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White Paper

Shallow drilling in the deep sea: a new technological perspective for the next phase of scientific ocean drilling

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Abstract
Important scientific targets for a better understanding of the earth system also require shallow drilling (1-150 m). This shallow drilling can't be conducted effectively, both in terms of costs and core quality, by the available drill ships. We suggest using sea-bed drill rigs for conducting shallow drilling campaigns within a post-2013 IODP. Sea-bed drill rigs like the MeBo, developed at the Marum Center for Marine Environmental Sciences at the University of Bremen, can be operated from standard research vessels. They are deployed on the sea bed and remotely controlled from the vessel. Since they are not affected by ship movements during the drilling process, optimal control on drill-bit weight can be achieved. This is a prerequisite for high core quality, especially in the upper tens to one hundred meters. The MeBo uses wire-line drilling technology and can drill down to 75 m below the sea floor both in soft sediments and in hard rocks. Future developments based on the wire-line technology include pressure core barrels for the recovery of sediments at in situ pressure with the MeBo, as well as probes for bore-hole logging. We have investigated the limits of sea-bed drilling. A second generation drill rig suitable for drilling down to 150 m below the sea floor based on the MeBo drill rig design would only be slightly larger and still could be operated world-wide from standard research vessels.

Introduction

The program of the IODP post 2013 will be led and driven by science and some of the scientific goals require new technologies. A close relationship between scientific goals and technological development has been very successful during the present phase of IODP. The riser-equipped drill ship CHIKYU was built for drilling deep holes and allowing safe drilling even in formations with unexpected high pressure flow of gas, oil or fluids from the well. Mission specific platforms are rented for drilling in regions that cannot be served by the drill ships CHIKYU and JOIDES Resolution.

However, it is also the case that the available technology is, at least in part, controlling the scientific questions marine geologists are working on. Within the precursor of the present IODP phase no proposals were submitted for drilling in shallow waters or in ice-covered seas because the only available drilling platform, the JOIDES Resolution was not able to drill in these areas. For similar reasons, research programs aiming to drill a number of shallow cores in the deep sea instead of drilling a few deep holes are not proposed within IODP since this kind of research can't be conducted effectively, both in terms of costs and core quality, by the available drill ships.

Within the last 10 years the possibilities for shallow drilling in the deep sea have improved substantially with the development of robotic drill rigs that can be operated from standard multipurpose research vessels [1,2,3,4,5]. In this paper we discuss new possibilities for shallow drilling in the program of the IODP post 2013.

What is shallow drilling?

The terminology for shallow, deep and ultra-deep drilling is not standardised. Holes drilled for gas and oil reservoirs are commonly referred to as deep drillings. They usually reach depths of more than 500 m below the ground surface. Deep and ultra-deep drilling (in continental crust typically more than 5000 m below the ground surface) typically require a careful management of drill fluid control for compensation of the drill-string weight and formation pressure as well as control of the drill direction (in standard cases vertical). Most of the scientific drilling within the present IODP has reached maximum drilling depths between 200 and 400 m below the sea floor (Fig. 1). For this paper we define drilling with a target depth of up to 100-150 m below the sea floor as shallow drilling.

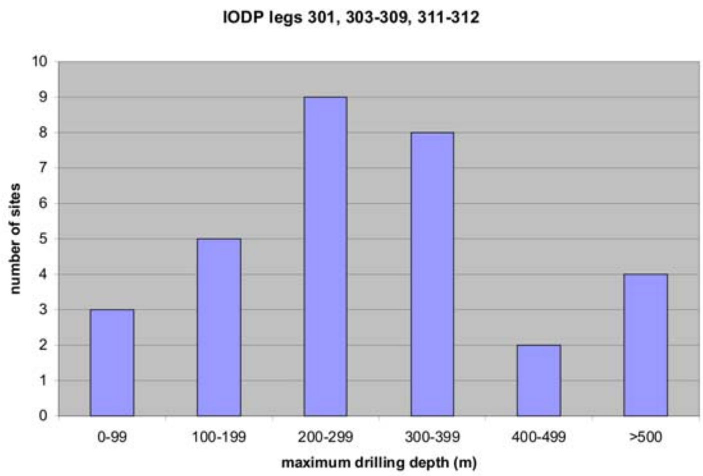

Figure 1: Statistics of the maximum drilling depth below sea floor reached by site during IODP Expeditions 301 to 312 (excluding Expeditions 302 and 310)

Does marine geologic research require shallow drilling?

