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Organic Biogeochemistry of Seamounts: a Review

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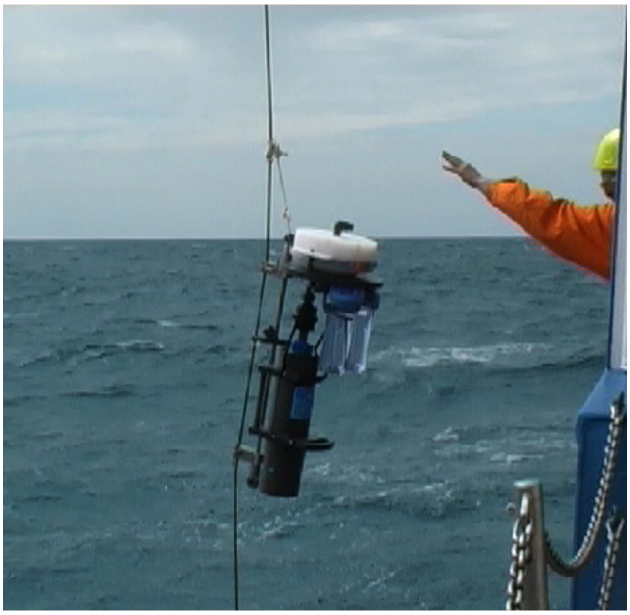

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Organic Biogeochemistry of Seamounts: a Review

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Introduction

Oceanic seamounts are underwater topographic features rising from the ocean floor over 1000m and that have a peaked or flat-topped summit below of the sea surface. There are tens of thousands of seamounts scattered in the deep sea, many of them still unchartered (Rogers; 1994; Wessel, 1997) but they are considered “hotspots” of marine life (there are often large zooplankton and fish stocks around them; see references in Dower and Mackas 1996 and Genin 2004) and biodiversity (e.g. de Forges et al., 2000; Worm et al., 2003), having many "endemic" species (de Forges et al., 2000). Less commonly, seamounts or seamount chains may exhibit reduction of prey biomass (Genin et al. 1988) or primary productivity indicators such as chlorophyll *a* (Venrick 1991) compared to the neighbouring open ocean. In any case they seem to exert an influence to their immediate environment and this is often referred as the “seamount effect”. Although it has long been recognised that physical processes may largely be responsible, the precise mechanisms are poorly understood. This review focuses on biogeochemical investigations around seamounts both in the water column and in sediments, although the physical and biological aspects of the studies, being intimately related, will also be mentioned.

Chlorophyll *a*

Chlorophyll *a* is a convenient marker for phytoplankton and proxy for primary productivity because it is easy to measure both *in situ* and in the laboratory; it has been used extensively to assess phytoplankton biomass and production around seamounts. The results from various studies, however, do not show a clear picture. The most common view invokes enhanced primary productivity over seamounts initiated by local upwelling and entrapment of nutrients by Taylor columns (Taylor, 1923; Uda and Ishino 1958; Hogg, 1973; Huppert, 1975; Huppert and Bryan, 1976; Boehlert and Genin, 1987; Dower et al., 1992; Nycander and Lacasce 2004) although direct evidence for this seems difficult to establish (for a review see Genin 2004).

Genin and Boehlert (1985) showed a high-chlorophyll, deep (80-100m), cold dome with spatial characteristics consistent with a Taylor column, above Minami-Kasuga Seamount (N. Pacific; summit at ~300m). The concentrations of chlorophyll *a* indicated residence time of a few days, but the chlorophyll anomaly was not observed closer to the surface. Furthermore, neither the uplifted isotherms nor the chlorophyll increase were observed during subsequent cruises a few days later. Genin and Boehlert (1985) supposed that entrapment in the order of days was necessary for the chlorophyll maximum to form and longer time scales would be needed to affect higher trophic level organisms. The intermittent nature of chlorophyll concentration increases around seamounts is highlighted by other studies. Dower et al. (1992) observed a dramatic increase in water turbidity around the rim of Cobb seamount summit (30–60 m depth, NE Pacific) and calculated that this was due to a seven-fold increase in chlorophyll *a*. However, such an increase was not observed during later repeated visits to Cobb Seamount. Indeed, Comeau et al., (1995) reported a relatively uniform distribution of chlorophyll *a* and incident light and very patchy values of primary production, over and away from Cobb seamount. Although nutrient isolines domed slightly upward above the seamount, it did not seem to enrich surface waters or stimulate production. Mouriño et al. (2001) observed local increases in chlorophyll *a* on the Great Meteor Seamount (NE Atlantic; summit at ~500m) that enhanced carbon incorporation rates and changes in phytoplankton species composition. These effects were also subject to a large degree of temporal and spatial variability both at seasonal and shorter time scales. The local differences were explained on the basis of short term variability of the physical field and differential heterotrophic activity between the seamount and its surrounding waters. Briefly it was shown that the ratio between the protein and chlorophyll *a* content of particulate organic matter was significantly higher ($P < 0.05$) over the seamount than further away. This was interpreted as an indication of a higher relative heterotrophic biomass over Great Meteor Seamount, which could efficiently graze a portion of the newly synthesized biomass. This is supported by the lower oxygen concentrations (4.7 mL L^{-1}) in the water column near the seafloor on the summit compared to higher values in the abyssal sediments around it (~7 mL L^{-1}; Heinz et al., 2004). Genin (2004) suggested that a persistent upwelling mechanism would only exist on very large topographic features (e.g. shelf breaks) and that the seamount effect on biological productivity should be expected downstream rather than above the summit because the upwelled water is often swept away before a patch of high phytoplankton biomass develops, unless some water-trapping occurs. The same author concluded that local upwelling and subsequent Taylor column is unlikely to explain various observed aggregations of micronekton and fish over seamounts.

