ground to the west is more red. Irrigation ditches (C) can be seen leading into central ditch B. Ditches containing water appear black. The ditches to the east of the main ditch do not respect the modern field boundary, and are evidence of previous drainage activities. A wall (D) can be seen running NW-SE to the main ditch. To the east of the ditch, a drainage ditch (E) replaces the course of the wall. It would appear that the area to the west of the main ditch was formerly cultivated, but that the land has now become too wet.

Daytime thermal
The limit of the area of ploughing in field A is again clearly visible. An old boundary (F) originates from the farmhouse and continues a small distance northwards. It then turns to the west (G). It lines up exactly with ditch E and wall D. This boundary is not clearly visible on any of the other images.

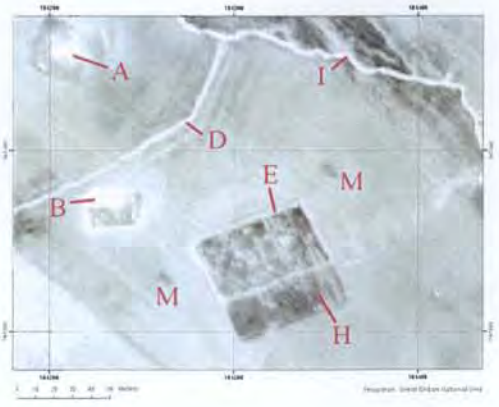
Night-time thermal
The limit of ploughing within field A is visible, as is a second enclosure (H) to the east. The occupied farmhouse (I) shows up as a relatively hotter area on the image, as does water in ditch B and the other irrigation channels (C). This helps us to determine which of the ditches are currently in use.

Figure 19
Kirkapol chapels, Tiree 104300, 747250

Bands 4, 3, 2 - true colour composite
The image shows the two chapels at Kirkapol. Chapel A is NMRS NM04NW1 and chapel B is NMRS NM04NW2. A track (C) leads from one chapel to the other, crossing a drainage ditch (D). Also visible is the later graveyard (E), claimed to have once held a third chapel (NMRS NM04NW9).

Bands 9, 7, 3 - false colour composite
The land around chapel B and the graveyard (E) is improved. To the north of ditch D, the land quality is poorer. The remains of a farmstead (F) are evident to the west of the graveyard, and immediately to the south of this structure there is an old road (G). This is the same track that is evident in figure 17. A set of parallel walls (H) pass across the improved land and appear to continue to the north of a stream (I) and into the poorer land.

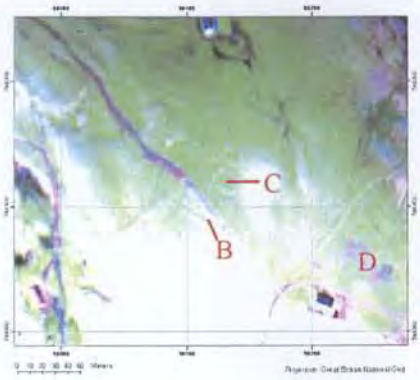
Daytime thermal
An extension (H) to the recent graveyard (E) is clearly visible in the daytime thermal image. Farmstead (F) and the track (G) are also clear. Ditch (D) has been cleared and the spoil has been dumped to the north (J) on the western side of path C and to the south (K) on the eastern side of the path. A buried wall (L) is clearly visible extending from chapel B to the graveyard (E).



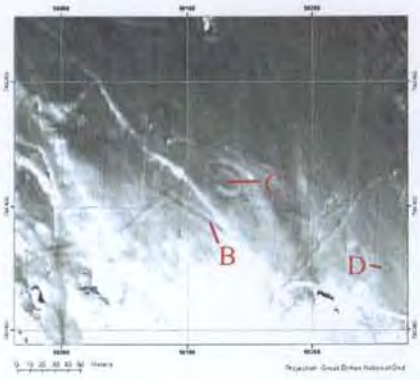
Night-time thermal
The two chapels (A & B) are clearly visible, as is ditch D and the stream (I). The more recent graveyard (E) and its extension (H) are also apparent. Two dark spots (M) are caused by an exposure of bare sand.

Figure 20
Enclosure, Barna sgeir, Tiree 98150, 748110

Bands 4, 3, 2 - true colour composite
The image shows an area of improved grassland close to the coast. A T junction of fences meets at (A). Below this, a rectangular enclosure (B) with the remains of a building in its north-eastern corner (C) is faintly visible. This structure does not appear on local or national records. The vegetation is broken at D by a series of regularly sized marks.



