ADEPD

Atlantic Data Base for Exchange Processes at the Deep Sea Floor

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Summary

The ADEPD project compiled biological and biogeochemical data from a range of international and national deep sea projects in the information system PANGAEA. Diverse data sets were brought together in an uniform data format and are made available to a wider public. More than one hundred biogeochemical variables and 114,000 published and unpublished data sets were compiled in the last two years in PANGAEA. A new and very simple approach to the data base via the world wide web was implemented. Now for the first time a large deep sea data base is easily accessible for the general public on: http://www.pangaea.de/Projects/ADEPD.

It became obvious that many data are clustered in some very well investigated areas of the Atlantic, but large regions are devoid of biological and biogeochemical data. This applies in particular for the Mid Atlantic Ridge, parts of the South Atlantic and Southern Ocean, while the eastern part of the Atlantic, northern North Atlantic and Arctic regions are well covered. Most deep sea research projects did not carry out geochemical and biological studies at the same locations. Therefore, the number of data pairs suitable for the investigation of empirical correlations is very low despite the high total amount of data gathered. Different methods employed for the determination of one parameter add further restrictions to the comparability of data sets. ADEPD applied empirical correlations to convert biomass measurements of small organisms to a uniform variable and to extend the data base available for regional analysis.
For the northern North Atlantic and some areas in the South Atlantic relationships between primary production and benthic fluxes of nutrients and oxygen have been established (this analysis was done as part of other projects using the ADEPD data base). In these regions the coverage of geochemical data is good enough to obtain a spatial resolution and define benthic provinces.

Two very different approaches to estimate total carbon flux and oxgen consumption at the deep sea floor of the world ocean were compared. A value of 5.33x10**13 mol O2/year is estimated from surface productivity and vertical carbon flux relationship while a value of 5.43x10**13 mol O2/year is estimated from sea floor benthic oxygen flux and organic carbon burial rate compilation. This close agreement may be fortuitous, but the estimates support each other and suggest that a reasonable assessment of global seafloor oxygen flux has been achieved. Regional differences in both assessments point to methodological shortcomings by one or the other method and to gaps in data coverage as well as gaps in knowledge in respect to carbon fluxes along continental margins. Evaluation of the data collection helped to identify gaps in data availability as well as systematic patterns and problems in deep sea biogeochemical research. It resulted in recommendations for further data collections and analysis of deep sea biogeochemical data.

1 Introduction

The global cycling of carbon and associated elements through the world’s oceanic systems is one cornerstone of the understanding of the linkage between climate and oceanic processes as well as the role of the long-term reservoirs of the deep waters and the bottom sediments. It is still one of the major goals of global ocean research to reconcile rates of surface water production and rates of vertical export with data on benthic turnover to arrive at a full description of transport, burial and turnover of matter within ocean basins. Furthermore, the deep sea ocean fluxes, albeit much smaller than those in surface waters, can be measured directly at a physical boundary and are less subjected to annual variability or short term variation. Therefore, they represent average flux rates and mirror, with some aberrations, average surface water productivity. It is to be expected that different surface water productivity and export in the biogeochemical oceanic “provinces” as defined by Longhurst (1995) influence the benthic regions and give rise to different biological and geochemical characteristics at the sea floor. Topography of the sea floor, deep sea currents and proximity to continental margins are likely to be further forcing functions for deep sea processes.

The deep sea floor is furthermore increasingly at the focus for potential exploitation. Oil drilling is now technically feasible in water depth up to 2000 m and the deepest commercial production well is located at 1853 m in the Roncador field off Brazil (Offshore Engineer 1999). Although dumping of wastes is at present not allowed due to the London Dumping Convention studies are being persued to test the potential for controlled sequestration of CO_2 in the deep sea (Brewer et al., 1999) or for the deposition of municipal and other wastes (Angel and Rice, 1996). Very intense ship traffic adds further anthropogenic impacts to the deep sea floor due to accidental loss of ships and cargo. At present no adequate data base and no tool exists to identify particularly sensitive areas in the deep sea and, thereby, aid political, economical and legal decisions. The deep sea floor has been generally recognized as a key global environment and improvement of the knowledge about this environment has been recommended as one European Grand Challenge in marine research (Le Pichon, 1995, Lochte, 1995).

Many data sets have been collected in the deep sea, particularly in the Atlantic, by different projects and have never been compiled beyond the individual project data management. Therefore, no common data base exists to achieve large scale analyses and assess deep sea processes in the Atlantic as a whole, connected system. The biological and geochemical key parameters describing standing stocks and rates of turnover can for practical reasons only be obtained at a few selected stations, hence, extrapolation of such data from individual points/stations to a larger spatial scale is a difficult task. It requires determination of empirical correlations or modelling of processes which link these limited data to ”master” variables for which a large data base is already available. In this way, the global ocean flux of particulate organic carbon was assessed in a first attempt from a limited set of benthic data (Jahnke 1996). Flux, turnover and burial of organic carbon in deep sea sediments was also assessed globally based on surface water primary productivity and sedimentological data (Romankevich et al. 1999). These two approaches were the first comprehensive attempts to link surface water and deep sea fluxes of organic carbon.

2 Aim of the project ADEPD

Aim of the project was to build up a joint data base for deep sea benthic data from a variety of sources and conduct preliminary geographical analysis of these data. The emphasis was placed on the North Atlantic, since it is this area for which the most comprehensive data sets are available from British, Dutch, French, German, Russian and American studies. Furthermore, it is the most perturbed region in the Atlantic due to intensive human activities. Equatorial, South and northern North Atlantic were included to arrive at a complete description of the whole Atlantic Ocean.

Specific objectives:
✦ to compile biogeochemical data from Atlantic deep sea sediments (benthic boundary layer) from various projects and from the literature,
✦ to convert data to common units and uniform variables,
✦ to link biological (biomass) to geochemical (fluxes of chemical species, etc.) data,
✦ to extrapolate data of biogeochemical processes at the sea floor obtained at individual stations to a basin wide scale using empirically established correlations to widely measured ”master” variables,
✦ to develop for well studied regions areal descriptions of ”benthic biogeochemical provinces” in the deep sea of the Atlantic,
✦to compare the estimated flux rates at the sea floor with data on surface water productivity and sedimentation,
✦to identify gaps in regional coverage as well as in scientific approach to be considered in future projects.

3 Approach

The data were delivered to the coordinator of the project and read into the information system PANGAEA by the data curator and the partner at the AWI, who is managing and servicing PANGAEA. Via the project home page all participants had access to the data and retrieval of larger data sets was supported by the curator. The new developments and the utility of the PANGAEA data informations system are described under “Developments and progress in the information system PANGAEA”. Under “Data collection” an overview of the data collection and the geographical coverage of data is given.

One of the major problems when comparing data from different projects is the use of different methods. It was a major task of this project to convert different types of measurements to common units. This applies in particular to biological measurements where we have attempted for example to obtain common biomass data from as diverse measurements as ATP, phospholipids and microscopic counts. This problem also applies to other types of variables, but is perhaps less obvious. Under “Total microbial activity and biomass” conversions to microbial biomass are described, as these represent the most difficult manipulations.

Linking of biological and geochemical data was achieved by comparing data from the same geographical location irrespective of sampling time. Therefore, seasonal variations had to be ignored in this analysis. If samples were not from the same station, which was only possible in some cases, data averages from geographical grids (1°x1° or 3°x3°) were compared. Since on most cruises geochemical and biological research is not carried out jointly, the number of data pairs which can be used for statistical analysis was surprisingly low. The results of these analyses are shown under "Total microbial activity and biomass”, “Meiofauna”, “Empirical relationships between pigment concentrations and oxygen flux”.

Since the main task of this project was to build up a joint data bank of deep sea biogeochemical data, only first steps of statistical and geographical analysis of these data could be achieved within this project. Regional analyses of benthic fluxes are presented under “Benthic fluxes of nutrients and oxygen”, “Overview of regional analysis of benthic fluxes in the South Atlantic”, “Global benthic fluxes of oxygen and carbon”. It has to be pointed out that due to the complexity of the task only some partners were involved in the analysis stage, but that this work would not have been possible without the joint effort of all partners in bringing the data together. Recommendations for future data collection and analysis as a result of our discussions and experiences within the project ADEPD are given under “Recommendations for future research”.

Developments and progress in the information system PANGAEA

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The use of information systems is still not very popular in most disciplines of marine science. Scientists prefer to deal with their personal data organization which, in the best case, might be a local, proprietary data base, in the worst case it is just a collection of spread sheet files. The complexity of the data of a specific scientific field also hampers the invention of common data systems. There are few examples in oceanography, were data are well organized accessible on the Web (e.g. WOCE, http://www.cms.udel.edu/woce); the reason is, that oceanographic data consist of just a few well defined parameters. In other disciplines with more complex data 'worlds', e.g. in bio- or geosciences, very few sites are known, where results are available to the public. A first successful step towards a public available biogeochemical data archive on CD was done by the BODC (British Oceanographic Data Center) with the biogeochemical data of the OMEX project (Ocean Margin Exchange, OMEX-I project data set, 1997). The amount of work and problems to solve was remarkable (Lowry, 1998).

Data are imported to the PANGAEA information system by the curator with a graphical user interface which is provided through the 4th Dimension proprietary front end software; relations between data and meta-information are also made during this procedure. A few seconds after the import, data can be retrieved on the Internet with the Advanced Retrieval Tool (ART) of PANGAEA (http://www.pangaea.de/Retrieval/). The use of ART requires that the user has a minimum of knowledge about the data model, how to formulate a retrieval and the definition of the project related parameters.

It was experienced in the ADEPD project that, after demonstrations of the information system PANGAEA on how to use and access the system, the participants still did not work with it in the sense of the projects objectives. Even though the retrieval is easy to use, it still needs some training due to the complexity of the biogeochemical data. To improve the acceptance and the usage of the common data base within the project, a new tool has been developed which is unique so far. The Direct Download Interface (DDI) enables the user to access the data from the relational data base just by a mouse click on a web page. ART enables the user/curator to define and save any specified output format of a data matrix and to define and save the related query to extract a required subset of data from the system. Format and query can be stored on a web server and related to a link on a web page. This procedure requires that the curator designs some web pages, including the most important meta-information for each single data set, which finally give the users access to the projects data by just a mouse click.

The web pages will be maintained after the termination of the project in responsibility of the coordinator. The data are archived in PANGAEA, which is long-term operated by AWI and MARUM and thus long-term usage of the data is ensured. Even though it looks as if the data are downloaded from a flat file directory of the IOW web server, using the links will always provide the user with the most recent data status. The great advantage of the DDI is, that a click on a link e.g. related to a certain parameter will include any data in the system, also those data, which were imported after the termination of the project. It stands to reason that a query can also be limited to data sets related to a specific project. The extraction of individually configured data sets from the system can only be done with ART.

The import of data sets and its publication on web pages can easily be done and is not time consuming if a well organized information system is used. As already experienced from other projects, also in ADEPD the major work for the data curator was
1. the collection of data from the various partners and
2. the harmonization of data and completion of metadata.
The amount of work of the data curator has been estimated as 20 % collection of data, 50% harmonization, 15% final quality control and import, 10% publication of data with DDI, 5% support, workshops, reports.

If partners are supportive in providing data in the requested formats, costs for data management could be reduced significantly. Due to this specific problem, which troubles most data collections, the amount of work for the data management in ADEPD was underestimated. Despite this difficulty an impressive amount of data were archived and published on the ADEPD web pages. The resulting comprehensive collection of biogeochemical data from the Atlantic sea floor is unique so far on the Internet.

Data Collection

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The data collection included altogether 103 biogeochemical variables, 21 of them were newly introduced to PANGAEA. In total 1800 published and unpublished data sets were gathered in the two years. Particularly for biological data this is a substantial improvement in respect to unification of diverse data collections. A list of variables and their formats is given under *variables*, compilation of all collected data is given under *list of data collection*.

The major projects providing data for this compilation are:

- BENGAL, BENBO, BOFS (NE Atlantic)
- BIOGAS (Continental margin NE Atlantic)
- BIOTRANS, BIO-C-FLUX, BIGSET (NE Atlantic)
- EUMELI (NE Atlantic off Africa)
- OMEX (Continental margin NE Atlantic)
- SEORQUA (NE Atlantic)
- SFB 313 (northern N Atlantic, Norwegian Sea)
- SFB 261 (equatorial and S Atlantic)
- Arctic projects
- div. Russian projects, data base "Carbon" (complete coverage of Atlantic)
- div. American data sets (NW Atlantic incl. shelf slope)
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In additons to such projects data from individual investigations were collected. Some of these data are as yet unpublished. The most comprehensive data sets are available for geochemical variables, e.g. total organic carbon (TOC) in sediments (Fig. 1). Biological data sets are much more clustered in some very well investigated areas of the Atlantic, but large regions are devoid of biological and biogeochemical data. As examples, the geographical distribution of measurements of chloroplastic pigments in the sediment (Fig. 2), oxygen consumption in the sediment (Fig. 3), macrofauna (Fig. 4), total microbial biomass (Fig. 6) and meiofauna (Fig. 7) are shown. In particular data from the central parts of the Atlantic and the Southern Ocean are very limited. While the continental margins and upwelling regions are fairly well studied, there is a lack of data from the central oceanic gyres. The poor data distribution in the western Atlantic is caused by the concentration on European projects in ADEPD and can be substantially improved if more data from American, Canadian and Russian colleagues are included.

As a result of the biased distribution of biological data it was difficult to find sufficient pairs of observation for statistical treatment. This has hampered the analysis of empirical correlations between biological and geochemical data (see under Total microbial activity and biomass", "Meiofauna", "Empirical relationships between pigment concentrations and oxygen flux").

Total microbial activity and biomass

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Microorganisms are the primary agents of the diagenesis of organic matter in marine sediments (Deming and Baross, 1993). Thus, a strong link between carbon fluxes and microbial activity and biomass can be expected. Accordingly, significant correlations between POC fluxes measured with sediment traps and bacterial biomass (Deming and Baross, 1993), oxygen consumption, bacterial activity and total microbial biomass (Boetius and Damm, 1998) have been found in different oceanic regions. One possibility for the calculation of carbon budgets for larger oceanic regions is to exploit the empirical correlations which link the limited data of sediment trap measurements to microbial variables for which a large data base is already available. Such variables could be benthic microbial biomass and activity. However, although many data sets of benthic microbial activity and biomass have been obtained in the last few years, they were never combined on a basin wide scale.

One of the goals of the ADEPD project was to collect and harmonize as many data on benthic microbial biomass and activity as possible - from the project partners and their collaborators as well as by including data from the literature. A number of different variables were compiled as parameters for microbial activity and biomass: bacterial biomass, total adenylates, DNA, phospholipids and the activity of different enzymes (hydrolytic and electron-transporting). For each of these parameters, about 100-200 datapoints entered the databank. These data are now available on the ADEPD home page. The data had to be converted into comparable units (if possible biomass carbon and molar carbon turnover). We also investigated if the data could be linked to other biological (pigment concentrations) or geochemical data (TOC, oxygen consumption, accumulation rates).

The data on microbial activity were highly diverse in terms of the different methods used. Each investigator focussed on different enzyme activities according to the specific scientific questions in each of the different studies. The data of all 13 activity parameters were collected and organized in the data bank with method descriptions and links to the investigators. The potential microbial hydrolysis of organic matter in the sediments can be studied using various model substrates for the different enzymes. This parameter is now used in pelagic as well as benthic environments as a parameter for the potential carbon turnover by the microbes. Good relationships between organic matter availability and the potential activity of the enzymes b-glucosidase and chitobiase were established in a variety of investigations. A compilation on the relationship between some enzymes and e.g. chloroplastic pigment concentrations (CPE) in the sediments showed that linear relationships can be found including data from very different oceanic regions (Fig 5, Lochte et al., 1999).

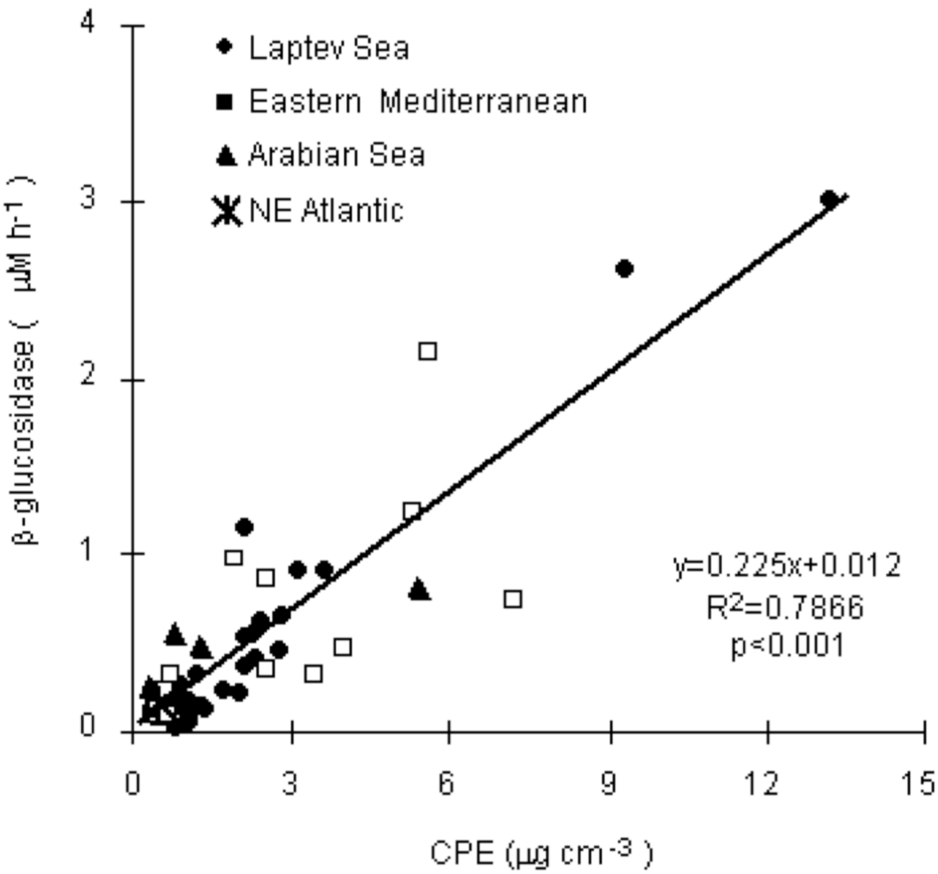

Figure 5: Correlation of b-glucosidase activity and chloroplastic pigments equivalents (CPE) in surface sediments (data from the Arabian Sea: Boetius and Pfannkuche unpubl. data)

The largest amount of data was available for ATP (200 data points), a variable which can be used for the estimation total microbial biomass. Other parameters of microbial biomass measured in several of the investigations were phospholipid concentrations and bacterial biomass determined by microscopy. One goal of our project was to establish a common conversion factor for each method to obtain comparable estimates of microbial carbon biomass.

Table 1 shows the conversion factors obtained for each method. By applying these empirical relationships based on linear regression analysis of all data for each parameter the different variables for microbial biomass were converted into carbon based total microbial biomass (TMB). Bacterial biomass (det. by microscopy) was also converted to TMB on the basis of linear regression with phospholipid concentrations, to account for other microbial organisms like fungi, yeasts and protozoa which contribute significantly to the total microbial biomass in sediments. DNA data were not converted, because either adenylates or phospholipids concentrations were available from the same samples. A total of 300 data on carbon biomass were obtained by this procedure. Figure 6 shows the distribution of microbial carbon biomass in the Atlantic.

