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Extreme marine environments

Objectives and results from selected MAST projects

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Extreme marine environments

Objectives and results from selected MAST projects

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Directorate-General for Research

Energy, environment and sustainable development programme

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PURPOSE OF THIS PUBLICATION

The purpose of this publication is to give an overview of the objectives, the main results and the major publications obtained from several MAST-III-funded projects and workshops in the specific field of extreme marine environments from 1996 to 1999.

ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

INTRODUCTION TO THE EXTREME MARINE ENVIRONMENTS

1. Definition of Extreme Marine Environments

Extreme conditions are conditions that define the limits of life in our planet; they are found in the deep ocean and at the poles. Short-term conditions can have dramatic consequences for the entire biosphere and evolution of life, as well as for the Earth's climate, because they can alter living conditions or even turn them irreversible. Through adaptation to extreme environments, micro-organisms play a considerable role in global material-cycling. On the above basis, extreme conditions and events are essential components in the assessment of anthropogenic and natural environmental change. The examination of extreme marine environments also contributes to the following. Deliverable of exotic, often economically important minerals, solutes and organics; micro-organisms which function under these conditions change their physical and chemical environment, including environments of commercial interest such as oil and gas reservoirs and sites of waste storage and dumping. Micro-organisms that adapt to extreme environments are extremophiles and will have biotechnological application, for example bio-remediation, waste treatment. Finally, of great importance is the development of deep-sea technologies for observation of extreme marine environments.

2. Objectives and Research Tasks of the Marine Science and Technology Programme (MAST III) for the Extreme Marine Environments

Technical areas supported within the MAST III programme (1994-1998)were: Marine Science, Strategic Marine Research, Marine Technology, and Supporting Initiatives (advanced training system, modelling, use of heavy experimental equipment, calibration techniques for marine instrumentation and observational equipment). The overall objective for the study of extreme marine environments was to understand the functioning of any ecosystems under these conditions, and to examine their physical, chemical, biological and geological processes, so as to determine their role in the global environment. The part of research for extreme marine environments included the following disciplinary areas, which the projects of the present study address.

3. The MAST III projects on Extreme Marine Environments

<u>MARINE SCIENCE</u>

The deep sea floor in the North Atlantic and the Mediterranean:

- Azores Mid-Oceanic Ridge Ecosystem Studies: An integrated research programme on deep-sea hydrothermal transfers and fluxes – *AMORES* (MAS3-CT95-0040)
- High resolution temporal and spatial study of the **BEN**thic biology and **G**eochemistry of a north-eastern **A**tlantic abyssal **L**ocality – *BENGAL* (MAS3-CT95-0018)

The ice-covered seas in the northern hemisphere:

- European Subpolar Ocean Programme Phase 2: The Thermohaline Circulation in the Greenland Sea - *ESOP II* (MAS3-CT95-0015)

Sedimentary processes in the deep sea, on the continental slope and on the shelf edge:

- **HY**drothermal **FL**uxes and biological production in the **A**e**G**ean - *AG-HY-FL* (MAS3-CT95-0021)

4. Third European Marine Science and Technology Conference, Lisbon, 23-27 May 1998: Section for the Extreme Marine Environments in Europe: *Extreme Marine Environments in Europe: Scientific and Technological results and challenges*

Some of the outcomes of this section were:

- Determination of the flux of dissolved substances leaving the sediment to return to the bottom water. More specifically, the flux of anthropogenically introduced material across this boundary. Moreover, the deep-sea biota response to the above flux of material has to be examined. Relative results from testing on models, have shown that exchange processes at the deep sea floor play an important role on the oxygen distribution in the oceanic water column and the atmospheric pCO. For a realistic estimation, in situ measurements have to be carried out.
- Microbial oxidation of reduced inorganic compounds by endosymbiotic bacteria is a common feature in hydrothermal vents and cold seeps of subduction zones. It produces a large benthic oxygen demand that affects the local bottom waters. An open field of research is the colonisation of hydrothermal vents by special communities, due to biological fixation, which leads to formation of precipitates, concentration of exotic metals and fractionation of extreme isotopes. Another open research field is the matrix-fluid interaction under extreme temperatures and pressures. More specifically, the phase separation during boiling of hydrothermal fluids, and transport and fractionation of elements.
- Studies on numerous deep brine lakes that have been discovered in the eastern Mediterranean Sea, which are anoxic hypersaline deep basins with the highest dissolved sulfide, magnesium, potassium and helium concentrations ever reported for marine environments. Their origin is not, so far, clearly known.
- Studies on diversity of thermophylic micro-organisms at deep sea hydrothermal vents in Eastern and Southwest Pacific and the mid-Atlantic (at the Guyana's Basin and the MAR) have succeeded in isolating, for the first time, aerobic thermophiles some of them assigned to the genus *Thermus* and several new spore-forming bacilli. Concerning anaerobic hyperthermophiles, investigations have revealed several heterotrophic anaerobic Archaea.
- A recent finding in deep-sea environments is mud volcanoes that consist of pure serpentinite slurries. Furthermore, gas hydrates, a mixture of water, methane and hydrocarbons, carbon dioxide and hydrogen sulfide, might be of great importance as a future energy source and because they may play a role on climate change through their rapid decomposition in shallow waters.

5. Workshop on Extreme Marine Environments, GEOMAR Kiel, 19-22 November 1998: *The deep ocean: A model for processes functioning under extreme environmental conditions*

An international workshop, co-organised by the European Commission, Directorate General XII, Marine Science and Technology Programme, and the German Ministry for Education, Science, Research and Technology. The essential goal was the better understanding of the extreme environmental conditions in the ocean, at the seafloor, and below the seafloor by European research groups, heading to the explanation of the contribution of such conditions and events in modeling approaches of environmental change. Results of the workshop indicated that *future research must concentrate on: a. identification of the major interacting parameters in complex geo- and bio-topes, b. assessment of frequencies and magnitudes of extreme events, c. modeling of the re-equilibration of environments after perturbation, d. prediction and evaluation of the potential dangers of extreme events, e. identification of feed-back mechanisms, and g. development of new technologies.*

6. The MAST Advanced Study Courses (ASC) relevant to the Extreme Marine Environments

- Deep Benthic Communities based on Chemosynthesis (Hydrothermal Vents and Cold Seeps), FR-Paris, September 1997

- Submarine Volcanism, Hydrothermal Vents, Associated Biota and Mineral Resources, ES- Barcelona, September 1996

OVERVIEW OF OBJECTIVES, MAIN RESULTS, AND MAJOR PUBLICATIONS FROM SELECTED MAST PROJECTS

Title: **AMORES**

Azores **M**id-**O**ceanic **R**idge **E**cosystem **S**tudies: An integrated research programme on deep-sea hydrothermal transfers and fluxes

Contract No: **MAS3-CT95-0040**

Sub-programme area: Extreme Marine Environments - ***The deep sea floor in the North Atlantic and the Mediterranean***

Duration of the project: February 96' - March 99'

