COWBAR COASTAL CLIFF MONITORING
STAITHES, N. YORKSHIRE

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Redcar and Cleveland Borough Council

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1. CONTEXT

- This report summarizes the Year 3 results from an ongoing monitoring program at Cowbar Nab, Staithes, North Yorkshire.
- The monthly monitoring program began in January 2011, and aims to build up a high resolution dataset on cliff face erosion.
- This report considers the results of the study up until March 2014.
- This report establishes the rate of erosion using the best attainable data, and uses this to highlight features observed in the nature of erosion as and when they arise.
- The monitoring program is being undertaken for and on behalf of Redcar and Cleveland Borough Council.

2. EXECUTIVE SUMMARY

The following tasks have been completed as part of this project in Year 3:

- Monthly high-resolution terrestrial laser scans of the cliff at Cowbar Nab have been undertaken, ongoing since January 2011, from a single position on the foreshore during low tides. Twelve (12) approximately monthly surveys were conducted during this period when tidal conditions allowed.

- Constant monitoring of the site is undertaken using a 3-axis seismometer, and a cliff face environmental monitoring system, allowing environment conditions and the timing of failure to be identified to explain the erosion data presented herein.

- The instrumentation is complemented by an innovative permanent terrestrial laser scanning system to observed changes to the cliff on a daily basis to locate rockfall on a day-to-day timescale. The installation of this equipment is now subject to removal upon request of the landowner.

The following data have been calculated for Year 3:

- A total volume of 460.53 m^3 in 4,815 discrete rockfall events occurred during this period.

- **The area averaged rate of retreat observed in the period March 2013 – March 2014 was 0.519 x 10^{-3} myr^{-1}**.

- **The modeled rate of retreat in the period March 2013 and March 2014 was 0.804 x 10^{-3} myr^{-1}**.

- The lowest monthly volume of rockfall was observed in October 2013 (0.284 m^3).

- The highest monthly volume of rockfall occurred in April 2013 (366.760 m^3).

- The maximum depth (relative to the cliff face) of any single rockfall observed on the cliff face during this period was 2.80 m, which occurred 6.7 m above the cliff toe above a previously undercut section.

- A notable rockfall sequence occurred during the early months of this monitoring period, contiguous with an area of previous failure. In total, this area lost 325.52 m^3 during this monitoring period (equivalent to a cube of dimensions 6.879 m, and 70.68 % of the total rock volume lost during this year). Note that some of the 'event' was captured in the Year 2 report.

- In response to the occurrence of this event, the monitoring frequency was increased to weekly intervals for a period of 4 weeks to mid-May, and then reduced after analysis of this data showed a reduction in the rate of rock loss from this section of the cliff face. Whilst there is no evidence in the monitoring data of the development of a deeper-seated failure, which would threaten the road and / or houses, the area that has experienced the largest rockfall beneath Cowbar Lane has undergone a sequence of change since the start of monitoring, and this is likely to continue. The general trajectory of the development of this failure is up- and across-cliff. The cliff profile in this location is overhanging. Failure depths up to 2.8 m upon this near-vertical cliff have been observed. As this area develops it is likely that failures will continue to this depth and magnitude.

- More widely, failure has been concentrated upon the rock cliff face itself, and no discernable change in the position of the cliff line above was observed during this period.

- Considerable month-on-month variability was observed (standard deviation in monthly total rockfall volumes = 103.9 m^3), with some months (October 2013) showing almost no discernible change.

- The spatial pattern of erosion is commensurate with marine driven erosion at the toe of the cliff, in addition to the continued failure of previously active areas of the cliff expanding. Work on the nature of this process, included outputs from monitoring at Cowbar has been published in Rosser et al., 2013.

- Propagation of existing failure scars, both vertically and laterally, is observed, and such features are likely to continue to develop in this manner in the future. We note that failures from previous years now coalesce, identifying areas of potential future failure.

- The widely jointed sandstone close to the crest of the cliff remains relatively intact compared to the shales and limestone beneath. Failure of the sandstone is likely to be less frequent but of larger magnitude, based upon our observations, which may lead to retreat of the cliff line.

- We observe minimal rockfall directly above the section of rock armor.

In comparison to Year 2, we observe:

- **Area average erosion rates was 37% of that in Year 2.** This decrease is significantly influenced by both the single rockfall reported above, in addition to an extended period of relative quiescence in rockfall activity since, in addition to overprint of interannual variability.

- **Modelled erosion rates show a 107% increase.** This increase represents interannual variability and accounts for the occurrence of the single rockfall reported above.

- The location of erosion in Year 3 is contiguous with areas of the cliff face that experienced erosion in Years 1 & 2, suggesting continued failure, propagation of rockfall scars and erosion of these areas during this most recent period.

The long-term (Year 1 to Year 3 end) erosion rates are as follows for the 39 months of monitoring at this site:

- **39 month area averaged erosion rate is 1.339 x 10^{-3} myr^{-1}.** This rate is based purely on the rockfalls we observe at site.

- **39 month modeled erosion rate is 1.293 x 10^{-3} myr^{-1}.** This rate considers the full range of possible rockfall sizes at this site, and will stabilize over time as a more complete range of event sizes is recorded. This approach overcomes the limitations of monitoring only a small area / non representative sample, during a limited time period (see: Barlow *et al.*, (2012) for methodology).

- Since the start of monitoring we observe a total of 906.542 m^3 of rockfall, sourced from 38,925 discrete rockfall events identified from monthly sequential monitoring. Note that the number of discrete areas of rockfall will reduce through time, as failure scars coalesce. Note also that figures provided in interim reports disaggregated volumes by weekly scan intervals, and so effectively double count volumes as compared to monthly scans.

- On average 1,156 discrete rockfall events occur at this site each month (in volumes > 2.5 x 10^{-4} m^3).

