Evolution of Filey Brigg

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Filey coastal slope stability and outflanking study

Scarborough Borough Council

20 April 2012

Halcrow

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Document history

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Contents

1 Introduction

1.1 Scope of work

Scarborough Borough Council commissioned Halcrow to undertake a review of future coastal change scenarios for Filey Brigg. This work forms part of the Filey coastal slope stability and outflanking study.

The work scope involves the following tasks:

- Use historical aerial photographs and Ordnance Survey maps to document changes in the Brigg through time and provide a geomorphological map of the current feature
- Review climate change projections for the region, covering the next 100 years and longer-term change
- Develop scenarios of future change of the Brigg using a semi-quantitative approach built on newly derived historical data and the NCERM approach. Future scenarios are to be presented for 20, 50 and 100 years. An assessment of 1,000 years is also to be attempted, but it is recognised that this time period is highly speculative due to uncertainties in sea-level rise.

1.2 Datasets used

This project has made use of historical aerial photography from 1940 to 2010, and historical Ordnance Survey maps that date from 1854 to present. Information on coastal processes were derived from the SMP2, the Filey Bay coastal strategy and annual monitoring reports produced by Halcrow/Royal Haskoning since 2002. The Geological Survey map for Scarborough was also referred to. Climate change data was derived from the UK climate impacts programme website. Other data has been sourced from the Filey Town outflanking study.

2 Geomorphology

2.1 Site description

The geomorphology of the Brigg was mapped using aerial photography and LiDAR from the Cell 1 2010 coastal survey (Figure 1, Figure 2). The geomorphological map describes the cliff morphology and composition of the Brigg and underpins subsequent assessment.

Filey Brigg is a narrow promontory that defines the northern extent of Filey Bay. It is c. 1.5km long and at low tide is c. 200m wide. At high tide, its width is generally less than 150m. The feature can be split into two sections: a c. 700m long landward section known as Carr Nase which is 40 to 44m above Ordnance Datum (OD); and a c. 800m long section that continues to the North Sea at elevations of less than 3m OD, which is only exposed at low tide (Figure 1, Figure 2). The intertidal part is the only section properly known as Filey Brigg (although the first series Ordnance Survey map of 1854 names this feature Filey Bridge). In this report, the term Filey Brigg is used to describe the combined landform of Carr Nase and Filey Brigg.

The Brigg is comprised of a bedrock platform overlain by glacial sediment (till). The bedrock comprises Middle Jurassic Bindsall Grit, which forms the majority of Filey Brigg *sensu stricto*, overlain by Lower Calcareous Grit, which underlies the majority of Carr Nase. Both rock units have a strike of WNW-ESE, which is parallel to the alignment of the Brigg. The rocks dip at angles of c. 5 degrees to the south, which means there is a thicker exposure of rock on the north face of the Brigg than the south (Figure 3). On the north face of the Brigg, near-vertical rock cliffs of 20 to 25m height are seen. They are indented into a series of small circular bays that are known as 'Doodles' (Figure 5). These are most likely determined by weakness caused by joint patterns. On the south face, there are no rock cliffs and the outcrop instead forms a platform that dips to sea level at c. 5 degrees (Figure 3, Figure 7, Figure 8).

The dipping promontory of bedrock is overlain with glacial sediment that has a flat top elevated c. 40m OD, flanked by steep cliffs of c. 30 degrees. The cliffs are characterised by a continuous series of mudslides that each have arcuate headscarps and elongate flow tracks (Figure 4, Figure 6, Figure 8). Some mudslides are vegetated, suggesting dormancy, but most are actively eroding through a combination of direct wave action, rainfall, surface runoff and erosion, and excess groundwater levels. Site inspections, which have been undertaken for over 10 years as part of the Cell 1 monitoring strategy and the earlier Filey Bay strategy study, have consistently indicated that the mudslides are highly active. Active mudslide headscarps on the north and south sides of the Brigg have coalesced to form narrow sections of the cliff top plateau, which in places are no more than 5m wide.

The geomorphological map allows cliff behaviour units to be identified for the Brigg. Due to the elevation and dip of the bedrock, the north face is characterised by composite cliffs, with till over bedrock, while the south face is characterised by simple cliffs formed in till (Figure 4).

Figure 1. Aerial photo (2010) (Data: Cell 1 Coastal Survey, 2010)

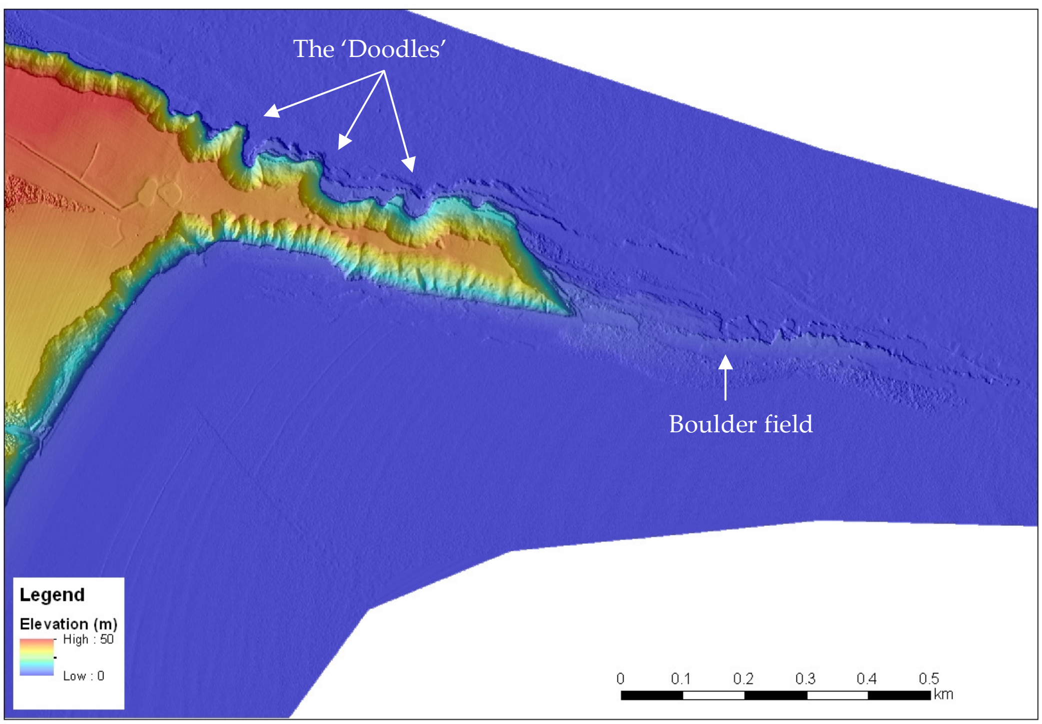


Figure 2. LiDAR map showing different elevation of Carr Nase and Filey Brigg (Data: Cell 1 Coastal Survey, 2010)

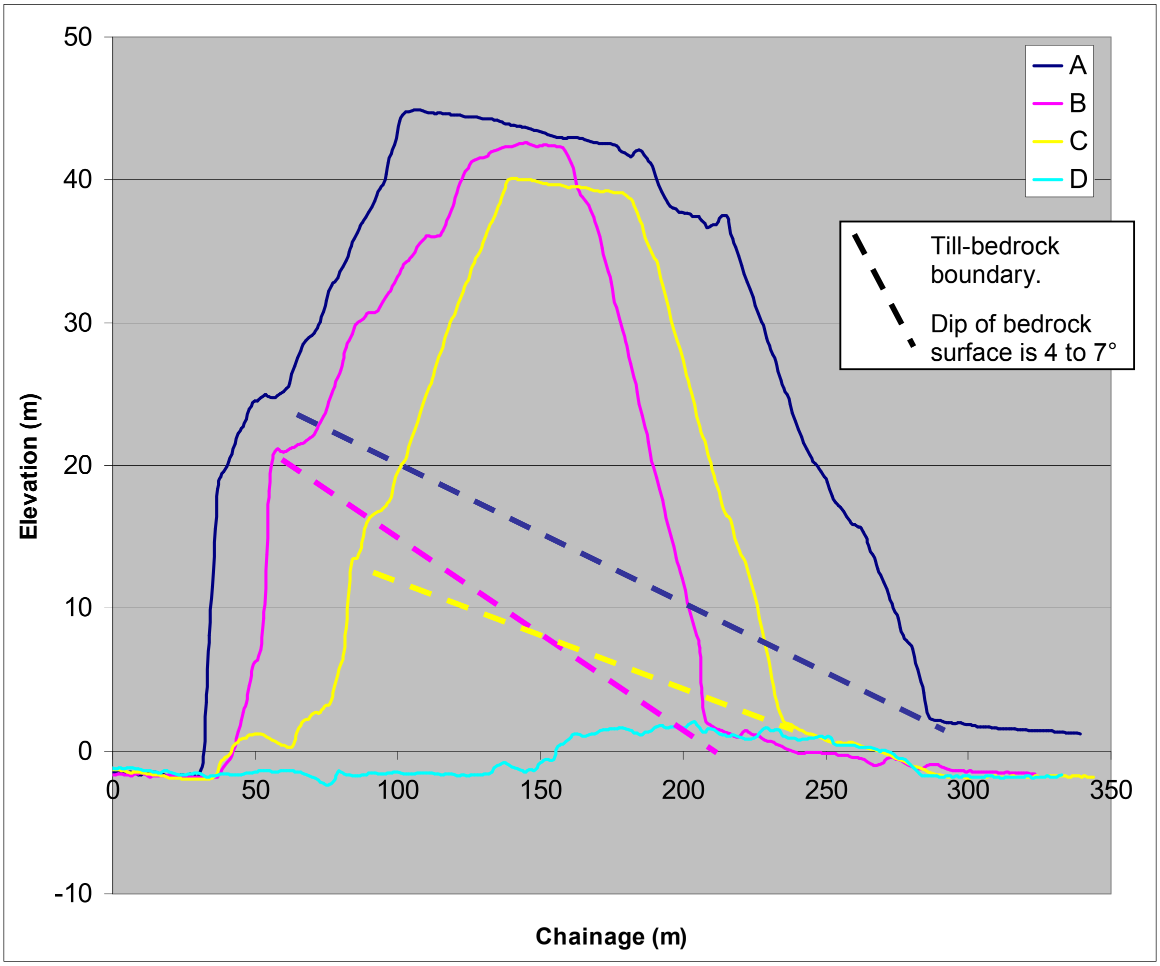


Figure 3. Cross sections through Filey Brigg. Postulated bedrock surface shown for reference. Location of cross sections shown on Figure 4.

