The Deep-Sea Frontier: Sustainable use of Europe´s deep-sea resources

Scientific needs and strategies

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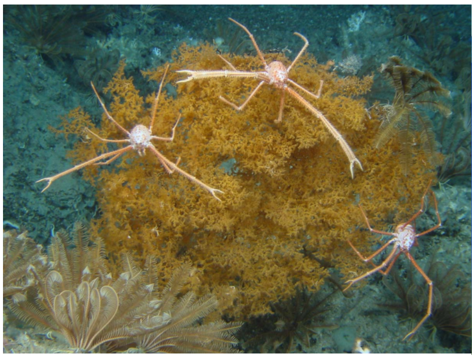

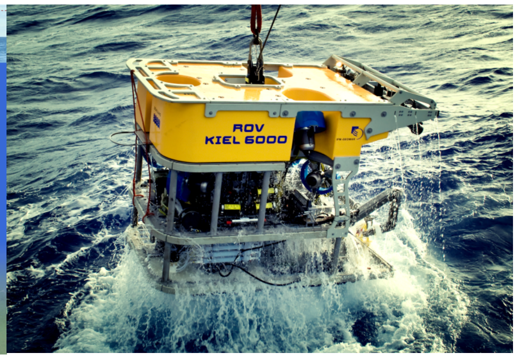

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Abstract

Europe is a globally leading player in deep sea research. Building on past achievements, which have been impressive, and consolidating Europe's position will require further integration and investment in deep sea research. During the meeting of the Deep Sea Frontier community in May 2009 it was agreed to further integrate the various European deep-sea communities beyond the three main pillars identified in the DSF foresight paper "the Deep-Sea Frontier: Science challenges for a sustainable future " (2007).

The participants agreed that research to support integrated deep-sea governance and management is an urgent issue to tackle during times of rapid global change and because of the high stakes and the societal relevance. In view of the possibility of using a joint programming approach in the mid to long term, it was felt that future research will need to broaden its scope and should cover a wide range of issues besides the topics addressed by the 3 pillars of the Deep Sea Frontier initiative. These issues include ocean and climate change feedbacks (including the long paleo-records), impacts of natural and anthropogenic events including, amongst other, continent-ocean transfers and organic, inorganic, radioactive and litter pollution; exploitation of living, mineral and energy resources; and carbon sequestration and their impacts on marine ecosystems. This wide range of issues could be tackled through the joint marine and maritime calls put forward by the Marine and Maritime Research Strategy adopted by the Commission in 2008. The originality of these calls is that they involve the pooling of financial resources by more than one theme of the Framework Program.

This document emphasizes major topics of deep-sea research with the potential to establish the basis for future joint programming activities in the marine domain. A joint marine call could be proposed for 2011. An alternative option of having integrated projects funded under the environment theme only could also be explored for 2012.

I. High societal relevance of the deep-sea research

Europe´s deep-sea margin stretches over a distance of 15,000km along the Atlantic Ocean from the Arctic to the Straits of Gibraltar through the Mediterranean to the Black Sea. Over half of the European territory is under water, and the overwhelming part of this territory is deep-sea, beyond the edge of the continental shelf deeper than 200m water depth where major marine ecosystems and resources of the future are concentrated. The deep-sea outstrips the terrestrial environment, not only in terms of volume but also in terms of biomass and biodiversity (habitats, species and higher taxonomic levels supported by very high genetic biodiversity). Within this area, deep-sea fisheries and oil and gas exploration and production are moving steadily into deeper water. Newly emerging industries such as blue biotechnology obtain useful products through the exploitation of deep-sea genetic biodiversity and show great potential for the future. Other potential growth areas include the exploitation of mineral resources, gas hydrates as an energy source and the use of the deep-sea as a reservoir for the sequestration of CO_2 (Carbon Capture and Storage – CCS –

technologies). Naturally most geo-hazards occurring on the coast are due to deep seafloor or sub-seafloor processes, like earthquakes (plate boundaries), volcanic eruptions, submarine landslides and the tsunamis that they generate. The deep-sea natural system is of paramount importance since it sequesters a large fraction of the anthropogenic carbon emissions, thereby mitigating climate change, but also suffers increased acidity, due to the dissolving of CO_2 in seawater, which may affect ecosystem structure and biogeochemical cycles. The marine system shows some indications of rapid change due to ongoing increases in water temperatures. Modern ocean sciences must therefore take into account and contribute to the debate on societal, legal and policy aspects. This point is recognized in the Marine Strategy Framework Directive for Europe, which requires more co-ordinated research to underpin the objectives of sustainable exploitation in the oceans.

The Lisbon Agenda sets out the European Union's strategy for competitiveness, growth and employment. The essential commitment to sustainability was recalled during the Goteborg submit of 2001. The Maritime Policy for the European Union clearly articulates that it will fully contribute to the Lisbon Agenda and the Goteborg declaration by exploiting the economic potential of the oceans and seas in harmony with the marine environment. This requires research to better understand the effects of global change on the marine environment and living resources. Research will lay the groundwork for the implementation of an ecosystem-based management approach that will ensure environmentally sustainable economic development on a regional basis. Research underpinning the development of new sustainable management policies and practices, experience of sustainable exploitation of offshore resources, and the knowledge capital it will represent, will create new opportunities for Europe to provide leadership in the global economy.

II. Key scientific questions

Earth and ocean processes operate spatially from millimetre to global scales and temporally from seconds to decades, centuries and more. The deep-sea encompasses a complex geo-bio-hydrosphere-atmosphere system and only a few parts of the interacting processes that are simplified in Figure 1 are fully understood. To better understand patterns and processes of the deep ocean across many time and spatial scales is a prerequisite and a societal need for a sustainable use of our deep-sea resources. Sustainability is based on the knowledge of natural processes and environments and preservation, as far as possible, of ecosystems. There is nowadays a wide recognition that research addressing science questions of societal priority such as understanding the impacts of climate change, acidification, natural and man-made events and exploitation of marine resources should be done in a multidisciplinary framework involving natural sciences, modelling, engineering and social sciences.

Understanding how deep-sea ecosystems and biogeochemical processes will respond to climate change will require increased attention in the near future. The Arctic Ocean as a hotspot of rapid environmental change will be a focal area of attention. Rapid changes in continent-ocean transfers and fluxes between the water column, the seafloor and the sub-seafloor, and how they modulate climate change or vary due to it need to be assessed and predicted. Major concerns are the spreading of anoxic zones and the acidification and modifications of other properties of deep waters. Tipping points and thresholds where an incremental change can provoke a significant and rapid regime shift (biological, biogeochemical or physical processes) will need to be identified, e.g. the turning off of dense shelf-water cascading events that re-oxygenate the deep-waters and fuel the deep ecosystem in the Mediterranean and in other key ocean regions worldwide. How sub-seafloor processes affect the seafloor and the water column also needs to be investigated, e.g. variations in the rates of methane release in cold seeps, which are likely to increase due to ocean warming. The genetic connectivity between deep-sea communities is an area that also needs to be explored. Finally, a better understanding of the impact of submarine geo-hazards on the deep-sea ecosystem, their response to climate change and the threat they pose to coastal locations are necessary. Deep-sea research is primarily based in the interconnecting fields of geo-sciences, physical oceanography, biogeochemistry, marine biology and ecology and socio-economics.