Bands 9, 7, 3 - false colour composite
The breaks in the vegetation at D are far clearer in this image. They are circular, with some having a very distinct edge. Features similar to these were seen throughout the survey area, often in areas of dune and far from modern habitation sites. Their significance is detailed in the Discussion, below. The enclosure and structure (B & C) are far more pronounced in this image.

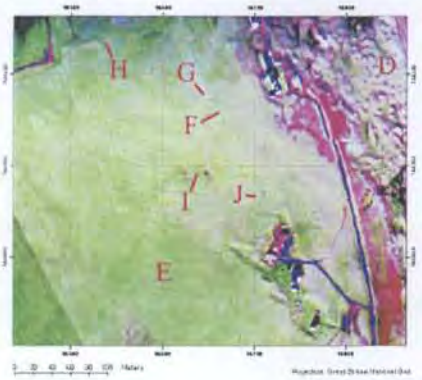


Daytime thermal
The daytime thermal image clearly shows enclosure B and structure C. The full extent of the enclosure is visible. One of the circular marks (D) shows up well on this image.

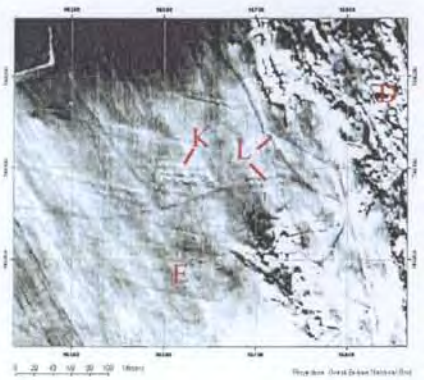
Night-time thermal
The enclosure (B) is barely visible on the night-time thermal image, probably indicating that it is not constructed of stone. There is a faint trace of C, so possibly some stone remains within this structure.

Figure 21
Possible chapel site, A'Chrois, Tiree 96700, 748100

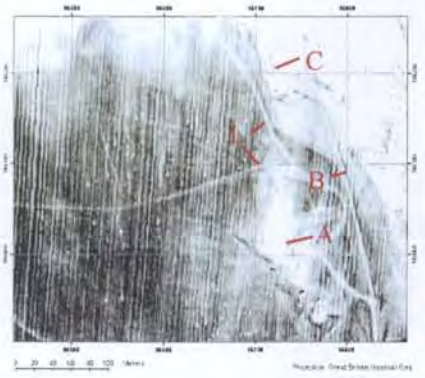
Bands 4, 3, 2 - true colour composite
The farm (A) is named A' Chrois, and the area is recorded as once having held a chapel. The field around the farm is used for grazing and few features are discernible within it. A rough road (B) can be seen leading to a line of crofts (C) to the north. A track branches off from this road to A' Chrois.



Bands 9, 7, 3 - false colour composite
The improved grassland shows up in stark contrast to the unimproved dunes (D) to the east. Horizontal cultivation ridges (E) are visible running WNW-ESE. A buried field boundary running NW from the farm can be seen at F. This is clearly cut by one of the cultivation ridges at G. The wall turns to the east at H. In the middle of the field, an area of disturbed ground (I) is visible. Close to the farm, there is an enclosure at J.

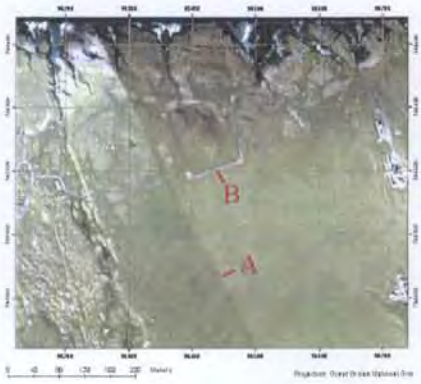


Daytime thermal
There appears to be a structure close to the area of disturbed ground noted at I. It is a rectangular enclosure (K) aligned E-W. The agricultural ridging (E) is pronounced and can be seen to have a different alignment from this enclosure. This area was subjected to GPR survey (Profile 4). The area of dunes (D) is unmistakable in this image. A set of tracks cross the field at L.