The map shows that the bedrock shore platform of the Brigg is formed from alternating zones of bedrock and boulder field. The boulder field derives from the break up of the gritstone that has remained *in situ* and forms a prominent north-facing sub-tidal low cliff visible on the LiDAR (Figure 2). As the boulder field is of lower elevation than the adjacent sub-tidal cliff, it is shielded from northerly waves. The persistence of the boulders suggests they can only be moved by the very strongest of storms.

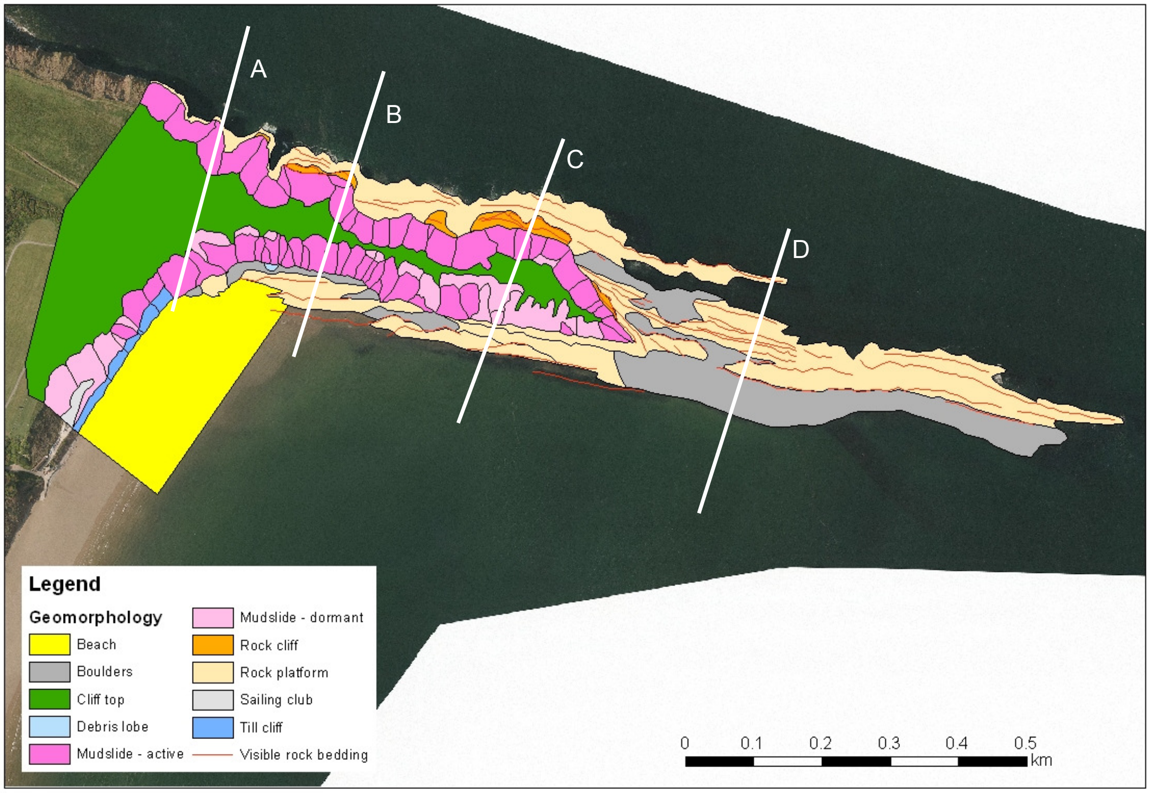


Figure 4. Geomorphology of Filey Brigg. Cross sections shown in Figure 3.

2.2 The cliff recession process

The process of cliff recession will differ according to cliff behaviour type (Figure 9):

- **Simple landslide systems**: a single high-frequency sequence of energy inputs from wave action and outputs as landslides with variable amounts of storage of landslide debris. A landslide debris storage zone may be apparent at the cliff toe affording limited buffering against toe erosion, but this is generally rapidly eroded. This system will be affected by erosion of the landslide toe and excess groundwater in the slide zone; therefore both sea level and rainfall are key forcing parameters of equal importance. Examples include the cliffs of Filey Bay and the southern side of Filey Brigg (e.g. Figure 8).

- **Composite cliff systems**: partly coupled sequences of contrasting simple sub-systems, typically comprising beds of soft rocks overlying harder rocks. Composite cliffs have a distinct morphology, with a shallow upper cliff face over a steeper lower cliff face and a tendency for high magnitude, low frequency failures. Composite cliffs are sensitive to changes in toe erosion and groundwater. Examples include the till-over-gritstone cliffs of the northern side of Filey Brigg (e.g. Figure 5).

Figure 5. Filey Brigg north CBUs. The 'Doodle's' are the indented bays in the gritstone

Figure 6. Filey Brigg north. Note till overlying gritstone cliffs and narrow cliff top plateau

Figure 7. Filey Brigg. Note southerly dip of the bedrock highlighted by scarps in wave breaker zone

Figure 8. Filey Brigg south CBUs. Note locations of vegetated cliffs in areas protected from dominant waves

The dominant wave direction in the region is from the NE, which means coast lines facing this direction are exposed to the maximum wave power. The cliffs on the north side of Filey Brigg are therefore exposed to higher potential wave erosion than those of the south side of the Brigg. However, the CBUs on the north of the Brigg are composite cliffs, meaning the wave energy acts on cliffs of relatively hard Jurassic grits, which are at least 15m high. Water level and wave climate data (Tables 1 and 2) show that even for 1:200 year events, the combined elevation of high water and waves will be c. 12m OD. Therefore the overlying weaker till is very unlikely to be directly-affected by wave energy. This suggests that the cliff erosion rates will be low and will be characterised by very slow erosion of the underlying limestone, together with surface erosion and episodic mudslides caused by rainfall, surface water run-off, and excess groundwater.

The CBUs on the south side of the Brigg are simple cliffs/landslides formed in till, but because they are in the lee of the dominant wave direction they are unlikely to be subject to rapid erosion. The CBUs in the northern part of Filey Bay are also simple cliffs/landslides formed in till, but these are likely to be exposed to direct wave erosion by refraction of wave crests around the Brigg, and consequently higher erosion rates should be expected. Evidence for historical cliff recession is presented in the next section.

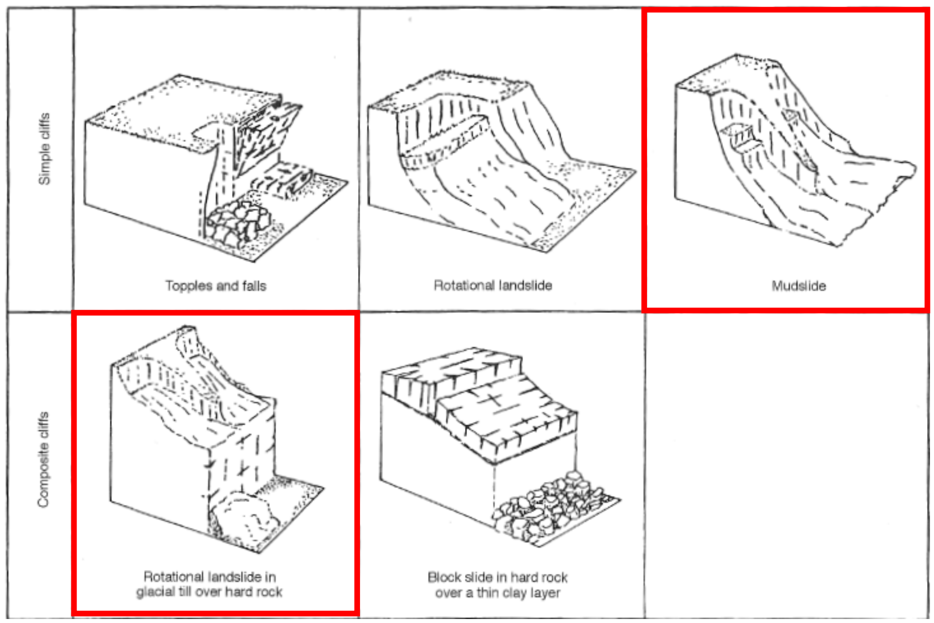


Figure 9. Cliff behaviour unit models relevant to Filey Brigg

Table 1. Water levels at Filey Bay (SMP2). Levels are reported to OD Newlyn. Chart Datum is approximately 3.0m below OD.

