Geosci. Instrum. Method. Data Syst. Discuss., 3, 347–369, 2013
www.geosci-instrum-method-data-syst-discuss.net/3/347/2013/
doi:10.5194/gid-3-347-2013

Geoscientific
Instrumentation
Methods and
Data Systems
Discussions
Open Access

Drilling cores on the sea floor with the remote-controlled sea-floor drilling rig MeBo

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Received: 11 June 2013 – Accepted: 26 June 2013 – Published: 1 July 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Sampling of the upper 50 to 200 m of the sea floor to address questions relating to marine mineral resources and gas hydrates, for geotechnical research in areas of planned offshore installations, to study slope stability, and to investigate past climate fluctuations, to name just a few examples, is becoming increasingly important both in shallow waters and in the deep sea. As a rule, the use of drilling ships for this kind of drilling is inefficient because before the first core can be taken a drill string has to be assembled extending from the ship to the sea floor. Furthermore, movement of the ship due to wave motion disturbs the drilling process and often results in poor core quality, especially in the upper layers of the sea floor. For these reasons, the MeBo drilling rig, which is lowered to the sea floor and operated remotely from the ship to drill up to 80 m into the sea floor, was developed at the MARUM Research Center for Marine Environmental Sciences at Bremen University. The complete system, comprising the drill rig, winch, control station, and the launch and recovery system, is transported in six containers and can be deployed worldwide from German and international research ships. It was the first remote-controlled deep sea drill rig that uses a wireline coring technique. Based on the experiences with the MeBo a rig is now being built that will be able to drill to a depth of 200 m.

1 Introduction

Conventional methods of sampling the sea floor from research ships include the use of vibracores, gravity cores and piston cores. With these robust and reliable instruments, cores with lengths of 5–15 m (up to 50 m in rare cases) can be retrieved in areas of unconsolidated sediments on the sea floor (Hebbeln, 2003). Dredging is used to collect blocks of hard rock lying on the sea floor.

Drilling ships are usually employed when longer sediment cores are necessary or if cores from hard-rock provinces are targeted (Hebbeln, 2003). These ships can drill cores down to several hundred meters, or even kilometers deep. However, the use of drilling ships is expensive, and not efficient for shallow drilling needs (McGinnis, 2009). Before the actual drilling process can begin, a drill string has to be assembled extending from the ship to the sea floor. Vibrations in the drill string and movements of the ship prevent optimal control of the drill-head pressure, which considerably compromises the core quality, especially in the upper tens of meters.

There are increasing needs both in research and industry for shallow drilling (Sager et al., 2003; Yetginer and Tjelta, 2011). The construction of foundations and anchors for offshore installations is very dependent on the geotechnical properties of the sea floor. Exploration for mineral deposits such as sulfide mineralization around hydrothermal systems or investigations of methane hydrate deposits also require the drilling of numerous shallow holes (Ishibashi et al., 2007; Spencer et al., 2011). Paleoclimate studies are enhanced by the ability to obtain cores that are longer than those from conventional methods because the marine sediments are an archive for the reconstruction of past environmental conditions. Studies of three-dimensional structures on the sea floor, such as mud volcanoes and slope slumps require a large number of shallow holes that cannot be effectively cored either by the conventional methods on current multi-purpose research vessels or by drill ships.

2 Examples and advantages of robotic drilling systems

Remotely operated drilling rigs are especially desirable in areas that are difficult to access. Prototype robots have been developed for various kinds of operations, including stone-quarry walls (Roboclimber: Molfino et al., 2005) and on the surface of mars (Hogan, 2005). Robotic drilling rigs that are lowered onto the sea floor from multi-purpose research vessels and that retrieve cores from the sub-bottom by remote control from the ship (Fig. 1) can help to fill the gap between relatively inexpensive conventional methods and the use of drill ships.

For deployment on the sea floor, drill rigs have been developed that use a single core barrel and can drill to a depth of up to 5 m, and other rigs that have a drill-pipe magazine (multi-barrel). The latter are able to screw extension pipes to the drill string and thus achieve significantly greater coring depths.

To our knowledge the first example was the MARICOR, developed in 1973 by Atlas Copco. This rig was configured for deployment on continental shelves down to 200 m water depth and a drilling depth of 60 m using a diamond rotary drilling method.

