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Investigating Pockmark Fields in the Danish Skagerrak

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1. Summary

A pockmark field was identified in the Skagerrak Natura 2000 area during 2017. Following this further work has been undertaken to determine whether these features contain authigenic carbonate, and thus whether they constitute EU Habitat Directive Type 1180. Fieldwork was undertaken in June 2020, using the R/V Aurora, with multibeam bathymetry data, Innomar parametric sub-bottom profiler data and sediment samples acquired from two are-as known to contain pockmarks.

During this work 226 pockmarks were identified. On the basis that these features are not draped by sediments and that fluid or gas escape ‘chimneys’ are located beneath them we believe these features to be active. Pockmarks in the nearer shore Area 1 are generally more distinct, whereas those in the farther offshore Area 2 coalesce. Furthermore, a large, complex pockmark containing a prominent clay mound is identified in the southwest of Area 1.

Seven sediment samples (6 x cores, 1 x grab) were acquired and analysed in the Aarhus University Geoscience laboratory. Results indicate that the pockmarks do not contain elevated carbonate concentrations in relation to areas outside pockmarks. A comparison of two cores within Area 1 provides a mean carbonate value inside the pockmark of 4.99%, compared to 5.73% outside. However, the prominent mound, which may be related to mud diapirism, provided the highest concentrations of 13%. A core from this larger pockmark yielded mean carbonate values of 8%.

On the basis that these features do not contain carbonate structures (e.g. crusts, nodules etc.) they do not constitute habitat type 1180. However, they are fluid seeps and do represent a different habitat within the sublittoral sediments.

2. **Introduction**

During 2017 the Geological Survey of Denmark and Greenland (GEUS) undertook a geophysical survey of the Skagerrak Natura2000 area for the purposes of habitat mapping. During this work over 300 seabed depressions, or pockmarks, were identified from the geophysical data (Multibeam bathymetry and Innomar Sub-bottom profiler) with negative relief of up to 8 m and diameter between 50 and 200 m. However, visual inspection via ROV proved inconclusive. These pockmarks are potentially very significant under the EU Habitat Directive (European Commission, 2013), as Habitat class 1180 represents ‘Submarine Structures made by leaking gases’. Within the habitat description the directive refers directly carbonate structures within pockmarks, and in order for pockmarks to be classified as habitat class 1180 the need to contain carbonate structures.
However, it may also be noted that a further EUNIS habitat type, seeps and vents in sublittoral sediments (A5.71) does not require the presence of carbonates.
To determine whether the pockmarks identified in the Skagerrak during 2017 represent EU Habitat class 1180 or another seeping or venting habitat type it is necessary to determine whether there is significant carbonate within the pockmarks.
To determine this MST requested that GEUS obtain more extensive geophysical data from the area of interest (see Figure 1) as well as sediment core samples from inside and outside the pockmarks, so that an accurate assessment of the carbonate content could be made.

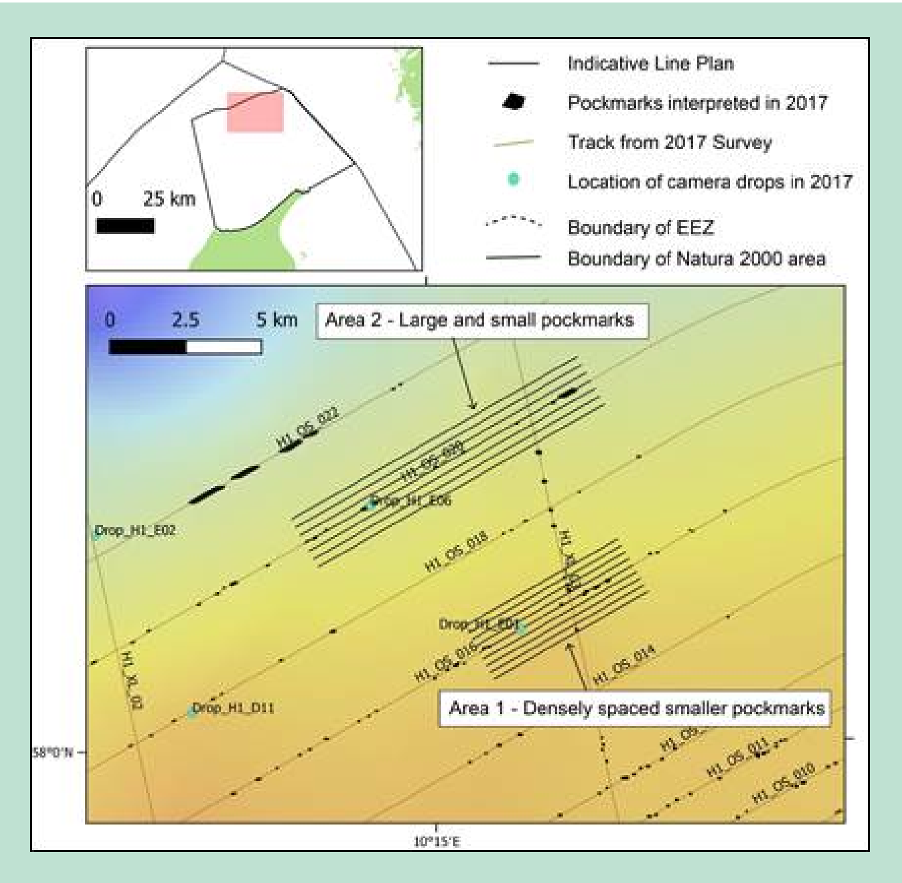

FIGURE 1. Location of area of interest within the Skagerrak Natura2000 area. Main panel shows the proposed survey line plan with the 2017 survey track and pockmark interpretation shown.

3. Methods

The following methods were proposed to MST by GEUS in early 2020 and this has formed the basis of the work undertaken:

- New geophysical survey of two pockmark areas (Area 1: 6.5 km x 2.5 km; Area 2: 9 km x 2.3 km), where distinct morphologies of pockmarks were seen in 2017. 100% bathymetry coverage and new Innomar data.
- Acquisition of sediment cores within and outside the pockmarks.

Once in the laboratory the sediment cores were to be split, XRF scanned and analysed for carbonate content to determine whether there are elevated carbonate levels within the pockmarks in comparison to the adjacent seabed (details of core positions are provided in section 3.1).

3.1. Fieldwork

Fieldwork was undertaken using the Aarhus University vessel R/V Aurora for a 24 hour survey period between the 10th and the 11th of June 2020.

Figure 2. R/V Aurora used for the fieldwork**.**

Weather conditions were fair during the survey, with some swell but this do not adversely affect the majority of the data. Due to the distance from shore (approximately 40 km) the vessel lost connection with RTK (Real Time Kinetic) height correction for the survey, and as such some additional measures (see below) were required in processing the bathymetry data. Survey operations consisted of geophysical survey (Reason 7125 Multibeam Echosounder and Innomar Compact SES Sub-bottom profiler) and sampling operations using a 3 m gravity corer, a Rumohr corer and a grab sampler. Sound velocity profiles were obtained at the start and end of the geophysical survey.
In total, one Rumohr lot core, five gravity cores and one grab sample were acquired during the operations. The Rumohr core was acquired in order to test if there was favourable conditions for using the gravity corer. Since this was the case, no further Rumohr Lot were taken. The five gravity cores (with total lengths between 262 and 280 cm) consisted of two core-pairs in

each of the two areas (Core 1 and 2 in Area 2, Core 3 and 4 in Area 1). The core-pairs were taken at representative pockmarks in the two areas, one core within and one core outside the pockmark, in order to be able to investigate variations in the pockmark sediments and control sediments outside the pockmarks. The distance between Core 1 (within pockmark) and Core 2 (outside pockmark with a distance of 200 m to the nearest pockmark edge) was 600 m, while the distance between Core 3 (inside pockmark) and Core 4 (outside pockmark, 40 m away from edge of pockmark) was 100 m (see also Fig. 8). In addition to the two core-pairs, one additional gravity core (Core 6) within a larger pockmark in the southwest of Area 1 was also acquired. This particular pockmark comprised a distinct mound from where a grab sample (Core 5) was taken (see also Fig. 8). The distance between gravity core 6 and grab sample (Core 5) was 35 m.