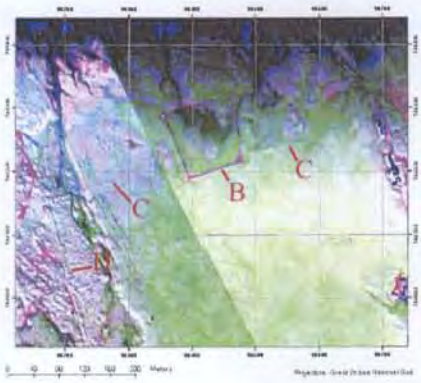


Night-time thermal
The night-time thermal image is badly affected by striping. The position of the buildings (A & C) and road (B) is clear. Also easily discernible are the tracks (L) which cross the field.

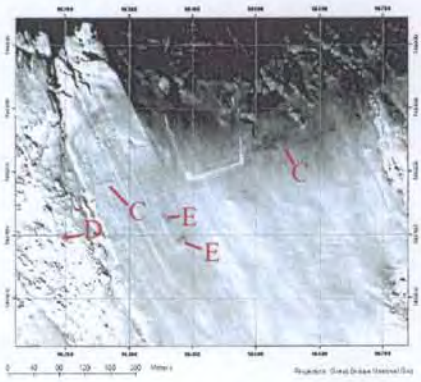
Figure 22
Buried wall, A' Chrois, Tiree 96200, 748150



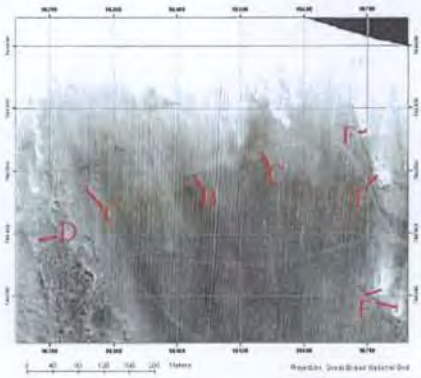
Bands 4, 3, 2 - true colour composite
The image is of the same area as figure 21, but is centred slightly to the west. A north-south wire fence (A) divides two areas of grazing land. A second wire fence (B) forms and enclosure for a bull. The western edge of the image is taken up by dunes.



Bands 9, 7, 3 - false colour composite
The line of wire fence (B) shows up very clearly, due to their being less vegetation around the edges of the enclosure. This may be due to the activities of the bull. A buried wall (C), aligned east-west, passes below the enclosure and into the dunes. It then returns to the south (D). Sand has drifted over the wall within the dunes and is forming a series of mounds along its course.



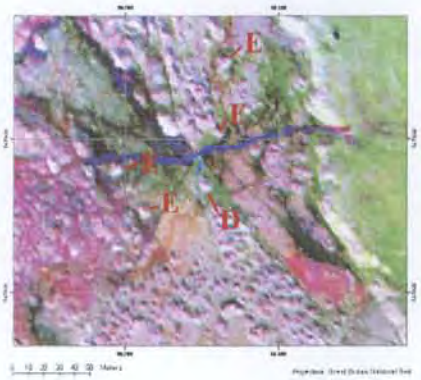
Daytime thermal
The line of the buried walls (C & D) are visible on the daytime thermal image. In addition, several humps (E) are evident as cold spots within the area of improved grassland. Further work is needed to establish whether these are man-made features or not.



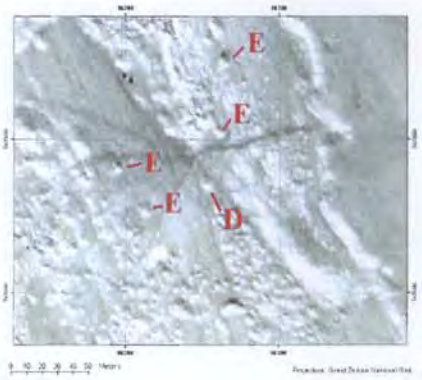
Night-time thermal
The night-time thermal image is badly affected by striping. The buildings show up as hot spots (F) and the enclosure for the bull (B) is also visible. More importantly, the line of the buried walls (C & D) can be seen. This indicates that with improved image quality, it would be possible to identify buried features on the night-time thermal images.

Figure 23
Cairn, A' Chrois, Tiree 96250, 747870

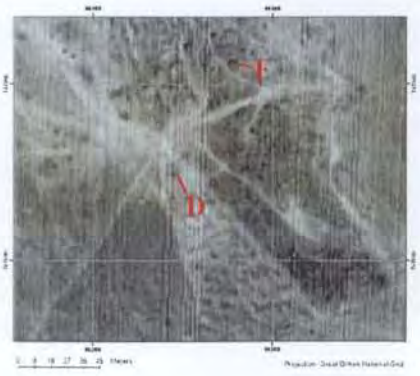
Bands 4, 3, 2 - true colour composite
The image shows the boundary between improved grassland (A) and an area of encroaching dunes (B). Areas of bare sand (C) show up white against the green vegetation. A cairn, (D), confirmed by a field visit and GPR survey (Profiles 1-3), is not clearly visible in this image.



