SURVEILLANCE OF THE NORTH-EASTERN ATLANTIC DUMPSITE FOR LOW-LEVEL RADIOACTIVE WASTE

THE SWISS OCEANOGRAPHIC RESEARCH PROGRAM ‘PROSPER’

Progress report

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ABSTRACT

This report describes the results of the research undertaken within the CRESP program by the Swiss group PROSPER, for the surveillance of the current dumpsite for low-level radioactive waste in the North-Eastern Atlantic. About 100 nephelometric profiles obtained during three cruises in the vicinity of the site provide a sound basis for the description of the benthic nepheloid layer structure. Statistical analyses show that the last 1000m of water above the bottom are influenced by resuspension processes or by lateral advection of particles detached from the surrounding relief. A mapping performed over a large area (200 x 200 km) confirms the accumulation of particles in topographic lows. Geochemical analysis of suspended matter and surficial sediment has been carried out in order to compare their elemental composition, and to determine the classes of particles which are more likely to be resuspended. The discrepancy between BNL and local sediment composition suggests that advective transport or resuspension of older bottom sediment, exposed following slumping from the hill slopes, could act in addition to the local resuspension of recent sediment.

KEY WORDS: North-East Atlantic, nepheloid layer, suspended particles, surficial sediment, carbonates
RESUME

Le projet PROSPER (Programme de Recherches Océanographiques Suisse Pour l'Elimination des Radionuclides) représente la contribution suisse à la surveillance du site d'immersion des déchets faiblement radioactifs en Atlantique Nord-Est. Ce site est en effet utilisé par la Suisse pour l'évacuation d'une partie de ses déchets depuis 1974. Le projet PROSPER s'intègre au programme international "CRESP" (Coordinated Research for Environmental Surveillance Program), coordonné depuis 1981 par l'Agence pour l'Energie Nucléaire (AEN). CRESPO a pour objectif de rassembler les données et connaissances scientifiques indispensables à la validation périodique du site actuel d'immersion, conformément aux dispositions prévues par le Mécanisme International de Consultation de l'OCDE (Organisation Coopérative de Développement Economique).

Ce rapport présente l'orientation des recherches entreprises par le groupe PROSPER, les moyens de travail à sa disposition, ainsi que les résultats obtenus au cours des trois premiers campagnes océanographiques réalisées entre 1982 et 1983 dans le cadre de collaborations internationales. Les observations effectuées concernent les couches néphéloïdes profondes et les sédiments de la région du site d'immersion. Près d'une centaine de profils néphélométriques et hydrologiques ont été obtenus à l'aide de bathysondes océanographiques. Des particules en suspension, collectées par filtration d'eau préllevée dans les couches profondes, ont été soumises à différentes analyses (Activation neutronique, microsonde EDAX, observation au microscope électronique). Plusieurs dizaines d'échantillons de sédiment superficiel, mis à notre disposition par le Nederland Instituut vor Onderzoek der Zee (NIOZ/Texel) lors de la première campagne de 1982, ont été étudiés en détail (géochimie, minéralogie, microbiologie).

ZUSAMMENFASSUNG


Die bis jetzt erhaltenen Daten erlauben es, die tiefliegenden Trübschichten dieses Gebiets des Ozeans zu charakterisieren (Konzentration der schwabenden Partikel und vertikale Gradienten, Dicke der Trübschichten im Verhältnis zur Topographie), die Zusammensetzung der schwabenden Partikel der Suspension mit derjenigen des Oberflächensediments zu vergleichen, die mineralogischen Variationen des Sediments in Funktion zur Tiefe zu bestimmen und eine Mikrobenaktivität der Tier- und Pflanzenwelt des Meeresbodens deutlich aufzuzeigen. Diese Daten wurden schon in die zweite ozeanographische Beschreibung der Versenkungsstelle im Nordostatlantik integriert, die die NEA, im Hinblick auf die Validierung von 1985, Ende 1984 publizieren wird.
1. INTRODUCTION

The disposal of radioactive waste is a responsibility facing each of the nations utilizing nuclear technologies. Two main categories of nuclear waste are considered, low and high level. Sea dumping is applied only for low-level waste, devoid of heat-generating material and long-lived fission products and heavy isotopes, which require special handling and disposal. Since 1967, the dumping of low-level radioactive waste in the deep sea has taken place under the control of NEA, the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD). To further the objectives of the Convention on the Prevention of Marine Pollution by Dumping Waste and Other Matter (London Dumping Convention), the OECD Council established in 1977 a Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Waste. According to the terms of this Mechanism, NEA prepared in 1980 a first review of the suitability of the present dumping site that has been used since 1974 under the NEA control (NEA, 1980). The Steering Committee of the NEA considered in 1980 that, on the basis of the review, the existing site was suitable for continued dumping for the next five years. At the same time, the Steering Committee agreed on the need for developing an internationally coordinated program to increase current knowledge of the processes controlling the transfer of radionuclides in the marine environment, so that future assessments could be based on more accurate and comprehensive scientific data.

An international Coordinated Research for Environmental Surveillance Project (CRESP) was then set up to yield the required scientific information and to build site-specific models for safety assessment (NEA, 1981). The Swiss contribution to CRESP is a fully dedicated oceanographic research program, called PROSPER (Programme de Recherches Oceanographiques Suisse Pour l'Elimination des Radionuclides), set up in 1981 on behalf of NAGRA (Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle), and described in a previous report (NYFFELER & ALDER, 1981).

This first progress report describes the results of this project. The purchased equipment, as well as the cruises performed in 1982 and 1983 are summarized in chapter 2. Field observations, sample analysis and interpreted results available till August 84 are presented in chapters 3 to 5. These results have already been integrated into two chapters of the second Interim Oceanographic Description of the North-Eastern Atlantic dumpsite, to be published by NEA in December 1984, and will therefore be taken into account for the next site suitability assessment, to be undertaken in early 1985.
2. THE "PROSPER" PROJECT

2.1 SCIENTIFIC GOALS

Effects of sea dumping on man and on the marine environment cannot be measured directly. Mathematical predictive models have to be developed to estimate the radiological impact in terms of risks and doses to critical groups of populations. In carrying out such an assessment, account has to be taken of all relevant pathways allowing dumped radionuclides to return back to man. As not only all marine phenomena but also some fundamental geochemical and biological processes have to be emphasized, the suitability review of the dumping site is essentially a multidisciplinary concept.

The modelling approach adopted for the next suitability assessment is to divide the problem into components (waste packages, ocean dispersion and sedimentation, dose to man and organisms), each of which is modelled separately according to the current scientific knowledge. This modular approach has the advantage that new submodels for each system component can be readily fitted into an overall framework. Sensitivity analysis using ranges of observed values can be performed for each model, in order to obtain realistic clues to the related variation of the key output parameters to be used as an input for the next modelling step. This approach is therefore more consistent than the "upper estimate of potential dose under pessimistic assumptions" concept used in the previous assessment. But it implies that suitable databases be available to perform reliable sensitivity analysis.

Research priorities discussed in the framework of CRESP by national scientific Experts (NEA, 1981) emphasized the paucity of knowledge and data regarding processes within the BBL (Benthic Boundary Layer). The bottom boundary layer plays a particularly important role, insofar as it is the transport medium through which radioactive material resuspended from the sediment might migrate into the upper water column. Local resuspension, supplemented by lateral transport along isopycnal surfaces, could also result in the upwelling of resuspended matter at the edges of the ocean basin.
If mixing and transport processes are reasonably well understood over flat topography, modelling over hilly areas, as those of the dumping site, is still difficult to formulate (HAIVOGEL, 1983). Transfer of radionuclides bound to sediment particles is controlled by a set of physical parameters, e.g. the speed of the current, but also by the geotectonical properties of the sediment and the chemical conditions, which are poorly documented at the dumpsite.

These considerations did provide a starting point for the design of the PROSPER project, oriented towards the field study of physical and geochemical benthic processes. Its main objectives are to supply new site-specific, deep-sea hydrological data, the concentration of particles in the BNL (Benthic Nepheloid Layers), and to compare geochemistry of the suspensions with the surficial sediment, in order to improve our understanding of the transfer mechanisms towards the overlying water.

2.2 CONCEPTION OF THE PROJECT

Participation of Switzerland in the monitoring of the dumpsite has been emphasized since 1979. But due to the lack of any permanent marine research in Switzerland, no basic oceanographic equipment was available to contribute practically towards the extensive field work emphasized within CRESP. A small team of three scientists was set up in 1981 on behalf of NAGRA, under the name of PROSPER group. It was in charge of materializing the Swiss contribution to CRESP, defined in a previous report (NYFFELER & ALDER, 1981). Instrumentation suited to the planned physical oceanographic research was acquired and collaborations were defined with the Swiss scientists interested in the multidisciplinary aspects of this project.

2.2.1 THE PHYSICAL OCEANOGRAPHY COMPONENT

As far as dumping is concerned, the most relevant question for the physical oceanographer is to assess what happens to the radionuclides which could be released from the sediment, supposed to be contaminated by some leaking waste packages. Remobilization can occur either by direct dissolution of the particles bearing the radionuclides, or by having such particles sheared off and resuspended by the bottom current. Various processes contribute to their dispersion, i.e. vertical mixing, advection along isopycnal surfaces, mesoscale processes involving oceanic eddies, and large scale phenomena leading to edge effects at the limit of the ocean basin.
More or less satisfactory models have been developed for each of these processes in the field of fundamental physical oceanography research. Existing regional eddy resolving models might be run to provide some clue to the transport and mixing conditions at the dumpsite, provided that a suitable database be available as input to such models.

Oceanography in the PROSPER program is intended to investigate physical processes within the benthic boundary layer (BBL), which are responsible for, or characterize, resuspension. Field observations have of course been performed in other parts of the ocean. Existence of thick benthic nepheloid layers, with high resuspended load, has been reported by Mc CAVE (1983) for the HEBBLE area. But the load of suspended matter and the structure of the BNL are known to vary broadly according to the local flow conditions and to the sediment characteristics (grain size distribution, compaction). Extrapolation of experimental values observed in other areas of the Atlantic ocean into site specific models must therefore remain speculative until comprehensive investigations are carried out at the current site, where quite different hydrographic conditions can be expected. A lot of valuable information can be gained from the study of resuspended matter, which is a natural tracer for short-term and small-scale phenomena. The distribution of its concentration reflects in some way the near bottom mixing intensity. Careful investigation of the BNL structure within and around the dumpsite through a regular grid of stations was therefore identified as an important topic to cover within the framework of the PROSPER program.

2.2.3 THE GEOCHEMICAL COMPONENT

Geochemical research is a key topic in the context of sea-dumping. It is intended to update information concerning the geochemical properties of sediments in order to allow an adequate modelling of the sorption/release processes. Study of the particulate matter suspended in the water is obviously also included in that research component.
A broad geochemical data base is already available for the North-Eastern Atlantic sediments in general, and has been used for the previous site suitability review (NEA, 1980). But more site specific information is needed, taking into account the variability of the sediment properties and the limited number of data available at the dumpsite itself. Partition of radionuclides (man-made and natural) within the sediment, chemistry of the interstitial water, bioturbation, diagenesis, Kd evaluation, sedimentation rate and resuspension processes are still poorly documented.

Geochemical research carried out within the framework of the PROSPER project is focused onto the transfer processes from the sediment towards the overlying water, and thus complements the physical oceanography component. The preliminary approach includes comparative study of the elemental sediment composition in various typical areas of the dumpsite (abyssal plain, hills, slopes), grain size analysis and specific composition of the various size fractions. Comparison with the composition of the particles suspended in the BNL should provide some clue to the relative contribution of the local resuspension and of the allochtonous particles advection, and to the build-up of the nepheloid layer. Mineralogical composition of sediments is an indicator of their origin, and changes in composition versus depth in the sediment reflect the long term evolution of the sedimentation regime.

2.2.4

THE MICROBIOLOGICAL COMPONENT

Microbial processes are responsible for the catalytic potential for geochemical reactions in sediment environments. Microbes are present in any ecosystem:
- if enough energy and nutrients are available to support growth and maintenance and
- if the physico-chemical conditions of the environment are not inhibitory to microbiological physiology.

Most deep-sea sediments are characterized by:
- a paucity of oxidizable organic matter
- an unlimited supply of oxidants at the sediment-water interface
- elevated hydrostatic pressure
- low temperature and
- lowered water activity due to high salt concentrations.

