

Deep Sea and Sub-Seafloor Frontier (DS³F)

Work Package 7

“Improving Technologies for Sub-Seafloor Sampling and Instrumentation”

Workshop
February 21-23, 2011
Grenoble, France

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1 – Abstract

Work package 7 addresses the “mission-specific sub seafloor sampling” technology at and beneath the seafloor. In total, ~25 scientists and engineers from seven European countries and two non-European countries (Russia and USA) participated at the workshop “*Improving technologies for sub seafloor sampling and instrumentation*” that was held in Grenoble, France, in February 2011 (Appendix 2). An international group of ~25 additional international drilling experts and engineers also became involved because the workshop was organized back-to-back with the final meeting of the EDP (Engineering Development Panel) of the IODP (Integrated Ocean Drilling Program). Various technology aspects of sub seafloor sampling were discussed during a 4 hour long joint session.

The general objectives of the workshop were to (1) review the state-of-art for scientific sub-seafloor sampling, (2) recognize critical technological needs for improving sub-seafloor sampling; (3) identify key areas where substantial European engineering development likely is to be achieved; and (4) discuss strategies for transferring technology developments to the European scientific deep-sea community.

The first objective was achieved by inviting key expertise and by organizing the workshop as a mix of presentations and discussions under the seven key technology areas for sub seafloor sampling identified prior to the meeting (Drilling technologies; Seabed drills; Long piston coring; Downhole logging and petrophysics; High temperature conditions; and Monitoring and instrumentation).

Critical technological development needed to achieve scientific goals was discussed in light of each work package. These needs include: Improved core recovery and quality in upper 100 m below seafloor, including the water-seafloor interface; deeper boreholes; development of uncontaminated coring and sampling methods; better in situ pressure cores; improved downhole logging, monitoring and drilling capabilities. Examples of the latter are improved abilities to perform geotechnical in-situ tests, sample gas, pore water, and water flow, and develop multi-instrumented corers.

It was clearly demonstrated that technology development is necessary for advancement in science as well as for obtaining more cost effective, safer and environmental-friendlier operations. Non-European actors are leading the engineering development in some areas, for example the development of deep drilling capacities are driven by groups in both Japan and US, but also by the European petroleum sector. However, substantial European engineering development has been achieved in five areas that should be further pursued: (1) Sea bed drills should be developed to expanded operation depths and improved logging capabilities; (2) Simple and non-expensive but yet very functional long-term instrumentation of shallow holes should be further developed. They should be ready to be employed from different platforms such as seabed drills; (3) Pressure sampling and (4) High-temperature tools should be further developed to preserve in-situ conditions for microbiology samples. Developers of high temperature tools should develop collaboration with the geothermal industry on Iceland; and (5) Long piston coring tools should further be developed regarding their capability of collecting large volume of cores.

Strategies for transferring technology developments to the European scientific community were discussed within the development of the next international scientific drilling program, as well as within the EU funding structure. Here, lessons to be learned by the petroleum industry and project management also were presented and discussed.

2 - Workshop objectives and programme

Investigation of the sub seafloor is essential to understand processes occurring in the deep sea. A large variety of tools has been developed either by industry or in academic groups, and these tools have been successfully used to obtain direct information by sampling or in-situ measurements.

Drilling is a key approach to direct sampling the sub seafloor and to providing boreholes that can be utilized for long term experiments. Since the late sixties, scientific ocean drilling has been conducted under the frame of successive international programs. The scientific community in Europe has currently access to scientific ocean drilling through the membership of ECORD (European Consortium for Ocean Research Drilling) to the international program IODP (Integrated Ocean Drilling Program)*. Additional, cheaper technologies also allow sampling the subsurface. Remotely operated seabed drills have been developed both for industry and for scientific purposes. Long piston coring provides cores up to ~75 m long of sediments. Box cores mostly fulfill the needs of the community interested in the seawater/seafloor interface. Industry has developed a large range of logging tools that are routinely used in scientific wells. In addition, instrumentation is deployed in boreholes for in situ experiments and long term monitoring.

New research targets require additional technological developments to meet with the scientific needs. In this general context, the workshop had several objectives:

- to review where we stand now in terms of technologies to directly investigate the subseafloor
- to identify the critical needs in technology required to fulfill the needs of the scientific community
- to identify key areas where Europe can make significant progress in the technology required
- to discuss possible strategies for making these technologies available to the science

The final goal was to develop strategies and recommendations to the various national and European programmes/funding bodies for a facilitated access to sub seafloor samples, in situ measurements and instrumentation.

Workshop Programme

Monday, February 21st

1 - Welcome (C. Mével and M. Ask)

2 – Summary of the science goals of DS3F and technological needs identified by the scientific workpackages

Moderator: Catherine Mével

- WP1 Lithosphere - biosphere interaction & resources: Gretchen Früh-Green
- WP2 Sedimentary seafloor and sub-seafloor ecosystems: past, present & future links: Gretchen Früh-Green
- WP3 Deep biosphere: R. John Parkes
- WP4 Sediment dynamics & geohazards: Achim Kopf
- WP5 Geofluids and gas hydrates: Achim Kopf
- WP6 Climate change & response of deep-sea biota: Thibault de Garidel-Thoron

3 - Drilling technologies

Moderator : Maria Ask

- G. Myers: "Riserless drilling with RMR »
- J. Thorogood: «Where is industry is going in terms of water depth, in-ice drilling capability and alternative techniques »
- B. Prevedel: "Land drilling innovations (e.g. GFZ InnovaRig) »
- Discussion

4 - Long piston coring and box coring

Moderator: Thibault de Garidel-Thoron

- Thibault de Garidel-Thoron: "Existing piston coring devices"
- Jean François Bourillet and Patrice Woerther : « Scientific coring : behaviour of giant piston corer and new insights on quality of the recovery".
- Discussion

5 - Seabed rock drills

Moderator: Bob Gatliff

- Bob Gatliff: Examples of seabed drill scientific use – what are the challenges ?
- Tim Freudenthal + Dave Smith: "Overview of existing seabed drills - necessary improvements"
- Discussion

6 - High temperature conditions

Moderator: Gretchen Früh-Green

- Gretchen Früh-Green: "Challenges in drilling hydrothermal systems"
- R. Asmundsson: "High temperature downhole instruments designed for wells drilled into supercritical reservoirs"
- Discussion

7 - Sampling devices

Moderator: Beth Orcutt

- J. Parkes: "The DeepIsoBUG System: description, results and developments."
- B. Prevedel : « Permanent downhole gas sampling and monitoring »
- B. Prevedel : « Status of the new Rotary pressure coring system (HYACE) »
- Discussion

8 - Wrap up for the day

Tuesday, February 22nd

9 – Monitoring and instrumentation

Moderator: Achim Kopf

- A. Kopf: -Instrumentation and monitoring of boreholes: measurements needed, flow of data, need for real time transmission
- B. Orcutt: "Long-term microbial observatory experiments in sediments and oceanic crust"
- P. Pezard: "Downhole hydrogeophysical monitoring"
- M. Ask: "Stress measurements in IODP holes"
- B. Prevedel: "Downhole monitoring strategies in ICDP and land drilling in general»
- Discussion

10 - Downhole measurements and petrophysics

Moderator: Sarah Davies

- Sarah Davies: "Scientific needs for borehole logging and petrophysics measurements"
- James Whetton: "Advanced Multi-Conveyance Logging in Small Diameter wells for Assured Data Acquisition: measurements and deployment methods »

- Masafumi Fukuhara: « "Petrophysical Logging vs Scientific Target" »
- Discussion

11 – Wrap up and preparation for the joint session with EDP

Moderator: M. Ask

- What are the most urgent developments
- Are there any bottlenecks?
- Are some development depending on other developments?

