

depths greater than 500m in regions of the Atlantic, Indian and Pacific oceans and some species have widespread distributions that extend into the Arctic. Their physical dominance of the macrofaunal of deep sea sediments in the north-east and north-west Atlantic, as well as the eastern, central and south-west Pacific, is reflected in the fact that they have been reported in densities of hundreds per 100m² to more than 2,000 per 100m² (Tendal & Gooday, 1981).

2.11.2 Conservation issues

The widespread distribution of xenophyophores, their synecology, and the fact that they can occur in very high densities has led to the suggestion that they are an important source of sedimentary and faunal heterogeneity and as such may contribute to maintenance of benthic diversity in the deep sea.

2.11.3 Conservation actions

Xenophyophores occur throughout the OSPAR maritime area and consequently no sites are singled out here for particular attention. If areas are found to be of special importance for this species in the future, conservation efforts may need to be focused on such locations. The more likely scenario is for xenophyophores to be one element of the benthos to be safeguarded through general conservation measures applied to the deep sea.

2.12 DEEP SEA MUD

Contribution by Maria C. Baker and Brian J. Bett. DEEPSEAS Group, George Deacon Division, Southampton Oceanography Centre (2001).

This directory covers a number of interesting and exciting deep-water habitats, biological communities and species. By contrast deep sea mud may seem a little “dull”. Plain deep sea mud is nevertheless the dominant habitat in the OSPAR maritime area; indeed it is the dominant habitat on this planet. Despite its apparently featureless nature, recent research has shown that deep sea mud supports a previously unexpected wealth of biological diversity. It is quite possible that the majority of animal species on this planet live in deep sea mud. Of the tens of millions of animal species that probably live on Earth today, it is quite possible that over 75 per cent of them will be found on the deep sea floor – although to date we are only aware of a tiny fraction of this diversity.

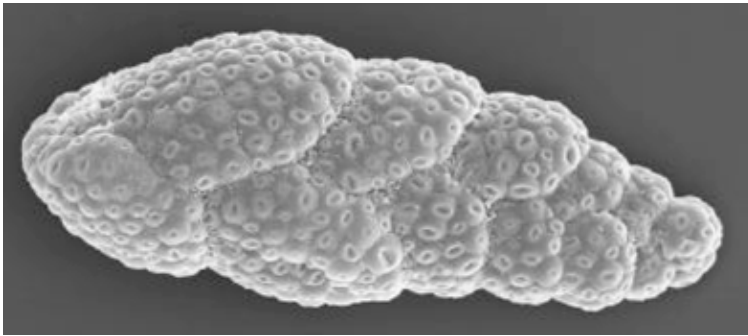
Muds and other deep sea sediments

Marine sediments are classified on the basis of the most abundant particle type found in a particular deposit. The abundance of a particle type is dependent upon: (1) the rate of its supply to the sediment, (2) the degree to which it is preserved in the sediment, and (3) the rate of sedimentation of other particles (Libes. 1992). In the deep sea, exposed hard rock is rare, being found only on steep continental slopes, seamounts and along mid-ocean ridges (Gage and Tyler, 1991). The only other substantial sources of solid substrata are: a) the polymetallic nodules or crusts that may form in some regions (for example, around the Goban spur in the north-east Atlantic, Karpoff et al., 1985), and b) glacial erratics (iceberg dropstones) that, for example, provide a significant habitat on the upper slope of the UK continental margin (Bett, 2001).

Deep sea sediments are primarily composed of clays or biogenic oozes, depending upon the productivity of overlying waters. Abyssal clay covers most of the deep-ocean floor. It

accumulates very slowly (1mm per 1,000 years), and it is mostly made up of clay-sized particles from the continents, carried by wind or currents. Biogenic oozes are derived from the remains of planktonic organisms and may be calcareous (from foraminiferans, pteropods and coccolithophores; see plate 6) or siliceous (from diatoms or radiolarians).

Plate 6: A benthic foraminiferan that uses planktonic coccoliths to construct its test (shell).



