Biogeosciences Discuss., 5, S3063–S3075, 2009
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Biogeosciences Discussions

Interactive comment on "Carbon mineralization and carbonate preservation in modern cold-water coral reef sediments on the Norwegian shelf" *by* L. M. Wehrmann et al.

L. M. Wehrmann et al.

Received and published: 19 February 2009

We thank the referees for their detailed comments. We sincerely appreciate their effort in helping us to improve this manuscript. Please find our responses to the general and specific comments below.

General comments:

Referee#1: I would however suggest providing (probably as web-based additional information) also the data for the cores that are not included in the figures (especially the off-reef cores).

Referee#2: Why there are almost no data presented for the off-mound cores (one exception: sulfate reduction rates)?

Due to the very large data set we decided to focus on the reef cores and to only give average background values for the off-reef sites. Inclusion of plots would only lengthen the manuscript without adding information that we could not convey in a sentence. We supply TIC/TOC and pore-water data from the off-reef cores 7-1 GC and 23-15 GC as supplementary material to the manuscript.

Furthermore, due to the very low porosity of the cores, it was not possible to get sufficient amount of pore-water for all analyses. However, we conducted measurements of SO42- and Cl- on both cores and ICP-OES analyses (Fediss, Mndiss, Ca2+, Mg2+, Sr2+) on core 23-15 GC. No hydrogen sulfide was detected in the pore-waters.

Referee#1: It also misses a thorough interpretation of the data and the data are not sufficiently referenced in the discussion thus weakening the basis from which conclusions were drawn.

Referee#2: (2) There is almost no linkage between the discussed matters and the figures showing the data.

We have noted this and have endeavored to make the linkage between the figures and discussion clearer throughout the manuscript.

Specific comments:

1 Introduction

Referee#1: 1 Introduction p. 4947 Line 21 to p. 4948 line 7 Some care should probably be taken when bringing the Norwegian cold-water coral reefs in context with cold-water coral carbonate mounds such as Challenger Mound. The reefs records cover thousands of years (post glacial) while the Challenger mound record spans millions of years.

Referee#2: (1) The authors represent a brief overview about the state-of-the-art of the research of cold-water coral ecosystems and their role on the global carbonate cycle, although for the latter still not much is known! Reasons for this might be (1) the high diversity of the appearance of cold-water coral ecosystems as they occur as patches, reefs or giant carbonate mounds, and (2) the variety in their temporal distribution in particular along the NE Atlantic, e.g. off Norway only reefs of post-glacial age are known whereas along the Irish margin cold-water coral carbonate mounds existed already for millions of years! For this reason, the authors should be careful in comparing Norwegian coral reefs with carbonate mounds (e.g. Challenger mound) of the Irish margin.

We agree with the referees that care should be taken to compare biogeochemical processes in recent cold-water coral reef sediments with processes in old carbonate mounds. It is our belief however, that by looking at a recent analog we can learn something about early diagenetic processes that not only effect recent sediments, but that may inform us about past processes in these older structures.

There is a great deal of interest in how the Irish mounds have formed, including their diagenetic and microbiological past. There is however, no detailed information as to diagenetic processes in such recent coral-bearing sedimentary environments. Albeit Challenger Mound is substantially older, we do not expect that biogeochemical processes and pathways have fundamentally changed over this very short period of geological time. Recent sediments are missing from Challenger Mound. Any data on the biogeochemistry of young cold-water coral bearing sediments has the possibility to provide insight on how these structures are generated. For instance, our finding of extremely low rates of organic carbon mineralization in the Norwegian reefs is consistent with observations in Challenger Mound.

3 Material and Methods

Referee#1: For easier comparison with other existing data sets, the amount of total inorganic carbon (TIC) could be also expressed as wt.% $CaCO_3$ (chapter 3.2; p. 4951;

first paragraph).

When converting TIC into wt.% CaCO3 values usually a factor of 8.33 is used which represents the ratio between the molecular weight of CaCO3 to C. In the sediments carbonate is however composed of a variety of carbonate phases e.g. low- and high-Mg calcite, aragonite or dolomite that comprise a significant amount of Mg and/or Sr. In this case the factor of 8.33 might lead to an over- or underestimation of the true TIC value when converted to CaCO3. We therefore decided to show solely TIC.

Referee#1: A break could be introduced into line 15 p. 4953 to indicate the change from analyzed data to modeled results (’calculate’ could also be changed to ’model’ in line 16).

Changed accordingly.

Referee#1: P. 4955; lines 17&18: Is the assumption that bioturbation and bioirrigation is limited to 10 cm viable? Are stratigraphic data available to support this assumption? Did biologist extract living megafuana from boxcores from the reefs?