Parameter	**No of data**	**conversion to**	**Regression**	**Regression coefficient**
ATP *(pmol cm-3)*	103	total adenylates *(pmol cm-3)*	y = 3.3x - 12	R2 = 0.996 p<0.001

Parameter	No of data	conversion to	Regression	Regression coefficient
total adenylates *(pmol cm-3)*	226	TMB *(µg C cm-3)*	y = 0.3x + 35	R2 = 0.465 p<0.001
bacterial biomass *µg C cm-3)*	97	TMB *(µg C cm-3)*	y = 1.2x + 28	R2 = 0.494 p<0.001

Table 1: Conversion of different parameters of microbial biomass into total microbial biomass (= TMB) in carbon units (µg C cm-3 sediment). TMB was calculated from phospholipid concentrations, based on the finding that 100nmol phospholipids is equivalent to 1 g C (Dobbs and Findlay 1993). The regression analyses are based on pairs of data from the same sample.

A relatively large data set is available for the eastern Arctic basins as well as for the East Atlantic. No data were obtained for the Midatlantic Ridge, the western parts of the Atlantic and Arctic as well as for the Southern Ocean. The data bank could be further improved by including U.S. benthic microbiologists as cooperation partners of future projects.

Bacteria make up the largest fraction of microbial biomass in deep-sea sediments and, hence, their biomass is presumably a good indicator for the trophic supply, i.e. the POC sedimentation to the seafloor (Deming and Baross 1993). It is believed that this relationship between POC input and microbial biomass is caused by the limitation of microbial growth due to the low supply of degradable organic matter to the deep sea. This is also the explanation for the relationship between POC flux to the sediments and oxygen consumption, i.e. carbon turnover. Thus, a correlation between microbial biomass and oxygen demand in the sediments is likely. However, this relationship was rarely tested in abyssal habitats. Our aim was to accumulate a large dataset of total microbial biomass to investigate emperical relationships which could potentially be used as proxies for oxygen consumption.

A total of 300 biomass data are available, however, very few data were from investigations with parallel biogeochemical measurements. Less than 10% of the data were linked to oxygen flux data, and these fell only within 5 grids of 1°x1° degree latitude and longitude. Thus, we were not able to obtain a sufficient data set to test the correlation of microbial biomass and oxygen flux on a basin wide scale. The reason for this missing link is that there are only very few benthic investigations in which geological, biogeochemical research as well as microbiology were carried out at the same stations. Such interdisciplinary studies of deep-sea areas are e.g. SEEP, Eumeli, OMEX, EQPAC, BIO-C-FLUX, BIGSET. However, these investigations mainly focussed on process studies and were carried out repeatedly at a few geographical locations only. Even including the available literature, the current data base for the Atlantic Ocean is not good enough to test the relationship between oxygen consumption and benthic microbial biomass and activity. This can only be improved by further field research, covering large oceanic regions with combined studies of benthic biology and biogeochemistry.

Meiofauna

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One objective of the ADEPD project was to accumulate information on the deep-sea meiobenthos of the Atlantic Ocean and to investigate whether these data could be linked to other biological and geochemical data to finally identify biogeochemical provinces at the deep seafloor. The sediment-inhabiting meiofauna is a major component of benthic ecosystems, particularly in the deep sea. However, due to a lack in standardisation of sampling, sorting and biomass determination techniques, the comparison of meiobenthic stocks on an ocean-wide basis is fraught with several problems (Thiel 1983; Tietjen 1992; Soltwedel submitted). Different sampling devices (various types of grabs and corers), subsampling strategies and extraction methods (especially the use of different lower size limits of sieve meshes) generally makes a comparison of meiofauna data from the literature a challenge. Within this project, it was decided to use all meiofauna data as given by the project partners and/or in the literature neglecting possible artefacts introduced by differing sampling procedures.

Figure 7 shows the number of meiofauna samples per 3 x 3° grid in the Atlantic and Arctic Oceans. A total of 298 data points, approx. 65% from the north-eastern side of the Atlantic Ocean, are available for an ocean-wide comparison. The data coverage is, of course, by far too patchy for basin-wide extrapolations, however, the set of meiofauna data might be sufficient to detect general trends in regional meiofauna distribution patterns and to compare meiofauna numbers with other biological and geochemical parameters.

A plot of meiofauna abundances against latitude (Fig. 8) shows clearly increasing ranges (meaning generally higher values) of meiofauna numbers in higher latitudes, especially for the northern hemisphere. Unfortunately, there are only very few data points available for the southern Atlantic Ocean and Antarctica to confirm a supposed mirror-image for the southern hemisphere. Figure 8 also depicts enhanced meiofauna abundances in the upwelling regions off NW- and SW-Africa, and a northward decrease in meiofauna numbers in the central (permanently ice-covered) Arctic Ocean, north of approx. 80°N.

Surface productivity and the flux of organic matter exert considerable control on benthic standing stocks in the deep sea. Consequently, also meiobenthic densities and biomasses should show perceptible differences in areas with different primary productivity in surface layers. Seasonal and interannual variabilities in primary production, and subsequently temporal variations in food supply to the benthos in different oceanic regions, might also result in temporal variability in benthic standing stocks, complicating a direct comparison of deep-sea meiobenthic data from the literature. Soltwedel et al. (1996) found some indications for growth reactions in deep-sea nematode assemblages to an episodic food supply. However, a measurable response in metazoan abundances to a seasonal or episodical input of particulate organic matter has never been observed in oceanic regions (Pfannkuche, 1993; Gooday et al., 1996). Thus, a comparison of metazoan meiofauna data although from various sampling periods over the year might generally be possible.

Figure 9: Correlations between meiofauna densities and
a) sediment bound pigment concentrations (CPE)
b) total organic carbon contents of the sediments (TOC)

A significant correlation ($p < 0.05$) could also be found between meiofauna abundances and total organic carbon (TOC) contents of the sediments (Fig. 9b). However, pairs of meiofauna and TOC data from the same station are already very limited ($n = 10$) and probably too sparse to confirm or negate a general relationship. This holds also for all other biogeochemical parameters and exposes a general disadvantage.

Only very few investigations were carried out comprising (meio)faunal studies as well as biogeochemical and geological research. Even when including all information available from the literature, the current data basis is not good enough to test relationships between faunal components and abiotic/biotic parameters on a basin-wide scale for the Atlantic Ocean. This can only be improved by further field research, covering large oceanic regions with combined studies of benthic biology and biogeochemistry.

Empirical relationships between pigment concentr. and oxygen flux

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The input of organic matter to the sea floor and biological turnover of this material measured as benthic oxygen consumption can be expected to show some relation-ships. Therefore, the data collected in ADEPD were tested for empirical correlations between benthic oxygen flux and other biological and geochemical parameters. As already pointed out in sections 6 and 7, only small data sets are available for comparison where measurements were carried out at one location. A relationship with oxygen flux could only be established for chlorophyll a concentrations in the surface sediment (Fig. 10). Since chlorophyll a is a labile organic compound it represents the short term input of organic matter and may, thus, reflect the direct biological response to organic matter supply.

Figure 10: Correlation between sediment oxygen demand (SOD) and chlorophyll a concentrations in the surface sediments.

The data set is unfortunately too small to draw far reaching conclusions from this correlation. Despite this restriction, we have pushed the analysis further and have estimated for some regions oxygen consumption based on the concentration of chlorophyll a in the sediments (Fig. 11). These estimates were compared to the analysis of oxygen fluxes by Jahnke (1996, Fig. 17). In the central parts of the Atlantic Ocean, where benthic acitivity is low, data estimated by both approaches compared well (Fig. 12). Larger differences of more than a factor of 2, both negative and positive, were found close to the shelf particularly under upwelling regions. Here considerable and highly variable export of organic matter from the shelf occurs. The rapid biological reaction to such imput of POC is possibly described better by the relationship to chlorophyll a concentrations than to organic carbon accumulation rates. However, many questions and uncertainties remain and require more detailed studies. It also implies that the highly variable regions along the continental margins are still insufficiently understood and, despite the apparently high numbers of measurements, are still undersampled.

Benthic fluxes of nutrients and oxygen

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Data on benthic fluxes of oxygen, silicic acid, and nitrate were incorporated into the PANGAEA data information system. The data set covers areas in the North Atlantic and in high southern and northern latitudes of the Atlantic Ocean. These data sets are based on projects of the Alfred-Wegener-Institute, the SFB 313 (Univ. Kiel), BIOTRANS, BIO-C-FLUX, and OMEX. Additionally, we investigated relationships between benthic organic carbon fluxes (derived by sediment uptake of oxygen) and primary production and considered the distribution of benthic fluxes of silicic acid and nitrate in different biogeographic provinces of the Atlantic Ocean. For these purposes the Geoinformation-System (GIS) Arc/Info was applied to couple various parameters and to derive for example the average and total remineralization rate of organic carbon for sediments from different subregions of the northern North Atlantic. In contrast to most previous considerations of benthic geochemical cycles in marine systems a GIS takes into account the spatial distribution of sampling sites by specific geostatistical procedures and ensures accurate calculation of sub-areas such as the shelf, slope or certain abyssal plains of the ocean (Schlüter et al., 1998).

For the northern North Atlantic (60-80°N, Fig. 13) the transfer of organic carbon from surface waters to the seafloor was calculated (Schlüter et al., in press). This calculation is based on an empirically derived relationship between the rain rate of remineralizable organic carbon, derived by in situ O2 profiles, primary production (remote sensing data of Antoine et al., 1996), and water depth (Fig. 14). The reliability of this attempt is supported by the good correspondence of calculated rain rates with an independent data set of particle trap studies and shipboard measurements of O2 profiles.

Figure 13: Sites of in situ and shipboard measurements of oxygen profiles, shipboard sediment incubation, and particle trap studies.

For water depths of > 500 m the total seafloor remineralization rate is 2.7 x 106 C yr-1 for the northern North Atlantic. Low and nearly similar average rain rates of 0.60 and 0.65 gC m-2 yr-1 have been derived for the deep basins of the Norwegian and Greenland Seas. Therefore, 1.7-1.8% of the primary production is transferred to the seafloor of these basins. A considerably higher average flux of 3.8 gC m-2 yr-1 was calculated for the Iceland Plateau, where ~3.3% of primary produced organic carbon reaches the seafloor. The sediments of the Iceland Plateau receive 1.0 x 106 tC yr-1 or ~37% of the organic carbon rain rate to the seafloor derived for the entire northern North Atlantic. The transfer of primary produced organic carbon below water depths of 500 and 1000 m suggests that 10.3 x 106 tC yr-1 and 4.5 x 106 tC yr-1 are exported from surface waters. This is 2-4.4% of the organic carbon produced in the photic zone of the northern North Atlantic east of Greenland (Schlüter et al., in press).

In addition to the northern North Atlantic regional budgets of organic carbon fluxes to the seafloor were derived for the northwest and equatorial Atlantic Ocean, using site-specific relationships. Besides organic carbon fluxes the regional distribution of nitrate and biogenic silica fluxes (derived by the efflux of silicic acid from the sediment) were investigated with special emphasis on the biogeographic provinces of the surface ocean as established by Longhurst (1995) (Fig. 15). This provides information about coupling and/or decoupling of surface water characteristics such as primary production, oceanographic features, and plankton communities with benthic fluxes.

Figure 14: Multiple regression of water depth, primary productivity (PP), and rain rate of remineralizable organic carbon to the seafloor. Only organic carbon rain rates derived by in situ O2 profiles were considered for this purpose.
Figure 15: Benthic silicic acid flux (a proxy for the rain rate of biogenic silica) in different biogeographic provinces as defined by Longhurst (1995) of the Atlantic Ocean. South polar domain (APLR, ANTA), South Atlantic domain (SATL), Westerlies domain (North Atlantic; NADR), north polar domain (ARCT). Data are from Hensen et al. (1998), Schlüter et al. (1998), and Zabel et al. (1998).

Overview of regional analysis of benthic fluxes in the South Atlantic

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The main portion of benthic flux measurements in the South Atlantic archived in PANGAEA during the term of the ADEPD-project have been collected in the Special Research Project 261 funded by the Deutsche Forschungsgemeinschaft (DFG). Generalized maps with regional distribution patterns of nutrient release rates (phosphate, nitrate and silicate) have been published by Zabel et al. (1998), Hensen et al. (1998, 2000).

Generally, close correlations between benthic fluxes and control parameters like primary production or the sedimentary content of organic carbon can be observed. In addition to the accumulation and burial rate of organic matter at the sea floor, the mineralogical composition of sediments play a considerable role in some nutrient cycling. It is important to note that the relationships mentioned above differ regionally (Fig. 16). Unfortunately, the data resolution in some regions of the central and southern Atlantic is still rather limited (e.g. West African upwelling area and partly along the eastern coast of South America), but new results from recent cruises will be expected in the near future. Another uncertainty is the potential effect of saisonality. Annual variation could shift the relative importance of some regions, but general patterns should not be affect. The expansion of the organic carbon data set collected in ADEPD enable a more detailed and promising identification and characterisation of biogeochemical provinces.

Figure 16: Regional distribution patterns of the diffusive silicate flux across the sediment-water interface in the eastern South Atlantic (A). Correlation between release rates and primary production for particular regions (B and C). From Zabel. et al. (1998).

Global benthic fluxes of oxygen and carbon

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Data Compilation

The sea floor oxygen flux results compiled in Jahnke (1996) was imported into the ADEPD data set and into the PANGEA data base. In addition the ADEPD project located several additional benthic oxygen flux data sets from the central and eastern basins of the South Atlantic, the central mid-latitude North Atlantic and the northern North Atlantic representing a total of 25 additional locations. Some of these data sets employed earlier, less accurate methodologies than are presently available. Never-the-less the results are generally consistent with the distributions reported by Jahnke (1996; Figure 17). The mean fluxes at 68% of the sites are with a factor of 2 and 92% are within a factor of 3 of the values reported in the earlier compilation. With the addition of the results from previously unrepresented regions, the ADEPD compilation of sea floor oxygen fluxes represents a significantly more complete description of benthic respiration than previously available.

Comparison to other estimates of seafloor oxygen fluxes

The flux of oxygen into bottom sediments can also be estimated as the difference between the flux of organic carbon to the sea floor minus the organic carbon burial rate times the O2:C ratio of the remineralization process. The organic carbon flux to the seafloor has been estimated using empirical relationships between fluxes of organic carbon (Jc) , net primary production (Pp) and depth (Z). Primary production was evaluated on the base of both primary production field measurements and surface chlorophyll concentrations (Cchl) estimated from CZCS satellite radiometer measurements during the 1978-1986 time period. There are estimates of primary production for the whole ocean at 0.17° x 0.17° resolution with an exception of some permanently cloud-capped arctic regions. The flux of organic carbon was estimated (Romankevich et al., 1999) using the relationship Jc = 33 Pp / Z (Tseitlin, 1993), where primary production is calculated from chlorophyll concentration Ln Pp = 0.436 + 0.52 Ln Cchl - 0.01 l Latitudel (Vinogradov et al., 1996). Oxygen flux was obtained by multiplying organic carbon flux by C:O2 ratio - 0.6 (Takahashi et al., 1985). A small correction was made to account for the amount of organic carbon permanently buried in the sediment (accumulation rate of Corg). Calculated oxygen flux for the Atlantic Ocean (resolution 1° x 1°) is shown in Fig. 18.

Overall, there is very good agreement in the estimated total carbon and oxygen fluxes to the deep seafloor (seafloor greater than 1000 m water depth; Table 2). A value of 5.33x1013 mol O2 y-1 is estimated from the surface productivity and vertical carbon flux relationship while a value of 5.43x1013 mol O2 y-1 is estimated from the sea floor benthic oxygen flux and organic carbon burial rate compilation. Considering that these estimates are obtained from completely different approaches and data sets, such agreement may be fortuitous. Never-the-less, these estimates support each other and suggest that a reasonable estimate of the global seafloor oxygen flux has been achieved.

While the total values agree well, the spatial distributions obtained by these distinct methods display differences. For example, fluxes in the central basins from benthic studies appear less than those estimated from productivity and vertical flux relationships. As discussed in Jahnke (1996) the low values in these regions estimated from sediment measurements may indeed be an artifact of the extrapolation and contouring methods employed in early sediment compilations. Another important difference is that sea floor fluxes do not appear to increase in the high northern latitudes in proportion to the increase observed in surface productivity. This suggests that the efficiency of carbon transfer from the surface to the deep ocean may vary with latitude although additional studies will be required to verify this idea.

Perhaps the greatest discrepancies occur near ocean margins (see also Empirical relationships between pigment concentrations and oxygen flux). Numerous factors may complicate the comparison of seafloor and vertical water column fluxes in these regions such as lateral transport of particulate organic materials, near bottom turbidity flows, dilution of organic matter by land-derived lithogenic materials, etc. Despite the discrepancies near the margins, high fluxes are estimated by both calculation strategies suggesting that these ocean boundary regions contribute significantly to the flux of organic carbon to the deep sea.

Fluxes	**Jahnke, 1996**	**Vetrov, Romankevich**
Flux C to seafloor (total), mol C yr-1		1.47 10**14
Flux O2 to seafloor (total), mol O2 yr-1		2.45 10**14
Flux C to seafloor > 1000 m, mol C yr-1	3.30 10**13	3.20 10**13
Flux O2 to seafloor > 1000 m,mol O2 yr-1	5.43 10**13	5.33 10**13
Flux C through the 1000 m depth horizon, mol C yr-1	7.20 10**13	1.13 10**14 (Flux C = 33 Pp/Z)
Flux O2 through the 1000 m depth horizon, mol O2 yr-1	1.20 10**13	1.88 10**14

Table 2: Fluxes of Corg and oxygen in the World Ocean

Recommendations for future research

During the project ADEPD gaps in data coverage and knowledge have been identified and some of the most pertinent problems are described in the above chapters. They are summarized briefly in the following and may serve to guide future research related to the biogoechemistry of the deep sea floor.

a) With respect to geographical data coverage it has to be noted that this analysis is only based on the data collected in ADEPD. Due to the concentration on European projects the eastern Atlantic is much better represented than the western Atlantic. This does not imply lack of data in those regions, but a lack of adequate representation of data from USA or Canada. Therefore, it is of great importance to include partners and data bases from American sources in future projects.
b) The data collection is by no means complete. During the course of the project new sources of data were identified which should be included in future data collections. This concerns not only the above mentioned American data, but also data from the EU and Russia. In particular, a great deal of biological data is in a preliminary state. These data need to be prepared before they can be imported into a data information system. Since it is very costly to sample and analyse such data in the first place, this hidden treasure should be made accessible. Such data "archaeology" may be carried out within other projects, but the necessary step of the final archiving in a data base with long-term stewardship and public access is in most cases not implemented. This important aspect of deep sea research needs to be persued on a long term basis.
c) Geochemical data show a much better geographical spread than biological data. Insufficient data coverage is still evident for the Mid Atlantic Ridge zone, parts of the South Atlantic and the Atlantic sector of the Southern Ocean. In contrast, in the north polar regions the data coverage is much better for most variables.
d) Biological data are generally much more restricted to specific well studied regions. Furthermore, geochemical, geological and biological investigations are rarely carried out jointly or in similar regions. This seems to be a systematic scientific pattern and a problem in deep sea research. The clustered geographical data coverage as well as lack of joint research severly hamperes the comparison between geochemical and biological data and extrapolation of biological data to basin wide scales. Therefore, interdisciplinary investigations including biological and geochemical studies seem essential to gain more understanding of deep sea processes.
e) The largest differences in estimates of oxygen fluxes are found at continental margins. This is obviously caused by many interacting processes affecting transport and biological turnover. Since rates of oxygen fluxes (and other process rates) are much higher in these regions compared to the abyssal plains these ocean boundary regions contribute significantly to the flux of organic carbon to the deep sea. However, the data coverage and the knowledge of processes at the continental margins are still insufficient and need further attention.
f) The data analysis carried out in ADEPD represents only a preliminary approach. More sophisticated statistical analysis with GIS tools including coupling of different variables for the characterization of sea floor regions promises significant scientific advances.