- The average monthly volume of rockfall is now 38.22 m^3, equating to 0.17 m^3 / month / m of coastline (equivalent to a cube of dimensions 0.55 m).

- The monthly volume of rockfall for this section of cliff remains on average lower than that observed elsewhere along this coastline (see: Rosser *et al.*, 2013), most likely due to the relatively low (< 30 m) cliff height. Retreat rates per unit area between this site and other monitored elsewhere on this coastline remain comparable in proportion to the cliff height / available rockfall source area.

The following conclusions have been drawn based upon our analysis of monitoring to date:

- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The reduction in rates of erosion reported here represents variability widely observed on such cliffs. This monitoring period demonstrates the possibility for larger-scale rockfall at this site.

- The rates of erosion observed at this site within each month are heavily influence by a low number (commonly < 3) of larger (> 1 m^3) rockfall. Where no such event occurs in any given month, the retreat rates are accordingly low. This year periods with no large events showed very low rates of averaged erosion.

- Continued analysis of the environment data shows limited correlation between environmental forcing and the erosion rates derived. The smallest events show some relationship; the largest events do not. The dominance of largest event on the mean erosion rates will continue to limited such correlation until a longer data set has been established, but in this monitoring period the contribution of the largest rockfall was countered by 8 months of relatively low rockfall activity.

- The concentration of erosion remains focused away from the ‘pinch points’ at this site, although a focus of activity is developing to the East of the rock armor. We also note that there were only a small number of rockfalls sourced on the section of cliff protected by the rock armour.

- No loss of cliff line was observed during this period, although critically this indicates cliff steepening via rockfall beneath, which will in time result in failure of the cliff top in future. We observe a sequence of larger failures, the development of which should be considered over the coming monitoring period.

- We will continue to refine the monitoring approach at the site, which in the forthcoming period will include real-time processing of the permanent scanning data, and a numerical analysis of the micro-seismic monitoring data.

3. MONITORING RESULTS

a. MONITORING RESULTS YEAR 3

- Table 1 summarizes the survey results from monitoring between January 2011 and March 2014, and reports the results from March 2013 to March 2014. Months since the beginning of the monitoring program (January 2011) are named 1, 2, 3 . . . to 39, with the corresponding date of the survey. The length of each survey epoch is calculated in days since the previous survey, and days since the first survey. For each month the total number of rockfalls and the cumulative total volume of rockfalls measured during this period are calculated, using the method described in previous reports.

- Total change between March 2013 and March 2014 is shown in Figure 1.

- Total change since the start of monitoring (January 2011) is show in Figure 2.

- The following erosion rates are calculated in two ways: (1) The total rockfall volume is averaged across the survey area. This is the conventional and widely used approach, but does not consider the limitations of small sample size, duration or survey area, and hence how representative the observations are of longer term behavior. (2) The modeling approach considers all possible rockfall sizes and overcomes the limitations of a small sample size and monitoring area, and therefore is considered to be more representative of long term behavior. We expect the area average and the modeled erosion rates to converge over time as a wider range of event sizes are included in the analysis.

- The total number of measured rockfalls between March 2013 and March 2014 was 4,815, with a total volume of 460.53 m^3. This equates to an area averaged erosion rate of **0.519x 10^{-3} myr^{-1}** over this period.

- The maximum monthly area averaged erosion rate was 4.979 x 10^{-3} myr^{-1} (April, 2013), and the minimum 0.004 x 10^{-3} myr^{-1} (October, 2013).

- The modelled erosion rate for this period is **0.804 x 10^{-3} myr^{-1}**, with a monthly maximum of 2.459 x 10^{-3} myr^{-1} (May 2013) and a minimum of 0.205 x 10^{-3} myr^{-1} (January, 2014). Note that in the modeling we assume a maximum event volume of 2,500 m^3, during a 100-year return period, which has not been exceeded to date.

- We highlight key features of the erosion observed between March 2013 and March 2014 in Figure 1, numbered (1) to (3), and discussed below:

- We observe several areas indicative of the continued development (failure) of rockfall scars that have previously experienced collapse (e.g. Figure 1 (1 – 3)). These are normally vertically and horizontally extensive (> 1 m), but in general shallow in depth relative to the cliff face (< 0.15 m), often associated with release along face-parallel joints or stress relief features.

- Several areas which underwent larger scale (> 1 m^3) failure in Years 1 & 2 continue to show quiescence, with minimal change on the now-exposed intact failure scar rock (e.g. area up and right of (1) in Figure 1). Whilst the fresh face of such areas remains unchanged, such features commonly are seen to extend laterally across the cliff (vertically and horizontally) albeit to a limited extent, as shown in the month by month expansion of rockfall scars (Figure 3).

- Clear evidence of marine driven toe-cut erosion via abrasion and wave hammer is visible (e.g. beneath (1) in Figure 1). This is shown in small-scale change (< *c.* 0.0001 m^3), concentrated in a zone < 2 m from the break in slope at the toe of the cliff. In certain locations, such as Figure 1(1), this abrasion is then seen to propagate vertically up the cliff, resulting in rockfall of a larger magnitude in volume.

- There is a minimal number of rockfall sourced from the section of cliff face directly above the rock armor, labelled in Figure 2, as opposed to those sections of cliff not protected by the rock armor (Figure 2(4)). Those rockfall which have occurred are relatively shallow in depth (< 0.25 m).

- Some change is observed in isolated patches on the surface of the glacial till cap at the top of the cliff. On the Eastern section of the monitored section (Figure 1 - left), much of this change is associated with vegetation growth, rather than mass movements.

