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RISER DRILLING
Access to Deep Subseafloor Science

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ABSTRACT. Riser-based drilling became available to scientists for the first time when the Japanese drilling vessel (D/V) *Chikyu* began operations in 2005. The introduction of a vessel that could take advantage of riser drilling technology was a key advancement as scientific ocean drilling transitioned from the Ocean Drilling Program to the Integrated Ocean Drilling Program. Because riser drilling enables control of downhole pressure, *Chikyu* opened a new frontier for scientists, allowing for deeper drilling and sampling of the subseafloor to at least 7 km depths. Riserless drilling uses seawater as drilling fluid, and technical difficulties may arise when the borehole becomes unstable. In contrast, riser drilling uses riser pipes that connect the ship to the wellhead at the seafloor (Figure 1). Circulation of weighted drill mud through the riser pipe stabilizes the borehole during deep drilling operations, allowing continuous sampling and data collection, including from cuttings, mud gas, and downhole logging. These samples and data allow characterization of in situ physical properties (e.g., stress, fluid pressure) and gas and fluid chemistry. Riser drilling operations in the Nankai Trough and off Shimokita Peninsula in Japan demonstrate the value of this technology to achieving new understanding of the processes occurring deep in seismogenic zones.

DEEP DRILLING CAPABILITY

Circulation of weighted drill mud through riser pipes (Figure 1) balances wellbore and formation pressures to prevent formation fluid from flowing into the borehole or caving in of the borehole. In addition, it helps clean the borehole by transporting drill cuttings to the surface, and it lubricates and cools the drill string, transmits hydraulic horsepower to the drill bit, and stabilizes the walls of the borehole until casing can be set and/or observatory equipment can be installed. These functions allow *Chikyu* to drill to previously unreachable depths, into the seismogenic zone or the upper mantle—current drilling capability is 7,000 meters below the seafloor (mbsf) in 2,500 m water depth. One drawback of using riser technology is that continuous coring is not feasible for ultra-deep drilling projects due to limited ship time; however, spot or sidewall coring allows collection of cores at selected, important depth intervals that are often identified in logging data. The gaps between the cored and non-cored intervals can be examined in geophysical borehole logs as well as in cuttings and mud gas samples.

GEOPHYSICAL LOGGING

Geophysical logging is a technique to measure formation characteristics in situ. Instruments with a variety of sensors are sent down the borehole on a cable either after the hole is drilled (wireline logging) or they are built into the drill collars and collect data as the hole is being drilled (known as logging while drilling, or LWD). Logging has been routinely used in scientific ocean drilling where core recovery is insufficient. The tools that can be used in riserless drilling are limited to the standard measurements (e.g., natural gamma ray, sonic velocity, resistivity, density, porosity) because of limitations in the diameter of the hole vs. the sizes of available logging tools.

Because of the larger diameter pipe, riser drilling can take advantage of a broader suite of logging tools available from industry and collect data such as high-resolution borehole images, nuclear magnetic resonance (NMR) measurements, formation tests, fluid samples, sidewall cores, and geochemical measurements. Stable borehole conditions provided by riser drilling also result in improved quality of geophysical logging data collected from the deep subseafloor.

Deep riser drilling (e.g., seismogenic zone drilling) is commonly completed with extensive LWD operations in addition to limited coring. LWD and mud logging, combined with limited core data, are invaluable for characterizing the entire drilled section. Deep scientific targets of riser drilling, which are traditionally interpreted using multichannel seismic reflection data, can be refined by check-shot surveys and look-ahead vertical seismic profiling while drilling. With such a breadth of tools available, conducting downhole logging while using the deep riser drilling technology on *Chikyu* will be a vital component of future scientific ocean drilling at great depths.

MUD CIRCULATION SYSTEM

In addition to improving borehole stability, mud circulation during riser drilling provides access to data that are not available for riserless drilling. Two main areas where riser systems have provided new data streams are cuttings and gas geochemistry. Cuttings produced by drilling are delivered to the drillship via the mud circulation system (Figure 1). These formation samples are extremely valuable for calibrating petrophysical interpretations based on geophysical logs, documenting the lithology and composition

