

Interactive comment on “Temperature characteristics of bacterial sulfate reduction in continental shelf and slope sediments” by J. E. Sawicka et al.

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We thank the referee for careful reading and commenting on the manuscript. We appreciate the generally positive evaluation of the manuscript and acknowledge the constructive critical comments. For convenience, original referee comments are also included and our responses are provided after each comment.

1. "The authors present only one temperature gradient block measurement of sulfate reduction per site investigated. Unfortunately, they have not sampled at least some of the sites repeatedly to test for the reproducibility and representativeness of their results. Nevertheless, they deduce from these single point/time measurements general

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conclusions, e.g. that the T-response of a sediment can be used as a “fingerprint to infer mixing of bacterial communities of different origins”. To my understanding, this interpretation goes too far, as long as it is unclear how representative the measurements are for the sites investigated. The very different T-profiles in the near-by arctic fjord sediments indicate a significant small-scale heterogeneity and the authors did not give a convincing explanation for this heterogeneity (see below). A comparison of repeated measurements, e.g. from some of the arctic sites, would significantly improve the validity of the presented conclusions. If this is not possible, the authors should carefully revise the interpretation of their data and comment on the reproducibility of their results."

Response: The reviewer is concerned that our measurements lack replicates, and argues that without knowledge of the reproducibility of our data the interpretations would not be sufficiently substantiated. Sediment from the western coast of Svalbard have been sampled several times in the past and tested for the temperature response of sulfate-reducing microorganisms. Temperature profiles and rates presented by previous authors are comparable to our findings (e.g., Sagemann et al., 1998; Arnosti et al., 1998; Arnosti et al., 2003; Robador et al., 2009). One of the sediments from the South Atlantic (Fig. 1e) was measured twice since the temperature response of this one was particularly unusual. We have added duplicate temperature curve to the figure 1 e. The standard deviation of these two measurements was about 5%. Thus, we trust the reproducibility of our results.

Secondly, the temperature difference between each measurement interval is 1.5°C. On an absolute temperature scale this temperature difference is small with regard to the temperature dependence of enzymatic responses. The degree of scatter of neighbouring data points therefore gives a measure of the precision of the method. We do not provide a standard error for each measurement, the interpolated trend for each temperature response experiment is both statistically substantiated as the temperature trend integrates the analytical uncertainty. We have incorporated this explanation in

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the Results section.

The reviewer further raises the point that we do not account for potential lateral heterogeneity in the Arctic fjord sediments. The reviewer is correct in that heterogeneity has been observed often when studying temperature response of SRB (e.g., Sagemann et al., 1998). However, the greatest variability was mostly in the range of the T_{opt} , which is not ecologically important for the permanently cold deep fjords. Ecologically more important is the critical activity at the *in situ* temperature near zero, where sulfate reduction rates were relatively constant in proportion to the activity at T_{opt} in the different Svalbard sediments. Hence we feel that our use of the T-profiles as a "fingerprint to infer mixing of bacterial communities of different origins" is justified. We understand the term "fingerprint" as a unique temperature profile generated by the presence of different temperature groups of microorganisms in individual sediments, but have changed this term to 'community temperature characteristics'.

In this work, we are also comparing Arctic intertidal flat sediment, which varies from -20°C to 6°C during a season, with permanently cold sediment near 0°C from the western fjords. The temperature optimum in this intertidal sediment is higher than that in the central fjords. However, this observation only supports our interpretation that the temperature of a whole community can be used as a type of 'fingerprint' for the temperature conditions of the location.