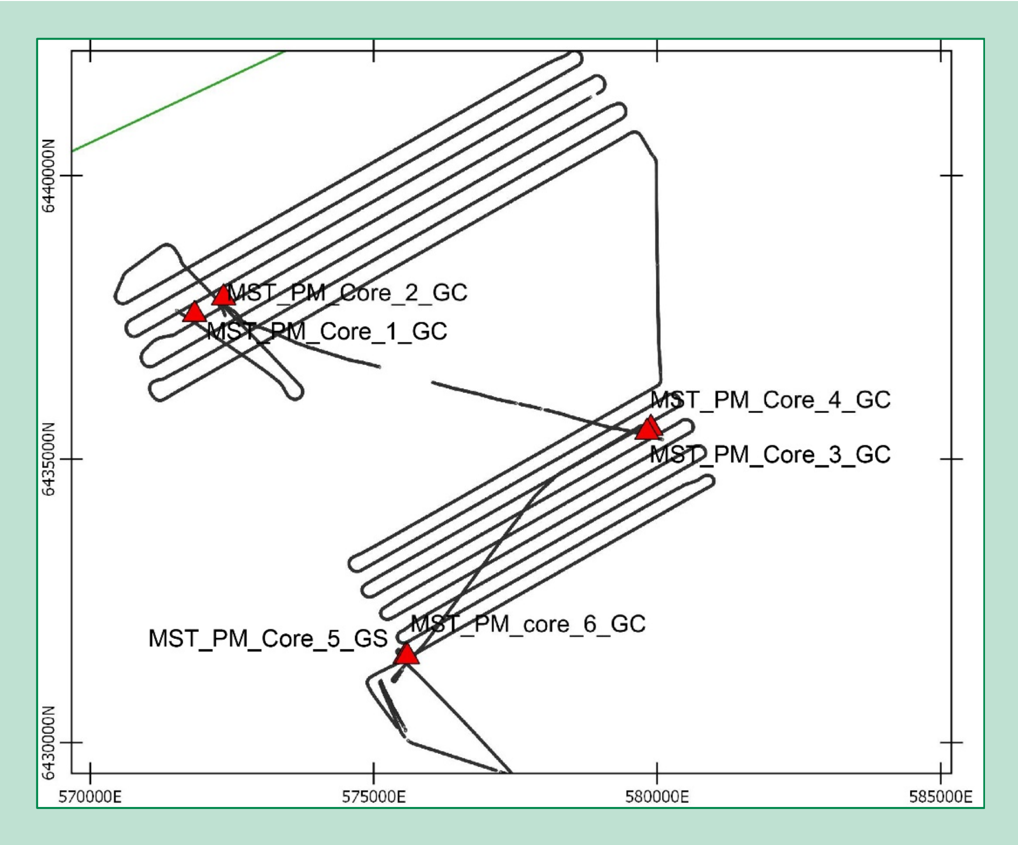

FIGURE 3. Track from the survey activity and location of cores. GC indicates gravity cores while GS indicates the grab sample

Bathymetry data was processed using EIVA Navimodel. Because of missing geoid height and RTK dropouts, there were some challenges, especially in areas of swath overlaps.
Data was translated according to the average GPS height of the area, significant spikes were smoothed. SVP corrections were applied in order to iron out frowning swaths. Manual height adjustments (up to about 20cm) on individual lines, were made (if necessary) to minimize disagreement in swath overlaps in combination with manual and histogram point cleaning. Due to the alternating GPS height solution and difficulties identifying when the RTK solution was on, it is estimated that areas with the ‘poorest’ swath overlaps has differences of up to about 30 cm in the outer swath regions, but in general error is expected to be less than this. Processed bathymetry soundings were subsequently gridded at 2 m resolution.

Table 1. Overview of geological samples obtained. Co-ordinates are WGS84 UTM zone 32N.

Core ID	Type	Easting	Northing	Water depth (m)	Core length (cm)	Comments
MST_PM Core_2_RU	Ruhmor	572354	6437698	116	85	
MST_PM Core_2_GC	Gravity core	572354	6437699	116	270	Uppermost 0.1 m lost on splitting. Upper section at 0.6 m is missing surface sediments
MST_PM Core_1_GC	Gravity core	571842	6437405	125	262	
MST_PM Core_3_GC	Gravity core	579887	6435398	115	277	Top sediments undisturbed - dark grey clay at base, olive brown at top
MST_PM Core_4_GC	Gravity core	579818	6435328	110	280	
MST_PM Core_5_GR	Grab sample	575557	6431376	100	NA	Clay, chunks, many shells
MST_PM core_6_GC	Gravity core	575592	6431372	102	270	Stiff Clay

3.2. Laboratory analysis

At the ship, the gravity cores were cut into 1-m sections (section numbers for each core denoted by roman letters I-III) to ease transport of the cores to cooling facilities at Aarhus University.
Sediment samples were analysed in Aarhus University (AU) Geoscience laboratory.
All gravity core sections were split length-wise in two halves. One half was used for sampling while the other half was photographed using the AU ITRAX core scanner, before being XRF scanned using the same facility.
For carbonate analysis, the gravity core sections were sampled at 25 cm intervals and one sample was also taken from the grab sample (Core 5). The sub-samples were oven-dried and subsequent analyses for carbonates were performed using the Hawk (Wildcat Technology) anhydrous pyrolysis carbon analysis system at the Lithospheric Organic Carbon (LOC) lab, Department of Geoscience, Aarhus University. A total of 27 samples were analysed, representing the samples from gravity core 3 and 4 and the grab sample (Core 5). Because of limited budget, gravity core 1, 2 and 6 have not yet been subject to carbonate analysis. Core 3 and 4 were selected over core 1 and 2 because they were acquired at an isolated discrete pockmark compared to core 1 and 2, that were acquired at a coalesced pockmark (please see Fig. 8).
Measurements were calibrated using the IFP 160000 standard. The accuracy and precision of measurements were better than 5%.

4. Results

4.1. Geophysics

Data acquired during the survey were of good quality and clearly identified the pockmarks on the seabed and evidence of fluid or gas escape from the subsurface. In total approximately 165 km of Innormar subbottom profiler data were acquired. Figure 4 shows an example of Innomar data from the pockmark area, here one pockmark (left-hand side) is crossed centrally and another more marginally.

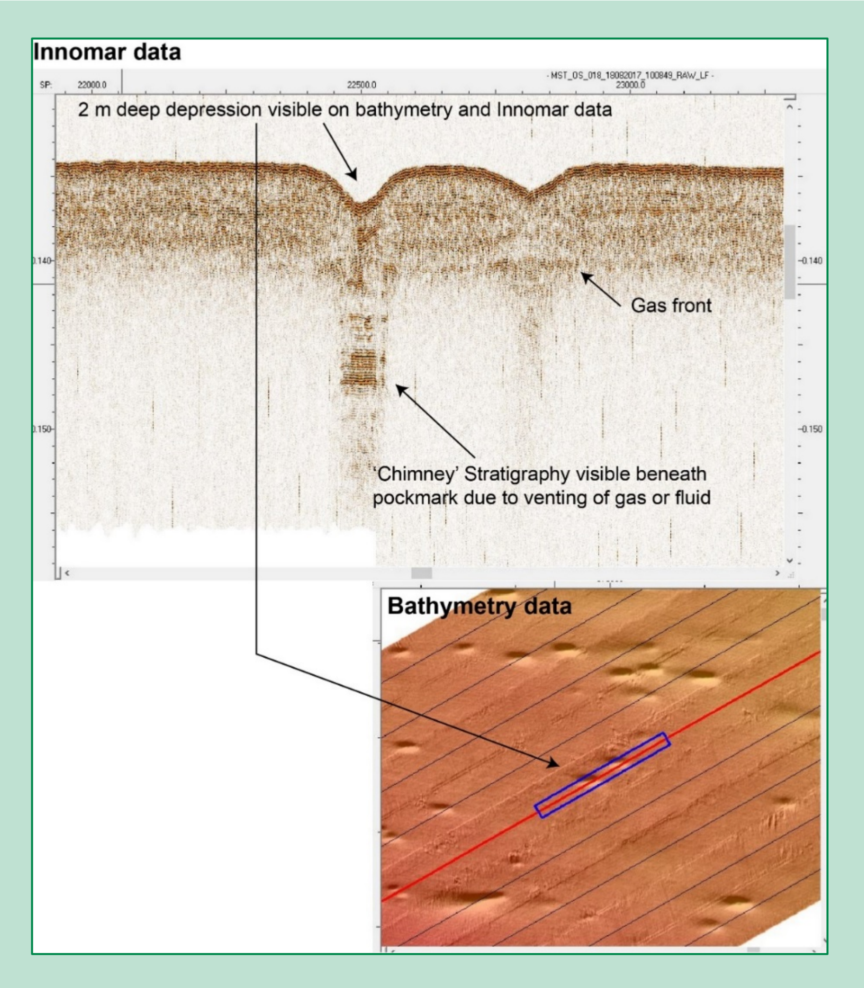

FIGURE 4. Example of identified pockmark with sub-surface 'Chimney'.

Neither pockmark shows evidence of an onlapping or draping surface unit, implying either that they are active or that there is a very low sedimentation rate. Indicated in Figure 4, a gas front that obscures underlying stratigraphy is generally present in the area. However, it is often absent below pockmarks indicating that gas or fluid has released enabling the Innomar data to image the stratigraphic sequence below the pockmarks. One example of this is shown in Fig. 4, where a ca. 75 m wide 'chimney' with clearly visible stratigraphy occurs below the left-hand pockmark. This is not so pronounced below the right-hand pockmark, and we believe this is because the Innomar data hits the side of the pockmark rather than the centre.
Similar constellations of pockmarks, gas fronts and 'chimneys' are reported from many other studies (e.g. Jensen et al., 2002; Brothers et al., 2012; Andresen et al. 2021).