- A new rockfall was noted during student fieldwork on the coast on 14th April 2013, triggering further more frequency monitoring and analysis. This data was collected after the submission of the first draft of the Year 2 report to RCBC, but was reported on in the interim due to the failure size. The key features were as follows:

    i. Approximately 27 m in cross-shore width, up to 17 m in height and up to 2.8 m in depth was released from the cliff between March 12th and April 14th (Figure 1(1), & Figures 4 – 6).

    ii. The rockfall occurred directly above an area which has been previously been observed to have experience marine undercutting, and was identified above as a potential location for future loss of material. The position of the rockfall relative to the location of Cowbar Lane is provided in Figure 7 for context.

    iii. The rockfall did not result in the loss of the cliff top at this location, although it is likely that this area will continue to fail, and rockfall scars will coalesce, in the future. The cliff is now undercut and retains a steeper angle and should be continued to be monitoring on a regular monthly basis. There is no visible evidence of a deterioration in the stability of the cliff above the location of this rockfall. Events (1) and (2) in Figure 2 have removed lateral and basal support for the rock mass above, which may in time increase the probability of failure of this section of the cliff. Failure depths to date have been up to 2.8 m, and it is likely that this magnitude of failure depth with continue.

iv. The initial volume of material lost during as a result of this rockfall was identified as 687.1 m^3. Further subsequent analysis revealed that this event multiple failures which span the 2012 – 2013 and this monitoring period as shown in Figure 3 and 6 which describe the evolution of this failure. The failure reported here was 325.5 m^3.

v. The period since this event has been quiet, with fewer rockfalls than have been observed in previous months. As a result the monitored erosion rate for years 1 – 3 is reduced as compared to that for years 1 – 2. The modelled rate is more stable as this accounts for the possibility of larger events such as this.

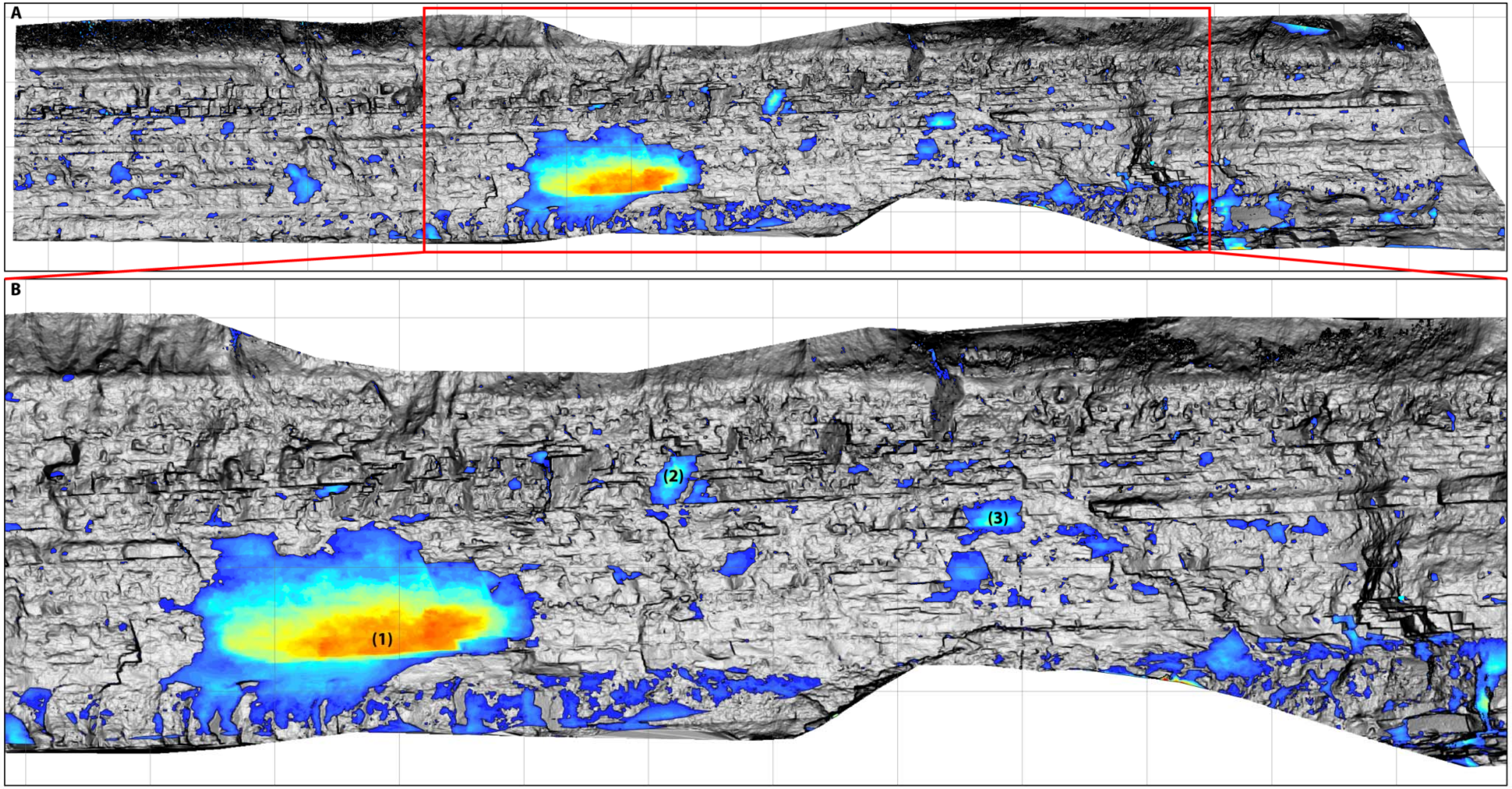

Figure 1. Monitoring erosion at Cowbar Nab between March 2013 and March 2014. **(A)** shows an elevation view of the rock cliff at Cowbar, displayed as if viewed from a point 100 m seaward from the cliff toe on the foreshore. The greyscale image is the slope of the cliff face, to provide indicative topography (hillshade), and the colours show erosion depth normal to the cliff face. Cold colours (blues) show erosion >= 0.1 m (the lower threshold of the change detection), and warm colours (orange to red) show erosion up to 3.5 m relative to the cliff face. The grid interval is 10 m in both horizontal and vertical axis. The red square delimits the extent of the area shown in B. **(B)** shows a close up view of the cliff directly beneath Cowbar Lane. The numerical labels are referred to in the body of the text.