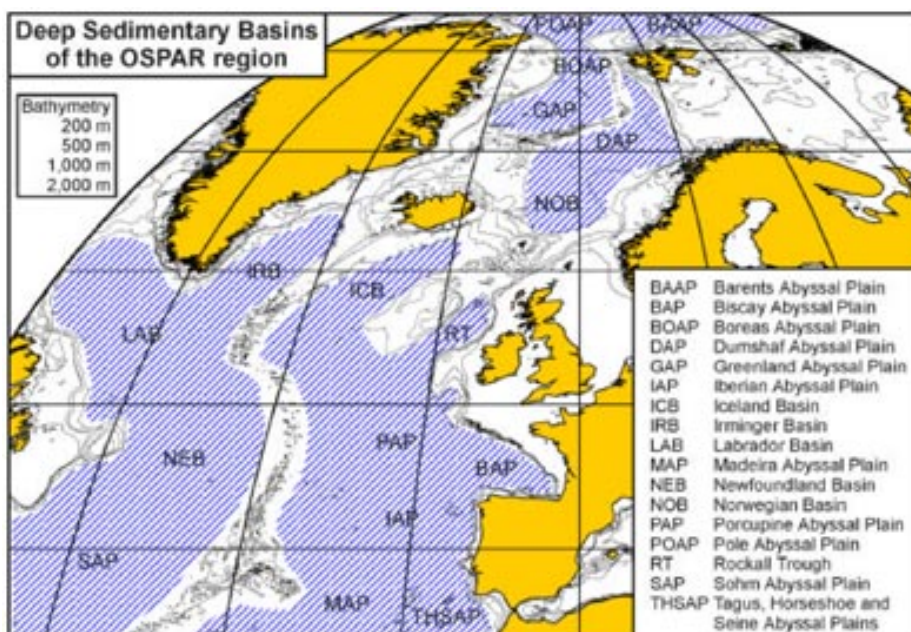
Photomicrograph courtesy of A. Hughes and A. Gooday, © SOC.

Accumulations of these oozes differ in thickness and distribution, governed mainly by primary production and water depth. Chemical, biological and physical processes in the ocean have the ability to destroy a large fraction of particles before they reach the deep sea floor. On abyssal plains the sediment blanket may be thousands of metres thick. The study of these thick layers of deep sea mud is used to answer questions about climate change, as these sedimentary layers preserve a unique record of past change (for example, Zahn, 1992, 1994; Thomas et al., 1995).

2.12.1 Occurrence in the OSPAR maritime area

A substantial part of the deep sea OSPAR maritime area is characterised by almost feature-less abyssal plain, comprising relatively flat areas that are located either side of the mid-Atlantic Ridge. Three main basins exist – the Newfoundland Basin in the north-west, the Porcupine Abyssal Plain (about 165,000 km²) in the east and the Iberian (about 107,000 km²) and Tagus abyssal plains (about 41,000 km²) in the south-east. All of these plains are >4,500m deep. Other basin and deep sea areas in the region are shown on figure 39.

Figure 39: Chart showing main sedimentary basins and deep sea areas of the OSPAR region.
(Provided by B. Bett, SOC)