Background: Three major tectonic plates (European, North American, and African) have their boundaries in the mid-Atlantic ridge ridge system near the Azores, Triple Junction. The Azores region has an unusually shallow position in the North Atlantic. During the MAST 2 MARFLUX/ATJ project, two hydrothermal sites were discovered: the *Lucky Strike* vent field at 37°15', and *Menez Gwen* vent field at 37°45'.
Lucky Strike is one of the largest hydrothermal areas known in the modern oceans, the hydrothermal system of which is controlled by a lava lake. For the depth of 1700 m, the maximum temperature (320° C) is close to the boiling point (340° C). Menez Gwen vent field has a temperature of 281°C° C, close to the boiling point. The Rainbow hydrothermal site belongs to the AMAR segment and had not been precisely located before the beginning of the project. The site is controlled by a cross cutting fault system, and was located during the MARFLUX/ATJ project from the very high particle content in the plume (German et al. 1996). Both the Lucky Strike and the Menez Gwen vent fields are above the depth at which a typical hydrothermal fluid starts to boil, whereas Rainbow vent field is below this depth.

Objectives: The project aimed to identify and quantify the fluxes within and from the hydrothermal vent ecosystem, the interactions between lithosphere and sea-water, and their impact on the ecosystems of the Mid-Atlantic Ridge (MAR), south-west of the Azores Triple Junction (ATJ). AMORES addressed to four themes:

Theme 1: The hydrothermal flux of heat and matter from vent-field to segment scale
Theme 2: Submersible geological and geochemical studies at the vent field scale
Theme 3: Biology of hydrothermal communities at the vent field scale
Theme 4: Supporting studies that involve explanation of the occurrence of hydrothermal venting, the mantle's structure and composition, the detailed setting of hydrothermal vent sites, data base management, and model testing.

The project involved seven cruises, that have supported the following study-areas:

- The physical, geochemical and biological dispersion of the neutrally-buoyant hydrothermal plume at a segmental scale;
- High- and low-temperature physical and chemical fluxes, and the internal structure of hydrothermal system at the vent field scale;
- The influence of depth through chemical, physical, and biological processes on hydrothermal vent systems, in the following active segments: a). *AMAR* segment – hydrothermal site Rainbow (2300 m, deep target), b). *FAMOUS* segment (2250-2600 m, deep target), c). *Lucky Strike* vent field (1700 m, shallow target), d). *Menez Gwen* vent field (800 m, shallow target).

Methodology and Achievements: Hydrothermal activity was investigated along three different sections of the slow-spreading Mid-Atlantic Ridge. At the scale of the individual study areas, there has been a difference of up to one order of magnitude from the model developed.. Finally, the model developed was partially confirmed by some recent work on the SW Indian Ridge. Methodology and results concern the following (according to themes):

Theme 1: This study was a multi-disciplinary investigation of the Rainbow hydrothermal plume (German et al. 1998 & 1999). The dispersing plume was traced and sampled for a distance of >50 km downstream. *In situ* sensors coupled with shipboard and shore-based analyses were used, as well as *BRIDGET*, a deep-towed hydrothermal plume instrument. Combined short-term and long-term physical oceanographic observations (extensive set of CTD, LADCP, nephelometry profiles, and long-term current meter moorings, respectively) have showed that *the plume is strongly directed to the north along the rift valley wall directly above the vent-site, and then east across a shelf into the adjacent segment.*

The neutrally buoyant plume is dominated by Fe oxy-hydroxides. These oxy-hydroxides are of much lower density than sulfides would be, so the flux of settling particulate material is reduced, compared to other vent-sites, and the total suspended particulate load behaves "conservatively".

There is an unusually high concentration of particle-associated microbial material within the dispersing plume. Although this material is dominated by *Crenarchaeota*, the *Euryarchaeota* (which include halogens and methanogens) are remarkably more abundant than is typical in this chemically-enriched deep-sea environment. Despite the high concentrations of dissolved CH_4 and microbiological activity within the Rainbow hydrothermal plume, there was no evidence for significant larval dispersal. Possible explanations include either a) the occurrence of aggressive predation of such larvae in the high biomass waters overlaying the vent-site or b) discontinuous reproduction of organisms at the vent-site, perhaps responding to seasonal inputs of organic carbon from the overlying water column (see Theme 3, below).

Theme 2: The study was based on results from the FLORES cruise, the first submersible investigation of the Rainbow hydrothermal field and the continuation of studies on the Lucky Strike and the Menez Gwen vent fields. Results have focused on the study of geological setting of hydrothermal fields, studies of plume and diffuse flows, hot fluid chemical composition on the seafloor, mineralogical and chemical compositions of sulfide deposits, Pb and Sr isotopic composition of fluids and sulfides, and study of helium isotopes in the hydrothermal fluids. The vent fluids in the Rainbow hydrothermal field, which is a high-temperature site that includes ultramafic rocks, display extremely high dissolved H_2 and CH_4 concentrations, high Fe concentrations, and high Fe/H_2S ratios

Four types of hydrothermal systems have been distinguished: 1. *Menez Gwen*, characterised by focused discharge, enhanced phase separation, volcanic control, and immature deposit, 2. *Lucky Strike*, characterised by focused discharge, volcanic control, and mature deposit, 3. *Rainbow* field, characterised by tectonic control, ultramafic rocks, and mature deposit, 4. *Saldanha Mound* and *South Lucky Strike*, characterised by regional diffuse discharge related to ultramafic rocks.

The occurrence of active hydrothermal systems in the shallow central topographic high with a high magmatic budget and in the ends of the three investigated segments with ultramafic rocks and high methane anomalies, has been identified. The occurrence in these two distinctly different environments *considerably enlarges the areas where potential hydrothermal vents can be found on slow spreading ridges.* The FLORES results showed that shallow depth near the Azores hot spot connects with both the volcanic style of eruption and the hydrothermal activity. Concerning the volcanic eruption, there is a limit between the effusive and explosive volcanism at 900 m of water. For the hydrothermal activity, the important point is that shallow targets Lucky Strike and Menez Gwen are above the boiling point, and the deep targets Amar and Famous are under the boiling point for a typical hydrothermal fluid. One consequence is a depletion of metals in the fluids and deposits at the shallow Menez Gwen site.

The composition of hydrothermal fluids and mineral deposits, and the associated chemical flux into the ocean vary depending on the geological setting and the underlying rock composition. Hot fluid chemistry is very much affected by *serpentinisation*, which generates a high flux of H_2 and CH_4 along the axis of the MAR. In these environments, deposits are enriched in Cu, Zn, Co, and Ni.