The British Geological Survey (BGS) operates two single-barrel drill rigs (Wilson, 2006). The 5-meter rockdrill (RD1) was developed in 1982. A smaller 1-meter drill can retrieve oriented core for paleomagnetic studies (MacLeod et al., 2002). In 2006 the BGS developed a multi-barrel rig that could drill to a depth of 15 m (Wilson, 2006) and which is presently upgraded for a drilling depth of 50 m.

In 1989/1990 the American company Williamson and Associates built a 3-meter drill rig (Johnson, 1991), and in 1996, 2005, and 2008 they produced the Benthic Multicoring Systems BMS-1, BMS-2, and BMS 3, respectively. The BMS drills are operated on the research ship Hakurei No. 2 by the Metal Mining Agency of Japan and can drill to a depth of 20 m (Ishibashi et al., 2007) in unconsolidated sediments or in hard rocks. In 2008 Williamson and Associates developed a sea bed drill rig called Autonomous Coring System (ACS) for the National Institute of Ocean Technology in India designed for recovering up to 100 m long core in 3000 m water depth.

The Australian company Benthic Geotech Pty Ltd has been operating the Portable Remotely Operated Drill (PROD) since 1997, a multi-barrel drill rig that can retrieve cores up to 100 m long in unconsolidated sediments or hard rocks (Stuart, 2004; Palanich, 2010).

In 2011 the Californian company Gregg Drilling together with several companies including Marl Technologies and Schilling Robotics developed the Gregg's seafloor drill for up to 150 m deep drilling for geotechnical purposes.

All of the described drill rigs are controlled and supplied with energy from the ship through a special steel-armored cable. These drilling tools present new possibilities for sampling from conventional research ships. The multi-barrel rigs are especially well suited for filling the growing need by both marine research and offshore industry for cores of 30–100 m length on the continental shelf areas as well as in the deep sea. These remote-control drills have significant advantages over drill ships.

- Ship and drill-string motion due to wind, currents and waves do not affect the quality of the drilling process because the work is done from a stable platform on the sea floor.
- Robotic drill rigs can be launched from various available multi-purpose research ships. This can reduce the mobilization costs for worldwide deployment.
- As a rule, drilling ships are expensive and heavily booked. By avoiding the time-consuming assembly of a drill string from the drilling ship to the sea floor, the use of drill rigs placed on the sea floor can be substantially more time and cost effective.

A similar concept to the remote-controlled drilling on the sea floor is implemented by drills mounted on submarine robots (Remotely Operated Vehicle, ROV). The ROV is used for navigation, data transfer, and energy supply. The MBARI ROV-mounted rig can drill horizontal cores with a maximum length of one meter (Stakes et al., 1997). The Rovdrill®, which was developed by Perry Slingsby, drills vertically and can attain depths of up to 20 m. The third generation of this development called Rovdrill 3 is designed for a maximum coring depth of more than 80 m (Spencer et al., 2011).

3 The sea floor drill rig MeBo

From 2004 to 2005, the sea floor drill rig MeBo (Fig. 2) was developed at the MARUM Center for Marine Environmental Sciences at Bremen University with funding from the Federal Government of Germany (Education and Research) and the State of Bremen (Freudenthal and Wefer, 2007). This is the first drill rig developed and operated by a

scientific institute that can drill cores up to 80 m deep in unconsolidated sediments and in hard rocks. It is the first robotic deep sea drilling rig in the world that can drill cores using both conventional and the advanced wireline methods.

As far as possible, MeBo uses reliable technology that has been time-tested in onshore drilling systems or on commercial ROVs. Special specifications for its construction included:

- convenience of transportation on land and sea
- ten tons maximum weight
- drilling capability in both unconsolidated sediments and hard rocks
- drilling depth of at least 50 m
- core diameter of 50–80 mm
- deployment depth up to 2000 m (with the option to 4000 m).

It was developed in close cooperation with the companies Prakla Bohrtechnik GmbH and Schilling Robotics. The German company Prakla Bohrtechnik GmbH in Peine was primarily responsible for the mechanical and hydraulic development. The California company Schilling Robotics developed the core-barrel magazine with the loading arm and also provided the telemetry system for data transfer and operating energy. MARUM was responsible for the system design, energy supply, and deployment concept, and also developed the control system (hardware and software) for the MeBo.