MLWS	MHWS	HAT	1:10yr	1:20yr	1:50yr	1:100yr	1:200yr
-2.30	2.50	3.10	3.57	3.72	3.81	3.95	4.04

Table 2. Wave climate. Significant wave heights for different return periods

Return Period	Wave Height Hs (m)*
1	5.1
10	7.2
50	8.1
100	8.1
200	8.1

2.3 Review of climate change projections

Climate change projections for the next 100 years are available from UKCP (UK Climate Programme). Changes in summer and winter rainfall over the last c. 50 years have been assembled by UKCP (Figure 10. Change in summer and winter rainfall in the United Kingdom 1961 to 2006 (UKCP09, 2011)) and show that the North Yorkshire coast has become up to 25% wetter. This pattern of increasing rainfall is expected to continue over the next 100 years.

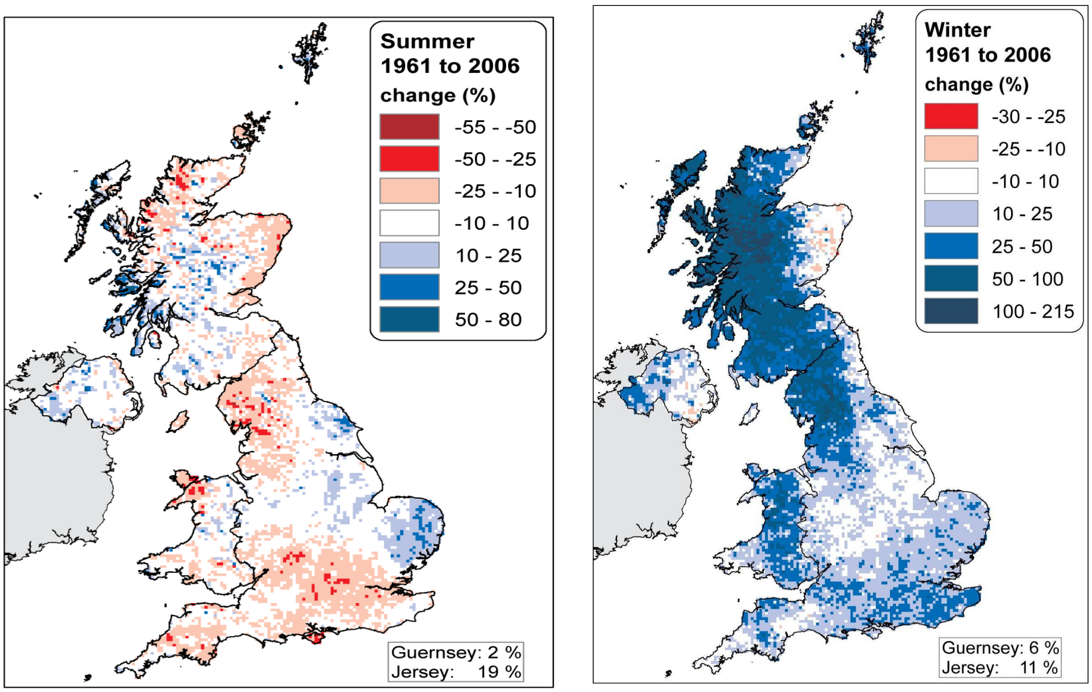


Figure 10. Change in summer and winter rainfall in the United Kingdom 1961 to 2006 (UKCP09, 2011)

Sea-level projections are also provided by UKCP and data for the Filey coast is presented in Figure 11. The graph shows projections for the three emissions scenarios (high, medium and low) and for the 5, 50 and 95 percentiles. Taken as a whole, the projections indicate a range of sea-level rise of c. 0.2 to 0.9m above 1990 levels in the next 100 years.

There is considerable uncertainty over sea-levels beyond 100 years, which are largely dependent on the timing and extent of melting of polar ice caps. However, a credible worst case scenario is for 20m of sea-level rise within the next 1,000 years.

The probable impacts of sea-level rise and climate change along Filey Brigg include:

- Increased effective rainfall leading to excess surface water run-off and groundwater levels that trigger more frequent mudslides and erosion
- Raised sea-levels causing waves to break higher up the beach/cliff leading to increased rates of cliff toe erosion.

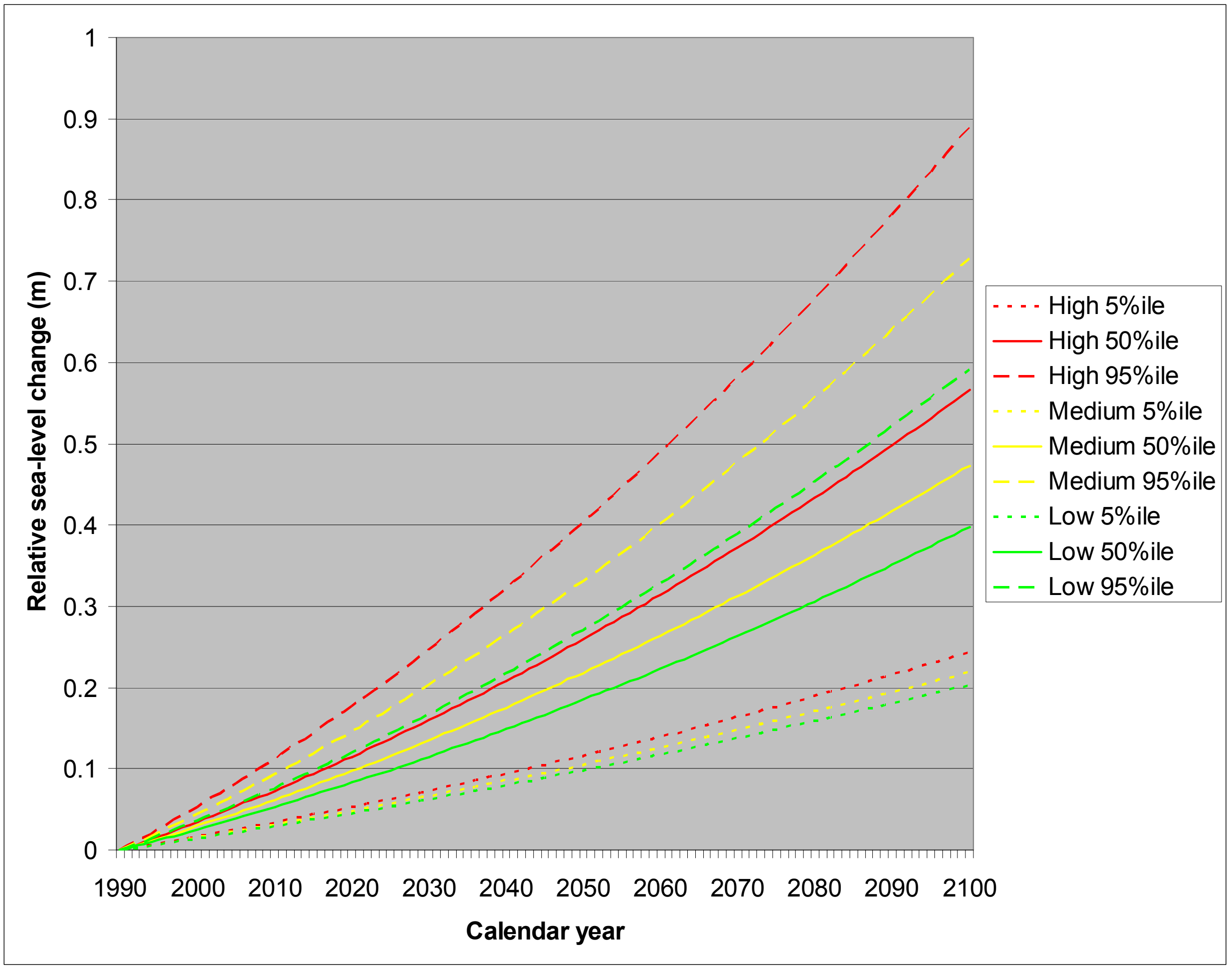


Figure 11. Relative sea-level rise projections for Filey Brigg (UKCP09)

3 Coastal change database

3.1 Historical coastal change

3.1.1 Data and accuracy

A new analysis of historical coastal change has been undertaken along Filey Brigg in order to support an alternative projection of future change. It is likely that the results of this new analysis will be similar to those presented above, however the data will provide independent validation of NCERM data.

The task involves using GIS to accurately map the coastline from the 2010 aerial imagery, from which historical change can be measured against and future change can be projected from. The same coastline feature can then be mapped from historical OS maps and aerial photos and the change in its position accurately measured. The rate of change can then be calculated for short periods of time (i.e. between OS map series revisions) and longer-term times (i.e. between the first series OS and present day maps). It is important to understand and mitigate sources of error in the measurements. Errors can be derived from three main sources:

- Mapping error: mistakes in the OS mapping, including confusion over which feature constitutes the 'coastline'. These have to be accepted;
- Interpretation errors: mistakes digitising the coastline caused by uncertainty over interpretation of features. For example, inaccuracies can occur when interpreting early OS maps that often use hachure symbology to delimit the cliff top, rather than a line. Care is also needed in the interpretation of aerial photography where vegetation growth can disguise the true cliff line. These are minimised by careful digitising at a consistent scale of 1:1,000 by an experienced geomorphologist;
- Rectification errors: poor fit of the map or photo to the national grid, associated with the rectification process. These can be calculated and must be reported when presenting historical rates of change.

A database of historical OS mapping has already been assembled for the Filey Town study. This has been enhanced with existing aerial photograph data from Scarborough Borough Council's records that date from 1999 to present and newly acquired photography dating from 1940, 1967 and 1988. The rectification errors for all these data are summarised in Table 3. The photography is reproduced in the appendix and on a disc that accompanies this report.