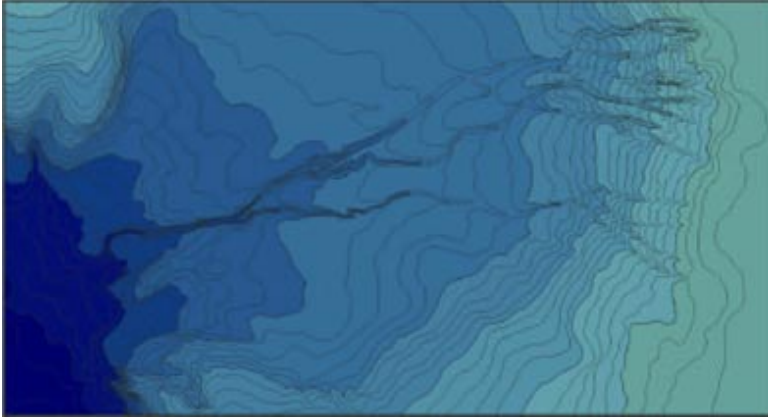


Bottom sediment accumulations vary according to the topography and the local current regime but are generally between 0.1km and 2km thick (OSPAR Commission, 2000). Pelagic ooze sediments (predominantly those rich in calcium carbonate) have been built up over millions of years, along with minor amounts of aeolian atmospheric dust and turbidity current sediments. Turbidity currents periodically transport terrigenous muds and pelagic sediments to the ocean basins. Major turbidity currents, originating from underwater landslips, may have a catastrophic and long-lasting effect on the fauna (Huggett, 1987). In addition, volcanic processes, ice rafting and bottom currents may have added to the sediments (Emery and Uchupi, 1984; Andrews, 1998). Deep, contour-following currents may produce significant local variations in sediments and consequently influence faunal distributions (Bett, 2001). In general, sediments become progressively finer with increasing depth and distance from land (Lampitt et al. 1986) except for some areas which have coarser sediments deposited via canyons onto the continental slope and rise (Mart et al. 1979). Consequently, the presence of canyons can have a significant impact on the composition of deep sea biological communities. An extensive network of submarine canyons and channels exist in the OSPAR region (see example in figure 40).

2.12.2 Deep sea mud communities

The deep sea fauna is essentially composed of animals similar to those found in coastal sediments, with many deep sea species belonging to the same families or genera as their shallow-water counterparts (Gage, 1997). The abundance of the benthic fauna generally decreases with reduced food supply and therefore decreases with increased depth. Consequently, the deep sea muds often harbour relatively low densities of fauna (Gage and Tyler, 1991).

Figure 40: Bathymetry of the Porcupine Sea Bight, showing an extensive canyon/ channel system. (Provided by B. Bett, SOC).



Megafauna

The most common surface-dwelling deep sea megafauna (larger animals) in the OSPAR region are the echinoderms, including holothuroidea (sea cucumbers, see plate 7), ophiuroidea (brittle stars), Echinoidea (sea urchins) and Asteroidea (sea stars). In the Rockall Trough, the brittle stars make up 27 per cent of the echinoderm species collected, and numerically they far outnumber (63 per cent) any other megafaunal group (Gage and Tyler, 1991).

Plate 7: Sea cucumber (Holothurian, *Psychropotes semperiana*) photographed at 4,000 m.



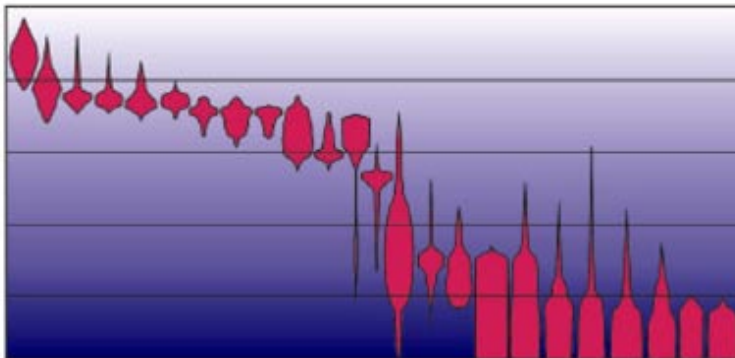
Photograph courtesy of DEEPSEAS Group, © SOC.

Sibuet (1985) found that holothurians were abundant in the Norwegian, Lofoten and Greenland Basins (depth range 2500 – 3700 m), occurring in densities of over 7,000 individuals per hectare (10,000 m²) in some areas. Studies on the Porcupine Abyssal Plain have shown that

holothurians, actinarians and, to a lesser degree, asteroids, constitute a major proportion of the invertebrate megafauna both in terms of abundance and biomass (Thurston et al., 1994). In addition to the echinoderms, various types of ‘worms’, sea spiders, amphipods and decapod crustaceans inhabit the deep sea-bed. Sessile fauna also inhabit deep sea muds, including the sponges, hydroids, sea pens, sea fans and deep sea corals (see also the chapters on corals and sponges in this directory).