Bioturbation in continental margin sediments is typically limited to the uppermost 10 cm (Jørgensen and Boudreau, 2001). Bioirrigation is more difficult to constrain. However, visual inspection of the sediment gave no cause to expect deep bioirragation. We found no structures that would indicate that bioirrigation occurred below the surface coral rubble.

Referee#2: (1) p. 4951, lines 5-6: As the data of only seven gravity cores are presented in this paper (see Table 1, chapter 4), the ranges of core length and water depth for these cores should be stated instead of the ranges of all collected cores of cruise ARK XXII/1a! (2) The numerous geochemical methods applied for the study are described in very detail. Check if the methods can be introduced in a more condensed way.

(1) Paragraph was changed accordingly.

(2) We tried to shorten this where possible, without losing the critical information.

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4 Results

Referee#1: The result section is quite long but nevertheless concise, representing the large amount of data included in the study. The section is well linked in with the figures and the readers’ attention is drawn to the relevant information. It only surprises me that no data on pore-water pH are presented. Are pH data not available or are they irrelevant for the study?

Concerning the apparent lack of direct pH measurements, there are two issues to note. First of all, we needed to constrain the carbonate system. The most reliable method is through the determination of total titratable alkalinity (TA) and dissolved inorganic carbon (DIC) (Millero, 1995). If one has measured these two parameters, there is no need to directly determine pH. Fortunately so, because pH measurements especially in sediments or suspension are not trivial and often are inaccurate. The so-called suspension effect (sometimes also referred to as the Pallman Effect) can cause significant deviations from true pH (Oman et al., 2007). Even in seawater particles suspensions (e.g. mud) the possible lowering of pH by 0.3 units will have a large effect on solubility calculations.

Referee#1: Further questions that arose while reading the results are: 1) What was the motivation for the selection of the presented data, 2) why are some proxies only presented for some cores and 3) why are none of the off-reef data presented?

(1) We felt that the different hypothesis would be best addressed, by a) giving an overview about biogeochemical processes at different zones within one reef, but b) also by investigating different reefs (Traenadjupet and Røst reef).

(2) After careful analyses of the principle solid-phase and pore-water components (e.g. TIC/TOC, SRR, SO42- and Fediss) which allowed for the conclusion that organic matter mineralization pathways and linked biogeochemical processes are rather similar (even if not at the same rates) at the different locations in Røst reef we decided to present CRS and sequential Fe extraction results only from one representative core from Røst

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reef (15-3 GC) and the reactive core 23-18 GC characterized by largest variations in the pore-water constituents.

(3) Please see reply in general comments section.

Referee#1: Chapter 4.2 (p. 4057 line 15-23) as mentioned before, TIC could be also expressed as wt.% $CaCO_3$ for easier comparison with other studies.

Please see reply in Method section.

Referee#2: (1) For the core description (p. 4956), revise past tense to present tense. (2) p. 4956, lines 2, 20: Revise Lophelia pertusa and Madrepora oculata to L. pertusa and M. oculata. These species are already mentioned with full name in chapter 1. (3) p. 4957, lines 6-13: Who did the microscopic analyses? This method is not mentioned in chapter 3. It becomes not clear, if these are the results of the authors or if they refer to other publications. Is the biogenic composition of the sediments based on qualitative or quantitative data? For the latter case, give the proportions of forams, coccos, diatoms and sponge spiculae in percentage. (4) For what reasons are some data/proxies are just shown for specific cores? Why there are almost no data presented for the off-mound cores (one exception: sulfate reduction rates)? The manuscript would benefit from an overview of which methods/ measurements were applied for which cores.

(1) and (2) changed according to the referee comment.

(3) Proportions of biogenic components were estimated by the authors based on multiple samples from smear-slide analyses on a petrographic microscope using cross-polarised light.

(4) Please see reply in general comments section.

5 Discussion

Referee#1: I would have appreciated a more thorough comparison of the data from the different reef-zones in the Røst as well as in the Traenadjupet Reef and between the two

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reefs and off-reef locations. What are the differences - what are the similarities? It does not become clear if the geochemical processes are linked with the coral coverages described in the lithology section and figure 2. Unfortunately the discussion is not as well linked-in with the figures as the result chapter.

Referee#2: (1) The discussion is lacking in a comparison between the two studied reef complexes as well as in a comparison between the on-mound and off-mound cores. Although the authors stated that the aim of the study is to investigate the impact of cold-water corals on biochemical processes in reef sediments, this relationship is not really emphasized in the discussion. (2) There is almost no linkage between the discussed matters and the figures showing the data.