Exceptions are ecosystems near active deep-sea vents and certain trenches.
As a consequence one does not expect high activity and large microbial populations in abyssal sediments. Most of the biomass which is produced in the photic zone is degraded by the time it reaches the bottom, leaving predominantly recalcitrant organic matter as the only energy source. This inhospitable environment selects the psychrophilic, barophilic and moderately halophilic microbes capable of living under oligotrophic conditions.

Recognizing the environmental conditions one has to contend with is essential in designing experiments to evaluate the role of microbes in deep-sea sediments. Though some experiments have been carried out under nutrient-poor conditions, and others under high pressure or low temperature (H.W JANASCH, Woods Hole; A.A YAYANOS, Scripps; R.Y MORITA, Corvallis) experience is altogether lacking on the effects of the combination of these conditions in laboratory experiments. The conversion of laboratory experience into ecologically significant information remains questionable as long as the prevailing environmental conditions cannot be simulated closely.

Deep sea microbiology is further hampered by the lack of routinely available sampling procedures which fulfill basic microbiological requirements (no contamination, maintenance of in situ conditions). Most procedures employed today are those used by geologists and geochemists. No precautions are taken to maintain undisturbed living organisms. Ingeniosity and technical know-how are needed to design and build specialized equipment for deep-sea microbiology.

Probably the most successful approach is the one followed by H.W JANASCH for the last decade: in situ experimentation employing manned submersibles and remotely controlled sediment landers. Although these techniques offer great potential for the exploration of the deep-sea for many scientific disciplines, it requires sophisticated technology and has remained accessible so far only to American and French microbiologists.
2.3 ACHIEVEMENTS OF THE PROJECT

Apart from the full financial support of NAGRA, the PROSPER program could not have been run without the participation of some national research institutions and the international collaborations established with scientists and laboratories involved in CRESP, who did provide the necessary shiptime and the facilities for sediment sampling during the cruises. More recently a collaboration was established with Prof. A. ROBINSON (Harvard University) and Dr M. MARIETTA (Sandia Lab., New Mexico), who proposed to assimilate the hydrological and nephelometric data collected during the cruises into a site specific regional-scale open-ocean eddy-resolving model with attached BNL.

2.3.1 PURCHASED EQUIPMENT

Equipment for the physical oceanographic measurements was selected in late 1981, according to the deep-sea work technical requirements. The short time available until the first cruise, scheduled in summer 1982, was a first challenge to PROSPER, as one of the apparatus had to be specially designed in the meantime.

The major equipment purchased consists of an oceanographic CTD probe measuring the hydrological parameters (Temperature, Conductivity, Depth), a high sensitivity nephelometer, (developed in collaboration with the CNEXO (Centre National d'Exploitation des Océans, Brest)), to determine the particulate load in the water, and a sonar altimeter for the positioning of the probes package with respect to the bottom. These devices, mounted close together in a stainless-steel frame which can easily be fitted onto any rosette water sampler, are lowered from the ship down to the bottom, with an electrical single conductor armored cable. A Coulter Couter Model ZM coupled with a multichannel analyzer has also been acquired, for the study of the suspended particles and sediment size distribution.

Data handling is performed with a computer system installed in a specially designed lab-container, to be fastened easily on the deck of any reasonable size research vessel. The main components of this instrumental set are described in the following paragraphs.
2.3.1.1 The deep-sea CTD probe

Vertical gradients of the hydrological properties (temperature and conductivity, used to calculate the salinity and the density of the seawater) are very small in the deep water, thus making essential the high resolution and accuracy of the sensors. The heart of the instrumentation set is a NEIL BROWN system, composed of a deep-sea Mark III CTD probe (underwater unit), and a microprocessed surface unit NBIS Mod 1150. This choice was based firstly on the high resolution of the sensors (0.0005°C for the temperature and 0.001 mmhos for the conductivity), on the broadly recognized reliability of these instruments among the users, but also on the technical assistance provided by the NEIL BROWN company to interface the various probes of the package. The NBIS underwater unit supplies power to the various devices, encodes their signals and ensures transmission of the whole data stream towards the deck unit, at a rate of 30 data frames per second.

2.3.1.2 The DIP nephelometer

Particle concentrations in the clear deep ocean water are low (less than 10 µg/liter) when compared to those observed in the coastal water or in the productive surface water. Optical measurements are currently the only possibility to obtain continuous profiles of parameters related to the particle concentration (light absorption or light scattering). But even when they are based upon very simple principles, availability at a commercial level of reliable instruments working in deep-sea conditions is limited.

The DIP nephelometer (Diffusiomètre Intégrateur Profond) used for our experiments is a prototype instrument built by CNEXO (Centre National pour l'Exploitation des Océans, Brest), according to an original concept suggested by BAUER & IVANOFF (1965) and put into practice by L.PRIEUR (Laboratoire de Physique et Chimie Marines, Villefranche-sur-mer) to build a shallow-water device.
The principle of the measurement is to collect the light scattered by the suspended particles within a small angle (between 2° and 5°) around the direction of a thin parallel light beam. The light absorption is balanced by monitoring the direct beam intensity. Theoretical considerations show that the choice of such a small scattering angle leads to the most reliable determination of the concentration, by minimizing the effects of the variation in the particle size distribution (MOREL, 1973). This principle is especially well suited to the small particles encountered within the deep-sea. The main working hypothesis is that the mean density of the bulk particle population is constant, which is a fairly realistic assumption for the deep-sea material.

Linearity and resolution of the apparatus have been checked in the lab with a standard suspension of small particles (Ø < 10 μm), corresponding to the size of the marine particles in the deep-sea. Sensitivity of the device did demonstrate to be high enough to resolve concentration steps of 1-2 μg/liter. Its linearity has been verified up to concentrations 1000 μg/liter, i.e. about ten times the concentration expected in the BNL.

2.3.1.3 The sonar altimeter

The BNL measurements are conducted very close to the sea bottom, typically from a few hundred meters above the sea floor down to the last meters of the water column. A precise monitoring of the position of the costly instrument package (probes and water samplers) is required. Distance of the probes with respect to the bottom is provided by an accurate BENTHOS sonar altimeter. The continuous display of that distance on the NBIS 1150 deck unit allows performance of relevant sampling down to the last meters above the bottom even in rough sea, insofar as oscillations of the ship, transmitted by the sea-cable, can easily be taken into account.
The computer system

The computer configuration used during the first two cruises in 1982 was limited to a single MINC PDP 11/23 system (Digital Equipment Corporation) for the acquisition and the storage of the data transmitted by the probes. Profiles of the various parameters were displayed in real time on a full-graphic monitor for the choice of relevant water sampling depths. Data were stored on a Winchester Disk (10 Mb), and transferred onto floppy disks at the end of each station for subsequent processing. This procedure was rather tedious and proved to be unsuited for a systematic survey with a high number of stations.

The computer configuration was therefore fully redesigned in 1983 on the basis of our first sea trials, taking into account that redundancy of the computer equipment may prevent costly interruptions of the field work. Plotting facilities and a more suitable data storage medium (magtape) have been added, as well as other Winchester disks to increase the memory capacity. A second PDP 11/23 processor was included for all the off-line tasks (plot, back-up), but also as a security in case of failure of the main unit dedicated to data acquisition. More recently, the 11/23 processors have been substituted by a more powerful and faster 11/73 processor.

Fig 1: The current computer configuration
Data handling on board has been identified as a key point in the planning of the general follow-up of the cruise, but mainly as a permanent check of the retrievability of the data. The computer software has been home-tailored to our needs, according to the real-time work requirements. A package of general-purpose subroutines has been developed and continuously improved to handle, validate and plot data on board ship.

2.3.2 EXPERTISE AND ANALYTICAL FACILITIES

External expertise and analytical facilities were required to carry out the geochemical component of the project. Various contributions have been proposed by national research and educational institutions. A scanning electron microscope, an EDAX microprobe and other equipment of the Institut Forel were available to perform detailed observations of the suspended particles and sediments (Dr J.M JAQUET, Département de Géologie, Université de Genève). The Laboratoire de Minéralogie de l'Université de Neuchâtel agreed to conduct the mineralogical study and various chemical analyses of the carbonate fraction of the sediments (Dr B.KUBLER and P.RUCH). Neutron activation facilities, including REE analysis, could be supplied by Dr A.WYITENBACH and L.TOBLER (Eidg. Inst. Für Reaktorforschung, Würenlingen). Analytical procedures are described in chapter 4.2

2.3.3 CRUISES

Since its establishment in 1981, PROSPER group and some of the associated Swiss scientists participated as guests in four cruises in the North-East Atlantic (fig.2). A first financial contribution of NAGRA to the Dutch DORA project (RUTGERS VAN DER LOEFF & LAVALEYE, 1984), allowed the Swiss team to take part in the M.S TYRO cruise in September 1982, organized by the NIOZ (Nederlands Instituut voor Onderzoek der Zee, Texel). Further shiptime was provided in October 1982 by MAFF (Ministry of Agriculture, Fisheries and Food laboratories, Lowestoft, UK) during a cruise with R.V CIROLANA.
Fig 2: The dumpsite (DS) and the NOAMP area

A close cooperation was established later on with DHI (Deutsches Hydrographisches Institut, Hamburg), which did result in the participation of the PROSPER's team in one 6-week cruise in 1983. Sound cooperative plans were established for the next cruises scheduled for late 1984 and 1985 (MITTELSTAEDT, 1984).

The two 1982 cruises, fully dedicated to the survey of the dumpsite, were a first trial for the PROSPER team and its equipment. The extension of the survey to the large nearby NOAMP area in 1983 and 1984, provided the opportunity to investigate medium scale phenomena. The sampling scheme during each of these cruises was established on a cooperative basis with the scientists of the host laboratory, taking into account their own program commitments.
2.3.3.1 Cruise M.S TYRO : 19.08. - 13.09.1982

This joint Dutch-Belgian-Swiss cruise was organized by the Netherlands Institut for Sea Research and performed with the M.S TYRO, within the framework of the Dutch DORA project for the surveillance of the dumpsite. The cruise track and the station locations are plotted in fig 3. All the heavy duty equipment available on board (winches, cables, large water samplers) was supplied by NIOZ.

A 3.5 kHz echosounder was operated during most of the time, to improve knowledge on the local bathymetry and on the bottom properties (layering, hardness, slumping events). NIOZ group did also operate the sediment sampling devices, i.e a Kullenberg gravity-corer (q=125 mm) and a Kristineberg Mark III box-corer (50cm x 50cm) collecting undisturbed samples of the surficial sediment (20-30 cm).

Fig 3: Cruise track and station locations for the M.S TYRO cruise (19.08-13.09.82)
Five Swiss scientists and technicians were involved in that cruise. Their main task was to carry out the hydrological and nephelometric measurements, to collect suspended matter and bottom sediment for subsequent geochemical investigations, and to perform experiments on bacterial activity.

The multidisciplinary research cruise plan, coupled with some time-consuming winch troubles, yielded only a small number of hydrological stations (8 stations), large enough, though, to gain some practical experience. Filtration of large volumes of water proved to be a time-consuming operation and not more than two stations per day could be sampled with one single set of bottles. Limitations in our computer system also became obvious. Improvement of the computer back-up procedure and of the data storage proved to be a first priority for cruises to come. Some technical problems were also encountered while operating the apparatus for the granulometric analysis of the suspended particles (Coulter Counter). The noisy environment and the relatively high level of vibration of the ship did not allow carrying out of reliable measurements.

Nevertheless, the quality of the physical oceanographic data, the numerous filters of suspended particles collected within the BNL, the subsamples of sediments made available by NIOZ, and the relevant number of microbiological samples prepared on board result in a very positive balance for that first cruise.

Cruise R.V CIROLANA : 21.09 - 08.10.1982

Two Swiss scientists were invited by MAFF (Ministry of Agriculture, Fisheries and Food, UK) to participate in a short cruise performed for another two weeks, after the break required for the transit of the lab-container from Texel (NL) to Grimsby (UK). As for the previous cruise, numerous operations were scheduled in the U.K program, including pressure tests of dummy waste packages, amphipods trapping, and some box-coring.
Seven successful CTD/nephelometer profiles were performed in less than three days in the western abyssal plain of the dumpsite, using the PROSPER's probes system (fig 4). Water samples were collected close to the bottom (between 2 and 100 m.) and have been analysed by MAFF for Rn 222 excess, to determine the eddy-diffusivity coefficient in the deep water.