When comparing different epochs of data to generate rates of change, errors are combined and then divided by the time between each epoch. This gives the range of error that must be applied when calculating rates of cliff recession. Given the relatively large errors of each epoch of mapping or photography, combined errors for short periods of time are high, while errors for long-term rates of change tend to be lower. The errors associated with inter-epoch rates of change are shown in Table 4.

These data mean that measurements of short term change from historical maps will be reliable. However, the most recent aerial imagery data are more accurate, measured rates of change between 2008 and 2010 are likely to be more reliable. Long-term rates of change from OS maps over the period 1854 to 2010 provide the most reliable evidence for historical change.

Table 3. Rectification errors (RMSE) of historical data used for cliff recession analysis

Year	Data	RMSE (±m)
1854	OS map	6.85
1893	OS map	6.44
1913	OS map	11.01
1929	OS map	9.42
1940	Aerial photograph	1.02
1967	Aerial photograph	0.82
1971	OS map	5.65
1973	OS map	5.77
1988	Aerial photograph	0.89
1999	Aerial photograph	4.68
2008	Aerial photograph	0.93
2010	Aerial photograph	0.1
2010	OS Mastermap	0

Table 4. Combined errors for calculating cliff recession rates

Time period	Combined RMS error (±m)
1854 to 2010 (map/photo)	0.04
1845 to 1893	0.34
1893 to 1913	0.87
1913 to 1929	1.28
1929 to 1971	0.36
1971 to 1973	5.71
1973 to 2010 (map)	0.16
1940 to 2010 (photo)	0.02
1967 to 2010 (photo)	0.02
1988 to 2010 (photo)	0.05
1999 to 2008 (photos)	0.62
2008 to 2010 (photos)	0.04

3.1.2 Coastal change database

Historical change is measured by comparing the position of the coastline over time. The coastline can be represented by a variety of features, depending on the geomorphology and includes the vegetation limit, cliff top, cliff toe or back of beach. In this study, the cliff top was taken as the feature most representative of the coastline and was digitised in each of the historical datasets at a consistent scale of 1:1,000 within GIS to minimise error.

The most accurately digitised cliff line is derived from the high quality 2010 aerial survey data where the LiDAR elevation model can be interpreted in conjunction with the aerial photograph. This line has therefore been used as a fixed baseline against which historical cliff top positions are measured against. Views of all the historical aerial images overlain with the 2010 coastline are provided in the appendix.

Historical change was measured for 30 coastal transects in the GIS. The distance from the landward end of each transect to the digitised cliffline was measured and the distances used to calculate rates of change (Figure 12). The data are shown in Table 5. Rates that are erroneous (i.e. indicating an advancing cliff) are marked with an asterisk (*), and those that are lower than the calculated error are marked with a dagger (†). The presence of erroneous data is clearly illustrated in Figure 12 that shows both retreat and advance of the coastline resulting from error in OS mapping and rectification errors on a highly indented coastline. Rates of change for other time periods have been calculated but rectification errors mean the rates are very inaccurate and they are not reported here.

Figure 12. Location of measured transects and digitised coastlines used in the recession analysis

Table 5. Filey Brigg cliff recession database

Transect	Location	Erosion rate (m/yr) (1854 to 2010)	Erosion rate (m/yr) (1854 to 1938)	Erosion rate (m/yr) (1938 to 2010)	Erosion rate (m/yr) (2008 to 2010)
1	Filey Bay North	0.31	0.33	0.38	-0.25
2	Filey Bay North	0.19	0.20†	0.23	0.90
3	Filey Bay North	0.08	0.05†	0.06	0.85
4	Brigg south	0.07	0.06†	0.07	-1.35
5	Brigg south	0.04†	-0.04	-0.05	-0.25
6	Brigg south	0.02†	0.02†	0.02	-1.30
7	Brigg south	0.03†	-0.07	-0.08	0.20
8	Brigg south	0.04†	-0.04*	-0.05*	-1.05*
9	Brigg south	0.04†	0.02†	0.02†	-1.10*
10	Brigg south	0.03†	-0.09*	-0.10*	-1.50*
11	Brigg south	-0.02*	-0.02*	-0.03*	-2.50*
12	Brigg south	-0.02*	0.08†	0.09†	1.40
13	Brigg north	0.03†	0.06†	0.07†	3.80
14	Brigg north	0.14	-0.04*	-0.04*	-3.15*
15	Brigg north	0.03†	-0.01*	-0.01*	1.15
16	Brigg north	0.04†	-0.25*	-0.30	0.70
17	Brigg north	0.08	-0.19*	-0.22*	0.10†
18	Brigg north	0.01†	0.08†	0.09†	1.15
19	Brigg north	0.08	0.14†	0.16	0.00†
20	Brigg north	0.05	-0.05*	-0.06*	0.70
21	Brigg north	0.07	0.01†	0.01†	1.05
22	Brigg north	0.07	0.10†	0.12†	1.35
23	Brigg north	0.05	-0.05*	-0.06*	1.40
24	Brigg north	0.04†	0.03†	0.04†	-3.60*
25	Brigg north	0.05	0.03†	0.03†	-0.10*
26	Brigg north	0.13	0.14†	0.16	-0.25*
27	Brigg north	0.01†	-0.02*	-0.03*	-0.35*
28	NW of Brigg	0.07	-0.03*	-0.04*	-1.35*

Transect	Location	Erosion rate (m/yr) (1854 to 2010)	Erosion rate (m/yr) (1854 to 1938)	Erosion rate (m/yr) (1938 to 2010)	Erosion rate (m/yr) (2008 to 2010)
29	NW of Brigg	0.10	-0.06*	-0.07*	-1.25*
30	NW of Brigg	0.03†	-0.09*	-0.11*	-1.00*

Overall, the data for each profile show:

- Long-term change data between 1954 and 2010 is reliable, with a large proportion of measured change being greater than the calculated error. Rates of change are low, with typical values being less than 0.1m per year
- Medium-term rates of change from 1854 to 1938, and 1938 to 2010 are less reliable and very few measurements are meaningful or within the calculated error. Reliable data points indicate erosion rates of less than 0.4m/yr
- Short-term change data between 2008 and 2010 are also unreliable, due to the short time interval and the error associated with the 2008 imagery. However, reliable data points indicate recession rates of up to 1 m/yr, with some locations showing significantly more.

Taken as a whole, these data indicate that average long-term cliff recession rates of the Brigg have been extremely low, however, episodic mudslide activity is able to generate very rapid but localised rates of recession. Despite concerns over the accuracy of the historical datasets available for detailed quantitative analysis, the conclusion of very low erosion rates is borne out by the historical mapping that shows the continued presence of the long and narrow plateau of till that forms Carr Nase.

Cliff behaviour units have previously been mapped in the study area as part of the Cell 1 strategic coastal monitoring programme and individual mudslides have been re-mapped as part of the current study. However, variability in the extent of CBUs through time due to mudslide headscarp erosion, combined with RMS errors in the input data, means that the resultant recession data is often inaccurate. It was therefore most appropriate to group the recession data into four generalised zones:

- northern section of Filey Bay from the sailing club to the Brigg, which comprises simple cliffs/landslides
- south facing side of Filey Brigg, which comprise simple cliffs/landslides
- north facing side of Filey Brigg, which comprises composite cliffs
- coast NW of the Brigg, which comprises composite cliffs.

These combined results are summarised in Table 6.

Table 6. Average recession rates for Filey Brigg

Location	Average erosion rate (m/yr) (1854 to 2010)	Maximum erosion rate (m/yr) 1854 to 2010	Average erosion rate (m/yr) (2008 to 2010)	Maximum erosion rate (m/yr) 2008 to 2010
Filey Bay North	0.19	0.31	0.88	0.90
Brigg south	0.04	0.07	0.80	1.40
Brigg north	0.06	0.14	1.14	3.80
NW of Brigg	0.07	0.10	No data	No data

3.2 Projection of coastal change

Based on the historical coastal change data (Table 6), projections of future change can be made. Four future time periods are presented: 20 years, 50 years, 100 years and 1,000 years. It is recognised that the 1,000 year scenario is highly speculative. Based on the climate change projections made in Section 3.2, the forecast mean sea-levels associated with these time periods for the medium emissions scenario, 50% probability are 0.1, 0.2 and 0.5m higher than current mean sea-level. The historical data are used to generate low, high and best estimate projections as follows:

- Low: extrapolation of long-term average rates of change from the period 1854 to 2010.
- Medium: based on the findings of Moore et al. (2010 [1]) extrapolated long-term average rates of change from the period 1854 to 2010 have been increased by 10% to account for the impacts of climate change
- High: extrapolation of long-term maximum rates of change from the period 1854 to 2010.

The results of these scenarios are shown in Table 7 and illustrated in Figure 13, Figure 14 and Figure 15. The results show:

[1] Moore R. Rogers J. Woodget A. Baptiste A. 2010. Climate change impact on cliff instability and erosion. FCRM>10. This paper assigns percentage increases in cliff recession rate based on climate change emissions scenarios (high or low) and cliff sensitivity to climate change (high, medium, low). Due to their aspect and geology, the Filey Brigg cliffs are expected to have low sensitivity resulting in a % increase in recession rate of 0 to 10%.

- In all three scenarios, access along the footpath that runs along the top of Carr Nase is indicated to be possible for the next 20 years, but the current pathway may need realignment. The view of the Brigg will be broadly unchanged over this period.