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Atlantic Data Base for Exchange Processes at the Deep Sea Floor

”ADEPD”

A proposal to the European Network for Research in Global Change (ENRICH)

Part I: anonymous part

1. Objectives

This scientific proposal falls under the Marine Science and Technology work programme related to global change (area A.2.1.). It addresses in particular the deep sea floor of the Atlantic with special emphasis on the North Atlantic. It builds up a network for the exchange of biogeochemical benthic data and aims at integrating present knowledge of processes at the deep sea floor. It is a supporting action contributing to JGOFS and with benefits for natural resource management.

1.1. Background - State of the art

The global cycling of carbon and associated elements through the world’s oceanic systems is one cornerstone of the understanding of the linkage between climate and oceanic processes addressed by the international Joint Global Ocean Flux Studies (JGOFS), a core project of the International Geosphere-Biosphere Programme (IGBP). In order to achieve a comprehensive view of oceanic biogeochemical cyles, the role of the long-term reservoirs of the deep waters and in particular the bottom sediments must be assessed. It is one of the major goals within the JGOFS programme to reconcile rates of surface water production and rates of vertical export with data on benthic turnover to arrive at a full description of transport, burial and turnover of matter within ocean basins. Furthermore, the deep sea ocean fluxes, albeit much smaller than those in surface waters, can be measured directly at a physical boundary and are less subjected to annual variability or short term variation. Therefore, they represent average flux rates and mirror, with some aberrations, average surface water productivity. Although the different national JGOFS programmes did not include specific benthic projects, there are a number of national and international European projects investigating benthic processes which are to some degree collaborating with JGOFS (see section 2). Therefore, it would represent a substantial optimization to make the deep sea biogeochemical data from various projects compatible with JGOFS data from the upper water column.

Since many biogeochemical key parameters describing standing stocks and rates of turnover can for practical reasons only be obtained at a few selected stations, the extrapolation of such data from individual points/stations to a larger spatial scale is difficult. It requires the determination of empirical correlations or modelling of processes which link these limited data to ”master” variables for which a large data base is already available. In this way, the the global ocean flux of particulate organic carbon was recently assessed from benthic data (Ref. 1). This very commendable work, however, suffers from scarce data and can, therefore, only arrive at approximate estimates. This work shows that the approach is feasible and that a general regional classification of the sea floor in terms of biogeochemical characteristica is be possible. Such a description of ”benthic biogeochemical provinces” of the Atlantic deep sea floor, analogous to the concept of upper ocean biogeochemical provinces (Ref. 2), will be one aim of this proposed project. The emphasis will be placed on the North Atlantic, since it is this area for which we have the most comprehensive data sets in particular from British, French, German and American projects. Furthermore, the North Atlantic is the most perturbed region due to human activities. The South Atlantic will naturally be included to arrive at a complete description of the whole Atlantic Ocean.

Such an areal biogeochemical description of the deep sea floor would not only contribute to the assessment of the role of oceanic processes in climatic changes, but is also a basic prerequisite for evaluation of any potential anthropogenic use of the deep oecan. It would enable the identification of particularly sensitive areas and, thereby, aid political, economical and legal decisions. The deep sea floor has been generally recognized as a key global environment and improvement of the knowledge about this environment has been recommended as one European Grand Challenge in marine research (Ref. 3, Ref. 4).

1.2. Objectives

The proposed project will establish a network of European researchers involved in geochemical and biological deep sea work. Through workshops, the build up of a joint data base and geographical analysis of these data this group will address the following objectives:

-to compile biogeochemical data from Atlantic deep sea sediments (benthic boundary layer) from various projects and from the literature. This compilation includes harmonisation of data (common units, conversion to uniform variables).

-to extrapolate data of biogeochemical processes at the sea floor obtained at individual stations to a basin wide scale using empirically established correlations to widely measured ”master” variables.

-to link biological (biomass) to geochemical (fluxes of chemical species, etc.) data.

-to develop an areal description of ”benthic biogeochemical provinces” in the deep sea of the Atlantic.

-to compare the biogeochemical processes at the sea floor to data on surface water productivity and sedimentation from JGOFS projects.

-to make the results of this study available to a wide user group, particularly within the JGOFS community, and to authorities involved in decisions about utilization of deep sea resources and deep sea protection.

-to identify gaps in regional coverage and to specify advanced data analysis approaches (kinetic models, coupling of different variables etc.) to be addressed by future projects.

1.3. Progress beyond the state of the art

The data, which have been produced within a number of different national or international projects, as well as relevant data from the literature will be made available in an easily accessible form. Since a number of these data sets are as yet unpublished or variables may have to be converted to common units, this compilation will produce a data base much larger than hitherto available. This is particularly so, if Russian data are incorporated.

The compilation of these data will allow to produce at a basin wide evaluation of processes at the deep sea floor. Based on this extensive data base, a much more detailed areal description than presently available would be possible. Such a compilation will be a valuable basis for assessments of oceanic carbon cycles and for an evaluation of potential use of deep sea areas by European nations.

It has to be made clear, however, that within this limited project only the foundations for a more advanced analysis of the data can be laid. Once the data base has been established, based on the projects outlined in section 2.1., future data additions can easily be made. It is also possible to transfer the data into the Geographic Information System (GIS) for advanced or specialized data analysis in future projects.

1.4. Originality and innovation

At present no compilation of data for deep sea biological and geochemical data of this extent exists for the Atlantic. It is also an important new step to combine biological and geochemical data for a geographical analysis of deep sea processes. The description of deep sea biogeographical provinces is not entirely new, but in view of the range of variables to be used for this analysis it is to be expected that a significantly improved geographical classification of the Atlantic deep sea floor will be achieved.

2. Work content

2.1. General approach

The tasks outlined below will be achieved by: a) two workshop meetings, b) the build up of the data base and c) first analysis of the compiled data according to the discussions during the work shops. Each partner participates in the compilation of data and undertakes some special tasks as outlined below. There are further interested researchers from the scientific community who wish to join in the workshops and contribute to the data base. Their participation in this project will be coordinated by the partners according to nation or field of research. Communication between the partners will be organised by the coordinator of the project via e-mail.

The main projects to be considered within this project are:

Acronym	*Area*	*Funding*
SFB 261	South Atlantic	German
div. AWI projects	Atlantic sector of the Southern Ocean	German
EUMELI	tropical North Atlantic	French
SEDORQUA	tropical North Atlantic	French
BOFS	Northeast Atlantic	British
PAP/MAP	Northeast Atlantic	British
BIOTRANS	Northeast Atlantic	German
BIO-C-FLUX	Northeast Atlantic	German
BIGSET	Northeast Atlantic	German
BENBO	Northeast Atlantic	EU
ALIPOR	Northeast Atlantic	EU
OMEX	Northeast Atlantic continental margin	EU
BIOGAS	Northeast Atlantic continental margin	French
SFB 313	North Atlantic, Norwegian Sea	German

In addition to these ongoing or recently finished projects, data from various American and Russian investigations in the Atlantic will be incorporated. This will strengthen the data coverage in the West Atlantic. There will be further smaller projects not mentioned here which will also be considered. Available literature data will be included.

The following variables may be included into the data base subject to the discussions on the first workshop:
Benthic flux measurements:

oxygen flux (benthic chambers and profiles)
nitrate flux (profiles)
phosphate flux (profiles)
silicate flux (benthic chambers and profiles)
inorganic carbon flux (benthic chambers and profiles)
radionuclide fluxes (inventories)

Biological parameters:

concentration of specific components, biogenic tracers
(e.g. pigments, barium)
biomass of organisms of different size groups in carbon
(derived from several variables:
-abundance and size of organisms for macro- and megafauna,
-ATP, Phospholipids, DNA for meio- and microfauna)
rate of bioturbation

Sediment particle composition:

concentration of organic carbon in surface sediments*
concentration of carbonate*
concentration of opal*
sediment accumulation rates*
sediment facies*

* = available from literature compilations

The project has four phases (see time table). In the initial phase, the first workshop of 3 days will be held during which the available data will be reviewed, the conversion to common units and variables will be established and build up of the data base will be discussed. The second phase is devoted to the compilation of data in the data information system and first analysis of data. In the third phase, the second workshop of 3 days will be held during which the achieved results will be evaluated, the final analysis of data will be discussed and publication and dissemination of results will be prepared. The last phase is used for final analysis of results, publication and dissemination of results.

2.2. Tasks

Task 1- Workshop I

Identifiy suitable datasets and variables to be collected in the data base.
Establish units and, where required, conversion factors to harmonize data.
Discuss procedure for data collection.
Introduce participants to the interactive use of the data information system (SEPAN).

Task 2 - Collection of data from various projects

For the collection and integration of data the interactive data bank system SEPAN will be used. At present the available data are very heterogeneous both in respect to the variables determined and sampling strategy / frequency. Thus, the integration requires normalizing of data and, particularly for biological data, the conversion of proxies (e.g. ATP) to basic data (biomass), where possible. Data of prime interest are those from oceanic regions, but data from continental slopes up to 500m water depth will also be included in the data base.

Task 3 - Data analysis and areal description of biogeochemical provinces

The different variables within the data base will, as a first approach, be analysed for correlations. This will provide information on relationships which may be utilized to extend the geographical coverage of data obtained at only a few stations. Spatial representation of key variables and description of “biogeochemcial provinces” will be prepared. Benthic turnover of matter will be compared with estimates of export of organic material from the upper water column for selected ocean regions. For advanced analysis of data the Geographic Information System (GIS) may be used. An export of data from SEPAN to GIS will be provided, but advanced analysis of data can not be achieved within this small project.

Task 4 - Workshop II

Review the data collection and their analysis for areal representation.
Identify gaps of knowledge and make suggestions for advanced analyses in future projects.
Prepare joint publications and WWW-presentation.

Task 5 - Publication and dissemination of results

The achieved results will be made available to the scientific public via joint publications in relevant journals. A wider user group will be addressed by a WWW site presenting the most pertinent results.

2.3. Data management plan and quality control

The data management plan includes the following steps:
- Data collection.
- Quality control (completeness of metainformation for the data sets, validity and objectivity of measuring and calibration methods, error checking within the data sets).
- Data publication (long term banking of data sets using an appropriate information system within the European science network providing retrieval via WWW, downloading of any portion of data and links to the scientific publications.
- Data retrieval and data handling support for working groups in the phase of interpretation.

Approach

The working groups in the different partner institutions will provide quality checked data in suitable form to the coordinator.The coordinator is responsible for supplying these data to the data bank. This will be done in close cooperation with the partner involved in data management. The data management partner is responsible for the processing and dissemination of data sets by providing the information system SEPAN (Sediment and Paleoclimate Data Network) for this purpose. In particular, the SEPAN-group will

- prepare data sets for publication (including transformation of data sets into consistent formats and procedural quality checking within the information system),
- provide a WWW homepage for project specific information including an entry level for data retrieval, and links to relevant home pages of project members
- prepare data sets and related metadata for mirroring on other sites,
- will support working groups by collecting project relevant data from previous works and
- supply software, data products, and interfaces for the visualization of data in mapping tools and Geographical Information Systems (GIS) for the synthesis of results.

The information system SEPAN was developed by partner B) (see section 7) as the first subsystem of PANGAEA (PaleoNetwork for Geological and Environmental Data) (Ref. 5). The project was financed by the German Ministry of Education, Science, Research and Technology (BMBF). The PANGAEA/SEPAN system uses client/server technology through the Intranet/Internet; the main database server is a DEC Alpha 8200 (4 processor, 2 GB internal memory, 50 GB hard disc capacity) running SYBASE Version 11 under DEC/UNIX as the database software. The user-friendly client software for access to the server was written in 4th Dimension and can be used for MacOS and Windows as well.

• The system PANGAEA/SEPAN is operable. From the beginning of the project, it can be used as the central facility to store all information, metadata as well as analytical data.
• Access to the data is realized in two ways. The client software allows a high functionality in retrieving data and can be installed in any group of the project. For simple world wide access on published data of the project, a web interface is provided.
• Due to the installation of the system in a computer center experienced in data management within a major research institute, the long time archiving of the data is ensured. There is no similar system available at this time.

3. Project milestones and deliverables

3.1. Milestones

The project milestones comprise the two workshops and the publication of the results. The time table gives an overview of the temporal distribution of the tasks. The project is envisaged to start in January 1998 and to run for two years. The workshops are planned for March 1998 and March 1999 and will last 3 days each. Collection of data and build up of the data bank will occupy the largest time section of the project from January 1998 to April 1999. Data analysis and dissemination of results occupy the second half of the project.

Table 1: Time table:

	1998												1999											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Task 1 -			**																					
Task 2 -	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**								
Task 3 -													**	**	**	**	**	**	**	**	**			
Task 4 -															**									
Task 5 -																		**	**	**	**	**	**	**

3.2. Deliverables

a) Data bank of deep sea biogeochemical data of the Atlantic

b) Spatial representation of key biogeochemical benthic variables

c) Areal description of ”deep sea biogeochemical provinces”

d) Publications (in scientific journals, WWW site)

e) Report of the project including identification of the gaps of knowledge and suggestions for advanced analysis of the data

4. Benefits

4.1. Added value

Data spread in a number of individual projects are of little use when trying to come to large scale assessments. The individual projects cannot achieve the integration of data called for. This particular task can be provided by the supporting action ADEPD for benthic biogeochemical data of the Atlantic. It therefore helps to extend the use of the data beyond the scope of the individual projects.

The areal biogeochemical description of the deep sea floor would contribute to the assessment of basin wide fluxes across the deep sea sediments. In addition to this objective, which contributes to the international climate change project JGOFS, it provides also an important data base for the evaluation of any potential anthropogenic use of the deep ocean. It would enable to identify particularly sensitive areas and, thereby, aid political, economical and legal decision finding processes.

4.2. Relevance of carrying out at European level

As pointed out above, the relevant data have been collected by a number of different European international and national projects. Only by compiling all these data and also including available American and Russian data (see 4.3.) a wide enough data coverage of the Atlantic ocean can be achieved to tackle the objectives of this proposal. The main target area of this project is the North Atlantic, an area of relevance for the European nations.

4.3. Transnational participation

The partners are from 10 different institutions located in 6 nations (Britain, France, Germany, Netherlands, USA and Russia). The inclusion of participants from outside the European Union is vital to this project, since important data particularly from the western Atlantic have been produced by American groups and need to be included in the data bank. Similarly, benthic data from various regions of the Atlantic have been collected by Russian groups. These data are not easily available and an attempt will be made to include relevant, qualitiy checked data as far as they are accessible.

5. Economic and social impacts

Understanding the natural processes at the deep sea floor and identification of potentially sensitive areas is a key requirement for assessments in respect to any anthropogenic use or protection of the deep sea. Thus, the basic information service provided by this project may aid in developing regulations/legislations for the use and protection of the deep sea floor.

Atlantic Data Base for Exchange Processes at the Deep Sea Floor

”ADEPD”

Part II: participants identified

6. Project management

The project comprises the coordinator and 9 partners.

The coordinator is responsible for management of the project and organization of the workshops, for maintaining communication between all partners, for input of data supplied by the partners to the data bank and will lead the dissemination of results. The input of data to the data bank will be carried out in close cooperation with the partner responsible for the data management. A SEPAN interface will be installed at the coordinators institute.

Each of the partners will participate in the workshops, supply quality checked data in correct format for the compilation in the common data bank and undertake specific tasks as outlined under section 7. This includes analysis of data and participation in the publications.

There are further scientists who are interested to join in the discussion and compilation of data. These additional experts will be invited to join the workshops and discussions. If they wish to contribute data, this will be coordinated by the partner who is resident in the same country or working in the same field of research. By this involvement of external experts, the extent of the data base, the quality of data analysis and the general discussions will be improved and widened to include a broader view.

Communication between all partners and interested scientists will be maintained via e-mail and the WWW homepage of the project.

7. The Partnership

7.1. Participants and task distribution

Partner A) Coordinator:
K. Lochte, A. Boetius
Institut für Ostseeforschung Warnemünde (IOW), Germany

- -coordination of the project
- -maintaining communication between all partners
- -input of data to data bank
- -leading dissemination of results
- -organisation of workshops
- -contributing data from the following projects: BIOTRANS, BIO-C-FLUX, BIGSET

Partner B):
H. Grobe, M. Diepenbroek, H. Thiel
Alfred-Wegener-Institut für Polar- und Meeresforschung Bremerhaven (AWI), Germany

- -providing and maintaining data information system SEPAN
- -supervising collection of data
- -WWW publication of data
- -transfer of data from SEPAN to GIS
- -contributing to the analysis of data
- -areal description of ”benthic biogeochemical provinces”
- -contributing data from the following projects: BIOTRANS, BIO-C-FLUX, OMEX

Partner C):
M. Zabel
Fachbereich Geowissenschaften, Universität Bremen (Uni Bremen), Germany

- -contributing to the analysis of data
- -areal description of ”benthic biogeochemical provinces”
- -contributing data from the following projects: SFB 261

Partner D):
M. Schlüter, O. Pfannkuche
Forschungszentrum GEOMAR Kiel (GEOMAR), Germany

- -contributing to the analysis of data in GIS
- -areal description of ”benthic biogeochemical provinces”
- -contributing data from the following projects: AWI Projects in the Southern Ocean (Atlantic sector), BIOTRANS, BIO-C-FLUX, BIGSET, OMEX

Partner E):
G. Shimmield
Dunstaffnage Marine Laboratory Oban (Dunstaffnage ML), UK
- contributing to the analysis of data in GIS
- areal description of ”benthic biogeochemical provinces”
- contributing data from the following projects: BOFS, BENBO, ALIPOR

Partner F):
C. Rabouille, S. Charbit, F. Bassinot
Centre des Faibles Radioactivites Gif-sur-Yvette (CFR Gif-sur-Yvette), France
- leading the analysis of data
- areal description of ”benthic biogeochemical provinces”
- contributing data from the following projects: EUMELI, SEDORQUA

Partner G):
M. Sibuet, A. Khripounoff, J. Galeron
IFREMER Centre de Brest (IFREMER Brest), France
- areal description of ”benthic biogeochemical provinces”
- contributing data from the following projects:EUMELI, BIOGAS, OMEX

Partner H):
W. Helder
Netherlands Institute for Sea Research (NIOZ), Netherlands
- areal description of ”benthic biogeochemical provinces”
- contributing data from the following projects: OMEX

Partners from outside the European Union:

Partner I):
R. Jahnke
Skidaway Institute of Oceanography (SIO), USA
- contributing to the analysis of data
- areal description of ”benthic biogeochemical provinces”
- contribution of data from American projects

Partner K):
A. Gebruk
P. P. Shirshov Institute of Oceanology Moscow (Shirshov Inst.), Russia
- areal description of ”benthic biogeochemical provinces”
- contribution of data from Russian projects

Table 2: Tasks and working groups

Involvement of the partners in the different tasks is indicated by
+ = minor involvement, ++ = major involvement, +++ = leading the task.

	task 1	task 2	task 3	task 4	task 5
partner A	+++	+	+	+++	+++
partner B	+	+++	++	+	+
partner C	+	++	++	+	+
partner D	+	++	++	+	+
partner E	+	++	++	+	+
partner F	+	++	+++	+	+
partner G	+	++	++	+	+
partner H	+	++	++	+	+
partner I	+	++	++	+	+
partner K	+	++	++	+	+

7.2. Competence of partners

The partners are all actively involved in biological or geochemical deep sea research for many years. They are experts in their field of research with numerous publications and have access to the relevant data. Most of the recent major deep sea programmes in Europe are represented by this group of experts as indicated by the list of projects from which data will be contributed to the ADEPD data base. The partners from outside the European Commission have been selected for their experience in this field. The previous assessment of oceanic fluxes by R. Jahnke (Ref. 1) is an important background information for this project and, therefore, he was chosen as the most suitable partner from USA. At the Shirshov Institute in Moskow biological and geochemical deep sea data from the Atlantic have been collected. A. Gebruk is an experienced deep sea biologist and will provide biological data. We hope to be able to include a further scientist involved in geochemical analyses.