Bands 9, 7, 3 - false colour composite
The difference between the improved land to the east and the dunes is very clear. The cairn (D) sits within an island of better vegetation. As it is stone built, it does not support this better vegetation and appears pink in the image. Other potentially interesting features (E) surround the cairn.



Daytime thermal
The cairn (D) shows up warmer than much of the surrounding area, as do the other potentially interesting features (E).



Night-time thermal
The cairn (D) is darker than the surrounding area. This indicates that it is colder due to it being stone-built. The other possible features (E) are much less clear, although F also appears much darker, and could also be stone built. Feature F, however, is not uniformly dark, the north side appearing colder than the south (see Discussion).

Ground Penetrating Radar Survey, Coll and Tiree

Alistair Rennie and Jim Hansom

Principles

Ground-Penetrating Radar (GPR) is comparable to other geophysical reflection techniques such as Seismic and Sonar. GPR emits a short pulse of high frequency electromagnetic energy, which passes into the ground (Davis & Annan 1989). The signal path is dependant on the high frequency dielectric properties of the ground. Stratigraphic layers and archaeology (via isolated objects) with differing dielectric properties will reflect the radar signal to differing extents. The reflected signals are stored, manipulated and interpreted to account for the dielectric properties of tomographical profiles. The time taken for the radar wave to pass into the ground, hit a reflector and return to the surface is a function of depth, and is known as the two-way travel time. Using an approximate speed for the sound wave (dependent on the sediment type and water conditions) the two-way travel times is used as an analogue for depth.

Procedures

The archaeological prospecting was carried out using a Pulse Ekko 1000 GPR system loaned from NERC. The system has a variety of antenna configurations, however during the field period the radar system was deployed in a reflection mode using fixed off-set reflection profiling. Target features illustrated within this report were subsurface archaeological features (approx. 0.5-2m in height and length) extending to a depth of approx. 2-3m. For these reasons the 225MHz antenna was used to achieve the target depth and resolve features of the appropriate size. Experiments were also undertaken with the 450 MHz antennae, but, as expected, it was found that the penetration was too shallow with this set up. The system set-up was taken from levels advised in the users manual (Sensors & Software 1999). These are conservative 'rule of thumb' guidelines, which when recalculated and checked, proved to be adequate.

Figure 24 GPR equipment in use on Coll

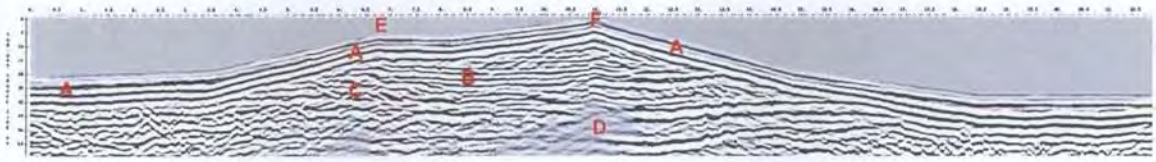
Archaeological targets were isolated by remote-sensing techniques and then located on the ground using a survey grid over the targets. The initial GPR profiles highlighted areas of interest and disturbance and were then focussed upon in increasing detail. The tomographical profiles presented in Profiles 1-6 are a selection of some of the surveys. Although only initial data processing has been applied, the main features of the internal architecture has been accounted for. This is especially evident with the cairn and graveyard.

Preliminary interpretation

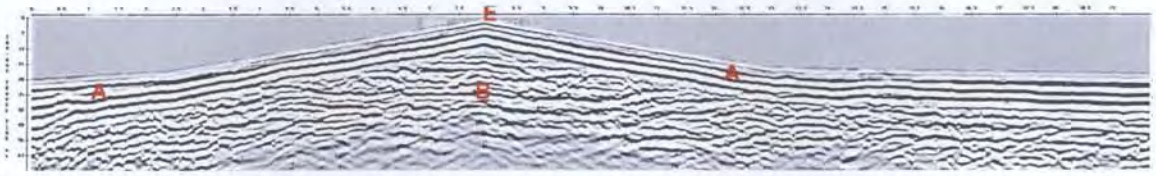
Cairn at A'Chrois, Tiree (96250E, 747870N) (see figure 23)