Fig 4: Cruise track and station locations for the R.V CIROLANA cruise (21.09-08.10.82)
Cruise F. S METEOR : 07.09 - 13.10.1983

This cruise, called NOAMP I, was organized by the Deutsches Hydrographisches Institut (DHI). It marked the starting of the NOAMP project (Nord-Ost Atlantisches Monitoring Program), an ambitious five year program funded by the Bundesminister für Forschung und Technologie. Its main goal is the description of the three dimensional water movements over short- and long-term periods, within a large area of the North-Eastern Atlantic in the vicinity of the current dumpsite (MITTELSTAEDT, 1984).

Five cruises of about six weeks duration each are planned in that area until 1985. Special emphasis will be put on the deep-sea processes. Five moorings bearing 5/6 current meters each will be deployed for the whole duration of the research. Two of them cover the whole water column, up to 400 m below the sea surface. Servicing will be supplied to the instruments every six months, on the occasion of the periodic cruises, during which extensive hydrographic work will be carried out by means of CTD probes. Some geochemical work is also planned to compare the actual radioactive burden in the NOAMP area and in the nearby dumpsite.

Four PROSPER team members were invited to the first cruise. They were in charge of carrying out the hydrological and nephelometric measurements, taking advantage of their sophisticated instrumentation. They could also collect sediment samples and suspended particles, in order to complement the work undertaken in 1982. No major technical problems were encountered during that cruise, except that one computer unit was damaged by an unexpected wave in the middle of the cruise. The 82 hydrological stations, smoothly distributed over the surveyed area, represented a significant improvement of our database.
Fig 5: Cruise track and station locations for the F.S METEOR cruise (07.09-13.10.83)
3. OBSERVATIONS AND RESULTS IN PHYSICAL OCEANOGRAPHY

The current physical oceanography data base consists of about 100 full depth nephelometric profiles obtained during the three 82/83 cruises at the dumpsite and in the NOAMP area. Raw data has been filtered to reject the unreliable values. Consistency of the filtered data has been checked by comparing the plots of the whole stations set. Some of the nephelometric profiles of the first two cruises had to be discarded, due to large data gaps (winch troubles and radio-interferences) or to a poor reliability resulting from an insufficient power supply to the nephelometer. During the NOAMP cruise, numerous water samples were collected and their salinity was determined on board with an AUTOSAL-GUILDLINE salinometer, to check the calibration of the CTD probe.

The pre-processed data, initially stored on cartridge tapes, has been translated onto standard tapes for further processing on big computers, such as the VAX 780 available at the University of Neuchâtel, and for pooling with the other scientists involved in the research. The detailed interpretation of the hydrological results is currently carried out by Dr E. MITTELSTAEDT (DHI), and only the main general hydrological features will be reported here. Special emphasis will be put on the nephelometric results, which represent quite an original data set.

3.1 HYDROLOGICAL PROPERTIES

As expected, the observed hydrological conditions in the NOAMP area and at the dumpsite are in good agreement with the classical structure of the water masses in that region of the North-Eastern Atlantic. One full-depth profile of potential temperature and salinity is presented in fig 6. Continuous profiling by means of the CTD probe enhances the complex hydrological structure in the Mediterranean water (around 1000m), identified by its high salinity and a corresponding temperature increase. Such complicated patterns, which are not resolved into great detail with the classical hydrological casts (DURANCE, 1983), reflect the progressive mixing of Mediterranean water with North Atlantic Central Water. Distribution of Mediterranean Water is very patchy over the surveyed area. Clearly visible at station C2 (dumpsite), it is hardly seen at station M16 (NOAMP), where an astonishing foliated structure is observed (fig 7).
Fig 6: Full depth hydrological profile at the dumpsite

Fig 7: Two signatures of the Mediterranean water
Water deeper than 1800m is very homogeneous, with a slight salinity maximum around 2500m corresponding to the North-Eastern Atlantic deep water. Within the last 1000m above the sea-floor, the vertical gradients of both potential temperature (T) and salinity (S) are weak (0.01-0.03°C per 100m for T and 0.003 °/oo per 100m for S). Near-bottom expanded profiles of these parameters are plotted in figure 8 (Station M71). Similarity of the two curves expresses the major influence of the temperature term in the algorithm used to calculate the salinity from the measured temperature and conductivity. An interesting feature is the step-like structure, to be associated with the near-bottom mixing.

Fig 8: Hydrological structure of the last 1000m above the bottom (station M71)
The main hydrological features of that region are summarized by a composite T/S diagram. All the hydrological profiles of the NOAMP area (raw data) are contained inside the dashed area of figure 9, reflecting the high variability of the surface and Mediterranean waters and the homogeneity of the deep-water.

Fig 9: Envelope of the T/S diagram (NOAMP 1) (adapted from MITTELSTAEDT, 1984)
3.2 NEPHELOMETRY

The calibration of optical measurements in terms of suspended solid concentration is critical. Despite the careful laboratory tests performed with the DIP nephelometer, field work did demonstrate that, for the low concentrations encountered, the definition of a baseline value ("concentration zero") was a serious problem. The slightest dirt on the optical ports may result in a shift of some µg/liter between consecutive stations. A long term light drift of the baseline was also observed, which is likely due to minute mechanical effects. As such small shifts do not affect the relative sensitivity of the apparatus, the measurements were adjusted with the following normalisation technique: from the literature, the particle concentration is known to be rather constant over a thick layer above the clear water minimum (in the Northern Atlantic deep water, around 3000m). The minimum concentrations between 8–12 µg/liter reported by BISCAYE & EITTREIM (1977) have been confirmed by the filtration and weighing of the suspended particles, performed during the NOAMP cruise (fig 10). All our nephelometric profiles have then been adjusted assuming a mean concentration of 10 µg/liter between 2500 and 3500m, which leads to quite realistic concentrations of 7-8 µg/liter at the clear water minimum.

![Graph](image_url)

Fig 10: Concentration of the suspended matter determined by filtration and weighing
Inaccuracy on individual profiles resulting from such a normalization is estimated to be less than 2 μg/liter, i.e. about 10% of the lowest values observed in the BNL (17 μg/liter) and quite insignificant for heavy loaded BNL (up to 100 μg/liter). The normalized profiles are statistically in good agreement with the "mean" profile obtained by filter weighing, although the number of filtrations performed at each station was not sufficient to allow a significant direct comparison between both methods.

Another practical problem was encountered during the NOAMP cruise. At some stations, medusa filaments were found to attach onto the nephelometer as it crossed the surface layer. Random masking of the direct light beam resulted in erratic and unreliable values, which were readily observed on the monitor. Such stations were restarted after cleaning of the instrument.

3.2.1 FULL DEPTH NEPHELOMETRIC PROFILES

Trends in the full depth nephelometric profiles can be described as follows (fig 11). The high signal of the nephelometer (C) in the surface water is due to large living cells, with high water content. It cannot be directly related to a real weight of suspended matter with the current calibration, but the scale in μg/liter is kept for convenience. Lower limit of that biologically active layer is marked by the sharp gradient of all parameters at the level of the main thermocline (50-100m), under which the nephelometer reading can readily be interpreted in terms of concentration. Big biogenic particles result in some spikes in the signal, the occurrence of which decreases with depth. In the Mediterranean water, the interleaved structure of the salinity and of the temperature is slightly reflected by the particle concentration.

Concentration then decreases slowly (about 5μg/km) towards the clear water minimum (2500m-3500m), which is taken as the upper level of the BNL, insofar as it marks the limit of the bottom influence. Indeed, the increase of the concentration towards the bottom is likely due to material originating from the ocean bottom, as confirmed by the maximum concentrations found at or just above the sea-floor. A near-bottom well mixed layer, homogeneous in concentration, was observed at most stations.
3.2.2 B.N.L STRUCTURE

Some typical profiles will be used to illustrate the variety of the B.N.L structure and the link with the thermal structure in the last 500m above the bottom (fig 12).

For the low near-bottom concentrations, the shape of the BNL is smooth, and a correspondence with the thermal structure is obvious (T8). This homogeneity of the near-bottom, well-mixed layer is interpreted as the result of a rather permanent resuspension regime. At some stations, an active vertical mixing can be inferred from the thickness of the mixed layer (up to 150 m).
Fig 12: Various typical BNL structures
The complexity of the BNL structure increases with the near-bottom concentration (M30). Secondary maxima of concentration (the so-called "interior" or "intermediate" layers) appear above the bottom well-mixed layer. This feature is attributed to periodic resuspension or to lateral advection of particles from the surrounding relief. Such processes may combine to produce thick mixed layers (up to 200m-300m above the bottom) with high particle concentration (M45).

An unusual structure has been observed at the station M71, where a very high concentration (85µg/l) is associated with a rather smooth nepheloid profile. No near-bottom mixed layer is visible in the thermal profile, whereas intermediate layers are identified between 200m and 400m by three steps of homogeneous temperature. The peculiarity of the station is that it is located on a slope, in a relatively shallow region (4200m) of the NOAMP area, in contrast with those stations with high suspension load, which are more likely found in the deep (>4500m). Such a structure is believed to correspond to some local "burst" event like slumping.

All the features concerning the BNL structure have been summarized by grouping profiles of low, medium and high near-bottom concentrations (fig 13). The upper limit of the BNL is then visually identified around 1000m above the bottom, regardless of the concentration, providing a first indication on the likely vertical range of migration of the resuspended particles. The quasi-logarithmic increase of the concentration towards the bottom is verified only for the low near-bottom concentrations (fig 13a-c). Heavy-load BNL show well developed bottom mixed layers and a high variability of the concentration up to 500m above the bottom.
Fig 13: Composite plots of the BNL structure for various near-bottom concentrations:
A) For Cmax < 35 µg/l (dumpsite)
B) For Cmax = 30-50 µg/l
C) For Cmax > 50 µg/l (NOAMP)
3.2.3 STATISTICS

Correlations between some BNL structural parameters have been used to statistically describe the consequences of resuspension processes. The simple parameters selected to perform this statistical analysis are presented in figure 14. A more comprehensive multivariate analysis of the whole set of NOAMP stations is currently under progress.

Depth of the station (Depth) and the maximum particle concentration (C_max) are two obvious key parameters. The depth of the clear water minimum (D_min) should reflect the influence of the bottom topography on the vertical migration of the BNL upper limit, whereas the thickness of the BNL (A_min) is more likely linked to the intensity of bottom resuspension and to local vertical mixing. But the small gradient of the concentration around the clear-water minimum, combined with the variability of the concentration, makes the determination of the position of that minimum rather imprecise. Uncertainty on the relative variations in the BNL thickness is reduced by using a more reliable parameter than A_min, i.e. the altitude with respect to the bottom of one reference concentration. We selected 15 µg/l (and therefore A_15) which clearly belongs to the BNL structure, and which is close enough to the value of the minimum of concentration.

Last parameter of interest is the net standing crop of particle per bottom surface unit (Crop) deriving from local or remote resuspension. Following BISCAYE & EITTREIM (1977), Crop is obtained by integration of the excess of concentration with respect to the clear-water minimum as:

\[
    \text{Crop} = \int_{\text{bottom}} (C - C_{(\text{cwm})}) \, dx
\]

Histograms of these parameters are presented in figures 15 to 17, for both the dumpsite and the NOAMP area, although the small number of stations (n=12) makes the statistics less relevant for the dumpsite (shaded area).
Fig 14: Structural parameters of the BNL

Fig 15: Histograms of the stations' depth (Depth) and of the clear water minimum depth (Dmin)
Fig 16: Histograms of the BNL thickness (A_{min}) and of the altitude of the C=15 \mu g/liter isoline (A_{15})

Fig 17: Histograms of the maximum concentration (C_{max}) and of the net standing crop (Crop)
Depth ranges between 3900m and 4800m for the NOAMP area, with a mean of 4435m. About 30% of the stations sampled (82 stations) are located between 4500m and 4600m. Stations at the dumpsite are slightly deeper and range from 4700m to 4800m. Smooth and gaussian-like histograms of Amin and A15 contrast with the trimodal distribution of Dmin. All these three parameters indicate thicker BNL at the dumpsite. Mean value of Cmax is 34 µg/l in NOAMP area and slightly lower (24 µg/l) at the dumpsite, where no values above 40 µg/l have been observed. As a result, statistical distribution of Crop is very similar for both areas (Mean 7.6 g/m² for NOAMP and 6.6 g/m² for the dumpsite). Such values are considerably larger than the figures reported by BISCAYE & EITTREIM (1977) for the same oceanic region (Crop= 0.7 g/m²). This discrepancy could come from the extrapolated nature of these authors' map in N.E Atlantic, where their station coverage is very sparse.