Bathymetry, current velocity, sediment type and bottom water-mass distribution all seem have a significant influence on the distribution and composition of megafaunal communities (Levin and Gooday, in press). Many, if not most, megafaunal species have quite narrow bathymetric (depth) ranges and exhibit ribbon-like distributions along continental margins (Billett, 1991; see figure 41). Consequently, there is more or less continuous change in megafaunal species composition with depth, although there may be particular depth bands within which there are greater rates of change in species composition (Gage, 1986; Billett, 1991). These bands of increased change in the megafauna mark the boundaries of deep sea depth “zones” (see Carney et al., 1983). These zones may be useful in defining deep sea biogeographic boundaries for environmental / conservation purposes (see further below).

Figure 41: Schematic representation of the depth distributions of the dominant holothurian species (sea cucumbers) in the Porcupine Sea Bight, depth range shown is 0-4,850 m. (Adapted from Billett, 1991, provided by B. Bett, SOC).



Before leaving the megafauna, it is also worth noting that there may be distinct megafaunal communities in ‘high energy’ (higher current speed) sandy habitats in the deep sea, although this habitat type is currently little known in the deep sea. Bett (2001) noted the presence of a highly unusual community of sediment surface dwelling megafaunal enteropneusts on a sandy contourite sheet at about 900 m in the Faroe-Shetland channel. Other studies in this area and the adjacent Faroe Bank channel have revealed other sand, and even gravel, dominated deep sea habitats (Bett and Jacobs, 2000), including a field of barchan sand dunes at 1,200 m inhabited by numerous small anemones (Wynn et al., in press).

Macro- and meio-fauna

In terms of the smaller size fraction of animals associated with deep sea muds, the main macrofaunal groups are the polychaetes (see plate 8), ‘other worms’, amphipods, tanaids,

isopods, bivalves and gastropods. Bett (2001) found that the macrofauna of the Rockall Trough and Faroe-Shetland channel was dominated by polychaetes and amphipods.

The ecology of this region is strongly controlled by hydrography with the temperature contrast between different water masses exerting a major influence on the distribution and diversity of the macrobenthos. A time-series study of macrofauna in the Rockall Trough at depths of 2,200 and 2,900 m showed a mean standing crop of >1,700 individuals per m² (Gage, 1979). Polychaetes were the dominant taxon (59.1 per cent of individuals) followed by tanaids, bivalves, isopods, scaphopods, amphipods and nemerteans. The meiofauna of the deep sea muds in the north-east Atlantic comprise a diverse assemblage of nematodes (see figure 42), copepods, ostracods and foraminiferans (Gage and Tyler, 1991; Vincx et al., 1994). Around 50 per cent of the meiofauna in the Porcupine Sea Bight is made up of a highly diverse community of foraminiferans (Gooday, 1986).

Plate 8: Macrobenthos; the “quill worm” (Polychaete, *Hyalinoecia tubicola*)

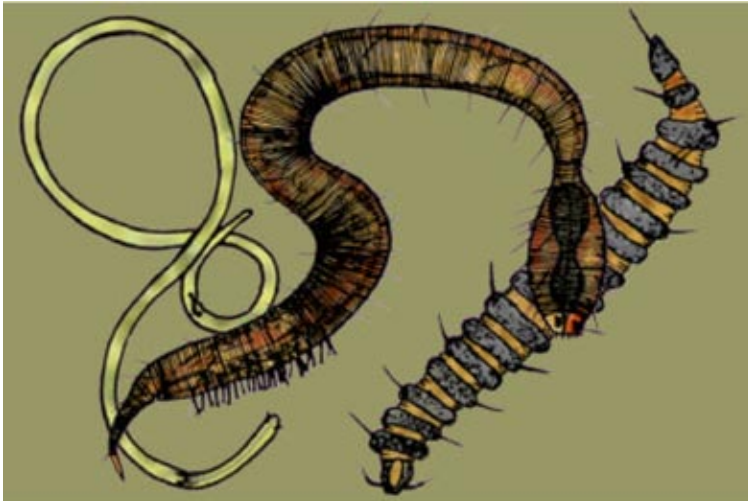


Photograph courtesy of DEEPSEAS Group, © SOC.

