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Interactive comment on "Impact of seasonal oxygen deficiency on the phosphorous geochemistry of surface sediments along the Western Continental Shelf of India" *by* Josia Jacob et al.

Josia Jacob et al.

josiajacob@gmail.com

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Author response to the Comment (RC C2744) by Refree #1

We thank the refree for his/her comments on our manuscript. The responses to the referee comments are as follows:

Refree's 1st comment: The authors have collected surface sediments (0-1 cm) from the western and eastern continental shelf of India to study seasonal oxygen deficiency influence on phosphorus geochemistry. In this process, they have also re-visited the

western continental shelf of India (WCSI) mainly to understand the influence of seasonal variations in hydrography (a period of six/seven months) on the geochemical behaviour of solid phase speciation of phosphorus in surface sediments (0-1 cm). The basic question that rises is whether the top 1 cm would represent a period of changes which can take place in a period of six months. It is rather difficult to appreciate this as the published sedimentation rates in the shelf region range between 0.56–19 mm/yr (Babu and Nath, 2005 and references therein; Bhushan et.al., 2005; Rao and Wagle, 1997). One centimetre of sediment they studied would represent a sedimentation history of $\sim$20 yrs if one considers the lowest sedimentation rate, but may correspond to sites with higher sedimentation rates. Higher sedimentation rates recorded in areas closer to river mouths. In view of lack of information on sedimentation rates in the areas they studied, it is difficult to agree with their interpretations. This raises further question as to whether the kinetics of diagenetic response of phosphorus in sediments to hydrographic changes in water column would be adequate in six months.

Author's response: We understand the concern expressed by the reviewer over the 0 - 1 cm sediment layer representing the seasonal variations of the phosphorus geochemistry in the surface sediments with the reported sedimentation rates referred by the reviewer. But much higher sedimentation rates have also been reported from the western continental margin of India. Somayagulu et al., 1999 have reported sedimentation rates ranging from 0.06 to 0.66 cm/yr for the region. Most of the published data on sedimentation rates are based on 137Cs, 210Pb and 14C dates from sediment cores. The sedimentation rates based on 14C dating technique reported from the study region (Somayjulu et al., 1999; Bhushan et al., 2001) are associated with several years of uncertainity which pose a further question on the suitability of these dates for estimating the sedimentation rates of surface sediments. Sedimentation rates based on sediment trap studies are unfortunately lacking from the study region.

Further, enhanced deposition/sedimentation of organic matter is a characteristic feature of hypoxic zones. They are also characterised by greater preservation of the deposited organic matter (Diaz and Rosenberg, 2008; Middelburg and Levin, 2009). In an earlier study on the total and labile organic carbon (TCHO and PRT) of the surface sediments (using the same 0-1cm layer of sediment samples used in the present study) along the WCSI during LSM and SIM, revealed marked seasonality. The total and labile carbon was higher and concentrated along the regions characterised by intense oxygen deficiency during LSM compared to SIM (Jacob et al., 2009). In section 4.1 of the manuscript, the higher TOC, TN and TP observed in the surface sediments of the WCSI during LSM along the regions experiencing intense oxygen deficiency is discussed. In the manuscript, the Section 4.2 and 4.3 discuss the response of the various phosphorus species to the varying hydrographical and productivity changes along the region during LSM and SIM. Hence marked seasonal behaviour was observed in all the geochemical parameters analysed in the surface sediment samples (0-1 cm) collected from the region during LSM and SIM. If the 0-1 cm sediment layer was an integral of several years (as the concern expressed by the refree), the geochemical parameters analysed would not have expressed the observed seasonal behaviour. Moreover, seasonality in the organic carbon fluxes from the euphotic later to the sediments are also observed even in the sediments of the deep Arabian Sea with higher fluxes during SWM than during SIM (Rixen et al., 2000; Gauns et al., 2005). Babu and Nath, 2005 has considered 0 – 10 cm sediment layer obtained from the grab sampler as surface sediments for their study on the influence of the permanent OMZ on the surface sediments of the eastern Arabian Sea.