Joint session with EDP (IODP Engineering Development Panel)

Wednesday, February 23rd

12 - Summary of discussions

Moderator: R. Gatliff

13 - Funding strategies and opportunities

Moderator: C. Mével

- J. Thorogood: “Project management”
- P. Besse: “The EUROGIA+ scheme”
- R. Gatliff: “Broadening the scope of ECORD in the next phase of ocean drilling”
- Discussion

14 – Conclusions

3 - List of participants

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Figure 1: Participants to the DS³F and IODP EDP joint session

4 - Science goals of DS³F and requirements for sub seafloor sampling and instrumentation

All six scientific work packages (WP1 to -6) were invited to present a summary of their science goals. They were encouraged to emphasize their need for access to the sub-seafloor and the associated specific technological requirements to meet their scientific goals.

WP1 - Lithosphere - Biosphere Interaction & Resources

This work package has three main science objectives:

- (1) Assess the importance of lithosphere-biosphere interactions in global element cycles
- (2) Assess the biodiversity of organisms relying on lithosphere-biosphere interactions (on and below the seafloor), the processes sustaining their populations, their ecological role, and biotechnological value
- (3) Deep-sea mineral resources: assessing global distributions and potential environmental impacts of seafloor exploitation

Addressing these science topics will require in particular an improved understanding how ocean hydrothermal systems work and how they sustain a deep biosphere. To achieve this

goal drilling into active systems will be essential.

The following key technological requirements and challenges have been identified:

- Capability to drill in to fractured hard rocks (in particular zero age basalts) with good recovery
- Access to high temperature (up to 350°) drilling and logging tools
- Ability to recover the ocean crust/seawater interface
- improved recovery when drilling into fault zones (detachment surfaces) and into mixed lithologies)
- Minimum contamination for microbiological studies
- Long-term monitoring in high temperature and corrosive environments
- Less expensive way to sample fluids & monitor boreholes (especially in low and moderate T environments)
- More complete downhole logging

WP2 - Sedimentary seafloor and sub-seafloor ecosystems: past, present & future links

This work package stresses the importance of understanding the processes occurring at the sediment-water interface, as the area of exchange between the pelagic ocean (with high macro faunal diversity & activity) and the sub seafloor ocean (with high microbial abundance, high microbial diversity and high microbial activity). The key questions are the following:

- (1) How do processes and community structure in the surface ecosystems affect the deep biosphere on millennial and greater time scales?
- (2) How do deep-seated sedimentary and tectonic processes impact the surface sediments? They need to be addressed in a variety of environments: low oxygen environments, seeps, mass flow/turbidites, cold water coral ecosystems, Arctic sub-ice ecosystem, and low (dark) energy environments. Access to the sub seafloor is essential.

The following key technological requirements and challenges have been identified:

- Recovery of the water/sediment interface
- Coring technology for complicated sediments (e.g. sands, permeable sediments)
- In situ measurement, in situ sample conditioning, in situ recovery
- In situ sampling: cheaper, cleverer and faster
- Simple and flexible cabled observatories/ Development of long-term monitoring devices (e.g. osmotic pumps and eddy correlation)
- Under ice sampling

WP3 - Deep biosphere

The deep biosphere is an important component of IODP. Located in sub-seafloor sediments and rocks, it is only accessible by drilling.

The following key technological requirements and challenges have been identified:

- Pressure coring and handling
- In situ analysis, experimentation, cultivation
- Accessing the extremes- deep cores, ancient deposits, interfaces, hot formations, hydrocarbon formations, deep fluids etc. –all with minimal contamination

WP4 – Sedimentary processes & geohazards

The main objectives of this work package are the following:

- (1) Assess the role of sedimentation rate on ecosystems
- (2) Identify the important processes related to dynamic sediment remobilisation and landsliding
- (3) Characterize areas on the continental slopes and In the deep-sea that are prone to geohazards (seismicity, landslides, etc.)
- (4) Focus on the development of countermeasures (i.e. risk assessment, monitoring of precursors)

The following key technological requirements and challenges have been identified:

- Sub-seafloor sampling will likely be mission-specific
- *In situ* measurements/monitoring
- Conventional and/or geotechnical drilling
- Autoclave sampling (in gas hydrate areas)

WP5 - Geofluids and gas hydrates

The main objective is to address the role of gas hydrate destabilisation on climate change. It is both an urgent scientific challenge and of high societal relevance. A focus will be given to the Arctic region and its sensitive ecosystems in general, and on the stability of gas hydrate and release of geofluids in particular.

The major science objectives are the following:

- (1) Identify the important processes related to fluid flow, gas hydrate formation, and various types of seepage
- (2) Find emerging technologies for future study of such systems and characterization / quantification of resources
- (3) Focus on the global impact of gas hydrate dissociation for mankind and ecosystems

Drilling into key fluid release chimneys has never been done before but it is of regional and global relevance. It will provide opportunities for fundamental, forefront interdisciplinary research involving geophysics and geology, geochemistry, biogeochemistry, microbiology and biology in times of global climate change.

The following key technological requirements and challenges have been identified:

- Imaging of gashydrates before drilling: site investigation and good pre-drill images of the subseafloor are extremely important for reaching drilling targets
- Gas hydrate sampling: in situ pressure samplers, to prevent gas hydrate destabilisation
- *In situ* fluid sampling
- Uncontaminated sampling of the deep biosphere associated with methane seepage
- Imaging of gas hydrates in boreholes
- Borehole monitoring: temperature, pressure, fluid flow, etc.
- Drilling in Arctic areas

WP6 - climate change and response of deep-sea biota

The major science objectives are the following:

- (1) Biotic response to perturbations on different time-scales and for different rates of change, including extinctions and evolution (threshold behaviour of both biota and the climate system)
- (2) Climate Sensitivity and biotic impact
- (3) Ocean acidification
- (4) Magnitude and Rate of sea-level change
- (5) Modes of Ocean and Ecosystem Variability
- (6) Ocean ventilation
- (7) Ocean-bio-geochemistry, eutrophication, primary productivity
- (8) Evolution of the hydrological cycle
- (9) Cryosphere, Arctic and Antarctic research

The following key technological requirements and challenges have been identified:

- Optimize identification and retrieval of high quality and large volume sediment cores by means of state-of-the-art deep-sea drilling vessel (DV *JOIDES Resolution* type) and large diameter piston/box coring
- Drilling in high-latitude areas, specifically the Arctic and Antarctic.
- Riser drilling in deep sea fans to study linkages between tectonics and climate
- MSP approach for a common European long piston coring system
- Mobile DOSECC (Drilling, Observation and Sampling of the Earth's Continental Crust) type coring system, particularly for lake drilling activities (e.g. ICDP, International Continental Scientific Drilling Program)
- Access to MeBo (Meeresboden-Bohrgerät) and BGS RD (Rock drill) 2 type systems (~50-100 m coring depths; 2-5 km water depths)
- Large volume coring systems such as the CASQ (Calypso Square) corer.