Despite the generally low densities of fauna associated with deep sea muds, it has been suggested that the species diversity of deep sea macrobenthos rivals that of tropical rain forests and coral reefs (Grassle et al., 1990; Grassle and Maciolek, 1992). It is estimated that there are up to 10 million species in the deep ocean (Grassle and Maciolek, 1992). Recent investigations have also indicated that the diversity of the deep sea meiobenthos (in the Rockall Trough) is also very high. In just a few small sediment cores from the deep Rockall Trough, Lamshead et al. (1995) recorded almost 100 species of free-living nematodes. Deep sea sediment dwelling nematodes may make up three quarters of all the planet’s animal species, previously estimated at about 30 million (Pearse, 1995). The high species diversity of macro- and meio-fauna inhabiting deep sea muds is thought to be maintained by biologically generated habitat heterogeneity (for example, bioturbation, see plate 9) and patchy food resources at the metre to centimetre scale (Grassle and Maciolek, 1992). Much of the deep sea-bed is covered with animal traces such as pits, burrows, mounds, tracks, faecal casts and resting traces resulting from the movement, burrowing, feeding, defecation or dwelling-construction by benthic

invertebrates and fish (Hollister et al., 1975). These traces can also provide crucial evidence of large, rare organisms living hidden below the sediment surface (Bett et al., 1995). It has also been suggested that hydrodynamic effects and variations in sediment type may play major roles in determining the local species richness of the animals inhabiting deep sea sediments (Etter and Grassle, 1992; Gage, 1997).

Figure 42: Meiobenthos; morphological variety in free-living marine nematodes
(Provided by B. Bett, SOC).



Demersal fish

Demersal fish may also be a significant component of the fauna associated with deep sea muds (see refer to section 2.10 specifically on deep sea fish). Studies of biomass in the Porcupine Sea Bight have shown that demersal fish have similar biomass values to the invertebrate fauna, and exhibit a similar decline in biomass with depth. The dominant families of demersal fish in the deep sea are the slickheads (alepocephalidae), grenadiers or rattails (macrouridae, see plate 10) and cusk eels (ophidiidae) (Merrett and Haedrich, 1977). The 505 species recorded from areas beyond the 200 m contour in the North Atlantic, represent 39 per cent of all known deep sea species (Merrett, 1994). On the Porcupine Abyssal Plain, three grenadier species and the synphobranchiid eel *Histiobranchus bathybius*, dominate the fish fauna and these are all large benthopelagic species.

Temporal variability in deep sea communities

Merrett and Haedrich (1997) suggested that in abyssal, open ocean settings in the North Atlantic, seasonal inputs of phytodetritus (the degraded remains of surface ocean plankton blooms) have a marked effect on the distribution of demersal fish species. This type of temporal variability in the deep sea is an important, though poorly known, issue for environmental protection / conservation.

Plate 9: Evidence of bioturbation on the deep sea floor



Photograph courtesy of DEEPSEAS Group, © SOC.

Plate 10: Rattail fish (*Coryphaenoides rupestris*) photographed at 1,100 m



Photograph courtesy of DEEPSEAS Group, © SOC.

A number of studies have found that the flux of organic carbon to the sea-bed is the primary control on mega-, macro- meio-faunal abundances in the deep Atlantic (see Levin and Gooday, in press). Areas of the Atlantic with the highest organic flux support the greatest infaunal densities and biomass. Patterns of species richness, dominance, taxonomic composition and abundance all seem to be influenced by the supply of organic matter to the deep sea floor (Gooday and Turley, 1990; Rice and Lamshead, 1994). Food supply to the deep sea floor has been shown to vary seasonally and inter-annually (Billett et al., 1983; Denser, 1986; Smith et al., 1994; Baldwin et al., 1998). Many studies have shown that the spring phytoplankton bloom is more intense and widespread in the North Atlantic than anywhere else in the ocean, leading to a greater degree of seasonality in surface production and to relatively predictable seasonal

inputs of phytodetritus to the deep sea-bed (Rice et al., 1994; Lampitt et al., 1995; Longhurst, 1998; Levin and Gooday, in press). This phytodetritus is composed of the remains of organisms from the upper water column and contains rich populations of bacteria (Lochte and Turley, 1988). The phytodetritus is prone to aggregation in depressions or behind mounds or obstacles on the sea floor (Thiel et al., 1990; Rice et al., 1994) and is easily re-suspended and redistributed by currents (Lampitt, 1985).