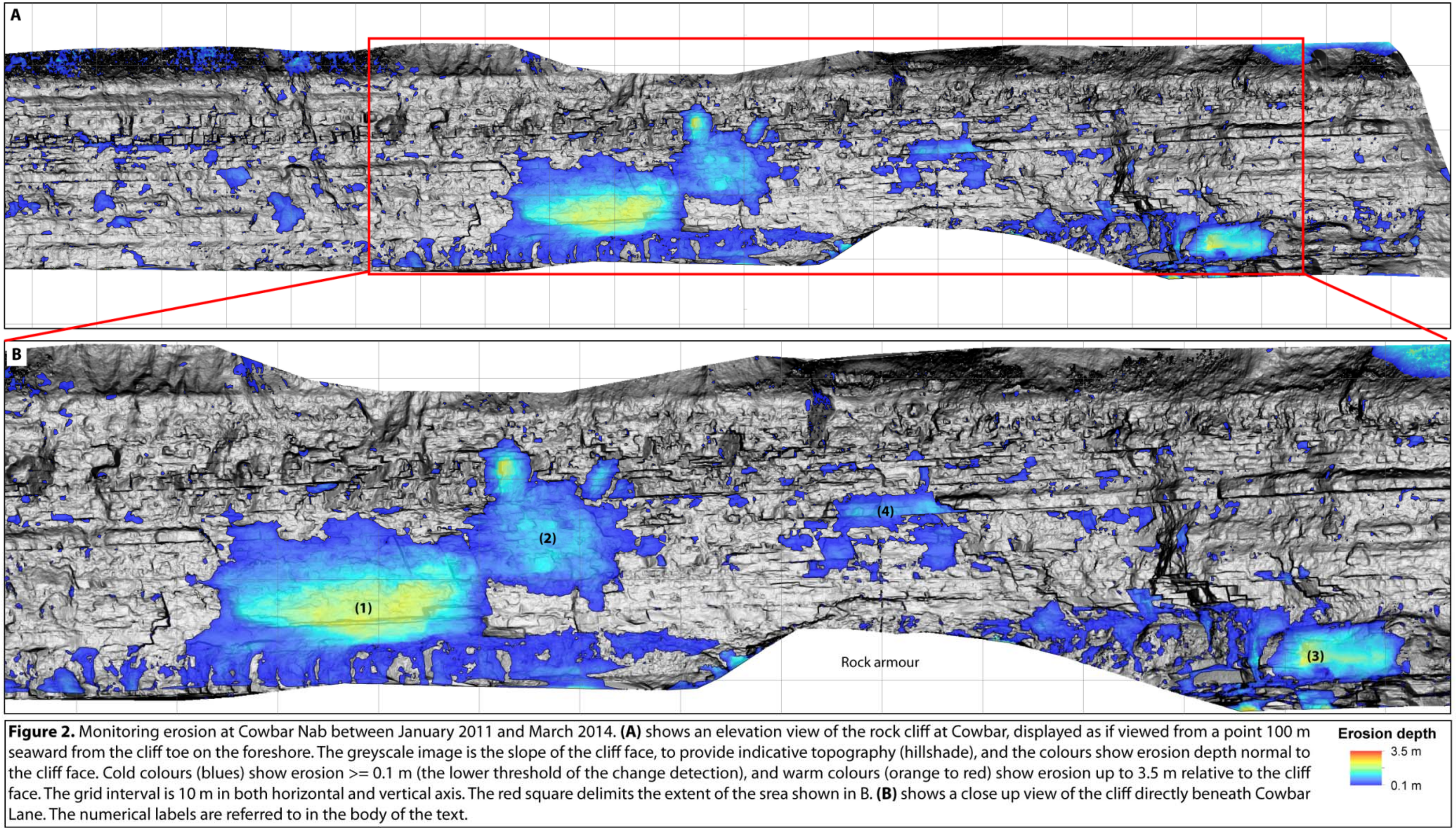

Figure 2. Monitoring erosion at Cowbar Nab between January 2011 and March 2014. **(A)** shows an elevation view of the rock cliff at Cowbar, displayed as if viewed from a point 100 m seaward from the cliff toe on the foreshore. The greyscale image is the slope of the cliff face, to provide indicative topography (hillshade), and the colours show erosion depth normal to the cliff face. Cold colours (blues) show erosion >= 0.1 m (the lower threshold of the change detection), and warm colours (orange to red) show erosion up to 3.5 m relative to the cliff face. The grid interval is 10 m in both horizontal and vertical axis. The red square delimits the extent of the srea shown in B. **(B)** shows a close up view of the cliff directly beneath Cowbar Lane. The numerical labels are referred to in the body of the text.