5 - Sub-Seafloor Sampling and Instrumentation: current situation and identified needs

Most of the workshop was dedicated to a review of where we stand in terms of technologies directly investigating the sub-seafloor, and where improvement is critical to meet our science objectives. Seven key areas had been identified prior to the workshop, and workshop participants were encouraged to organize their presentations around these topics.

5.1 - Drilling technologies

This first topic addressed drilling from drilling vessel platforms.

From the beginning, scientific ocean drilling has relied on the technology developed by oil and gas industry. Ocean drilling is either implemented from drilling vessels or drilling platforms when the water depth is appropriate. Successive ocean drilling programs have traditionally relied on a dedicated drilling vessel, initially DV *Glomar Challenger*, replaced in 1985 by DV *JOIDES Resolution* currently still in operation, after a major refit in 2009.

In the current set up of IODP, with its multiplatform approach, IODP aim at open access to most oceanic environments to the international scientific community (Figure 2). In the current phase of IODP, the concept of MSPs (Mission Specific Platforms) has been introduced by

ECORD, and the riser drilling vessel *CV Chikyu* has been introduced by Japan, in addition to the pre-existing *DV JOIDES Resolution* that has been provided by USA. MSP platforms are contracted on a case-by-case basis to drill in shallow waters and ice covered areas. Using existing industry platforms for scientific purposes, MSPs have expanded the range of scientific goals that can be addressed by IODP, for example by drilling dramatically different environments, from the high Arctic to shallow reef in the tropics. The *DV Chikyu* is equipped with a riser system that allows drilling into unstable formations and to greater depths (6-7 km).

The drilling technology within the IODP and its predecessors has often been adapted from industry that routinely drill wells to greater depths than normally performed by the IODP. The deepest non-riser borehole drilled by *DV JOIDES Resolution* is 2111 mbsf (m below seafloor), and the deepest riser-drilled borehole by *DV Chikyu* is 3700 mbsf (under non-IODP operations). As a comparison, the deepest off-shore oil well ever drilled reached a vertical depth of 10683 m (Transocean Ltd., *Deepwater Horizon*). Because scientists have requirements that differ from what is routinely achieved within the industrial world, the technology also has been modified to meet the specific needs of scientists.

What is unique is with scientific drilling is the water depth, as well as the borehole depth, and the rocks to be recovered. Science targets generally are located in much deeper waters than industry targets. The deepest site ever drilled by the scientific ocean drilling program is located in 7044 m water depth, compared to the deepest exploration well drilled by industry (as of year 2009) was located just below 3051 m water depth. In addition, most scientific studies require continuous, good quality, sampling. Adapted coring systems developed by TAMU (Texas A&M University) over the years are routinely used within the IODP. For example, the APC (Advanced Piston Corer) has proved its efficiency to recover relatively undeformed sediment sections, essential for paleoclimate reconstructions.

There are still long standing issues, however. Drilling does not allow the recovery of the first decimeters or even several meters beneath the seabed and, therefore, does not provide samples for the water/seafloor interface. Good recovery in some formations, such as young fragmented basalts, sands, mixed lithologies, fault zones, etc., is still problematic. Starting holes in bare rocks remains a challenge. The current *DV Chikyu* riser system has a water depth limitation of 2500m, leaving a large percentage of the ocean basins out of reach for deep drilling. Work is progressing to expanding the water depth capacity to 4000 m water depth.



Figure 2: Three types of drilling platforms in IODP: a) Non-riser drilling with *DV JOIDES Resolution*, b) Riser drilling with *DV Chikyu*, c) mission-specific drilling (here: Example of Arctic drilling).

Because drilling targets become deeper and deeper also for industry, the water depth boundary is being expanded and the last generation of industry riser vessels is designed for 3700m.

A promising emerging technology is being developed: the RMR (riserless mud recovery) system allows a continuous circulation of engineered mud that leads to better well control. RMR systems can be applied for various drilling vessels after relatively minor modifications. A mud suction module is located at the seafloor that returns the mud from the borehole to the ship through a separate pipe. It provides a continuous rock record using cuttings even with low core recovery. The RMR system creates two pressure gradients, the hydrostatic pressure that starts from the DV and includes the water column and the well pressure that starts from the seafloor and include the drill mud and the formation pressures. Therefore, it is often referred to as dual gradient drilling. In contrast, all pressure gradients start from the DV for riser drilling. The RMR system represents an alternative technology to drill deep holes in very deep waters. It is already in operation in water depths up to 1600m, and Ocean Leadership is leading the work within IODP together with the oil and gas industry to make this technology available for ultra deep water and scientific drilling. The muds are generally rated up to 250°C, which limits the areas where deep drilling can be achieved with this system.

As mentioned above, industry is expanding their deep water capabilities for new vessels, but also regarding the drilling system. Parallell development of advanced riser designs and dial gradient system is occurring. Actions to improve core recovery include improvement on the active heave system as well as development of seabed drill rigs (see further Section 5.2). New generations of in-ice units are developed, as well as the drilling planning aspects are the focus of industry efforts. For drilling in the Arctic, the operational methods are well understood. However, drilling planners must address logistics, specialist units required for water depth range, and station keeping aspects

Industry is developing “mechanical Earth modelling” methods for a drillability analysis and risk reduction. Extensive work is also being done to understand the drill string dynamics. In conclusion, industry is actively developing technologies of potential benefit to the science community. New hardware and drilling systems promise radical new opportunities. Engineering and modelling methods may well be of use in the planning of scientific projects. It is essential to maintain a continuous dialogue between academia and industry. However, commercial rigs do not always provide the core quality required for scientific drilling. This led GFZ (GeoForschungsZentrum, Potsdam) to build the InnovaRig, based on oilfield technology combined with mining drilling.

5.2 - Seabed drills

Seabed drills are remotely operated drilling tools deployed from standard vessels directly on the seafloor. There are a number of advantages for using seabed drills rather than a drilling vessel/platform. They are up to 4 times cheaper to operate than a standard drill Ship. They can be operated on vessels with other coring systems. They collect high quality cores both in soft sediments and hard rocks. They can collect core samples that cannot be collected by any other means from the seawater/ocean floor interface. In addition, the BGS drill allows collecting directly oriented samples, which may be critical for tectonic studies.

A number of tools have been developed worldwide, either by industry or by academic groups. Industry is presently more and more interested in seabed based drilling units. Europe is at the

forefront of scientific seabed drills, with the tools developed at MARUM (Center for Marine Environmental Sciences), Bremen (MeBo) and at BGS (British Geological Survey), Edinburgh (RD2), see Figure 3. They are routinely operated from research vessels to address scientific questions in a wide range of environment.