The computer center has 15 years of experience in data management and in the design and implementation of databases. They are experienced particularly with benthic and geological data (Ref. 5).

The project will be coordinated by K. Lochte, who has been involved in serveral deep sea projects in the last 16 years. She has led the discussion on “Benthic exchange processes in the deep sea” as part of the Grand Challenge “Variability of the deep sea floor” formulated by ECOPS as a long term goal for European marine research (Ref. 4). The Institut für Ostseeforschung is presently coordinating the large European project BASYS in the Baltic Sea and has the appropriate experience for the coordination task.

8. Financial information

A breakdown of costs according to tasks is given in the following. The two figure label of each individual position of this breakdown appears in Table 3 to identify the costs. An annual breakdown has not been provided here, as the expenditures in both years are nearly equal.

A nominal effort of 10 day was fixed for each partner to make the respective data sets available for the data base. This time does not nearly cover the actual amount of effort spent, as each partner contributes more time in order to carry out the tasks.

The central server of the PANGAEA-System will be operated by the center free of charge (contribution 180 000 ECU/year) and 6 scientists are involved in the development and management of the PANGAEA/SEPAN information system. But the data management plan needs financial support for the application of the information system to the ADEPD project, including installation, software support and data retrieval.

Task 1): Workshop I

1.1. travel costs for all partners and invited additional scientists (in total approx 20 persons) (partners B - G)
1.2. costs for administration of workshop (partner A)

Task 2): Collection of data from various projects
2.1. Licence for SEPAN data bank system (partner A)
2.2. costs for data bank management (partner B)
2.3. cost for making data available (effort 10 days) (partners A-G)

Task 3): Data analysis and areal description of biogeochemical provinces
no extra costs

Taks 4): Workshop II
4.1. travel costs for all partners and invited additional scientists (in total approx 20 persons) (partner B-G)
4.2. costs for administration of workshop (partner A)

Taks 5): Publication and dissemination of results
no extra costs

Table 3: Breakdown of costs according to partners and tasks

All costs in Table 3 are given in ECU. The costs for the effort spent to compile the data has been estimated as 10 days for each partner; the cost per day are estimated as 200 ECU. This may be used to pay assistance.
For the travel costs to the two workshops the number of participating persons per partner is indicated. The workshops are running for 3 days each.

	task 1	task 2	task 3	task 4	task 5	SUM
partner A	2 000 (1.2.)	6 000 (2.1.) 2 000 (2.5.)		2 000 (4.2.)		12 000
partner B	300 (1.1.) 1 pers.	15 000 (2.2.)		300 (4.1.) 1 pers.		15 600
partner C	600 (1.1.) 2 pers.	2 000 (2.5.)		600 (4.1.) 2 pers.		3 200
partner D	1 000 (1.1.) 3 pers.	2 000 (2.5.)		1 000 (4.1.) 3 pers.		4 000
partner E	3 300 (1.1.) 3 pers.	2 000 (2.5.)		3 300 (4.1.) 3 pers.		8 600
partner F	3 300 (1.1.) 3 pers.	2 000 (2.5.)		3 300 (4.1.) 3 pers.		8 600
partner G	3 200 (1.1.) 3 pers.	2 000 (2.5.)		3 200 (4.1.) 3 pers.		8 400
partner H	1 000 (1.1.) 2 pers.	2 000 (2.5.)		1 000 (4.1.) 2 pers.		4 000
partner I	2 500 (1.1.) 2 pers.	2 000 (2.5.)		2 500 (4.1.) 2 pers.		7 000
partner K	2 500 (1.1.) 2 pers.	2 000 (2.5.)		2 500 (4.1.) 2 pers.		7 000
SUM:	19 700	39 000		19 700		78 400

9. Exploitation plan

The results of this project will be primarily exploited by making the data bank available to the international JGOFS scientific community. The data bank will be maintained after termination of the project, since future expansion of the data base is desirable and provided for by the data information system SEPAN.

The project will also in its final report suggest further ways of advanced data analysis to make optimal use of the complied data. This may form the basis for future research projects. Such analyses may for instance be focussed specifically on questions related to exploitation of the deep Atlantic.

9.1. Dissemination of results

The results of this project will be made available in two ways:

Publications in scientific journals and JGOFS news letter: This will address the scientific community involved in JGOFS and related fields of research.

Production of a WWW information: This will show the most pertinent results in an easily understandable form and also give information how to access the data information system. This way the results will be made available to a wider public (e.g. from industry, governmental agencies etc.).

9.2. Target user group

The international Scientific Steering Committee of JGOFS has implemented a Benthic working group with the aim to link the processes in the upper oceanic water masses established by direct measurements and modelling to the processes at the sea floor. This will finally provide a link between JGOFS and PAGES. The results of this project will therefore make the necessary benthic information available for global flux estimations of JGOFS. The data bank will be made available to members of this community upon request.

The results of this project will be made available to governmental agencies involved in environmental protection and potential anthropogenic use of the deep ocean. The project will provide basic information required for environmental protection measures or exploitation. Up to now, this information is not available in such condensed and easily accessible form.

9.3. Contribution to management for the sustainable use of the ocean

The North Atlantic Ocean surrounded by industrialized nations will be more subjected to anthropogenic disturbances than other oceanic regions. In particular, the need to dump different types of waste may increase as storage on land is limited. Such activities require well founded assessments of their impacts on the respective environment in order to protect sensitive areas and to regulate the exploitation of this resource. The data bank will contribute the essential information for such an assessment.

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Web - Pages of the EU project

ADEPD

Atlantic Data Base for Exchange Processes at the Deep Sea Floor

(1998-2000) EU MAST-III project MAS3-CT97-0126

ADEPD

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Objectives

This project falls under the work programme of EU/MAST (Marine Science and Technology) related to global change (area A.2.1.) and will establish a network of European researchers involved in geochemical and biological processes in the deep sea of the Atlantic. The network will be used for the exchange of biogeochemical benthic data and aims at integrating present knowledge of processes at the deep sea floor. It is a supporting action contributing to JGOFS (Joint Global Ocean Flux Studies), with benefits for natural resource management. In the current project phase, data are being compiled and archived in PANGAEA. Direct access to this data is provided by means of a direct download interface via the world wide web. For further information download the ADEPD proposal in PDF format (ADEPDPRO.PDF).

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Retrieval of analytical ADEPD data from PANGAEA

The PANGAEA information system provides powerful interactive tools to assist in the exploration of the data of numerous laboratories and researchers, along with applications which may help to map and plot this information. Down below, a short-cut is offered to retrieve sets of data relevant to ADEPD. To take full advantage of special options, users are encouraged to formulate their own queries. Please acknowledge that **full access** to unpublished analytical data is restricted by **password**. Downloading of large data sets though generally being possible may be affected by the situation in the web and the queue of current requests. For more information consult the tutorial or contact the PANGAEA hotline.

A. Boetius (Data)

- Biogenic tracers (enzyme activities, ATP, DNA, phospholipids, plant pigments)
- Benthic organisms (bacteria)
- Physical properities (porosity)

A. Gebruk (Data)

- Benthic organisms (totals of meio- and macrofauna, proportion of feeding types)

W. Helder (Data)

- Benthic profiles (oxygen, plant nutrients, metals, total organic carbon)
- Physical properties (porosity, pore water)

R. Jahnke (Data)

- Benthic fluxes and profiles (carbonate, total organic carbon, nitrate, opal, quartz)

G. Korneeva, A. Vetrov, E. Romankevich (Data)

- Sediment particle composition (carbon, carbonate)
- Benthic fluxes and profiles (accumulation, sedimentation)
- Biogenic tracers (enzyme activities)

O. Pfannkuche (Data)

- Sediment particle composition (C/N ratio)
- Biogenic tracers (plant pigments)
- Benthic organisms (meiofauna, macrofauna)

C. Rabouille (Data)

- Benthic profiles (oxygen, nitrate, silicate, phosphate)

M. Schlüter (Data)

- Biogenic tracers (opal)
- Benthic fluxes, profiles (inorg. carbon, organic compounds, oxygen, metals)
- Physical and physico-chemical properties (porosity, pH, alkalinity)

G. Shimmield, J. Foster (Data)

- Biogenic tracers (opal)
- Benthic fluxes, profiles (metals, sedimentation, accumulation, mixing)
- Physical properties (porosity, dry bulk density)

M. Sibuet, J. Galéron (Data)

- Biogenic tracers (plant pigments)
- Benthic organisms (totals of meio-, macro- and megafauna)
- Benthic profiles (carbonate, total organic carbon)

T. Soltwedel (Data)

- Biogenic tracers (adenylates, DNA, plant pigments, particulate proteins)
- Benthic organisms (bacteria, meiofauna)
- Physical properties (porosity)

M. Zabel, C. Hensen (Data)

- Benthic fluxes, profiles (inorg. carbon, organic compounds, oxygen, metals)
- Physical and physico-chemical properties (pH, Eh, alkalinity)

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Atlantic Data Base for Exchange Processes at the Deep Sea Floor

Compilation of all data collected in ADEPD by the partners of the project

Variable	Partner A	Partner B	Partner C	Partner D	Partner E	Partner F	Partner G	Partner H	Partner I	Partner K	Lit	SUM
Accumulation rate					22					493		515
Adenylates	34	125										159
Age model		16	1									17
Alkalinity			187	20								207
Alpha-Glucosidase activity	117											117
Aluminum		2	5		4							11
Aluminum (water)			1	10								11
Ammonium			184	4				38				226
Amylolytic enzyme activity										53		53
ATP	72	8									24	104
Bacteria, abundance	84	41									13	138
Bacteria, biomass	50	41									3	94
Barium		4	5		4							13
Barium (water)			36									36
Beta-Fucosidase	9											9
Beta-Glucosidase activity	120											120
C:N ratio				14								14
Calcium		2	6									8
Calcium (water)			67									67
Calcium carbonate		145	1	7			19		1309	919		2400
Carbon, carbonate				7							26	33
Carbon, total		1		7				16				24
Carbon, total inorganic			6									6
Carbon, total organic		144	6	7		6	21	26	1193	931	59	2393
Carbonate, inorganic, flux									11			11
Chitobiase	120											120
Chloride			47									47
Chlorophyll a	78	248		189			11				42	568
Chlorophyll pigment equivalent	78	244		205			11				25	563
d13C, organic matter								6				6
d15N, organic matter								11				11
Density, dry bulk					4							4
Density, wet bulk						1						1
Deposit feeder, abundance										69		69
DNA		96									24	120

Eh			197									197
Esterase	60											60
Esterase activity	56											56
ETSA		139									10	149
FDA		62										62
Fluorine (water)			54	17								71
Formation factor				22								22
Hydrogen sulfide			14									14
Iron		2	7									9
Iron (water)			132					13				145
Iron, ferrous, divalent (water)								25				25
Lead 210				2	32					15	15	64
Lipase	117											117
Lipids	16											16
Macrofauna, abundance				9			46			186	30	271
Macrofauna, biomass				9			46			208	33	296
Magnesium		2	2									4
Magnesium (water)			37									37
Manganese		2	6									8
Manganese (water)			118	18				13				149
Manganese, manganous, divalent (water)								25				25
Median		8										8
Megafauna, abundance							16					16
Megafauna, biomass							16				59	75
Meiofauna, abundance		127		86			100			16	286	615
Meiofauna, biomass		76		22			98				22	218
Methane (water)			1									1
Mixing depth					4						15	19
Mixing rate					9						10	19
Nitrate			214	29		27		13			21	304
Nitrate + Nitrite								25				25
Nitrate flux			146						13		7	166
Nitrite				20				38				58
Nitrogen								26				26
Opal				69					1787	463		2319
Oxygen		26										26
Oxygen (water)			27	51		23		58			24	183
Oxygen flux			14					11	13		104	142
Peptidase	120	19										139
pH			194	21								215
Phaeopigments	39	244		189							18	490
Phosphatase	60											60
Phosphate			4									4
Phosphate (water)			245	4				28				277
Phosphate flux			171									171

Phospholipids	55	92										147
Porosity	25	213	117	5	4	1		9		52	31	457
Potassium		2	1									3
Potassium (water)			4									4
Protease		26										26
Protein	37	246										283
Proteolytic enzyme activity										54		54
Quartz									1785			1785
Resistivity formation factor								47				47
Sedimentation rate					22					36		58
Silicate				31								31
Silicate (water)			204			13		38				255
Silicate flux			197	112								309
Strontium			1									1
Strontium (water)			41									41
Sulphatase	60											60
Sulphate			72									72
Sulphate (water)								15				15
Susceptibility						1						1
Suspension feeder, abundance										63		63
Titanium			4		4							8
Urea								9				9
Velocity, compressional wave						1						1
Xylosidase	38											38
SUM	1445	2403	2776	1186	109	73	384	490	6111	3558	901	19436

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Tab. 1: Parameters, units etc. For more information see protocol.

Parameter	Abbreviation	Unit	Min. value	Max. value	Default format
Oxygen	O2	mymol/l	0	500	###0.0
Oxygen, flux	SOD	mmol/m**2/d	0	100	##0.00
Nitrate	NO3	mymol/l	0	50	##0.00
Nitrate, flux	NO3 flux	mmol/m**2/d	-20	5	##0.00
Silicate	SiO4	mymol/l	0	1000	###0.000
Silicate, flux	SiO4 flux	mmol/m**2/d	-10	0	##0.00
Carbon, inorganic, flux	C inorg flux	mmol/m**2/d	-100	0	##0.00
Calcium carbonate	CaCO3	%	0	100	##0.00
Carbon, total organic	TOC	%	0	50	##0.000
Opal	Opal	%	0	100	######0.00
Aluminium	Al	%	0	20	##0.000
Titan	Ti	%	0	3	##0.000
Barium	Ba	ppm	0	5000	######
Barium, biogenous	Ba, bio	ppm	0	10000	#####
Thorium 230, activity	230Th act	dpm/g	0	0	##0.000
Thorium 230, activity, standard deviation	230Th act ±	dpm/g ±	0	0	##0.000
Lead 210	210Pb	dpm/g	0	200	##0.00
Lead 210, standard deviation	210Pb	dpm/g ±	0	100	##0.00
Mixing rate	Db	cm**2/a	0	100	##0.000
Mixing depth	Mix dep	cm	0	50	##0.0
Sedimentation rate	SedRate	cm/kyr	0	500	####0.000
Sedimentation rate, standard deviation	SedRate ±	cm/kyr ±	0	0	##0.000

Accumulation rate, mass	MAR	g/cm**2/ka	0	1000	###0.0000
Accumulation rate, mass, stand. dev.	MAR ±	g/cm**2/ka ±	0	100	##0.0000
Porosity	Porosity	% vol	0	100	##0.00
Macrofauna, metazoa, abundance	Macrof. metaz. abund	#/m**2	0	10000	####0
Macrofauna, metazoa, biomass	Macrof. metaz. biom.	gC/m**2	0	100	##0.0
Megafauna, invertebrata, abundance	Megaf. invert. abund	#/m**2	0	200	##0
Megafauna, invertebrata, biomass	Megaf. invert. biom.	gC/m**2	0	200	##0.0000
Meiofauna, metazoa, abundance	Meiof. metaz. abund	#/m**2	0	1000000	######0
Meiofauna, metazoa, biomass	Meiof. metaz. biom.	gC/m**2	0	100	##0.00
Bacteria, abundance	Bact. abundance	#10**9/cm**3	0	100	##0.00
Bacteria, biomass	Bact. biomass	gC/m**2	0	0	##0.000
Suspension feeder, abundance	Susp. abund.	%	0	100	##0.0
Suspension feeder, biomass	Susp. biom.	%	0	100	##0.0
Deposit feeder, abundance	Depos. abund.	%	0	100	##0.0
Deposit feeder, biomass	Depos. biom.	%	0	100	##0.0
Replicates	Replicates	#	0	10	##
Active layer	Active layer	cm	0	200	##0
Adenylates	Adenylate	nmol/cm**3	0	100	###0.000
Phospholipids	Phospholipids	mymol/cm**3	0	0	##0.000

Proteolytic enzyme activity	Protease	mg protein/cm**3	0	100	##0.0
Amylolytic enzyme activity	Amylase	mg carbohydrate/cm**3	0	300	##0.0
Phaeopigments (sediment)	Phaeopigments	myg/cm**3	0	100	##0.00
Chlorophyll a (sediment)	Chl-a	myg/cm**3	0	100	##0.000
Sediment depth	Depth	m	0	10000	######0.000
Depth, max.	Depth max.	m	0	10000	######0.000
Depth, min.	min. Depth	m	0	10000	######0.000

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Chlorophyll, phaeopigments, chlorophyll pigment equivalents	97kb
Small organism biomass	100kb
Meiofauna	94kb
Macro- and Megafauna	101kb
Total organic carbon	108kb
Calcium carbonate	114kb
Sedimentation rate (upper meter)	121kb
Accumulation rate (upper meter)	132kb