Theme 3: The study has concentrated on the communities that live on the periphery of active vents on three sites of the ATJ area at decreasing depths, so as to find the influence of pressure on the structure, the composition, and the functioning of the system. The theme has particularly addressed: biogeography, microdistribution of organisms, nutritional transfers and the food web, physiological adaptations of marine habitats, reproduction and dispersal of marine habitats.
Rainbow, Lucky Strike, and Menez Gwen were explored and described (Desbruyères et al. submitted). Populations in the two shallower ATJ fields differ from those in other MAR sites, *Bathymodiolus azoricus* being dominant. Composition and structure of communities varied with the depth gradient. Caridean shrimps swarms dominate the deepest site; mussel beds are found at the periphery of sites. Mussel beds are more noticeable in the two shallower sites, and cover the active edifices (structures). The major ecological structuring factor between the three areas is the mineral particle flux. As the ridge gets shallower, non-vent carnivorous animals occupy the vent area feeding on the vent communities. Phase separation processes occurring at the shallowest vents are a major environmental factor, which can explain the basic differences between deep-sea and shallow vents where no specialised fauna are found. Reproduction and dispersal studies suggest discontinuity in reproduction and recruitment likely driven by POM (particulate organic matter) fluxes of photosynthetic origin. The study of the food-web using natural isotope ratios, shows an important connection of chemoautotrophic and photoautotrophic based ecosystems in the ATJ area, which cannot be considered as independent systems.
A deep-sea versatile in situ auto-analyser, ALCHIMIST (AnaLyser CHIMique In SiTu), was adapted and operated by a deep sea submersible. It is based on Flow Injection Analysis and colorimetric detection. It provides real time simultaneous in situ determination of nitrite + nitrate and total sulfide concentrations related to a precise positioning of the sample inlet. The in situ analysis was performed at 1700m depth, over hydrothermal vent biological communities. Further work can concentrate on the extension of the range of parameters that can be analysed in situ.
Chemical differences associated with ultramafic rocks in the hydrothermal sites did not appear to produce major faunal modifications. There is likely to be only one biogeographical province in the hydrothermal vent sites of the MAR, between 15°40' and 38°N. Concerning the homologous habitats, nutrient (H_2S and CH_4) concentrations, metallic ion concentrations, and temperatures hardly varied from one field to another, probably due to the high dilution of the fluids at the organism level.

Theme 4: Results have concentrated on the following:

- The *mantle structure studies* have been achieved after sampling across the MAR close to the Azores, but also elsewhere, and by studying the data collected during a cruise. A large asymmetry was confirmed in the upper mantle structure of the Azores and this is the biggest influence of the hotspot on the MAR. To the north, the plate boundary has proved to be regionally orthogonal to the spreading direction, while to the south it is regionally highly oblique (sloping?). So *non-transform discontinuities are more frequent and better developed in the south compared to the north.* Recent trace element and isotopic data analyses have shown that the depleted mantle in the region from 31°N to 41°N is not a homogeneous reservoir.
- The study of comparison of the location of hydrothermal vents on the SW arm of the ATJ with that on the northern and eastern arms have involved independent studies of the AMORES partners away from the Azores region. These studies led to

the *production of a preliminary model so as to predict the location of hydrothermal vent sites*. Study of the occurrence of hydrothermal venting on the MAR north of the ATJ has been impossible, but combination of knowledge of venting south of the Azores with that from other regions of the Atlantic has led to the following conclusions:

1. *At slow spreading ridges a strong heat supply alone is not enough to induce hydrothermal venting*
2. *Venting is not a simple linear function of spreading rate*
3. *The presence of extensive faulting associated with frequent and well-developed non-transform offsets plays an important role in the control of seafloor hydrothermal* activity.

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Title: **BENGAL**

High resolution temporal and spatial study of the **BEN**thic biology and **G**eochemistry of a north-eastern **A**tlantic abyssal **L**ocality

Contract No: **MAS3-CT95-0018**

Sub-programme area: Extreme Marine Environments – ***The deep sea floor in the North Atlantic and the Mediterranean***

Duration of the project: February 96' – January 99'

Background: The site studied was on the Porcupine Abyssal Plain, centered on 48° 50'N: 16°30'W, at a depth of about 4850m, some 270nm to thesouth-west of Ireland. This locality was also sampled and studied under MAST I and II contracts, in 1989, 1991 and 1994. Those previous studies established that there was significant variability in the sediment chemistry and the abundance, size structure, taxonomic make-up, and behavior of the benthic community at abyssal depths. Moreover, they demonstrated that abyssal benthic ecosystems in the northeast Atlantic were subjected to major seasonal and interannual variations in biogenic fluxes.

Billett et al. (1983) had revealed the deposition of phytodetrial material at the 2000 m deep Porcupine Seabight, south-west of Ireland, using photographic techniques. Subsequently, other observations proved that in the NE Atlantic mass fluxes of fresh organic matter towards the bottom also occur in regions hundreds of km off-shore (Thiel et al, 1990).

Objectives: The general objective of the BENGAL project was to identify, quantify and model the principal processes within the abyssal benthic boundary layer (BBL) which affect the permanent sedimentary record of the incoming chemical flux. The project studied how the physics, chemistry and biology of the abyssal benthic boundary layer responded to and modified the chemical input from the overlying surface layers, and how these processes might affect the palaeoceanographic record in the underlying sediment. A highly seasonal abyssal locality in the NE Atlantic, Porcupine Abyssal Plain, was studied over one complete annual cycle. The specific objectives were to:

1. Quantify and characterise the incoming vertical flux of organic and inorganic material, as well as its re-suspension in the near-bottom layers, using sediment traps, transmission-meters, and mid-water cameras
2. Measure the rate of the incorporation of the above flux into the sediment column, and the fluxes across the sediment-water interface, using *in situ* landers, sediment column chemical analysis and sediment profile imaging
3. Study the interaction between the incoming chemical input and the benthic biota, including bioturbation, using conventional sampling and analysis, and *in situ* instrumentation and experimentation
4. Use the resulting data for developing predictive models for the effect of the pulsed incoming flux on the benthic boundary layer and *vice versa.*

The above were incorporated into four work-packages (WP), including 90 Tasks:

- WP1 investigated the primary flux of particulate material to the seafloor, as well as the long-term sedimentary record at the BENGAL site
- WP2 studied the interactions between the particulate flux and the activity of the benthic community
- WP3 investigated the composition and activities of all faunal-size classes in the benthic boundary layer food-web (including microbiota, protozoan and metazoan meiofauna, macrofauna, megafauna, fish and near-bottom zooplankton, micronekton, and scavengers). It also studied the trophic relationships between the various elements of the benthic community
- WP4 aimed at integrating the resulting data from the other work-packages, through modeling and data management.