2."General comments: The interpretation of the obtained temperature profiles in the discussion (4.1) is not consistent. The authors hypothesize that environmental temperatures select for specific microbial populations. The high temperature optima of respiration in some of the arctic sediments, which apparently contradict latter hypothesis, are explained (P684, L.22) by a significant temperature offset between microbial respiration (measured in their experiment) and growth (relevant for T adaptation). In contrast, the low temperature optima for microbial sulfate reduction (respiration) measured in the deep-sea sediments and another arctic sediment (Kongsfjorden) are seen as indication for the low temperature optima for growth of the microbial population

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(P685, L.12ff). It is not convincing that the temperature response of respiration should significantly deviate from the temperature response of microbial growth only in some of the arctic fjords (e.g. Smeerenburgfjorden) but not in others (Kongsfjorden). Hence, no convincing explanation for the $>10^{\circ}\text{C}$ difference in temperature optima of near-by arctic shelf sediments is given. The authors should give a consistent interpretation of the T-profiles in the arctic sediments or comment on the limits of their interpretation."

Response: The temperature optimum (T_{opt}) of the respiration of the bacterial community and their respective growth in permanently cold sediments is often far from the *in situ* temperature that the bacteria experience and there is always an offset between the T_{opt} of growth and that of bacterial respiration (Feller, 2007; Isaksen and Jorgensen, 1996). The primary interpretation of our data is that environmental temperatures select for psychrophilic, psychrotolerant, and mesophilic populations. It is not clear which processes dominate to regulate the T_{opt} of a mixed community. Differences in T_{opt} in nearby Arctic fjord sediments have been reported before (e.g., Sagemann et al., 1998). Smeerenburgfjord, at the northwestern tip of Spitsbergen is a narrow protected coastal strait open to the Fram strait in the west and towards the Arctic Ocean in the north. It is strongly affected by warm, Atlantic-derived water that is constantly supplied from the south and flushed to the north (Carroll et al. 2011). This process might affect benthic conditions and contribute to the import of less adapted microorganisms with higher T_{opt} or even displace the well adapted microorganisms. The other two sites were located deep within the Kongsfjorden and Krossfjorden. Kongsfjorden is an open fjord and creates along with Krossfjorden a system that merges before opening into Fram strait. Both, coastal and Atlantic Water flows into it and there is significant freshwater and sediment influx in the summer from melting snow, precipitation, glacial calving and runoff that might transport also allochthonous community with new temperature characteristics that leaves an imprint in the form of different T_{opt} (Cottier et al 2005). We will discuss the point raised by the reviewer in the sections pointed out by the reviewer in the paper.

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3. "Furthermore, the discussion on the effects of sediment transport (discussion 4.3) on the temperature response of the microbial population is confusing. In a first statement, the authors describe the Argentinean slope sediments as psychrophilic/psychrotolerant and explain the higher T-optimum in the Namibian slope with a down slope deposition of mesophilic sulfate reducers (P687, L. 7ff). In the next sentence, the authors describe that also the Argentinean and Uruguayan slope sediments are affected by down slope sediment transport, but in this case the deposition of sediment with mesophilic organisms results in broadening the temperature curve. The authors should explain, why in Namibia sediment transport results in a higher T-optimum and in Argentina in a broader T curve with a lower T-optimum. As long as no repeated measurements of the T-response of SRR in the same sediments are available, it's hard to judge if the T response of the Namibian slope (Fig. 1 panel c) and the Argentina slope (Fig. 1 panel d,f) are significantly different."

Response: We infer the temperature response of a microbial community from multiple characteristics of a temperature-SRR curve, i.e., the T_{opt} , E_a , but also the relative rate at the in-situ temperature. We have expanded our revised manuscript to explain the multiple parameter approach better. As mentioned before, the temperature interval between measured points is 1.5° and the degree of scatter of neighboring data points serves as an assessment of the reproducibility and gives a measure of the precision of the method. The reviewer is right that based on T_{opt} alone it is hard to judge if the T responses of the Namibian slope (Fig. 1 panel c) and the Argentinian slope sediments (Fig. 1 panel d,f) are significantly different. However, although the two temperature profiles of South Atlantic slope sediments differ in terms of their T_{opt} , both curves have the highest SRR in a range that can only be explained by the presence of mesophilic and psychrotolerant populations. The broadness of the peak near the T_{opt} is an additional property that likely reflects the quantitative mixture of mesophilic and psychrotolerant populations. A sharper peak near the T_{opt} would therefore indicate a dominant psychrotolerant community with a more uniform T_{opt} . Source area temperature characteristics and the amount of sediment transported downslope relative to sediment that has