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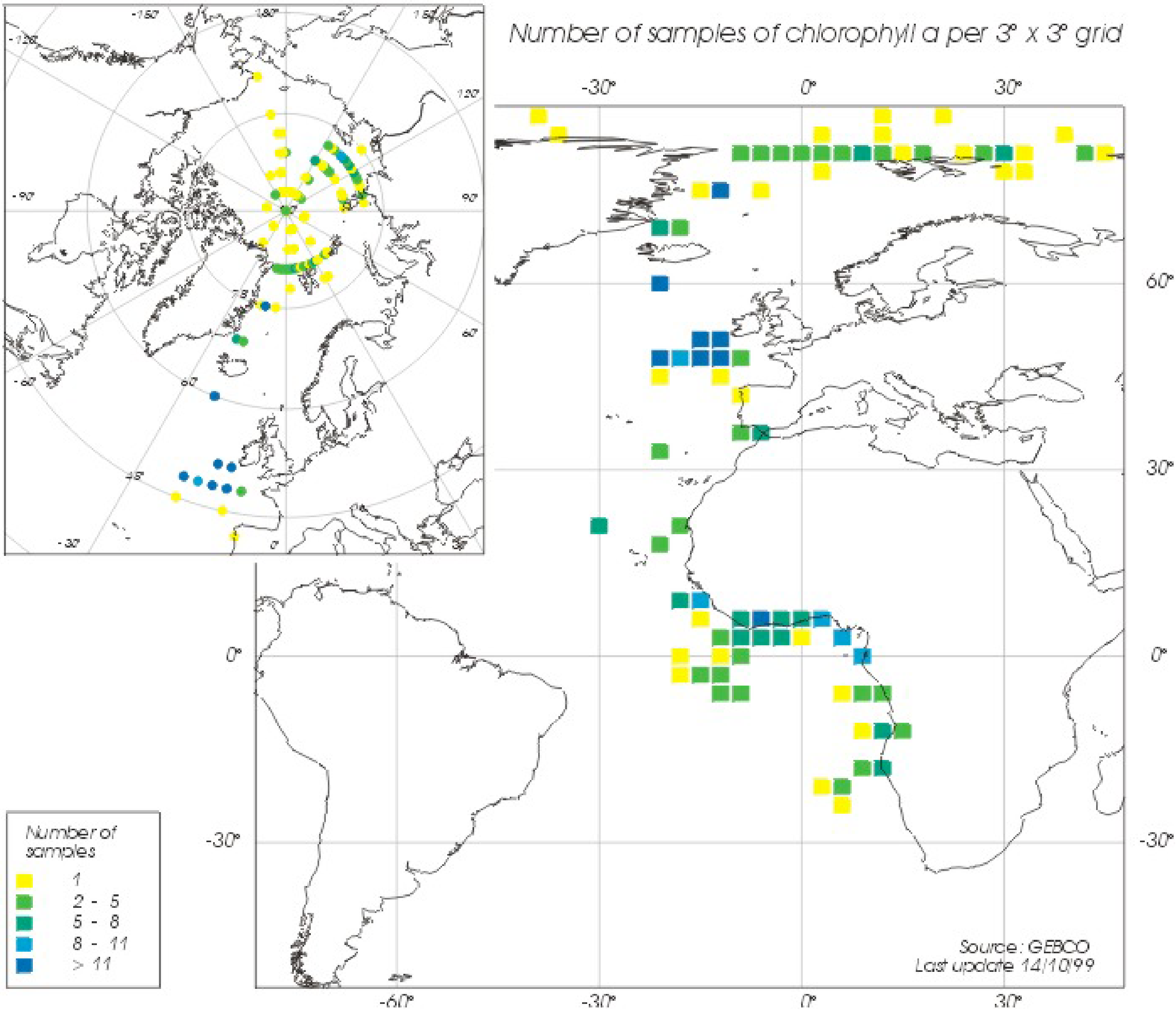
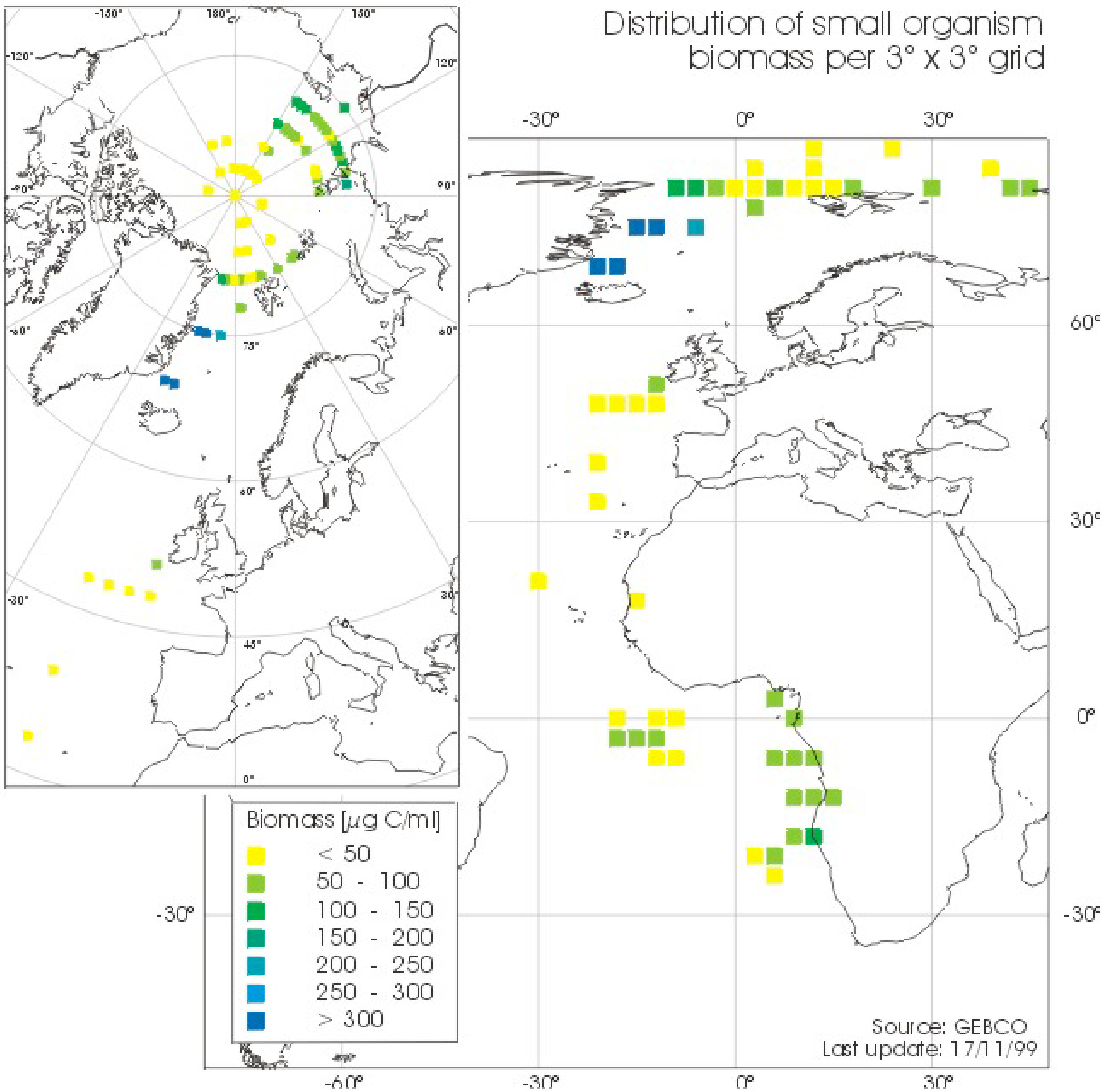
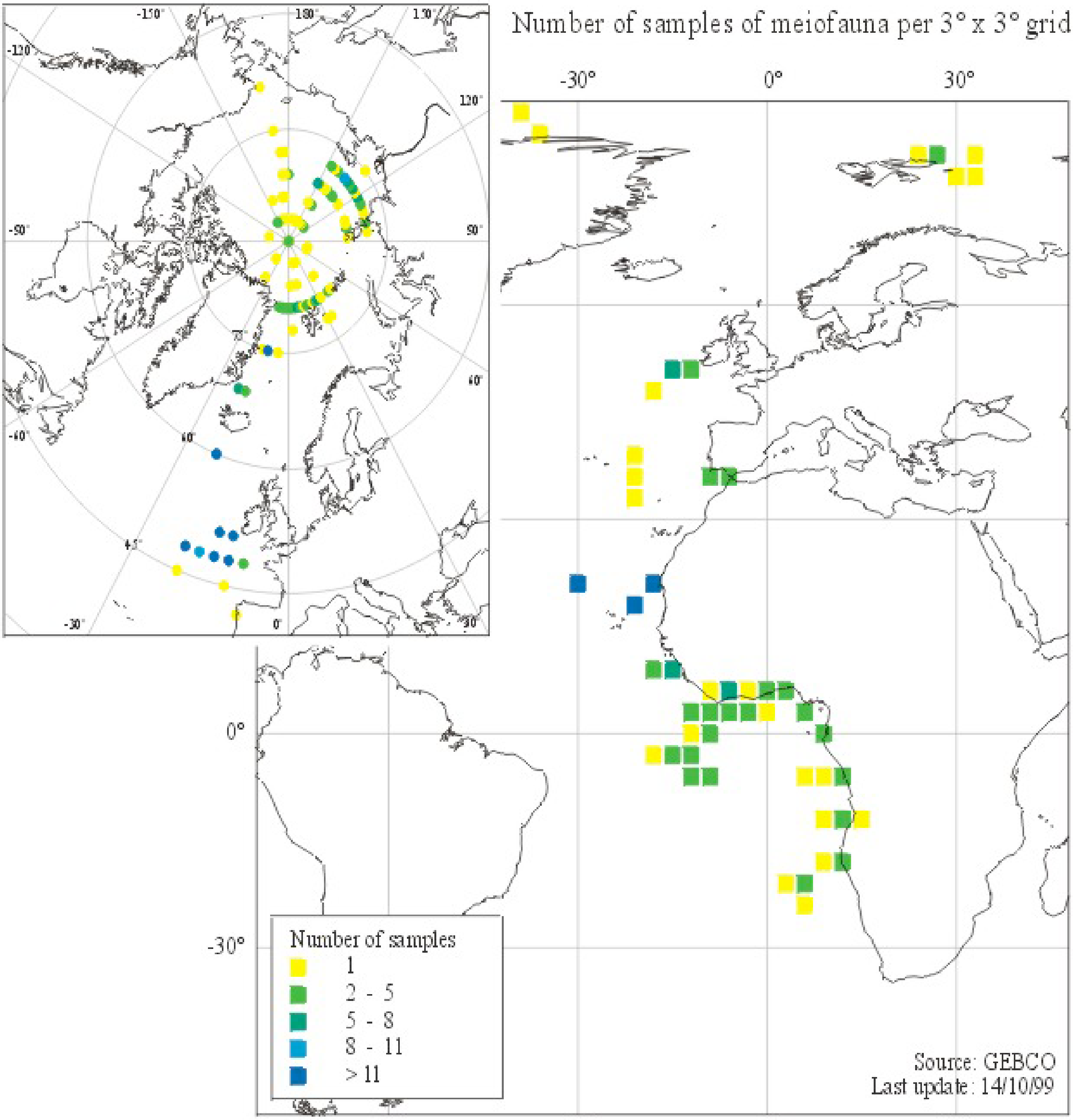


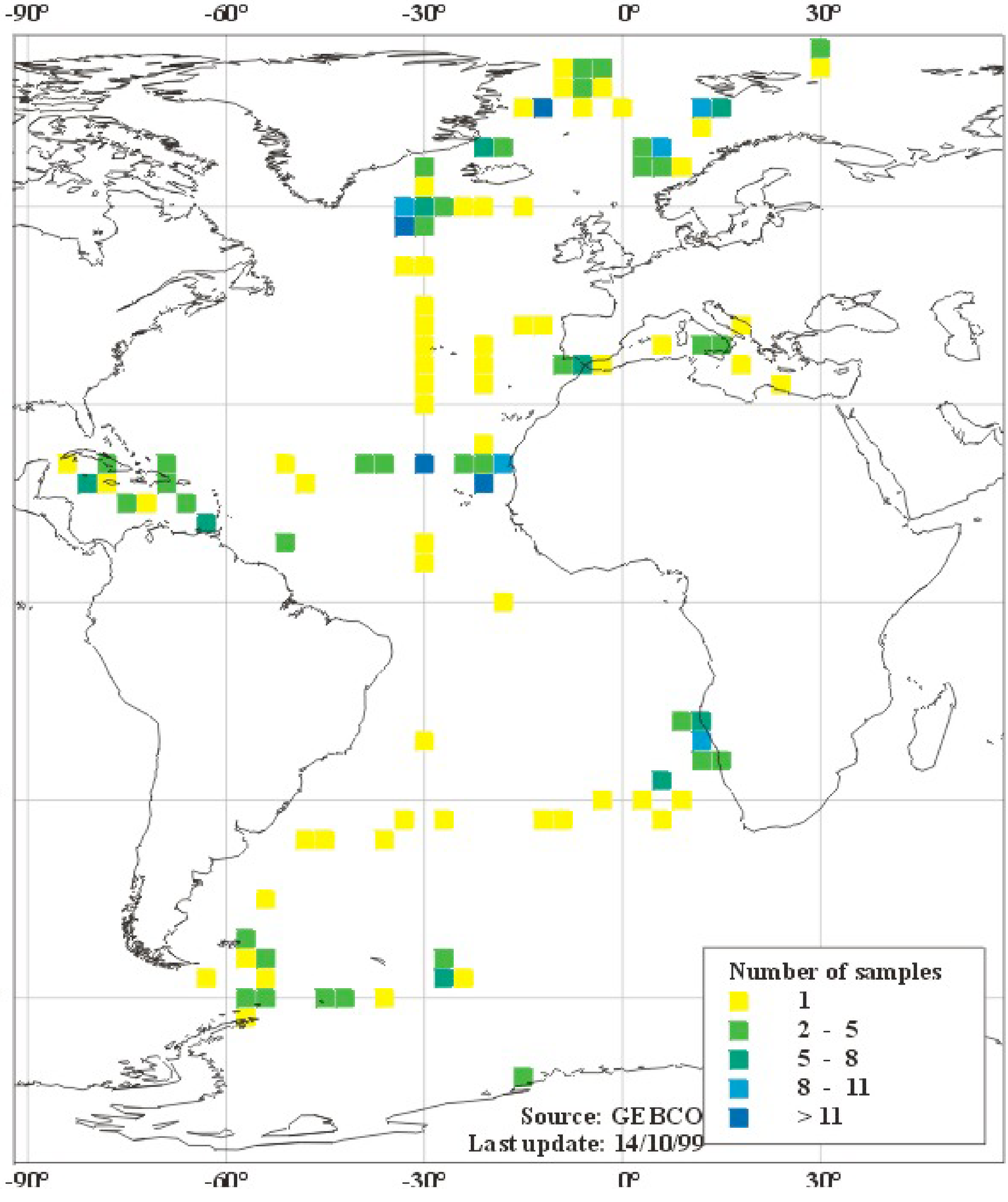
Number of samples of chlorophyll a per 3° x 3° grid
-30°
0°
30°
60°
30°
0°
-30°
-60°
Number of samples
1
2 - 5
5 - 8
8 - 11
> 11
Source : GEBCO
Last update 14/10/99


Distribution of small organism
biomass per 3° x 3° grid
Biomass [µg C/ml]
< 50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
> 300
Source: GEBCO
Last update: 17/11/99
-30°
0°
30°
60°
-60°

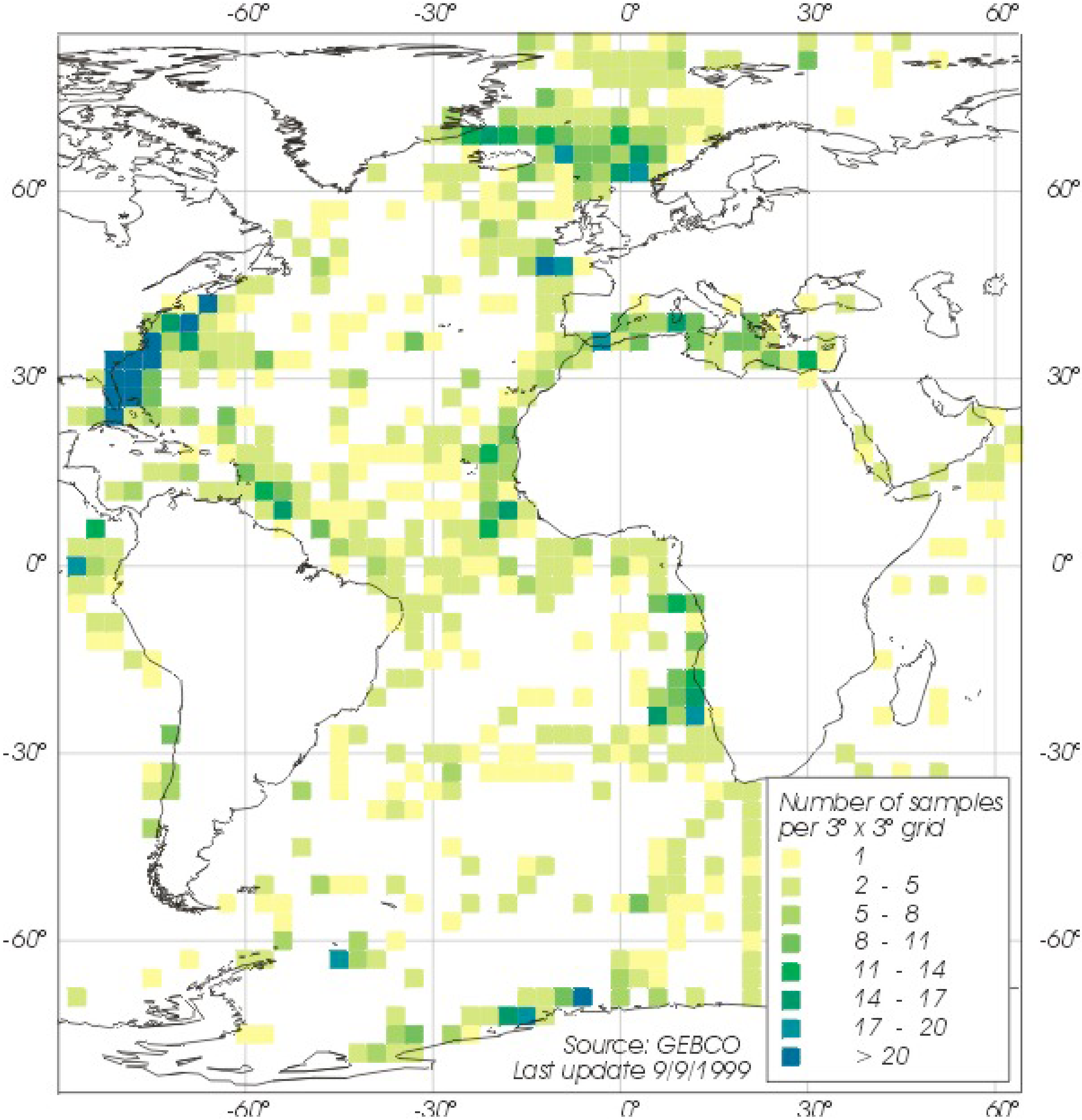


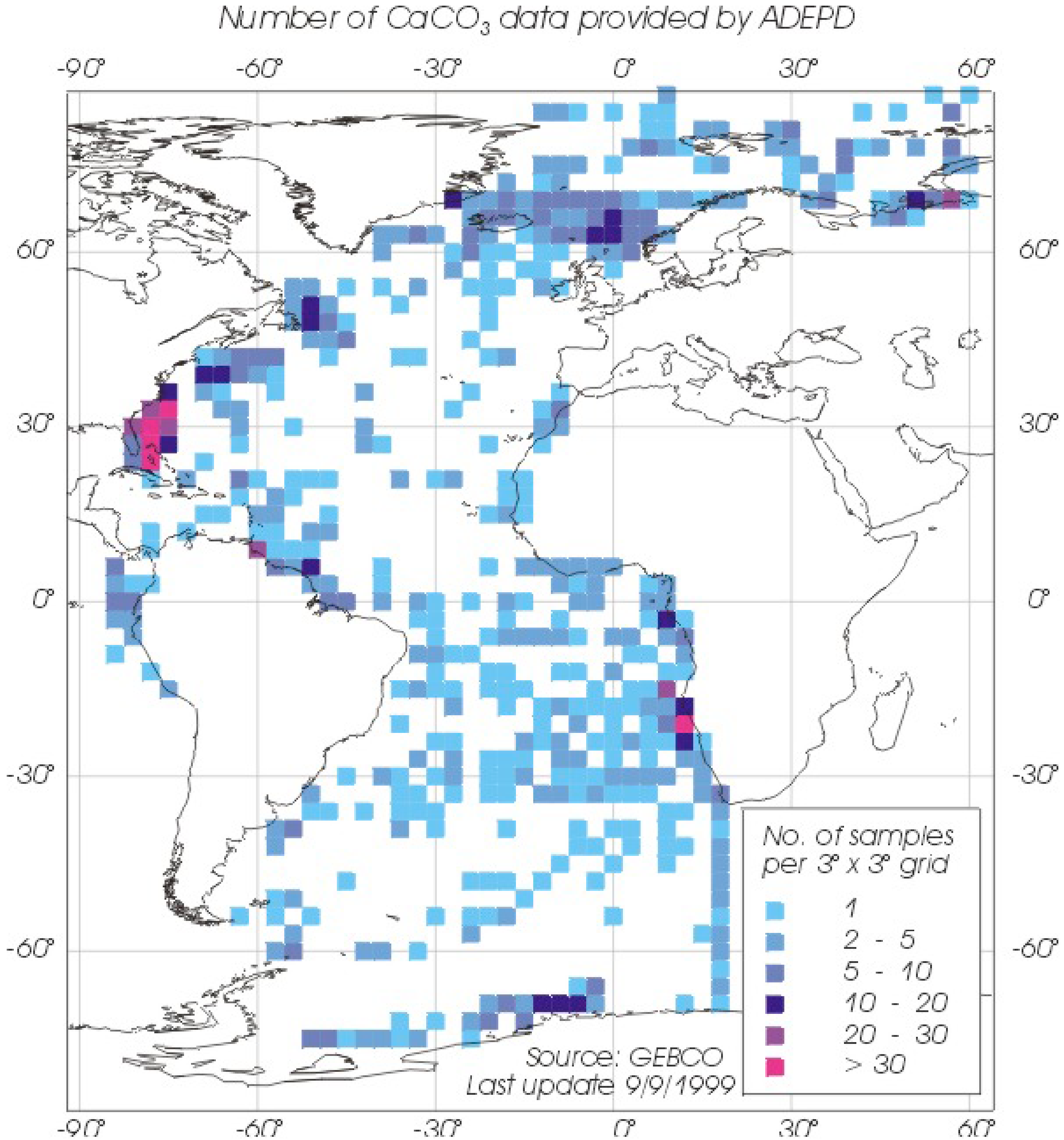
Number of samples of meiofauna per 3° x 3° grid
-30°
0°
30°
60°
-60°
Number of samples
1
2 - 5
5 - 8
8 - 11
> 11
Source: GEBCO
Last update: 14/10/99