Methodology and Achievements: BENGAL addressed the following specific topics, according to the several work-packages:

WP1: One study of this work-package was concentrated on the monitoring of the quantitative and qualitative temporal and spatial variations in particle flux over a full seasonal cycle. Strong seasonal particle fluxes occurred during the summer months at the BENGAL site, as measured by sediment traps at 1000m, 3000m, and 4750m (100m above bottom). Large changes in dry mass flux were measured, particularly at 1000m. The particle flux during the summer contained considerable labile (unstable, but nutritious) organic compounds, such as sterols, fatty acids, proteins, and DNA. Radionuclide data processing indicated that, for 1997, most of the flux was vertical than having arisen from a lateral advection. Resulting data from BENGAL sediment traps, together with results from other sediment trap studies carried out in the same area since 1989, have formed a very *large and long-running data set that establishes a European long-term oceanic monitoring station.*
Another study has involved the monitoring of the hydrodynamic regime within the BBL. The response of the benthic community to the seasonal deposition of organic matter at the PAP site was examined using phytopigments as biomarkers. In 1997, surprisingly, the sediment trap flux maximum was not seen in a similar rise in phytopigments within the sediment. Time-lapse photographs of the seabed did not detect any deposition of phytodetritus either. In the past the seabed had disappeared from view under a green carpet of marine compost, but not in 1997. Long-term measurements of current speed and direction have shown that current speeds are generally low. During geochemical, radionuclide, and nephelometer studies it was proved that re-suspension occurs within 100m of seabed, but there was no proof for transport of material away from the BENGAL site. There is considerable inter-annual variation in the mass deposition of organic material. In September 1996, material was of a relatively fresh character suggesting that a major deposition event had occurred in this year During the other seasons (March 97', Jul 97', Oct 97'), such fresh material was apparently absent, at least within the seabed. Other BENGAL data suggest that the epibenthic megafauna re-worked the fresh phytodetritus so rapidly that it did not appear in the time-lapse photographs or in the sediment. The gut contents of certain megafauna were full of phytodetritus in July 1997.
Another investigation involved measuring of mass solute fluxes across the sediment/water interface in different seasons. Measurements of fluxes across the sediment/water interface were carried out using three types of lander. Higher mass solute fluxes were expected for the summer months, but, surprisingly there was evidence of higher activity in September 1996. Spatial variability in parameters such as sediment community oxygen consumption (SCOC) was much higher than temporal variability, between September 1996 and March 1998. The very low input of fresh organic matter into the sediment in 1997, must have had an effect on SCOC. In addition, the benthic silica cycle was measured at the PAP site. The downcore profiles of porewater silicic acid and biogenic silica are low. Typical silicic acid profiles increase at the sediment/water interface, showing that dissolution in 1997 mostly occurred in the sediment. This also agrees with the low amounts of organic matter incorporated into the sediment in 1997.

WP2: One study studied the temporal kinetics of organic matter (OM) and the relation of OM distribution to the microbiota and meiofauna abundance and distribution. The results gave detailed chemical data for finely sliced sediment core sections that were collected with a multiple corer. This corercauses little disturbance to the critical sediment/water interface during sampling. The analyses included sterols, fatty acids, proteins and phytopigments. The data for chlorophyll-α and its products showed that there was a weak pulse of fresh organic matter into the sediment in the summer of 1997, in comparison with the measurements for 1996 and 1998. That was confirmed by the finding, through the time-lapse camera observations, that little fresh detritus was incorporated into the sediment in 1997.

WP3: One study dealt with a quantitative analytical description of the composition and activities of all benthic faunal-size classes. The dominant lipids of seven species of abyssal holothurian (NE Atlantic Ocean) (*Oneirophanta mutabilis*, *Pseudostichopus villosus*, *Psychropotes longicauda*, *Deima validum*, *Paroriza prouhoi*, *Amperima rosea*, and *Molpadia blakei*) have been examined during this study, concerning their composition and metabolism. Fatty acid compositions are qualitatively similar to those of shallow water holothurians, but relatively higher amounts of unsaturated compounds in the deep-sea animals are found, owing to the adaptation of the latter to maintain membrane fluidity at high pressure and low temperature. Sterol distributions of abyssal holothurians were complex, with mixtures of C_{26}-C_{30} sterols being present in all animals. *Amperima rosea* is the only species having cholest-7-enol (the dominant product of *de novo* biosynthesis in shallow water animals) as a major component. It also, alone, appears to assimilate 4α-methyl-sterols directly, and contains high amounts of steryl-sulphates. The rest of the animals do not appear to biosynthesise their sterols *de novo*. Certainly, inter-species differences in the free sterol distributions reflect their different feeding strategies. Amperima rosea increased in abundance by two orders of magnitude during the BENGAL period, compared with sampling before BENGAL. Gut content analyses showed it fed preferentially on phytodetritus. The high abundance and feeding strategy could be one reason why the high organic matter flux recorded by the sediment traps was not seen in the time-lapse photographs, or in changes in sediment chemistry or SCOC.
Another study examined the relation the activity of benthic fauna to the sedimentary record, and assessment of burial dynamics. Studies of the feeding activities of the benthic fauna, together with the organic analyses, showed that only the most recalcitrant organic compounds are buried deep in the sediment. Spatial variability of organic and inorganic carbon recycling rates in PAP sediments was larger than temporal variation (seasonal and inter-annual), during the period 1996-1998. Dissolved organic carbon (DOC) fluxes were comparable to ΣCO_2 fluxes during all BENGAL cruises, implying that organic carbon recycling rates are underestimated if only inorganic carbon and/or oxygen fluxes are measured. Finally, on an annual basis 98% of the particulate organic carbon (POC) and 53% of the particulate inorganic carbon (PIC) deposited in these sediments were recycled to the overlying water. The method used the Göteborg lander for *in situ* sampling of benthic solute fluxes and pore water solutes, in which one of the four experimental chamber modules was exchanged with a gel-peeper module for high vertical resolution (Brünnegård, 1999, in preparation). A polyacrylamide gel was found to give the best results.

WP4: A time-dependent model was developed of early diagenesis in sediments. The model can be used to calculate profiles of oxygen, nitrate and organic carbon profiles. The model was developed to simulate the deposition of phytodetritus. Another achievement is a CD-ROM product including geochemical, benthic-biological, and oceanographic data collected by the BENGAL project at the Porcupine Abyssal Plain site. This product will be published as an ISBN registered publication.

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Progress in Oceanography (in preparation) – BENGAL Special Volume:

Material supply to the abyssal seafloor in the northeast Atlantic R.Lampitt, K.Kiriakoulakis, O.Ragueneau, A. Vangriesheim & G.Wolff

Controls on the organic chemical composition of settling particles in the north-east Atlantic Ocean. K. Kiriakoulakis, E. Stutt, S. Rowland, A. Vangriesheim, R. Lampitt & G. Wolff.

Fluxes of labile organic matter in the NE Atlantic.

M. Fabiano, M. Armeni, R. Danovaro, A. Dell'Anno, A. Pusceddu, & G. Wolff.

Microbial assemblages associated to sinking particles in the Porcupine Abyssal Plain (NE Atlantic). S. Vanucci, R. Danovaro, A. Dell'Anno, M. Fabiano, R. Lampitt & A. Pusceddu.

Aspects of near bottom dynamics and particle fluxes on the PAP site. A. Vangriesheim, B. Springer & R. Witbaard.

Annual and interannual variability of sedimentary recycling in the North Atlantic Ocean (BENGAL site) studied with a non-steady-state model C. Rabouille, R. Witbaard & G. Duineveld.