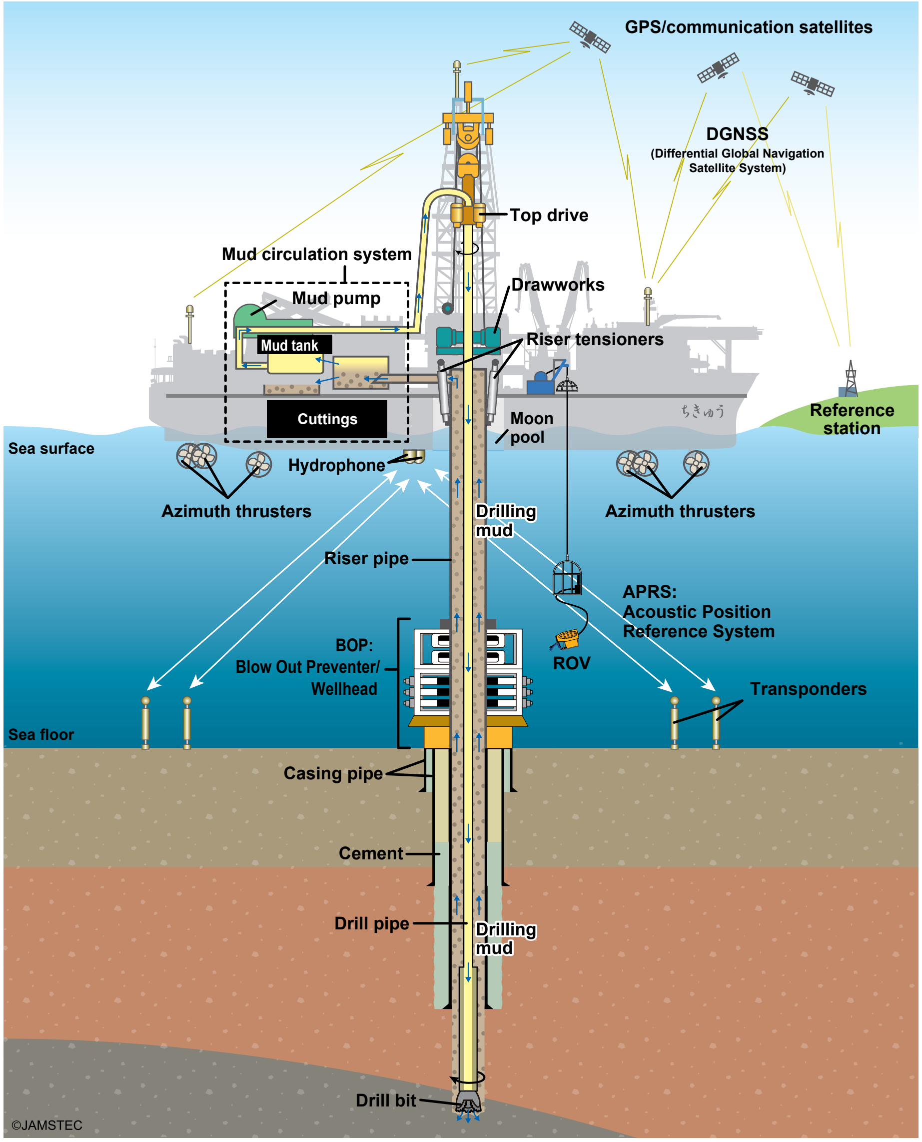

FIGURE 1. The riser drilling system.

of the formation, and providing fossils for age dating of the formation. These cuttings-based data allow routine geological assessment even in intervals where scientific cores are not collected.

Instead of or in addition to gas samples collected in situ using wireline pressure cores or advanced logging-based fluid samplers, wellhead gas samples can inform multiple studies that include thermal history, microbial activity, and fluid flow. Wireline sampling technologies require additional ship time and only provide a few point measurements, whereas mud gas analysis during riser drilling provides a means of gathering data on formation gases continuously. Gases released from the formation during drilling are delivered to the surface via a closed-loop system, and are continuously monitored and sampled with mud degassing instrumentation.

Shipboard gas analysis and sampling are used for continuous safety monitoring by assessing the composition of hydrocarbon gases (e.g., C_1–C_5), a crucial component for any drilling operation. Gases can also be analyzed shipboard for non-hydrocarbons and isotopes (e.g., δ^{13}C-methane), providing near-real-time data on board. Analyses of these data aid contamination, fluid flow, and fluid source studies. Gas samples can also be sealed and sent to shore for more detailed elemental or isotopic studies. As continuous gas and cuttings analyses are relatively new to scientific ocean drilling, it is expected that the data they produce and their future scientific impact will expand as more scientists participate in studies that use riser drilling.