An alternative explanation of the ‘seamount effect’ is that this reflects increased fluxes of suspended organic material at seamounts due to amplified bottom flows over abrupt topographies (Eriksen, 1982, 1991; Mohn and Beckmann, 2002a,b) that could sustain high local densities of benthic organisms, zooplankton and fish (Genin et al., 1986; Genin et al., 1992; Dower and Mackas 1996; Genin 2004). Additionally some authors have suggested that large-scale entrapment of water by topographically rectified currents (Fig. 1) helps retain larvae around seamounts, further enhancing benthic recruitment (Mullineaux, 1994; Mullineaux and Mills, 1997; Beckmann and Mohn, 2002) at least at some locations (e.g. Fieberling Guyot; NE Pacific, summit at ~500 m). This mechanism can also increase the downward flows of high quality particulate organic matter (POM) to benthic communities over the centre of the seamount (Brink 1995; Mullineaux and Mills, 1997).

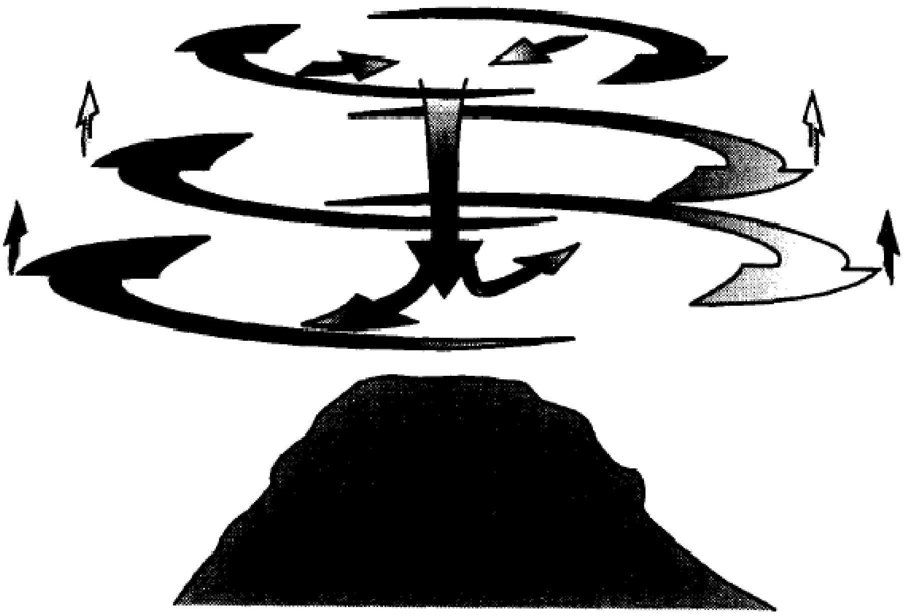

Fig. 1. From Mullineaux and Mills (1997). Three-dimensional diagram of mean flows in the tidally rectified circulation cell, showing the character of azimuthal (clockwise, decreasing in strength with height above bottom), radial (strongly outward at the seamount summit, weaker and inward above), and vertical (strongly downward at the centre, weaker and upward at periphery) flows. Diagram is not to scale; e.g. horizontal flows are much stronger than vertical ones.

Other workers suggested that more than one processes can be operative in the vicinity of seamounts (Venrick 1991; Odate and Furuya 1998). The former author found low chlorophyll concentrations above the Emperor Seamount Chain (western subarctic Pacific) and attributed this to the advection of low Chl *a* water along the seamount chain rather than in situ changes. Odate and Furuya (1998) measured two deep (75-90 m) chlorophyll maxima above Komahashi No. 2 Seamount (NW Pacific, offshore Japan, ~290m summit) in June 1991. They suggested that the first was due to upward transport of nutrients caused by topography-current interactions over the seamount as it coincided with uplifted isotherms. The second maximum however, did not coincide with the uplifted isotherms, but was associated with relatively saline water which occurred in a broad subsurface layer extending into the bottom of the euphotic zone. Lateral intrusion of an allochthonous water mass originating to the south was suggested to explain this implying that different processes may be operative on the same seamount at within short time-scales.