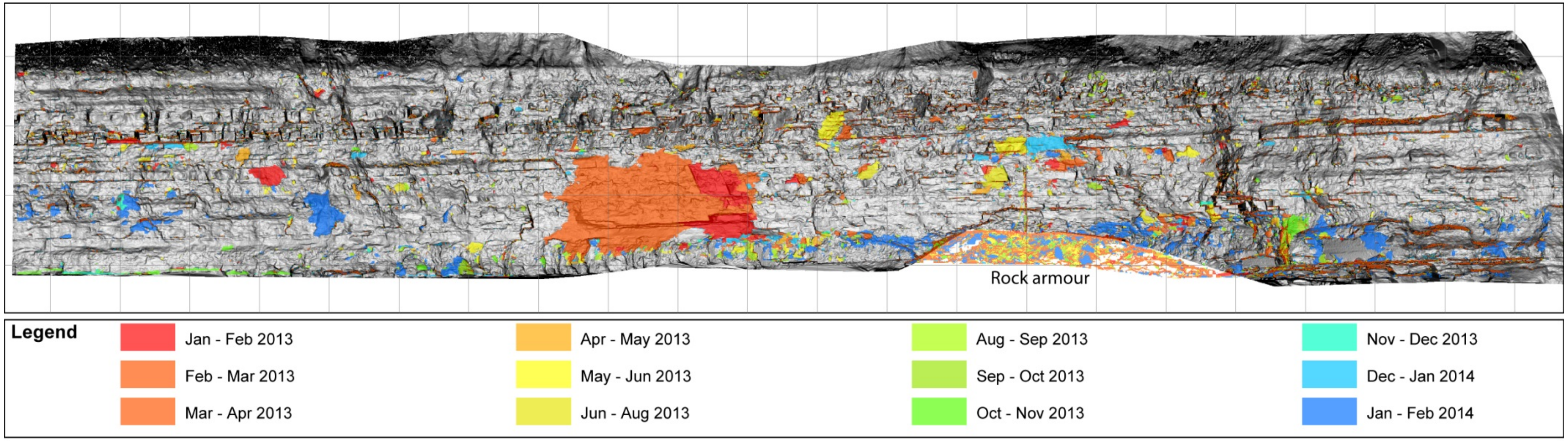

Figure 3. Monitoring erosion at Cowbar Nab between January 2013 and March 2014. The plot shows the the extent of recorded rockfalls for each month between January 2013 and the end of February 2014, each month with a unique colour. The grid interval is 10 m in both horizontal and vertical axis.

Figure 4: Photograph (14/04/13) showing the location and extent of the rockfall observed between 14th March and 14th April, with debris pile below. Note people for scale.

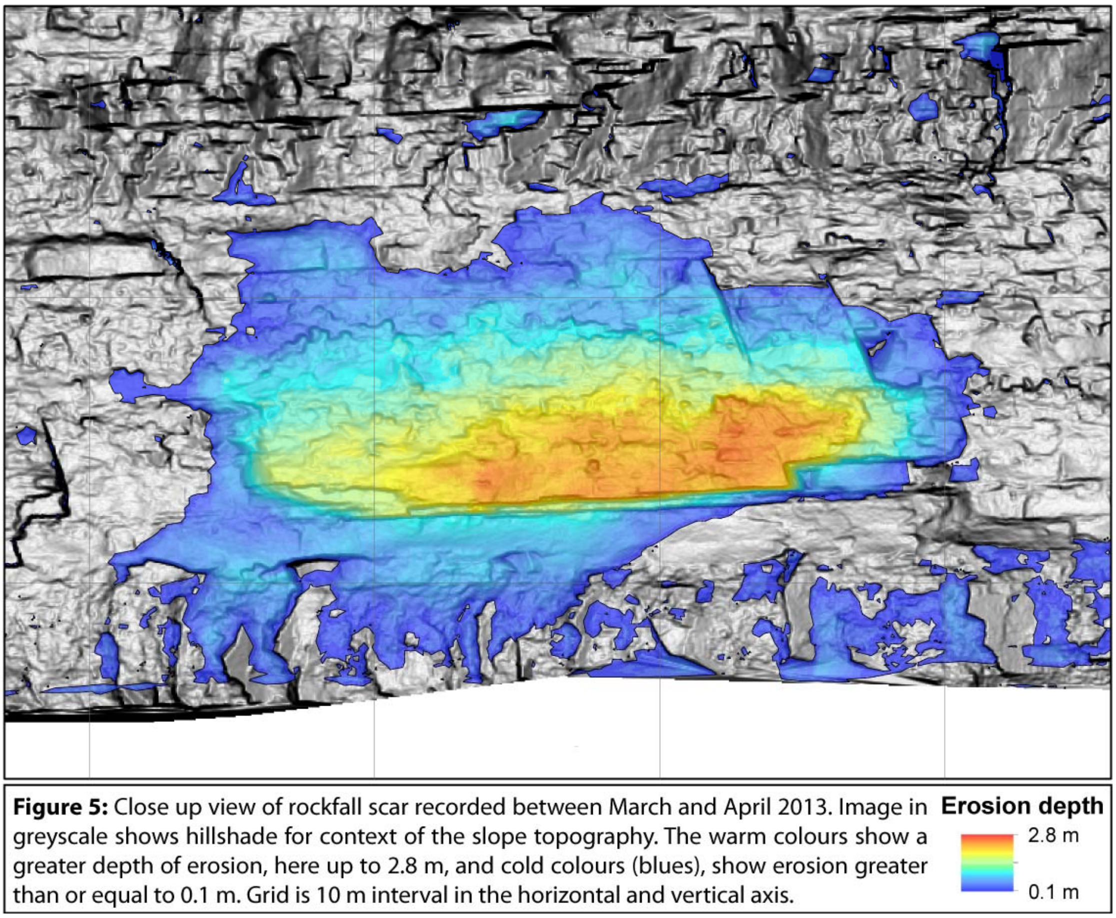

Figure 5: Close up view of rockfall scar recorded between March and April 2013. Image in greyscale shows hillshade for context of the slope topography. The warm colours show a greater depth of erosion, here up to 2.8 m, and cold colours (blues), show erosion greater than or equal to 0.1 m. Grid is 10 m interval in the horizontal and vertical axis.