Mud circulation can enhance core recovery and quality from the deep subseafloor, even from gas/fluid-rich or highly fractured formations. In combination with cuttings, recovered cores are available for scientific examination and interpretation, including lithology, physical and geomechanical properties, and geochemical characteristics.

ACHIEVEMENTS OF SCIENTIFIC RISER DRILLING IN THE NANKAI TROUGH AND OFF SHIMOKITA

Riser drilling was a key component of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), a series of 13 Integrated Ocean Drilling Program and International Ocean Discovery Program (IODP) expeditions that began in 2007 and will conclude in 2019. NanTroSEIZE employed both riserless and riser drilling to collect sediments and fluid/gas in the Nankai trough subduction zone off the Kii Peninsula, Japan. The program was designed to investigate fault mechanics and seismogenesis along a subduction plate boundary fault system through direct sampling, in situ measurements, and long-term monitoring in conjunction with allied laboratory and numerical modeling studies. The seismogenic zone targeted at ~5,200 mbsf at Site C0002 was the deep target centerpiece of NanTroSEIZE. This unprecedented deep ocean borehole could only have been achieved using riser-based drilling and a carefully planned casing program.

Through combined riserless and riser drilling and associated scientific operations, significant knowledge of the Nankai seismogenic zone has been gained. Borehole logging and core data were used to estimate in situ stress orientations and magnitudes (e.g., Lin et al., 2016; Huffman et al., 2016; Kitajima et al., 2017; Oohashi et al., 2017). Isotopic analyses of mud gas during riser drilling in the Nankai Trough allowed near-real-time assessment of the transition from biogenic to thermogenic methane, providing insights into the thermal state of the formation and the extent of methanogenic microbial activity (Strasser et al., 2014; Tobin et al., 2015). Mud gas concentration analyses showed increased methane concentrations near the base of the Kumano forearc basin sediments, which may be the result of upward fluid migration (Strasser et al., 2014; Ijiri et al., 2018). The culmination of 10 years of IODP NanTroSEIZE deep drilling efforts, Expedition 358 in October 2018 was designed to characterize the megasplay fault/plate boundary fault at seismogenic/slow slip depths (~5.2 km below the seafloor).

Earlier, the primary targets of IODP Expedition 337 drilling, off Shimokita Peninsula, Northeast Japan, were coal and shale beds in a forearc basin in order to examine the limits of life in the deep biosphere and the ecological roles of deep life in biogeochemical carbon cycling. Riser drilling with a blowout preventer (BOP) and drilling mud adjusted to balance the formation pressure were essential for drilling in this hydrocarbon-bearing basin. Expedition 337 achieved the world record for the deepest subseafloor depth from which core samples have been retrieved, 2,466 mbsf.

Based on rigorous contamination assessment efforts during Expedition 337, multiple lines of geochemical and microbiological evidence demonstrated that a heterotrophic microbial ecosystem exists even at subseafloor depths down to ~2.5 km and that it contributes to biological carbon cycling within the lignite-associated sedimentary habitat (Inagaki et al., 2015). Formation fluid and gas samples were collected in situ using a wireline logging tool following an extensive suite of geophysical logging runs that included all fundamental logging tools, detailed borehole imaging, NMR measurement, and in situ analysis of the formation fluids. The samples and data sets collected resulted in significant scientific discoveries, including determining the energy limits for active microbial life in deep subseafloor sedimentary habitats (Inagaki et al., 2015; Tanikawa et al., 2018). IODP Expedition 337 greatly expanded our knowledge of the deep subseafloor biosphere, a theme central to IODP.

SUMMARY AND FUTURE PERSPECTIVES

By providing access to continuous sampling (fluids, gases, and rocks) and data sets (e.g., advanced logging), riser drilling has opened the door not only to drilling deeper into the subseafloor but to a new era of drilling science. In the coming decades, riser drilling will give scientists access to more data, in situ tests, and samples from deep inside Earth. By using robotics and information technologies, samples and data collected continuously will be acquired and processed automatically. In situ borehole experiments such as the (Extended) Leak-Off Test (XLOT) will also be conducted more frequently. XLOT is a technique to measure the in situ stress field (based on the least compressive stress value) by shutting off the wellhead and pumping fluid into the borehole to increase the pressure until fluid enters permeable formations or a fracture is formed. These approaches will enhance the volume of data acquired during drilling, and using advanced telecommunication technology many of them will be delivered quickly to onshore scientists for further processing, analysis, evaluation, and interpretation. Riser drilling coupled with long-term borehole observatories may be a crucial step toward such data-driven, automated, real-time science in the future.

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