A lander adapted gel peeper module for the in-situ extraction of sediment pore waters at high vertical resolution using diffusive equilibration. J. Brunnegard, H. Stahl, A. Tengberg, P. Hall, A. Vershinin, S. Hulth & C. Rabouille.

The benthic silica cycle in the North-East Atlantic O. Ragueneau, M. Gallinari, H. Stahl, S. Grandel, A. Tengberg, D. Rickert, R. Witbaard, P. Hall & R. Lampitt.

Imbalance in the carbonate budget of surficial sediments in the North Atlantic Ocean: variations over the last millennium. C. Rabouille, H. Stahl, F. Bassinot, A. Tengberg, J. Brunnegard, P. Hall, K. Kiriakoulakis, J-L. Reyss, L. Dezileau, P. Crassous, P. Roos & R. Lampitt

Biogeochemical processes at the sediment-water interface in a North Eastern Abyssal Locality (BENGAL – Area). S. Varnavas & D. Panagiotaras.

Bacterial Abundance and Activity in deep sea sediments from the Eastern North Atlantic. D. Eardly, M. Carton, J. Gallagher & J. Patching.

Stainforthia fusiformis (Williamson) (Protista, Foraminiferida) at the Porcupine Abyssal Plain:a remarkable eurybathyal opportunist. A. Gooday & E. Alve.

Evidence for episodic recruitment in a small opheliid polychaete species from the abyssal NE Atlantic A. Vanreusel, N. Cosson-Sarradin, A. Gooday, G. Paterson, J. Galeron, M. Sibuet & M Vincx

Are temporal patterns among meiofaunal and macrofaunal taxa (quantitative distribution) at an abyssal NE Atlantic site influenced by sediment lipids chemistry ? J. Galeron, J. Sibuet, M. Vanreusel, A. Mackenzie, K. Gooday, A.J. & Wolff, G.

Impacts of trophic disturbance on benthic fauna at the abyssal NE Atlantic sites (BENGAL and EUMELI): a comparative experimental approach. N. Cosson-Sarradin, M. Sibuet, D. Desbruyères, A. Khripounoff & P. Crassous.

Temporal and spatial variability in deep-sea megafauna. D. Billett, B. Bett, A. Rice, M. Thurston, M. Sibuet, J. Galeron & G. Wolff.

Lipids in selected abyssal benthopelagic animals: links to the epipelagic? S. Buhring & B. Christiansen.

Temporal variability of megafauna from time lapse photography. B. Bett & B. Wigham.

Food web structure of the benthic community at Porcupine Abyssal Plain (NE Atlantic): a stable isotope analysis. K. Iken, T. Brey, U. Wand & P. Junghans.

What controls the appearance of phytodetrial layers on the abyssal seabed? R.Lampitt, B.Bett & A.Vangrieshiem.

Steroid supplies may limit the distribution of large benthic organisms in the deep-sea. M. Ginger, K. Mackenzie, K. Kiriakoulakis, D. Boardman, D. Billett & G. Wolff.

Response of Oneirophanta mutabilis (Holothuroidea) to the seasonal deposition of phytopigments at the Porcupine Abyssal Plain in the NE Atlantic. R. Witbaard, G. Duineveld, A. Kok, J. van der Weele & E. Berghuis.

Sediment distribution, enzyme profiles and bacterial activities in the guts of Oneirophanta mutabilis, Psychropotes longicauda and Pseudostichopus sp. - What do they tell us about digestive strategies of abyssal holothurians? D. Roberts, H. Moore, J. Berges, J. Patching, M. Carton & D. Eardley.

Simulation of the impact of a temporal detrital flux on the entire sediment community of an abyssal NE Atlantic site M. Mahaut, D. Billett, J. Galéron, P. Lamont, J. Patching, M. Sibuet & A. Vanreusel.

Title: **ESOP-2**

European **S**ubpolar **O**cean **P**rogramme Phase **2**: The Thermohaline Circulation in the Greenland Sea

Contract No: **MAS3-CT95-0015**

Sub-programme area: Extreme Marine Environments – ***The ice-covered seas in the northern hemisphere***

Duration of the project: January 96' – February 99'

Background: Nowadays, there is a considerable need for better understanding of the operation of the oceanic circulation of the high latitude regions. These areas are key areas for the oceanic carbon sink and the transfer of heat from low to high latitudes. They also determine the state of the deep sea and the flushing of the world ocean basins. The ESOP-2 project has been a continuation of the *ESOP-1* (MAS2-CT93-0057, Jul 93'- Dec 96'), which in turn was the continuation of the *Greenland Sea Project*. ESOP-1 has made basin-wide studies, so as to determine the large scale role of the ice cover, and meso-scale studies (in the region of the Odden ice tongue in the mid-latitude Greenland Sea), so as to determine the mechanisms by which sea ice is involved in deep convection in winter, and to estimate CO_2 uptake through cooling, convection and biological fixation.
Results from the above projects on the large scale, showed that most of the sea ice in the Greenland Sea enters from the Arctic Basin via Farm Strait, and contributes a fresh water flux, at a range of latitudes, to the surface waters. It also affects ocean-atmosphere energy exchanges. Some sea ice also forms in winter within the Greenland Sea, and the salt flux associated with rapid ice growth is thought to be a critical factor in the onset of deep convection. Deep convection is a vitally important process from a climatic point of view since it leads to carbon dioxide transport into the deep ocean, and to renewal of the deep waters. The region where this interaction occurs has been identified as the Odden ice tongue in the mid-latitude Greenland Sea. In addition, investigations during the Greenland Sea project and ESOP-1 indicated that the initial convection is haline and caused by brine release, but it almost always results in the melting and/or removal of the ice-cover; the final stage of the convection is likely to be thermal.

Objectives: The overall objective of the project is to understand the *thermohaline circulation in the Greenland Sea*, its sensitivity and impact on global ocean circulation, using experience gained from ESOP-1 project. In particular, ESOP-2 used intentional release of an anthropogenic tracer (SF_6), isobaric floats, the observation of standard hydrographic parameters and transient tracers partly from a permanently moored and internally recording CTD, a complete coverage of the carbon cycle, remotely sensed and direct measurements of sea ice fluxes, and an integrated small, meso and large scale modeling. Finally, the combined field and modeling techniques aimed at the understanding of the role of the Greenland Sea in the "Global Conveyer Belt", and to make realistic predictions of climate change.
The specific objectives are. a. to understand the oceanic thermohaline circulation on meso and large scales, and its dependence on surface fluxes of heat, fresh water and momentum, b. to study fresh water fluxes into and out of the central Greenland Sea region, c. to evaluate the role of convection areas in ocean/atmosphere gas exchange, and investigate the role of thermohaline circulation in CO_2 transport, d. to use observations so as to improve and calibrate coupled atmosphere/ocean models.
The project has been divided into four workpackages: WP1 involved the tracer experiment and ocean physics, WP2 the ice-ocean interaction, WP3 was devoted to carbon cycle, and WP4 to modeling.

