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Editorial

Faunal perspectives on paleoproductivity

The present volume contains a selection of papers based on presentations given at a special session "Foraminiferal Proxies of Paleoproductivity", organised at the Forams'98 conference in Monterrey, Mexico, 8–10 July, 1998.

In the context of global change studies, adequate reconstructions of past paleoproductivity fluctuations are indispensable. To answer the crucial question of how fluctuations in the organic carbon pump are related to climate change, we need to develop satisfactory methods to quantify the various aspects of marine productivity, such as primary production, the *f*-ratio (ratio between new and total production), export production, and the fate of the organic carbon upon arrival at the ocean floor. A large array of proxies has been developed to provide partial answers, many of which are based on the fossil remains of planktonic and benthic foraminifera. An excellent overview of the most commonly used micropaleontological proxies can be found in Wefer, G., et al. (In: Fischer, G., Wefer, G. (Eds.), 1999. Use of Proxies in Paleoceanography: Examples from the South Atlantic. Springer Verlag, Berlin, Heidelberg, pp. 1–68). The use of planktonic and benthic foraminiferal microfossils to define paleoproductivity proxies follows two fundamental approaches: (1) the proxies are based on the chemical composition of their carbonate tests (e.g. $\delta^{13}C$, Cd/Ca); or (2) the proxies are based on abundance variations and general faunal characteristics of the fossil assemblage.

The principal aim of the special session "Foraminiferal Proxies of Paleoproductivity" was to define the "state-of-the-art" within the second approach, relating to the application of faunal characteristics to reconstructions of paleoproductivity, and to identify the main directions of research from which significant future ameliorations of the existing foraminiferal proxies may be expected. Within this context, the key question is how the existing, mostly semi-quantitative, methods can be modified to yield better quantitative estimates of the various aspects of paleoproductivity. The second aim of the special session was related to the growing concern that proxies based on the chemical composition of microfossils can only be trustworthy if we know how the chemistry of foraminiferal tests is affected by the living organisms' ecology. All too often, foraminiferal tests are considered as merely an inorganic medium, rather than the result of a complex interaction of a living organism and its environment. There is a serious risk that such "black box" proxies that ignore ecology will provide convincing, but non-realistic, reconstructions. To avoid such problems, it is crucial that foraminiferal ecology is intensively studied, and used to improve proxy calibrations.

Foraminifera are an important group of unicellular organisms which, in case of benthic foraminifera, may even be dominant in terms of biomass (Gooday et al., 1992. In: Rowe, G., Patiente, V. (Eds.), Deep-sea Food Chains and the Global Carbon Cycle, NATO ASI Series C, 360, Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 63–92). Their relatively low position in oceanic food webs (most of them are primary consumers), and their excellent fossilisation potential, makes them ideal representatives of ancient marine environments. The presence of benthic as well as planktonic foraminifera allows a very broad coverage of almost all oceanic environments. Foraminifera have been used as proxies for a whole range of oceanographic parameters: sea surface temperature and salinity, water mass structure, paleoproductivity, bathymetry, ice coverage, etc.

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With respect to paleoproductivity, the faunal characteristics have been used in two fundamentally different ways:

1. Proxies using foraminiferal flux values (BFAR, PFAR; benthic or planktonic foraminiferal accumulation rate) are based on the assumption that foraminiferal test production (and preservation in fossil sediments) covaries with primary production (in the case of planktonic foraminifera) or export production (in the case of benthic production).
2. Proxies based on the faunal composition may follow various approaches. In the simplest cases, paleoproductivity estimates are based on the presence, absence, relative or absolute abundance of certain marker species. More elaborate methods concentrate on functional groups of species typical of certain conditions, based on morphological analogies, or — better — on direct observations in recent ecosystems. Finally, quantitative paleoproductivity estimates can be based on multivariate statistical methods, such as principal component, factor, or correspondence analyses. These methods require a profound knowledge of the recent ecology of the species used. Circumventing this requirement, proxy methods have been developed on the basis of purely statistical empirical relationships between environmental conditions and faunal characteristics, such as multiple regression analysis, or modern analogue techniques. The main advantage of the latter methods is the easy availability of quantitative estimations. Potential pitfalls are formed by ancient "no analogue" conditions, in which the observed relationships between faunal characteristics and the environmental parameter to be reconstructed may no longer be valid, and by the possible presence of morphologically hard to distinguish "cryptic" species/genotypes with different habitat preferences.

This volume presents 9 papers, which treat various aspects of the relationships between paleoproductivity and foraminiferal faunas. The topics vary from micro-scale (the response of the individual to ecological conditions), via meso-scale (the response of a foraminiferal fauna to the downward flux of organic matter) to a basin-wide scale (intra-basinal faunal differences in response to equivalent changes in productivity).

Kitazato et al. present preliminary results of a four year seasonal survey of benthic foraminiferal faunas at a 1430 m deep site in Sagami Bay. This is the first time deep ocean benthic foraminiferal faunas are monitored over a longer period of time. The authors present the most detailed example known today of the close coupling between pelagic and benthic ecosystems. Seasonal maxima in the flux of organic carbon to the sea floor are responsible for a direct foraminiferal production response. The data show that some taxa are much more opportunistic than others. Especially deep infaunal taxa show only a weak response to the seasonality in the downward organic flux.