Some topics that are cross cutting themes are of paramount importance:

- Interactions between ecosystem functioning and service, biodiversity, biogeo-chemistry, physical processes and climate.
- Natural and anthropogenic change, global and regional ocean regime shifts.
- Impacts of habitat destruction and pollution on ecosystems.
- Submarine geohazards
- Impacts of marine exploration and extraction of energy, mineral and living resources
- Connecting scientific research to the public, stakeholders and policy makers.

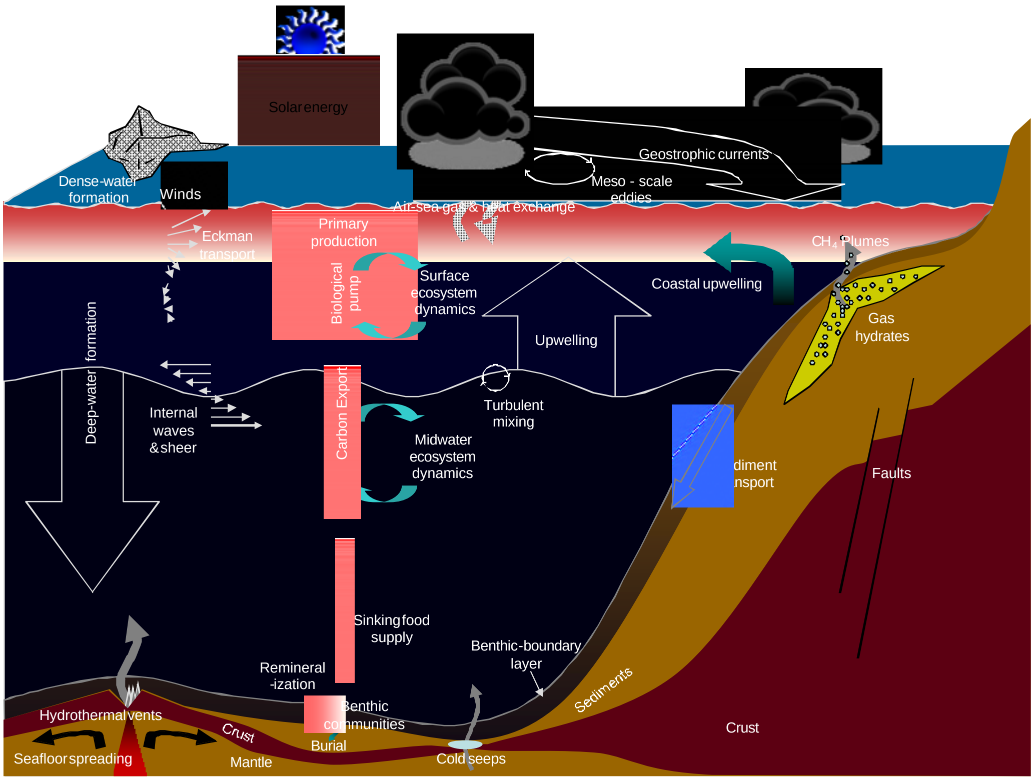

Fig. 1: Illustration of major processes in the marine environment indicating the interconnection of atmospheric, surface ocean, biological pump, deep-sea, and solid earth dynamics. This figure is based on similar figures prepared by the ESONET NoE and the US Ocean Observatories Initiative (compiled by Ruhl et al., subm.).

II.1 Interactions between ecosystem functioning and service, biodiversity, biogeochemistry, physical processes and climate

Deep-sea ecosystems provide goods (including food, bioactive molecules, oil, gas, minerals) and services (climate regulation, nutrient regeneration and supply to and from the photic zone). Their profound involvement in global biogeochemical and ecological processes is essential for the sustainable functioning of the biosphere and for human well being.

Recent results indicate that ecosystem functioning (e.g. prokaryote carbon production or nutrient regeneration) is positively and exponentially related to biodiversity in all deep-sea regions. Such relationships between biodiversity and ecosystem functioning and efficiency suggest that a higher biodiversity supports higher rates of ecosystem processes and an increased efficiency with which these processes are performed. The exponential relationship between biodiversity and ecosystem efficiency supports the hypothesis of the existence of mutually positive functional interactions (ecological facilitation). It has been estimated that a biodiversity loss of 20-25 % can result in a 50-80 % reduction of deep-sea ecosystem key processes, and their consequent collapse. This would have significant consequences in terms of the services provided by these ecosystems and suggest that the conservation of deep-sea biodiversity can be crucial for the sustainability of the functions of the largest ecosystem of our biosphere. More work is urgently needed to verify these early results.

Deep sea biodiversity is poorly known and estimates of species numbers are uncertain even within orders of magnitude. For microbes, the new rapid sequencing techniques have shown that we know only a very small fraction of existing biodiversity and the ecological role and the service of most of them is unknown.

Even if some specific ecosystems such as spectacular hot spots like hydrothermal vents or cold seeps are clearly depending on sub-seabed fluid flow inputs, the overwhelming part of the deep-sea communities are dependent on organic material produced in the photic zone. This pelagic-benthic coupling is a very dynamic process. The routes of transport differ according to geographic region but in general it is expected that the increased stratification of the ocean surface that could result from climate change will lead to much lower food inputs to the deep sea sediments. As a result the oceans will gradually become impoverished in benthic organisms, a process that will be accelerated by the lower oxygen concentrations that are expected to arrive as a consequence of less intense vertical mixing and deep water circulation, and higher temperatures. Less benthic organisms mean less bioturbation and bioirrigation and less reworking of organic matter in deep-sea sediments. Lower oxygen concentrations will also increase the rates of denitrification and, therefore, of nitrate removal from the oceans, leading to lower nutrient availability and lower productivity (see also section II.2 of this document). Another major threat is ocean acidification which will make large parts of the water column under saturated for $CaCO_3$ and reduce or even inhibit shell formation of many organisms, including molluscs, foraminifers and corals (including the deep sea dwelling cold-water corals).

We can, therefore, expect significant changes in the community structure of benthic and deep-water organisms over a relatively short period of time. It is unclear how many species will be able to adapt to these rapid changes and, as species interactions determine the composition and functioning of biological communities, one may expect gross changes in these parameters. At the present state of knowledge it is impossible to predict what may happen and what the consequences may be for the stability, the resilience and the productivity of marine ecosystems.

II.2 Natural and anthropogenic change, global oceanic regime shifts: a growing cause for concern

The global ocean is a complex system which displays natural internal variability across a wide range of scales. This is evident in both short-term (e.g. diurnal to seasonal) and long-term (e.g. inter-annual to decadal) time-scales. However, there is evidence that human activities are tipping the delicate balances and exchange processes in the natural system. For example, individual studies and long-term time series observatories are capturing temperature and salinity anomalies in deep water masses that are associated with contemporary global warming trends. In addition, the global ocean is being exposed to soaring levels of CO_2 in the atmosphere, which are largely driven by man's activities.