Even though, the seasonal sampling along the shelf during the two seasons LSM (September – October, 2003) and SIM (April – May, 2004) had a time interval of only six months there were vast differences in the hydrography, productivity and redox condition of the bottom waters which has been discussed in detail in the manuscript (section 3.1.1). Among the five phosphorus species except Pdet all the other fractions (Pbio, PFe, Paut, Porg) are sensitive to productivity variations and/or redox condition of the overlying water column (Ruttenberg, 1992). The influence of the seasonally developing hypoxia (during summer) on the phosphorus geochemistry of the surface sediments

(well documented from hypoxic zones) have also been reported from other similar environments (Aigar, 2001; Kemp et al., 2005; Mort et al., 2010). But the most discussed phosphorus species is PFe since it is redox dependent. Laboratory experiments have also shown rapid mobilisation of phosphorus from the sediments even during short-term (17 days) exposure to anoxic bottom waters (Hietanen and Lukkari, 2007). Hence the observed response of the various phosphorus species of the surface sediments to the changing productivity, organic carbon fluxes and bottom water oxygenation conditions during LSM and SIM is quite expected/obvious which is discussed in detail in the manuscript.

Refree's 2nd comment: The second question is again about the interpretations of seasonality changes. The sediments are mainly from shelf region (water depths: 50 to 150m) and the continental shelf region is prone to alongshore currents and resuspension. Shetye et al. 1990 (J.Mar. Res.48, pp.359-378) have observed a 150 km wide southerly surface current in water depth of 50 m along continental shelf of western Indian margin during summer monsoon. The southerly surface current replaced northerly current during winter. The clay mineral studies of Rao and Rao (Cont. Shelf Res. 15(14); 1995; 1757-1771) have shown that the clay minerals delivered by the west flowing Indian rivers were distributed along the western Indian coast due to long shore currents and cross-shelf transport. Thus, 'in situ' nature of sediments which the authors are assuming may not be true unless they prove otherwise unequivocally.

Author's response: From the clay mineral studies, Rao and Rao, 1995 has inferred that the shelf sediments are not affected by alongshore currents. From their studies, the river-borne clay minerals are abundant along the continental slope mostly transported by south-flowing currents during SW monsoon. But along the south western continental margin (between 15°N and 10°N) cross shelf transports also dominate. However, in these regions also the influence of river-borne clay minerals is more on the outer shelf/shelf break and slope compared to inner shelf sediments. From their study, the northerly current associated with NE monsoon had little effect on clay mineral distribution due to limited discharges from the rivers during the season. From the C/N ratios many authors have reported organic carbon along the western continental shelf to be marine in origin (Paropkari et al., 1987; Bhushan et al., 2001; Agnihotri et al., 2008). The C/N ratios for the surface sediments during both the seasons (LSM and SIM) is given in table 1 and is discussed in the manuscript under section 4.1 from which it can be inferred that the sedimentary organic matter is mainly marine in origin. However, the physical processes such as resuspension, redistribution, the semi-annual reversal of the currents etc along the study area seems to have some effect on spatial redistribution of Pdet along the shelf during SIM which will be discussed in detail in the revised version of the manuscript.

Refree's 3rd comment: The authors have adopted 'a selective interpretation of data', the main focus being on PFe fraction. Their data shows that only PFe fraction has responded to seasonal suboxic/hypoxia Why only the PFe fraction should respond, when other forms of reactive P would also respond. Earlier studies in the Arabian Sea (references quoted by authors) have shown a clear response of all the P-reactive fractions to the permanent suboxic conditions prevailing in the Arabian Sea. This needs an explanation.

Author's response: From Fig. 7 and Fig. 8 of the manuscript, it is clearly understood that there is a strong response of the various reactive phosphorus species analysed (PFe, Paut, Porg) to the varying hydrographical and productivity patterns observed along the WCSI during the two sampling periods (LSM and SIM), which is discussed in detail under section 4.2. One of the main objectives of this study is to examine the hypothesis that the release of phosphorus from the surface sediments due to the redox conditions prevailing along the shelf leads to the higher dissolved inorganic phosphate observed in the shelf waters during LSM. In addition, the most noticeable hydrographical feature along the western continental shelf during LSM is the development of the seasonal suboxia to which PFe is the most sensitive among all the phosphorus species analysed. Hence it is discussed in detail under section 4.3.

We hope that our responses are satisfactory in addressing the major comments raised by the reviewer.