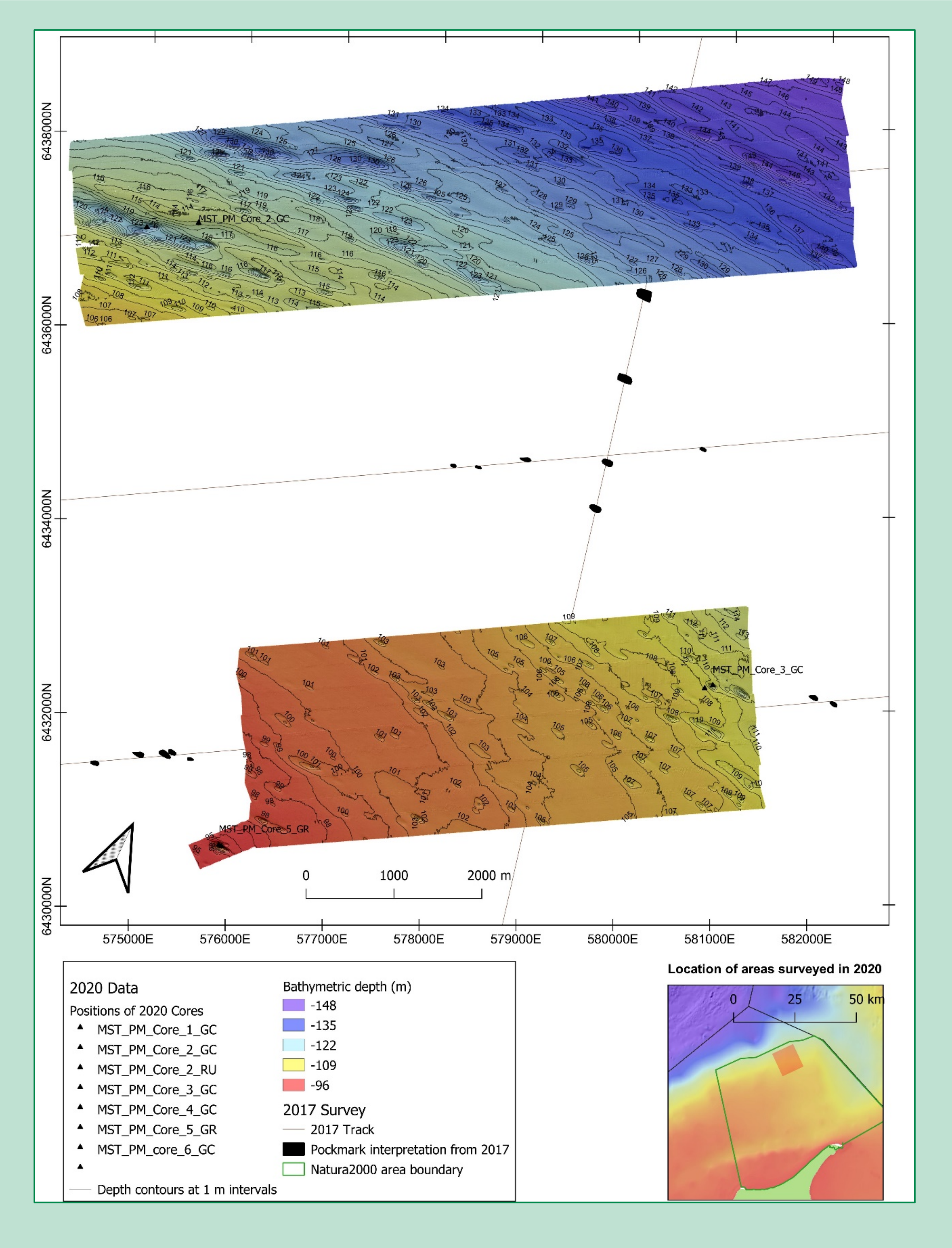

FIGURE 5. Overview of newly acquired data, with respect to the 2017 track plot and pockmarks identified during that year's survey.

Figures 5 to 7 show the bathymetry data acquired during the survey, two areas (area 1 - covering 13 km^2 – nearshore and area 2 – covering 19 km^2 – offshore) were mapped with 100% coverage and water depths ranged from 96 to 148 m below mean sea level. Numerous pockmarks were found in both areas, with a total of 226 interpreted, of which 103 are located in area 1 and 123 in area 2.

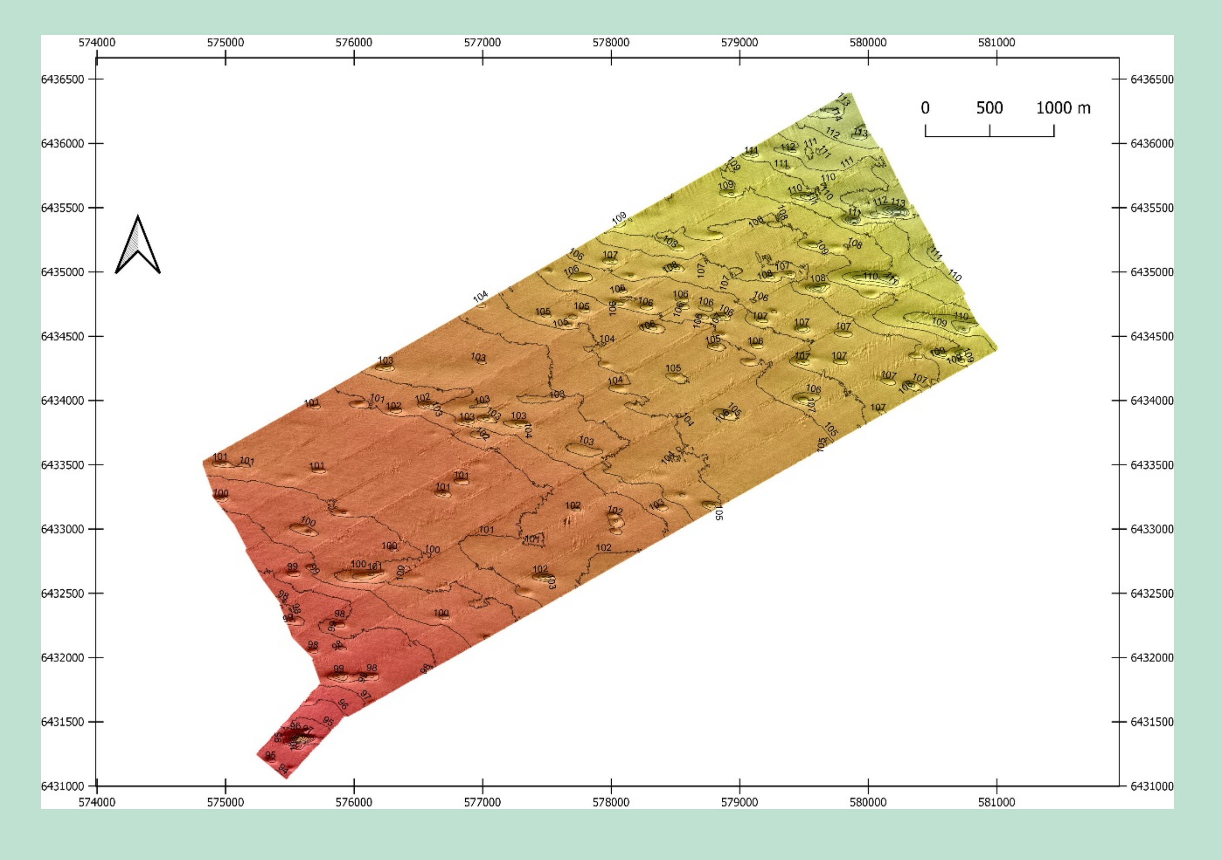

FIGURE 6. Bathymetry acquired in ‘Area 1’, where 103 pockmarks were identified following the survey.

In general, the pockmarks in area 1 are distinct and clearly defined (Figure 6), relief is generally 2 to 3 m and diameters are between 50 and 100 m. There are exceptions to this, when pockmarks coalesce and in the large pockmark in the far southwest of the area (sampled by gravity core 6 and grab sample (Core 5)). This particular pockmark was identified on the approach to the survey area (it was outside of the planned survey area) and is 8 m deep, has a diameter of some 200 m and contains a prominent mound of approximately 4 m height (Figure 8.C).