Table 7. Projected recession distances for Filey Brigg

Location	Scenario	20 years (m)	50 years (m)	100 years (m)
Filey Bay North	Low	3.8	9.4	18.9
	Medium	4.2	10.4	20.8
	High	6.1	15.3	30.6
Brigg south facing	Low	0.8	2.0	4.0
	Medium	0.9	2.2	4.4
	High	1.4	3.5	7.1
Brigg north facing	Low	1.2	2.9	5.9
	Medium	1.3	3.2	6.5
	High	2.8	6.9	13.8
NW of Brigg	Low	1.3	3.4	6.7
	Medium	1.5	3.7	7.4
	High	2.1	5.2	10.4

- In all scenarios access along footpath that runs along the top of Carr Nase is projected to be interrupted within 50 years. This occurs at two locations where mudslide headscarps are projected to retreat back to a point where they coalesce to form a knife-edge on the Carr Nase footpath. Depending on the scenario, between 10 and 70m of the cliff top will be lost. The eastern end of Carr Nase is also forecast to be eroded, with up to c. 50m being lost. This will mean that the view of the Brigg from Filey will noticeably change over this time period.

- Over the next 100 years, all scenarios indicate that the cliff top footpath will be almost entirely lost, with between 70 and 220m projected to be eroded from the plateau, depending on the scenario. Around 100m of till is projected to be lost from the eastern end of Carr Nase, causing a rocky platform to emerge. The elevation of the platform is projected to be c. 12m on its north side dipping down to c. 3m on the southern side. The platform will therefore still project above HAT and afford protection to the northern part of Filey Bay from the dominant northeasterly waves. At this time, the view of the Brigg from Filey will be considerably different to that of today. Projections suggest that the Carr Nase cliff plateau will project c.200m and will be fronted by a series of low till pinnacles and the rocky platform currently present.

- By 1,000 years, it is likely that coastal erosion will have entirely removed the till cliffs of Carr Nase and that only the rock platform of Filey Brigg will remain, albeit as a longer feature with its till cap removed. Sea-level rise means that the low rock platform will have a progressively decreasing impact on wave refraction, which means the northern part of Filey Bay will no longer be afforded protection from northeasterly storms.

Figure 13. 20 year projection using new data

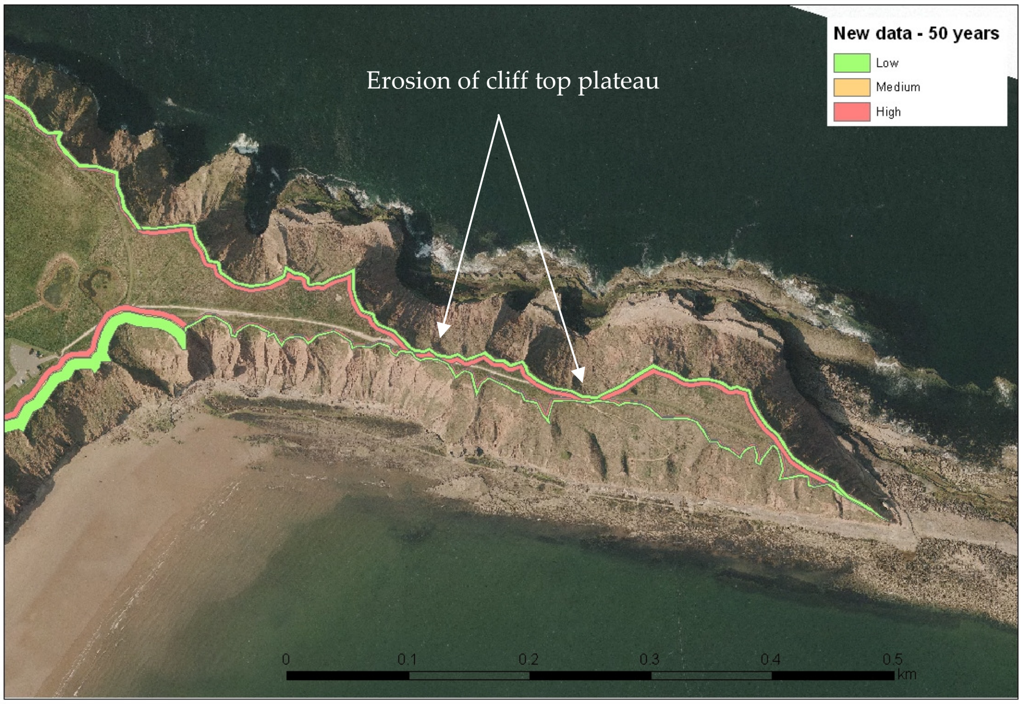


Figure 14. 50 year projection using new data

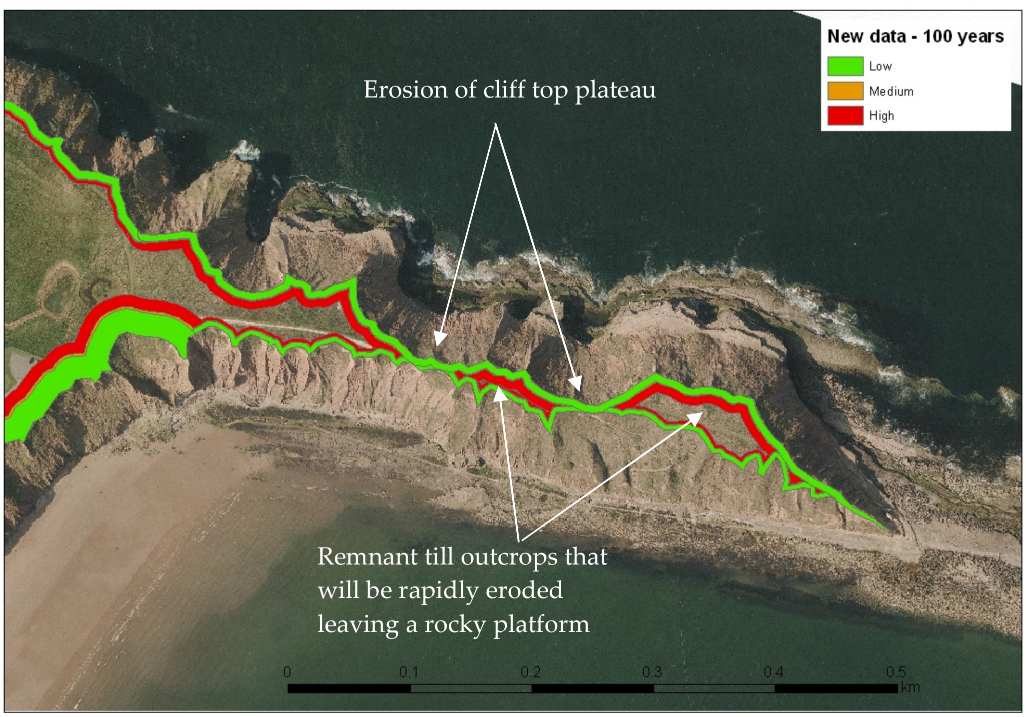


Figure 15. 100 year projection using new data

3.3 The national coastal erosion risk mapping (NCERM) project

The national coastal erosion risk mapping project (NCERM) was undertaken by Halcrow for the Environment Agency which uses coastal erosion concepts and models first developed for Futurecoast. Its aim is to publish robust and consistently-derived projections of coastal erosion in the public domain, as a component of the Agency's 'What's in your backyard' web pages. In this report, NCERM projections are presented as a validation exercise of the projections for the Brigg presented above.

NCERM uses a methodology that combines projections of historical coastal recession rates to determine future erosion losses over timescales of 20, 50 and 100 years. It accounts for coastal management policies as defined in shoreline management plans and also assuming a scenario of no active intervention to simulate the natural behaviour of cliffs. Projections are provided for stretches of coast that are sub-divided into a series of cliff behaviour units (CBUs). Where defences are present, NCERM always takes 55 years as the maximum residual life for defences in line with Defra guidance. NCERM assumes that following the failure of defences and re-activation of erosion the recession rate will initially accelerate. The acceleration takes place until the receding coastline 'catches up' with the point that it would have reached if it had been undefended and allowed to erode naturally. Following this, coastline recession will continue at the normal predicted rate for the epoch under consideration. This is a realistic interpretation of the likely response of a coastline which has been defended for a long time becoming re-exposed to marine processes, although there are limited case studies of this process.

Over each time period, results are presented that show 5%, 50% and 95% probability losses from erosion, which account for uncertainty associated with cliff recession processes and impacts of climate change and sea level rise. The default cliff recession data on which projections are based are taken from the Futurecoast project (Halcrow 2002) and historical data held in current shoreline management plans (SMP2). However, prior to public release, a comprehensive validation process was undertaken allowing local authorities to review, and where necessary update, the historical cliff recession rates. Projections of cliff recession are taken from a baseline 'coastline' that was digitised from current Ordnance Survey mapping. In many places of active coastal change, the Ordnance Survey is not an accurate representation of the 'coastline' and consequently it is important to check the baseline from which NCERM is projecting erosion. In the case of Filey Brigg, when the NCERM coastline is compared to the 2010 aerial imagery, it is clear that there are a number of inaccuracies including sections of coast that are currently further seaward and further inland than NCERM indicates, due to inaccuracies in OS data. On an individual CBU basis, these errors are generally insignificant and to not invalidate the overall results. NCERM recognises three types of coastline:

- **erodible coasts** that have simple cliffs or landslides that behave in a predictable manner, which can be assessed using NCERM.
- **floodable coasts** that are low lying areas identified by Environment Agency flood maps. They are not subject to erosion and are not covered by NCERM. Floodable coasts are not considered further in this methodology.
- **complex cliffs** that behave in a non-linear way with multi-tiered landslides that are difficult to predict through simple extrapolation of historical recession rates.

