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4. OFFSHORE DIAMOND CORING SYSTEMS: A REVIEW OF KNOWN SYSTEMS AND A COMPARISON WITH THE ODP DIAMOND CORING SYSTEM[1]

Karl O. Sandvik[2] and Alexander C. Skinner[3]

SUMMARY

The ODP offshore Diamond Coring System (DCS) represents the third generation of continuous "piggy-back" coring systems. With the first generation it was possible to reach down to 500 m below the drill floor. The aim of the second-generation development has been to reach as far as 1000 m below the drill floor with the use of H-size diamond coring equipment. So far a depth of approximately 600 m has been successfully reached offshore of Norway by the Continental Shelf and Petroleum Technology Research Institute (IKU) with the drillship *Bucentaur*. The ultimate objective of the ODP DCS system is to extend the method to the capacity of 7000–8000 m below the drill floor.

The most important modifications in the ODP concept are threefold:

1. The introduction of a secondary heave compensator in order to reduce motion left by the main compensator and by the different strain behavior of the two drill strings.
2. The separate and more efficient running of the different drill strings.
3. The lack of a seabed template with which to clamp the API drill string at the seabed.

The first realistic test of the ODP concept was carried out on ODP Leg 124E, at Site ENG-1 (now Site 773) in about 1650 m of water. In this review we give an update on what has been achieved in the UK and Norway prior to Leg 124E, make a comparison between the IKU/*Bucentaur* and the ODP systems, and finally make some comments regarding the ODP method.

INTRODUCTION

This review relates mainly to the known offshore coring history which has derived from the U.K. and Norwegian offshore mapping activities of the British Geological Survey (BGS) and the Continental Shelf and Petroleum Technology Research Institute (IKU), Norway. These activities have included continuous diamond coring in a variety of rock types from soft sedimentary rocks to conglomerates, glacial tills, gneisses, and igneous rocks. In addition, some comments on similar systems which were deployed for research or mineral- and site-investigation work with which BGS was involved on a consultancy or advisory basis, or are aware of, are also included.

THE FIRST GENERATION OF OFFSHORE DIAMOND CORING SYSTEMS—"PIGGY-BACK" CORING

The BGS offshore mapping program commenced in 1968 and utilized shallow coring techniques as one of the main tools to evaluate seismic stratigraphy. Initial operations used uncompensated, over-the-side drilling platforms which used a shell and auger drilling and sampling method to advance the borehole to bedrock, and then a rotary top drive (power swivel) was suspended on guide wires above the borehole and a conventional or wireline coring system was attached to it for coring into the bedrock. The system obtained good-quality cores but was severely limited both by handling facilities and the requirement for good-weather working.

Vessel modifications and replacements introduced heave compensation for the drill string and the use of 5-in. API Grade E drill pipe with bored-out (to 4-in. ID) tool joints. Special bottom-hole assemblies (BHA's) allowed the use of an API wireline core-barrel system with an array of inner barrel types designed for the collection of core from seabed to total depth (TD) irrespective of the geological formations encountered. However, the use of large-diameter core bits necessary for this system frequently meant that progress was slow in hard formations, especially if they were encountered at shallow depths below seabed. Therefore, methods were investigated under which a mining-type drill string could be deployed while the API string remained as a conductor and casing for the secondary drill string.

Early experiments simply hung-off the API string or casing on bumper subs, and another string was run inside using the same power swivel or a smaller one on the same guide wires. Although weight on bit was poorly controlled, as was stability, until the smaller hole achieved some depth, core recovery was good and usually always better than that achieved with the API coring string. Full use was made of those techniques by Wimpey Laboratories and Coe-Metcalf Shipping (both U.K. companies) in contracts with BGS and the U.K. National Coal Board throughout the 1970's and early 1980's.

The development of the present configuration of offshore diamond coring systems probably originated in 1980 with a system set up for work with British Gas in Morecambe Bay. The system was fitted to the Heerema vessel *Mariner* by Seacore, Ltd. (of Cornwall, U.K.), which mounted a small Longyear mining rig in "piggy-back" fashion on top of the API power swivel, using the same compensation system as the main string. After all the API work had been completed, the mining string was run via the Longyear system through the API string, and good-quality cores were obtained in difficult drilling conditions. The system was proved to be a viable one, and "piggy-back" coring became feasible—at least for shallow-water work (<150 m water depth).