Shallow drilling can complement or replace deep drilling. Effective methods for carrying out shallow drilling are especially required for shallow targets like sulfide ore deposits [6] and serpentinization processes. In many cases several shallow holes rather than a single deep hole have to be drilled in order to investigate the lateral heterogeneity or 3-dimensional architecture of, e.g., oceanic crust formation [7], pockmarks, mud volcanoes, mound structures [8], or slope instability structures.

In November, 2000, a workshop was held in Texas to discuss the "Requirements for Robotic Underwater Drills in U.S. Marine Geologic Research" [9]. A variety of research targets were identified that require efficient sampling possibilities in the range of 1 to 100 m (or more) below the sea floor. These targets include the subsurface biosphere, hydrothermal mineral deposits and fluid circulation in the upper crust, crustal hydrology, ocean lithosphere, convergent margins, seamount evolution, oceanic plateau formation, paleoceanography, and gas hydrates. The workshop participants strongly recommended building a variety of sea-bed drill rigs (1m, 3-5m and 50-100m drilling depth) that can be deployed from standard research vessels in order to meet the tremendous requirements for shallow drillings in marine sciences. The need for shallow drilling was also emphasised during four ESF-Magellan workshops: in 2007 ("Exploring Escarpment Mud Mound Systems and Mud Volcanoes with new European strategies for sustainable mid-depth coring", organised by S. Spezzaferri et al.); in 2008 ("COCARDE: Cold water carbonate Reservoir systems in Deep Environments", organised by S. Spezzaferri et al., and "Lithospheric heterogeneities, hydrothermal regimes, and links between abiotic and biotic processes at low spreading ridges", organised by C. McLeod et al.); and in 2009 ("Beyond 2013: The future of European Scientific Drilling Research", organised by G. Camoin et al.).

What are the existing technologies for shallow drilling?

Dedicated drill ships are used in science in order to get long cores both from soft sediments and hard rocks. However, these special vessels are expensive and their operation is not time effective when only short drilling is required. The drill string has to be built up through the entire water column before sampling can be started. Precise navigation and heave compensation are required in order to minimise disturbances during the coring process and to control drill-bit pressure. Especially in the upper tens to one hundred meters, core quality is usually poor when drilling with a drill ship into the deep sea floor.