The system comprises the drill rig, the winch with 2500 m of armored special cable, a launch and recovery system (MeBo-LARS), the control unit, a workshop with replacement parts, and storage for the drill pipe. The control unit, workshop, and drill-pipe storage are each accommodated in a 20′ transport container. The winch is in a transport frame the same size as a 20′ container. The drill rig and the MeBo-LARS are each stowed in a 20′ open-top container, whereby the LARS has to be disassembled for storage and transport. The containerized transport concept allows quick and efficient worldwide transportation of the system as well as the rapid assembly and breakdown on the research vessel being used (Fig.3).

The MeBo is about 6.6 m tall and has four supporting feet that are lowered before landing on the sea floor to insure the stability of the rig on a soft or uneven bottom (Fig. 4). Setting the drill rig down on the sea floor and retrieving it onto the ship after coring is completed are made possible by the umbilical, a special steel-armored cable. With the system's present umbilical the MeBo can be deployed in water depths down to 2000 m. Copper wires and optical fibers in the center of the umbilical are used for energy supply to the drill rig and for data transfer between the rig and the control container.

The MeBo is hydraulically powered. Four hydraulic pumps powered by 3000-V electric motors provide a working pressure of up to 207 bars greater than the ambient pressure. Several underwater cameras and sensors are used to monitor the drilling process.

The central element of the MeBo is the feed system with the drill head (Fig. 4). It includes the mast as a guide for the carriage, which is cable-driven by the hydraulic feed cylinder. The feed system supplies the necessary pressure for drilling and pushing the drill string into the hole, and for disassembling the drill string later. The drill head provides rotation and the necessary torque for screwing the drill pipe together and for the rotary drilling. It has a hollow spindle to allow the flushing water into the drill string with the help of the flushing water pump. We flush with sea water to cool the drill bit and to wash the loose drill cuttings out of the hole.

The necessary core barrels and drill pipe are stored in two rotating magazines. Depending on the geology of the sub-bottom, these magazines can be loaded with different kinds of core barrels. A loading arm is used to remove the required pipe from and replace it into the magazine. This is used in combination with a stationary foot clamp to hold the drill string, and a rotating chuck on the drill head to assemble and break down the drill string. In conventional drilling techniques a second stationary clamp is necessary for casing pipe, which is needed to stabilize the hole.

4 Wireline drilling technique

To our knowledge MeBo is the first remote-controlled deep sea drill rig that uses the wireline drilling technique. With this method, after penetration of one core length (2.35 m is used for the MeBo) the core barrel holding the cored sample is pulled up through the drill string. For this, a steel cable with an "overshot" (grabbing device) is dropped into the drill string after the drill head is released from the string (Fig. 5). When the core barrel is pulled out of the drill string the overshot is released and the core barrel with the core sample is placed into the magazine. The loading arm takes a new empty core barrel from the magazine and inserts it into the drill string. The inner core barrel is dropped through the drill string, its fall moderated by the water in the string, and at the bottom it is stopped by a shoulder ring in the drill pipe. After lengthening the drill string by an additional joint of pipe (drill rod) from the magazine, and screwing it to the bottom-hole assembly, the next core can be drilled.

Wireline drilling is often used in drilling systems on land. This method is considerably faster than conventional drilling, which requires breaking down the complete drill string after each penetration of a single core length to retrieve the core (McGinnis, 2009). In wireline drilling there is no need for an additional casing pipe to stabilize the hole because the drill string remains in the hole for the duration of the drilling process. This is especially important in soft formations to avoid the risk of hole collapse while the core is being retrieved.

The advantages of wireline drilling are evident, and were discussed at the workshop "Requirements for robotic underwater drills in U.S. marine geologic research" in 2000 (Sager et al., 2003). In fact, the first prototype of a robotic drill rig for deployment on the sea floor, the MARICOR, was designed for wireline drilling. This system, developed by Atlas Copco, included an elevator system by which the core was pulled up to the deck of the research vessel immediately after it was drilled. The MARICOR Project, however, was cancelled after its first trials (A. Oden, personal communication, 2003). All subsequently until 2007 developed remote-controlled drill rigs for use on the sea floor (BMS, PROD, Rovdrill) use the conventional drilling procedure. Because wireline drilling involves a much higher complexity of operational steps, we at MARUM also initially decided to configure the MeBo for conventional coring. After four successful research expeditions with the MeBo through 2007 (Freudenthal and Wefer, 2007), we undertook the further developmental decision to upgrade the MeBo for use with the wireline technique.