Complex cliffs and relict cliffs are not covered by NCERM and require more careful analysis on a case-by-case basis

The 15 CBUs in the Filey Brigg study area are all classified as 'erodible coast' and none are currently defended. In all cases, the SMP policy over all timescales is no active intervention (NAI).

The NCERM projections for the Brigg over the next 20, 50 and 100 years are shown in Figure 16, Figure 17 and Figure 18. In each case, the 5, 50 and 95% probabilities are highlighted.

Figure 16. NCERM 20 year projection

NCERM does not make projections for periods beyond the next 100 years. The figures show:

- very little change is projected along the Brigg over the next 20 years and the cliff top footpath will remain intact under all probability scenarios. More significant erosion is projected for the coastline to the west and south of the Brigg, but outflanking is not indicated.
- very little change is also projected along the Brigg over the next 50 years, with the cliff top footpath remaining intact under all probability scenarios over this time. More significant erosion is projected to continue to the west and south of the Brigg, but outflanking is still not indicated. At this time, the view of the Brigg from Filey will be, broadly speaking, unchanged.

- more significant erosion of the Brigg is projected over the next 100 years and it is likely that the feature will change considerably affecting the view from Filey and access to the cliff top path. There is a 50% probability of Carr Nase being split into two sections by retreating mudslide headscarps, meaning the cliff top footpath will be impassable. There is a 5% probability of the whole Brigg being outflanked by cliff recession at its western end, meaning the cliff top path will be lost and the view will change considerably.

Figure 17. NCERM 50 year projection

3.3.1 Comparison of new data and NCERM

When the NCERM projections are compared to the new data presented above, it is evident that the baseline 'coastline' from which NCERM projects coastal change is inaccurate, being c. 10 to 20m too far seawards at a number of locations on the north side of the Brigg. Other differences relate to the mapping of CBUs and the historical recession rates applied to each. In detail, a comparison of the projections shows:

- Both approaches project similar change over the next 20 years, with only limited erosion that does not lead to loss of the footpath or a significant change in the profile of the Brigg
- There are differences in the projections over the next 50 years, with NCERM showing little change, but the new analysis indicating possible loss of the cliff top path at locations. The differences between the projections are primarily caused by inaccuracies in mapping of the NCERM coastline.

- Over the next 100 years, both projection approaches indicate significant change to the Brigg and loss of the cliff top footpath. NCERM indicates a 50% probability of the footpath being severed in one location and a 5% probability of it being severed in two locations. The new data suggests that a more significant section of footpath will be lost even in the low scenario. Over the next 100 years, the view of the Brigg from Filey is likely to change significantly, with the plateau being shortened and dissected by mudslides to form a series of ‘pinnacles’.
- NCERM does not provide erosion scenarios beyond the next 100 years. However, the 100 year projection for the western part of the Brigg where it joins Filey Bay shows significant erosion, which suggests the till capping of the Brigg (i.e. Carr Nase) will be outflanked and subsequently eroded over the next 1,000 years. This inference is supported by the new cliff recession data. The morphology of the Brigg is therefore likely to change considerably over this time period and a low, narrow rocky promontory is likely to evolve.

Figure 18. NCERM 100 year projection

3.4 Visualisations

Based on the combined results of the cliff recession analysis, a series of visualisations have been prepared. These are based on the central estimate recession distance for the time periods 50, 100 and 1,000 years after present (Figures 19, 20 and 21). A visualisation for the next 20 years has not been presented as limited change is expected to occur.

Figure 19. Projection for the next 50 yrs viewed from Coble Landing

Figure 20. Projection for the next 100 yrs viewed from Coble Landing

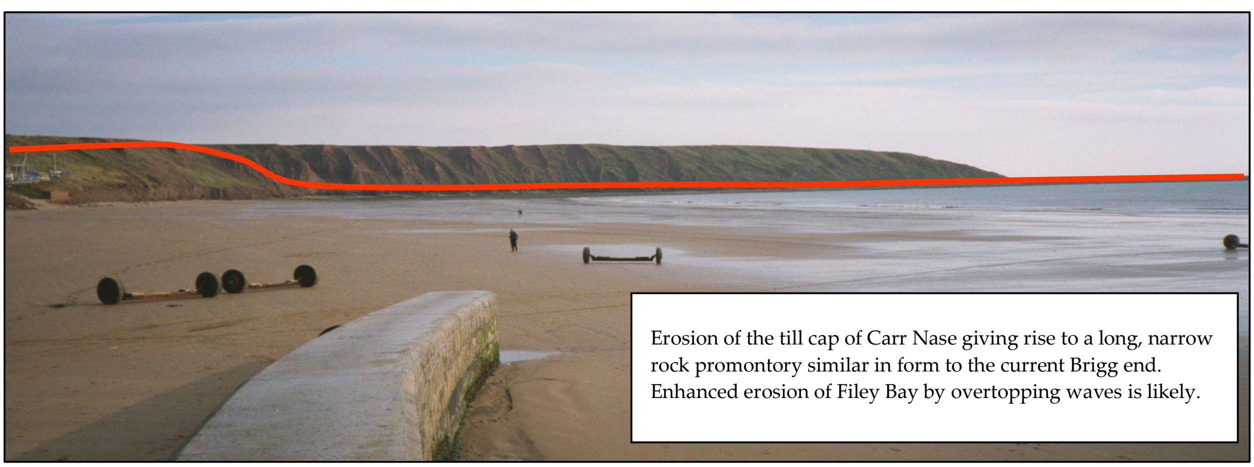


Figure 21. Projection for the next 1,000 yrs viewed from Coble Landing

4 Conclusion

This report provides a new geomorphological assessment of Filey Brigg (i.e. the landform that comprises the till plateau Carr Nase and the rocky promontory of Filey Brigg). Using remote sensing data from the 2010 coastal monitoring aerial survey a new geomorphological map is presented, together with up-to-date mapping of cliff behaviour units (CBUs) and an accurate cliff top line. The results show that Carr Nase is a till ridge that rests on a gritstone promontory that dips to the south at c. 5 degrees. This southerly dip means the CBUs on north and south sides of Filey Brigg are different: those on the north face are composite cliff units comprising vertical gristone cliffs 15 to 25m high, overlain by 20 to 25m of till, while those on the south side are simple cliffs/landslides that comprise 40 to 45m of till. The till cliffs on both sides of the Brigg are subject to episodic mudslide activity. A review of climate change and sea-level rise projections at the site are presented and their impact on the coastline is commented on.

These data underpin an assessment of historical coastal change at the Brigg, which makes use of historical Ordnance Survey maps and rectified aerial photography. Much of the historical data are of poor quality for coastal change assessments, due to uncertainty in the mapping of the cliff top in old maps and low accuracy rectification in aerial photography due to poor ground control on the Brigg. Consequently, projections use long-term average rates of change, which allow errors to be minimised. Error has been further reduced by projecting change based on average rates of recession for the north and south sides of the Brigg, rather than on single measurements that may be erroneous. Projections are made using these data for the periods 20, 50 and 100 years from now. In each time period, high, medium and low recession scenarios are presented, based on the historical database and the likely impacts of climate change. A projection for the next 1,000 years is also presented as a guide of the likely form of the Brigg at this time. The results of the new projections are then compared to results from the national coastal erosion risk mapping project (NCERM), which forms part of the Environment Agency's 'what's in my backyard' webpage. NCERM provides projections of coastal change for the same time periods as above at 5%, 50% and 95% probability estimates, which are equivalent to the high, medium and low scenarios.

The two sets of results are in broad agreement and indicate localised erosion in 20 years time that has only a limited effect on the profile of the Brigg, or access along the cliff top footpath. By 50 years, both projections indicate that mudsliding will have caused headscarps on the north and south sides of Carr Nase to coalesce and sever the cliff top path. At this time, the overall length of Carr Nase is projected to reduce from direct wave erosion. By 100 years from now, ongoing mudsliding is projected to have eroded much of Carr Nase, leading to loss of the footpath and formation of isolated pinnacles of till where it is at its widest. NCERM indicated significant erosion at the western margins of Carr Nase suggesting that the feature may suffer from outflanking. By 1,000 years, mudsliding and sea-level rise is expected to have eroded the till forming Carr Nase leaving the underlying gritstone bedrock as a low and narrow promontory. This feature will be similar to the sub-tidal rocky outcrop of Filey Brigg and will have north facing cliffs up c. 20m high in the west (where Carr Nase currently joins the main coastline) dipping to 0m OD to the east. At this time, erosion of cliffs in the north of Filey Bay is expected to be higher than present as the protective effect of the Brigg is removed.