The Cairn is ellipsoidal in shape, covered in grass with isolated stones showing. Profile 1 passes over the long axis and is intersected at 11m and 7m by Profiles 2 and 3 respectively. Generally the first ground parallel reflectors (A) are a function of the air and ground waves and can be ignored. Below these reflectors the internal architecture can be seen, including horizontal reflectors (B), disturbed ground (C) and a strong central reflector (G). Signal attenuation was noted at point D, this was below the highest point of the cairn, and subsequently the area where the signal had to travel further. The profile seen is consistent with the internal architecture of a stone-built cairn surrounding a strong central reflector of an unknown nature, possibly a slab or slabs.

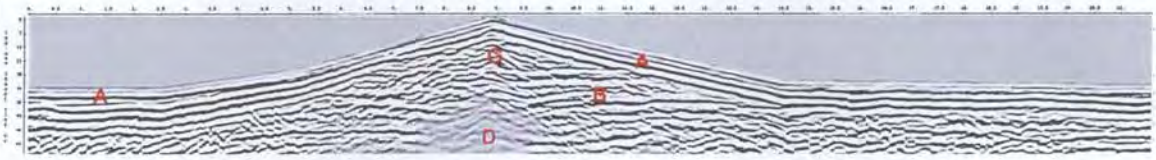
Profile 1; transect T0022b, The internal structure of the Cairn via the long axis.



Profile 2; transect T0024b, The internal structure of the Cairn across the lower crest (7m).



Profile 3; transect T0023b, The internal structure of the Cairn across the highest crest (11m)



Point A: Air and Initial Ground waves can be ignored,

Point B: Sub horizontal reflectors continue across the cairn,

Point C: Area of disturbance,

Point D: Signal attenuation,

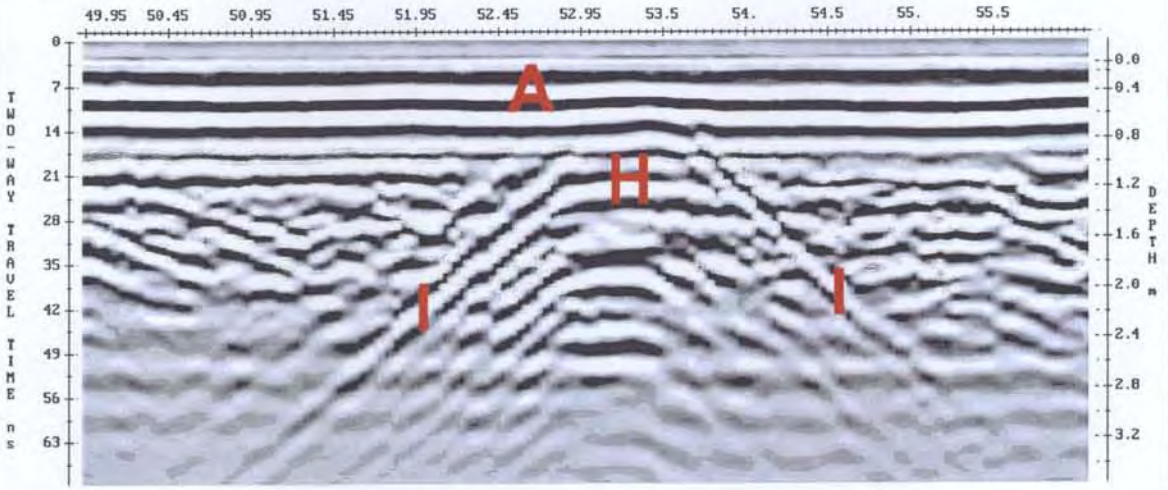
Point E & F: location of profiles 2 and 3,

Point G: Strong central reflector

Grave at A'Chrois, Tiree (96595E, 748125N) (see figure 21)

The target is a horizontally topped structure located in a field behind A'Chrois. Profile 4 (presented below) is comparable with other reflectors found in the immediate vicinity, whose juxtaposition suggested alignment in two parallel rows. Further investigations showed these targets to be non-continuous targets approximately 2m in length and 0.5m in width. The profile has not yet been topographically adjusted as the surface above the target was flat. As with the previous profiles the first ground parallel reflectors are a function of the air and ground waves and can be ignored. Below these, 0.5m horizontal reflectors are present. The radar cone intersects the reflectors as it approaches from an angle and this produces the steeply sloping rising and falling limbs (Point I) on either side. This pattern is consistent with that expected from a capstone of a grave.