In contrast to land-based drilling systems, remote-controlled operation of wireline drilling cannot be manually supported. During the upgrade of the MeBo for use with wireline drilling, special attention was therefore given to the processes that are normally supported by the drill foreman on the rig. These include guiding the overshot into the drill string with an additional manipulator, checking the landing of the inner core barrel on the shoulder ring, secure winding of the winch for the cable, releasing the overshot from the core barrel after retrieval from the drill string (Freudenthal et al., 2012), and preparation of the overshot for the next application.

Due to the space saved in magazine storage for the additional pipe needed for conventional drilling, the maximum drilling depth is increased from 50 m to over 80 m with the wireline method (Table 1). The advantages of the wireline method have been demonstrated on 9 expeditions with MeBo since 2008. Average core recovery rates were close to 80 % in different type of geologies including hemipelagic muds, gas hydrate bearing sediments, sands, glacial till, and carbonate rock. Since wireline coring tools were initially developed for hard rock drilling we developed special adaptions for improving the core recovery for soft sediments. Examples of cores collected in different types of sediments are shown in Fig. 6.

5 Auxiliary equipment

An autonomous probe for obtaining bore-hole measurements has also been developed for use with the MeBo. In a procedure called logging-while-tripping, the probe, equipped with its own energy source and data storage, is lowered into the drill string after the last

core barrel has been retrieved. After the probe has landed on the shoulder ring at the bottom of the hole, the drill string is pulled out and disassembled. The probe, while being raised with the drill string, continuously measures the geophysical properties of the borehole and the in situ sediments and rocks. Major advantages of the logging while tripping method are a minimum time requirement for the bore hole logging since the drill string has to be tripped out anyway as well as the capability of logging unstable formations since the drill string stabilizes the drilled hole during the logging.

Figure 7 shows the results of core drilling and borehole logging at station GeoB 16602 drilled during the RV SONNE expedition SO221 in May 2012 in the South China Sea. One gravity core and three MeBo deployments were conducted within about 100 m distance at the continental slope of the South China Sea in 950 m water depth. A drilling depth of more than 80 m was reached by flushing through the upper ten 10 m (reach of the gravity corer) and core drilling below. The parallel holes were drilled in order to get more sample material and close gaps in the drilling profile. By splicing the records a continuous profile is obtained for paleoclimate reconstructions in this area sensitive for changes in the South East Asian monsoon system. During two of the MeBo-deployments bore-hole measurements were conducted with a spectrum gamma ray probe in the logging-while-tripping-mode. This probe measures the natural gamma ray intensity and analyses the spectrum with respect to the concentrations of the three natural gamma ray emitting elements potassium, uranium, and thorium. A close correlation of the logging profiles is observed between the independently acquired profiles at this site. Natural Gamma Ray intensity (NGR) ranges from 44 to 90 gAPI. The variations in NGR are mainly attributed to changes in concentrations of potassium (0.5–1.6 %) and thorium (4.1–13.0 ppm), whereas uranium concentrations are fairly low (1.2–3.1 ppm).

Clays are the main host minerals for thorium and potassium in marine sediments. The variability in natural gamma ray intensity can therefore be interpreted as an indicator of changes in terrestrial sediment input into the South China Sea at the two sites. Since the monsoon system is a key factor controlling weathering and terrigenous material transport by rivers, the borehole logging results will help reconstructing past climate changes in that area.

Borehole instrumentation and the hydraulic sealing of the borehole against the overlying ocean body with a CORK (Circulation Obviation Retrofit Kit) is required for long term-monitoring of borehole pressure changes related, for example, to earthquakes and fluid migration within the sediments (Becker and Davies, 2005; Kopf et al., 2011). An autonomous MeBo-CORK instrument was developed that can be deployed with the MeBo after core drilling is completed (Kopf et al., in preparation). It was installed in a custom built MeBo drill string termination and deployed for the first time in June 2012 during an expedition of the research vessel SONNE (Fig. 8). It contained pressure and temperature transducers in the borehole as well as outside the borehole for sea-floor reference. This instrument also includes a data logger, a battery unit, and an acoustic modem for data transfer. Unlike other CORK systems the MeBo approach does not require installation assistance by ROVs (Becker and Davies, 2005) and is, therefore, versatile to install.