Appendix A Historical aerial photos

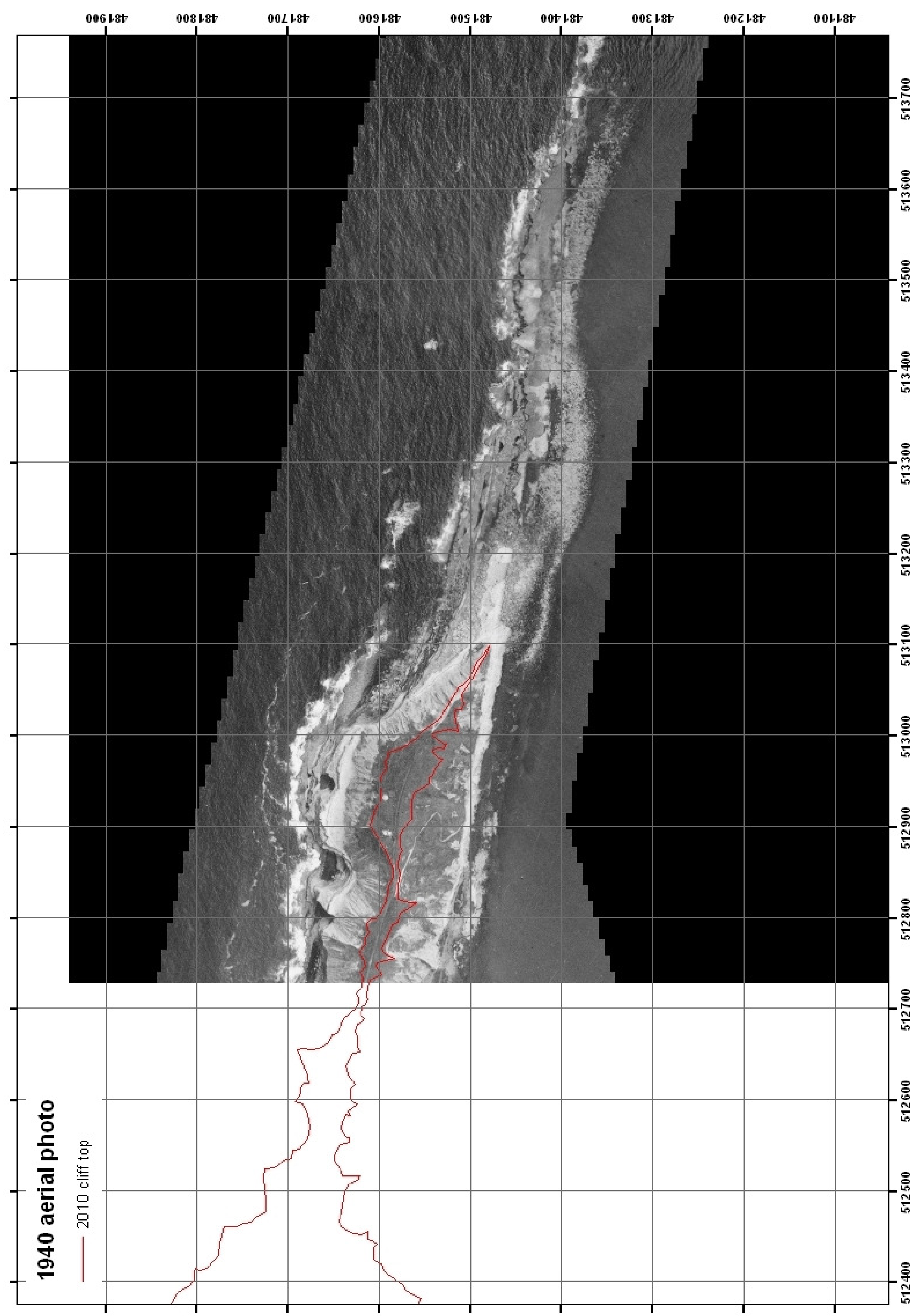
Photo date	Source	Copyright holder
1940	English Heritage National Monuments Record	National Monuments Record*
1967	English Heritage National Monuments Record	National Monuments Record*
1988	English Heritage National Monuments Record	National Monuments Record*
1999	Scarborough Borough Council	Scarborough Borough Council
2008	Scarborough Borough Council	Scarborough Borough Council
2010	Scarborough Borough Council	Scarborough Borough Council

*Copyright of these data is retained by the National Monuments Record. The data may be used for internal purposes or private research. The data must not be copied, published or otherwise made available without the written permission of the National Monuments Record at the following address:

NMR Enquiry and Research Services, English Heritage, The Engine House, Fire Fly Avenue, Swindon, SN2 2EH.