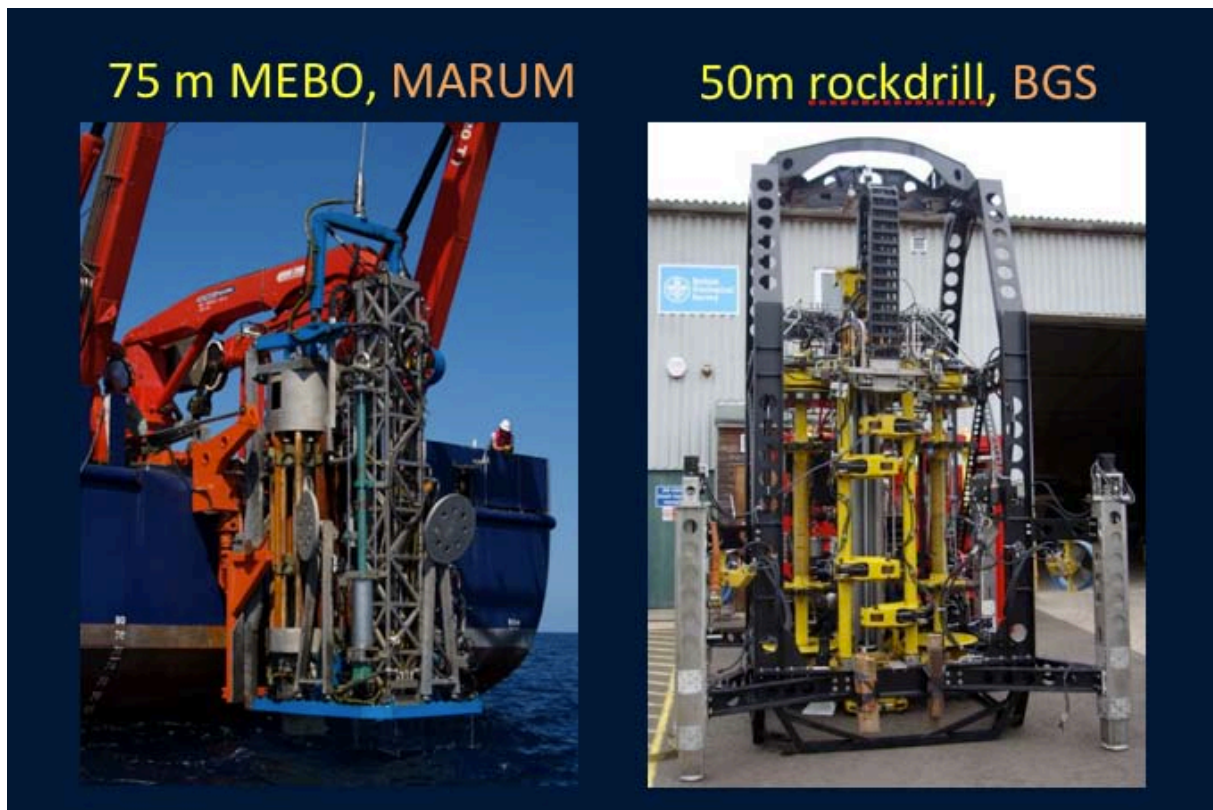


Figure 3: MEBO (left) and BGS Rock Drill 2 (right)

Although it is a proven and efficient technology, there are currently some limitations in the use of these tools. The maximum water depth is 2 km for MeBo and 4 km for BGS RD2. The drilling depth is constrained by rig power, magazine capacity, drill tool size, weight, etc. Maximum drilling depth reaches 75m for MeBo and 50m for BGS RD2. Several of the industrial sea bed drill rigs allow for greater penetration, for example, down to 125 m (PROD), 90m expandable to 200 m (ROVdrill3), 150 m (GREGG seafloor drilling system).

Logging is currently restricted to low energy consumption tools, spectral and induction tools but it would be possible to adapt magnetic susceptibility and optical sensors. There are developments and testing ongoing at MARUM. There is also a strong potential in using boreholes for in situ monitoring. This requires the development of specifically adapted instrumentation to fit with the borehole diameter, as well as the use of an ROV to deploy instrumentation (see Work package 8, Infrastructure & Synergies).

In conclusion, remotely operated seabed drills are promising, relatively cheap tool to use, but require further development to better meet the needs of the science community.

5.3 - Long piston coring



Figure 4: Piston coring using a) Calypso corer, b) WHOI long core , c) CASQ (CALypso SQUARE) corer.

Piston coring is traditionally used from all research vessels around the world to collect sediments from the seafloor. A number of systems have been developed worldwide, all derived from the Kullenberg corer that can be operated theoretically at all water depths with various maximum sampling depths. The Calypso corer developed by IPEV (Institut Paul Emile Victor, Brest) and operated from the research vessel RV Marion Dufresne has the sampling depth record of 75m (Figure 4a). In comparison, the WHOI Long Core (Woods-Hole Oceanographic Institution) can collect cores up to 50 m in length (Figure 4b); the STACOR© corer, developed by IFP (French Institute of Petroleum) and Fugro, reaches depths of 35 m; and ~20 m of penetration has been obtained by the hydrostatic corer Selcore that was developed jointly in Norway by Selantic AS and the University of Bergen. Selcore is designed as a gravity piston corer, but it also has potential as a seabed seismic hammer source (http://www.geo.uib.no/hjemmesider/yngve/docs/hydrostatic_corer.pdf).

Scientists require more and more material as analytical methods diversify. To avoid duplicating coring operations at the same site and save shiptime, IPEV developed the CASQ, a square gravity corer with a 25x25 cm section (Figure 4c). It provides a larger amount of sediments but its sampling depths is limited to 12 meters. There are also lighter devices aiming at capturing the water/upper sediments interface. They vary from boxcores to multic gravity orer.

All these tools have proved very efficient. In particular, the Calypso corer is the key tool to the IMAGES (The International Marine Past Global Change Study) community interested in paleoclimate variations during the last million years (<http://www.images-pages.org/home.html>). It has been routinely deployed around the world oceans to collect cores for the international science community. However, despite this remarkable success, a number of issues have been identified when using this system. If not well understood, they may have an impact on the interpretation of the cores, in particular in terms of dating and evaluating sedimentation rates. Below follow some of the problems that are occurring:

- Oversampling/undersampling depending on the formation
- Disturbance in sedimentological fabrics
- Voids and lack of recent sediments
- Gas expansion
- Inability to penetrate/recover coarse sediments- poor positioning (latitude, longitude, depth)

IPEV and IFREMER (L'Institut Français de Recherche pour l'Exploitation de la Mer), with additional advice from Genavir, SHOM (Service Hydrographique et Océanographique de la Marine) and some French Universities are currently joining efforts to improve the sampling quality. Sensors installed on the corer allow studying these problems. There is clearly room for improvement. Assessment of corer behaviour allows better settings to:

- reduce the duration of the elastic recoil phase
- increase the success rate of operations
- improve the penetration
- improve quality and geometry of recovery
- provide corrected depths

The tool must be chosen as a function of the objective. It may be relevant to combine the use different coring system at the same site to cover all aspects.