Number of samples of macrofauna per 3° x 3° grid

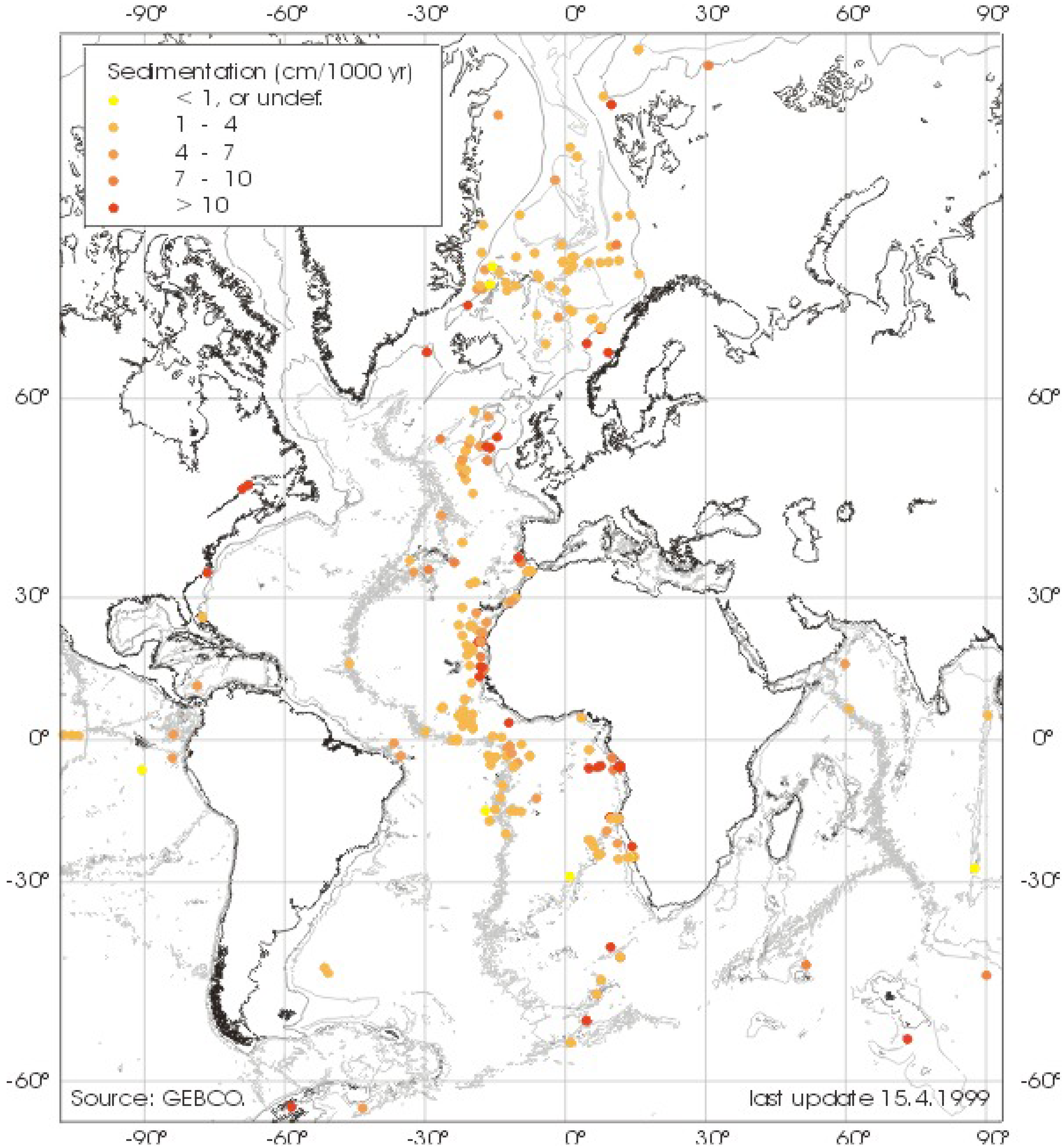


Number of Atlantic deep-sea TOC data available from PANGAEA

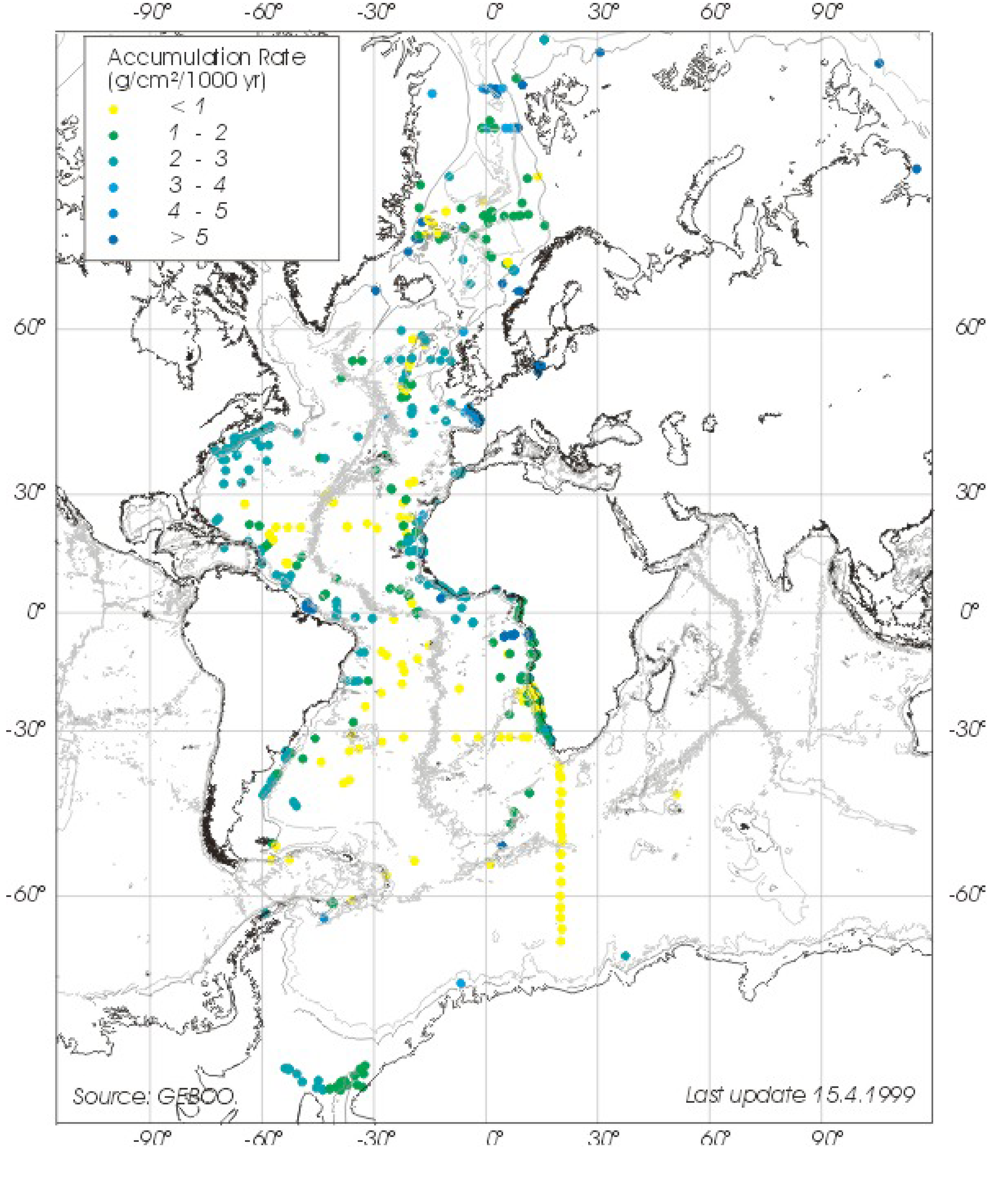




Number of $CaCO_3$ data provided by ADEPD
-90°
-60°
-30°
0°
30°
60°
No. of samples per 3° x 3° grid
1
2 - 5
5 - 10
10 - 20
20 - 30
> 30
Source: GEBCO
Last update 9/9/1999



Sedimentation (cm/1000 yr)
< 1, or undef.
1 - 4
4 - 7
7 - 10
> 10
-90°
-60°
-30°
0°
30°
60°
90°
60°
30°
0°
-30°
-60°
Source: GEBCO.
last update 15.4.1999



Accumulation Rate
(g/cm²/1000 yr)
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
-90°
-60°
-30°
0°
30°
60°
90°
60°
30°
0°
-30°
-60°
Source: GEBOO.
Last update 15.4.1999

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Summary

The ADEPD project compiled biological and biogeochemical data from a range of international and national deep sea projects in the data information system PANGAEA. Diverse data sets were brought together in an uniform data format and are made available to a wider public. More than one hundred biogeochemical variables and 114,000 published and unpublished data sets were compiled in the last two years in PANGAEA. A new and very simple approach to the data base via the world wide web was implemented. Now for the first time a large deep sea data base is easily accessible for the general public on: http://www.pangaea.de/Projects/ADEPD

It became obvious that many data are clustered in some very well investigated areas of the Atlantic, but large regions are devoid of biological and biogeochemical data. This applies in particular for the Mid Atlantic Ridge, parts of the South Atlantic and Southern Ocean, while the the eastern part of the Atlantic, northern North Atlantic and Arctic regions are well covered. Most deep sea research projects did not carry out geochemical and biological studies at the same locations. Therefore, the number of data pairs suitable for the investigation of empirical correlations is very low despite the high total amount of data gathered. Different methods employed for the determination of one parameter add further restrictions to the comparability of data sets. ADEPD applied empirical correlations to convert biomass measurements of small organisms to a uniform variable and to extend the data base available for regional analysis.

For the northern North Atlantic and some areas in the South Atlantic relationships between primary production and benthic fluxes of nutrients and oxygen have been established (this analysis was done as part of other projects using the ADEPD data base). In these regions the coverage of geochemical data is good enough to obtain a spatial resolution and define benthic provinces.

Two very different approaches to estimate total carbon flux and oxgen consumption at the deep sea floor of the world ocean were compared. A value of 5.33×10^{13} mol O_2 y^{-1} is estimated from surface productivity and vertical carbon flux relationship while a value of 5.43×10^{13} mol O_2 y^{-1} is estimated from sea floor benthic oxygen flux and organic carbon burial rate compilation. This close agreement may be fortuitous, but the estimates support each other and suggest that a reasonable assessment of global seafloor oxygen flux has been achieved. Regional differences in both assessments point to methodological shortcomings by one or the other method and to gaps in data coverage as well as gaps in knowledge in respect to carbon fluxes along continental margins.

Evaluation of the data collection helped to identify gaps in data availability as well as systematic patterns and problems in deep sea biogeochemical research. It resulted in recommendations for further data collections and analysis of deep sea biogeochemical data.

1 Introduction

The global cycling of carbon and associated elements through the world's oceanic systems is one cornerstone of the understanding of the linkage between climate and oceanic processes as well as the role of the long-term reservoirs of the deep waters and the bottom sediments. It is still one of the major goals of global ocean research to reconcile rates of surface water production and rates of vertical export with data on benthic turnover to arrive at a full description of transport, burial and turnover of matter within ocean basins. Furthermore, the deep sea ocean fluxes, albeit much smaller than those in surface waters, can be measured directly at a physical boundary and are less subjected to annual variability or short term variation. Therefore, they represent average flux rates and mirror, with some aberrations, average surface water productivity. It is to be expected that different surface water productivity and export in the biogeochemical oceanic "provinces" as defined by Longhurst (1995) influence the benthic regions and give rise to different biological and geochemical characteristics at the sea floor. Topography of the sea floor, deep sea currents and proximity to continental margins are likely to be further forcing functions for deep sea processes.

The deep sea floor is furthermore increasingly at the focus for potential exploitation. Oil drilling is now technically feasible in water depth up to 2000 m and the deepest commercial production well is located at 1853 m in the Roncador field off Brazil (Offshore Engineer 1999). Although dumping of wastes is at present not allowed due to the London Dumping Convention studies are being persued to test the potential for controlled sequestration of CO_2 in the deep sea (Brewer et al., 1999, in press) or for the deposition of municipal and other wastes (Angel and Rice, 1996). Very intense ship traffic adds further anthropogenic impacts to the deep sea floor due to accidental loss of ships and cargo. At present no adequate data base and no tool exists to identify particularly sensitive areas in the deep sea and, thereby, aid political, economical and legal decisions. The deep sea floor has been generally recognized as a key global environment and improvement of the knowledge about this environment has been recommended as one European Grand Challenge in marine research (Le Pichon, 1995, Lochte, 1995).

Many data sets have been collected in the deep sea, particularly in the Atlantic, by different projects and have never been compiled beyond the individual project data management. Therefore, no common data base exists to achieve large scale analyses and assess deep sea processes in the Atlantic as a whole, connected system. The biological and geochemical key parameters describing standing stocks and rates of turnover can for practical reasons only be obtained at a few selected stations, hence, extrapolation of such data from individual points/stations to a larger spatial scale is a difficult task. It requires determination of empirical correlations or modelling of processes which link these limited data to ”master” variables for which a large data base is already available. In this way, the global ocean flux of particulate organic carbon was assessed in a first attempt from a limited set of benthic data (Jahnke 1996). Flux, turnover and burial of organic carbon in deep sea sediments was also assessed globally based on surface water primary productivity and sedimentological data (Romankevich et al. 1999). These two approaches were the first comprehensive attempts to link surface water and deep sea fluxes of organic carbon.

2 Aim of the project ADEPD

Aim of the project was to build up a joint data base for deep sea benthic data from a variety of sources and conduct preliminary geographical analysis of these data. The emphasis was placed on the North Atlantic, since it is this area for which the most comprehensive data sets are available from British, Dutch, French, German, Russian and American studies. Furthermore, it is the most perturbed region in the Atlantic due to intensive human activities. Equatorial, South and northern North Atlantic were included to arrive at a complete description of the whole Atlantic Ocean.

Specific objectives:

- to compile biogeochemical data from Atlantic deep sea sediments (benthic boundary layer) from various projects and from the literature.
- to convert data to common units and uniform variables.
- to link biological (biomass) to geochemical (fluxes of chemical species, etc.) data.
- to extrapolate data of biogeochemical processes at the sea floor obtained at individual stations to a basin wide scale using empirically established correlations to widely measured ”master” variables.
- to develop for well studied regions areal descriptions of ”benthic biogeochemical provinces” in the deep sea of the Atlantic.
- to compare the estimated flux rates at the sea floor with data on surface water productivity and sedimentation.
- to identify gaps in regional coverage as well as in scientific approach to be considered in future projects.

3 Approach

The project organized two workshops:

- Workshop 1: number of data sets, variables and format of data to be compiled were determined
- Workshop 2: progress of data compilation and their geographical

coverage was assessed, the analysis of the data was discussed.

All further contacts were via e-mail and the home page of the project (http://www.pangaea.de/Projects/ADEPD).

A list of participating institutions with all scientists involved is given under participants.

The data were delivered to the coordinator of the project and read into the data information system PANGAEA by the data curator and the partner at the AWI, who is managing and servicing PANGAEA. Via the project home page all participants had access to the data bank and retrieval of larger data sets was supported by the data curator. The new developments and the utility of the PANGAEA data informations system are described under "Developments and progress in the information system PANGAEA". Under "Data collection" an overview of the data collection and the geographical coverage of data is given.

One of the major problems when comparing data from different projects is the use of different methods. It was a major task of this project to convert different types of measurements to common units. This applies in particular to biological measurements where we have attempted for example to obtain common biomass data from as diverse measurements as ATP, phospholipids and microscopic counts. This problem also applies to other types of variables, but is perhaps less obvious. Under "Total microbial activity and biomass" conversions to microbial biomass are described, as these represent the most difficult manipulations.

Linking of biological and geochemical data was achieved by comparing data from the same geographical location irrespective of sampling time. Therefore, seasonal variations had to be ignored in this analysis. If samples were not from the same station, which was only possible in some cases, data averages from geographical grids (1°x1° or 3°x3°) were compared. Since on most cruises geochemical and biological research is not carried out jointly, the number of data pairs which can be used for statistical analysis was surprisingly low. The results of these analyses are shown under "Total microbial activity and biomass", "Meiofauna", "Empirical relationships between pigment concentrations and oxygen flux".

Since the main task of this project was to build up a joint data bank of deep sea biogeochemical data, only first steps of statistical and geographical analysis of these data could be achieved within this project. Regional analyses of benthic fluxes are presented under "Benthic fluxes of nutrients and oxygen", "Overview of regional analysis of benthic fluxes in the South Atlantic", "Global benthic fluxes of oxygen and carbon". It has to be pointed out that due to the complexity of the task only some partners were involved in the analysis stage, but that this work would not have been possible without the joint effort of all partners in bringing the data together.

Recommendations for future data collection and analysis as a result of our discussions and experiences within the project ADEPD are given under “Recommendations for future research”.

All cited literature for all these sections a given under “References”

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Atlantic Data Base for Exchange Processes at the Deep Sea Floor

Developments and progress in the information system PANGAEA

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The use of information systems is still not very popular in most disciplines of marine science. Scientists prefer to deal with their personal data organization which, in the best case, might be a local, proprietary data base, in the worst case it is just a collection of spread sheet files. The complexity of the data of a specific scientific field also hampers the invention of common data systems. There are few examples in oceanography, were data are well organized accessible on the Web (e.g. WOCE, http://www.cms.udel.edu/woce); the reason is, that oceanographic data consist of just a few well defined parameters. In other disciplines with more complex data 'worlds', e.g. in bio- or geosciences, very few sites are known, where results are available to the public. A first successful step towards a public available biogeochemical data archive on CD was done by the BODC (British Oceanographic Data Center) with the biogeochemical data of the OMEX project (Ocean Margin Exchange, OMEX-I project data set, 1997). The amount of work and problems to solve was remarkable (Lowry, 1998).

Data are imported to the PANGAEA data information system by the curator with the graphical user interface which is provided through the 4th Dimension proprietary front end software; relations between data and meta-information are also made during this procedure. A few seconds after the import, data can be retrieved on the Internet with the Advanced Retrieval Tool (ART) of PANGAEA (http://www.pangaea.de/Retrieval/). The use of ART requires that the user has a minimum of knowledge about the data model, how to formulate a retrieval and the definition of the project related parameters.

It was experienced in the ADEPD project that, after demonstrations of the information system PANGAEA on how to use and access the system, the participants still did not work with it in the sense of the projects objectives. Even though the retrieval is easy to use it still needs some training due to the complexity of the biogeochemical data. To improve the acceptance and the usage of the common data base within the project, a new tool has been developed which is unique so far. The Direct Download Interface (DDI) enables the user to access the data from the relational data base just by a mouse click on a web page.

ART enables the user/curator to define and save any specified output format of a data matrix and to define and save the related query to extract a required subset of data from the system. Format and query can be stored on a web server and related to a link on a web page. This procedure requires that the curator designs some web pages, including the most important meta-information for each single data set, which finally give the users access to the projects data by just a mouse click. On the ADEPD pages, the user has the choice to access data.