3.2.4

CORRELATIONS

A linear correlation matrix between the structural parameters has been calculated from the 82 stations of the NOAMP area (Tab I). The high correlation between Amin and Dmin is obviously a consequence of the definition Depth=Dmin+Amin, and of the small range of variation of Depth. Crop correlates pretty well with all the parameters except Dmin and Depth. The general poor correlation of Dmin cannot be ascribed only to the imprecise positioning of the clear water minimum, but is more likely linked with the trimodal distribution of that parameter. This assumption is confirmed while plotting Dmin versus Depth. Three clouds of points are clearly visible whereas other parameters (A15,Amin,Cmax) tend to increase with depth (fig 18).

<table>
<thead>
<tr>
<th></th>
<th>Depth</th>
<th>Cmax</th>
<th>Dmin</th>
<th>Amin</th>
<th>A15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cmax</td>
<td>.36</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Dmin</td>
<td>.23</td>
<td>.06</td>
<td>*</td>
<td>-.83</td>
<td>*</td>
</tr>
<tr>
<td>Amin</td>
<td>.35</td>
<td>.15</td>
<td>-.83</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>A15</td>
<td>.52</td>
<td>.45</td>
<td>-.15</td>
<td>.44</td>
<td>*</td>
</tr>
<tr>
<td>Crop</td>
<td>.52</td>
<td>.70</td>
<td>-.36</td>
<td>.65</td>
<td>.74</td>
</tr>
</tbody>
</table>

Tab I: Correlation matrix for the BNL structural parameters (n=82)
Fig 18: Variation of the BNL structural parameters as a function of the station depth
3.2.5 MAPPING

Two West-to-East transects across the dumpsite (cruises 1982) show a link between the vertical distribution of the particle concentration and the bottom topography. The high concentrations are located in the valleys and the low concentrations above the hills (fig 19).

![Figure 19: Two transects of the suspended particle concentration across the dumpsite (Station locations in Fig 3 & 4)](image)

The regular grid of the NOAMP stations gives the opportunity to improve the description of that topographical effect through a mapping of those parameters used in the statistical analysis. The mapping was performed with the KRIPTLO code (NYFFELE, 1983). Relevance of the stations grid was checked by comparing the detailed SEABEAM map in the central NOAMP area, with the bathymetric charts obtained with KRIPTLO for following data files:

a) Depths extracted from the continuous sounding records along the ship-track (600 points)
b) Depth recorded at the station (log-book) also by echo-sounding (100 points, stations and current-meters mooring positions)
c) Maximum depth of the profiles (from the depth gauge of the CTD, 82 points)
Although small scale topographical features cannot be resolved by the interpolation code, general trends are still fairly well restored, even when using only the 82 points of the stations grid.

Results of the mapping for Depth, Cmax, Dmin and A15 are presented in figure 20. Only three isopleths have been drawn for each parameter, in order to avoid unrealistic and confusing patterns.

Fig 20: Mapping in the NOAMP area
3.3 DISCUSSION OF THE RESULTS

Results presented in the chapter have been mainly obtained from pre-processed data. Some work is still required to extract all the relevant information. Further analysis of the nephelometric profiles will for instance provide additional results regarding the near-bottom gradients, the occurrence and the thickness of the "interior mixed-layers", the correlation between BNL and thermal structure and other features which have not yet been taken into account. Assimilation of the hydrological data into suitable models simulating the deep-sea processes will be of great help for an improved interpretation of the nephelometric data. But some of the observed features are already of relevance for the updated oceanographic description of the dumpsite and of its surroundings.

a) The upper limit of the benthic nepheloid layer was found around 1000m above the sea-floor. The BNL seems to be slightly thicker at the dumpsite than in the NOAMP area.
b) The near-bottom well mixed layer is often less than 100m. This is in agreement with the Rn222 measurements performed by GURBUTT (unpublished), showing that the near-bottom mixing is a rather fast process.
c) The thick bottom mixed layers (up to 300m) observed in the NOAMP area, are not believed to originate solely from local resuspension. Such high concentrations and thick BNL might result from an accumulation in the deep, of allochtonous particles sheared off from the surrounding relief and laterally advected. This assumption would be consistent with the distribution of the maximum concentration and with the numerous interior layers observed in the deep valleys.
d) The influence of bottom topography on the distribution of nepheloid layers is clearly demonstrated by the mapping performed in the NOAMP area, the main features of which can be extrapolated to the nearby dumpsite.
e) Thick BNL with high particle concentration are located in the deep area and low concentrations are found over the hills, with a trend for the upper level of the BNL to run roughly parallel to the bottom. The rising of the upper level of the BNL over the highs is therefore unlikely to result in massive upwards transfer of suspended matter.
f) How permanent are the observed structures is still questionable. But the smooth horizontal trends and the spatial scale of the patchiness support the hypothesis of regional scale driving effects (20-50 km) supplemented by periodical or burst resuspension. This hypothesis could be confirmed by repeated surveys, possibly at various seasons within the year.
4. OBSERVATIONS AND RESULTS IN GEOCHEMISTRY

4.1 SAMPLES

Most of the samples used to date for geochemical studies have been collected at the dumpsite during the DORA 82 cruise (M.S TYRO). They consist of surficial sediment subcores and suspended particles collected by filtration of large volumes of water. Some filters of suspended particles collected in the NOAMP area were also used for comparison purposes.

4.1.1 SEDIMENT SHORT CORES

Surficial sediment (0-30cm) has been subsampled from a Kristineberg box-corer at eight stations (T1, T2, T4, T6, T8, T11, T13, T15 see fig 3). The diameter of the subcores is 5.5cm and their length varied from 10 to 30 cm, depending on bottom hardness. The subcores were kept in a vertical position with their overlying water and stored at 4°C until extrusion and slicing in the laboratory.

4.1.2 SUSPENSOIDS

Suspended particles were collected by filtration of the water sampled with 10 or 30 liter PVC samplers (GENERAL OCEANIC). Sampling depths were selected according to nephelometric profiles displayed on the CTD monitor. Filtration was performed on board, with clean N2 under moderate pressure (2-3 kg/cm2), using two types of filters:

a) NUCLEPORE polycarbonate, 0.45 μm porosity
b) SARTORIUS nitrocellulose, 0.45 μm porosity

In both cases, NUCLEPORE drain discs were used as support. The low concentration of suspended matter required filtration of large volumes of water (40 to 60 liters) to extract a significant amount of material on the filter (0.5-1.5 mg/filter). Filtered volume was limited by the clogging of the membrane. Particles resuspended in the water overlying the box-corer were also collected onto the same types of filters. An aliquot of turbid water was sampled and hand-pressure filtered with a plastic syringe.
After filtration, the membranes were rinsed with filtered, demineralized water. Particle concentration was determined later on by weighing the dried membranes and by subtracting the blank values previously determined for each filter. The same balance and identical experimental conditions were used for both operations.

4.2 ANALYTICAL METHODS

The filters and the sediment samples have been shared among the various Swiss research teams, to be analyzed by the methods summarized in the next paragraphs. Each of these analyses provides specific information on the samples. Neutron activation is a time consuming, rather expensive but powerful tool. It is specially well suited to study small changes in composition for small series of samples, because numerous elements can be determined simultaneously with a great precision. Although less precise and more difficult to calibrate, the EDAX microprobe is a fast technique to investigate the major elements composition of the individual particles, visualized on the scanning electron microscope. Atomic absorption and colorimetry were used to analyze the major elements in the HCl soluble carbonate fraction. Mineralogical composition of two grain-size fractions of the sediment was determined by Xray diffraction analysis.

The results obtained by these various techniques are discussed separately in the corresponding paragraphs, providing some new input in the description of the particles and sediment geochemical properties in the dumpsite region.

4.2.1 NEUTRON ACTIVATION

Neutron activation analysis was performed by E.I.R with thermal and epithermal neutrons, using the pneumatic transfer system of the SAPHIR-reactor. Sediment analyses were carried out on 100mg of sediment. Each sample was irradiated 4 times under different conditions and counted 11 times, using standards for each element. The coefficient of variations are:

- <20% for Mg, Ti, Sb, Ta, U,
- <10% for Tb, Zn
- < 5% for the other remaining 24 elements.

Detail of the analytical procedure is described in a technical report (TOBLER & WYTTENBACH, 1983).
4.2.2 EDAX MICROPROBE AND SCANNING ELECTRON MICROSCOPE

A direct observation of the particles and of the sediment texture was carried out with a PHILIPS 501B scanning electron microscope (SEM), and the analysis of the major elements with the coupled EDAX 9100/60 microprobe. Prior to SEM and EDAX determinations, small pieces of the filters are mounted on carbon stubs, and carbon (80nm) or gold (40nm) coated. The same preparation is used for pressure-pelletized sediment samples. In this case, the analysis is repeated for various grain-size fractions, after wet-sieving through nylon sieves (6-250 μm mesh-size), followed by ANDREASEN pipette separation. Separation efficiency is checked by COULTER COUNTER analysis.

4.2.3 ANALYSIS OF THE CARBONATE PHASE

The carbonate phase of the sediment is isolated by digestion in 1n/HCl at 80°C (30 minutes). Dissolved cations are determined by atomic absorption (PERKIN ELMER 604) and anions by colorimetry (TECHNICON). The insoluble residue is dried, weighed and related to the total rock.

The total carbon (Ctot= Cmin + Corg) is determined from the CO2 released during the combustion of a known amount of the sediment sample. The Cmin fraction is determined from the CO2 released by the insoluble residue during an H3PO4 attack. Both measurements are conducted with a WOHRSTOFF CARMHOMAT. Accuracy of the carbonate content determination with that method is ±1%.

4.2.4 MINERALOGICAL ANALYSIS

Mineralogical composition has been determined for 75 sediment samples. For each one, the bulk sediment and two fractions of the HCl insoluble residue (<2 μm and 2-16 μm), isolated by centrifugation are analysed with a PHILLIPS 1011 Xray diffractometer. The identified minerals have been confirmed by SEM observation and by microprobe analysis. The small amount of suspended matter collected on the filters was not sufficient to carry out the Xray mineralogical study on the suspensoids, although some minerals have been identified by SEM and EDAX observations.
4.3 RESULTS OF THE ANALYSIS OF THE SUSPENDED MATTER

Geochemical study of the suspended particles has been limited by the small amount of suspensoids collected by the filtration technique, and by the small number of filters in each profile. Nevertheless, the results obtained provide the first set of data available to characterize the suspended matter at the dumpsite, and give some indication on the resuspension processes.

4.3.1 MICROMORPHOLOGY OF THE PARTICLES

Direct observation of the filters with SEM shows that BNL suspensoids consist mainly of coccoliths with a diameter \(<10\ \mu m\) with a very small number of large particles. Diatoms with fragile setae observed at various levels in the NOAMP area, are quasi-absent in the dumpsite BNL. Abundant silica spheres are observed in the North-Atlantic Deep Water (2000m). The SEM observations confirm the high variety of particles at all levels.

4.3.2 ELEMENTAL COMPOSITION

Most relevant information on the elemental composition of the bulk suspensoids has been gained by neutron activation analysis. It has been determined on six filters sampled at the station T13, and on six filters of particles sampled in the water overlying the box-corer. The results of the neutron activation analysis are presented in table II.