5.4 - Sampling devices

Specific sampling devices are required for particular scientific goals. At the workshop, the discussions focused mainly on *in situ* pressure sampling, which is key to a number of scientific goals. ICDP has developed gas and fluid sampling programs to fulfill the need for real-time analysis of drill-mud gases during land drilling to know concentrations of CO₂, CH₄, H₂, and radon. Several methods are used:

- Real-time analysis of drilling mud gas. This method was applied by IODP during drilling in NanTroSEIZE (The Nankai Trough Seismogenic Zone Experiment). It is used to detect fault zone (at SAFOD, San Andreas Fault Observatory at Depth), CO₂ monitoring, Gas membrane sensor.
- U-tubes devices in downhole observatories for fluid sampling. Fluid monitoring during pump tests

There are no major engineering challenges currently for land-based real-time gas analysis, as many different technologies exist. One potential development is the use of U-tube devices for microbiological sampling (if appropriate sterilization controls are useable).

Attempts to develop *in-situ* pressure sampling were initiated by gas hydrate research. Gas hydrates have a stability field restricted to specific P- and T conditions. Therefore, when brought to the surface, they tend to dissociate and melt, making it impossible to study them in laboratory conditions. For the completely new field of the deep biosphere, pressure sampling is also critical, to isolate the bacteria under *in situ* living conditions.

The systems described below were developed within projects funded by the EU and the DFG (German Research Foundation), which involved a consortium of industry and academia. Partners include: TU Berlin, TU Clausthal, University Cardiff, Fugro, Geotek. The tools that have been developed are HYACE (Hydrate Autoclave Coring Equipment), HYACINTH (HYACE Tools in new Tests on Hydrates), and PRESS (Pressurized Sub-sampling and Extrusion System). These systems started being developed in the late nineties and have been successfully used during ODP (Ocean Drilling Program) and IODP expeditions thereafter.

The DeepIsoBUG system coupled with the HYACINTH pressure-retaining drilling and core storage system and the PRESS core cutting and processing system enables deep sediments to be handled without depressurization (up to 250 bar), and anaerobic prokaryotic enrichments and isolation to be conducted up to 1000 bar. Currently, samples can be collected <250 bar,

and then incubated <1000 bar – allows for studying piezotolerant – piezophilic microbes. Tests with sediments from IODP X311 (Cascadia Margin) and Gulf of Mexico show that there is significant growth of cells under pressure compared to without, that enriched microbes come from many environmentally relevant phyla, that the enriched microbes can also grow at 1 atm (piezotolerant). Another concept, the MAC-OMEGA pressurized multicorer, designed by Ursula Witte (Aberdeen) with TU-Berlin – is currently in development.

There are still challenges for routine collection and maintaining of pressurized sample.

- There is a desire to be able to collect and maintain sediments >250 bar, to be able to study true piezophiles under in situ conditions. The current limitation is the flapper valve on the HYACE – it would be very difficult to design a safe-to-operate system for >250 bar.
- Current operation of HYACINTH+PRESS is very time consuming and limited by available devices. In general, only 1-2 depths could be sampled during an entire expedition.
- There is a need for a sampling device for microbiological work coupled to the MAC-OMEGA system, akin to a giant pressurized syringe.

5.5 - Downhole measurements and petrophysics

Downhole logging measurements provide continuous data from strata beneath the seafloor and are the only source of in situ information about the physical properties of rocks (or sediments) and fluids. Routinely measured during industry and scientific (ODP/IODP) drilling, log data integrated with core information (lithology, mineralogy, fabric, physical properties) can be used to address key geological questions, including how the underlying geology controls the petrophysical properties, what are the spatial and temporal relationships in palaeoclimate studies, where fluids will flow within the earth's crust and how to estimate the abundance and distribution of hydrates beneath the sea-floor.

Downhole logging tools are primarily developed by the oil and gas industry and state-of-the-art tools have been developed to do generate a range of data. Primarily developed to characterize reservoir lithologies (sandstones, carbonates and mudstones), they are used in the ocean crust with varying degrees of success. However, the measurements for oilfields are not necessarily similar to those needed by the science community. There is the potential for developing tools with industry driven by need. But it is essential for the science community to state precise specifications.

There are ongoing joint technology developments between industry and academy in Europe, for example ShiFT at EPC (The European Petrophysics Consortium), Montpellier, and HPHT (high pressure high temperature) logging tools spectral gamma ray and BHTV (borehole televiewer) tools developed for geothermal (see also Section 5.6). Examples of technology developments that have been developed by industry but later is used by the scientific community include NMR for Hydrates, Hydrates temperature (Fukuhara, et al. AAPG Memoir 89), and logging from non-standard platforms (i.e. seabed rock drills). There are particularly requests for resistivity images from seabed rock drills. Industry is involved in tool development, for example industry advice is accessing know-how (e.g. tool delivery) for scientific expeditions and oilfield slimline technology; Unknowns are tool developments from the community e.g. microbiological downhole tools; and Core petrophysics: discrete S-wave measurements.

5.6 - High temperature conditions

Penetration of the seafloor is likely to encounter high temperature conditions in areas of high thermal gradients (close to magma chambers, in active hydrothermal systems) and at the bottom of deep holes (beyond several kilometers, depending on local temperature gradients). This raises the issue of the resistance of tools. Attempts by ODP and IODP to drill in hydrothermal systems have been really challenging. In several occasions, the high temperature conditions encountered have resulted in the damaging and destruction of tools, for example melting of plastic liner commonly used to retrieve cores, melting of temperatures probes.

The major advances in this field come from the geothermal industry. Iceland, in particular, has been at the forefront, with the IDDP (Iceland Deep Drilling Project). A number of instruments have now been built and applied in Icelandic high temperature areas, under the HiTI (High Temperature Instrumentation) project supported by the EC under the Framework Program 6 (FP6). It gathers partners both from academia and SMEs. Major progress has been made and most tools resist to temperatures up to 300°C: temperature, pressure, flow measured up to 400°C (multisensory developed by CALIDUS Engineering), a wireline system developed by BRGM (France), the natural gamma radiation spectrum gauge as well as the 300° borehole tele-viewer from ALT (Luxemburg). GFZ (Germany) has expanded to 280°C the maximum temperature of their fiber-optic distributed temperature sensing system that allows to instantaneously measure temperature at any depth simultaneously. Geochemical tracers are used up to 350°. HiTI MultiSensor in IDDP-1 well (CalEng) Geosciences Montpellier (France) is conducting laboratory deformation and resistivity experiments at high temperature to better understand the behaviour of in these extreme conditions.

To expand the current limit, continued high temperature tool development as well as laboratory and field testing are required. Among the challenges that remain to be addressed in future years to expand the limits of high temperature drilling and borehole monitoring, the following are particularly critical:

- Additional physical parameters at high temperature, including seismic, sonic and resistivity micro-imaging.
- Pressure and temperature sensing in the 400-600°C range.
- Seismic while drilling methods.
- TEM and MT at higher resolution.
- Fluid sampling.
- High temperature electronics.