De Rijk et al. show that the bathymetrical distribution of many Mediterranean benthic foraminiferal taxa is controlled by export production. A strong west–east decrease in primary (and export) production is translated into a shallowing of the bathymetrical range of many dominant species. It appears that most taxa are typical of a fairly narrow range of labile organic carbon flux; an observation which can directly be applied in paleoproductivity studies.

On the basis of a comparison of two stations from the Gulf of Lions (Western Mediterranean), — Schmiedl and co-authors add a clear example to the accumulating evidence that the trophic level is the dominant factor in many oceanic environments controlling the density, composition and microhabitat of the benthic foraminiferal fauna. Both stations are at a very comparable waterdepth, one in the axis of a submarine canyon, the other on the open slope. In the canyon environment, which is characterised by a higher organic flux, and probably a lower oxygen penetration in the sediment, the benthic foraminiferal faunas are much richer, with a well-developed deep infauna. The more oligotrophic slope environment, on the contrary, has a much poorer fauna, strongly dominated by epifaunal and shallow infaunal elements.

Wollenburg and Kuhnt present a big data set of benthic foraminiferal faunas from the Arctic Ocean. They show that a strong relationship between the local carbon flux and the composition of the benthic foraminiferal fauna exists also in this extremely seasonal environment, which may be used as a tool to reconstruct former changes in paleoproductivity in this area.

Mackensen and co-authors concentrate on the $\delta^{13}C$ of live specimens of three benthic foraminiferal species, with different microhabitats, and a very different isotopic behaviour. Their paper shows ample evidence that the isotopic ratio is strongly influenced by ecological strategies of the various species (e.g. microhabitat, feeding mode), and that single species $\delta^{13}C$ and/or $\Delta\delta^{13}C$ (epifaunal–infaunal) records can only be used as paleoproductivity proxies if the ecology of the various taxa is perfectly known.

Herguera presents new data for the calibration between the BFAR (benthic foraminiferal accumulation rate) and the organic flux to the sea floor, and shows an application of the BFAR method in the eastern Equatorial Pacific. Rather surprisingly, in the last glacial period, sites north of the equator show a much smaller increase in export production (with respect to recent values) than sites just south of the equator.

Fenton et al. discuss planktic foraminiferal disappearance sequences prior to full glacial aplanktonic zones in the Red Sea. They suggest that these sequences are not the direct result of increasing salinity, but rather reflect complex reorganisations of hydrography, food availability and subsurface oxygenation. These reorganisations are ascribed to expansion of the dominance of NE monsoonal circulation over the entire Red Sea.

Almogi-Labin et al. use benthic and planktonic foraminiferal records to reconstruct paleoproductivity in the Gulf of Aden. They observe higher productivity during glacial periods, related to increased vigour of the NE winter monsoon during these periods, a conclusion that is corroborated by the previous paper. Almogi-Labin et al. caution that previous reconstructions of glacial conditions in the Arabian Sea may need to be revisited to account for the productivity relationship with the NE monsoon.

Vénec-Peyré et al. reconstruct paleoproductivity in the Socotra (Somali) Basin for the last 72,000 years, using a combination of planktonic foraminiferal and radiolarian proxies. Their observation of increased productivity during isotopic stages 1 and 3 is confirmed by geochemical proxies such as organic carbon, biogenic barium and phosphorus. Like in most other upwelling areas, local variability of the productivity signal may be important.

These 9 publications present ample evidence for the important potential of foraminifera as paleoproductivity proxies. In all papers, foraminiferal faunal changes can clearly be coupled to changes in primary production or export production. The papers dealing with recent ecosystems suggest that direct application of the observed relationships (between benthic foraminiferal faunas and export production) is possible, with a quantitative resolution that is at present only attained by the BFAR-method.

In spite of these promising results, many foraminiferal proxies remain characterised by a lack of quantification. Better calibrations of the observed relationships in recent ecosystems are urgently needed. The main problem lies in the fundamental impossibility to compare living and fossil faunas. It is at present almost unknown how a living assemblage is transformed (in terms of BFAR/PFAR, but also of faunal composition) by taphonomical processes. We only vaguely know which part of the living fauna ultimately fossilises, and which species are enriched in comparison to other, less resistant, taxa. Also, our knowledge of interspecific differences in reproductive turnover rate is minimal, even if it is essential for a correct interpretation of the fossil record. The very limited general knowledge about the seasonal variability of foraminiferal faunas further inhibits fully quantitative interpretations. The more results we obtain, the clearer it becomes that even deep sea benthic faunas show a strong seasonal variability, with many species growing and reproducing (and secreting their test) in very short periods of time. This seasonality affects especially the benthic foraminifera living at the sediment surface, whereas abundances of deeper infaunal taxa appear to remain more constant through the year. Due to this seasonal variability fossil faunas may be strongly biased towards the productive season. In addition, isotopic records based on epifaunal taxa (such as *Fontbotia wuellerstorfi*) may represent atypical conditions, such as phytodetritus falls.

The ecological complications identified above, and doubtless also an equal or greater number of other influences, determine an inherent reliability problem to the proxy reconstructions. Therefore, foraminiferal micropaleontologists should not only continue efforts towards quantifying paleoproductivity, but they should also ensure that the determination of confidence limits is given very serious attention. It would appear that substantial amelioration of the quality of foraminiferal proxy methods cannot be achieved by simply increasing the bulk of data sets that underlie the various transfer functions, but should instead be sought in improvement of our knowledge of the recent ecology of benthic and planktonic foraminifera.

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