The benthic fauna of deep sea muds respond to this seasonal input of organic matter. Seasonal growth and reproduction have been noted in a number of deep sea invertebrates in the North Atlantic, including sponges, actinarians, brachiopods, protuberant bivalves, echinoids, asteroids, ophiuroids, spider crabs and hermit crabs. Evidence suggests that these characteristics may be linked to the seasonal variations in the availability of food (Gage and Tyler, 1991). In addition, dramatic changes in populations of megafauna have been observed on decal scales in the abyssal north-east Atlantic (Billett et al., in press; Bett et al., in press). For example, on the Porcupine Abyssal Plain the holothurian *Amperima rosea* exhibited a massive increase in abundance from four to 6,500 individuals per hectare between the periods 1989-1994 and 1996-1999. It is thought that these long-term changes are correlated with changes in the quantity and/or quality of phytodetrital flux to the sea floor. Knowledge of the scope for these natural seasonal and long-term changes in the fauna of deep sea areas is essential to the appropriate management of the deep sea mud habitat.

2.12.3 Conservation issues

Our knowledge of large-scale patterns of diversity in the deep sea is restricted to a few major taxa and based on very limited sampling and geographic coverage (Rex et al. 1997). The invention of the box corer enabled marine biologists to retrieve a quantitative sample of deep sea sediment and compare species number and type to other parts of the world's oceans. However, to date, only about 500 m² of a total of 270 million km² of deep ocean floor has been sampled in a quantitative manner.

Given declining natural resources in shallow waters and the increased demand for ocean products, deep sea environments are now considered more seriously for exploitation. In the past, the deep sea environment has been exposed to the disposal of industrial wastes, munitions, radioactive wastes, sewage sludges and dredged spoils, all of which were permitted to be dumped within the OSPAR region. Today, the main threats to this environment are from offshore hydrocarbon exploitation and deep sea fisheries. The offshore oil and gas industry is still in its early stages. Impacts on benthic communities from drill cuttings are largely confined to the immediate vicinity of drill sites. Localised contamination by drilling fluids has been detected in deep sea sediments to the west of Shetland (Faroe-Shetland channel), although the dominant hydrocarbon signal in the area originates from surface vessels and terrestrial sources (Bett, 2001).

The deep-water demersal trawling industry is already well developed in the OSPAR region (see Figure 43 and Plate 11). Evidence of trawling impacts has been reported in the deep-waters to the west of Scotland. These are characterised by sea-bed trawl marks and areas of disturbed sea-bed, likely a function of commercial deep-water trawling (Bett, 2000; Roberts et al., 2000). Deep-water corals located in open sediment areas (for example, the "Darwin Mounds") are already threatened by this activity (Baker et al., 2001). Widespread, unregulated exploitation

could severely impact deep sea mud communities. Around one third of the benthic species present in the deep waters of the Atlantic Ocean appear to be endemic (i.e. restricted to that environment), and the degree of endemism increases with depth (Vinogradova, 1997).

Figure 43: The physical scale of deep sea trawls. (Provided by B. Bett, SOC).