5.7 - Monitoring and instrumentation



Figure 5: CORK deployment on the Chikyu

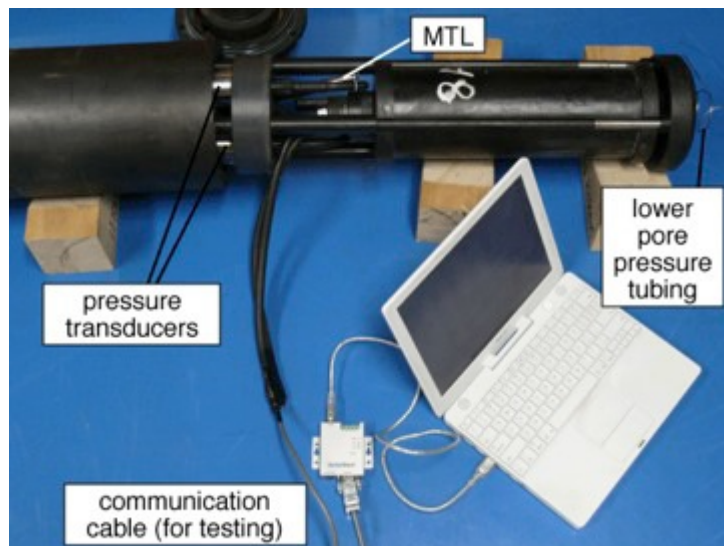


Figure 6: SmartPlug/GeniusPlug

Boreholes provide unique opportunity for conducting experiments in the subsurface and for long term monitoring. It is an essential approach to investigate active processes such as fluid flows in the subsurface or earthquake generation.

To allow reestablishment of equilibrium in in-situ conditions (necessary to understand hydrogeologic state and processes) the need for sealed-hole experiments was identified by the science community. It led to the development of CORKs (Circulation Obviation Retrofit Kit) by ODP. The original CORK was a simple instrumented seal plugged in the borehole. The concept evolved over the years with the ACORK (Advanced CORK) that allows multi-zone isolation in the borehole with packer systems. Moreover, the range of sensors deployed in the sealed borehole became more diversifies. The initial simple T and P measurements evolved

toward more complex instrumentation (strainmeters, tiltmeters, borehole seismometers, chemical sensors, osmotic samplers, etc.).

CORKs are emplaced for long periods of time (from months to years) during which data are recorded. Data can be retrieved periodically using ROVs. But ideally data are transmitted in real time through cabled seafloor observatory. For instance, a CORK deployed in a borehole of the Juan de Fuca plate is now connected to the “Neptune Canada” cabled network. The IODP NanTroSEIZE project, to investigate the Nankai seismogenic zone off Japan, includes an ambitious long term monitoring program (see <http://www.jamstec.go.jp/chikyuu/eng/Expedition/NantroSEIZE/index.html>). The plan is to connect CORKs emplaced in boreholes to the DONET cabled seafloor observatory network. Initially developed by Earth scientists to investigate active processes, the CORK approach has now attracted the microbiology. Exciting new developments include the connection of umbilicals to sample the fluids, colonization experiments to avoid contamination and attempts to image life in the borehole (UV). A major CORK experiment is planned during IODP expedition “Mid-Atlantic Ridge microbiology” at North Pond in the fall of 2011. The installation of CORKs require long term planning that includes servicing with ROVs, to retrieve the data and/or change batteries, etc. For long term monitoring, coordination with seafloor observatories is essential.

The tendency towards more and more complex instrumentation has resulted in difficulties in implementation. Problems may result from various factors, from hole collapse that complicates installation through stuck instruments to instrument failure (for example packer systems). Moreover, complex CORKs are very expensive to develop. Therefore the need for arrays of simple, cheap, instruments coupled to one or two complex CORKs has been identified. Condensed to a bare minimum, the first-generation “mini-CORK”, termed SmartPlug, was designed by ECORD scientists from Germany and Canada to record formation pressures and temperatures. The second-generation “mini-CORK”, termed GeniusPlug, consists of a SmartPlug to which an extension containing an osmo-sampler for fluid geochemistry and a FLOCS (Flow-Through Osmo Colonization System) unit for microbiology are added at the bottom. The successful initial deployments during the NanTroSEIZE project have shown that the “mini-CORK” concept may be a feasible, low cost approach to time-series data and, in case of the GeniusPlug, samples.

In parallel, the concept of “downhole multisensor monitoring array” is being considered. To address specific science questions such as distribution of gas hydrates, landslide dynamics, CO₂ monitoring, strain in soft sediments, etc., there is a need to combine different measurements in boreholes. These may include electrical conductivity and magnetic resonance measurements, fiber optics (temperature, strain), hydrodynamics and fluid flow. Currently these measurements are done in several associated holes. A single well solution would be the ideal option, but is hard to achieve owing to space limitations.

6. The European Contribution to Enabling Science Goals

In the previous section, a wide range of technological needs and challenges that will help the science community achieve its goals are identified. These include in particular:

- Increased water depth capability of riser systems and/or development of the alternative
- Better understanding of drilling parameters to improve core recovery

- Increased capabilities of seabed drills (water depth, drilling depth, logging options, geotechnical measurements with onboard CPT, placement of long-term sensors, etc.)
- Better monitoring of the piston coring process to improve core quality
- Systematic instrumentation of corers deployed during long piston coring operation to measure in-situ conditions during the coring
- Lighter and safer techniques to maintain *in situ* conditions
- Adaption of industry logging tools to academic needs (i.e. logging in small diameter holes)
- Logging from non standard drilling platforms (seabed drills)
- Need for a new generation CORKs, simple, affordable and easy to operate
- Need for multi-sensor arrays for borehole instrumentation

These technological challenges are in essence in line with those identified in the Technology Roadmap that has been developed by the IODP EDP (Engineering Development Panel), available at: www.iodp.org/edp.

Substantial progress can rely on technology transfer from industry. However, some needs are unique to academic fields. Academic groups should take the lead, in cooperation with industry when appropriate. Given the current expertise existing in Europe in universities/institutes, the workshop participants identified five major areas in which they felt that Europe could play a leading role.

Seabed drills

Several workpackages identify the need for access to seabed drills, as a cheaper drilling tool that can be deployed from a conventional vessel, but also as tool fit to recover the seawater/seafloor interface. Although industry is now interested, MARUM and BGS are the leaders for scientific seabed drills, developed specifically to meet scientific requirements. There are plans, in particular at MARUM, to expand the depth capabilities up to 200 m in the near future. Adding logging capabilities and allowing fluid sampling is also an important challenge that is being addressed. Another important goal is the instrumentation of boreholes generated by seabed drills for long-term monitoring. This would allow the monitoring of an array of holes at a reasonable cost, compared to the EORK concept developed within IODP. Clearly, in the next decade, seabed rock drills and associated instrumentation will become standard tools for subseafloor sampling.

Long piston coring

There is a strong expertise in Europe in long piston coring, the central tool of the IMAGES community, but also used for sedimentology investigations. Despite other recent developments, the calypso corer remains the longer sampling depth. It has been developed and is operated by IPEV (Institute Paul Emile Victor, Brest) and is operated from the Marion Dufresne. IFREMER, but also NOC (and others?) are also routinely using piston cores. IPEV and IFREMER are already sharing their experience to improve the core quality. The main challenges for the next decade are two longstanding goals that have never been achieved:

- recovery of sandy layers
- expanding the sampling depth to 100 m

Another avenue of development is to outfit the corer with instruments. To systematically document *in situ* conditions, appropriate sensors could be installed on the corer. This

information is precious in particular to directly document the living conditions of micro-organisms of the deep biosphere. Dialogue between the piston coring operators/developers and the deep biosphere community is required.