The global ocean is interconnected with the terrestrial and atmospheric systems. For instance it has an unrivalled capacity to act as a natural reservoir for much (up to 30%) of the carbon dioxide (CO_2) being emitted into the atmosphere by human activities. Indeed, the surface waters of the entire subpolar North Atlantic have for many years continued to be persistently under saturated giving rise to a perennial CO_2 sink. However, this continued air-sea flux of CO_2 has a profound consequence for oceanic chemistry and nutrient inventories. One impact is ocean acidification which may create adverse effects on oceanic ecosystem diversity and functioning. The long-term effect on marine organisms and their ecosystems are still difficult to predict and long-term datasets are required. Recent evidence from upper ocean CO_2 partial pressure (pCO_2) time-series data at the PAP station off Ireland sustained observatory (49°N, 16.5°W) indicate that the oceans' capacity in the North Atlantic to absorb CO_2 may in fact be declining. However, little is known about the longer-term potential of the global ocean to act as a CO_2 sink. In addition, parallel changes to the physical environment (e.g. mixed layer depth and stratification) are intimately linked with the net community production and the oceanic uptake of CO_2. This influences the percentage of carbon drawdown that is sequestered and that which is re-ventilated from subsurface respiration. Most benthic communities in the open ocean depend on food that sinks from surface waters or is advected from the coastal ocean and are thus affected by changes in coastal waters and surface production even hundreds of miles far and thousands of meters above. These animals also have important roles in determining how much of the carbon that reaches the seafloor is either retained in the contemporary carbon cycle or sequestered in marine sediments.

Deleterious reduction in available oxygen, or hypoxia, is also a growing phenomenon in the world's ocean. Natural hypoxic and anoxic basins are well known features of the world's ocean. However, the expansion of hypoxic and anoxic conditions, particularly in coastal areas and continental shelf regions, is a cause of concern because changes in oxygen concentration can be important in structuring marine communities. A main factor appears to be an increase in anthropogenic organic pollution in many coastal waters. High CO_2 concentrations and increased levels of organic pollution in the coastal and intermediate waters are stimulating primary productivity, and thus increasing the biological oxygen demand, depleting the oceans in oxygen and promoting the spread of hypoxia in the pelagic and benthic environment. Oxygen deficiency can cause the mass mortality of many functionally important species. On a large-scale, this may lead to an overall decline in global marine biodiversity and an increase in the abundance of opportunistic organisms, such as bacteria and protists that tolerate low-oxygen conditions. Hypoxia is likely to affect significantly the structure and function of pelagic and benthic communities, the biogeochemistry (nutrient regeneration) of the oceans and benthic-pelagic coupling.

Surprisingly little is known about the consequences of disrupting the structure and composition of ecosystems on organic matter cycling despite the potentially disastrous ecological and economic implications of such changes for productivity, carbon cycling, and living resource availability like fish stocks. Without a large-scale reduction of anthropogenic nutrient input to the sea, hypoxia will continue to spread. It is therefore vital reaching a greater understanding of biological and biogeochemical processes within oxygen-deficient environments, both natural and anthropogenically induced, so that predictions about the impact of hypoxia on the global ocean and climate can be better constrained and policy makers better informed. Little is known regarding the influence of physical and chemical gradients (e.g. of temperature, oxygen concentration, pH and organic enrichment) on pelagic and benthic ecosystems, or how changes in these gradients will influence the biodiversity of ecosystems and the efficiency with which they are able to process organic carbon.

What will be the consequences of ocean regime changes? In order to understand the short-term and long-term processes it is vital that we need to continuously measure key variables in the oceans in space and time. It is also vital that we have a multidisciplinary and interdisciplinary approach to understand the complex processes from the surface to the seafloor and that research and development continues to increase sensor accuracy and to design and test sensors for even more key variables in the oceans.

II.3 Impacts of habitat destruction and pollution on ecosystems

Our understanding of anthropogenic impacts on deep-sea habitats has only developed very recently and is lagging behind the rate of destruction itself. Until now our knowledge is restricted to relatively few studies in a small number of geographical areas. Human activities in the deep-sea include fishing, hydrocarbon drilling, cable and pipeline lying, dumping (e.g. sewage sludge and radioactive waste) and littering, with possibly seabed mining and carbon injection in the future. Deep-sea environments are probably among the most vulnerable to disturbance. Apart from chemosynthetically driven communities (hydrothermal vents, cold seeps), the deep sea ecosystem exists on food material from the upper ocean sometimes delivered in pulses when ‘phytodetritus’ can visibly accumulate on the deep-sea floor. Thus at some times of the year deep-sea communities may be supplied with abundant food but at others they may be food-limited although our understanding of this periodicity remains far from complete. In cascade-fueled regions deep-sea communities could be significantly fed only once per decade or so. Deep-sea species are typically slow-growing and often long-lived. They are frequently very biodiverse and some habitats, such as those formed by cold-water corals and sponges, form highly complex structured habitats that are particularly vulnerable to physical damage and smothering.

Of all anthropogenic activities in the deep sea it has become clear that deep-sea fisheries, primarily bottom trawling, has had the greatest and most widespread physical environmental impact. Following declines in shallow shelf seas fisheries in the 1950s and 1960s fishery activity has expanded to progressively deeper areas with larger, refrigerated vessels and stronger trawl gear capable of fishing rough shelf edge and seamount grounds. Areas supporting coral and sponge habitats that had previously been unfishable by trawling were trawled for the first time. Evidence of widespread damage to deep-sea coral habitats has accumulated over the last decade leading to the establishment of trawl closure areas in several parts of the world. Trawl marks are also evident in soft deep-sea sediments, with some of the earliest photographic records dating from the late 1980s. As well as collateral damage to benthic habitats, deep-sea trawling has dramatically depleted deep-sea fish populations – a reality masked in catches statistics because deep-sea fisheries serially deplete one stock after another hiding the overall decline. Recent evidence suggests that the impact of deep-sea fisheries may extend beyond the depths actually fished to affect deeper-dwelling fish populations. International concern over the damage caused by deep-sea trawling, notably on the high seas, led in late 2006 to UN General Assembly Resolution 61/05 calling upon states to protect 'vulnerable marine ecosystems' from destructive fishing practices. The effects of habitat loss by trawling on deep-sea communities is hard to quantify, but the loss of a complex biogenic coral and sponge habitat that has developed over millennia will have far-reaching effects for local biodiversity and potentially lower the resilience of other areas that rely upon presently unknown larval dispersal routes.