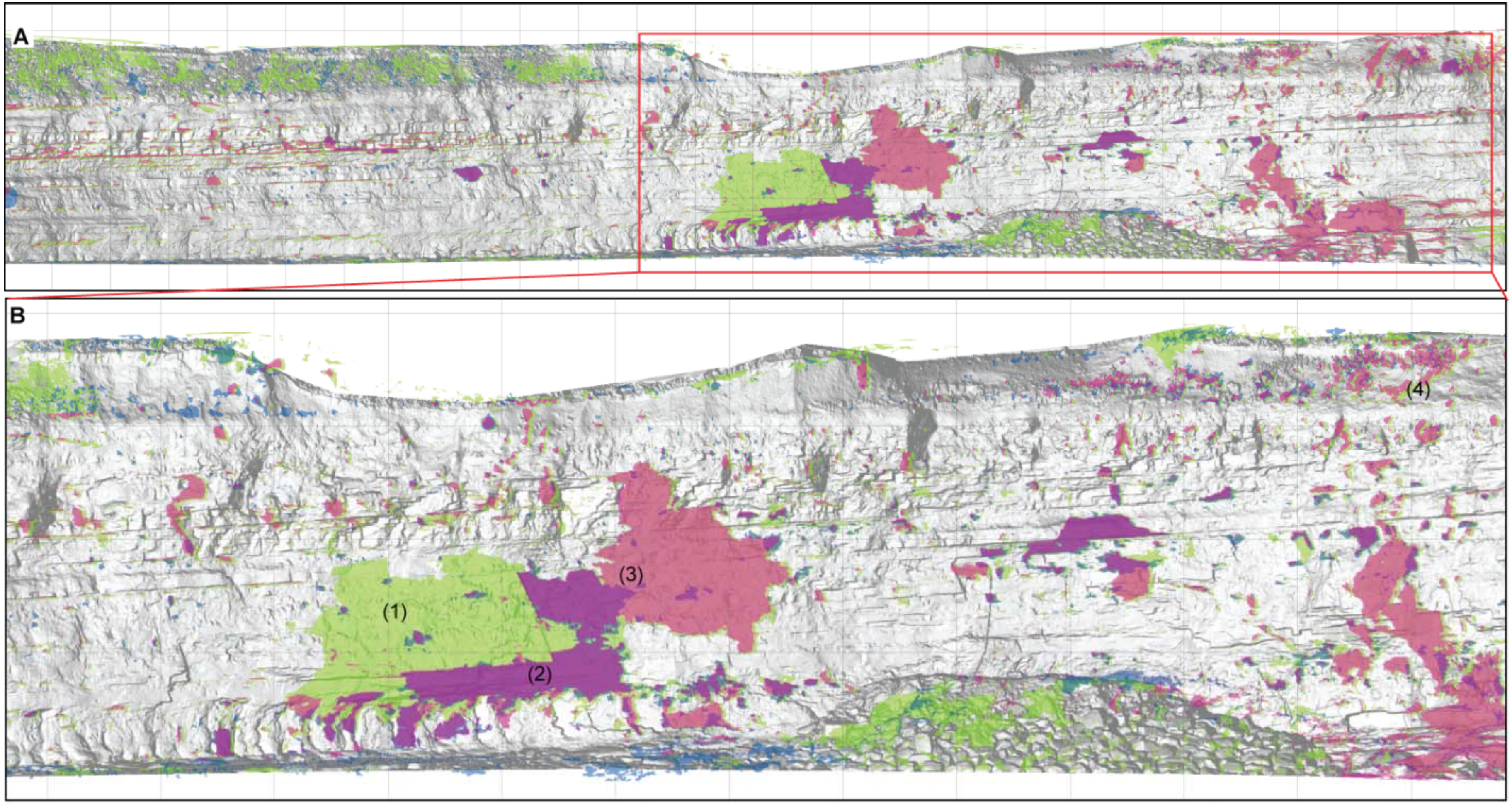

Figure 6. Areas of erosion > 0.1 m normal to the cliff face durign YEAR 1 (14th January 2011 and 26th March 2012) (BLUE), and during YEAR 2 (26th March 2012 and 12th March 2013) (RED), and during April 2013 (12th March to 25th April 2013) (GREEN). PURPLE areas change sections of the cliff face which changes in both Years 1 and 2. **(A)** shows elevation view of the rock cliff at Cowbar, as seen from a point 100 m seaward from the cliff toe on the foreshore. The grey-scale image gives indicative cliff face topography (hillshade). The grid interval is 10 m in bother horizontal and vertical axis. The red square delimits the extent of the section displayed in (B). **(B)** shows a close up view of the section of cliff directly beneath Cowbar Lane. Figure 7 gives the position of the rockfall shown above relative to Cowbar Lane.