Particulate Organic Carbon

Examinations of the quantity, quality and provenance of particulate organic matter (POM) around seamounts might help elucidating some of the above questions, but there have been relatively few studies of that nature. Investigation of POC fluxes around two North Pacific Seamounts, Horizon Guyot (summit at ~1500m) and Magellan Rise (summit at ~3100m), using sediment traps revealed that the fluxes were higher at the base of the seamounts (~5000m) than their summits (Smith et al., 1989). Additionally, organic carbon demand at the benthic boundary layer of both summits, calculated from sediment community oxygen consumption, was consistently higher than the measured downward flux. It was proposed that high current speeds over the summits that keep material in suspension and reduce the trapping efficiency of the sediment traps, may have lead to the underestimation of POC concentrations that may be available to the ecosystem. These results highlight the need for sampling/measuring laterally advected as well as sinking, particulate material over and around seamounts in order to obtain a reliable estimate of the quantity and quality of particulate organic material that is available to seamount systems.

Wishner et al. (1995) reported a decrease of suspended mean POC concentrations (from CTD casts) above the summit of the Volcano 7 Seamount (Eastern Tropical Pacific; 730m depth; 89 $\mu g\ L^{-1}$) towards its base (3400m; 20 $\mu g\ L^{-1}$). Data was collected in summer 1988 and the same authors found increased zooplankton abundances and feeding rates close to the summit. However it is unlikely that these observations are related to a “seamount effect” as its summit impinges on a pronounced OMZ that seems to control organic matter concentrations. POM within OMZs is usually higher than in comparable oxygenated midwater regions due to reduced decomposition and moreover POM usually decreases with depth.

Suspended POC, PN and chlorophyll concentrations (measured from CTD casts) were determined around two Atlantic tropical seamounts offshore Brazil (Rocks of São Pedro and São Paolo; summit <200 m) by van Bröckel and Meyerhöfer (1999). These seamounts have large fish stocks around them and are traditional fishing grounds for local fishermen. Visual observations in this study confirmed this. All biological and biogeochemical parameters showed strong small scale vertical and horizontal variability although concentrations of POC and PN, were high and C/N ratios were close to the Redfield stoichiometry indicating that the POM was unaltered (i.e. “fresh). However no relationship with the seamount topography was established and the same was true for phytoplankton composition. This coincided with the apparent absence of topographically-induced upwelling around these features (Travassos et al. 1999). van Bröckel and Meyerhöfer (1999) after highlighting the seasonal variability that may “mask” the results, suggested that large fish stocks in the vicinity may be maintained either by fish aggregation for spawning close to the seamounts or (and) by feeding on the rich benthic community maintained by enhanced material supply over the seamounts rather than by locally triggered primary productivity.

Sediments

Benthic faunal assemblages are often thought to reflect surficial primary productivity (for a review see Gooday 2002), thus, in theory, examination the benthos of a seamount and surrounding areas could point to potential ‘seamount effects’ regarding primary productivity. This seems to be the case in Cobb Seamount in the north Pacific (Dower et al 1992) as high benthic biomass was observed on the summit and high chlorophyll concentrations were measured above it. In contrast pelagic-benthic decoupling on top of the Magellan Rise was evident (Reimers and Wakefield, 1989). Flocculent material that overlaid surficial sediments was significantly more degraded than passively deposited phytodetritus in adjacent sediment traps. This was attributed to the rapid action of surface-feeding benthic organisms that left residual material which was then resuspended and re-deposited as ‘floc’ with a very different composition than phytodetritus.

Heinz et al., (2004) observed lower levels of surficial sedimentary organic carbon at the summit of the Great Meteor Seamount than in the slopes and the adjacent abyssal plain (Fig. 2) and suggested that this may be due to an accumulation of material from the top during lateral and vertical transport and resuspension processes. Discrepancies between organic carbon content and foraminiferal abundances in the sediments at certain stations led them to speculate on the fluxes and quality of organic material, however no analyses on its composition or flux measurements were carried out to clarify this. Winnowing of material from summits of seamounts and ridges by strong currents has been suggested to be result in low organic carbon preservation in these areas compared with open oceanic basins Weber et al, (2000).

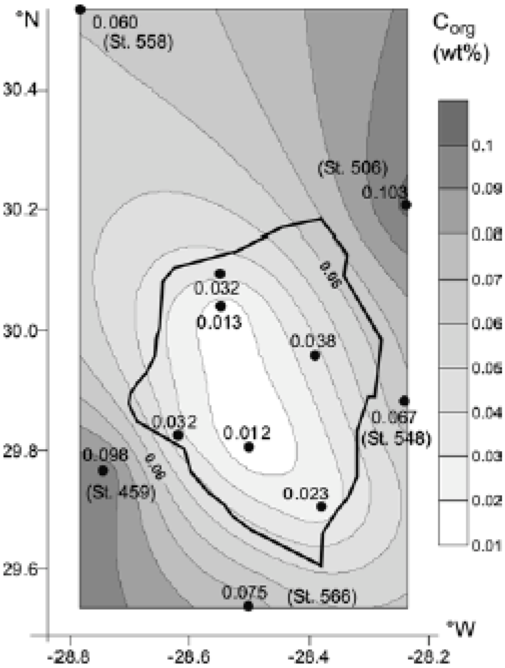

Fig. 2 From Heinz et al., (2004). Organic carbon content (wt%) in surface sediments and gradient simulation around the Great Meteor Seamount.

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