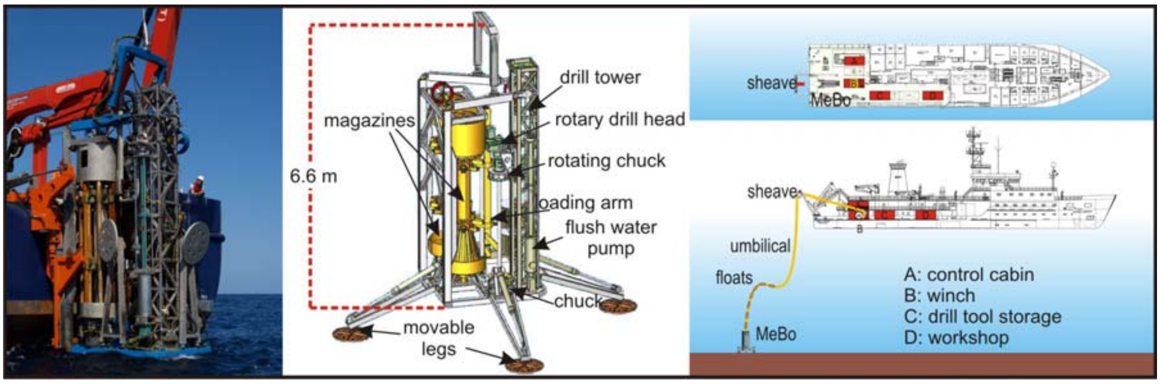

Figure 2: Deployment scheme of sea-floor drill rigs exemplified by the MeBo. Left: MeBo during deployment from the research vessel RV MARIA S. MERIAN in April 2007. Middle: schematic overview on the drill rig. Right: Schematic deployment scheme from a research vessel like RV MARIA S. MERIAN.

Robotic drill rigs deployed from multipurpose research vessels are an important alternative for shallow drilling in the deep sea [2,3,4]. They are deployed on the sea bed and remotely controlled from the research vessel via an umbilical (Fig. 2). We distinguish single-barrel type and multiple-barrel type sea-bed drill rigs. The latter type can achieve deeper penetration into the sea floor by building up a drill string with barrel and rods that are stored on magazines on the rig. Like the typical Remotely Operated Vehicles (ROVs) used in science and offshore industry, these sea-bed drill rigs have a telemetry system for data transfer and energy supply as well as their own hydraulic power source. A similar concept of robotic drilling is realised by drill rigs that are mounted on an ROV [1,5]. In that case the ROV is used for navigation as well as for organizing data transfer and energy supply to the drill rig. An overview of existing sea-bed drill rigs is given in table 1.

Table 1: Existing sea-bed operated drills (modified after McLeod et al., 2009: "Seabed rock drilling: previous scientific results and future applications", Poster presentation at EGU 2009)

Drill	Operator	Type	Water depth	Penetration
BGS RD1	BGS	Single barrel rock drill + vibrocorer	2000 m	5 m
BGS RD2	BGS	Multi-barrel	3500 m	15 m
BRIDGE Oriented corer	BGS	Single-barrel rock drill, oriented core	5500 m	1 m
MeBo	Marum, Bremen	Multi-barrel, wire-line	2000 m	75 m
*BMS	Metals Mining Agency, Japan	Multi-barrel	6000 m	30 m
*PROD	Benthic Geotech, Australia	Multi-barrel, CPT	2000 m	125 m
*Rovdrill	Perry Slingsby	Multi-barrel, ROV-operated (vertical)	3000 m	19 m
MBARI ROV Rockdrill	WHOI	4xsingle barrel, ROV-operated (horizontal)	4000 m	1 m

*Only used commercially to date

Compared to drill ships, robotic sea-bed drill rigs have several advantages. They are not affected by any ship movements due to wind or waves. Since they operate from a stable platform on the sea bed, optimal control of drill-bit pressure can be achieved, which is prerequisite for optimal core quality. Sea-floor drill rigs can be operated from vessels of opportunity. This reduces mobilisation efforts compared to dedicated drill ships and allows world-wide operation. Compared to drill ships that require building up a drill string through the entire water column before starting the coring process, the operation of sea-bed drill rigs is much more time effective for shallow drilling.

The sea-floor drill rig MeBo (The abbreviation "MeBo" stands for "**Me**eresboden-**Bo**hrgerät", the German expression for sea-floor drill rig) that was developed in 2004/2005 at the Marum Center for Marine Environmental Sciences at the University of Bremen is capable of sampling soft sediments and hard rocks [4]. In 2006/2007 it was upgraded for the use of wire-line drilling technology. After drilling a core section (a stroke length of 2.35 m is used for the MeBo) the inner core barrel containing the drilled core is hooked up inside the drill string using a latching device (overshot) attached to a steel wire. When the inner core barrel is pulled out of the drill string it is grasped by a loading arm, the overshot is unlatched, and the core barrel is stored in the magazine. An empty inner core barrel is taken out of the magazine by the loading arm and inserted into the drill string. A 2.35 m rod is taken from the magazine and attached to the drill string by a threaded connection. As soon as the rotary drill head is connected to the drill string the next section can be drilled.