The changes in the composition along individual profiles are weak. In figure 21, the concentration of each element is related to the concentration of the same element in the particles of the overlying water (box-corer) at the station T13. The profiles of the various elements in the suspensoids are plotted versus altitude above the bottom. The Ca and Sr trends could be interpreted, for that particular station, as a slight resuspension of the carbonate-rich surficial sediment. The small changes in the relative concentration for the other elements (Co, La, Fe, Al) should therefore be mainly a consequence of the dilution by large carbonate particles in the last meters of the bottom layer (0-10m).
| Filter Station | Gewicht | Na | Al | Cl | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Sr | I | Ba | La | Au |
|----------------|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|                | ppm      | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| F-71           | 13       | 2   | 0.56 | 3529 | 1.89 | 8241 | 18.3 | 3.23 | 2857 | 796 | 800 | 1.37 | 13.0 | 1354 | 114 | 1325 | 13.6 | 4.82 |
|                |          | 113 | 1.53 | 781 | 0.14 | 93 | 0.12 | 127 | 12 | 81 | 2.0 | 0.36 |
| F-72           | 13       | 4   | 0.62 | 3174 | 2.17 | 10400 | 615 | 16.8 | 3.31 | 1535 | 59.0 | 311 | 0.3 | 760 | 76.0 | 2.76 | 10.2 | 1366 | 103 | 1605 | 9.7 | 5.61 |
|                |          | 205 | 2.3 | 127 | 0.07 | 866 | 12 | 0.87 | 105 | 11 | 180 | 2.1 | 0.32 |
| F-73           | 10       | 0.61 | 9069 | 1.85 | 16590 | 5670 | 17.7 | 3.02 | 1033 | 41.5 | 697 | 0.11 | 262 | 1.3 | 115 | 7.0 | 0.07 | 124 | 11 | 166 | 2.6 | 0.33 |
|                |          | 393 | 0.5 | 115 | 0.11 | 299 | 1.7 | 113 | 11 | 300 | 2.7 | 0.33 |
| F-74           | 13       | 75  | 0.52 | 2454 | 2.14 | 5200 | 5869 | 18.6 | 3.15 | 1033 | 41.5 | 697 | 0.11 | 262 | 1.3 | 115 | 0.07 | 124 | 11 | 166 | 2.6 | 0.33 |
|                |          | 404 | 2.6 | 113 | 0.11 | 299 | 1.7 | 113 | 11 | 300 | 2.7 | 0.33 |
| F-75           | 13       | 250 | 0.57 | 4139 | 1.89 | 10098 | 5421 | 18.4 | 3.05 | 1033 | 41.5 | 697 | 0.11 | 262 | 1.3 | 115 | 0.07 | 124 | 11 | 166 | 2.6 | 0.33 |
|                |          | 250 | 2.6 | 113 | 0.11 | 299 | 1.7 | 113 | 11 | 300 | 2.7 | 0.33 |
| F-76           | 13       | 500 | 0.44 | 2677 | 2.19 | 3193 | 6955 | 21.1 | 3.15 | 1033 | 41.5 | 697 | 0.11 | 262 | 1.3 | 115 | 0.07 | 124 | 11 | 166 | 2.6 | 0.33 |
|                |          | 250 | 2.6 | 113 | 0.11 | 299 | 1.7 | 113 | 11 | 300 | 2.7 | 0.33 |

* Der angegebene Fehler (1 σ) bezieht sich auf die Reproduzierbarkeit.

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**Tab II: Neutron activation analysis of the suspended matter (a) and of the particles collected in the box-corers overlying water (b)**
Fig 21: Vertical profiles normalized to the box-corer overlying water particles concentration
- Suspensoids profile at station T13
- Sediments profile at station T6
EDAX measurements of the major elements, performed on the whole set of filters (dumpsite+NOAMP), are presented in fig 22. They do not reveal major differences between the BNL and the non-BNL particle composition at the same depth, although some slight decrease towards the bottom of the biogenic silicious debris, in the last 500 meters of the water column, is observed with SEM. The scattering of the observed values cannot be ascribed only to the technical limitations of the method, but mainly reflects the astonishing variety of particles observed with SEM on individual samples (Plate 1-3). Similar heterogeneity was already reported by CHESSELET & LAMBERT (1977) during GEOSECS.

Some trends versus depth can be identified for Fe/Al, Silicates, Biogenic silica, and to a lesser extent for Calcium Carbonate. Silicate enrichment in the BNL at the dumpsite with respect to NOAMP, and a corresponding depletion of the biogenic silica would point towards a different influence of the bottom sediment in the BNL build-up for the two areas.

Fe/Al values of the BNL particles are intermediate between those of the clear water minimum and of the surficial sediment, indicating the possibility (but not the proof), of a BNL deriving from local resuspension. Indeed, available data on the sediment composition would demonstrate that even its finer fractions still have a silicate percentage not exceeding 23%, which decreases to 14% for the suspensoids of the water overlying the box-cores. This would indicate that straightforward resuspension of local surficial sediment could not contribute enough silicate matter to account for the observed BNL composition (JAQUET, 1984).
Fig 22: Composition of the suspended particles (major elements by EDAX)
Suspensoids of the surface water (70m) in the English Channel. Diatoms and organic matter. (__: 100 μm)

Suspensoids at the dumpsite. Station T13, 5 meters above the bottom in the BNL. Mainly coccoliths with some silicious punched fragments. (__: 10 μm)

Large size fraction of the washed surficial sediment at the dumpsite (0-1cm) Station T4, 4360m Forams (Globorotalids) (__:100 μm)

Plate 1: Examples of micrographs (suspensoilds and surficial sediment)
Plate 2: Identification of mineral by EDAX (Kaolinite)
Plate 3: Identification of mineral by EDAX (Feldspar)
4.4 RESULTS OF THE ANALYSIS OF THE SEDIMENT

The large number of sediment samples and the amount of material available result in a more comprehensive analysis than for the suspended particles. In particular, it was possible to study the variability of geochemical parameters as a function of the depth in the sediment (vertical profiles), and the changes in the top layer (0-2cm) resulting from the location (depth, bottom topography) of the station (horizontal profiles).

4.4.1 MICROMORPHOLOGY OF THE SEDIMENTS

Observations on the various subcores show that the surficial sediment (0-30cm) can be classified into two main types:

a) Foram-coccolith ooze with ice-rafted lithoclasts (mostly on topographic highs)
b) Foram-coccolith ooze without lithoclasts (mostly in the valleys)

Grain size histograms are clearly polymodal, with one mode 1000 μm, (lithoclasts), a second mode around 125 μm (Globigerina), and a third one between 2 and 6 μm (Coccoliths). This distribution is reflected in the composition as silicates, biogenic SiO2 and CaCO3 (fig 23). Calcium carbonate and silicate are higher in the coarse and the fine fractions, whereas SiO2biog predominates between 16 and 32 μm where diatoms, silicoflagellates and radiolarias are relatively abundant (Tab III).

![Fig 23: Variation of the major elements composition in various grain size fractions (Station T8)](image-url)
<table>
<thead>
<tr>
<th>Size (μm)</th>
<th>Forams</th>
<th>Coccoliths</th>
<th>Diatoms</th>
<th>Radiolaria</th>
<th>Silico-flagell.</th>
<th>Lithoclasts</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5</td>
<td></td>
<td>XXX</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>0.5-1</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>1 - 2</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XX</td>
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<tr>
<td>2 - 4</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4 - 8</td>
<td>XX</td>
<td>XX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8 - 16</td>
<td>XXX</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>16 - 32</td>
<td>XXX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>32 - 63</td>
<td>XXX</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>63 - 125</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>125 - 250</td>
<td>XXX</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>250 - 500</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>500 - 1000</td>
<td>XXX</td>
<td></td>
<td></td>
<td>XX</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XXX</td>
<td>X</td>
</tr>
</tbody>
</table>

XXX: abundant  XX: present  X: rare

absent or not observed

Tab III: Major components of size-fractions in the surficial sample M83/4402m (with ice-rafting)
4.4.2 MINERALOGY OF THE SEDIMENT

The mineralogical analysis is illustrated by the results obtained on the subcore of station T8, which are presented in fig 24 to 26. The relative concentration of each mineral is related to the intensity of its characteristic X-ray diffraction peak, expressed in % of the total diffraction pattern.

For the <2μm fraction, only slight trends are visible, except the clear decrease of the mica with depth in the core (fig 24). The variations of the relative intensities along the profiles are weak enough to support the early conclusion of a quasi-constant mineralogical composition of the small fraction, suggested by RUTGERS VAN DER LOEFF & LAVALEYE (1984).

![Fig 24: Mineralogical composition of the <2μm fraction](image)
In contrast, three trends are identified in the 2-16 μm fraction (fig 25):

a) An increase with depth in the core for : $f_k(F), p_l(P), q_z(Q), s_m(ph(H)$

b) A decrease with depth in the core for : $c_hl(CHL), k(K)$, strongly for $m(M)$

c) No trend versus depth for $c_p(t(C)$

---

**Fig 25:** Mineralogical composition of the 2-16 μm fraction
The ratios of the relative intensities in these two fractions are plotted versus depth in fig 26.

Again, three typical trends are present:

a) Ratio decreasing with depth for $f_k$, $p_l$, $q_z$, and also slightly for $a$mph, cpt
b) Ratio increasing with depth for $c.hl$, m
c) Strong increase versus depth : $k$

Such trends provide some indications regarding the evolution of the sedimentation regime and the likely origin of the sediment.

**Fig 26: Ratios of the Xray relative intensities in the two fractions**
The group a) is an indicator of detritism. The relative increase of the small fraction in the more recent sediment indicates a progressive decrease of the detritic input since the last glaciation, even though this effect is partially obscured by the bioturbation in the upper layer of the core (0-10 cm).

The trends of b) and c) groups suggest that the changes in the ratios could be interpreted not only as intrinsic changes in the granulometry of the detritic input to the sediment during the last post-glacial period, but may include other oceanographic features (transport and settling processes linked with internal dynamics), depending on climate variations. For instance, the high relative increase of the 2-16 μm fraction in the recent sediment for K (group c) is related to an increasing input from tropical/temperate origin.

The results of the mineralogical study performed to date can be summarized as follows:

a) The composition of the mineral fraction being expressed as % of the non-carbonate phase, the various trends observed versus depth in the cores (and therefore versus age of the sediment) are interpreted as the result of slow changes in the sedimentation regime.

b) From a mineralogical point of view, these trends correspond to a decreasing ice-rafted material input, which was higher just after the last glaciation. This would be confirmed by the granulometric repartition of the various minerals.

c) The origin of the non-carbonate fraction of the sediment can be speculated from its mineralogical composition. Warm tropical origin being excluded as a main source, Canadian belt, Norwegian Sea area but also metamorphic belt of Asturias could be postulated (RUCH et al, 1984). Of relevance is the absence of smectite in the 2-16 μm fraction and the high index of crystallinity for the micas and phengites (0.13-0.17 deg 2θ).

d) The evolution of the granulometry of kaolinite could be discussed further, taking into account the possible influence of the southern part of the deep circulation of the North-Eastern Atlantic, but also the progressive "kaolinisation" of Northern Europe.
Neutron activation analysis has been performed on 7 surface sediment samples (0-2cm) at the stations T1, T2, T4, T6, T13, T15 and on 10 splitted samples (0-22 cm) from the station T6. This allowed the precise determination of 31 major and trace elements. As an example, table IV (col.A) gives the composition of the surface sediment at the station T6.

The concentrations of the individual elements within all 17 investigated sediment samples (surface sediment and vertical profile) show a moderate variation, typically a factor 2, for lattice-held elements. This variation can be explained for all elements (except Mn, Br, and I, see later) by the different silicate/CaCO3-ratio of the individual sediment samples. Therefore, most elements correlate strictly with Th, which is a typical case of a lattice-held element. As an example, the correlation between Al and Th is given in figure 27. Sr correlates with Ca, Ca/Sr being (5.0 ±0.2) x 10^{-3}, which is normal for calcareous oozes (KARPOFF,1984). Ca correlates negatively with Th.
### Experimental Results