The web pages will be maintained after the termination of the project in responsibility of the coordinator. The data are archived in PANGAEA, which is long-term operated by AWI and MARUM and thus long-term usage of the data links is ensured. Even though it looks as if the data are downloaded from a flat file directory of the IOW web server, using the links will always provide the user with the most recent data status in PANGAEA. The great advantage of the DDI is, that a click on a link e.g. related to a certain parameter will include any data in the system, also those data, which were imported after the termination of the project. It stands to reason that a query can also be limited to data sets related to a specific project. The extraction of individually configured data sets from the system can only be done with ART as the only solution.

The import of data sets and its publication on web pages can easily be done and is not very time consuming if a well organized information system like PANGAEA is used. As already experienced from other projects, also in ADEPD the major work for the data curator was

1. the collection of data from the various partners and
2. the harmonization of data and completion of metadata.
3. The amount of work of the data curator has been estimated as 20 % collection of data, 50% harmonization, 15% final quality control and import, 10% publication of data with DDI, 5% support, workshops, reports.

If partners are more supportive in providing data in the requested formats, costs for data management could be reduced significantly. Due to this specific problem, which troubles most data collections, the amount of work for the data management in ADEPD was underestimated. Despite this difficulty an impressive amount of data were archived in PANGAEA and published on the ADEPD web pages. The resulting comprehensive collection of biogeochemical data from the Atlantic sea floor is unique so far on the Internet.

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Data Collection

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The data collection included altogether 103 biogeochemical variables, 21 of them were newly introduced to PANGAEA. In total 114,000 published and unpublished data sets were gathered in the last two years. Particularly for biological data this is a substantial improvement in respect to unification of diverse data collections. A list of variables and their formats is given under variables, compilation of all collected data is given under list of data collection.

The major projects providing data for this compilation are:

- BENGAL, BENBO, BOFS (NE Atlantic)
- BIOGAS (Continental margin NE Atlantic)
- BIOTRANS, BIO-C-FLUX, BIGSET (NE Atlantic)
- EUMELI (NE Atlantic off Africa)
- OMEX (Continental margin NE Atlantic)
- SEORQUA (NE Atlantic)
- SFB 313 (northern N Atlantic, Norwegian Sea)
- SFB 261 (equatorial and S Atlantic)
- Arctic projects
- div. Russian projects, data base “Carbon” (complete coverage of Atlantic)
- div. American data sets (NW Atlantic incl. shelf slope)

In additons to such projects data from individual investigations were collected. Some of these data are as yet unpublished.

The most comprehensive data sets are available for geochemical variables, e.g. total organic carbon (TOC) in sediments (Fig. 1). Biological data sets are much more clustered in some very well investigated areas of the Atlantic, but large regions are devoid of biological and biogeochemical data. As examples, the geographical distribution of measurements of chloroplastic pigments in the sediment (Fig. 2), oxygen consumption in the sediment (Fig. 3), macrofauna (Fig. 4), total microbial biomass (Fig. 6) and meiofauna (Fig. 7) are shown. In particular data from the central parts of the Atlantic and the Southern Ocean are very limited. While the continental margins and upwelling regions are fairly well studied, there is a lack of data from the central oceanic gyres. The poor data distribution in the western Atlantic is caused by the concentration on European projects in ADEPD and can be substantially improved if more data from American, Canadian and Russian colleagues are included.

As a result of the biased distribution of biological data it was difficult to find sufficient pairs of observation for statistical treatment. This has hampered the analysis of empirical correlations between biological and geochemical data (see under Total microbial activity and biomass", "Meiofauna", "Empirical relationships between pigment concentrations and oxygen flux").

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Total microbial activity and biomass

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Microorganisms are the primary agents of the diagenesis of organic matter in marine sediments (Deming and Baross, 1993). Thus, a strong link between carbon fluxes and microbial activity and biomass can be expected. Accordingly, significant correlations between POC fluxes measured with sediment traps and bacterial biomass (Deming and Baross, 1993), oxygen consumption, bacterial activity and total microbial biomass (Boetius and Damm, 1998) have been found in different oceanic regions. One possibility for the calculation of carbon budgets for larger oceanic regions is to exploit the empirical correlations which link the limited data of sediment trap measurements to microbial variables for which a large data base is already available. Such variables could be benthic microbial biomass and activity. However, although many data sets of benthic microbial activity and biomass have been obtained in the last few years, they were never combined on a basin wide scale.

One of the goals of the ADEPD project was to collect and harmonize as many data on benthic microbial biomass and activity as possible - from the project partners and their collaborators as well as by including data from the literature. A number of different variables were compiled as parameters for microbial activity and biomass: bacterial biomass, total adenylates, DNA, phospholipids and the activity of different enzymes (hydrolytic and electron-transporting). For each of these parameters, about 100-200 datapoints entered the databank. These data are now available on the ADEPD home page. The data had to be converted into comparable units (if possible biomass carbon and molar carbon turnover). We also investigated if the data could be linked to other biological (pigment concentrations) or geochemical data (TOC, oxygen consumption, accumulation rates).

The data on microbial activity were highly diverse in terms of the different methods used. Each investigator focussed on different enzyme activities according to the specific scientific questions in each of the different studies. The data of all 13 activity parameters were collected and organized in the data bank with method descriptions and links to the investigators. The potential microbial hydrolysis of organic matter in the sediments can be studied using various model substrates for the different enzymes. This parameter is now used in pelagic as well as benthic environments as a parameter for the potential carbon turnover by the microbes. Good relationships between organic matter availability and the potential activity of the enzymes b-glucosidase and chitobiase were established in a variety of investigations. A compilation on the relationship between some enzymes and e.g. chloroplastic pigment concentrations (CPE) in the sediments showed that linear relationships can be found including data from very different oceanic regions (Fig 5, Lochte et al., 1999).

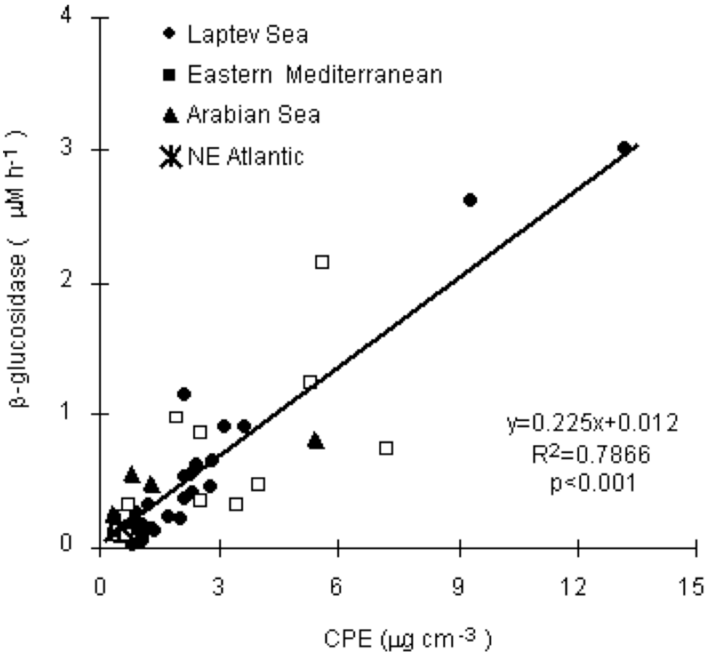

Figure 5: Correlation of b-glucosidase activity and chloroplastic pigments equivalents (CPE) in surface sediments (data from the Arabian Sea: Boetius and Pfannkuche unpubl. data)

The largest amount of data was available for ATP (200 data points), a variable which can be used for the estimation total microbial biomass. Other parameters of microbial biomass measured in several of the investigations were phospholipid concentrations and bacterial biomass determined by microscopy. One goal of our project was to establish a common conversion factor for each method to obtain comparable estimates of microbial carbon biomass.

Table 1 shows the conversion factors obtained for each method. By applying these empirical relationships based on linear regression analysis of all data for each parameter the different variables for microbial biomass were converted into carbon based total microbial biomass (TMB). Bacterial biomass (det. by microscopy) was also converted to TMB on the basis of linear regression with phospholipid concentrations, to account for other microbial organisms like fungi, yeasts and protozoa which contribute significantly to the total microbial biomass in sediments. DNA data were not converted, because either adenylates or phospholipids concentrations were available from the same samples. A total of 300 data on carbon biomass were obtained by this procedure. Figure 6 shows the distribution of microbial carbon biomass in the Atlantic.

Table 1: Conversion of different parameters of microbial biomass into

total microbial biomass (= TMB) in carbon units (µg C cm-3 sediment). TMB was calculated from phospholipid concentrations, based on the finding that 100nmol phospholipids is equivalent to 1 g C (Dobbs and Findlay 1993). The regression analyses are based on pairs of data from the same sample.

Parameter	Number of Data	Conversion into:	Regression	Regression Coefficient
ATP (pmol cm-3)	103	total adenylates (pmol cm-3)	y = 3.3x - 12	$R^2 = 0.996$ $p<0.001$
total adenylates (pmol cm-3)	226	TMB (µg C cm-3)	y = 0.3x + 35	$R^2 = 0.465$ $p<0.001$
bacterial biomass (µg C cm-3)	97	TMB (µg C cm-3)	y = 1.2x + 28	$R^2 = 0.494$ $p<0.001$

A relatively large data set is available for the eastern Arctic basins as well as for the East Atlantic. No data were obtained for the Midatlantic Ridge, the western parts of the Atlantic and Arctic as well as for the Southern Ocean. The data bank could be further improved by including U.S. benthic microbiologists as cooperation partners of future projects.

Bacteria make up the largest fraction of microbial biomass in deep-sea sediments and, hence, their biomass is presumably a good indicator for the trophic supply, i.e. the POC sedimentation to the seafloor (Deming and Baross 1993). It is believed that this relationship between POC input and microbial biomass is caused by the limitation of microbial growth due to the low supply of degradable organic matter to the deep sea. This is also the explanation for the relationship between POC flux to the sediments and oxygen consumption, i.e. carbon turnover. Thus, a correlation between microbial biomass and oxygen demand in the sediments is likely. However, this relationship was rarely tested in abyssal habitats. Our aim was to accumulate a large dataset of total microbial biomass to investigate emperical relationships which could potentially be used as proxies for oxygen consumption.

A total of 300 biomass data are available, however, very few data were from investigations with parallel biogeochemical measurements. Less than 10% of the data were linked to oxygen flux data, and these fell only within 5 grids of 1°x1° degree latitude and longitude. Thus, we were not able to obtain a sufficient data set to test the correlation of microbial biomass and oxygen flux on a basin wide scale. The reason for this missing link is that there are only very few benthic investigations in which geological, biogeochemical research as well as microbiology were carried out at the same stations. Such interdisciplinary studies of deep-sea areas are e.g. SEEP, Eumeli, OMEX, EQPAC, BIO-C-FLUX, BIGSET. However, these investigations mainly focussed on process studies and were carried out repeatedly at a few geographical locations only. Even including the available literature, the current data base for the Atlantic Ocean is not good enough to test the relationship between oxygen consumption and benthic microbial biomass and activity. This can only be improved by further field research, covering large oceanic regions with combined studies of benthic biology and biogeochemistry.

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Atlantic Data Base for Exchange Processes at the Deep Sea Floor

Meiofauna

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One objective of the ADEPD project was to accumulate information on the deep-sea meiobenthos of the Atlantic Ocean and to investigate whether these data could be linked to other biological and geochemical data to finally identify biogeochemical provinces at the deep seafloor.

The sediment-inhabiting meiofauna is a major component of benthic ecosystems, particularly in the deep sea. However, due to a lack in standardisation of sampling, sorting and biomass determination techniques, the comparison of meiobenthic stocks on an ocean-wide basis is fraught with several problems (Thiel 1983; Tietjen 1992; Soltwedel submitted). Different sampling devices (various types of grabs and corers), subsampling strategies and extraction methods (especially the use of different lower size limits of sieve meshes) generally makes a comparison of meiofauna data from the literature a challenge. Within this project, it was decided to use all meiofauna data as given by the project partners and/or in the literature neglecting possible artefacts introduced by differing sampling procedures.

Figure 7 shows the number of meiofauna samples per 3 x 3° grid in the Atlantic and Arctic Oceans. A total of 298 data points, mainly (approx. 65%) from the north-eastern side of the Atlantic Ocean, are available for an ocean-wide comparison. The data coverage is, of course, by far too patchy for basin-wide extrapolations, however, the set of meiofauna data might be sufficient to detect general trends in regional meiofauna distribution patterns and to compare meiofauna numbers with other biological and geochemical parameters.

A plot of meiofauna abundances against latitude (Fig. 8) shows clearly increasing ranges (meaning generally higher values) of meiofauna numbers in higher latitudes, especially for the northern hemisphere. Unfortunately, there are only very few data points available for the southern Atlantic Ocean and Antarctica to confirm a supposed mirror-image for the southern hemisphere. Figure 8 also depicts enhanced meiofauna abundances in the upwelling regions off NW- and SW-Africa, and a northward decrease in meiofauna numbers in the central (permanently ice-covered) Arctic Ocean, north of approx. 80°N.

Surface productivity and the flux of organic matter exert considerable control on benthic standing stocks in the deep sea. Consequently, also meiobenthic densities and biomasses should show perceptible differences in areas with different primary productivity in surface layers. Seasonal and interannual variabilities in primary production, and subsequently temporal variations in food supply to the benthos in different oceanic regions, might also result in temporal variability in benthic standing stocks, complicating a direct comparison of deep-sea meiobenthic data from the literature. Soltwedel et al. (1996) found some indications for growth reactions in deep-sea nematode assemblages to an episodic food supply. However, a measurable response in metazoan abundances to a seasonal or episodical input of particulate organic matter has never been observed in oceanic regions (Pfannkuche, 1993; Gooday et al., 1996). Thus, a comparison of metazoan meiofauna data although from various sampling periods over the year might generally be possible.

Figure 9: Correlations between meiofauna densities and

a. sediment bound pigment concentrations (CPE)
b. total organic carbon contents of the sediments (TOC)

A significant correlation ($p < 0.05$) could also be found between meiofauna abundances and total organic carbon (TOC) contents of the sediments (Fig. 9b). However, pairs of meiofauna and TOC data from the same station are already very limited ($n = 10$) and probably too sparse to confirm or negate a general relationship. This holds also for all other biogeochemical parameters and exposes a general disadvantage.

Only very few investigations were carried out comprising (meio)faunal studies as well as biogeochemical and geological research. Even when including all information available from the literature, the current data basis is not good enough to test relationships between faunal components and abiotic/biotic parameters on a basin-wide scale for the Atlantic Ocean. This can only be improved by further field research, covering large oceanic regions with combined studies of benthic biology and biogeochemistry.

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Empirical relationships between pigment concentrations and oxygen flux

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The input of organic matter to the sea floor and biological turnover of this material measured as benthic oxygen consumption can be expected to show some relation-ships. Therefore, the data collected in ADEPD were tested for empirical correlations between benthic oxygen flux and other biological and geochemical parameters. As already pointed out in sections 6 and 7, only small data sets are available for comparison where measurements were carried out at one location. A relationship with oxygen flux could only be established for chlorophyll a concentrations in the surface sediment (Fig. 10). Since chlorophyll a is a labile organic compound it represents the short term input of organic matter and may, thus, reflect the direct biological response to organic matter supply.

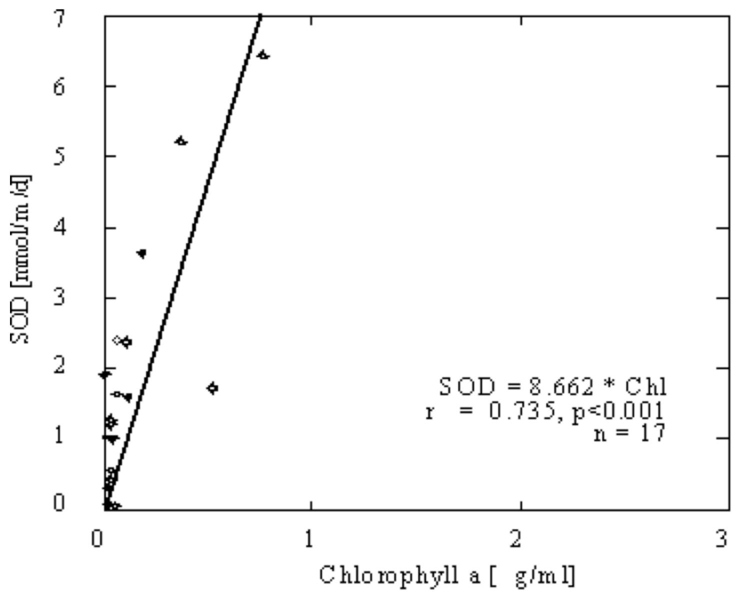

Figure 10: Correlation between sediment oxygen demand (SOD) and chlorophyll a concentrations in the surface sediments.

The data set is unfortunately too small to draw far reaching conclusions from this correlation. Despite this restriction, we have pushed the analysis further and have estimated for some regions oxygen consumption based on the concentration of chlorophyll a in the sediments (Fig. 11). These estimates were compared to the analysis of oxygen fluxes by Jahnke (1996, Fig. 17). In the central parts of the Atlantic Ocean, where benthic acitivity is low, data estimated by both approaches compared well (Fig. 12). Larger differences of more than a factor of 2, both negative and positive, were found close to the shelf particularly under upwelling regions. Here considerable and highly variable export of organic matter from the shelf occurs. The rapid biological reaction to such imput of POC is possibly described better by the relationship to chlorophyll a concentrations than to organic carbon accumulation rates. However, many questions and uncertainties remain and require more detailed studies. It also implies that the highly variable regions along the continental margins are still insufficiently understood and, despite the apparently high numbers of measurements, are still undersampled.

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Benthic fluxes of nutrients and oxygen

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Data on benthic fluxes of oxygen, silicic acid, and nitrate were incorporated into the PANGAEA data information system. The data set covers areas in the North Atlantic and in high southern and northern latitudes of the Atlantic Ocean. These data sets are based on projects of the Alfred-Wegener-Institute, the SFB 313 (Univ. Kiel), BIOTRANS, BIO-C-FLUX, and OMEX.

Additionally, we investigated relationships between benthic organic carbon fluxes (derived by sediment uptake of oxygen) and primary production and considered the distribution of benthic fluxes of silicic acid and nitrate in different biogeographic provinces of the Atlantic Ocean. For these purposes the Geoinformation-System (GIS) Arc/Info was applied to couple various parameters and to derive for example the average and total remineralization rate of organic carbon for sediments from different subregions of the northern North Atlantic. In contrast to most previous considerations of benthic geochemical cycles in marine systems a GIS takes into account the spatial distribution of sampling sites by specific geostatistical procedures and ensures accurate calculation of sub-areas such as the shelf, slope or certain abyssal plains of the ocean (Schlüter et al., 1998).

For the northern North Atlantic (60-80°N, Fig. 13) the transfer of organic carbon from surface waters to the seafloor was calculated (Schlüter et al., in press). This calculation is based on an empirically derived relationship between the rain rate of remineralizable organic carbon, derived by in situ O_2 profiles, primary production (remote sensing data of Antoine et al., 1996), and water depth (Fig. 14). The reliability of this attempt is supported by the good correspondence of calculated rain rates with an independent data set of particle trap studies and shipboard measurements of O_2 profiles.

