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Time-series measurements of settling particulate matter in Alfonso Basin, La Paz Bay, southwestern Gulf of California

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A R T I C L E   I N F O

Article history:
Received 25 March 2013
Received in revised form
28 April 2014
Accepted 3 May 2014

Keywords:
Sediment trap
Organic matter
Carbonate
Biogenic silica
Lithogenic
Eolian
Ballast ratios

A B S T R A C T

More than 200 sediment trap samples were collected at 310 or 360 m depth during 2002–2009 from the center of the 410 m-deep Alfonso Basin in La Paz Bay, an arid, subtropical embayment of the southern Gulf of California. Sample splits were analyzed for total mass flux (TMF), particulate organic carbon (POC), inorganic carbon ($CaCO_3$) and opal (biogenic silica BioSi). The lithogenic (Litho) and biogenic fluxes (Biogen), but especially the particulate organic matter (POM) and $CaCO_3$, fluxes are relatively high compared with those recorded in a number of other coastal basins at depths less than ~500 m. The average yearly Litho fluxes (mean of 133 ± 158 g m^{-2} yr^{-1}) are well correlated with the frequency of strong wind gusts and reflect the relative proximity of the mooring to shore and the importance of eolian transport. The sedimentation patterns are influenced by monsoonal shifts—cool temperatures and strong northerly winds in late fall and winter sustain a well-mixed deep surface layer and high lithogenic fluxes, whereas progressive heating and relatively weak southerlies in summer and fall lead to a shallower, more-stratified surface layer with lower nutrient levels, limited productivity and generally low particulate fluxes. There is considerable interannual variability in the size of the various fluxes. This is likely related to a number of regional and internal factors whose timing, intensity and interactions remain to be resolved.

Although there is an inverse relationship between SST and satellite-derived net primary production (NPP) estimates, no correlation was found between NPP and the POC, $CaCO_3$ and BioSi fluxes ($r^2 < 0.05$ and $p > 0.05$). Significant correlations ($p < 0.001$) do exist, however, between the POC flux and the total mineral flux as well as with the $CaCO_3$, Litho and BioSi fluxes ($r = 0.86$, 0.82, 0.79 and 0.69, respectively). As suggested by the ballast ratio hypothesis, the strength of these correlations follows the relative density of the individual ballast components. Among the ballast minerals, the Litho fraction correlates strongly with $CaCO_3$ ($r = 0.84$), both fluxes being important during the windy cool season. The lithogenic fraction accounts for almost half of the total mass flux and is clearly a significant ballasting agent in this continental margin basin.

1. Introduction

La Paz Bay is a pristine environment of great biodiversity and productivity that supports an abundant variety of megafauna, including at least 16 cetacean species of temperate, tropical, and subtropical affinities, a growing colony of California sea lions and is visited by whale sharks and spine-tail devil rays (Pardo et al., 2013; Kahru et al., 2004; Reyes-Salinas et al., 2003; Lluch-Cota and Teniza-Guillén, 2000; Rodriguez Castañeda, 2008). The bay was designated as part of the "Área de Protección de Flora y Fauna Islas del Golfo de California" by the government of Mexico in 1978, was recognized as a UNESCO World Heritage site in 2005 and since 2007 includes the Parque Nacional del Archipelago de Espiritu Santo.

Despite the importance of the ecotourism industry it attracts, very limited monitoring of the environmental conditions in the bay has been carried out. To supplement the short-term studies undertaken to date of the oceanographic conditions (e.g. Jiménez-Illescas et al., 1997; Salinas-Gonzáles et al., 2003; Obeso-Nieblas et al., 2004; Monreal-Gómez et al., 2001) and ecology of the bay (e.g. Martínez-López et al., 2001; Reyes-Salinas et al., 2003), a sediment trap was deployed to measure the flux and composition of sinking particles in the bay.

The deepest portion of Alfonso Basin, the structural depression that occupies most of the northern portion of La Paz Bay (Fig. 1),

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http://dx.doi.org/10.1016/j.csr.2014.05.005