6 MeBo200

Based on the experience of the successful MeBo development and deployments we are presently developing with funds of the Federal Government of Germany (Ministry of Education and Research) the second generation MeBo called MeBo200. This drill rig will be able to conduct core drilling down to 200 m below sea floor. It is developed within a cooperation of the company BAUER Maschinen GmbH – responsible for the drill mechanics and hydraulics – and MARUM. By optimizing the interplay between loading arm, chucks and feeding system we were able to increase the stroke length from 2.35 to 3.5 m. The MeBo200 is mounted in a 20′ transport frame. Thereby it was possible also to increase the loading capacity of the magazines which together with the increased stroke length results in a substantial increase of the drilling depth capabilities.

7 Summary and conclusions

The sea floor drill rig MeBo is a robotic drill rig that is deployed on the sea bed and remotely controlled from the research vessel. H-size drill tools for wire line core drilling are stored on two magazines on the drill rig and allow drilling down to 80 m below sea floor for coring soft sediments as well as hard rocks. A 2500 m long umbilical is used for lifting the 10 to heavy device as well as for energy supply and data transfer. The MeBo system comprises the drill rig, the lift umbilical winch, control station, and the launch and recovery system, and is transported in six containers. It is deployed worldwide from German and international research ships and proved its capability during 13 scientific expeditions between 2005 and 2012. Average core recovery rates of close to 80 % where achieved in different types of geologies including hemipelagic muds, gas hydrate bearing sediments, sands, glacial till, and carbonate rock. Next to core drilling the MeBo is used for bore hole logging in the logging while tripping method as well as for the instrumentation of bore holes for long term monitoring of pressure and temperature changes within the sediments. The experiences with the MeBo are now used for developing a second generation drill rig called MeBo200 capable of drilling down to a depth of 200 m below sea floor.

Acknowledgements. The authors thank the MARUM personnel for their valuable contributions to the development and operation of the MeBo. Development of the MeBo was supported by the Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research) and by the State of Bremen. Operational support was provided by funding from the DFG (DFG-Forschungszentrum/Excellenzcluster “The Ocean in the Earth System”), by the Senatskommission für Ozeanographie (Senate Commission for Oceanography), and the coordination headquarters for the METEOR/MERIAN. We also thank the captains and crews of the research ships *METEOR*, *MARIA S. MERIAN*, *SONNE*, *POURQUOI PAS?*, and *CELTIC EXPLORER* for their support during the research expeditions with the MeBo.

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Table 1. Comparison of drill pipe sizes used by the MeBo for conventional and wireline drilling.

	Conventional	Wireline
Pipe size	T2-101	HWL
Drilling diameter	103 mm	103 mm
Core diameter		
Hard rock	84 mm	65 mm
Sediment	80 mm	57 mm
Core length	3000 mm	2350 mm
Maximum drilling depth	~ 50 m	~ 80 m

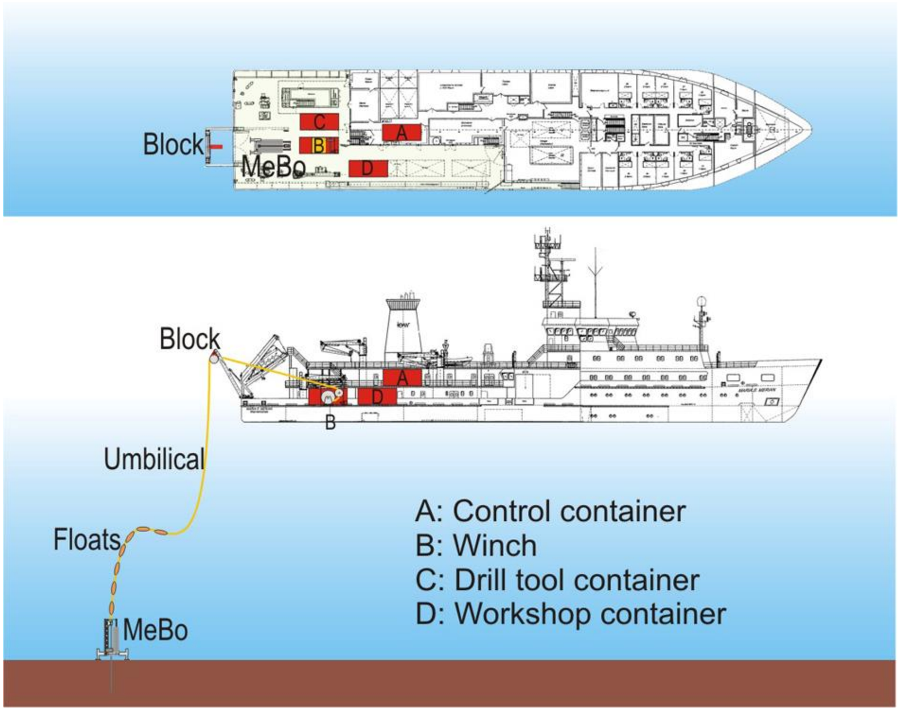

Fig. 1. Typical operational setup for a remote-controlled drill rig that is lowered to the sea floor. As an example, the sea-floor drill rig MeBo and the research vessel *Maria S. Merian* is shown.