***In situ* pressure sampling**

There is a high demand for in situ pressure sampling and core transfer under pressure, in particular for microbiology and gas hydrate studies. The first tools (HYACE, HYACINTH, PRESS) were developed by Consortium of industry and academia. Partners included TU Berlin, TU Clausthal, University Cardiff, Fugro, and Geotek. Although some of the initial partners have lost interest, the expertise is still there in Europe.

Beyond the current applications in academia (essentially gas hydrates trapped in sediments and the deep biosphere), there are other potential fields of research that may benefit of in situ pressure sampling. In particular, people working in carbon capture/sequestration (CCS) may be interested in the HYACE system for work looking at carbon dioxide. They might be interested in partnering to design a higher pressure system.

High temperature tools

WP1, and to some extent also WP3, are in demand for coring in relatively high temperature regimes in hydrothermal fields or deep to ultradeep boreholes. The geothermal industry has been the driver of the development of high-temperature tools and Iceland is at the forefront. There is already a consortium of universities and SMEs built around ISOR in Iceland. The tools developed for continental drilling have to be modified for offshore applications. A temperature capability of 400°C would fit with most science objectives in hydrothermal fields. In these environments, corrosion is also a challenge. At moderate temperatures, below the limit of life currently established at ~120°, contamination problems (possibly generated by the tools themselves or by circulation in boreholes) need to be carefully investigated.

Borehole instrumentation

Investigating active processes is one of the high scientific priorities for future studies of the deep-sea frontier. Europe can play a leading role by specializing in relatively simple instruments that can be installed either in holes drilled by conventional drilling vessels or with seabed drills. The handling of the tools with ROVs instead of a conventional drill string will result in substantial cost reduction. The development of the SmartPlug and the GeniusPlug demonstrate that the expertise exists. A critical challenge is the implementation of the “downhole multi-sensor monitoring array”, that will allow to combine all measurements in a single hole.

The EC-funded EMSO (European Marine Seafloor Observatory) project, currently in progress, is developing methods of recording and transmitting data from the seafloor and the water column. Offering the possibility of monitoring processes occurring in the subsurface is a key contribution. In most scientific cases, a seafloor observatory should include the third dimension, i.e. documentation of active processes occurring in the subsurface. For example, understanding the functioning of cold seeps at the seafloor requires the monitoring of fluid flows in the subsurface. Teaming up with EMSO will be crucial to share expertise and develop systems that are compatible/interoperable.

Joint session with the IODP Engineering Development Panel (EDP)

EDP is composed of international experts in all fields of technologies related to subseafloor direct investigation (see <http://www.iodp.org/edp/> for details)

The panel is familiar with the needs of the scientific community, and over the past years has developed a comprehensive road map for the technological developments required to meet them. However, in the current tight budget situation of the IODP, there is no substantial funding within the program to implement this road map. Therefore, all initiatives from interested parties have to rely on 3rd party funding, and outside contributions to the implementation of specific aspects of this road map are most welcomed by the panel.

The session with the DS³F workshop participants and the EDP panel meeting participants was kicked off by a „Tour de table“ and a short presentation by the coordinator of what DS³F is about and will try to achieve. The results of the discussion among the DS³F workshop participants were presented to EPD. In the light of the established expertise of various groups in Europe, the panel endorsed the five identified areas for future focus in engineering development associated with subseafloor sampling and instrumentation.

The EDP, and its chair Bill Ussler, expressed their full support of the DS³F initiative in EDP Consensus 1102-04: DS3F Initiative: The EDP strongly endorses the ongoing efforts by Work Package 7 (WP 7), Mission-specific sub-seafloor sampling within the European Union coordination project - “Deep Sea and Sub-Seafloor Frontier” (DS3F). The EDP recognizes that this effort has the potential to contribute to needed and important engineering development for the new IODP, and that the source of funding would be outside that currently is contributed by ECORD to the IODP. This information is routed to other IODP bodies, including IODP-MI (IODP Management International, Inc.), STP (Scientific Technology Panel), SPC (Science Planning Committee), Lead Agencies, IWG+ (International Working Group+).

7. Possible organization and funding strategies in Europe

7.1 Towards a distributed infrastructure for sub-seafloor sampling and instrumentatin in Europe

Expertise in the identified technologies exists in Europe, but it is disseminated in various universities, institutes and even SMEs. To make significant progress, strong collaboration between research & operational groups across Europe would be beneficial.

Most activities related to scientific drilling have been undertaken under the frame of successive international programmes (DSDP, ODP, IODP). In the current phase, Europe not only participates as a contributing member, but has developed the concept of “Mission Specific Platforms” (MSPs) contracted on a case-by-case basis in areas not accessible to the other drillships operated by IODP, DV *JOIDES Resolution* and DV *Chikyu*.

To operate MSPs, ECORD has set up the “ECORD Science Operator” (ESO), a consortium of universities/institutes that all contribute to the operations. This set up was facilitated by the ECORD-Net project funded under FP6 (2004-2008), that helped set up the structure and organization of ECORD. ESO is composed of three main entities each of them with a specific expertise. The British Geological Survey is in charge of the management as well as

platform contracting and operation. MARUM overlooks the core curation, analyses and storage - these activities are largely integrated with the BRC (Bremen Core Repository), one of the three core repositories of IODP. EPC (European Petrophysics Consortium) is a consortium composed of the University of Leicester (UK), Geoscience Montpellier (France) and the University of Aachen (Germany) and in charge of downhole and petrophysics measurements. Up to now, and as stated in the MoU signed between ECORD and the Lead Agencies of IODP (NSF, USA and MEXT, Japan), ESO has implemented IODP expeditions using exclusively drilling platforms, from conventional geotechnical vessels to a lift barge. However, for the future phase, the ECORD council is willing to expand the MSP concept to other tools; in particular seabed drills and possibly long piston corers, to better meet the needs of the science community and also decrease operating costs when possible. As part of this process, ESO is actually currently scoping a project to drill the Atlantis massif at the Mid-Atlantic Ridge using a seabed drill to allow a better sampling of a large detachment fault surface. Therefore, in the future, ESO is likely to contract not only large drilling platforms, but also alternative tools such as seabed drills to be operated on regular vessels.

Although the new science plan has been released in June 2011, the future of IODP (post 2013) is not yet settled. However, it has already been decided that the new organization, which is still under discussion, will give more independence to the “implementing organizations” (IOs) that operate the drilling platforms. This is an opportunity for Europe to seize solutions that include affordable seabed drills or other strong European technological branches and select drilling targets according to the infrastructural opportunities and ECORD budget constraints. As can be seen from active IODP drilling proposals, mission-specific platforms can cover niches of utmost scientific challenge and timely topics. Hence, tendencies in Europe to complement the commingled IODP funds on the national level with some project-based funding by 3rd parties (be it industry, foundations, the EC, etc.) may offer chances for combined projects where IODP is paying the drilling operations while the 3rd party funds site surveys, borehole instrumentation, or research on the core or data recovered from the cruise. This avenue should be explored further during the remainder of DS³F.