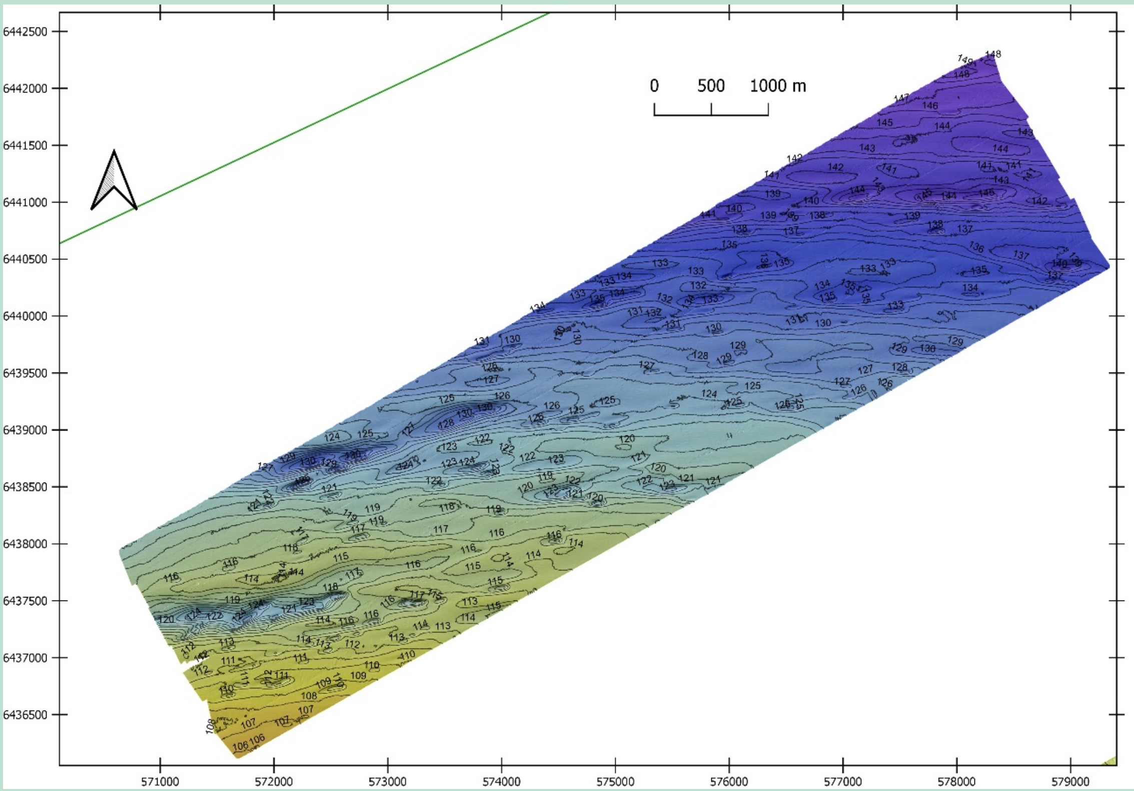

FIGURE 7. Bathymetry acquired in the deeper water ‘Area 2’, where 123 pockmarks have been identified.

Area 2 is located on a break in the northern Vendsyssel slope and deepens by approximately 50 m from the southwest to northeast. There seem to be two morphologies of pockmarks or depressions visible in this area. Clearly defined and distinct pockmarks as observed in area 1, and more complex depressions that appear coalesced and that form elongated depressions (clearly visible in Figure 7).

These elongate depressions are significantly larger than the more isolated pockmarks with relief of up to 9 m (Figure 8.A) and widths ranging from 200 to 300 m lengths, in the mapped area exceed 1000 m. There are three major elongate depressions in the area and their long axes are all aligned approximately west to east.

Figure 8 shows some of these identified features in more detail, alongside the locations of samples taken on the cruise with locations selected on the basis of the bathymetry and Innomar data. There were five 3 m gravity cores acquired: two each in areas 1 (Core 3 and 4) and 2 (Core 1 and 2) where samples were positioned inside and outside prominent depressions, and one further core (Core 6) in the centre of the large complex pockmark at the southwestern limit of area 1 (Figure 8.C). A grab sample (core 5) was taken from the summit of the prominent mound within this pockmark (see also Fig. 10 and 11). The grab sampling method was chosen above a gravity core to reduce the risk of damaging the corer and due to lack of time at the end of the survey period.

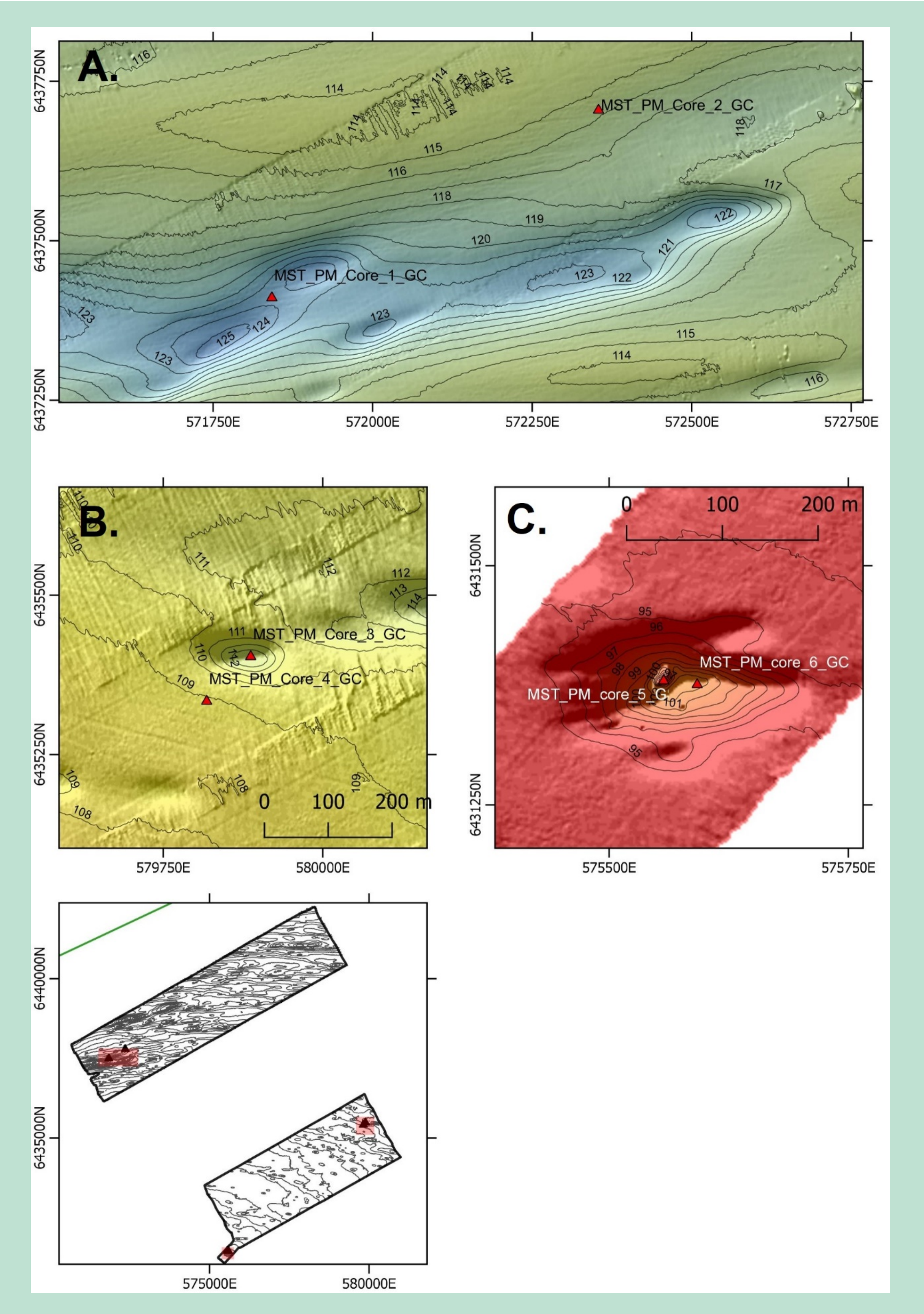

FIGURE 8. Locations of cores and grab samples with respect to newly acquired bathymetry data. A. Pockmarks Area 2. B. Pockmarks Area 1. C. Complex pockmark and mound (see Figure 10 for 3D view).

4.2. Core and sample analysis

As described in section 3.2, gravity cores were split, photographed and XRF scanned in the AU Geoscience laboratory. Sub-samples were taken from the grab sample (Core 5) as well as at 25 cm intervals for the gravity core sections for percentage $CaCO_3$ analysis in the Hawk analyser.
Visual inspection of the cores did not reveal shells, though it may be that carbonaceous micro or nano fossils are present.
Analysis has been performed on cores 3, 4 and 6. This represents sampling inside and outside a prominent pockmark in area 1 (Figure 8.B), as well as core 6, within the complex pockmark southwest of area 1, and 'Core 5' the Grab sample situated on top of the prominent mound within this pockmark (Figure 8.C).

4.2.1. Carbonate content

Table 2 and Figure 9 and 10 present the carbonate content analysis results.

TABLE 2. Overview of initial carbonate analysis of cores PM 3 and PM 4. Roman lettering (I-III) indicate the specific (up to 1 m long) core sections.

Position	Gravity core section name	Depth in core section [cm]	Sample#	Depth cm bsf	CaCO3 (%)	TOC (%)	HI
Inside Pockmark (gravity core 3)	MST-PM-3-III	5	9	5	4.61	1.87	104
	MST-PM-3-III	30	10	30	4.56	1.95	121
	MST-PM-3-III	55	11	55	4.27	1.99	114
	MST-PM-3-III	70	12	70	4.21	1.75	128
	MST-PM-3-II	5	5	82	4.77	2.12	136
	MST-PM-3-II	30	6	107	3.68	1.86	126
	MST-PM-3-II	55	7	132	3.8	1.88	118
	MST-PM-3-II	80	8	157	3.88	1.93	128
	MST-PM-3-I	5	1	182	3.99	2.15	136
	MST-PM-3-I	30	2	207	3.93	1.95	129
	MST-PM-3-I	55	3	232	9.02	1.1	141
	MST-PM-3-I	80	4	257	9.26	1.22	128
Outside Pockmark (gravity core 4)	MST-PM-4-III	5	21	5	4.22	1.89	115
	MST-PM-4-III	30	22	30	4.26	1.81	118
	MST-PM-4-III	55	23	55	3.15	1.49	100
	MST-PM-4-III	75	24	75	3.94	1.52	105
	MST-PM-4-II	5	17	85	6.36	1.06	124
	MST-PM-4-II	30	18	110	4.07	1.57	95
	MST-PM-4-II	55	19	135	8.55	1.15	143
	MST-PM-4-II	80	20	160	7.64	1.13	138
	MST-PM-4-I	5	13	185	4.03	1.69	95
	MST-PM-4-I	30	14	210	4.41	1.58	112
	MST-PM-4-I	55	15	235	9.08	1.01	117
	MST-PM-4-I	80	16	260	9.06	1.15	118
On mound (grab sample)	MST-PM-5		25	0	12.96	1.25	66
Within Complex Pock-	MST-PM-6-III	5	26	5	8.42	1.07	159
	MST-PM-6-III	30	27	30	3.53	1.94	115
	MST-PM-6-III	55	28	55	8.75	1.29	144