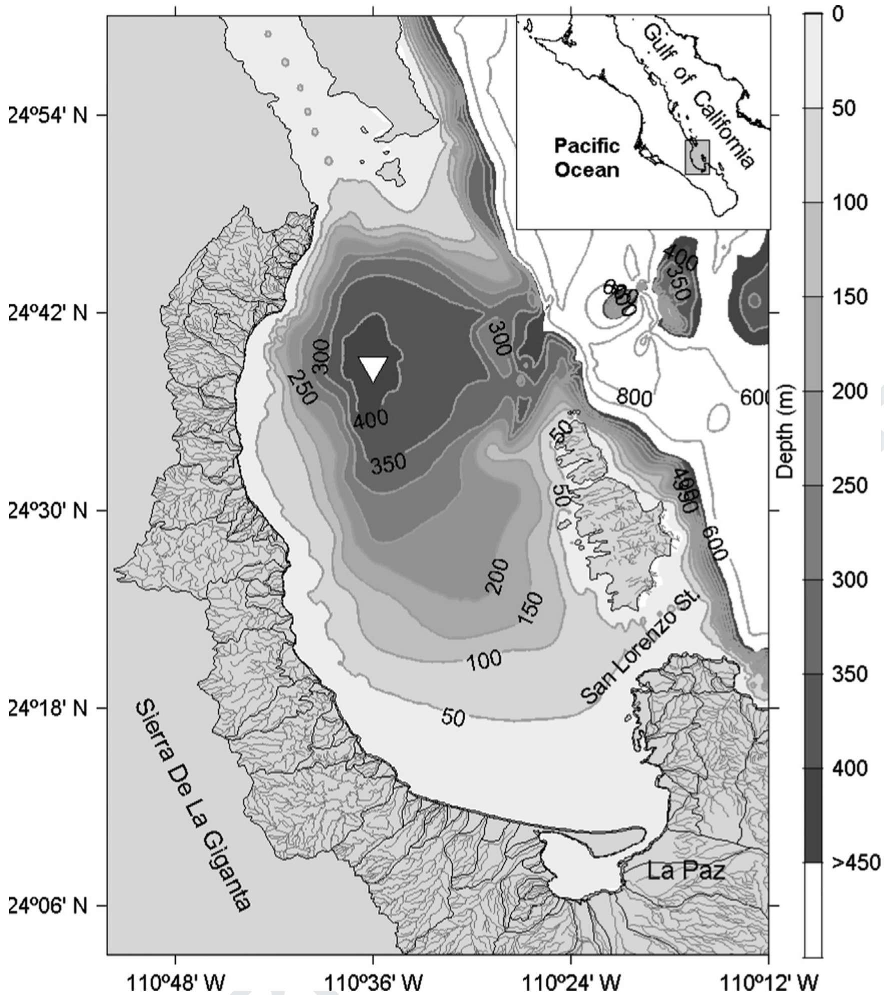

Fig. 1. Map showing the bathymetry of Bahîa de La Paz, its limited drainage basin and the location of the sediment trap mooring (white triangle).

was chosen as the site of the sediment trap mooring because: (a) it is a natural focus for sedimentation, (b) water movements are weak in the subsurface, (c) the dissolved oxygen concentration in the deep water is very low (< 0.5–$1.0\,\text{mL L}^{-1}$) so that the occurrence of "swimmers" is limited, (d) the site is close to the land-based laboratories in La Paz and can be readily visited for periodic complimentary studies of the water column and servicing of the mooring, and (e) the data complements the time-series of sedimentation flux measurements carried out in Guaymas Basin between 1991 and 1997 in the central Gulf of California (Thunell, 1998).

Dugdale and Goering (1967) first formulated the concept of "new" primary production, further developed by Eppley and Peterson (1979), and that of the. "nutrient pump" (Emerson et al., 2001), representing the net flux of biologically produced organic matter from the surface to the interior of the oceans. Concerns about global warming led to research on how such "export' production, estimated with the aid of sediment trap data, might modulate the increase in atmospheric CO_2. A number of studies linked the variability in sediment trap fluxes to seasonal and interannual changes in hydrographic conditions and productivity in surface waters of the open ocean (e.g. Honjo et al., 1999; Thunell, 1997; Deuser et al., 1995; Deuser, 1986). Newer work (e.g. Karl et al., 1996; Lampitt and Anitia, 1997; Elskens et al., 2008), however, revealed an uncoupling between primary production and the flux of particulate organic carbon (POC) below the surface layer, indicating that other factors control the transfer of organic matter to deeper waters and the seafloor. Some of the ecosystem structure complexity affecting the transfer was discussed by Lutz et al. (2002, 2007). Consequently, although production in the surface ocean must provide for the biogenic particulate matter fluxes at depth, using sediment trap information to infer changes in the ecology of plankton in the photic zone is not straightforward.

Although it has long been known that the rate of organic carbon decay decreases as a power function with depth (e.g. Martin et al., 1987; Armstrong et al., 2002) showed that asymptotic models including the ratios of ballast particle fluxes, including lithogenic and biogenic ($CaCO_3$ and opal) "mineral" fluxes to the POC flux lead to better predictions of organic carbon losses in the bathypelagic zone. "Ballast" particles are solid inorganic particles (biogenic tests, clay- or sand-sized particles) to which organic matter (OM) can be adsorbed and whose greater density augments the settling velocity of POM. Whereas POC:ballast flux ratios were found to be high and variable in the surface ocean, they converge to narrow ranges of values in the deep (below 1500–2000 m) ocean (Armstrong et al., 2002, 2009; Klaas and Archer, 2002). Thunell et al. (2007) showed that a similar convergence affects the POC flux at much shallower depths (200–1200 m) in the Cariaco Basin. In this context, the role of ballast components, particularly the lithogenic flux, in Alfonso Basin needs to be addressed.

The underlying scientific objectives of the present study were to examine processes related to export production and biogeochemical cycles in a subtropical, arid continental margin basin. To this end, the fluxes of the principal components of the settling particulate matter are examined over an 8-year period and compared with changes in satellite-derived estimates of sea surface temperature (SST) and primary productivity (PPN), wind

Please cite this article as: Silverberg, N., et al., Time-series measurements of settling particulate matter in Alfonso Basin, La Paz Bay, southwestern Gulf of California. Continental Shelf Research (2014), http://dx.doi.org/10.1016/j.csr.2014.05.005