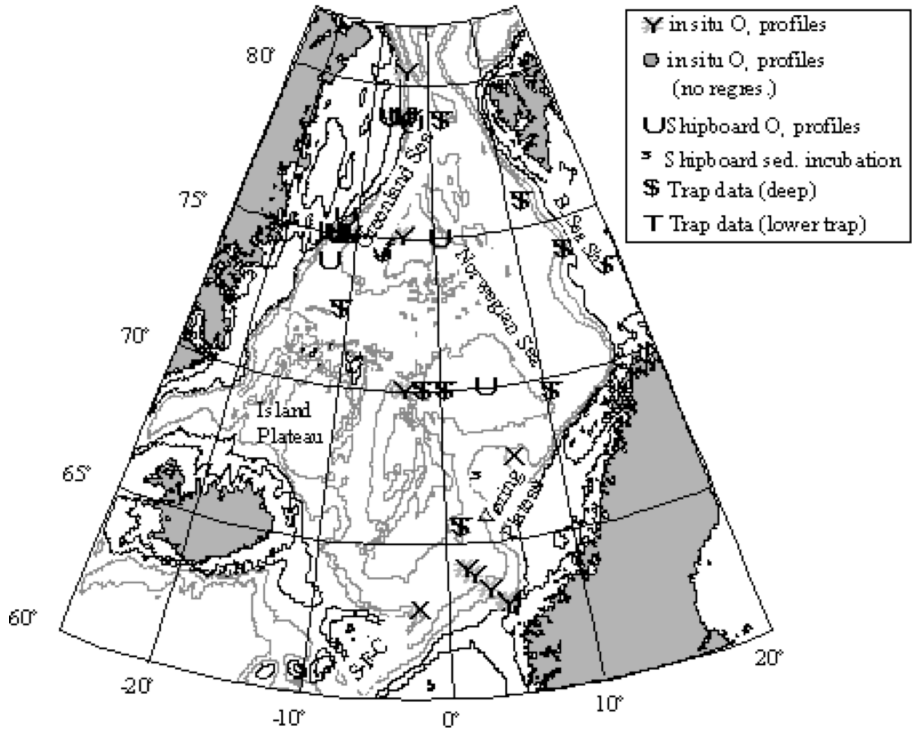

Figure 13: Sites of in situ and shipboard measurements of oxygen profiles, shipboard sediment incubation, and particle trap studies.

For water depths of > 500 m the total seafloor remineralization rate is 2.7 x 10^6 C yr^{-1} for the northern North Atlantic. Low and nearly similar average rain rates of 0.60 and 0.65 gC m^{-2} yr^{-1} have been derived for the deep basins of the Norwegian and Greenland Seas. Therefore, 1.7-1.8% of the primary production is transferred to the seafloor of these basins. A considerably higher average flux of 3.8 gC m^{-2} yr^{-1} was calculated for the Iceland Plateau, where ~3.3% of primary produced organic carbon reaches the seafloor. The sediments of the Iceland Plateau receive 1.0 x 10^6 tC yr^{-1} or ~37% of the organic carbon rain rate to the seafloor derived for the entire northern North Atlantic. The transfer of primary produced organic carbon below water depths of 500 and 1000 m suggests that 10.3 x 10^6 tC yr^{-1} and 4.5 x 10^6 tC yr^{-1} are exported from surface waters. This is 2-4.4% of the organic carbon produced in the photic zone of the northern North Atlantic east of Greenland (Schlüter et al., in press).

In addition to the northern North Atlantic regional budgets of organic carbon fluxes to the seafloor were derived for the northwest and equatorial Atlantic Ocean, using site-specific relationships.

Besides organic carbon fluxes the regional distribution of nitrate and biogenic silica fluxes (derived by the efflux of silicic acid from the sediment) were investigated with special emphasis on the biogeographic provinces of the surface ocean as established by Longhurst (1995) (Fig. 15). This provides information about coupling and/or decoupling of surface water characteristics such as primary production, oceanographic features, and plankton communities with benthic fluxes.

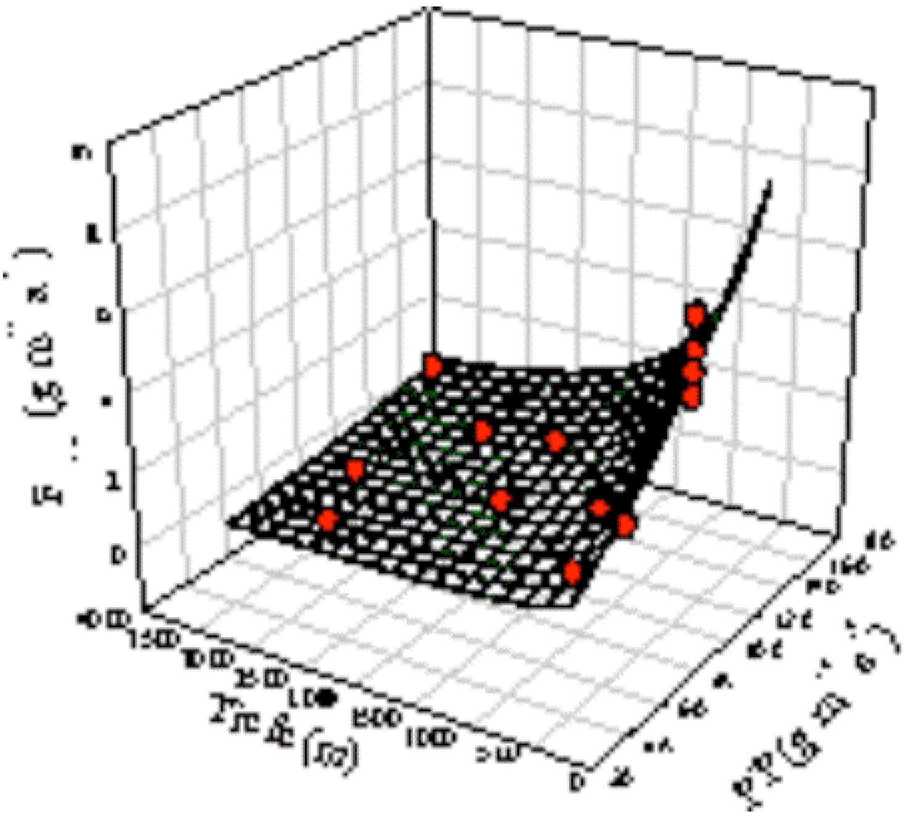

Figure 14: Multiple regression of water depth, primary productivity (PP), and rain rate of remineralizable organic carbon to the seafloor. Only organic carbon rain rates derived by in situ O_2 profiles were considered for this purpose.

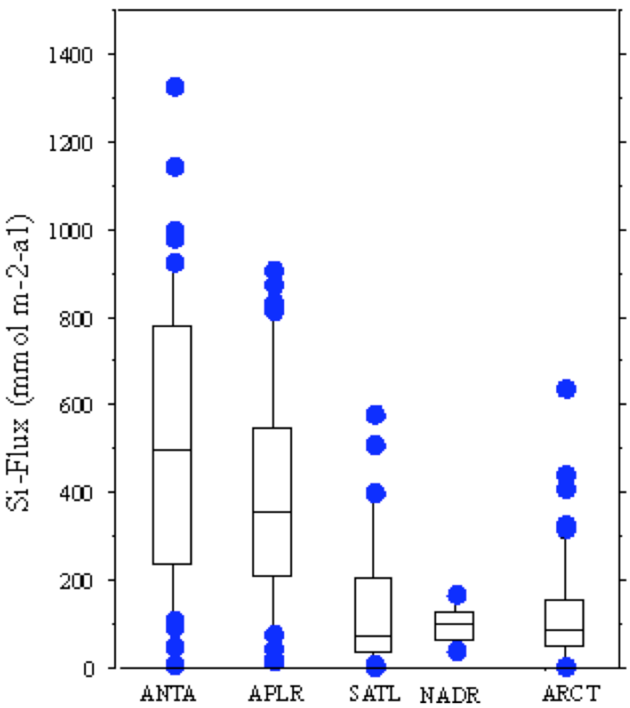

Figure 15: Benthic silicic acid flux (a proxy for the rain rate of biogenic silica) in different biogeographic provinces as defined by Longhurst (1995) of the Atlantic Ocean. South polar domain (APLR, ANTA), South Atlantic domain (SATL), Westerlies domain (North Atlantic; NADR), north polar domain (ARCT). Data are from Hensen et al. (1998), Schlüter et al. (1998), and Zabel et al. (1998).

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Overview of regional analysis of benthic fluxes in the South Atlantic

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The main portion of benthic flux measurements in the South Atlantic archived in PANGAEA during the term of the ADEPD-project have been collected in the Special Research Project 261 funded by the Deutsche Forschungsgemeinschaft (DFG). Generalized maps with regional distribution patterns of nutrient release rates (phosphate, nitrate and silicate) have been published by Zabel et al. (1998), Hensen et al. (1998, 2000).

Generally, close correlations between benthic fluxes and control parameters like primary production or the sedimentary content of organic carbon can be observed. In addition to the accumulation and burial rate of organic matter at the sea floor, the mineralogical composition of sediments play a considerable role in some nutrient cycling. It is important to note that the relationships mentioned above differ regionally (Fig. 16). Unfortunately, the data resolution in some regions of the central and southern Atlantic is still rather limited (e.g. West African upwelling area and partly along the eastern coast of South America), but new results from recent cruises will be expected in the near future. Another uncertainty is the potential effect of saisonality. Annual variation could shift the relative importance of some regions, but general patterns should not be affect. The expansion of the organic carbon data set collected in ADEPD enable a more detailed and promising identification and characterisation of biogeochemical provinces.

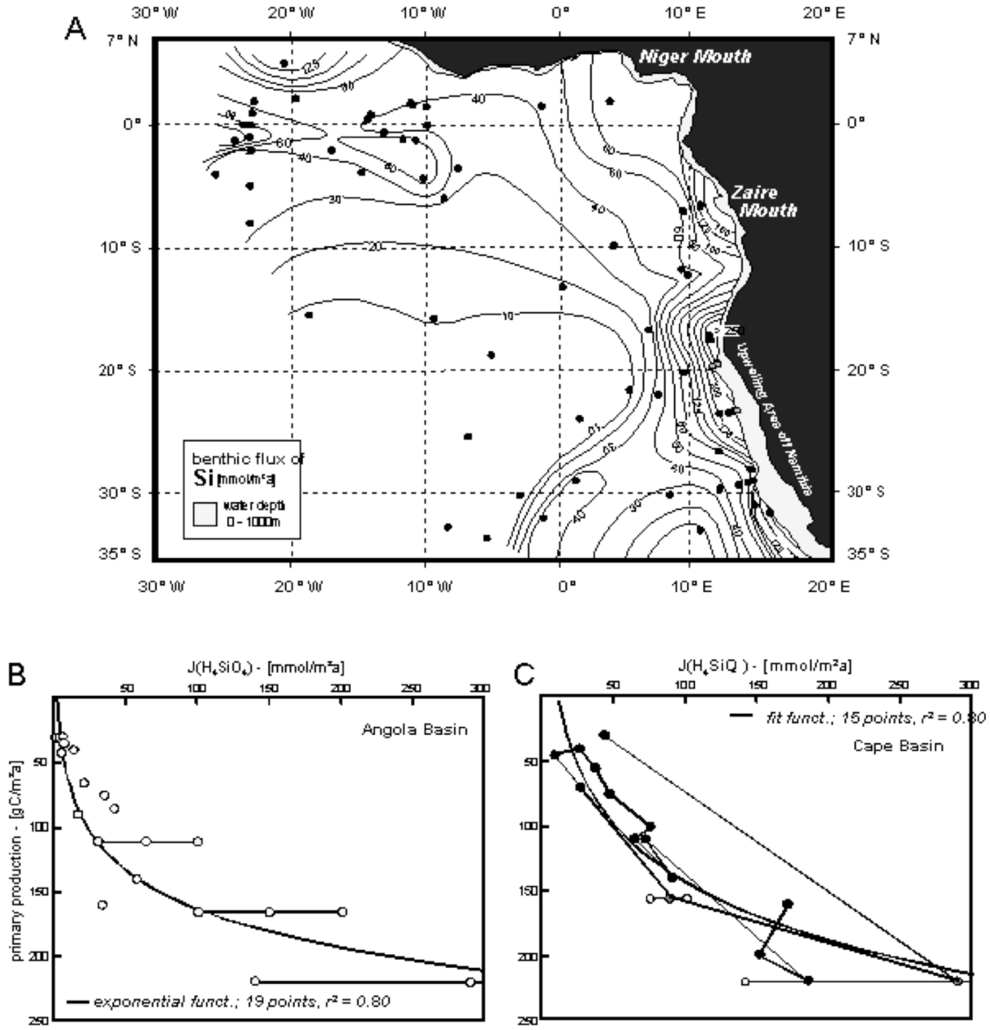

Figure 16: Regional distribution patterns of the diffusive silicate flux across the sediment-water interface in the eastern South Atlantic (A). Correlation between release rates and primary production for particular regions (B and C). From Zabel. et al. (1998).

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Global benthic fluxes of oxygen and carbon

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Data Compilation

The sea floor oxygen flux results compiled in Jahnke (1996) was imported into the ADEPD data set and into the PANGEA data base. In addition the ADEPD project located several additional benthic oxygen flux data sets from the central and eastern basins of the South Atlantic, the central mid-latitude North Atlantic and the northern North Atlantic representing a total of 25 additional locations. Some of these data sets employed earlier, less accurate methodologies than are presently available. Never-the-less the results are generally consistent with the distributions reported by Jahnke (1996; Figure 17). The mean fluxes at 68% of the sites are with a factor of 2 and 92% are within a factor of 3 of the values reported in the earlier compilation.

With the addition of the results from previously unrepresented regions, the ADEPD compilation of sea floor oxygen fluxes represents a significantly more complete description of benthic respiration than previously available.

Comparison to Other Estimates of Seafloor Oxygen Fluxes

The flux of oxygen into bottom sediments can also be estimated as the difference between the flux of organic carbon to the sea floor minus the organic carbon burial rate times the O_2:C ratio of the remineralization process. The organic carbon flux to the seafloor has been estimated using empirical relationships between fluxes of organic carbon (J_c) , net primary production (P_p) and depth (Z). Primary production was evaluated on the base of both primary production field measurements and surface chlorophyll concentrations (C_{chl}) estimated from CZCS satellite radiometer measurements during the 1978-1986 time period. There are estimates of primary production for the whole ocean at 0.17° x 0.17° resolution with an exception of some permanently cloud-capped arctic regions. The flux of organic carbon was estimated (Romankevich et al., 1999) using the relationship $J_c = 33\ P_p / Z$ (Tseitlin, 1993), where primary production is calculated from chlorophyll concentration $\ln P_p = 0.436 + 0.52 \ln C_{chl} - 0.01\ |Latitude|$ (Vinogradov et al., 1996). Oxygen flux was obtained by multiplying organic carbon flux by C:O_2 ratio - 0.6 (Takahashi et al., 1985). A small correction was made to account for the amount of organic carbon permanently buried in the sediment (accumulation rate of C_{org}). Calculated oxygen flux for the Atlantic Ocean (resolution 1° x 1°) is shown in Fig. 18.

Overall, there is very good agreement in the estimated total carbon and oxygen fluxes to the deep seafloor (seafloor greater than 1000 m water depth; Table 2). A value of 5.33×10^{13} mol O_2 y^{-1} is estimated from the surface productivity and vertical carbon flux relationship while a value of 5.43×10^{13} mol O_2 y^{-1} is estimated from the sea floor benthic oxygen flux and organic carbon burial rate compilation. Considering that these estimates are obtained from completely different approaches and data sets, such agreement may be fortuitous. Never-the-less, these estimates support each other and suggest that a reasonable estimate of the global seafloor oxygen flux has been achieved.

While the total values agree well, the spatial distributions obtained by these distinct methods display differences. For example, fluxes in the central basins from benthic studies appear less than those estimated from productivity and vertical flux relationships. As discussed in Jahnke (1996) the low values in these regions estimated from sediment measurements may indeed be an artifact of the extrapolation and contouring methods employed in early sediment compilations. Another important difference is that sea floor fluxes do not appear to increase in the high northern latitudes in proportion to the increase observed in surface productivity. This suggests that the efficiency of carbon transfer from the surface to the deep ocean may vary with latitude although additional studies will be required to verify this idea.

Perhaps the greatest discrepancies occur near ocean margins (see also Empirical relationships between pigment concentrations and oxygen flux). Numerous factors may complicate the comparison of seafloor and vertical water column fluxes in these regions such as lateral transport of particulate organic materials, near bottom turbidity flows, dilution of organic matter by land-derived lithogenic materials, etc. Despite the discrepancies near the margins, high fluxes are estimated by both calculation strategies suggesting that these ocean boundary regions contribute significantly to the flux of organic carbon to the deep sea.

Table 2: Fluxes of C_{org} and oxygen in the World Ocean.

Fluxes	**Jahnke, 1996**	**Vetrov, Romankevich**	
Flux C to seafloor (total), mol C yr^{-1}		$1.47\ 10^{14}$	
Flux O_2 to seafloor		$2.45\ 10^{14}$	

(total), mol O_2 yr^{-1}			
Flux C to seafloor > 1000 m, mol C yr^{-1}	$3.3\ 10^{13}$	$3.2\ 10^{13}$	
Flux O_2 to seafloor > 1000 m,mol O_2 yr^{-1}	$5.43\ 10^{13}$	$5.33\ 10^{13}$	
Flux C through the 1000 m depth horizon, mol C yr^{-1}	$7.2\ 10^{13}$	$1.13\ 10^{14}$	Flux C = 33 P_p / Z
Flux O_2 through the 1000 m depth horizon, mol O_2 yr^{-1}	$1.2\ 10^{13}$	$1.88\ 10^{14}$	

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Recommendations for future research

During the project ADEPD gaps in data coverage and knowledge have been identified and some of the most pertinent problems are described in the above chapters. They are summarized briefly in the following and may serve to guide future research related to the biogoechemistry of the deep sea floor.

a. With respect to geographical data coverage it has to be noted that this analysis is only based on the data collected in ADEPD. Due to the concentration on European projects the eastern Atlantic is much better represented than the western Atlantic. This does not imply lack of data in those regions, but a lack of adequate representation of data from USA or Canada. Therefore, it is of great importance to include partners and data bases from American sources in future projects.
b. The data collection is by no means complete. During the course of the project new sources of data were identified which should be included in future data collections. This concerns not only the above mentioned American data, but also data from the EU and Russia. In particular, a great deal of biological data is in a preliminary state. These data need to be prepared before they can be imported into a data information system. Since it is very costly to sample and analyse such data in the first place, this hidden treasure should be made accessible. Such data "archaeology" may be carried out within other projects, but the necessary step of the final archiving in a data base with long-term stewardship and public access is in most cases not implemented. This important aspect of deep sea research needs to be persued on a long term basis.
c. Geochemical data show a much better geographical spread than biological data. Insufficient data coverage is still evident for the Mid Atlantic Ridge zone, parts of the South Atlantic and the Atlantic sector of the Southern Ocean. In contrast, in the north polar regions the data coverage is much better for most variables.
d. Biological data are generally much more restricted to specific well studied regions. Furthermore, geochemical, geological and biological investigations are rarely carried out jointly or in similar regions. This seems to be a systematic scientific pattern and a problem in deep sea research. The clustered geographical data coverage as well as lack of joint research severly hamperes the comparison between geochemical and biological data and extrapolation of biological data to basin wide scales. Therefore, interdisciplinary investigations including biological and geochemical studies seem essential to gain more understanding of deep sea processes.

e. The largest differences in estimates of oxygen fluxes are found at continental margins. This is obviously caused by many interacting processes affecting transport and biological turnover. Since rates of oxygen fluxes (and other process rates) are much higher in these regions compared to the abyssal plains these ocean boundary regions contribute significantly to the flux of organic carbon to the deep sea. However, the data coverage and the knowledge of processes at the continental margins are still insufficient and need further attention.
f. The data analysis carried out in ADEPD represents only a preliminary approach. More sophisticated statistical analysis with GIS tools including coupling of different variables for the characterization of sea floor regions promises significant scientific advances.

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