#### Inferred Contributions (in %) to Sediment (C): CaCO₃ Silic. Hydrox.

<table>
<thead>
<tr>
<th>Element</th>
<th>Sediment (A)</th>
<th>Sediment (B)</th>
<th>Inferred Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>32.0 ± 0.2</td>
<td>0.68 ± 0.08</td>
<td>99.8 ± 0.2</td>
</tr>
<tr>
<td>Sr</td>
<td>1700 ± 20</td>
<td>1990 ± 1300</td>
<td>52 ± 48</td>
</tr>
<tr>
<td>Mg</td>
<td>4800 ± 367</td>
<td>0.2 ± 0.68</td>
<td>0 ± 0.08</td>
</tr>
<tr>
<td>Si</td>
<td>2.9 ± 0.1</td>
<td>28.5 ± 0.8</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Al</td>
<td>12300 ± 100</td>
<td>9300 ± 2100</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>K</td>
<td>3876 ± 45</td>
<td>27900 ± 700</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Ti</td>
<td>642 ± 60</td>
<td>5930 ± 260</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Cr</td>
<td>13.5 ± 0.2</td>
<td>122 ± 4</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Sc</td>
<td>2325 ± 14</td>
<td>19900 ± 500</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Th</td>
<td>2217 ± 20</td>
<td>17400 ± 800</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>HF</td>
<td>488 ± 5</td>
<td>4900 ± 300</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Sb</td>
<td>180 ± 15</td>
<td>1600 ± 100</td>
<td>0 ± 100</td>
</tr>
<tr>
<td>Fe</td>
<td>6100 ± 26</td>
<td>39400 ± 1600</td>
<td>0 ± 75 25</td>
</tr>
<tr>
<td>V</td>
<td>21.3 ± 0.4</td>
<td>136 ± 6</td>
<td>0 ± 74 26</td>
</tr>
<tr>
<td>U</td>
<td>367 ± 11</td>
<td>2000 ± 30</td>
<td>0 ± 63 37</td>
</tr>
<tr>
<td>As</td>
<td>2140 ± 100</td>
<td>11100 ± 1500</td>
<td>0 ± 60 40</td>
</tr>
<tr>
<td>Co</td>
<td>5980 ± 50</td>
<td>10800 ± 200</td>
<td>0 ± 21 79</td>
</tr>
<tr>
<td>Mn</td>
<td>623 ± 6</td>
<td>308 ± 10</td>
<td>0 ± 6 94</td>
</tr>
<tr>
<td>Na</td>
<td>1830 ± 54</td>
<td>8300 ± 700</td>
<td>na</td>
</tr>
<tr>
<td>Zn</td>
<td>25 ± 1</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Ta</td>
<td>50 ± 5</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>La</td>
<td>8752 ± 43</td>
<td>26493 ± 451</td>
<td>29 ± 39 32</td>
</tr>
<tr>
<td>Ce</td>
<td>14681 ± 79</td>
<td>48823 ± 1100</td>
<td>7 ± 43 50</td>
</tr>
<tr>
<td>Nd</td>
<td>8517 ± 75</td>
<td>19467 ± 399</td>
<td>30 ± 30 40</td>
</tr>
<tr>
<td>Sm</td>
<td>1725 ± 13</td>
<td>3418 ± 104</td>
<td>38 ± 26 36</td>
</tr>
<tr>
<td>Eu</td>
<td>305 ± 3</td>
<td>708 ± 23</td>
<td>39 ± 24 37</td>
</tr>
<tr>
<td>Tb</td>
<td>264 ± 8</td>
<td>556 ± 39</td>
<td>40 ± 27 33</td>
</tr>
<tr>
<td>Yb</td>
<td>745 ± 12</td>
<td>1758 ± 87</td>
<td>42 ± 30 28</td>
</tr>
<tr>
<td>Lu</td>
<td>110 ± 1</td>
<td>279 ± 14</td>
<td>40 ± 32 28</td>
</tr>
<tr>
<td>Br</td>
<td>8 - 12</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>I</td>
<td>31 - 37</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 ± 0 ± 0</td>
</tr>
</tbody>
</table>

**Notes**

A) Values are for washed and dried sediments. Water content of the original sediment is 46% by weight. The mean and its standard deviation of 5 samples are given. (na = not available)

B) Residue resulting by treating sediment samples with HCl n for 20 min. The mean and its standard deviation of 4 samples are given.

C) As derived by the analysis of the sediment and of the silicates in the sediment, as well as by correlation analysis of the elements against Th. The content of silicates in the sediment is 11.6%.

---

Tab IV: Chemical composition of the sediments by NAA (Station T6/0-8cm) (WYTTENBACH & TOBLER, 1984)
Analysis of whole sediment samples and of the residue remaining after partial dissolution of sediments with 1n/HCl (see Tab IV, col.B), together with correlation analysis of the results versus Th allowed the partition of the individual elements between the three main components of the sediment (see Tab IV, col. C):

- CaCO₃ (biogenic)
- Silicates (detritial)
- Fe-Mn-oxyhydroxides (authigenic)

It should be noted that although Fe-Mn-oxyhydroxide is clearly discernible as a different component, its mass is strictly correlated to the mass of silicates in the individual surface samples of the dumpsite area, thus pointing to a remarkable constancy in the chemical composition of sedimentation within the area. The following masses (in μg) are bound to Fe-Mn-oxyhydroxide connected with 1g of sediment (station T6):

Fe:1300, Mn:585, V:5, Co:4.6, La:3

Mn/Co=127 in this phase is somewhat higher than the value Mn/Co=88 proposed for the Pacific by GREABEAL & ROSS (1984).

4.3.2.1

VERTICAL PROFILE

The vertical variation of the elemental composition was investigated at station T6 from the surface of the sediment to a depth of 22 cm (10 sections, 31 elements). The main features can be summarized as follows:

a) The profiles of all elements are smooth. There are no zigzag curves as found in the top 30 cm of the Pacific cores (GREABEAL & ROSS, 1984). This points to a rather uncomplicated and smooth history during the last 10,000 years as far as sedimentation and diagenesis at the dumpsite are concerned.

b) The concentrations within the topmost 8 cm of the sediment (5 samples) are very constant for all elements (except Br and I). This constancy is attributed to the extensive mixing by bioturbation.
Fig 28: Profiles of Ca and Th (station T6)

Fig 29: The concentration of different groups of elements in the profile of station T6

(All elements between Si and Co (Tab. IV) behave like Co. Normalisation to Th has been done to offset the variations in the carbonate/silicate ratio. Iodine behaves similarly to Br)
c) Below the zone of bioturbation, there is a gradual increase of all elements from 8 to 22 cm, except Ca, Sr, Br and I which decrease (fig 28). Since the Th-normalized concentrations of all lattice-bound elements and of V, Fe and Co remain constant throughout the profile (fig 29a), it must be assumed that this increase of the unnormalized concentrations is due to an increase of detritical material (silicates) and a corresponding decrease of biogenic CaCO3. At the station T6 (4600m), the amount of silicates is estimated to be 11.6% in the top 8 cm and 20.9% at 22 cm. This change is attributed either to a change in the depositioning material with time, or to the diagenesis of CaCO3. This process responsible for the change in the silicate/CaCO3-ratio must be slow compared to bioturbation, since it is not manifest in the bioturbation layer.

d) Mn shows a different behaviour insofar as its Th-normalized concentration does not stay constant with depth, but shows a slight but significant decrease of about 20% relative to the zone of bioturbation (fig 29b). Since the sediment is well-oxygenated to a depth of 1m, a simple reductive dissolution of MnO2 would not be expected. However it might be that microbially-mediated decomposition of organic matter is responsible for a certain remobilization of Mn.

e) Br and I show a different behaviour insofar as they decrease approximately exponentially over the entire depth (0-22 cm) with a half-thickness of 10 cm for Br and of 25 cm for I (fig 30). This is attributed to the decomposition of organic material, which is a generally accepted host for Br and I. Since the concentration of both elements is not homogenized in the top layer, it follows that the decomposition of the organic material is a faster process than bioturbation.
Fig 30: Vertical profiles of Br and I at station T6
PARTITION OF THE MAJOR ELEMENTS BETWEEN THE
CARBONATES AND THE SILICOCLASTICS

The sediment is composed of two main phases:

a) the "labile" carbonate phase including
   sulfates, phosphates, Mn and Fe oxyhydroxides,
   biogenic amorphous silica, clay and organic
   matter.

b) the "non-labile" phase (quartz, heavy minerals,
   alkaline feldspar, micas, chlorites)

The hydrolysis of the phyllosilicates increases
with the decrease of the grain size. Most
sensitive are the small smectites, then the mixed-
layered minerals, the chlorites and the
clinoptilolite.

A speciation after extraction is required to
ascrize the major (and some trace) elements to the
carbonate or crystalline phases. As most of the
extractors are not very efficient for sediments
with a high carbonate content (around 80%), we
applied the standard method of dissolution by HCl,
(1n/HCl, during 30' at 80°C), in use since 1967 in
our laboratory, which extracts surely all the
cations from the carbonates.

A slight fraction of the sulfate, phosphate and
metallic oxyhydroxide cations are also dissolved.
Part of the fresh organic matter and some of the
smallest phyllosilicates are likely to be
hydrolysed. All minerals with bivalent Fe
(sulphurs, smectites, trioctahedral chlorites,
hornblendes and even the phengites) may be washed
out pro parte, thus releasing Mg, Al, Si and K.
The dissolved cations are ascribed to the various
phases by a linear correlation analysis with:

a) the insoluble residue (IR) which represents the
   silicoclastics

b) the mineral carbon from the carbonates

c) the organic carbon (organic matter with some
   adsorbed cations)

Samples and analysis

40 samples of sediment from the dumpsite have
been analyzed. The results for 32 samples of
three box-cores (stations T1, T6 and T8) are
presented in table V. Concentrations of the
anions and cations are expressed as % of the
total rock. As the sediment is not washed
prior to the attack, some minor contribution
of the interstitial water cannot be excluded.
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Tab V : Results of the analysis of the HCl soluble phase
The organic carbon, which is determined subsequently by dissolution of the insoluble residue with H3PO4, is not represented in table V. Cross-plots, linear correlation and multivariate analysis have been applied to this data set.

4.4.4.2

The carbonate phase

The only carbonate identified by X-ray diffraction analysis is calcite. Its diffraction peaks match with a stoichiometric calcite, without any solid-solution as Mg or Fe++. The determined Cmin originates thus only in the CO3 of the calcite, and aragonite is totally absent. The purity of the calcite is confirmed by the chemical analysis, with r=0.99 (n=32) for Cmin and Ca. Most of the Mg does not belong to the carbonate phase, as r= -0.93 (n=32) for Cmin and Mg. The sediment contains neither Mg-calcite, nor dolomite or ankerite. Surprising is the bad correlation Cmin/Sr (r=0.16) which is often better for carbonate sediments. Similar results have nevertheless been reported by PARRA (1980) in the Norwegian sea, where the Sr bound with biogenic material (low productivity) is diluted by the terrigenic input, then distributed southward.

4.4.4.3

The elements of the siliciclastic phase

As mentioned previously, some elements of the siliciclastic phase are likely to be dissolved during the HCl digestion. Concentration of such elements should thus increase jointly with the insoluble residue (IR), as confirmed by the correlation coefficient of table VI. The partial dissolution of the small mica supplies K(r=0.95), Al(r=0.86), SiO2(r=0.78) and part of Fe(r=0.96). Mg(r=0.95) is released by the chlorites, as well as some Fe and Si. The clinoptilolite and the hornblende provide Si, K, Na, Fe, and Mg. Part of the Si originates also from the biogenic silica, which is naturally not very stable. The high correlation between Al and phosphates (r=0.91) points towards either an Al-P04 chelation or the existence of another mineralogical phase not detected by our X-ray diffraction analysis.
4.4.4.4.

The non-correlated elements

Sr, Na, and SO4 do not correlate with Cmin or with the insoluble residue, neither with any of the cations or anions (Table VI). The interstitial water is postulated as a possible origin. This hypothesis should be confirmed by repeating the analysis using sediments rinsed with deionized water.

As the Corg content is very low (mean 0.2%), its associated cations or anions are unlikely to interfere significantly with the partition between the two phases. In any case, the high correlation between Cmin and IR (r=−1.00) confirms that the influence of any other geochemical relation would be very low, i.e. at the level of the trace elements. The antagonism between authigenic carbonates, exogenic siliciclastics, interstitial water and sea-water is a characteristic feature for this type of sediment.

MATRICE DE CONVARIANCE RESP. DE CORRELATION

NOMBRE D' OBSERVATION : 32
NOMBRE DE VARIABLES : 12
MINIMUM SIGNIFICATIF DU COEFFICIENT DE CORRELATION A 0.01 : r = 0.4487

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Tab VI: Correlation coefficients between the various elements of the labile phase and IR (RI)
4.4.4.5

Vertical profiles

Similar trends are observed in the three profiles of table V. The increase of IR (and of its associated elements Fe, K, Mg, Al, SiO₂) versus the depth in the core is obviously balanced by a decrease of Cmin and Ca. In each profile, the upper 6-10 cm are rather homogeneous for all the observed elements, confirming thus the conclusions of the NAA analysis of the bulk sediment (4.4.3). But the thickness of this upper layer, likely to be homogenized by the bioturbation, varies from station to station. Below the bioturbated layer, IR is strictly correlated with the depth in the core ($r=0.998, n=6$ at station T6). But the value of IR, at the same level in the three cores, varies as a function of the station depth. For the station T6 (4570m), IR ranges from 10.5% in the surfical sediment to 17.5% (19-22 cm). For the station T8 (4725m), the range is from 12% to 14%, and for the deepest station T1 (4800m), the range is from 23% to 67% (fig 31). This would point towards some continuity in the carbonate dissolution rate below the current lysocline level during the last 10,000 years.