(1) The point is well-taken. With regard to a comparison of the data from the different reef zones at Røst reef, it appeared that differences in microbial-driven diagenesis in sediments underlying coral rubble zone, clay zone and top of reef are minor. Nevertheless, we tried to include a more thorough interpretation of the different zones. Traenadjupet reef strongly differs from Røst reef in shape and zonation. Both cores at this reef were taken at the edge of the cigar-shaped structure while we were not able to core the reef top. Comparison of the two stations at Traenadjupet reef is therefore limited. It becomes clear however, that the reactive core 23-18 GC showed the highest microbial activity of all cores taken from both reefs. Furthermore, we made appropriate revisions to highlight the differenced between on-reef and off-reef sites more careful in the text.

(2) Please see reply in the general comment section.

Referee#1: 5.1 p. 4961; line 21: Is it possible to explain what ’extremely low rates of anaerobic carbon mineralization’ means. Does it make sense to give comparisons from literature?

To our knowledge, this is the first data set showing sulfate reduction rates (SRR) and profiles of pore-water constituents from cold-water coral reef sediments. Thus, the

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comparison to the literature is limited to non-coral bearing sediments. On p. 4963 line 2 we compare our results to SRR determined by Kostka et al. (1999) at a site north of the Lofoten islands because of the close proximity of this location. However, we included more examples for rates from other locations on the continental margin and from a warm-water coral reef setting to allow the reader a better evaluation of extremely low rates of anaerobic carbon mineralization.

Referee#1: P. 4963 line 9-22; the hypothesis that the coral frameworks decouple the pelagic system from the sediments is very appealing. It would be however even more convincing if the interpretation would be supported by references to the relevant sections in the data figures. Can differences be detected for different reef zones and what is the influence of the coral cover (coral rubble verse living reef)?

The differences in microbial-driven diagenesis in sediments underlying coral rubble and clay zones and tops of reefs are minor. What is amazing is that we have a hugely vivacious ecosystem represented by the cold water coral reefs and none of the energy, at least in terms of organic carbon, gets stored in the deeper sediments. If there were no coral pieces buried in the sediment, one would never expect that such a dynamic ecosystem existed here. The coral structure and surface (living structure rubble, etc.) must be extremely efficient in Corg turnover.

Referee#1: P. 4964 line 8 - p. 4965 line 2; this should be moved into the introduction. This is a long paragraph for data (not shown) that could be shortened to for example: "Low methane concentrations in the reef sediments (values) provide do not provide any evidences for hydrocarbon seepage at the reef sites" - as is true for almost all cold-water corals reefs. Furthermore, the data presented do not necessarily support the hypothesis of an environmental control on coral reef formation it is just the alternative hypothesis.

Referee#2: (3) p. 4964, line 8 and the following: This paragraph needs to be moved to chapter 1 as it constitutes a summary of the most important discussion within the cold-water coral research: which factors influence or control the development of cold-water coral ecosystems.

The point is well-taken. We have moved some of the discussion back into the introduction and shortened the discussion on environmental controls. However, we do think that our data is consistent with the environmental control hypothesis and we will continue to stand by this statement. As the reviewer writes, the lack of hydrocarbons in cold-water coral reefs is true, the opposite impression still broadly exists in the literature. There is, indeed, very little published data on methane distributions in sediments underlying modern cold-water coral ecosystems. Our data is a clarifying contribution.

Referee#2: Would it make sense to combine the paragraphs p. 4962 line 6-14 and p. 4965 line 4-11 and discuss then together as both metal ion and sulfide concentrations are linked and metal-sulfides precipitate? And again, can that be supported by referring to the data and data figures? P. 4965 line 12 to p. 4966 line 3; provides a lot of background information that could probably form an individual sub-chapter in the introduction.

We have tried to integrate the parts of this discussion by referring to the figures and clarifying the text. However, we do distinguish between dissimilatory metal oxide reduction, important carbon mineralization pathways and the chemical interactions between iron and reduced sulfur species, and their role in carbonate dissolution/precipitation processes. Our model for the role of iron-sulfide reactions on the carbonate reactions is a key outcome of this study. It is also important to compare this mixed carbonate-siliciclastic system with other carbonate systems that have been previously studied. The reactions discussed here have implications for carbonate preservation that go beyond just cold-water coral reef systems.

Referee#2: P. 4966 line 19-27; are XRD data available to further support this interpretation?

We conducted XRD analyses in order to verify our interpretation. However, due to the high overall carbonate content of the sediments it was not possible to detect whether the aragonite content in core 23-18 GC increased with depth. This demonstrates the power of pore-water analyses.

Referee#2: P. 4966 line 15; calculated should be changed to modeled

Changed.

Referee#2: (4) p. 4964, lines 9-10: There is a need for additional referencing as indicated:

Henriet, J.-P., De Mol, B., Pillen, S., Vanneste, M., Van Rooij, D., Versteeg, W., Croker, P.F., Shannon, P.M., Unnithan, V., Bouriak, S., Chachkine, P., 1998. Gas hydrate crystals may help build reefs. Nature 391, 647-649.

Reference included.