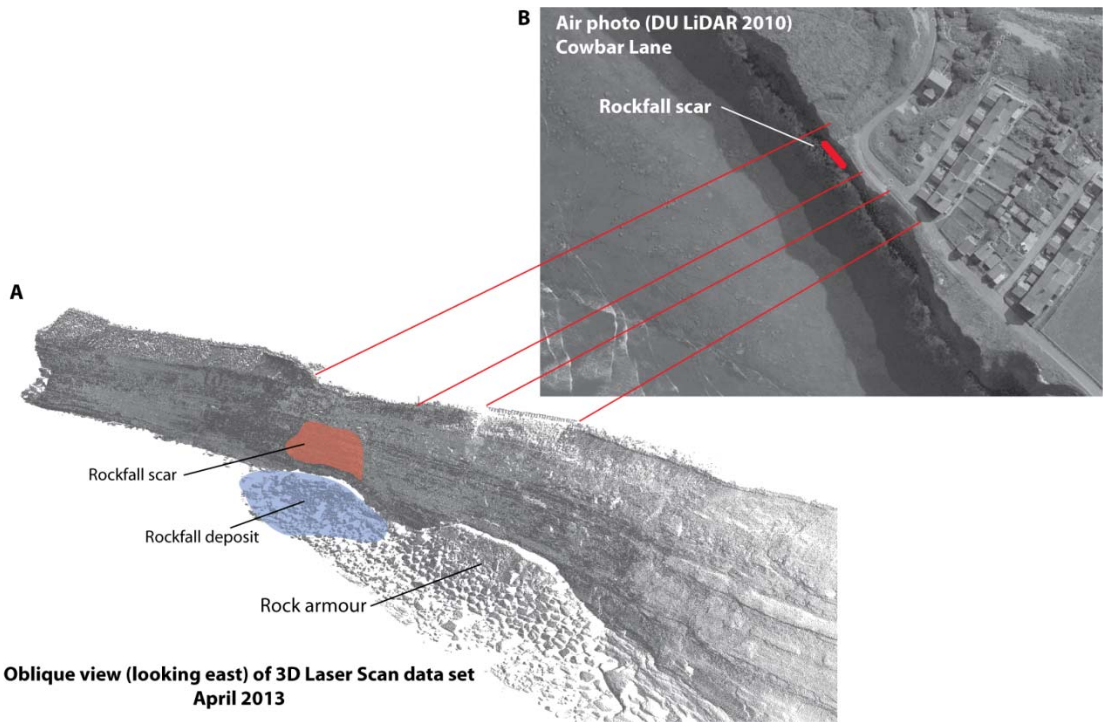

Figure 7. Location of the rockfall relative to Cowbar Lane. **(A)** shows a 3D point cloud collected from the terrestrial laser scanner, viewed obliquely. **(B)** Shows and air photo collected during a LiDAR survey in 2010.

b. COMPARISON OF YEARS 2 TO 3, AND LONG-TERM EROSION RATES

- **Area average erosion rates in Year 3 have reduced to 37% during of the Year 2 rate.** This decrease is dominated by the single rockfall reported above, and the period of quiescence thereafter, in addition to the overprint of interannual variability.

- **Modeled erosion rates show a 136% increase during Year 3 and compared to Year 2.** This increase represents both interannual variability and the influence of the single rockfall event reported above, and the following period of relatively minimal erosion.

- With the exception of the rockfall event discussed above, the location of erosion in Year 3 is almost exclusively within the same areas of the cliff face that experience erosion in Years 1 & 2, suggesting continued failure and erosion of these areas.

- The long-term (Year 1 and to Year 3 end) erosion rates are as follows:

    - **39 month area averaged erosion rate is 1.339 x 10^{-3} myr^{-1}.** This rate is based purely on the rockfalls we observe at site.

    - **39 month modeled erosion rate is 1.293 x 10^{-3} myr^{-1}.** This rate considers the full range of possible rockfall sizes at this site, and overcomes the limitations of monitoring only a small area / non representative sampling duration.

- Since the start of monitoring we have observed 906.542 m^3 of rockfall.

- On average 1,156 rockfall occur at this site each month (in detectable volumes above 2.5 x 10^{-5} m^3).

- The average monthly volume of rockfall per month is 38.22 m^3.

- The monthly volume of rockfall for this section of cliff is, on average, lower than that observed elsewhere along this coastline, most likely due to the relatively low (< 30 m) cliff height and hence more limited rockfall source area.

- We highlight key features of the erosion observed between January 2011 and March 2014 in Figure 2, numbered (1) to (4), and discussed below:

    - The largest area of failure captured in Years 1 & 2 (Figure 2 (1, 2)), continues to grow, predominantly laterally across the cliff face. The depth of the failure also increases, suggesting continued failure at this site, to a greater extent compared to that observed in Years 1 & 2. The failure is both joint (structure) and rock-strength controlled as can be seen by the jointed-limited failure perimeter, and is therefore likely to continue developing in a similar manner over coming years. At present we see no indication of continued vertical propagation of this failure which would ultimately result in a failure of the cliff line above. It should however be noted that this failure is steepening this cliff section, which over time will readjust, resulting in failure of the cliff top in the area adjacent to Cowbar Lane. The timescale over which this process may occur is not known, but we note that the highest rates of change observed occur in this location. Other similar features of continued failure are seen in Figure 2(3, 4).

- We see some areas that experience large scale failure (> 1 m^3) in Year 1, but which stall and show no additional change in Year 2 (see overlaps in Figure 6, for example).

- Toe cutting leading to rockfall above, in seen in Figure 2(3), with some evidence of a continued processes of attrition of the toe and then release of material above, where kinematically permissible. At present it remains unlikely that the depth of toe cutting is sufficient to instigate a deeper-seated failure of the rock mass above that would threaten to result in step-back of the cliff line, although continued monitoring may help identify the development of such failures. Such a step back is not beyond what is possible at this site, but remains not probable at present.

- Some evidence of small-scale slumping is seen in the glacial till, but only in isolated positions. Such failures are located in positions of steep till, with sparse vegetation. At present areas that are experiencing this type of failure, are at sections of the cliff line at the greatest distance from Cowbar Lane.

Table 2. Combined erosion rates for Years 1 to 3 for the monitored cliff section. Rates are derived using the methods outlined in the Appendix.