Methodology and Achievements: ESOP-2 has resulted in a number of findings, the most important of which the *evidence for climate processes* and the *understanding of circulation of the Greenland Gyre*. At least one unknown mechanism has been detected in addition to deep-water formation from processes earlier proposed. During five cruises, the occurrence of the tracer in the bottom water was studied. In the winter, deep-water forming processes transported water masses labelled with the tracer from 300m to more than 3km depth, causing storms on the seabed. In addition to the new mechanism of deep-water formation (large-scale movement of water), several local chimney effects have been observed. They are local events of water mixing (thin currents), which take water from the surface straight down to the bottom. One chimney, detected in May 1997, takes surface water down to a depth of 2km. Concerning the circulation of the Greenland Sea Gyre, it was found that the North Atlantic Current transports Atlantic water into the West Spitsbergen Current, further north. Near Fram Strait, it splits into three major branches. The Return Atlantic Water, the western one of the three, forms the eastern side of the East Greenland Current (EGC). Polar Surface Water leaves the Arctic Ocean through Fram Strait, and flows with the EGC along the western periphery of the Greenland Basin. Finally, at about 73° N, the Jan Mayen Current splits eastward from the EGC, carrying both Return Atlantic Water and Polar Surface Water. More specific results of ESOP-2 concentrate on the following:

Long term trends and interannual variability: The data analysed in this project are for a circular area from 73.5° to 76.5° N and 9° W to 3° E. This area is sub-divided into smaller circles and rings from the centre of Greenland Sea, each one analysed separately. The central part of the analysed area was examined for temperature and salinity evolution, for the period 1986-1998. Concerning temperature, in the vertical, two regimes were distinguished. Below about 2000m depth, the deep water indicated a general warming which was constant over the period of observation. The average increase was 0.13° C. The layer above 2000m was also under warming, though frequently interrupted by convective events that led to a cooling of the water column. The deepest of those events occurred in the winters of 1987/88 and 1988/89, when mixing was observed to 1950m.
As for salinity evolution, measurements during the late 1980s and during the ESOP-1 and ESOP-2 periods showed that the top 300m of the water column undergo a strong seasonal variability. Overall, there is a deepening of this low salinity layer, from about 150m in the late 1980s to more than 350m at the end of the period of observation. The water column can be divided into three basic layers, which display a different temporal behavior. The top 250m undergo strong seasonal variability, and heating during the summer reaches this depth. Vertical exchanges and complete mixing occur in this top layer almost every year. The layer underneath was sporadically affected by intermediate depth convection during the winter in 1993, 1994, 1996 and 1997. Below 2000m depth, there was no short-term variability, but rather a smooth sinking of the isotherms after 1989. Temperature increase in this deepest part of the water column has been almost constant over time, and was not affected by the smaller convective events of 93/94 and 96/97. The upper boundary of this layer coincides approximately with the depth for which the Greenland Sea Gyre is laterally separated from the adjacent basins.

Tracer release and spreading: The tracer release experiment has been the most important result of ESOP-2, an innovative technique (one of the three experiments of this kind, executed in the open ocean) to measure general circulation of the ocean, and to validate ocean modeling in recent years. The tracer, sulfide hexafluoride (SF_6), is a non-toxic, very inert anthropogenic compound, used in industrial applications since the beginning of the century. It is not abundant in the environment, and destroyed by UV radiation in the upper atmosphere. It is considered as a "marine tracer" because it can be reliably, quickly, and relatively cheaply measured in sea water, with a detection limit of $< 5\times10^{-17}$ mol / kg. The experiment started in August 1996, with the release of 320kg of SF_6 in the centre of Greenland Sea Gyre, on an isopycnal surface situated at about 300m depth. The tracer was released in streaks, in a rectangle.

The mean vertical profiles in and around the gyre were obtained, as well as the horizontal spread of the tracer, so as to understand vertical mixing processes and estimate large- scale circulation in the Arctic, Nordic Seas, and the northernmost North Atlantic, respectively. Concerning the former, the rates for turbulent mixing are about 100 times higher than those found in the thermocline of the sub-tropical Atlantic. Diapycnal mixing in the Greenland Sea is clearly very rapid compared to typical open ocean values. The amount of water involved in convection, was more precisely defined as smaller for 1997 than that estimated so far, despite the fact of the convective event. That was due to homogenisation of the water column down to the depth of convection. Results for the horizontal spread of the tracer, showed that transmission of the tracer out of the Greenland Sea Gyre has been slow. 25 months after the release, about 1% SF_6 had reached Fram Strait and was heading north into the Arctic Ocean. Several percent was found in the lower East Greenland Current as far south as the sill of Denmark Strait, which shows considerable though not very large exchange between the EGC and Greenland Sea. About 6% was found in the Norwegian Sea. Overall, about 70% of the tracer remained in the Greenland Sea domain.

Mesoscale circulation: During ESOP-2, a large-scale Lagrangian float experiment has been run. Its most important result was that after having been released for periods of 300 days near the centre of the Greenland Gyre, all the floats from the first releases came inside a circle within a 100 nautical miles radius, centered over the deepest part of the Greenland Basin. This indicated that circulation inside the gyre remains quite tight (fixed) for the whole year, without any breaking up during spring or summer time. The above result was confirmed during the second year floats experiment, with 10 out of 12 floats remaining in the Greenland Gyre after one year. This also corresponds to the fact that most of the tracer remained inside the gyre one year later.

Another result came from calculation of float trajectories, and concerns the documentation of an extremely active meso-scale eddy field embedded in a deep mixed patch resulting from deep convection located above the deepest part (> 3500m) of the Greenland Basin. It was mainly in and around this mixed patch that many floats were trapped for about one year. The final result arising from thefloats experiment is the documentation of long-lived anticyclonic eddies (>1 year). They consist of a central core set in a solid-body rotation for approximately two-days period, limited to a radius of 5km from the eddy center of rotation and characterized by a strong negative relative vorticity (vortical movement).

Sea ice convection: The first systematic study on ice kinematics in the Greenland Sea region was done during the ESOP-1 project and covered the years 1993 and 1994; a high variability of the sea ice flux through Fram Strait was measured. Total mean ice transport for these two years was estimated at 1700km^3/year. There is a discrepancy between this estimation and other estimates based on numerical modeling, and it is due to the uncertainties in knowledge of ice thickness distribution. A dynamic-thermodynamic ice model was used to expand the time series of sea ice flux further to the past. Results showed a high interannual and seasonal variability. The average seasonal cycle indicated that the highest fluxes are reached in the winter months with maximum flow in December, and minimum in the summer months (August).

The relation of sea ice dynamics and the salinity of the underlying ocean was also investigated. Ice dynamics were studied by releasing ice drifters, brine drainage rates by direct sampling of frazil and pancake ice, and ice type distribution by shipborne validation of satellite remote sensing. In addition, a salt flux model was generated, so as to estimate the resultant salt fluxes from the above observations. Salt flux was measured for the winter 96'-97'; the flux was strongly negative in the region that faces the southern edge of Odden, and strongly positive along the inner edge of Odden and in Nordbukta. After a number of years without an Odden sea ice feature in the Greenland Sea, it can be estimated that ice transport from the Arctic Ocean through Fram Strait is negatively correlated with the size and duration of the Odden sea ice feature.