Referee#2: (5)p. 4964, lines 22-23: There is a need for additional referencing as indicated:

Dorschel, B., Hebbeln, D., Foubert, A., White, M., Wheeler, A.J., 2007b. Hydrodynamics and cold-water coral facies distribution related to recent sedimentary processes at Galway Mound west of Ireland. Marine Geology 244, 184-195.

Mienis, F., de Stigter, H.C., White, M., Duineveld, G., de Haas, H., van Weering, T.C.E., 2007. Hydrodynamic controls on cold-water coral growth and carbonate-mound development at the SW and SE Rockall Trough Margin, NE Atlantic Ocean. Deep Sea Research I 54, 1655-1674.

White, M., Mohn, C., de Stigter, H., Mottram, G., 2005. Deep-water coral development as a function of hydrodynamics and surface productivity around the submarine banks of the Rockall Trough, NE Atlantic. In: Freiwald, A., Roberts, J.M. (Eds), Cold-Water Corals and Ecosystems, Springer, Heidelberg, pp. 503-514.

White, M., Roberts, J.M., vanWeering, T.C.E., 2007. Do bottom-intensified diurnal tidal

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currents shape the alignment of carbonate mounds in the NE Atlantic? Geo-Marine Letters 27, 391-397.

References included.

Referee#2: (6) p. 4964, lines 27-29: Remove Kenyon et al. (1986) from the reference list, this paper is not dealing with cold-water corals. There is a need for additional referencing as indicated:

Freiwald, A., 2002. Reef-forming cold-water corals. In: Wefer, G., Billett, D., Hebbeln, D., Jorgensen, B.B., Schlüter, M., van Weering, T.C.E. (Eds), Ocean Margin Systems, Springer, Berlin, Heidelberg, pp. 365-385.

Roberts, J.M., Wheeler, A.J., Freiwald, A., 2006. Reefs of the deep: The biology and geology of cold-water coral ecosystems. Science 312, 543-547.

Roberts, J.M., Wheeler, A.J., Freiwald, A., Cairns, S.D., 2009. Cold-water corals. The biology and geology of deep-sea coral habitats. Cambridge University Press, 336 p.

Wheeler, A.J., Beyer, A., Freiwald, A., de Haas, H., Huvenne, V., Kozachenko, M., Olu-Le Roy, K., Opderbecke, J., 2007. Morphology and environment of cold-water coral carbonate mounds on the NW European margin. International Journal of Earth Sciences 96, 37-56.

References changed accordingly.

6 Conclusions

Referee#1: The last have sentence p. 4970 line 17-19 ’...and provide a model for initial...’ should probably be deleted as the Norwegian coral reef and Irish coral mounds represent quite different sedimentary systems of different time scales.

Referee#2: (1) p. 4970. lines 18-19: The authors should be careful in comparing Norwegian coral reefs with carbonate mounds of the Irish margin (see also Introduction comment (1)).

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We are not discussing the genesis of the Challenger mound or any other mounds but the fundamental underlying microbial-mediated diagenesis in cold-water coral containing sediments. Granted there are differences in aspects of sedimentology and age, however, the basic biogeochemical processes are the same. Our data from the Norwegian mounds are consistent with biogeochemical observations from Challenger Mound. The recent sediments from the Norwegian reefs provide a model for how diagenesis could occur in the surface sediments for other cold-water coral dominated sediments. Until now, any insight along these biogeochemical lines has been missing.

Figures

Referee#2: Table 1 (1) Add column with core length.

Column with core length was added.

Referee#2: Figure 1 (1) 1a: The gray arrows indicating the water circulation cover the indication of the study areas. The flow direction of the currents is hardly to see. (2) 1b c: The coordinates and water depth numbers are much too small and are not readable. Overall, the maps are of low resolution. (3) 1b: The location of core 7-1 GC is not indicated on the map.

(1) We adjusted the arrows so that they are more visible. (2) Font size of coordinates and water depth were increased. We will additionally try to increase the resolution of the maps.

(3) 7-1 GC is included in the map of the revised manuscript.

Jørgensen B.B., Boudreau B.P.: Diagenesis and sediment-water exchange, in: The Benthic Boundary Layer: Transport Processes and Biogeochemistry, edited by: Boudreau B.P. and Jørgensen B.B., Oxford University Press, New York, 440 pp., 2001.

Millero F.J.: Thermodynamics of the Carbon-Dioxide System in the Oceans, Geochim. Cosmochim. Ac. 59(4), 661-677, 1995.

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Oman SF, Camoes MF, Powell KJ, Rajagopalan R, Spitzer P.: Guidelines for potentiometric measurements in suspensions Part A. The suspension effect, (IUPAC Technical Report), Pure Appl. Chem. 79(1), 67-79, 2007.

Interactive comment on Biogeosciences Discuss., 5, 4945, 2008.