Year	**Month**	**Month**	**Year**	**Survey date**	**Survey epoch length (days)**	**Running total of days**	**Number of rockfalls**	**Total volume of rockfalls (m^3)**	**Area average erosion rate (x 10 -3 myr^{-1})**	**m/f modelled erosion rate (x 10-3 myr^{-1})**
1	1	January	2011	14/01/2011	0	0	0	0.000	0.000	0.000
	2	February	2011	18/02/2011	35	35	990	31.690	2.770	3.344
	3	March	2011	21/03/2011	31	66	969	31.000	2.710	2.816
	4	April	2011	28/04/2011	38	104	1036	33.150	2.900	1.716
	5	May	2011	20/05/2011	22	126	4	0.130	0.010	0.000
	6	June	2011	17/06/2011	28	154	21	0.680	0.060	0.022
	7	July	2011	21/07/2011	34	188	660	21.110	1.850	0.484
	8	August	2011	25/08/2011	35	223	560	17.930	1.570	2.684
	9	September	2011	27/09/2011	33	256	972	31.110	2.720	4.554
	10	October	2011	21/10/2011	24	280	802	25.660	2.240	4.642
	11	November	2011	17/11/2011	27	307	708	22.650	1.980	3.850
	12	December	2011	19/12/2011	32	339	207	6.620	0.580	0.176
	13	January	2012	17/01/2012	29	368	609	19.480	1.700	1.760
	14	February	2012	23/02/2012	37	405	1323	42.330	3.700	2.816
	15	March	2012	26/03/2012	32	437	1108	35.450	3.100	2.860
	Total after 1 year	-	-	-	-	**437**	**9969**	**318.990**		
	1 year average	-	-	-	**31**	-	**664.6**	**22.790**	**1.992**	**2.115**
2	16	April	2012	18/04/2012	23	460	2074	19.390	1.620	1.480
	17	May	2012	09/05/2012	21	481	1346	24.510	2.950	2.370
	18	June	2012	19/06/2012	41	522	356	3.090	0.360	0.220
	19	July	2012	14/07/2012	25	547	101	2.910	0.330	0.210
	20	August	2012	02/08/2012	19	566	334	2.540	0.390	0.210
	21	September	2012	08/09/2012	37	603	598	7.790	0.880	0.170
	22	October	2012	03/10/2012	25	628	5312	11.150	0.570	0.350
	23	November	2012	15/11/2012	43	671	3231	7.320	0.630	0.360
	24	December	2012	13/12/2012	28	699	227	12.230	0.650	0.450

	25	January	2013	06/01/2013	24	723	2891	2.850	0.510	0.140
	26	February	2013	11/02/2013	36	759	4379	20.240	5.290	1.090
	27	March	2013	12/03/2013	29	788	946	14.930	2.600	2.010
	Total	**-**	**-**	**-**	**-**	**328**	**24141**	**128.950**		
	Average	**-**	**-**	**-**	**29**	**-**	**2368**	**13.040**	**1.398**	**0.755**

	Total over 2 years	**-**	**-**	**-**	**-**	**765**	**34110**	**447.940**		
	2 year average	**-**	**-**	**-**	**31**	**-**	**1222**	**17.228**	**1.718**	**0.009**

3	28	April	2013	25/04/2013	44	832	160	366.760	4.979	1.500
	29	May	2013	23/05/2013	28	860	559	1.027	0.014	2.459
	30	June	2013	25/06/2013	33	893	251	7.225	0.098	0.234
	31	July	2013	22/07/2013	27	920	553	8.523	0.116	0.250
	32	August	2013	20/08/2013	29	949	349	6.828	0.093	0.229
	33	September	2013	17/09/2013	28	977	463	40.337	0.548	0.215
	34	October	2013	21/10/2013	34	1011	641	0.284	0.004	0.384
	35	November	2013	18/11/2013	28	1039	409	7.378	0.100	0.418
	36	December	2013	03/12/2013	15	1054	349	6.862	0.093	0.534
	37	January	2014	17/01/2014	45	1099	517	7.036	0.096	0.205
	38	Febraury	2014	18/02/2014	32	1131	309	1.743	0.024	1.127
	39	March	2014	15/03/2014	25	1156	255	4.600	0.062	2.096
	Total					**1156**	**4815**	**460.530**		
	Average				**30.7**		**401**	**38.217**	**0.519**	**0.010**

	Total over 39 months					**1156**	**38925**	**906.542**		
	39 month average				**30.4**		**963**	**23.856**	**1.339**	**1.293**

4. SUMMARY AND CONCLUSIONS – YEAR 3

The following conclusions have been drawn based upon this analysis:

- **The area averaged rate of retreat in Year 3 alone was 0.519 x 10^{-3} myr^{-1}**.
- **The modeled rate of retreat in Year 3 alone was 0.804 x 10^{-3} myr^{-1}**.
- **The 39 month area averaged erosion rate since the start of monitoring is 1.339 x 10^{-3} myr^{-1}.**
- **The 39 month modeled erosion rate since the start of monitoring is 1.293 x 10^{-3} myr^{-1}.**
- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The fluctuation of erosion rates reported above, both month-on-month and year-on-year, is commensurate with the variability in rockfall patterns observed more widely on this coastline, and beyond.
- This monitoring period has witnessed a rockfall of volume > 300 m^3. Failures of this size are a natural and expected component of coastal cliffs. We note that this area of the monitored cliff section has continued to evolve via a sequence of rockfall since the beginning of the monitoring campaign, and there is no reason to believe that this will cease in future. The trajectory of the rockfall scar appear to be both up- and across-cliff. Further monitoring and close scrutiny of the possible ways in which this failure may develop through time is recommended.
- The concentration of erosion is currently focused away from the 'pinch points' at this site. We observe continued erosion in Year 3 at areas of the cliff that underwent erosion in Years 1 and 2.
- No loss of cliff line was observed during this period, although continued rockfall at the site this indicates cliff steepening, which will in time result in failure of the cliff top. Continued monitoring will help identify where and when this may occur.
- There is no evidence in the monitoring data of the development of a deeper-seated failure which would threaten the road and / or houses above, but we do identify a pattern of rockfalls on the cliff face below.
- We recommend continuation of the monitoring to identify any deviation from the behavior experienced to date.

5. References

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6. Document control sheet

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