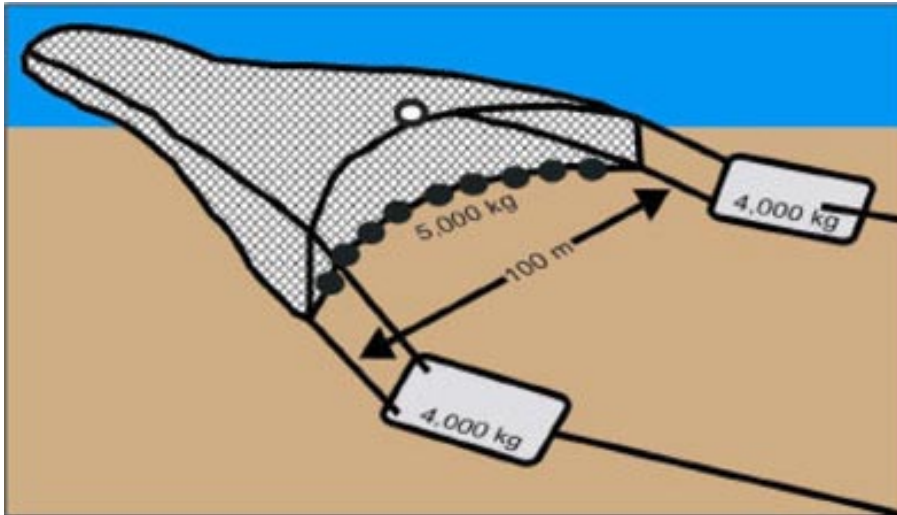


Plate 11: Greenland Halibut; a deep-water species targeted by the fishing industry in the waters west of the UK.



Photograph courtesy of DEEPSEAS Group, © SOC.

In addition to these two threats, pollution in the form of pesticides and PCBs have been found to be present in muds from remote parts of the deep ocean (Pain, 1996). Accumulations of trace metals have been detected in deep-water fish from the Rockall Trough (Mormede and Davies, 2001). Although most deep sea muds are remote from major land-based contaminant discharges,

shipping activities (past and present) have littered the sea-bed with debris. For example, clinker (burnt coal slag) from old steamships is present throughout the world's oceans (Heezen and Hollister, 1971).

There have been a number of significant studies of anthropogenic impacts on deep sea mud communities. One of the most detailed studies concerns the impact of the ocean dumping of 42 million tonnes of sewage sludge in 2,500 m of water, 106 nautical miles south-east of New York Harbour, between 1986 and 1992. This dumping impacted deep sea animal communities. It had significant effects on the metabolism, diet and faunal composition of organisms in the area (see <http://marine.usgs.gov/fact-sheets/sewage/title.htm> for further details of this study). There have also been notable studies on the potential impact of large-scale manganese nodule mining. For example, the DISCOL experiment in the Peru Basin (south-east Pacific) reported increased abundances of the benthic fauna that persisted for at least three years after the initial disturbance of the sea-bed (Thiel and Schriever, 1990). There were also significant changes to the sediment-depth distributions of macrofauna and reductions in species diversity (Borowski and Thiel, 1998). Although manganese nodule mining is unlikely in the OSPAR maritime region, the nature of the impact may be very similar to the, as yet unstudied, impact of deep sea demersal trawling that is evident in the region (Bett, 2000).

2.12.4 Conservation actions

Deep sea muds cover a substantial part, not only of the sea-bed in the OSPAR region, but also of the entire planet, and indeed may be regarded as the dominant habitat on our planet. The fauna associated with this environment play an important role in ecological processes. By implementation of conservation actions relating to other offshore habitats, communities and species within the OSPAR region, some of the deep sea mud habitat will be preserved automatically. However, it is clear from the extensive scientific investigations of the fauna associated with deep sea muds in the north-east Atlantic area that significant environmental and ecological variation occurs over a wide range of spatial and temporal scales. A network of MPAs may, therefore, be necessary to encompass all of the various biogeographic realms found in this region. For example, the UK continental margin encompasses two highly distinct deep-water provinces: the 'temperate' Rockall Trough and the 'arctic' Faroe-Shetland channel, which have correspondingly distinct ecologies (Bett, 2001).

2.13 SPONGE FIELDS

Contribution by Gerd Konnecker, Independent sponge expert, UK

Sponges (*Porifera*) are a unique group of aquatic animals with no relationship to any other living animal phyla. With the exception of a small number of species belonging to the order *Haploscleridae*, all sponges are entirely marine. There is an incredible variety of sponge species in the north-east Atlantic and globally that come in all sorts of shapes and sizes. Sponges are common in shallow water, but some species have been found to a depth of 2,500m. These deep sea sponges known collectively as pharetronidae exhibit an ancient trait – a massive internally fused skeleton. Geologists recognise them as important reef builders. Other sponges, *Hexactinellidae* are confined to waters that are generally several hundred metres in depth. The bulk of the sponge fauna are *Demospongiae*.