Tel: 01793 414600

Fax: 01793 414606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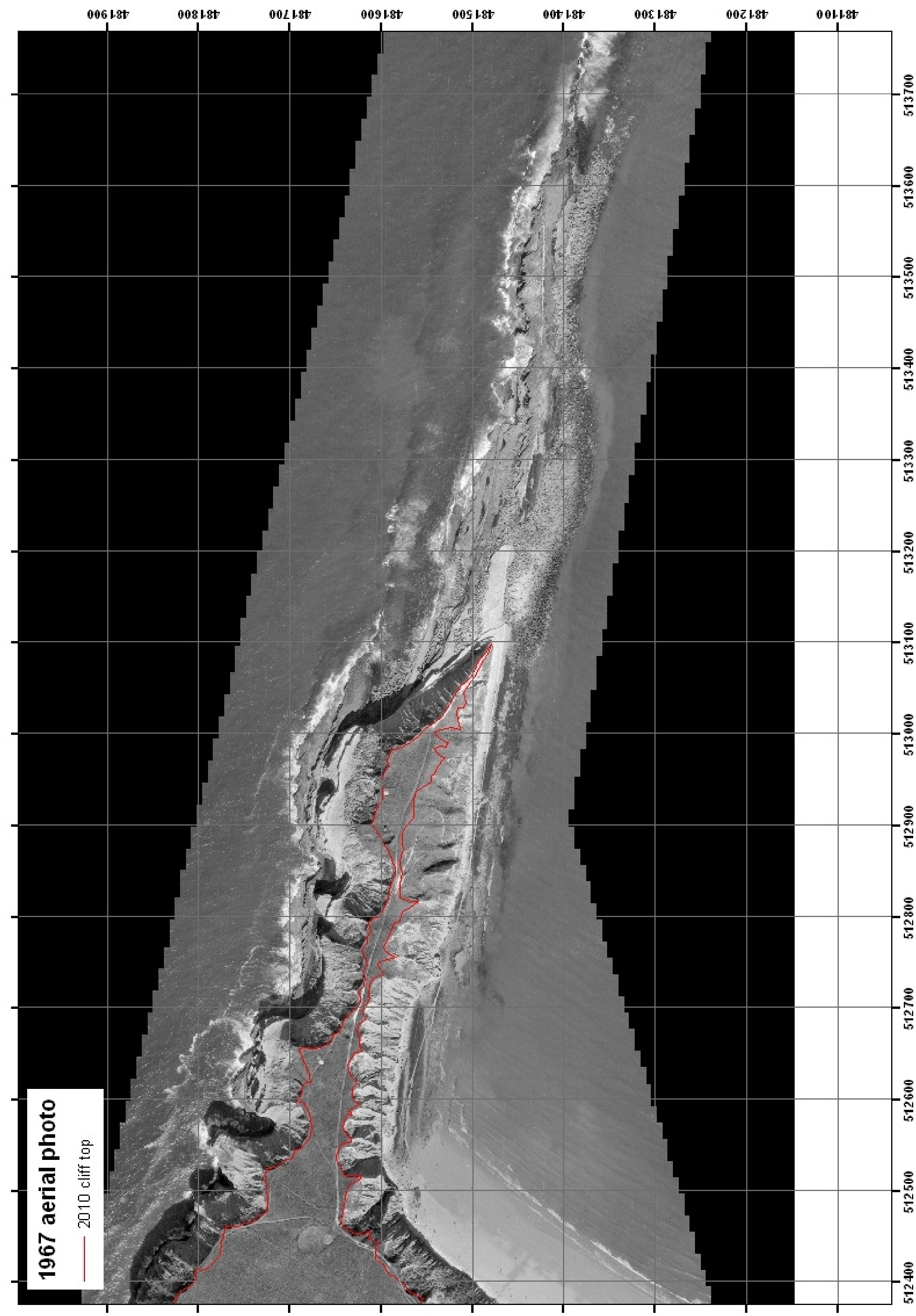
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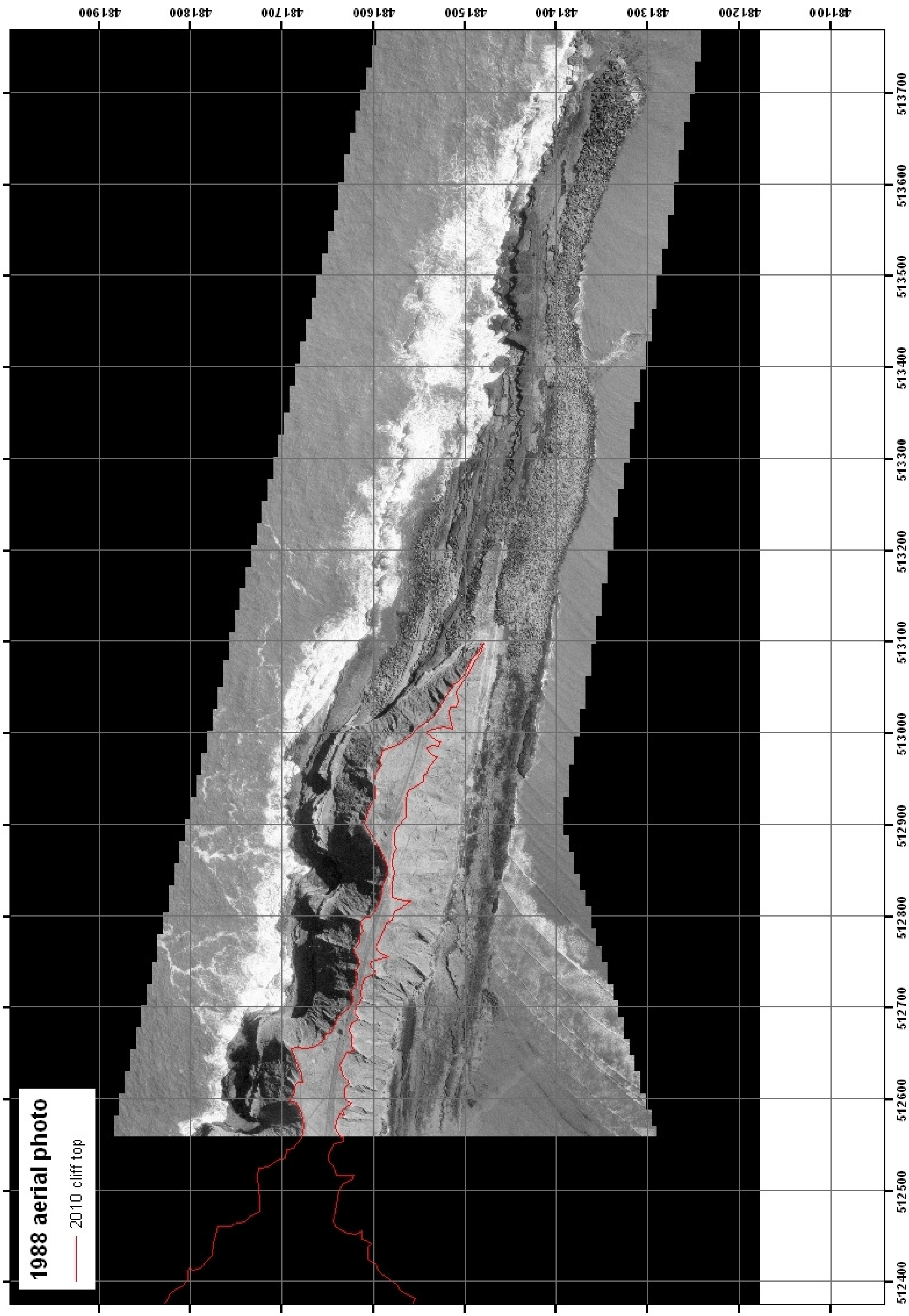
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1999 aerial photo
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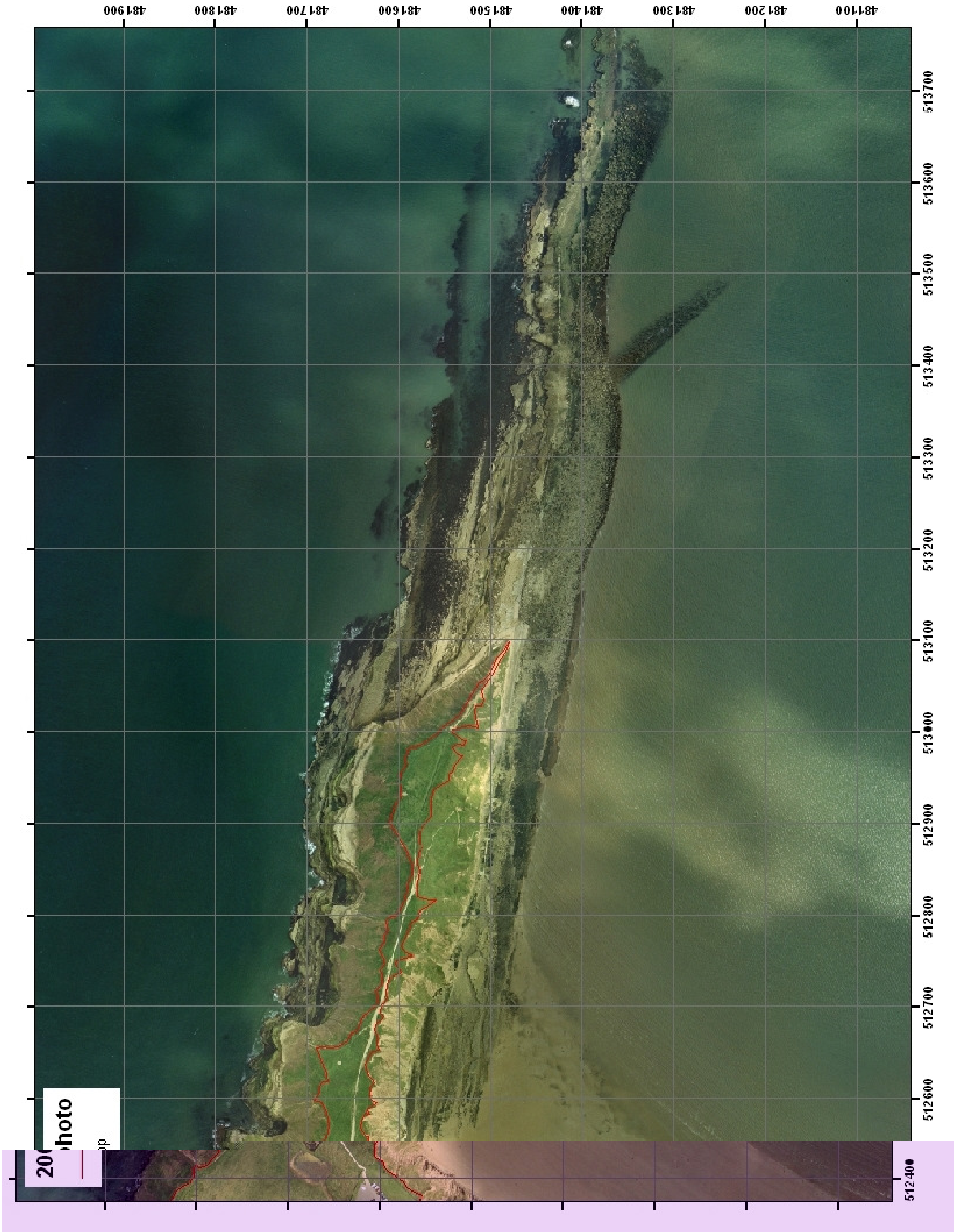
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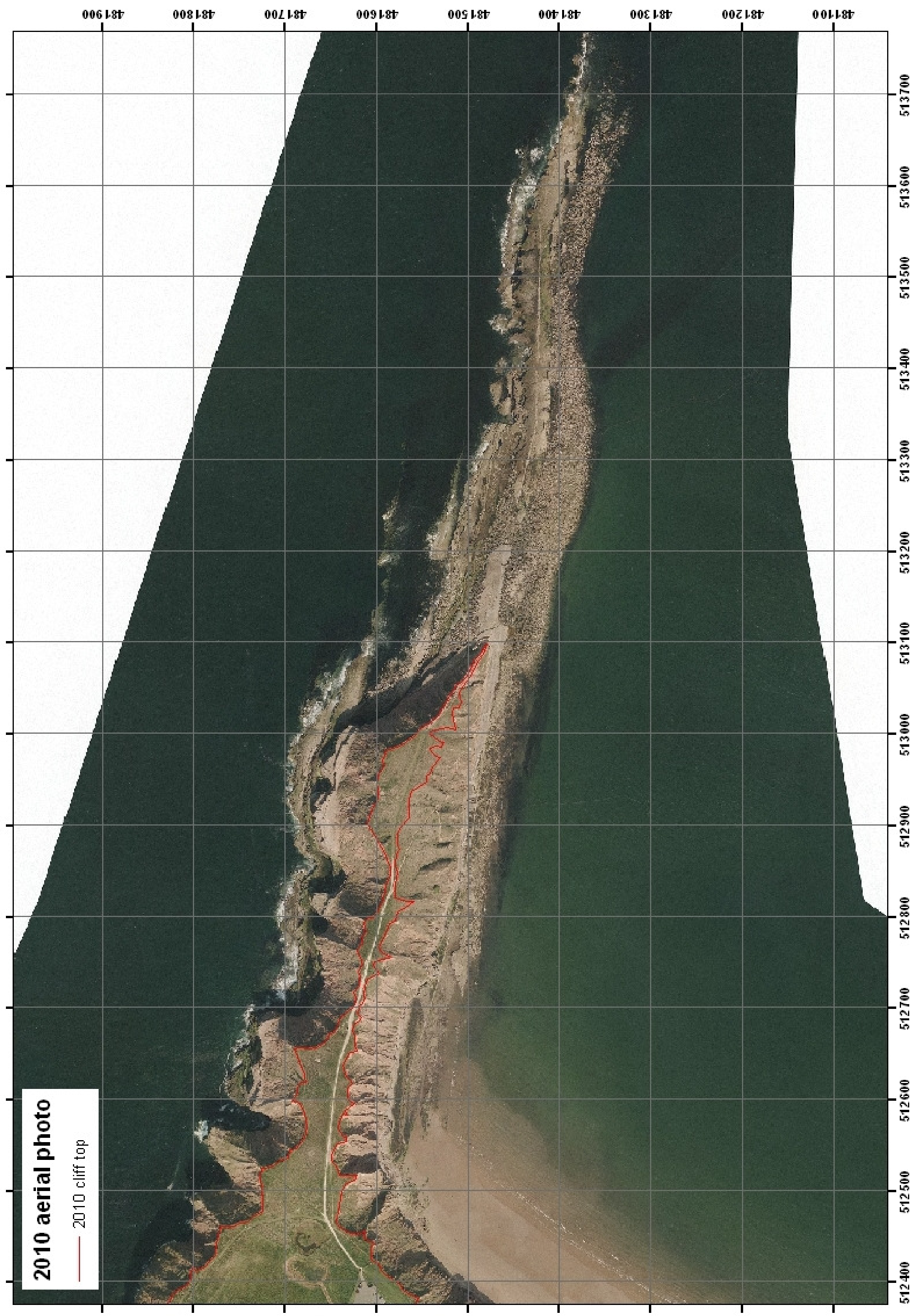
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