Profile 4 Grave at A'Chrois, Tiree



Point A: Air and Initial Ground waves can be ignored,

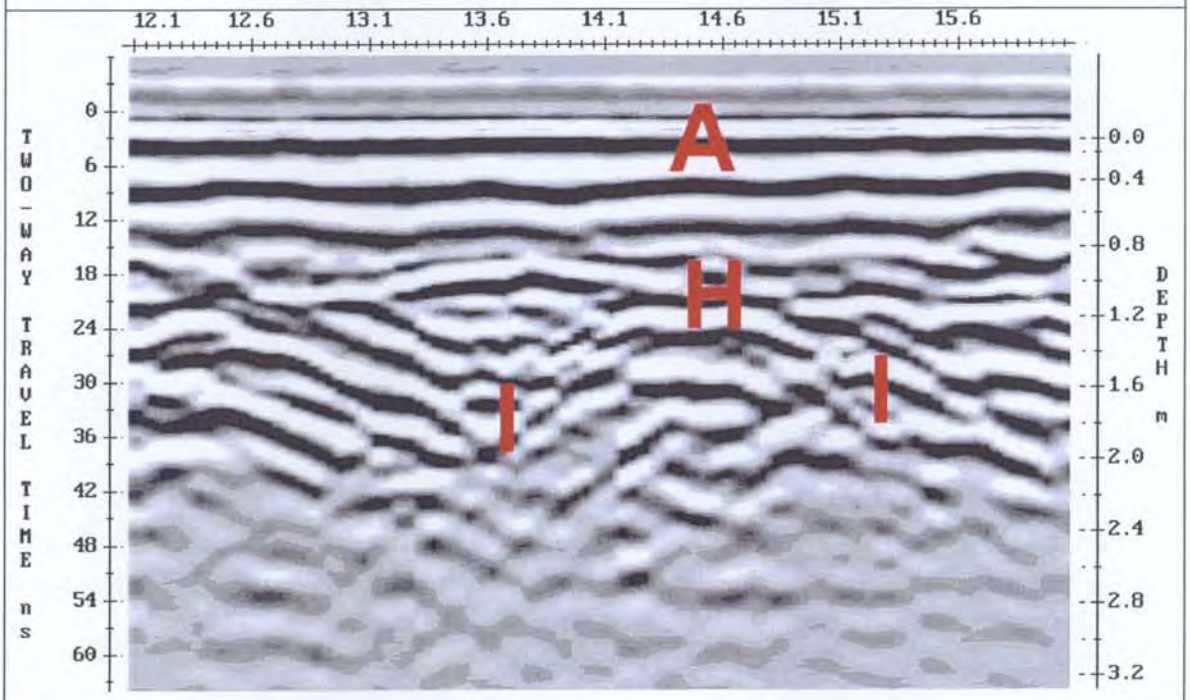
Point H: Strong horizontal reflectors

Point I: Steeply sloping reflectors

Grave - dated to 1918 - within existing graveyard at Crossapol (10126E, 7532N)

This profile is currently being topographically corrected. However, when this is done, the following changes to the architecture will be evident. Central point H will become more upstanding and the lines at points I will steepen since the ground surface domes at this point over the axis of the 1918 grave. At the same time, the lines at points I will flatten. The resultant GPR profile will then resemble that of Profiles 4 and 6. However it is known that this grave is modern and thus has no capstone. Although there is a strong horizontal reflector, it is probably not composed of stone. In this respect it probably differs from the others and so its GPR signature is more muted.