	MST-PM-6-II	5	29	75	8.37	1.07	159
	MST-PM-6-II	30	30	100	8.01	1.17	135
	MST-PM-6-II	55	31	125	7.67	1.1	144
	MST-PM-6-II	80	32	150	9.33	1.26	109
	MST-PM-6-I	5	33	175	9.07	1.06	140
	MST-PM-6-I	30	34	200	8.81	1.04	143
	MST-PM-6-I	55	35	225	8.18	1.04	155
	MST-PM-6-I	80	36	250	8.95	1.11	125

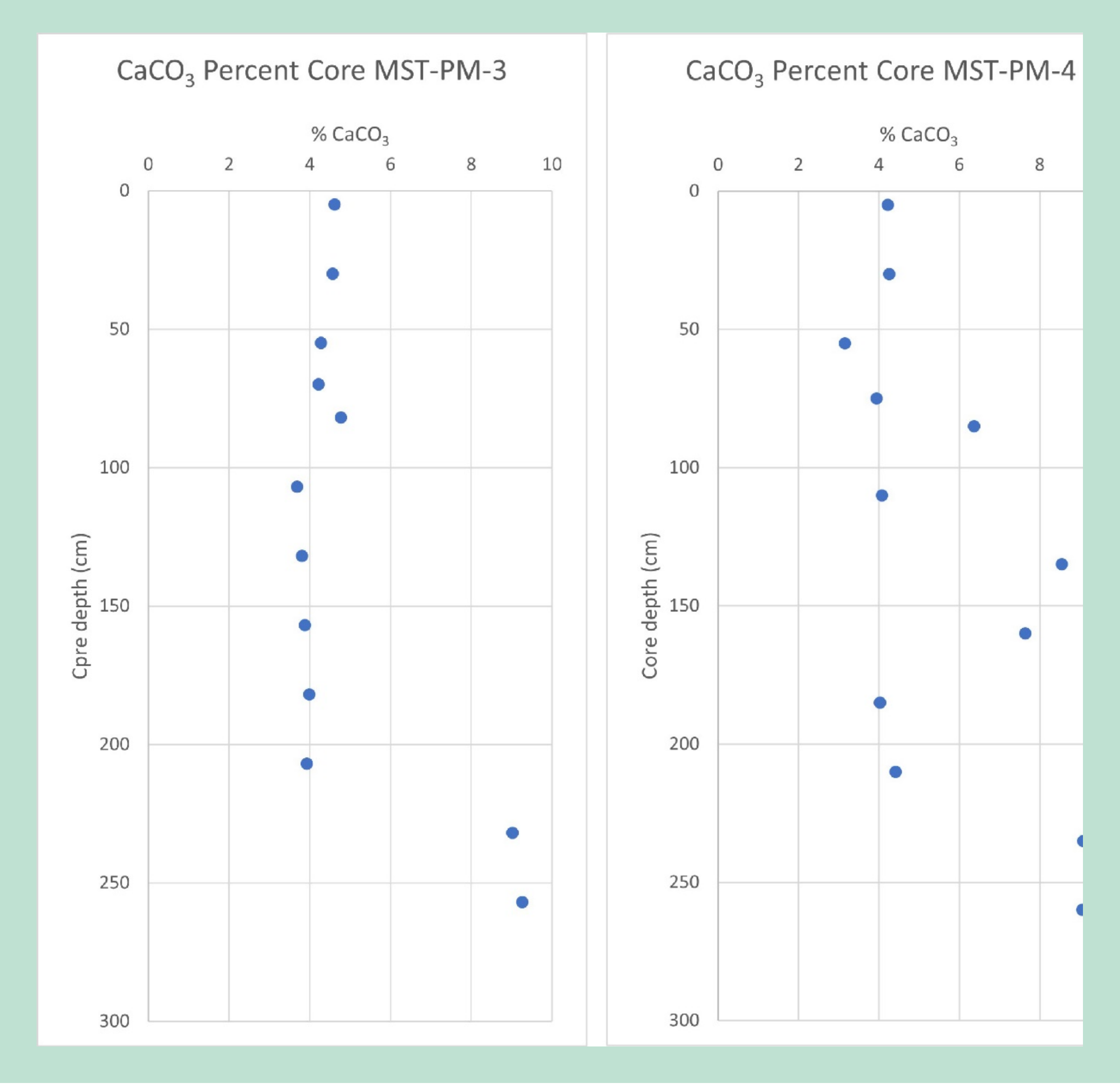

FIGURE 9. Carbonate percentages for cores PM 3 (inside pockmark) and PM 4 (outside pockmark).

From Figure 9 it is apparent that the $CaCO_3$ concentration is not higher within the pockmark than it is outside. From investigation of the values in Table 2 it is seen that the mean value inside the pockmark is 4.99%, and outside it is 5.73%. Thus, on average the sediments outside the pockmark have higher concentrations of carbonates.
This evidence leads us to infer that carbonates are not significantly produced in the pockmark targeted by gravity core 3.

However, there are further points of note. The values inside the pockmark are significantly more consistent (around 4%) until an increase to 9% at 2.3 m below seafloor. Outside the pockmark, a ca. 4% background value is also apparent. There is however significantly more variation than in the core inside the pockmark. At this point we are unsure to the precise cause of this difference, it could point to a further carbonate control within the pockmark, potentially related to only intermittently active fluid venting.
The highest $CaCO_3$ concentration observed was within the grab sample (core 5) on the prominent mound, where a value of 13% was recorded.

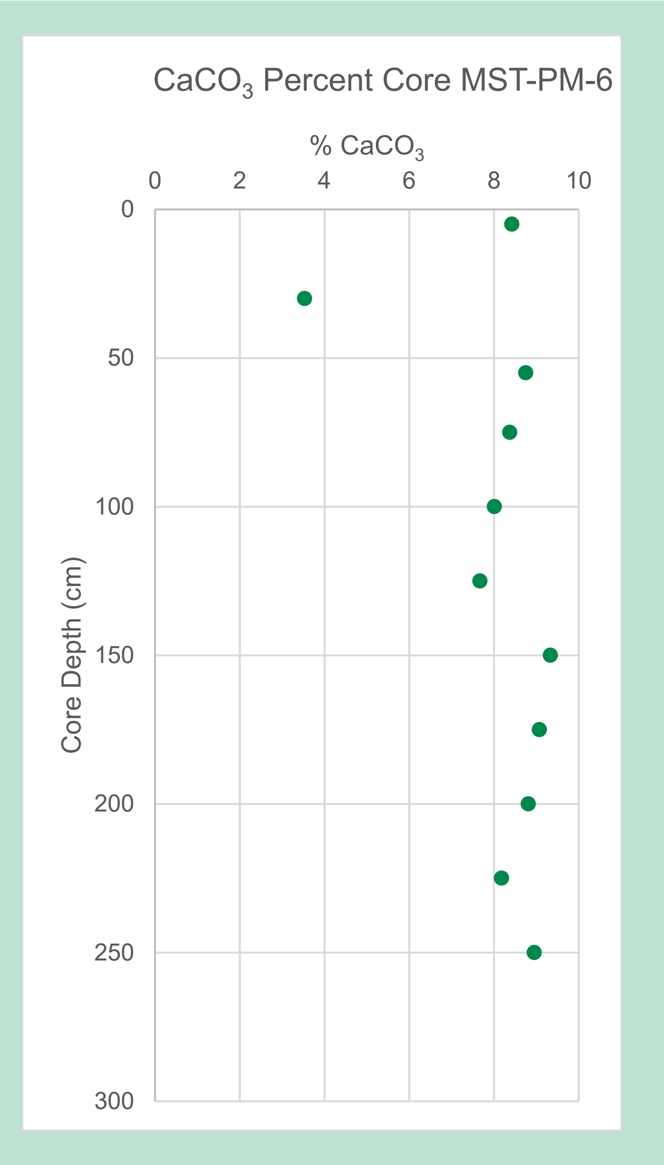

FIGURE 10. Carbonate percentages for core 6 (within larger complex pockmark). Following a delay, caused by the shut-down of the Aarhus University Geoscience Laboratory during the COVID19 outbreak, core PM-6 was also analysed for carbonate content. The results of this analysis are shown in Figure 10.

In general the core shows a carbonate content of around 8% (mean value = 8.1%), with little variation down core. This is approximately twice the value from Core PM-3, situated within the Area 1 pockmark.

4.2.2. XRF results

Core scanning using the ITRAX scanner in AU Geoscience has provided bulk sediment composition for 31 elements (measure of intensity, not percent content). We present the results for Calcium, Iron, Sulphur and Chlorine to provide an overview and comparison between core samples (see Figures 11 to 14).