The deep-sea is not remote from the effects of anthropogenic climate change. As discussed above, there is growing evidence that deep water mass structure is changing and warming signals have already been detected in the deep sea. Global predictive models of the oceanic carbonate system imply that ocean acidification will not only affect shallow seas, but the deep as well. It was estimated that the depth at which seawater is saturated with respect to aragonite (the mineral form of calcium carbonate secreted by many marine organisms, including scleractinian corals) will shallow rapidly in the coming century. If these estimates are correct, many regions that currently support cold-water coral habitats could become under saturated with respect to aragonite. Currently there have been very few attempts to study the ecophysiology of any cold-water coral. First results pointed to a dramatic sensitivity to increased temperature with great concern over their likely sensitivity to the predicted shallowing of the aragonite saturation horizon.

Finally, it is important to note that the issues summarized here will not act alone and their combined effects will have complex, potentially synergistic and unpredictable effects on deep-sea ecology. For example, any alteration to primary productivity in the shallows will cascade through the food web altering food supply to deep-seabed organisms. We often have very little information on how deep-sea species reproduce and how neighboring populations are linked and connected genetically by larval exchange. The only means of addressing these uncertainties is by working in a broad, integrated manner across an ocean basin using, for example, newly developed genetic markers to investigate these key conservation questions. Allied with a better understanding of deep-sea biodiversity and the environmental sensitivities of key ecosystem engineering species we can develop the capacity to inform effective future ecosystem based management strategies for the deep sea.

II.4. Submarine geohazards

Natural submarine geohazards (earthquakes, volcanic eruptions and volcanic-island flank collapses, landslides, seafloor fluid expulsions) are geological phenomena operating at or below the seafloor. They can cause a situation of high risk for off-shore and on-shore structures and the coastal population. Addressing submarine geohazards means understanding their spatial and temporal variability, their triggers, the pre-conditioning factors including the physical processes that control their evolution. A large sector of the international scientific community recognizes an obligation to contribute to the mitigation of the potentially destructive societal effects of submarine geohazards.

The study of submarine geohazards requires a multi-disciplinary scientific approach: geohazards must be studied through their geological record; active processes must be monitored; geohazards evolution must be modelled. Ultimately, the information must be used for the assessment of vulnerability, risk analysis, and development of mitigation strategies.

In contrast with the terrestrial environment, the oceanic environment is rather hostile to widespread and fast application of high-resolution remote sensing techniques, accessibility for visual inspection, sampling and installation of monitoring stations. Geophysical surveys, sampling, drilling, with related down-hole logging and in situ measurements, long term observatories at the seafloor and down-hole should be viewed as indispensable tools of an international and coordinated multi-disciplinary scientific approach to address submarine geohazards.

The European territory is particularly vulnerable to submarine geohazards. The historic and archaeological record of submarine geohazards that have afflicted human populations around Europe's coasts extends back at least 8000 years. Few examples include: Stromboli Island volcanic activity, consequent submarine landslide and tsunami (2002); Izmir Bay tsunami (1999); Nice Airport landslide (1979); Rhodes (1920), Messina (1908), Lisbon (1755), Catania (1693) and Crete (365) earthquakes and tsunamis; Santorini eruption, caldera collapse and tsunami (3500 years B.P.), and Storegga slide and tsunami offshore Norway (8200 years ago). Within global-ocean geohazards, the situation of the Mediterranean basin concerning submarine geohazards is particularly vulnerable due to a dense spatial distribution of geohazards (submarine landslides, volcanic flank collapses, volcanic island eruptions, earthquakes and associated tsunamis). Clearly, the high frequency and the close proximity to tsunami sources and impact areas, and the high density of population along its coastlines (160 million inhabitants sharing 46,000 km of coastline which receives an average of 135 million visitors annually) requests improved measures and predicted as well as warning capabilities.

In addition to this, geohazards are also geological processes that impact on the natural environment. In this respect, submarine landslides and sediment mass transport alter significantly the marine ecosystems. During this process, rapid methane gas emissions from the sea floor can have the potential to reach the atmosphere and contribute to the global warming. Under this aspect, the seafloor of the European sector of the Arctic Ocean represents a huge area undergoing the most dramatic warming induced by climate change. It is speculated that such warming has already triggered massive methane release from the seafloor. The nature and the rates of such important processes must be understood in order to contribute to the forecasting of global warming.

II.5 Impacts of exploration and extraction of energy and mineral resources

As our planet's oil and gas reserves diminish, energy companies increasingly look further offshore for new resources. The oil and gas exploitation in deep waters below 400m will continue to increase over the coming 20 years as higher prices make deeper exploitation economically attractive; frontier areas such as the Arctic will become a focus of interest.

Other potential growth areas include the exploitation of gas hydrates as an energy source or the use of the deep-sea as a reservoir for the sequestration of CO_2 providing capital in the potentially lucrative carbon trading market. New technologies combining gas hydrate mining and CO_2 sequestration (substitution technique) have recently been investigated.

34% of the worldwide oil production was already produced offshore in 2004, mostly in shallow waters, and is estimated to increase to 40% by 2015. During the same period, offshore gas production should increase to 34%. It has been estimated that, by then 60% of the oil and gas reservoirs will be exploited in water depths from 500 – 3000 meters. The continued increases in world energy demand, forecast long term increases in the price of hydrocarbons as well as the global transition to natural gas as a cleaner, more efficient fuel source should be a significant driver for European Deep Sea research initiatives.

Currently some 5% of GDP of Europe is generated directly from marine-based industries and services. This number is significant though employment in the offshore sector is not that high at present. Energy supply from deep water resources may become a vital additional resource for economic growth, employment and social development in Europe. One major goal of the EU is to become the most sustainable and energy-efficient economy in the world by 2020. To meet this demand for sustainable development without additionally contributing to global climate change and pollution of the marine environment is a big challenge. This demand is even more critical in the Arctic than in other places in the world as the ecosystems are more fragile there. The Arctic lower shelf and deep-waters regions will however probably become the largest natural gas supplier to continental Europe. Here, the importance of the Barents Sea will increase as 17% of the reserves are located in this area, but so far only 1% is produced there. A secure energy supply from the deeper waters off Europe is possible but can only be achieved after detailed baseline studies on the environment including new strategies on deep-sea monitoring around future exploration sites. Exploitation and environmental monitoring in the deep-sea represent major technological and engineering challenges. They can be drivers of survey, maintenance, monitoring and reduced environmental impact related to engineering innovations. A main objective of the European Maritime Policy should be to fully exploit the economic potential of the oceans and seas in harmony with the marine environment. Research into these areas will create opportunities for Europe to provide leadership in the global economy through the development of new sustainable management policies and practices. Experience of sustainable exploitation of offshore resources and the knowledge capital can be exported to other parts of the globe.