The wire-line coring technique is much faster than conventional drilling, which requires repeated recovery of the entire drill string each time the end of stroke is reached. No casing is needed for wire-line drilling since the drill string stays in the drilled hole during the entire drilling process. This is especially important when drilling in soft formations or in hard rocks with sediment overburden, because it prevents a collapse of the drilled hole during the recovery of the drilled core sections.

Where are the limits of robotic drilling at the sea floor?

World-wide operation of sea-bed drill rigs on vessels of opportunity requires easy transportation of the drilling system in standard shipping containers. The largest systems are the PROD (Portable Remotely Operated Drill, designed and operated by the Australian company Benthic Geotech) and the MeBo. Both rigs have a weight of about 10 tonnes and each is transported within a 20 foot container. Transportation of the total system including winch, launch and recovery system, control cabin, workshop and drill tools requires 5-6 containers. While the PROD reaches a maximum drilling depth of about 125 m at a core diameter of about 44 mm, the MeBo can drill down to 75 m with a core diameter of about 63 mm.

Based on the concept of the MeBo we have evaluated the maximum drilling depth that can be reached and still allow containerised transport and operation from the larger available research vessels (height of A-frame 8 – 10 m, SWL > 20 tonnes, free working deck space about 20 m in line with A-frame). It would be possible to double the stroke length by increasing the length of the mast and the magazines by about 2.5 m. A drill rig based on the MeBo design capable of drilling down to 150 m below sea floor would have a height of about 8.5 m, a weight of about 13 tonnes and could be transported within a standard 40–foot shipping container.

Motivated by the demand for safe and low-cost borehole measurements, especially under instable borehole conditions and for the remotely controlled drill rig MeBo, members of the German Scientific Earth Probing Consortium (GESEP), including the MARUM, plan to develop memory borehole sondes, simultaneously recording parameters like magnetic susceptibility and electric conductivity in the logging-while-tripping mode. In this mode an autonomous memory probe is lowered into the drill string after completion of the core drilling. At the bottom, the probe latches into the outer core barrel where normally the wire-line inner core barrel fits. The sensors are located at the lower part of the probe that extends out of the drill string into the open borehole as well as in the upper part of the probe inside the drill string logging through the pipe. The bore hole is logged quasi continuously while the drill string is pulled out of the drilled hole.

In the near future (2010/2011) it will also be possible to deploy pressure core barrels with the MeBo. This is a development within the BMBF/BMWi project SUGAR aiming to sample and recover sediments at in situ pressure in order to investigate and quantify the gas content of the sediments, especially where gas hydrates occur.

Is an international drilling project like IODP an appropriate platform for shallow drilling campaigns?

All drilling technologies should be able to be deployed within an international drilling project to wherever the best targets to solve scientific issues of global reach occur. This principle is partly realised already within the present Mission Specific Platform approach (MSP) within IODP. At present, MSP campaigns are restricted to working areas that cannot be accessed by the drill ships JOIDES Resolution and CHIKYU. The MSPs have had a tremendous scientific impact by accessing areas previously unexplored (shallow water and Arctic drilling). New scientific fields of global reach can also be addressed when the MSP concept is expanded to include tools like sea-bed drill rigs in the deep sea, allowing the most efficient method of core recovery.

Sea-bed drill rigs are efficient with respect to both core quality and to the costs of a shallow drilling campaign. However, costs are still high enough that the majority of the countries participating within IODP wouldn’t be able to afford such a campaign within a national approach. We believe not only that the IODP (infra-)structure is perfect for conducting shallow drilling campaigns but also that the program itself can profit by emerging new scientific targets with the aid of sea-bed drill rigs.

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