Profile 5 Known Graves at Crossapol



Point A: Air and Initial Ground waves can be ignored

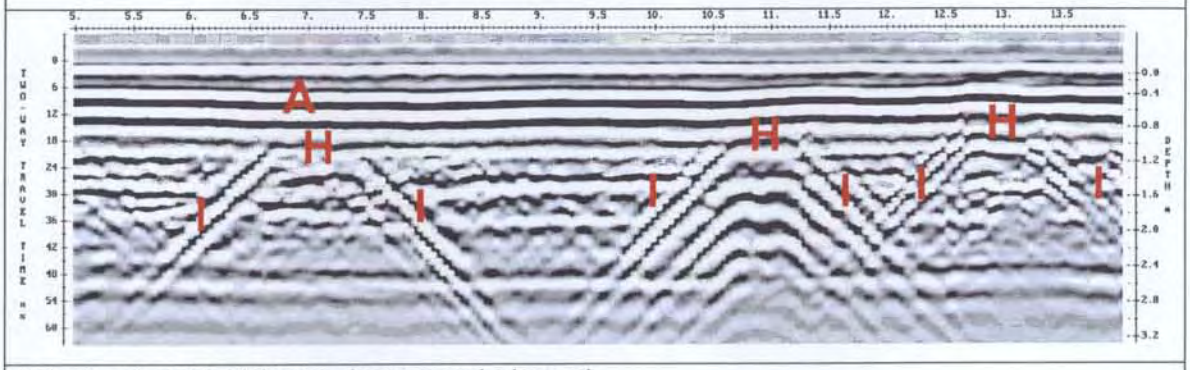
Point H: Strong horizontal reflectors,

Point I: Steeply sloping reflectors

Graves within extended graveyard at Crossapol (10126E, 7532N)

These strongly reflecting signatures are very similar to those in Profile 4 and of a similar size and spacing. The profile was taken at an angle over the target area and so the dimensions probably reflect the long axis of the suspected graves and this may also explain the spacing. This pattern is consistent with that expected from a series of capstoned graves.

Profile 6 Graves in extended grave yard at Crossapol



Point A: Air and Initial Ground waves can be ignored,

Point H: Strong horizontal reflectors

Point I: Steeply sloping reflectors

Discussion

The following discussion is based on the images (Figures 14 –23) and GPR Profiles (1-6) displayed in this report.

Figure 14 shows an area where a chapel is known to have existed. A graveyard, badly affected by coastal erosion, still exists close to the sea. A flat area of improved machair exists around the farm at Crossapol. This is easily distinguishable on the 9, 7, 3 false colour composite from the area of dunes to the east and the boggier land to the west. The daytime thermal image helps to highlight a wall running across the improved land. It also shows areas of disturbed ground on either side of the wall. A field visit indicated that there was rabbit disturbance within the area, but pottery was found within the rabbit scrapes. The area was subjected to a GPR survey. This detected the buried wall and the area of disturbance. It has not yet been possible to characterise the nature of the disturbance, but there is a possibility that it relates to the lost chapel.

A GPR survey was also carried out within the known graveyard (Profile 5). A line outside the graveyard wall was also surveyed, and this indicated that the area of burials extends beyond the present graveyard boundary (Profile 6).

Figure 15 shows a former area of cultivation within a dune field on Coll. No houses exist today in this area. The 9, 7, 3 false colour composite is again good at showing areas of improved land from the surrounding dunes and areas of bog. The daytime thermal image is very good at highlighting low grass-covered walls that form the enclosures and other boundaries. The night-time image helps to differentiate between ditches, tracks and walls, not easily done on the other images.

Figure 16 also shows an area of former cultivation on Coll. In this image the 9, 7, 3 false colour composite clearly indicates areas of agricultural ridging. A group of cairns was found within this area, and these are detectable on the daytime thermal image. By comparing the thermal image with the 4, 3, 2 true colour composite it is possible to distinguish them from areas of bare sand.

Figure 17 shows and abandoned farmstead that now exists only as a series of low, grass-covered humps. The farmstead is shown on the First Edition Ordnance Survey map as a ruin. It is detectable on all images, but it is the daytime thermal image that gives the greatest definition, allowing individual buildings to be seen. The GPR was used to confirm the size and nature of the buried farmstead.

A buried track, also known from the First Edition map, shows up on the night-time thermal image in one field. It is not visible on any of the other images within this field. Its visibility on the night-time thermal image is due to the type of vegetation cover within the field at the time that the image data were collected.

Figure 18 shows the course of an old field boundary within a ploughed field. Very few fields were ploughed at the time that the image data were collected. The boundary shows up clearly on the daytime thermal image. GPR was used to determine the nature of the boundary. It was not able to detect any buried stone, suggesting that it was not stone-built.

The image also shows numerous drainage ditches. Some of these are still in use, others are not. The night-time thermal image clearly shows which of the ditches contain water.

Figure 19 shows the area around the Kirkapol chapels. A wall running from the chapel to the graveyard was confirmed by GPR survey. The survey also suggested the presence of several burials in the area.

Of interest is the way that the extension to the graveyard, barely detectable from its surroundings in the 4, 3, 2 true colour composite, shows up very clearly on the daytime and night-time thermal images.