Ocean mining of various mineral resources has enormous economic potential. Until recently, deep-seabed mining had not developed into a commercial reality. However, over recent years at least two companies, Nautilus and Neptune Minerals, have developed techniques to mine seafloor massive sulphide deposits on a commercial basis. Once again, the environmental impacts of this activity are not well understood but, at least over the mined area, we may anticipate a substantial benthic impact, even if the exploitation will be conducted on fossil (non-active) hydrothermal deposits. The wider ecosystem effects depend on many factors including how far and at which depth tailings are discharged, how tailing plumes are dispersed and whether the areas being mined support any locally endemic species that would be vulnerable to extinction. In addition to the new prospects of mining massive sulphide deposits there could be commercial potential in mining manganese nodules which if brought into reality might disturb an area of the deep seafloor half the size of Germany over a 15 year time period. As with sulphide and nodule mining, the likely impact of attempts to extract deep-sea methane hydrate deposits are also poorly understood although local impacts to sediment-dwelling fauna and possible wider impacts from any seafloor slumping caused by hydrate dissociation have both been raised as concerns.

To address the issue of sustainable development data from different sources are to be integrated, including oceanographic, biological, ecological, geophysical, geological, sedimentary, hydrological, social and economic data. Assessments of the impact of different management strategies on the resource base, the environment and on social-economics will be required. This will be done through the development of methodologies such as dynamic models and indicator frameworks. Deep Sea research programmes can thus support the development and growth of ocean-based industries across a diverse range of scientific projects.

II.6 Connecting scientific outcomes to the public, stakeholders and policy makers

In the light of an increasing realization of the extent of human impacts on the oceans and seas, over the last 10–15 years the international community has adopted ambitious goals and targets to safeguard the marine environment and its resources. During the 2002 World Summit on Sustainable Development held in Johannesburg, world leaders agreed inter alia on: to achieve a significant reduction in the current rate of loss of biological diversity by 2010; the introduction of an ecosystems approach to marine resource assessment and management by 2010; the designation of a network of marine protected areas by 2012; (UN, 2002: Chapter IV). At the European level, many of these goals and targets have been incorporated into national action plans and various European policies adopted under the EU and the OSPAR and Barcelona Conventions.

The objectives of the EU's marine and maritime research strategy are to understand the Good Environmental Status (GES) of our seas and to maximize the value we extract from our seas in a way that is compatible with their GES. The current governance shift towards ecosystem-based management and the ecosystem approach by the EU requires the integration of fisheries, conservation, and other sectoral approaches, supported by robust marine spatial planning. Integrated knowledge from the natural and socio-economic sciences is urgently needed to provide the information in support deep-sea governance. This information will be required to feed into:

- EU Habitats Directive and Natura 2000;
- Integrated Maritime Policy for the EU;
- Thematic Strategy for Marine protection and the associated directive;
- EU Common Fisheries Policy;
- OSPAR and the Barcelona Conventions
- United Nations Convention on the Law of the Sea (UNCLOS)
- Convention on Biological Diversity
- Census of Marine Life and its descendents

At the global level, there is presently a heavy international policy focus on deep-sea ecosystems and resources, both within and beyond areas of national jurisdiction that is being informed by an increasing, but still limited, scientific understanding of deep-sea process. These issues are being discussed in various fora, including the UN General Assembly (UNGA), the Food and Agriculture Organization of the UN (FAO), global conventions such as the UN Convention on the Law of the Sea (UNCLOS), the Convention on Biological Diversity (CBD), regional multilateral agreements and conventions such as Regional Fisheries Management Organizations (RFMOs) and Regional Sea Conventions and Action Plans (RSCAPs).

A crucial requirement to implement all these goals, targets, policies and processes is the availability of sound, high-quality scientific data and information from the marine environment to assess the progress achieved and to set the directions for further work. Hence the importance of providing the critical scientific information and ensuring that it reaches the right users – in this case the policy makers. A key element in bringing about change and regulation is the attitude of the public and hence a strong outreach component is also essential, using a variety of media.

Specific expertise on socio-economic and governance aspects of the deep-sea (including the valuation of deep-sea goods and services) is still very sparse. The European Environment Agency is currently launching the European Ecosystem Assessment (EURECA) which will assess the state of ecosystems in Europe in 2010 and their possible development beyond 2010. EURECA will include an assessment of the stocks, flows and value of selected ecosystem goods and services under different policy-relevant scenarios. It is intended to be ready in 2012 and contribute to the Millenium Ecosystem Assessment follow-up as a sub-global assessment. Particular attention is paid to improve the knowledge base regarding ecosystem functioning and services, developing and applying tools for political decision making at European level, and outreach to stakeholders.

III. Strategies & Tools

The strategy to develop Deep Sea research is to investigate the topics of major concern in key areas such as: ecosystem goods and services, biodiversity hotspots, areas of accelerated environmental change, sites of increased anthropogenic impacts, areas of high geo-hazard risks with a high degree of a combination of these patterns.

The hostile nature of the deep sea environment requires solutions of a similar level of complexity facing space research, sophisticated technological solutions and a multidisciplinary approach. The number of existing and planned large deep-sea infrastructure projects will be drivers of new surveys, maintenance, monitoring and reduced environmental impact engineering products and methodologies. The provision of information and communication technology (ICT) infrastructure for cabled observatories and sub-sea platforms will similarly drive innovation in mass data storage and processing, sensors and autonomous platform technologies. Key components will include access to surface support ships and research vessels, deep-sea vehicles and associated equipment; improved high resolution mapping and imaging of the seabed and the sub-seabed; advanced sampling technologies for rocks, sediments, fluids, fauna and microbes; in situ measurements for key oceanographic, geological and biogeochemical parameters; access to drilling facilities for a variety of scientific tasks, including borehole monitoring; sustained in situ observation and monitoring, including repeated high-resolution surveys, continuous measurements, and event-triggered sampling and analyses; global databases and sample archives; paleoceanographic proxies to complete the brief instrumental records in the deep ocean on climatic time scales.

Some key tools and large infrastructure for future Deep Sea research are:

III.1 Eurofleets

EUROFLEETS is a process aiming at bringing together the existing European Research Fleet owners, to enhance their coordination and promote the cost-effective use of their facilities (oceanographic fleets and associated marine equipments) in order to support the efficient provision of essential research services for monitoring and sustainable management of the Regional Seas and the Oceans and allow access to all European scientists. EUROFLEETS aims to:

- Structure and durably integrate, on European scale, through an e-platform the way that the research vessels are operated and their capacities made interoperable,
- Use in a more cost-efficient manner the existing European ocean/global and regional fleets,
- Facilitate a wider sharing of knowledge and technologies across fields and between academia and industry,
- Promote greener and sustainable research vessel operations and responsibility,
- Provide all European Researchers with a full access to high performing research fleets to conduct marine research,
- Foster the coordinated and joint development of European fleets in terms of capacity and performances.

At the very centre of this EUROFLEETS I3 project, the Trans National Access (TNA) will facilitate over a 3 years period (2010, 2011 and 2012) access to:

- the pool of 5 Global/Ocean Class research vessels for high sea areas and their associated equipment (Remotely Operated Vehicules - ROVs, submersibles (Le Nautile), 3D seismics, corers, Autonomous Underwater Vehicules - AUVs, and sensors such as echo-sounders, sonars, Automatic Doppler Current Profilers - ADCPs…), through one call,
- the pool of 14 Regional Class vessels for European seas, through 2 successive calls.