We suggest to build on the ECORD/ESO experience and develop a **distributed infrastructure for sub-seafloor sampling and instrumentation** in Europe relying on existing disseminated expertise and tools. This network of partners with a recognised expertise to better serve the technological needs of the science community will allow to:

- Develop stronger collaboration between research & operational groups across Europe (e.g. MARUM Bremen and BGS seabed drills)
- Increase the visibility of the different nodes of the network by appearing as a strong, integrated entity
- Avoid duplication
- Operate the tools with a concerted approach and therefore facilitate access to the scientists
- Share knowledge and experience in order to facilitate the necessary improvement of existing technologies
- Develop joint projects and jointly seek or funding. New funding opportunities will be explored, such as other Ministries (beyond Research) at the national level (Industry, Environment, etc.), the European Commission (hopefully as a support to the DS³F), joint ventures with industry (SMEs and larger companies), EUROGIA+ (see below), etc.
- Provide capabilities for sustainable use of samples and data, following the excellent model of the successive ocean drilling programs that is based on open access
- Provide training for younger generations
- Facilitate links with other programmes as well as with international partners

This distributed infrastructure will be open to all scientists in Europe, either via organized programmes (such as ECORD/IODP and IMAGES) or as a support to projects developed by individual PIs. Sharing expertise with the ICDP is crucial, because ocean and continental drilling operate common tools, and have the same data management and core curation issues. Moreover, ICDP commonly drills in lakes, i.e. under water in lacustrine settings. The distributed infrastructure approach will make the interaction other existing infrastructures easier. This will be key for the relationships with **EMSO** (European Multidisciplinary Seafloor Observatory) in particular.

Most of the tools described in this report are operated from surface oceanographic vessels. Access to shiptime will be essential to fulfill the needs of the science community. Currently, only scientists from major oceanographic countries have access to significant research fleets. Moreover, the research fleets are mostly operated at the national level, although some agreements exist between major operators (France, Germany, UK, and a few others). The **EUROFLEETS** scheme, initiated by the European Commission within FP7, offers access to major vessels in Europe, but remains currently extremely limited in available shiptime. Securing this scheme and expanding the available shiptime to allow implementation of projects addressing processes in the sub-seafloor and therefore operating access to tools.

7.2 - A potential funding scheme for technological developments: EUROGIA+

Among potential new avenues of funding, the EUROGIA+ scheme should be explored, as was presented by Pierre Besse (EUROGIA+ Vice-President & Technical Committee Chairman). This scheme initiated from the recognised need to mitigate the energy consumption and related CO₂ emission growths by providing cleaner and safer technologies and processes to produce energy from all available resources in the energy mix, from fossil to renewable energy sources. In this overall context, EUROGIA+ is the EUREKA cluster dedicated to energy technologies. It includes the full energy mix: renewable energies and decarbonization of fossil fuels. It received from EUREKA a 5-year mandate to run its R&D program, from project proposals evaluation to selection and label.

EUROGIA+ promotes and facilitates partnerships between industrials and researchers *across EUREKA member countries*. It promotes projects to Public Authorities and facilitates access to national financial support. Its ultimate goal is to help develop low-carbon energy technologies that are environmentally friendly while providing an affordable energy supply that satisfies the growing energy demand.

EUROGIA+ encourages partnerships between competencies covering a large spectrum of disciplines. It addresses two main domains:

- 1) Critical Energy Technologies (geothermal, oil and gas)
- 2) Enabling technologies: Tools fabrication & Installation; Information & Communication Technologies (ICT); Materials; Energy Efficiency; and Education and training

Submitting a project is a two steps process: (1) the Project Outline (PO) is a short document addressing basic evaluation criteria. Hearing of the Principal Investigator (PI) and evaluation are conducted by the Technical Committee; and (2) If the first step is passed, the Full Project Proposal (FPP) is a complete proposal's description and is also evaluated by the Technical Committee.

To be successful a project should promote industrial Innovation but demonstrate that it is a proven concept and be market-oriented. The Consortium Structure should be balanced and include both academia and industrial partners. It should emphasize existing commercial prospects. Finally, the project should fit with national priorities and practices. A successful project is labeled and the funding comes from the national level. Up to now, a total of 210 M€ have been requested in “Projects Outlines” of which 77 M€ have been labeled.

The supporting countries are currently Austria, Belgium, Croatia, Denmark, France, Germany, Hungary, Iceland, Ireland, Israel, Monaco, Norway, Poland, Slovenia, Spain, and Turkey. Hopefully, this list will expand in the future. There is some overlap with the ECORD member countries (in italics), but some of the major actors are missing, in particular Germany and UK.

This scheme looks particularly promising to develop joint projects between academia and industry.

7.3 – Management of complex projects

John Thorogood, Drilling GC, and retired from British Petroleum and formerly ECORD delegate of the EDP, raised the issue of the management of complex technological development projects. The industry has been working very hard with management of large projekct for cost-efficiency issues. He made a number of recommendations that should be considered by scientific drilling operations in general and potential PIs of future development projects in particular:

- Technological development projects share unique features.
- The goal may be clear but the route to it cannot be predicted with confidence
- Multiple technology and operational options available to achieve project goals
- Activity will be cost constrained
- New technologies may arrive to alter the direction of the project
- Major show-stoppers can arise unexpectedly during planning
- Operations may take place close to the limits of the technologies involved
- Subsurface conditions may differ profoundly from the prognosis
- Unforeseen problems may force termination of operations
- Effective operations will involve multiple contingencies, defined rules and change protocols

Thorogood insists that the clarity of objectives is critical to ensure success but recognizes that articulation of objectives is a non-trivial task.

8 - Conclusions

Direct access to the subsurface is key to all six scientific workpackages of the DS³F project. Scientific ocean drilling has been traditionally conducted within the frame of international programmes. In the current phase, IODP, the formation of a unique consortium in 2003 to join IODP as a single member allowed Europe to play a major role. ECORD (European Consortium for Ocean Research Drilling) provides access to Mission Specific Platforms within the frame of IODP. The ESO (ECORD Science Operator), in charge of implementing MSP expeditions, has developed knowledge in drilling operations and associated activities.

Existing technologies cannot fulfill all the technological requirements expressed by these work packages. The need for specific developments to achieve their scientific goals has been stressed. Particular areas in which Europe can play a leading role have been identified by the workshop participants and endorsed by the experts of the IODP Engineering Development Panel during a joint session. These are the following:

- Seabed drills
- Long piston coring
- High pressure sampling devices
- High temperature tools
- Borehole instrumentation

To facilitate the necessary engineering developments, it is suggested to develop a distributed infrastructure in Europe for seafloor sampling and instrumentation, building on the expertise and tools disseminated across the continent. This network will have an increased visibility and should facilitate the obtention of funding. It should build on the successful ECORD project. This infrastructure could be used by various programs, such as ECORD (operating MSPs within the IODP framework) and IMAGES, as well as individual projects. Link with other major infrastructures in Europe should be developed, in particular with EMSO.

Beyond financial support from standard research funding at the national level, possible avenues for funding are the European Commission, other Ministries (such as Ministries for Industry, for Environment, etc.), industry, etc. Opportunities in the EUROGIA+ scheme, a cluster of EUREKA, should be explored, although not all European countries are involved. To insure success, particular attention should be given to the management of engineering development projects.

Europe has a great opportunity to play a major role in technological development for sub seafloor sampling and instrumentation. A better coordination of the existing distributed expertise and tools will facilitate the set up of ambitious projects. Innovative projects requested by the scientific community should rely of the joint efforts of academia and industry, and in particular of creative SMEs (Small and medium enterprises).