![Fig 31: Variation of the IR content versus depth in the cores as a function of the station depth](image)
5. OBSERVATIONS AND RESULTS IN MICROBIOLOGY

The concept of the microbiological aspects within the PROSPER surveillance program has been outlined in chapter 2.2.4. The main objective of the preliminary experiments conducted during the DORA cruise (M.S TYRO) was to demonstrate the presence of bacteria in the top sediment layers and to partially characterize the composition of the microbiota. High resolution gas chromatography was used to analyze microbial signature molecules from phospholipid and lipopolysaccharide fractions of the dumpsite sediment. High concentrations of phospholipids 5 to 10 cm below the sediment surface indicate that living microbial populations exist there under microaerobic conditions. Gram negative aerobes, indicated by hydroxy fatty acids, are predominantly localized in the top sediment layer (0-5cm). The bacterial density is too low for direct observation or enumeration by microscopy, hence only sensitive capillary gas chromatographic techniques offer possibilities to analyze the structure of the microbial community in this ecosystem. The details of the analytical procedure and the results of this microbiological component of the PROSPER program are presented in annex I.
6. CONCLUSIONS

The current dumpsite for low level radioactive waste in the North-Eastern Atlantic has been utilized since 1974 for the elimination of part of the Swiss radioactive waste, under the control of the Nuclear Energy Agency (NEA). The PROSPER project is the first opportunity for Switzerland to take part actively in the international effort for the scientific monitoring and surveillance of this site. The full financial support provided by NAGRA since 1981 has allowed setting up of a small research team, which has participated so far in four cruises organized within the framework of the international CRESP program. This program is coordinated by the Nuclear Energy Agency.

The scientific aim of the Swiss contribution is to investigate the remobilization of the radionuclides by resuspension of the deep sea sediment. Relevant results concerning the structure of the benthic nepheloid layer and the suspended load variability have been obtained. These results demonstrate that the resuspension process is unlikely to result in a massive upwards flux of the remobilized sediment, excluding such a direct transfer as a critical pathway for the radionuclides. The horizontal advection of the suspended matter, concluded from the differences in the composition of the suspended particles and of the surficial sediment, has still to be evaluated. The regional models developed by the Harvard group will be used for that purpose. The simulations will have to be compared with the nephelometric observations, supplemented by the results of the long-term current measurements, actually under way (DHI). Geochemistry and mineralogy of numerous samples, studied by various Swiss laboratories and educational institutions, provide relevant data on the particle and sediment composition. The knowledge of the chemical element partition between the main phases of the sediment contributes towards a better understanding of the sorption/release processes, which are of major importance for the evaluation of the Kd ratio to be used for the various radionuclides in the radiological assessment. The mineralogical study indicates that the changes in the sedimentation regime since the last glaciation are slow, confirming thus that the dumpsite area fulfills the sedimentary stability requirements.
The results available up to August 1984 are summarized in this progress report. Parts of them have been presented and discussed at the 5th International Ocean Disposal Symposium in Corvallis (Oregon State University, September 84). The research program however is still in progress. A fourth successful cruise was carried out in autumn 1984 in the NOAMP area in collaboration with the DHI, adding 80 nephelometric stations to our current database. The PROSPER group has already been invited to participate in the last cruise of the NOAMP program in autumn 1985. Three scientific papers are actually in preparation and will be submitted for publication within two months to "Deep Sea Research" and "Marine Geology".

Since the CRESP program has been set up in 1981, its participants have recognized that the publishing delays of most of the scientific journals were incompatible with the dynamics of the program, taking into account the deadline for the next site validation (late 1984). Progress reports and straightforward discussion of the results during the CRESP annual meetings (La Spezia in 1982 and Hamburg in 1983) have been chosen as the most appropriate and fastest way to make available the scientific information related to the program. Indeed these open discussions between scientists during such technical meetings have proved to be also highly efficient in updating the research plans and thus reinforce the international cooperation. They allowed e.g. the PROSPER team to be invited on board the F.S METEOR, on the basis of the evaluation of the preliminary results obtained during the two previous cruises with NIOZ and MAFF.

The overall swiss contribution to the CRESP program was widely appreciated among the scientists involved. Part of the results presented in this progress report has been integrated into two chapters of the updated oceanographic description of the dumpsite. This key document, to be published by NEA at the end of 1984, shall be used by the Experts designated to reevaluate the suitability of the current site for continued dumping over the next five years. During the last annual meeting of the Sea Bed Disposal Programme (SDP) in Berlin (March 84), the hydrological and nephelometric results of the NOAMP I cruise have also been recognized as a key data set for the tuning of regional oceanographic models, which are part of the SDP feasibility assessment. Therefore, these data have been pooled with the Physical Oceanography Group of Harvard University and with the Sandia National Laboratory (New Mexico) which is running such models on big computers (CRAY-1). The instrumental resources and skill developed since 1981 within the PROSPER program could thus readily be used in the framework of the Sea Bed Disposal Programme, for which a declared swiss contribution is still expected.
The results of the PROSPER program however, go beyond the specific problems of the dumpsite monitoring. They also represent a relevant contribution to marine science in general, as demonstrated by the proposal of the Bureau National des Données Océaniques (Brest) to integrate our results into its data bank for the Atlantic.

During the last session of the Executive Group for Research on Sea Disposal of radioactive Waste (Paris, sept. 84), most of the national representatives of the dumper and of the non-dumper countries recognized the scientific impact of the CRESP program, and confirmed their intention to continue to support it during the coming years. The surveillance of a dumpsite for radioactive waste has indeed to be conceived on a long term basis, and a special commitment might be expected from those nations which have dumped in the past or which forsee doing so in the future.

7. ACKNOWLEDGMENTS

The PROSPER program is fully supported by NAGRA (Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Baden). The authors wish to thank NIOZ, MAFF and DHI for the cruise opportunities and the crews of M.S TYRO, R.V CIROLANA and F.S METEOR for their assistance during the work at sea. We would like to express our appreciation to the Eidgenössisches Institut für Reaktorforschung for providing the neutron activation facilities, and to M. Tobler who performed the analysis. We acknowledge also Dr B. Kübler and his technical staff at the Laboratoire de Minéralogie et de Pétrographie de l'Université de Neuchâtel for his analytical work. Last but not least, we thank all the swiss scientists who participated in the cruises, with a special mention for F. Godet and C-H. Godet who developed all the software and managed to keep our computer running even in the worst working conditions.
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ANNEX I
Partial Characterization of a Microbial Ecosystem in Deep Sea Sediments: A progress report.

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Summary

High resolution gas chromatography was used to analyze microbial signature molecules from phospholipid and lipopolysaccharide fractions of deep sea sediments (4000-4500 m) from the Northeast Atlantic. High concentrations of phospholipids in sediments 5 to 10 cm below the surface indicate that living microbial populations exist below the surface under microaerobic conditions. Nitrate might be formed here by nitrifying bacteria. Cis-vaccenic acid and two cyclopropane fatty acids indicate the presence of facultatively anaerobic bacteria, possibly denitrifiers. No "signatures" of sulfate reducers could be found within the top 20 cm. Gram negative aerobes, indicated by the hydroxy fatty acids, are predominantly localized in the top layer (0-5 cm). The bacterial density is too low for direct observation or enumeration by microscopy hence only sensitive capillary gas chromatographic techniques offer possibilities to analyze the structure of the microbial community in this ecosystem.

Introduction

Whether or not deep-sea sediments from the NEA dumpsite are suitable for the ecologically safe deposition of radioactive wastes depends, among other factors, on the physiological response of the microbiota to the perturbations introduced by the dumping operations and the kind of foreign materials deposited in this ecosystem. Microbial activity could thereby be stimulated by the additional supply of nutrients and biochemical energy or by local temperature increase (Jannasch, 1984b). It could also be impaired by inhibitors or radiation.

The concept of the microbiological aspects within the PROSPER surveillance program has been outlined in chapter 2.2.4. As we pointed out there we are fully aware of the limited possibilities of drawing generalized conclusions from only a few measurements. The state of the field of deep-sea microbiology has been reviewed excellently by Jannasch and Taylor (1984a). These experienced investigators also conclude: "... present-day approaches in deep-sea microbiology reveal a lack of compatibility between
fundamental but relatively simple field studies on growth of natural populations and laboratory experiments with pure cultures under well-defined conditions. Results of the former are often characterized by logistic constraints of work at sea, e.g. insufficient data to permit statistical treatment. Laboratory studies, on the other hand, are done with organisms removed from their natural habitat for some time and grown in media not reflecting the in situ nutritional conditions."

We report here on observations on a few samples collected during the Dutch DORA mission in 1982. Corresponding geochemical parameters which have been measured during this mission were reported by M.M. Rutgers van der Loeff and M.S.S. Lavaleye (1984). It is the objective of this preliminary report to demonstrate the presence of bacteria in the top sediment layers and to partially characterize the composition of the microbiota.

**Materials and Methods**

**Samples and extraction procedures:** Subcores were taken in PVC liners from a box core collected at station 11. The top 20 cm of the sediment were divided into 4 fractions, freeze dried and analysed according to the procedures outlined in figure 1. Ten to 20 g of dry sediment were extracted for 2 hrs. with a five fold volume of a solvent mixture containing chloroform, methanol and water (1:2:<0.8). Then chloroform and water were added to bring the extractant to the final composition of 2:2:1.9 \((v/v, \text{CHCl}_3:\text{CH}_3\text{OH}:\text{H}_2\text{O})\). After standing for 24 hrs. in a darkened room the heavy chloroform fraction was separated from the residue on top and from the aqueous phase (White et al. 1983). The residue and the organic phase were analysed further for fatty acids from lipopolysaccharide (LPS) lipid A and for fatty acids from the phospholipids. The chloroform fraction was separated by chromatography on activated silicic acid. Neutral lipids were eluted with chloroform, glycolipids with acetone and polar lipids with methanol. The phospholipids which were contained in the methanol fraction underwent mild alkaline methanolysis (King et al. 1977). The resulting fatty acid methyl esters (FAME) and the hydroxylated fatty acid methyl esters (OH-FAME) were separated from each other and from the plasmalogens by thin layer chromatography. The FAME and OH-FAME were then separated and the components identified with capillary gas-liquid chromatography (Bobbie and White, 1980, Parker et al. 1982). Samples were injected onto a 30 m fused silica capillary column coated with nonpolar SE-30 operated in the splitless mode with 0.5 min venting time.
The LPS in the residue from the initial solvent extraction were hydrolized with HCl, extracted and the OH-FAME of lipid A were recovered with thin layer chromatography (Parker et al. 1982). These OH-FAME also were analyzed by capillary gas-liquid chromatography.

**Designation of FA and OH-FA from their corresponding FAME and OH-FAME:** The designation 18:1 w 7 c indicates the number of carbon atoms (18), the number of double bonds (1) and the position of unsaturation (7) from the distal end to the carbonyl carbon (w). The suffixes c and t denote cis and trans configuration respectively; the prefixes a, i, br and delta indicate anteiso-, iso-, unspecified branching or the presence of a cyclopropane ring in the carbon chain. In hydroxy fatty acids, e.g. 3-OH 17:0 the position of the hydroxyl group (3) within the carbon chain is counted from the side of the carbonyl carbon.

**Microscopy:** Samples for scanning electron microscopy (SEM) were prepared in cacodylate buffer containing glutaraldehyde, formaldehyde and ruthenium red. They were then dehydrated in ethanol and dried at the critical point for CO₂. Fluorescence microscopy was done with acridine orange staining.

**Growth of bacteria:** Enrichment of bacteria was carried out for a series of physiological types in the appropriate growth media. Final isolation of a pure organism, however, was done from only one culture under denitrifying conditions. The medium for this organism contained per liter: \((\text{NH}_4)_2\text{SO}_4\) 0.33g as N- and S-source, \(\text{MgCl}_2 \cdot 6\text{H}_2\text{O}\) 4.06g, \(\text{CaCl}_2 \cdot 2\text{H}_2\text{O}\) 0.07g, KCl 0.37g, NaCl 20.45g, \(\text{KH}_2\text{PO}_4\) 0.13g, trace elements, vitamins, Casaminoacids, Yeast extract, \(\text{NaHCO}_3\)-buffer 23 mM, NaN₃ 50 mM as electron acceptor. Lactate, malate, succinate or glutamate were added as non-fermentable carbon and energy sources. Incubation was carried out at 27°C and pH 7.2 in Hungate tubes. Gas formation was followed with Durham tubes.

For details of the analytical procedures the cited references should be consulted.