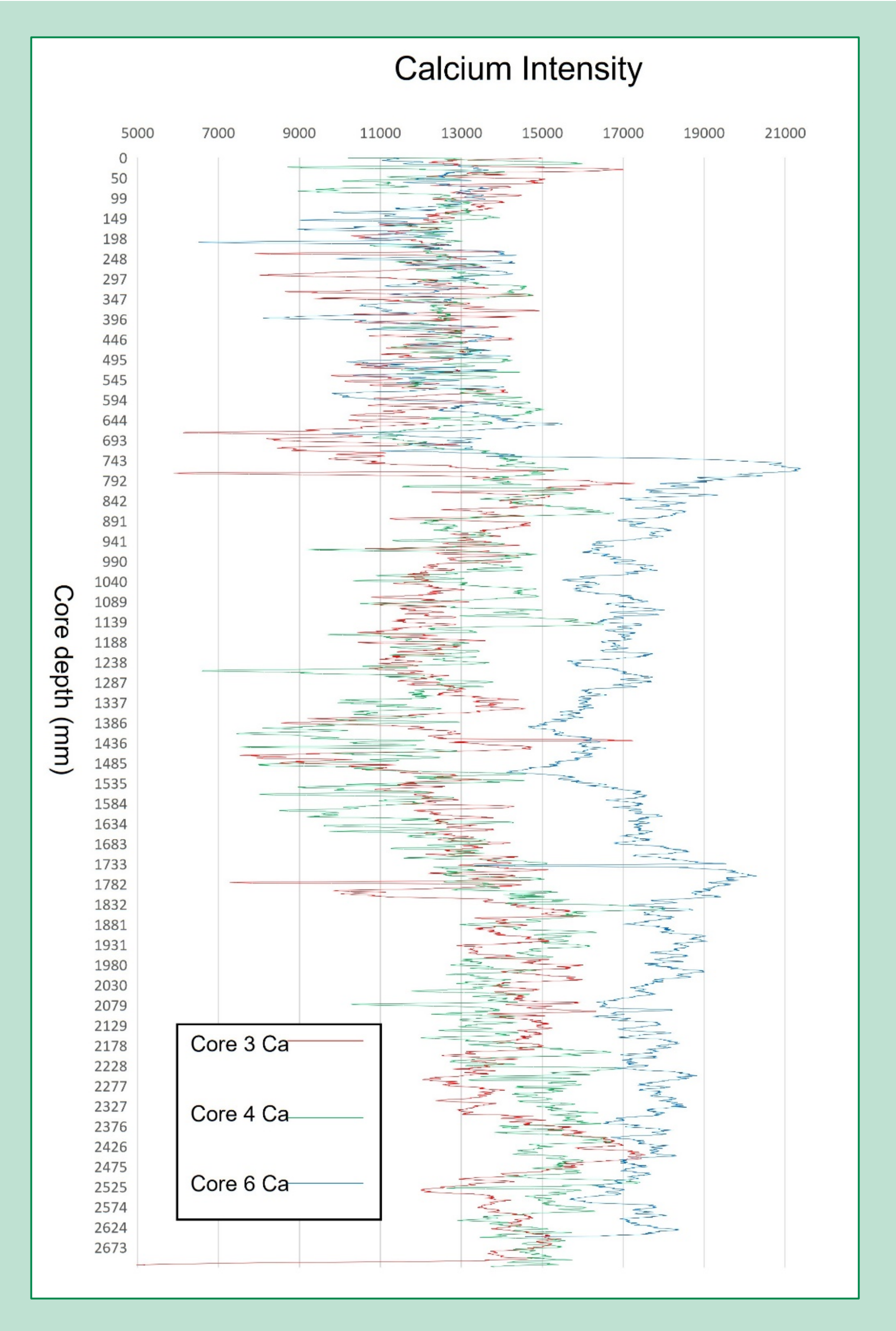

FIGURE 11. Calcium content (Intensity measurement) for Cores 3, 4 and 6.

Calcium values are shown in Figure 11, in marine sediments above the carbonate compensation depth, away from terrestrial sediment sources, calcium maybe considered a proxy for calcium carbonate. This carbonate may be sourced from marine shells or authigenic carbonate.

From the results shown in Figure 11, it is apparent that there is no clear difference between the calcium content of core 3 (within the pockmark) and core 4 (outside the pockmark). Core 6, shows apparently higher values at depth.

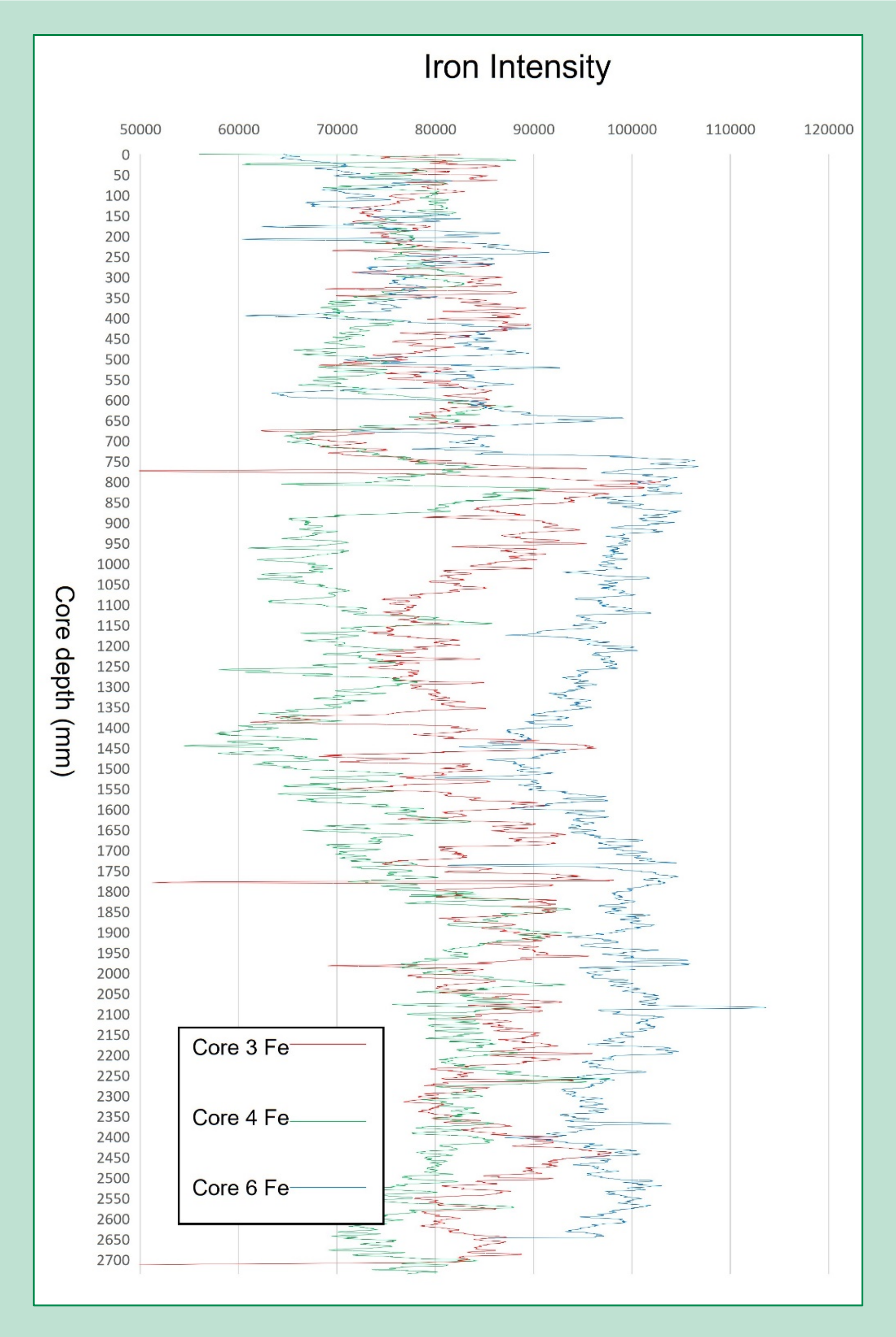

FIGURE 12. Iron content (Intensity measurement) for Cores 3, 4 and 6.

Shown in Figure 12, iron is generally associated with clay content and clastic material. By definition, these clay particles are fine grained. The data in Figure 12 is noisy and there is not a clear difference between cores 3 and 4. However, it does appear that the iron values are lower in the central part (800 to 1500 mm) of core 3 (inside pockmark) than core 4 (outside pockmark). Core 6 generally has higher iron values.