Carbon cycle and carbon fluxes: During the project, it has been shown that the Greenland Sea is a year round sink of CO_2, but with strong interannual and seasonal contrasts. The uptake of atmospheric CO_2 is positive during all year, in the order of $69\pm16gC/m^2y$ or $20\pm4\times10^{12}gC/y$, if integrated over the ice-free part of the Greenland Sea. Anthropogenic carbon is removed by deep-water production (below 1500m) in a rate 10 times less than the air/sea flux. As 2/3 of the production of intermediate waters (200-1500m) probably comes from convection in the Greenland and Iceland Sea, anthropogenic carbon removal by deep-water production increases by a factor of 10, therefore is equal to the atmospheric uptake of carbon.
The uptake of carbon in the Greenland Sea is controlled equally by biological primary production and heat loss. The combined effect of the uptake by these processes is that surface water leaving Greenland Sea is of higher concentration of total dissolved inorganic carbon than the inflowing, warmer surface water. A significant fraction of the outflowing surface water flows to the south into the Iceland Sea, where it may mix down into deep water that flows into the deep North Atlantic.

Dissemination of results: Two ESOP-2 CD-ROMs are available: a. one prepared at ICES, containing cruise specific data, and b. one produced at the Danish Meteorological Institute, containing model outputs from the ESOP-2 models.

Major Publications:

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Vinje, T., Nordlund, N., Kvambekk, A., 1998. Monitoring ice thickness in Fram Strait. Journal of Geophys. Res. Vol 103, 10,437-10,449.

Title: **AG-HY-FL**
Hydrothermal fluxes and biological production in the Aegean

Contract No: **MAS3-CT95-0021**

Sub-programme area: Marine Systems Research - ***Sedimentary processes in the deep sea, on the continental slope and on the shelf edge***

Duration of the project: February 96' - January 99'

Background: Major hydrothermal systems have been found along the Hellenic Volcanic Arc at Methana, Sousaki, Milos, Santorini, Kos, Yaki and Nisiros. Geothermal areas have also been found in many coastal regions and islands around the edge of the Aegean Sea, including the regions around Antemus, Volvi-Langada, Strymon, Nestos-Xanthi and Alexandroupoli basins, in the north, Lesbos in the east, and the Gulf of Maliachos and Sperchios basins in the west. The areas studied in this project were mainly Milos, but also Methana, Santorini, Kos, and Lesbos, which are shown in *Figure 1*. Previous studies in those areas have recently been reviewed by Dando et al. (1999, in press).
The project examined the biogeochemical processes and fluxes in relation to hydrothermalism in different time and space scales, in the back arc area of the Aegean Sea, the Sea of Crete. Hydrothermal areas around Milos were examined as part of previous EC-funded, MAST-1 and MAST-2 projects that looked at areas of high sulfide and methane concentrations and at interfaces between oxic and anoxic conditions. These studies showed that 35 km^2 of seabed around Milos were hydrothermally active. Areas of seabed were influenced by hydrothermal brine with a composition similar to that in the reservoir 1 km below. Free CO_2 flux was estimated to be 1-4% of the global mid-ocean ridge flux. Layers of algo-minero-bacterial mats, containing sulphur-oxidising bacteria, up to 100m across, overlay the seeps. It was also found that bacterial H_2S oxidation lowered the pH to 2 and released high concentrations of phosphate. Additional phosphate, ammonia, silicate, and other nutrients were released by the venting of hydrothermal fluids and gases. Finally, episodic events were verified, including earthquakes, white smoker activity, and release of brines, resulting in a bottom-held (hugging) submarine "fog".

Objectives: The overall objective was the assessment of the effect of hydrothermalism on the chemistry, production and biodiversity of the oligotrophic Sea of Crete. More specifically, the project involved four objectives:

1. Determination of the extent of submarine venting, measurement of bacterial production and export, quantification of geochemical fluxes and their modification by bacterial growth. Finally, establishment of the periodicity of venting, the role of episodic events due to storms, and seismicity.
2. Estimation of the effects of naturally occurring excess nutrients and CO_2 on the photosynthetic rate of phytoplankton, benthic diatoms and cyanobacteria, and on chemosynthesis by sulphur-oxidising bacteria.
3. Comparison of the diversity of bacteria and epifauna in venting and non-venting areas, estimation of the importance of chemosynthesis in comparison with photosynthesis in the food-web.
4. Isolation, identification, and characterization of bacteria from vent sites (hyperthomophiles and halophiles) with bio-product potential.

Methodology and Achievements: The major achievements of the project are the following, according to the 8 main tasks into which the project was divided:

Task 1 has involved fieldwork organisation and logistics. There were four major field trips to the submarine hydrothermal field offshore Milos, on June 96', September 96', June 97', and June 98'. There was also a field trip to Kos, in September 97'. Additionally, several cruises have taken place. During the *Meteor* cruise of December 97' to Milos, Santorini, and the western part of Kos, important achievements were: a. two hot GKG cores obtained from 110m depth, one with gas bubbling that lasted for

24h after retrieval, b. a hot multicore from Santorini Caldera and the discovery of high methane concentrations outside the Caldera, c. the discovery of a new hydrothermal field south of Kos and the detailed mapping of Milos vents and hydrothermal plumes.

Task 2 involved the study of seismic records (microseismicity) and of the relation of the records with venting periodicity. A seismic network of five three-component, triggering mode digital stations, was installed on Milos Island in the summer 96', and recorded 400 local micro-earthquakes and 500 signals. The analysis indicated low seismicity, probably associated with hydrothermal activity. The sources producing the recorded micro-earthquakes were typical sources of volcanic activity, most probably related to the existing volcanoes of Fyriplaka and Trachilas. The longer period signals may be related to venting procedures, and the micro-earthquake trains may originate from very small sources which act as microfractures in a self-organised critical system. This process possibly connects to changes in pore pressure. A data base of seismic records has been established.

Task 3 examined the influence of water pressure changes on venting activities, the measurement of water currents and levels in the area near the vents, and aimed at explaining, by a mathematical model, the water dynamics in Palaeochori Bay, Milos. Gaso-hydothermal vent positions were located by echo-sounders and accurately mapped using DGPS, allowing detailed vent maps to be produced for the Milos hydrothermal fields (*Figure*). A schematic geological section through Palaechori Bay, from the shore southwards, is presented in *Figure*. The basement consists of a fractured metamorphic rock with block movements along the faults. It is overlain by marine and volcaniclastic sediments of various thickness, consisting predominantly of sand with variable mud and gravel components. Permeability is locally highly variable; it ranges from the nearly impermeable, due to the formation of hydrothermal precipitates, to the highly permeable. Three fluid sources could be distinguished by their acidity, chlorinity and enrichment of solute contents, compared to ambient sea water. a. a magmatic source indicated by the presence of a mantle-derived He component, b. fluids showing seawater-rock interactions in the deeper crust, c. fluids displaying fluid-sediment-bacterial interactions in the upper few dm of the sediment.