European research vessel operators will work together to coordinate the collation and assessment of all vessel schedules in an effort to evaluate vessel availability and to co-ordinate supply and demand across Europe. Proposals would be presented and evaluated on the basis of improving coordination of cruises, including possible exchange of scientists and services, improved geographical coverage and organization of joint operations.

EUROFLEETS will jointly develop an innovative and generic software combining all necessary functionalities for cruise preparation (pre-knowledge maps, data, transects, images, sensors calibration), for collection, linking, processing and display of scientific data acquired during sea cruises, and for export of data and information to the main marine data centers and networks. It will cover:

- recovery and treatment of data from ship sailing instruments, usual sensors on board ship (temperature, salinity, etc), multi beam echo sounders data for bathymetry and imagery, sensors on board submarines instruments (ROVs, AUVs,), photos and videos, etc, and for each data on a geo-referenced basis,

- data import/export through satellite ways and standardized connection with on shore data centers headed up by SeaDataNet.

A widen sea access will be proposed to such oceans as North and South Atlantic, the Indian Ocean as well as to all the EU regional seas identified in the Marine Strategy directive: Artic Sea, Baltic Sea, North Sea, Celtic Sea, East Atlantic, Western and Eastern, Mediterranean, Black Seas.

III.2 Ocean observatories

Much of what we know about the oceans is the result of ship-based expeditionary science. But, it is now clear that to answer many important questions in the ocean and earth sciences, a co-ordinated research effort of long-term investigations is required. The achievement and strengthening of the concept of seafloor-based observatories and the integration of sensors into monitoring modules into more complex multi-parameter observing systems with better performance, has the potential to greatly advance the relevant sciences. Furthermore, long time-series measurements of critical parameters, such as those collected using observatories, are needed to supplement current ship-based investigations and systems. Linking observational data with sensors located on or below the seafloor such as seismometers and sediment pore water pressure sensors (International Ocean Drilling Program - IODP), in the water column such as ocean currents and biogeochemical fluxes (Ocean Sites), and at the sea surface provide a unique opportunity to transform current multidisciplinary efforts into highly effective interdisciplinary science, combining geological, physical, chemical and biological observations. Observatories networked at the seafloor level will offer Earth and Ocean scientists new opportunities to study multiple, interrelated processes over time scales ranging from seconds to decades. These include episodic, periodic, and ontogenetic processes with periods from seconds to geological timescales (Fig. 2). Progress in understanding links between natural and anthropogenic change, ecosystems, the use of natural resources, and geohazard warning is critical to meet societal need for sound policy decisions and hazard monitoring.

The integration of researchers using and developing ocean observatories is rapidly growing under the coordination of the European Seas Observatory NETwork (ESONET) Network of Excellence and the European Ocean Observatory Network (EuroSITES), European Multidisciplinary Seafloor Observatory (EMSO) Preparatory Phase and other related efforts. From the European level observatory researchers will be able to contribute to the Global Earth Observation System of Systems (GEOSS) and Global Monitoring of Environment and Security (GMES) programmes. Various sites have already been identified in the high Arctic (global change, impact on ecosystems and biogeochemical cycling, methane release, slope failures, high exploitation potential), or in the Mediterranean, Marmara and Black Sea (earthquakes, tsunamis, pollution, impact on ecosystems and biogeochemical cycling).

ESONET identified two main classes of ocean observatories: cabled and stand alone systems (Figure 3).

Cabled observatories are irreplaceable in cases where large amounts of information must be acquired for operation in real time for geohazard warning, seismic data processing purposes, and in the future for operational oceanography. Cabled connections also offer other relatively unique advantages including reduced dependence on in situ power supplies, communication rates, and the need to have a surface buoy for the satellite-based communication.

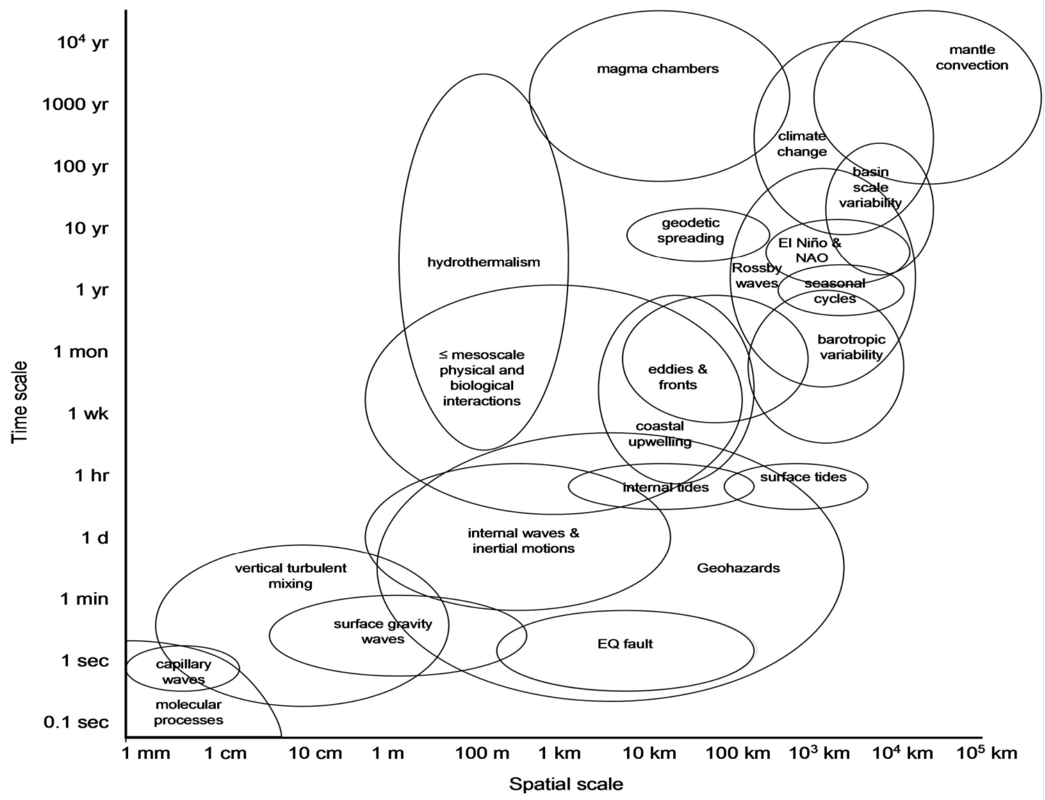

Fig. 2: Illustration of how major processes being investigated in Earth and ocean science have intersections in time and space scales of known importance. Collecting interdisciplinary measurements across these scales using ocean observatories is now viewed as one of the principle ways of understanding the connections between them, as well as their socioeconomic impacts.