Sincerely Josia Jacob on behalf of the co-authors

Reference

Aigar, J.: Seasonal variations of the P geochemistry in the surface sediments of the Gulf of Riga, Baltic Sea, Chemosphere, 45, 827–834, 2001.

Agnihotri, R., Kurian, S., Fernandes, M., Reshma, K., D'Souza, W. and Naqvi, S.W.A.: Variability of subsurface denitrification and surface productivity in the coastal eastern Arabian Sea over the past seven centuries, The Holocene, 18, 755 – 764, 2008.

Babu, C.P., and Nath, B.N.: Processes controlling forms of phosphorus in surficial sediments from the eastern Arabian Sea impinged by varying bottom water oxygenation conditions, Deep-Sea Res., 52, 1965–1980, 2005.

Bhushan, R., Dutta, K. and Somayajulu, B.L.K.: Concentrations and burial fluxes of organic and inorganic carbon on the eastern margins of the Arabian Sea, Marine Geology, 178, 95-113, 2001.

Diaz, R.J. and Rosenberg, R.: Spreading dead zones and consequences for marine ecosystems, Science, 321, 926, 2008.

Gauns, M., Madhupratap, M., Ramaiah, N., Jyothibabu, R., Fernandes, V., Paul, J.T. and Prasanna Kumar, S.: Comparative accounts of biological productivity characteristics and estimetes of carbon fluxes in the Arabain Sea and Bay of Bengal. Deep-Sea Research II, 52, 2003-2017, 2005.

Hietanen, S. and Lukkari, K.: Effects of short-term anoxia on benthic denitrification, nutrient fluxes and phosphorus forms in coastal Baltic sediment, Aquatic Microbial Ecology, 49, 293-302, 2007.

Jacob, J., Jayaraj, K.A., Habeeb Rehman, H., Chandramohanakumar, N., Balachandran, K.K., Raveendran, T.V., Thresiamma Joseph, Maheswari Nair and Achuthankutty, C.T.: Biogeochemical characteristics of the surface sediments along the western continental shelf of India, Chem. Ecol., 25, 135–149, 2009.

Kemp, W.M., Boynton, W.R., Adolf, J.E., Boesch, D.F., Boicourt, W.C., Brush, G., Cornwell, J.C., Fisher, T.R., Glibert, P.M., Hagy, J.D., Harding, L.W., Houde, E.D., Kimmel, D.G., Miller, W.D., Newell, R.I.E., Roman, M.R., Smith, E.M., and Stevenson, J.C.: Eutrophication of Chesapeake Bay: historical trends and ecological interactions, Mar. Ecol. Prog. Ser., 303, 1–29, 2005.

Middelburg, J.J. and Levin, L.A.: Coastal hypoxia and sediment biogeochemistry, Biogeosciences, 6, 1273-1293, 2009.

Mort, H.P., Slomp, C,P., Gustafsson, B.G., and Anderson, T.J.: Phosphorus recycling and burial in Baltic Sea sediments with contrasting redox conditions, Geochim. Cosmochim. Ac., 74, 1350–1362, 2010.

Paropkari, A.L., R.ao, ChM. and Murthy, P.S.N.: Environmental controls on the distribution of organic matter in ecent sediments of the western continental margin of India, in: Petroleum Geochemistry and Exploralion in Afro-Asian Region., edited by: Kumar, R.K., Dwivedi, P., Banerjie, V. and Gupta, V., Balkema, Rotterdam, 347-361, 1987.

Rao, V.P. and Rao, B.R.: Provenance and distribution of clay minerals in the sediments of the western continental shelf and slope of India. Continental Shelf Research 15, 1757-1771, 1995.

Rixen, T., Haake, B., Ittekot, V.: Sedimentation in trhe western Arabian Sea the role of coastal and open-ocean upwelling. Deep-Sea Research II, 47, 2155-2178, 2000.

Ruttenberg, K.C.: Development of a sequential extraction method for different forms of phosphorus in marine sediments, Limnol. Oceanogr., 37, 1460–1482, 1992.

Somayagulu, B.L.K., Bhushan, R., Sarkar, A., Burr, G.S., Jull, and A.J.T.: Sediment deposition rates on the continental margins of the eastern Arabian Sea using 210Pb,

137Cs and 14C, Science of the Total Environment 238, 429 – 439, 1999.

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