Task 4 had the objective to determine chemical and bacterial fluxes from hydrothermal fields into the Aegean Sea. Around Milos Island, diffuse but widespread hydrothermal venting in shallow water (intertidal-150m) occurs. Despite its diffuse nature, hydrothermal activity leads to slight but measurable changes in the water column. Vent water composition varied a lot, due to mixing of hydrothermal reservoir fluids, vapor condensate and seawater, altered by interactions of fluid-sediment-bacteria in different proportions, in the gasohydrothermal vents. Compositions ranged from nearly seawater with only slightly reduced pH, to higher or lower salinity fluids with a pH as low as 3 and with large enrichments in heavy and trace metals. Phase separation was a common feature at these shallow vents. The dry gas phase was mainly CO_2, with significant amounts of H_2S, CH_4 and H_2. *In-situ* measurements of temperature, pH, red-ox potential, H_2S and O_2 confirmed that the shallow water vent sites were extreme environments with low pH, high sulfide content, and high temperature. Repeated measurements during three fieldtrips to the same sites have demonstrated the stability of some of the vents over a two years period.
Gas composition, as well as flow rate, varied both between sites and between vents. The collected gases contained up to 95% CO_2, 9% H_2, 3% H_2S, and 1.8% CH_4. Calculations of the number of vents per area, the average fluids flow rate, and their free and dissolved gas composition can lead to an estimation of the global

importance of the Aegean vents in geochemical budgets. Results of the project show that hydrothermal gas fluxes coming from the Aegean vents play a very important role, considering that a vent may consist of thousands of single outlets clustered together and that there are tens of vent fields off Milos and more in the rest of the Aegean Arc.
Higher values of particulate material as well as phytoplankton and zooplankton, were found during bottom water analyses, in June 97' than in September 96'. Bottom water samples were enriched in particulate organic carbon and nitrogen, total particulates and chlorophyll southwards from the active vent areas, and these components may be exported from the Bay in the observed bottom water current. The suspended particulate material (SPM) from venting waters, collected by SCUBA divers, was analysed for Fe, Mn, Cu, Pb, Al, Ba, Sr, Ca, Si and Li. Sediment trap moorings located along a transect from the active vent zone to an area free of any major vent influence showed during a 3-month summer period that mass fluxes were on average 7 to 9 times higher at the vent site than at the other stations and had a completely different pattern over time. At the vent zone, fluxes reached a maximum of 5.9 g m^{-2} d^{-1} compared to 1.0 and 1.1 g m^{-2} d^{-1} at the other sites. Organic C and N fluxes showed similar trends with two periods of pulsed sedimentation of organic material observed only at the vent site (POC flux up to 1.4 g m-2 d-1 at the vent against 0.1 g POC m^{-2} d^{-1} at the other stations). Particles collected at all stations were largely of pelagic origin and not directly related to phytoplankton production; large brown fecal material was important at the vent site in September. The presence of hyperthermophilic Archaea and the chemical signature of the sedimenting particles suggest that the high organic fluxes at the vent area are associated to the hydrothermal activity.

Task 5 aimed at measurements of the fluid, heat, chemical and bacterial fluxes from individual hydrothermal vent sites, and the determination of their periodicity. A lander system for *in situ* long-term measuring and sampling of diffuse submarine hydrothermal vents at shallow water depths (200-300m) has been developed and tested. It consists of a long-time measuring cell – IPGVENT (Institute for Petrography and Geochemistry VENT system), a long-term sampling system LOVESA (Long-term Vent Sampler), an ultra low flow meter, an energy pack, and a funnel for collecting hydrothermal fluids. Thermo-chains were also set up with the lander, to measure the heat flux in a wider area. The lander was be used as an underwater short- or long-term measuring unit, giving data and water samples for a few days or for up to half a year. The data measured were pH, conductivity, temperature, O_2 and H_2S contents, and water samples are of 100ml volume and are tested for major and trace element analysis.

Task 6 was devoted to the study of biodiversity and with the culture of organisms with bio-product potential, by comparing the diversity of organisms at vent and non-vent sites, and explaining the differences in terms of physical and chemical environment and the food-web. The diversity of the microbial species at the vent sites studied was large, and a high percentage of new taxa were found. The high biodiversity of Bacteria, Archaea and epifaunal species surrounding the vents, can be explained by the complex conditions in the region of the vents. Some of the new taxa of microbes found are expected to be of biotechnological potential. Epifaunal diversity was unexpectedly high (over 200 species recorded at the shallower Milos vents), although no vent-specific species were found. Hydrothermalism was shown to increase species richness by creating greater spatial heterogeneity, by operating as an "intermediate disturbance" (mortality due to toxic fluids) and by inducing higher recruitment. Other effects of vent activity on epibenthic communities include the reduction of biological cover (only at a very local scale), modified trophic condition for suspension-feeders and enhanced deposition of carbonates by bioconstructional organisms. The discovery of several exotic warm water species around the vents suggests that the biota at vent sites in the Mediterranean can be used to predict changes in the ecosystem, which may occur as a result of rising sea temperatures.

Task 7 had the overall objective to determine the effects of hydrothermalism on benthic and pelagic primary production. The water column was always dominated by respiring rather than photosynthesising organisms. No significant difference was found between plankton production at venting and non-venting sites, despite a large range of inorganic carbon concentration. Small changes in ambient temperature had, on the contrary, a considerable effect on plankton respiration and a less effect on plankton photosynthesis. Photosynthetic rates in the water column did not appear to be enhanced by the venting. However, in two vent sites, high such rates were measured on bottom water samples and may be due to re-suspension of an active benthic algal mat. Much of the photosynthetic productivity, at least in the shallow water sites south of Milos, may be due to the sea-grass meadows, and carbon from this source may be a major input to the heterotrophic bacteria surrounding the vents. Particulate organic matter fluxes to the bottom were exceptionally high for short periods of 10-20 days in the vent area compared to the control area, due to high pelagic activity and the fallout of fecal faecal pellets. The sedimenting material had a vent signature (presence of thermophilic Archaea, stable isotope composition). However, the contribution of bacterial productivity at the vents to zooplankton production is currently unclear.

Task 8 involved the data management of the project. All the data coming from the different partners are collected from Consiglio Nationale delle Richerche, Instituto per lo Studio della Dinamica delle Grandi Masse Stazione Oceanografica, and are stored, creating inventories. Finally, *technology implementation plans* have been set up by GEOMAR (DE) and University of Kiel, for the exploitation of the following that resulted through the project. a. A low-velocity thermistor flow meter, b. a submarine gas flow meter, c. cultures of 53 strains of *hyper-thermophilic Archaea* isolated from the hydrothermal sites at a temperature of 90 °C.

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