**Results and Discussion**

The geochemistry of this ecosystem is dominated by the carbonatious skeletal remains of the foraminfera which have been deposited here for the last several thousand years (Fig.2). The density of bacteria, however is too low for direct observation in the SEM. Fluorescence microscopy revealed low numbers of bacteria and, among the countless empty foraminiferal exoskeletons, always some with an acridine orange stainable cellular content. They might
belong to benthic forms of foraminifera which might also be partially responsible for the turbations observed within the top few centimeters of the sediment.

Phospholipids are membrane components in procaryotic and eukaryotic organisms. They show a rapid turnover in growing cells. The phosphoester bonds are hydrolyzed easily so that phospholipids do not accumulate in sediments as organic remains of dead biomass. The extraction scheme (Fig.1) insures that the phospholipids isolated represent components from the living biomass of the biota. Since no obvious macro-or meiofaunal components were present in our samples one may assume that the phospholipids extracted originate predominantly from bacteria and protozoa (foraminifera). Within the top 20 cm of the sediment the highest concentrations of phospholipids are found 5 to 10 cm below the surface (Tab.1). The distribution within the sediment depth analyzed shows that 27.4% of the phospholipids stem from the top 5 cm interval, 57.3% from the second, 6.5% and 8.3% from the third and fourth fractions respectively. This indicates that the zone with the largest microbial biomass is buried below the sediment surface. However the biomass of the surface fluff, which could not be investigated, is not considered in this discussion.

The organisms here exist at an oxygen concentration of 3.2 to 1.5 mg/l (Fig.3). In this layer nitrate reaches 50μmolar which is the maximal value in the concentration-depth profile; it is twice as high as the nitrate concentrations in the overlying bottom water. Total organic carbon decreases from an average of 2.2 mgC/g sediment dry weight at the sediment-water interface to a more or less constant value of 1.3 mgC/g sediment dry weight in depths below 10 cm (average of carbon determinations in sediments from 7 different stations, data not included). Both the concentration and consumption of carbon point to slow reaction rates under oligotrophic conditions. A comparison with the oxygen profiles (Fig.3) leads one to suspect, that more oxygen is consumed than would be needed for the oxidation of the carbon. The nitrate profiles support the notion that some of the oxygen is used by nitrifying bacteria. Nitrobacter sp. and Nitrosomonas sp. might catalyze ammonia and nitrite oxidation according to:

$$\text{NH}_4^+ + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_2^- + 2 \text{H}^+ + \text{H}_2\text{O}$$

$$\text{NO}_2^- + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_3^-$$

Nitrate consumption below 10 cm sediment depth coincides with low oxygen concentration. These conditions would favour facultatively anaerobic, denitrifying bacteria. Enrichment and isolation of such an organism was successfully accomplished (Fig.4). It grows in media with salt concentrations corresponding to sea water salinity. The organism needs to be characterized further.

Quantitatively most important are saturated and mono- and polyunsaturated fatty acids with chain lengths of 16 and 18 carbon atoms (Tab.1). The high concentrations of cis-vaccenic acid (18:1 w 7 c) is indicative of the presence of anaerobes since this fatty acid is produced by the anaerobic fatty acid desaturase pathway. cis-vaccenic acid was also found in the deeper sediment layers analyzed. The two cyclopropane fatty acids (delta 17:0 and delta
19:0) may be used as markers for facultative anaerobes. The presence of these fatty acids down to 20 cm sediment depth indicates the widespread occurrence of possibly denitrifying facultative anaerobes. No branched fatty acids are present in the sediment fractions analyzed. Since branched fatty acids are commonly used as markers for sulfate reducing bacteria it may be concluded that this group of bacteria does not exist in the microbial community of the upper sediment layers. Only the top sediment layers contain detectable amounts of long-chain (>20 C atoms) polyenoic fatty acids which are characteristic for eukaryotic microbes (here foraminifera).

Hydroxy fatty acids from phospholipids originate from gram negative bacteria. The data presented in table 2 show that the largest populations of gram negatives occur among the aerobes in the top sediment layer (35%) and among the denitrifiers in the 15 to 20 cm fraction (32%). The distribution of the OH-FA from lipopolysaccharides (Tab.3) in the upper three fractions coincides with the distribution of the OH-FA from phospholipids. The relative abundance within the three top fractions is 51%, 27% and 22% for the OH-FA from the phospholipids and 45%, 27% and 28% for the OH-FA from the lipopolysaccharides. Lipopolysaccharides are predominantly formed by gram negative bacteria. One may conclude therefore that the top sediment layer contains the largest population of gram negative bacteria, while the 5 to 10 cm fraction is the layer with the largest total biomass.

Conclusions

With the approach followed during this investigation we were able to partially characterize the community structure of an NEA deep sea sediment ecosystem in different depths. This was possible because methods already existed to quantitatively and qualitatively extract signature molecules from living organisms from a complex environmental sample (Fig.5). This chemical approach has been designed and refined by D. White and collaborators, it makes use of the possibility to extract and identify specific cellular components (Fig.6). Experience is still lacking however for direct translation of the amounts of signature molecules measured into cellular biomass of the ecosystem. Other methods exist to evaluate the nutritional status and catalytic capabilities of the communities in particular ecosystems (Fig.7).

From the few data presented here it would be premature to make generalized conclusions about the NEA deep sea–sediment ecosystem.

Acknowledgments

We thank David White for introducing us to the chemical procedures. One of us (J.P.K.) was able to learn the methods in his laboratory.
Literature cited


Table 1: Fatty acid methylesters from the phospholipids of four deep sea sediment fractions

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Sediment fraction</th>
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<tr>
<td></td>
<td>0-5 cm</td>
</tr>
<tr>
<td></td>
<td>(nmol/g dw)</td>
</tr>
<tr>
<td>14:0</td>
<td>-</td>
</tr>
<tr>
<td>15:0</td>
<td>-</td>
</tr>
<tr>
<td>i 15:0</td>
<td>19.76</td>
</tr>
<tr>
<td>a 15:0</td>
<td>-</td>
</tr>
<tr>
<td>i 16:0</td>
<td>12.67</td>
</tr>
<tr>
<td>16:4 w 1</td>
<td>-</td>
</tr>
<tr>
<td>16:1 w 10</td>
<td>19.77</td>
</tr>
<tr>
<td>16:1 w 9</td>
<td>-</td>
</tr>
<tr>
<td>16:1 w 7 c</td>
<td>158.92</td>
</tr>
<tr>
<td>16:1 w 7 t</td>
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</tr>
<tr>
<td>16:1 w 5</td>
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<td>17:1 w 9</td>
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</tr>
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<td>i 17:0</td>
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<td>17:1 w 6</td>
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<tr>
<td>18:4 w 3</td>
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</tr>
<tr>
<td>18:2 w 6</td>
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</tr>
<tr>
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<td>18:1 w 9 c</td>
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<td>18:1 w 7 c</td>
<td>255.77</td>
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<td>18:1 w 7 t</td>
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<tr>
<td>delta 19:0</td>
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<td>19:0</td>
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<td>20:0</td>
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<td>20:1 w 15</td>
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<td>20:4 w 6</td>
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</tr>
<tr>
<td>20:3 w 6</td>
<td>-</td>
</tr>
<tr>
<td>22:1 w 9</td>
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</tr>
<tr>
<td>22:6 w 9</td>
<td>16.07</td>
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<tr>
<td>24:1 w 9</td>
<td>-</td>
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Total: 1002.77 2098.61 236.85 302.9

standard: 10-Me 16:00
Table 2: Hydroxy fatty acid methylesters from the phospholipids of four deep sea sediment fractions

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<tr>
<th>OH-fatty acid</th>
<th>0-5 cm</th>
<th>5-10 cm</th>
<th>10-15 cm</th>
<th>15-20 cm</th>
</tr>
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<td>i-OH 13:0</td>
<td>11.90</td>
<td>4.96</td>
<td>2.44</td>
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<tr>
<td>3-OH 13:0</td>
<td>8.68</td>
<td>-</td>
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<td>1a-OH 15:0</td>
<td>42.79</td>
<td>9.64</td>
<td>28.05</td>
<td>57.05</td>
</tr>
<tr>
<td>2a-OH 15:0</td>
<td>4.16</td>
<td>3.68</td>
<td>-</td>
<td>12.28</td>
</tr>
<tr>
<td>i-OH 16:0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.23</td>
</tr>
<tr>
<td>i-OH 17:0</td>
<td>42.42</td>
<td>23.46</td>
<td>3.83</td>
<td>11.85</td>
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<td>3-OH 17:0</td>
<td>10.98</td>
<td>5.25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>OH 18:1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.22</td>
</tr>
<tr>
<td>2-OH 18:0</td>
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<td>18.06</td>
<td>13.22</td>
<td>27.24</td>
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<tr>
<td>2-OH 19:0</td>
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<td>6.19</td>
<td>3.65</td>
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<td>OH 20:0</td>
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<td>5.36</td>
<td>10.06</td>
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<tr>
<td>3-OH 21:0</td>
<td>7.35</td>
<td>6.63</td>
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<td>10.69</td>
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<td>7.57</td>
<td>6.38</td>
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<td>3-OH 24:0</td>
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<td>3.11</td>
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<tr>
<td>3-OH 25:0</td>
<td>3.29</td>
<td>2.41</td>
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</tr>
<tr>
<td>Total</td>
<td>191.29</td>
<td>99.17</td>
<td>82.22</td>
<td>176.38</td>
</tr>
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</table>

standard: 16:0 alcohol
Table 3: Hydroxy fatty acid methyl esters from lipopolysaccharides of deep sea sediment fractions

<table>
<thead>
<tr>
<th>OH-fatty acid</th>
<th>0-5 cm (nmol/g dw)</th>
<th>5-10 cm (nmol/g dw)</th>
<th>10-15 cm (nmol/g dw)</th>
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<tbody>
<tr>
<td>i-OH 13:0</td>
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<td>4.00</td>
</tr>
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<td>6.08</td>
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<td>2.87</td>
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<td>2.34</td>
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<td>2.51</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>183.84</strong></td>
<td><strong>110.28</strong></td>
<td><strong>111.67</strong></td>
</tr>
</tbody>
</table>

Standard: 16:0 alcohol
Figure 2: The NEA-deep sea sediment: SEM-photographs
Fig.2.1 (9450x): Native sediment
Fig.2.2 (2160x): dito
Fig.2.3 (120x): Foraminiferal skeletons
Fig.2.4 (216x): dito
The density of bacteria is too low to be observed directly in the SEM.
Figure 3: Oxygen and nitrate concentration–depth profiles from 3 cores of the DORA mission
(Data compiled by M.M. Rutgers van der Loeff). Sediment samples from core 11 were analyzed for microbial marker molecules. We suspect nitrifying processes as the source of the elevated nitrate concentration in the microaerobic zones of the upper sediment layers.
Figure 4: SEM-photograph of isolated bacteria
Enrichment under denitrifying conditions performed as described in materials and methods. Strain to be further purified and characterized.

Figure 5:

COMPOSITION OF ENVIRONMENTAL SAMPLES FROM SEDIMENTS

Organic part
- Living biomass
- Organic detritus
- Anthropogenic organics

Inorganic part
- Inorganic detritus
- Erosion products
- Chemical precipitates
- Anthropogenic inorganics
Figure 6:
BIO-GEO-CHEMICAL INDICATORS OF MICROBIAL BIOMASS

FROM CELL WALLS AND MEMBRANES:

e.g. Phospholipids, Etherlipids, Fatty acids, Peptidoglycans, Muramic acid, Amino acids, Teichoic acids, Teichuronic acid

FROM CELL WALL ASSOCIATED STRUCTURES:

e.g. Polysaccharide slimes and capsules
     Lipopolysaccharides (LPS)
     Uronic acid

FROM INTRACELLULAR INCLUSIONS:

e.g. Poly-beta-hydroxy acids (PHA)
     Elemental sulfur, Polyphosphate

FROM SPORES:

e.g. Dipicolinic acid

FROM THE CYTOPLASM:

e.g. Nucleic acid polymers (DNA, RNA)
     Nucleotides (ATP, ADP, AMP etc.)
     Specific enzymes

FROM THE CELL'S ENVIRONMENT:

     Metabolites

Components from different cell entities contain signature molecules which indicate kind and amount of biomass present and/or its nutritional status.
Figure 7:

INFORMATION ON LIVING BIOMASS IN SEDIMENTS

Amount ? — Quantity, Density
Community structure ? — Speciation
Nutritional status ? — Capabilities
Catalytic activities ? — Organisms, Enzymes,
Reaction Rates