A Standalone Observatory (SAO) builds on state of the art technology and more completely integrates interdisciplinary science with sophisticated telecommunication and allows a bidirectional communication for timely data return and sensor control, and long-term flexibility in the location of the systems. The increasing maturity of SAOs enables adaptive observing systems either for remote areas or as emergency response which increase access while reducing costs. SAO‘s can provide long-term ocean measurements from almost any location in the ocean. They can be located in very remote ocean areas far from land, with daily feedback, where the cost of laying a telecommunication cable would be prohibitive. They can be deployed for a fraction of the cost of a cabled observatory system but their operating costs can be larger than those of cabled observatories. A major advantage of standalone observatories are that they can be easily transported and assembled at any given location and thus can be efficiently used for shorter term (2-5 year) studies or moved to locations in response to specific events (e.g., a submarine volcanic eruption or environmental catastrophes like shipping accidents) and areas with rapidly changing environmental conditions.

All the methods described above provide in situ measurements at different times and positions in the ocean water body. Underwater acoustics represents an important remote sensing technique for deep ocean observation, analogous to satellite remote sensing in the atmosphere. Acoustic tomography and thermometry provides acoustic travel time between acoustic sources and receivers at few millisecond accuracy. Through inversion techniques, average ocean temperature and currents can be retrieved at high accuracy. Acoustic data are also important for underwater navigation of floats and gliders, and for transmission of data between modems.

Use of deep sea observatories can potentially be a useful tool for oceanographic data collection, including installation of acoustic systems that can be used for data collection, data transmission and navigation of vehicles. Especially the possibility to offer cables observatories with power supply and data transmission to land can be very beneficial. The possibility to download data from oceanographic moorings in near real time and to recharge batteries on sensors and computers will be a major advantage. Instruments that are mounted on bottom-anchored moorings are most relevant to connect to a deep sea observatory. For example, one of the receiver moorings of a tomography system can be located at the observatory, allowing data to be transmitted to land via the cable. Data collecting platforms that are located in the vicinity of an observatory can potentially transfer data to the observatory. A future scenario is to have oceanographic AUVs with docking station at an observatory where batteries can be recharged, data downloaded and new missions programmed by the operator on land. Other innovative observing techniques can be developed based on such observatories.

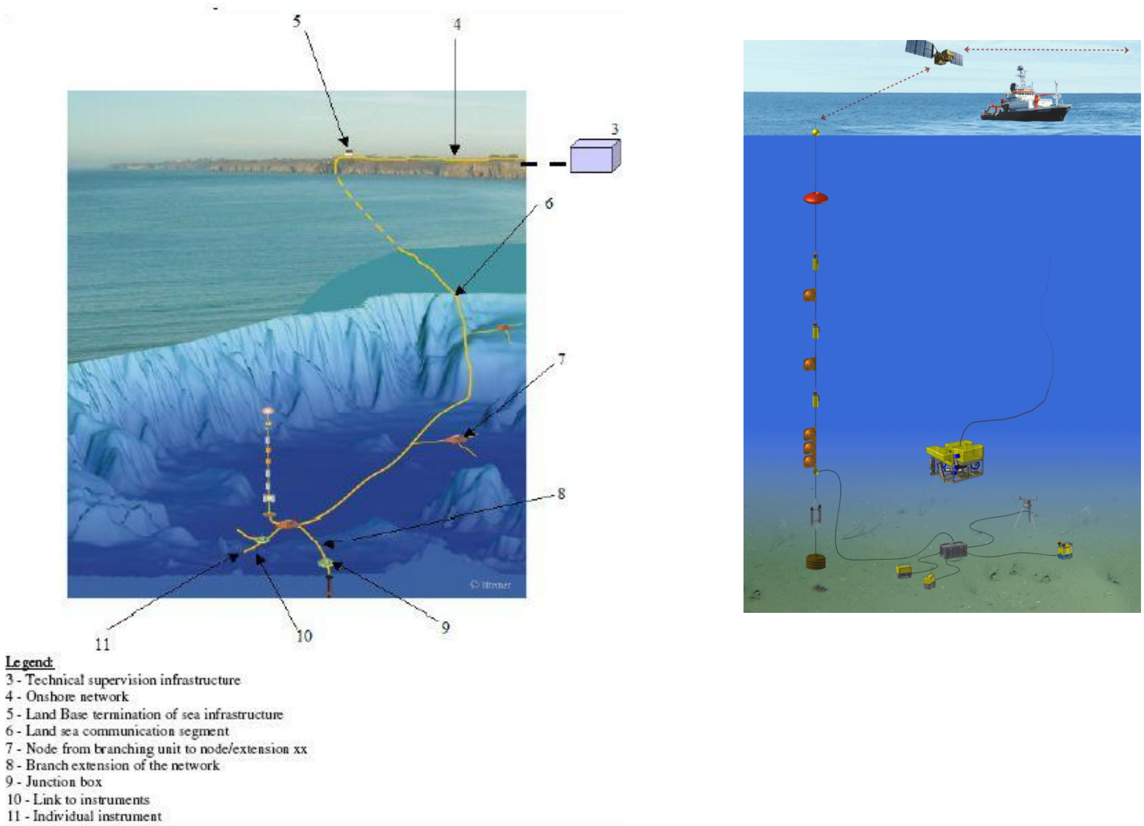

Fig. 3: Examples of a generic cabled observatory (left) and a standalone observatory (right).

III.3 Autonomous vehicles and oceanographic moorings

Multidisciplinary research and monitoring of the ocean water column from surface to seafloor requires a network of stationary and moving platforms. Oceanography, including physical, chemical and biological disciplines, uses research vessels as the main platform for data collection along 2D sections or in 3D volumes of water masses. Data are obtained both from automated sensors and from laboratory analysis of water samples taken at different depths. Chemical and biological data are to a large extent obtained from analysis of water samples. Bottom anchored moorings with instruments at different depths on a vertical cable are used to collect time series of physical parameters (temperature, salinity, currents) and sampling particle fluxes including organic matter over months and years. Usually, anchored moorings are deployed in sections to obtain a 2D field of the observed parameters. New mooring technologies also provide CTDs that can go up and down on the cable according to a pre-programmed schedule.

A new and almost revolutionary technology is the use of automated floats and gliders. The global ARGO program (http://www.argo.ucsd.edu/index.html) consists of more than 3300 floats that sample most of the world oceans from surface to about 1000 m depth. The data are transmitted via satellites when the floats come to the surface every 10 days. While floats drift passively with the current, gliders can be remotely steered by an operator via satellite communication when they are at the surface. Gliders have no propulsion and therefore low energy consumption, allowing operation for more than 6 months over a distance of more than 3000 km. The maximum diving depth is currently 1000 m. The long operation time and the capability to obtain vertical profiles make gliders very attractive for oceanographic research world-wide. However, operation at great depths or close to the seafloor remains problematic.