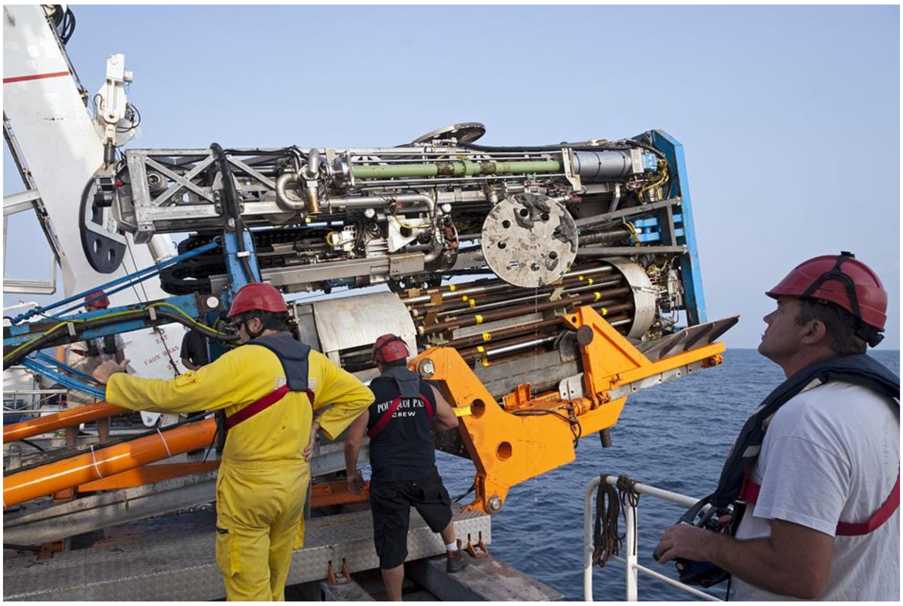

Fig. 2. The sea-floor drill rig MeBo during the deployment start from the research vessel R/V *POURQUOI PAS?* in November 2011 (Photo: T. Klein, MARUM).

Fig. 3. View toward the stern on the working deck of the research vessel Meteor during deployment of the MeBo. In front are the workshop and control containers, behind them the drill pipe storage and winch, and behind those the launch and recovery system for the MeBo (Photo: V. Diekamp, MARUM).

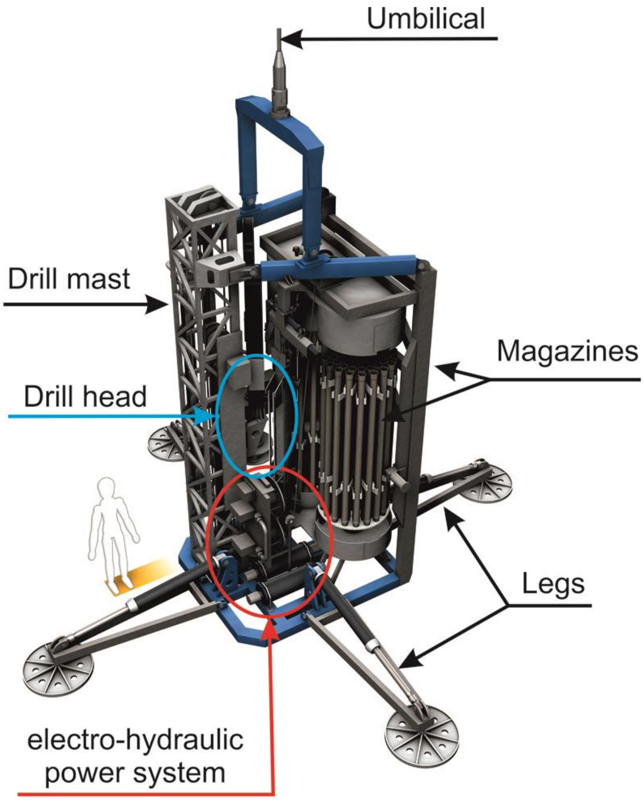

Fig. 4. Schematic overview of the major components of the MeBo.