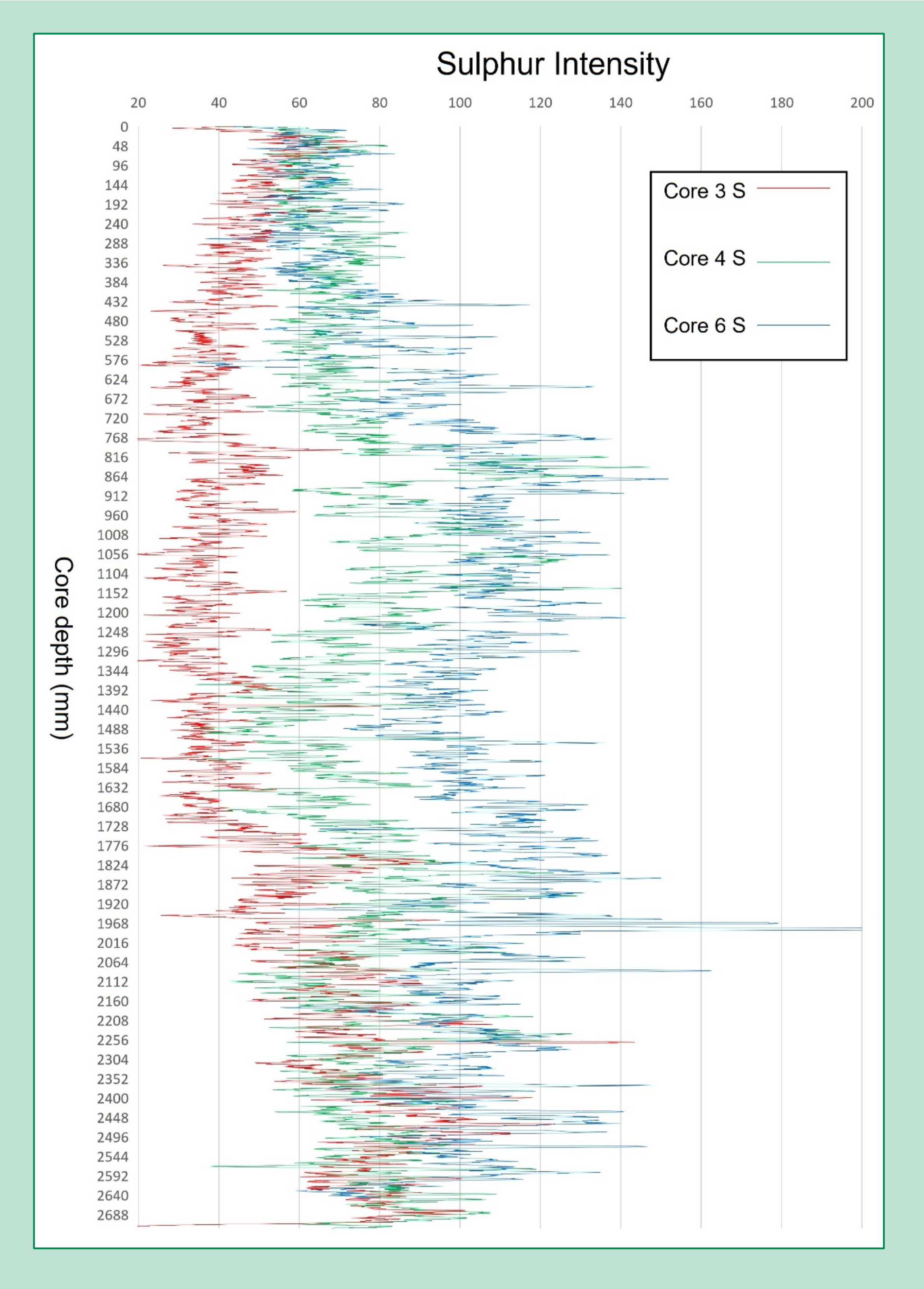

FIGURE 13. Sulphur content (Intensity measurement) for Cores 3, 4 and 6.

Figure 13 shows values for sulphur, which may be equated to bulk sediment sulphate content. Sulphur may also be related to pyrite (FeS_2) and a potential proxy for productivity. The results show that core 3 (within pockmark) has lower sulphur values than core 4 (outside pockmark) to 1400 mm below seabed. After this the values are more consistent. Core 6, within the larger pockmark has intensity values significantly greater than both cores 3 and 4.

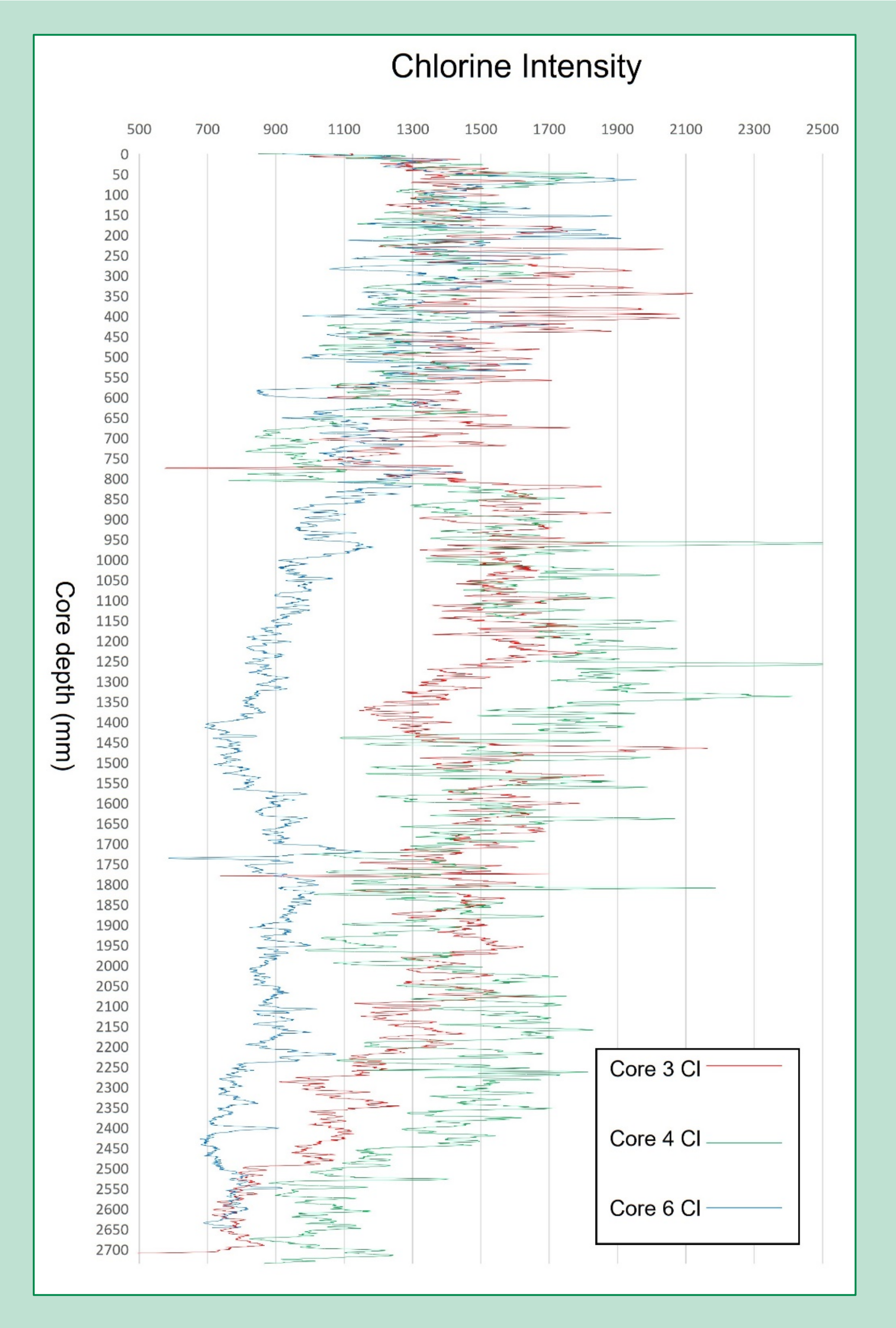

FIGURE 14. Sulphur content (Intensity measurement) for Cores 3, 4 and 6.

Figure 14 shows chlorine intensity for the three cores. A major component of sodium chloride (NaCl) it has been argued that a reduction in chlorine may be caused by freshwater input (e.g. as in the case of gas hydrate dissociation – Maslin et al., 2010). In this analysis, cores 3 and 4 show no discernible difference, core 6 appears to show lower chlorine levels from 800 to 2500 mm below seabed.

5. Discussion

Results from the investigation of the pockmarks identified in 2017 confirm the presence of an extensive field of pockmarks within the Skagerrak Natura 2000 area. Within the 32 km^2 of seabed that was mapped with multibeam bathymetry during the survey we identified 226 pockmarks, which, based on lack of sediment cover and the presence of ‘chimneys’ below appear active.
However, sediment core analysis from area 1 demonstrates that pockmarks do not contain elevated carbonates in comparison to the adjacent seabed. This is evidenced by carbonate content and XRF calcium values. It, therefore, appears that carbonates are not being produced in these pockmarks. Thus, we conclude that these features do not constitute habitat type 1180. They would be classed as EUNIS habitat A5.71 (seeps and vents in sublittoral sediments). However, the prominent mound and large pockmark in the southwest of area 1 requires additional discussion.

5.1. Prominent mound within large pockmark

Figure 10 shows a 3D representation of the pockmark and mound, also visible in Figure 8.C. The mound is some 4 m high, within the pockmark that is 8 m deep. The grab sample from the mound yielded the highest $CaCO_3$ values, at 13%, and its prominence implies an increased strength relative to the surrounding sediments. Furthermore, the sediments within gravity core 6 (see Table 1) were notably stiffer than the others collected. This core sample yielded $CaCO_3$ values averaging 8.1%, significantly higher than found in the other cores analysed.