Figure 20 shows a small enclosure with a structure within it. This was one of several such enclosures noted on Tiree. It does not appear in local or national records. The enclosure and structure are most clearly visible on the daytime thermal image. Also present are several circular features. These were noted in many areas on Coll, but especially in remote dune areas. When first seen, their circular shape and diameter led to speculation that they were hut circles. The night-time images showed hot-spots around the circular features, which did not appear on the other images. A field visit soon revealed these features to be cattle feeders (figure 25). Trampling caused the difference in vegetation and soil temperature; the hotspots were the cows themselves!

Figure 26 Cows around a cattle feeder.

Figure 21 shows the land around A' Chrois, another area that was once the site of a chapel. The 9, 7, 3 false colour composite shows clearly the difference between the areas of dune and the improved machair. It also helps to highlight buried walls and evidence of past agricultural activity. The landowner told us that the field had not been ploughed for at least 50 years, due to worries about sand-blow. The 9, 7, 3 false colour composite image indicates an area of disturbed ground, which is also evident on the daytime thermal image. The area of disturbance is aligned E-W and was subject to a GPR survey. Several transects were made within the area of disturbance and the anomalies encountered have been interpreted as possible burials (Profile 4).

Figure 22 also shows A' Chrois. Buried walls are evident in the images, passing from the area of machair into an encroaching dune field. The walls are evident even when covered with drifting sand. The way that the sand is forming a series of mounds along the line of the wall is clearest in the 9, 7, 3 false colour composite. Recognition of this pattern of burial may make it possible to locate more deeply buried boundaries by observing the pattern of the overlying dunes.

Figure 23 shows a cairn within a dune field. The cairn has been confirmed by a GPR survey (Profiles

1-3). The detection of cairns within such an area is difficult, due to the blown sand forming mounds. It is suggested that the cairn is detectable by looking at a combination of images. It appears warm on the daytime thermal image, as do surrounding humps. On the night-time thermal image it appears uniformly cold. The uniformity of its temperature may be a result of it being stone-built. Other humps, formed of wind blown sand, display a warm side, (facing south) and a cold side (facing north).

Conclusions

The Airborne Remote Sensing project of Coll and Tiree has demonstrated that the technique can be very useful for locating archaeological monuments in areas of sand. As the researchers gained more experience in interpreting the images, so the number of actual sites detected (as opposed to natural features) increased. The features detected ranged from walls, to enclosures, to farmsteads, to individual buildings, to cairns.

Viewing the images on the computer allowed rapid scans of complete areas of landscape to be made. Having a set of different windows open meant that different band combinations could be viewed simultaneously. Larger features, such as field enclosures (figures 15 and 16) were easily detectable, especially on the daytime thermal images. Once a feature was identified the image could be 'zoomed into' allowing greater detail to become apparent. As the images were geo-referenced, co-ordinates for all identified features were immediately available. Ordnance Survey landline maps were also added to the images to allow checking of target location against a map.

The dunes are problematic areas for recognising features, partly due to the nature of the topography. The numerous bumps and hollows display warm (south facing) and cold (north facing) sides, where the sun has had a chance to warm up the ground. This is apparent even in the night-time thermal images. It is thought that by combining the ATM data with LIDAR, it will be possible to make compensations for this effect. Having said that, features were visible within the dunes, examples being the buried wall (figure 22) and the cairn (figure 23).

It is felt that this a very worthwhile technique, but that further work is needed to determine whether other factors play an important role in the ability to locate archaeological features. One factor may be the time of year that the image data are collected. A prolonged spell of cold weather followed by a couple of warm days may encourage thermal differences to become more apparent. Time of year will also have an affect on vegetation cover, and flights flown after long dry periods towards the end of summer will allow the 9, 7, 3 false colour composite to show up vegetational stresses before they become apparent on conventional aerial photography. Flights flown on sunny days will enhance the effect of the sun shining on south-facing slopes, so perhaps dull days would show more differences.

The amount of information contained within the images is enormous, and further analysis of the collected data will be undertaken. Attempts will be made to clean up the night-time thermal images, and other researchers will review the images. Having said that, this initial review of the evidence has demonstrated that the use of Airborne Remote Sensing is appropriate for the large sandy areas around Scotland's coast.

Acknowledgements

The NERC Airborne Remote Sensing Facility

Historic Scotland

Richard Tipping and Jo Thomas, University of Stirling

Jim Hill and members of the Coll Archaeological Society

Dr John Holliday and Catriona Hunter at An Iodhlann, the Tiree Archive.

We are also grateful to all landowners for allowing us access during field-work.

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