[1] Harding, B. W., Storms, M. A., et al., 1990. *Proc. ODP, Init. Repts.*, 124E: College Station, TX (Ocean Drilling Program).
[2] Continental Shelf and Petroleum Technology Research Institute (IKU), P.O. Box 1883, N-7001 Trondheim, Norway.
[3] Marine Geophysics and Offshore Services Research Programme, British Geological Survey, Murchison House, West Mains Road, Edinburgh, United Kingdom.

Seacore, Ltd., then engineered a similar "piggy-back" system to fit the dynamically positioned (DP) drilling vessel *Pholas* in order to meet the contract requirements for an IKU project offshore of northern Norway and in the Barents Sea. A modified Longyear system, capable of handling mining rods to a total string length of up to 500 m, complete with its own wireline and mud-circulation system, was mounted in the *Pholas* derrick and serviced with power from units below deck. Primarily that configuration was used to reduce weight hanging in the derrick. In order to assist with API string stability and firmly lock the BHA downhole, a seabed jacking system, commonly used for site-investigation work, was utilized purely as a clamping mechanism. The use of this seabed-template system enabled the BHA plus the drill string below the seabed to "hang" between the template and the base of the hole with a preselected bit weight, while the weight of the template itself (10–15 metric tons) provided the reaction force for the heave compensation and also provided a tension with which to keep the API string reasonably straight in the water column, all this without disturbing the downhole portion of the string.

The operation was successful but highlighted the need for a stable API drill string when it is used as a casing, as problems occurred on one borehole where the seabed-template clamps failed and "piggy-back" coring continued in relatively bad weather. A requirement for stronger pulling and string holding power within the "piggy-back" unit, which was in danger of dropping the diamond coring string because of lack of pull-back capacity when over 400 m of string was deployed, was also highlighted. Once again, good core was recovered, in many cases in unbroken lengths up to 2 m long. IKU concluded that the system would meet their requirements for coring, followed by petrophysical logging, but that a more suitable diamond coring machine would have to be found in order to cover the Norwegian needs for the next few years.

Seacore and Coe Metcalf, Ltd., have carried out other projects both in the U.K. and Norway using similar equipment and the DP vessel *Pholas*. A French contractor, GeOcean (a subsidiary of Comex and Geodia), has also worked a "piggy-back" diamond coring system from *Pholas* offshore of Angola and the People's Republic of Congo using a Wirth top-drive system. Part of the Gaviota oil field, offshore of northern Spain, was also site-engineered using an offshore diamond coring system for at least one of the surveys.

THE IKU/*BUCENTAUR* DEVELOPMENT

The most sophisticated offshore diamond coring system run in full "piggy-back" fashion is that engineered for the DP drilling vessel *Bucentaur*, owned by Farmand Survey of Norway.

The background for the IKU interest in continuous diamond coring is the interest of the oil industry and the authorities in Norway in collecting geological data in areas of offshore Norway where Cenozoic, Mesozoic, and Paleozoic rocks occur beneath the seafloor sediment. IKU recognized the need for development of a diamond coring system which could be used to carry out shallow drilling in the vast Norwegian area with water depths of less than 500 m, with the possibility of extending this to water depths of 1200–1300 m when required. IKU had several criteria for this new system:

1. Use of standard mining equipment where possible.
2. No motion on the API bit after diamond coring has started.
3. Seabed template with television camera and inclinometer, and the ability to clamp the template to the drill string.

The system that was finally developed used information from an attempt at coring "piggy-back" fashion with a small Diamec diamond drilling rig offshore of Libya where the *Bucentaur* was assisted by Encore, Ltd., a U.K. exploration drilling company. The system proved to be too light for offshore use. Atlas Copco had a new Diamec concept on the drawing table, and that machine was targeted to 1000 m with H-rods. For various reasons, development was postponed several years, and discussions with other manufacturers of diamond coring equipment resulted in a prototype system being developed for *Bucentaur* by Diamant Boart (Belgium) for an IKU charter in the Barents Sea. The prototype system highlighted a number of problems and development areas. A revised system, capable of handling at least 1000 m of H-size mining rod in 3.03-m (10-ft) lengths with computer-aided drilling assistance, was developed by Diamant Boart in close consultation with Farmand Survey and Encore Drilling.