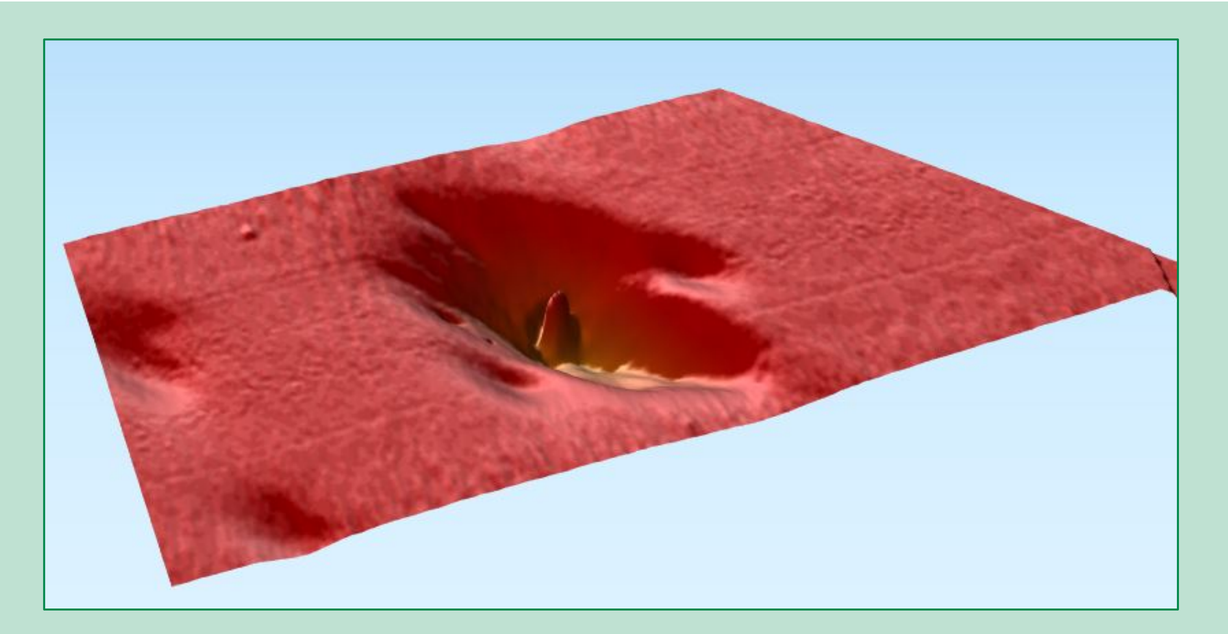

FIGURE 15. 3D image of large pockmark and mound within area 1 (10 x vertical exaggeration).

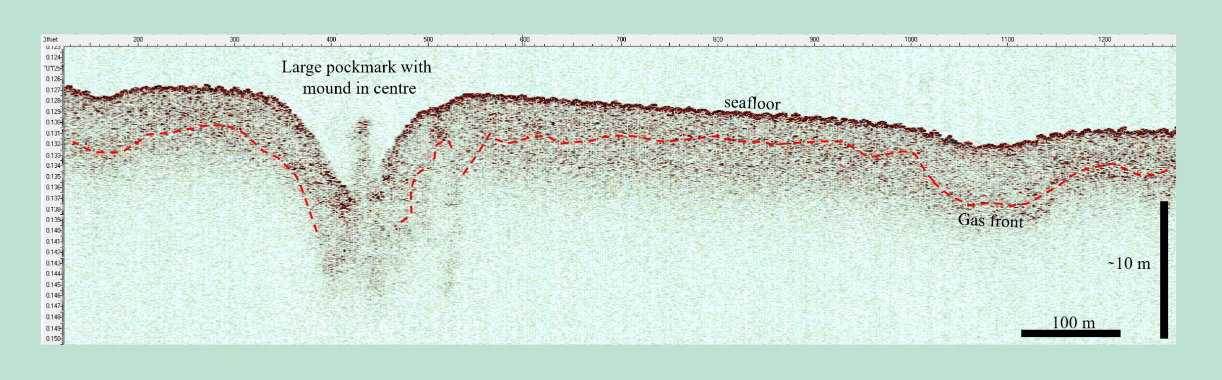

FIGURE 16. Subbottom profiler line from 2020 across the large pockmark and mound within area 1 (13 x vertical exaggeration).

It is possible that this feature presents a different habitat case than the other pockmarks identified. Work in locations such as the North Sea, Nile delta and deep water Congo Fan (e.g. Hovland et al., 1987, 2002; 2005; Gay et al., 2006; Mazzini et al., 2006; Gonthareth et al., 2007; Andresen et al., 2008) has identified mud cones, mounds and carbonates with fluid and gas escape structures such as pockmarks. However, the carbonate content of these features varies, but may be between 50 and 60% (Mazzini et al., 2006).
No carbonate structures (e.g. crusts or nodules) were observed within the grab or core sample from the pockmark and mound. Although elevated with respect to the other samples analysed in this study, the carbonate percentages are low with respect to what would be anticipated from an authigenic carbonate (e.g. which would be >50% (Mazzini et al., 2006)). We also note that the observed carbonate content in the samples analysed is very similar to background sediment carbonate content in the central North Sea where bulk sediment carbonate levels of 8% are reported (BGS, 1986).

5.2. Larger pockmarks in area 2

One of the reasons for surveying the two different areas was to investigate the apparent difference in sizes of pockmarks, with the more limited data from 2017 suggesting that larger pockmarks were present in this area.
With the more complete dataset in our possession we are able to suggest that the larger depressions in area 2 result from the coalescence of smaller pockmarks under the activity of bottom currents. The elongate trenches in area 2, which are aligned approximately west to east, match the orientation of the bottom current in this area.
Ocean circulation in the Skagerrak may be characterised as an anti-clockwise gyre, dominated by Atlantic water flowing south down the Norwegian Channel and the northward flowing Jutland current that flows from the North Sea, eastward across the Skagerrak before mixing with fresh and cold Baltic Sea water (Conradsen and Heier-Nielsen, 1995; Gyllencreutz et al., 2005). Approaching the Norwegian coast, these water masses divert to the northwest and exit the Skagerrak. The bottom current circulation mirrors this upper flow, as is demonstrated in the study site by the elongation of pockmarks in a west to east direction.
Thus, we suggest that these larger, elongate structures are the result of interaction between gas or fluid release, the bottom current and the steeper slope that causes enhanced sediment erosion in this location as opposed to area 1. Similar correlation between elongated pockmarks and bottom current erosion was described by Andresen et al. (2008) for Miocene paleo-pockmarks in the Danish North Sea.

6. **Conclusions**

Following geophysical and geochemical investigations into the pockmark field identified in the Danish Skagerrak during 2017 we make the following observations with regards abundance and morphology:

1. The seabed pockmarks are present, with 226 individual pockmarks mapped during this study;
2. Area 1 (nearer to shore) contains more distinct pockmarks with diameters between 50 and 100 m, and relief of between 2 and 3 m;
3. Area 2 (in deeper water) contains pockmarks that appear to have coalesced into larger features, with widths between 200 and 300 m and lengths >1000 m;
4. A larger, complex pockmark is located southwest of Area 1, it has a diameter of 200 m, relief of 8 m and has an internal mound some 4 m in height.

Geochemical investigations were undertaken to ascertain whether these pockmarks contain carbonates. From our results we state:

1. The core sampling a characteristic pockmark within area 1 (MST-PM-Core-3) does not contain elevated carbonate with respect to the adjacent core (MST-PM-Core-4) situated outside of the pockmark. Indeed the mean carbonate value outside the pockmark (5.73%) is greater than the mean value inside the pockmark (4.99%);
2. XRF results showed no increase in calcium within the pockmark compared to outside;
3. The large pockmark, located southwest of area 1, showed slightly elevated carbonate concentrations (8%) and the mound within this pockmark contained the highest concentration of carbonate sampled in the study (13%), however these values are significantly lower than would be anticipated from carbonates produced in situ.

On this basis, we conclude that there are no carbonate structures within the pockmarks investigated and they do not constitute habitat type 1180. It seems likely that the carbonate identified within the cores analysed is caused by detrital micro and nano fossils.
These features are likely to be formed via fluid escape, with the mound a mud cone similar to those described elsewhere (e.g. Andresen et al., 2008).

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Investigating Pockmark Fields in the Danish Skagerrak

This report describes the results of the fieldwork curried out in June 2020 to investigate the pockmarks in the Skagerrak area that were identified in 2017 survey conducted by GEUS. The current work was to investigate whether these features contain authigenic carbonate, and thus constitute EU Habitat Directive Type 1180. Fieldwork was undertaken using the R/V Aurora, with multibeam bathymetry data, parametric sub-bottom profiler data and sediment samples acquired from two areas known to contain pockmarks.

During this work 226 pockmarks were identified. On the basis that these features are not draped by sediments and that fluid or gas escape ‘chimneys’ are located beneath them we believe these features to be active

Seven sediment samples (6 x cores, 1 x grab) were acquired and analysed in the Aarhus University Geoscience laboratory. Results indicate that the pockmarks do not contain elevated carbonate concentrations in relation to areas outside pockmarks. A comparison of two cores within Area 1 provides a mean carbonate value inside the pockmark of 4.99%, com-pared to 5.73% outside. However, the prominent mound, which may be related to mud diapirism, provided the highest concentrations of 13%. A core from this larger pockmark yield-ed mean carbonate values of 8%.

On the basis that these features do not contain carbonate structures (e.g. crusts, nodules etc.) they do not constitute habitat type 1180. However, they are fluid seeps and do represent a different habitat within the sublittoral sediments

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