III.4 Mission-specific drilling

The deep-sea environment is influenced by a number of processes that are occurring beneath the seafloor, and the need for mission-specific sampling tools is equally diverse and highly multidisciplinary. Various deep-sea ecosystems are sustained by fluid venting that supply nutrients (methane, sulphur, metals) at plate margins (e.g. mid-ocean ridges, subduction zones, and transform margins). Fluid flow is guided by faulting patterns and is, therefore, influenced by tectonic activity. Several sub-seafloor processes generate hazardous events such as earthquakes, tsunamis, volcanic eruptions and flank collapses, sediment mass wasting and submarine landslides. Gas hydrate, i.e. natural gas embedded in “ice crystals”, is trapped in sediments under specific pressure and temperature conditions; changes in environmental conditions may result in a sudden discharge of huge volumes of methane gas that may trigger submarine slides, and influence the climate. Moreover, the material deposited on the seafloor represents a record of environmental changes over time. In particular, the sediments are invaluable archives of climate change, essential to predict the future. The sub-seafloor formations also host a completely unexpected and little explored deep biosphere. The sub-seafloor environment can only to some degree be studied by remote methods. Drilling has the major advantage of providing samples and boreholes that can be re-entered, in which downhole measurements of in situ properties and installations of instruments for long-term observation can be made. Access to sub-seafloor samples of drill cores, as well as logging data and long-term monitoring in boreholes, allows key questions to be addressed, and therefore is absolutely essential to understand deep sea sub-seafloor processes and how they affect ecosystems nowadays.

Sub-seafloor sampling can been achieved using different types of tools. Ocean drilling to large depths requires the operation of sophisticated and expensive drill ships. Therefore, their operation is best achieved through international collaboration in large scientific programmes such as IODP. However, the European consortium ECORD (www.ecord.org/index.php), which is a contributing member of IODP, offers access to mission-specific drilling platforms leased on a case by case basis to operate in areas not accessible by large drill ships. This cost efficient approach stands in line with EU large-scale infrastructure projects (e.g. EuroFleets) an may involve piston coring to recover up to 60 m sediment, or new seafloor drill rigs operable from a standard vessel as developed by BGS [www.bgs.ac.uk/science/marine_operations/sampling_equipment.html] and MARUM at the University Bremen [www.marum.de/en/Sea_floor_drill_rig_MeBo.html]).

There are two key aspects to be recognised in sub-seafloor sampling and drilling:

a) to understand the sub-bottom processes and how they affect the surface (fluid flow, nutrient supply, etc.),
b) to collect sub-bottom samples as a window into the past in order to learn about ancient ecosystems and paleo-environmental conditions that may have caused extinction of species, global warming, etc.

To address these issues, the current drilling, sampling, logging and observation technology must be further developed to improve the quality of samples and borehole measurements. This will ultimately lead to the sustainable use of the deep-sea and sub-seafloor, and a closer link to industry equally interested in understanding the sub-bottom of the continental margins and oceanic crusts (e.g. hydrocarbons, offshore construction, CO_2 sequestration). How to organise the access to these sub-seafloor sampling tools for the future European science community is also a fundamental goal in the future.

III.5 Data information system

Complex and large scale approaches in science must be complemented by an infrastructure assimilating and supplying reliable data and data products from distributed sources in a timely and efficient way. For this purpose a service-oriented federated system is needed building on and integrating all facilities in Europe handling oceanographic or related data. Sharing and open access to research data not only helps to maximize the research potential of new observational technologies and networks, but provides greater returns from public and industries investment in research and monitoring. In fact in the last years many initiatives and projects have pushed forward the implementation of common policies and infrastructure. The OECD Principles and Guidelines for Access to Research Data from Public Funding (OECD 2007) provide broad policy recommendations to the governmental science policy and funding bodies. The EU Directive INSPIRE obliges Member States to facilitate discovery of data holdings. The GEOSS concentrates capacities worldwide and heads for the implementation of a global network of observatory systems based on common standards. At EU level the GMES promotes the establishment of European capacity for Earth Observation and the European Marine Observation and Data Network (EMODNET), which is expected to be operational around 2014/15 (ESF 2008), aims to build a marine data information service. The IOC network of National Oceanographic Data Centers (NODC – IODE) – on the European side prepared by SeaDataNet – and the ICSU World Data System (WDS) – in Europe WDC-MARE – are important building blocks for EMODNET. Research in oceanography is supported by a number of EU projects (ESONET/EMSO, Eurosites, Acobar, MyOcean, HERMIONE, CoralFISH, ECORD - the EU part of IODP et al.). All activities must be negotiated with the needs of science and other stakeholders and should be closely linked to running projects addressing information infrastructure.

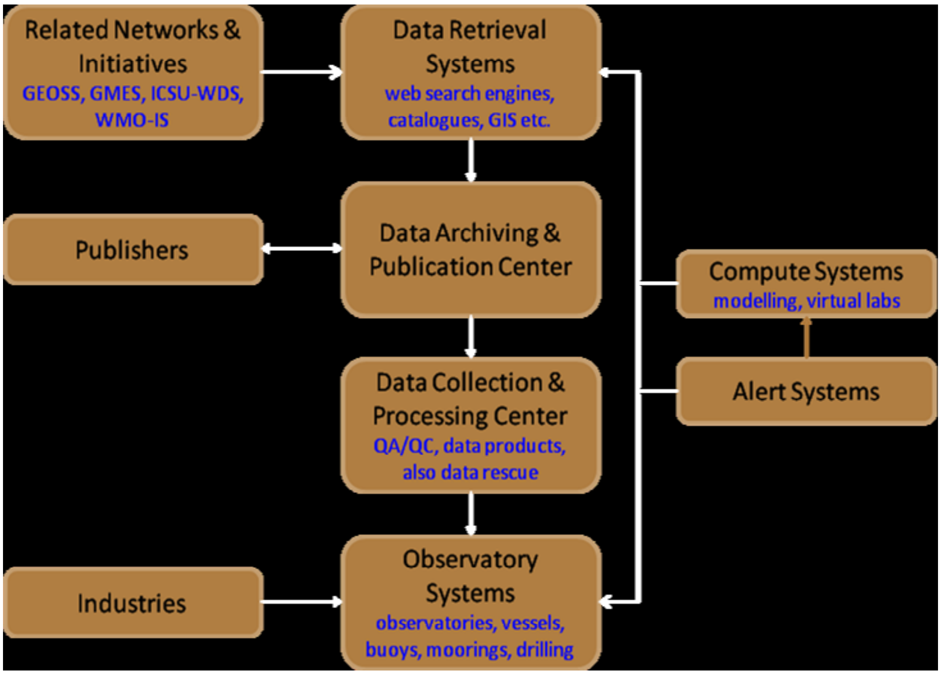

Fig. 4: Data Information System. Crucial in a federated system is the division of labour according to the capabilities of participating facilities. Essential functions (roles) comprise data production, collection, processing, archiving, publication, and dissemination. In addition, brokers are needed for linkage to related networks (incl. libraries), computing facilities, publishers (journals), and industries. Adoption of globally accepted standards (essentially OGC and ISO 19xxx family of standards) compensates for the heterogeneity and dynamics of requirements and developments.

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