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resided in the cold slope environment for a longer period likely determine the outcome of the overall temperature response. Endmember quantification of the clastic mixture to resolve the different origins by means of sedimentological analyses has been made based on analysis of bottom nepheloid layer transport, ^{230}Th fluxes and ^{14}C radiocarbon analyses for the Namibian and Argentine slope (Mollenhauer et al., 2006 EPSL, Mollenhauer et al., 2007 G3 and Inthorn et al., 2006a,b Geology and DSRII). These studies form the basis for the argument of lateral bacterial admixtures presented here, but the interpretations presented there also emphasize the temporal and spatial variability in lateral export intensity, which will likely affect the proportional mixtures of microorganisms with different temperature adaptation. We would like to emphasize that at present, there is no supplementary method available that could better discriminate the fine-tuned temperature adaptations of active complex communities. Such studies would require quantitative proteomic studies, but the available methods likely lack the resolution in terms of expression level required here.

P675, l. 24: Jørgensen and Kasten (2006) is missing. It is included now.

P677 L. 10: When did you sample the Svalbard sediments? 2007 or 2008 as given in P.679 l.6? We have sampled the Svalbard sediments in 2008. It is corrected now.

P677, L. 21: Carr 2002 is missing. It is included now.

P679 l.13: Did you also analyze the samples from 1998/1999 with the method of Kallmeyer et al. 2004? The samples were analyzed by hot chromium reduction method described by: Fossing, H. and Jørgensen B.B.: Measurement of bacterial sulfate reduction in sediments. Evaluation of a single-step chromium reduction method. Biogeochemistry, 1989, 8,205-222. This information and the reference was included.

P679, L.22ff and Fig. 1: Did you incubate the samples in replicates at the single temperatures? Give error bars in Fig. 1. We have incubated Argentinean samples from the depth 3400 (Fig. 1 panel e) twice and have included error bars for this measurement.

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P.684L.28: Replace allow by prevent. Done.

P 686. L. 26ff: Please give a reference for these Ea values. Sagemann 1998 reports values of 38-74 kJ mol-1 for permanently cold arctic sediments. We corrected the range according to Sagemann 1998.

P687, L.2f: This sentence is misplaced. The sentence was shifted to the middle of the same paragraph.

This reference are included in the revised version of the manuscript:

Cottier, F., Tverberg, V., Inall, M., Svendsen, H., Nilsen, F., Griffiths, C.: Water mass modification in an Arctic fjord through cross-shelf exchange: the seasonal hydrography of Kongsfjorden, Svalbard. *J. Geophys. Res.*, 110, C1 2005. doi:10.1029/2004JC002757.

Feller, G.: Life at low temperatures: is disorder the driving force? *Extremophiles*, 11, 211-216, 2007.

Fossing, H. and Jørgensen B.B.: Measurement of bacterial sulfate reduction in sediments. Evaluation of a single-step chromium reduction method. *Biogeochemistry*, 8, 205-222, 1989.

Mollenhauer, G., McManus, J.F., Benthien, A., Muller, P.J., Eglinton, T.I.: Rapid lateral particle transport in the Argentine Basin: molecular ^{14}C and ^{230}Th evidence. *Deep Sea Res. Part I: Oceanogr. Res. Pap.*, 53, 1224–1243, 2006.

Mollenhauer, G., Inthorn, M., Vogt, T., Zabel, M., Sinninghe Damsté, J.S., Eglinton, T.I., Aging of marine organic matter during cross-shelf lateral transport in the Benguela upwelling system revealed by compound-specific radiocarbon dating. *G3*, 8, 2007. Q09004, doi:10.1029/2007GC001603.

Interactive comment on *Biogeosciences Discuss.*, 9, 673, 2012.

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