Fig. 5. View of the lower fixed foot clamp of the MeBo. The “overshot” is lowered into the drill string on a steel cable (Photo: MARUM).

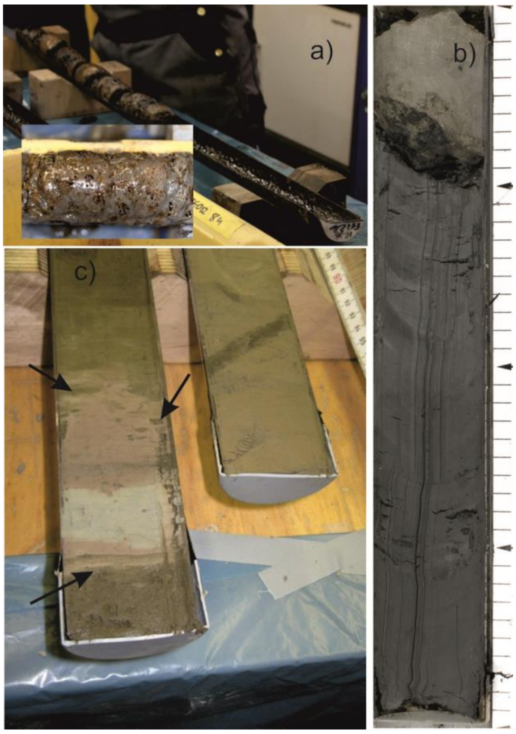

Fig. 6. High quality cores were drilled with MeBo from massive gas hydrate layers **(a)**, and hemipelagic muds containing authigenic carbonate precipitates **(b)** and ash layers **(c)**. Arrows point to sharp contact at the base of the ash layer and bioturbation structures at the top which are indicators of minimum disturbance of the sediments during drilling (Photos: MARUM).

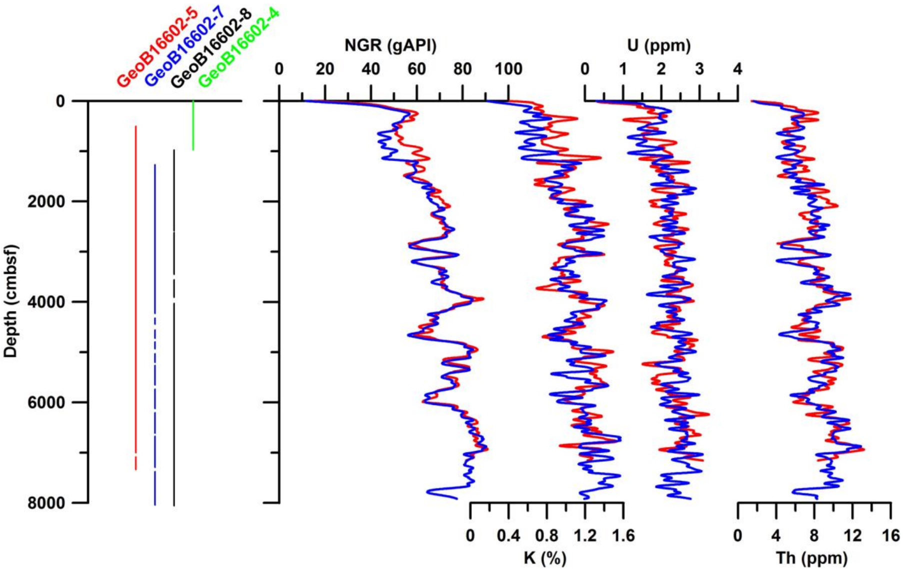

Fig. 7. Core recovery with a gravity core (GeoB16602-4) and three separate MeBo deployments (GeoB16602-5, GeoB16602-7, GeoB16602-8) and bore hole logging results of MeBo deployments GeoB16602-5 and GeoB16602-7 at the continental slope of the South China Sea in 950 m water depth.

Fig. 8. Picture of a MeBo-CORK installed in June 2012 with MeBo off the coast of Japan. The picture was taken a few days after installation with a towed camera sled, the Ocean Floor Observation System (OFOS) of the research vessel *SONNE*. Note the imprint of the base frame and of the legs of the MeBo on the sea floor. The distance weight on a 2 m rope at the lower right of the picture belongs to the camera sled and assists the winch driver in assessing distance to sea floor (Photo: MARUM).