The outcome is the DBH 1500S diamond coring rig, which, in its offshore configuration, is now the "piggy-back" diamond coring system routinely used on the *Bucentaur* down to approximately 600 m below the drill floor. The depth limitation is imposed by the vessel's derrick and heave-compensating system capacities. To date, it has successfully completed four large-scale projects for IKU in the Barents Sea and one offshore of mid-Norway, together with a further two for the Danish government offshore, where chert was successfully drilled. A further contract has been executed with the Norwegian road authorities in which Precambrian gneisses were cored.

The chert and chalk coring carried out for the Danish authorities may have some relevance to the ODP uses of the DCS system. During this project it was found that weight on bit and revolutions per minute (rpm) both had to be increased when chert was encountered (typically to 1500 kg and 600–700 rpm), and each time that a chert unit was penetrated the core barrel was retrieved prior to any more coring taking place—in case of a core jam, which would then allow the bit to "push through" the softer chalk formation without coring. Careful control of rotation, weight on bit, mud-flush volume, and fluid pressure was extremely important, and core-production rate was 2–3 m/hr. The same system also cored a clayey till with cobble-sized inclusions of rock. For this exercise an extended core barrel was also used in the wireline system, and recovery ranged from 70% to 100%.

As with the system developed for *Pholas*, a seabed template is used to clamp the API drill string at seabed when the API borehole is completed, and, as an additional refinement of the drilling compensator, it is linked by a "hard-tie" system to the compensator of the seabed template and is actively driven by it.

Several modifications must be made to the derrick before the ship can extend the present drilling depth with its "piggy-back" system. For an IKU drilling project in May/June 1989, an attempt will be made to reduce the load of the API string on the compensator and derrick as follows.

Inflatable buoyancy members will be added to the API drill string approximately 30 m below sea level and will be inflated after API drilling has been completed, thus "buoying off" sufficient weight to allow safe deployment of the "piggy-back" H string. Depending on the results of the trials, further possibilities may be the addition of solid floaters of a foam-type material at regular intervals along the upper part of the submerged drill string, which would not affect the API drilling. A planned drill-floor modification will allow buoyant sections of 1–1.5 m in diameter and approximately 3 m in length to be added; each will have a buoyant lift of 1–2.5 metric tons. Provided that sea currents do not prohibit this deployment, most of the API string weight theoretically could be "hung off," and the limiting factor to the deployment depth of the "piggy-back" system then would be the holding capacity of the DBH 1500S coring machine.

Examples of the API drilling and DCS coring performances using the *Bucentaur* are given in Table 1. In this table the time utilization at the site (exclusive of transit) is given for the two drilling operations in 1988. It shows that the actual time used on diamond coring (exclusive of running pipe and repairs) accounts for 50% of the time.

The DBH 1500S diamond coring system is also used for slim-hole hydrocarbon exploration on land in the U.S.A. by Amoco. It is run for Amoco by Tonto Drilling, which has assisted with the design and operation of the ODP DCS system.

THE ODP DIAMOND CORING SYSTEM

All of the systems described have three features in common: (1) they depend on running an initial drill string, which then acts as a casing for the second string; (2) they do not use any heave compensation other than that available for the main drill string; and (3) they use a seabed template, especially in second-generation systems, with which to clamp and thus hold the drill string and BHA rigid from the seabed to the base of the initial borehole. Effectively what has been attempted, and has ultimately proved very successful, was to emulate a land situation for the secondary string, which could then be more sensitive to good wireline coring techniques.

These principles have been extended to the DCS system installed on the *JOIDES Resolution* for ODP Leg 124E. The concept of a secondary string with its own top drive and handling system remains essentially the same, but other considerations and deep-water deployment have dictated a number of extra requirements or design changes which make it different in a number of ways. No attempt is made here to specify or detail the machinery of the DCS except to say that all of it is more robust than those systems described (as befits its intended use), but the main conceptual differences are outlined below.

1. As the string deployment envisaged (at minimum) is over three times that of the "piggy-back" systems described, and the main heave compensator on the ODP vessel does not totally eliminate heave, a secondary compensator is required to actively maintain weight on the diamond bit within acceptable levels. Both the insensitivity of the main compensator and the differing stretch within the two deployed strings contribute to the bit-weight fluctuations imposed on the diamond coring bit.

2. The DCS system is not a true "piggy-back" system; it stands to one side while the API borehole is made instead of residing on top of the API top drive. Furthermore, the API string is allowed to ride in the borehole uncompensated and with the top drive disconnected while the main part of the DCS string is made up in 90-ft stands independently of the DCS system. The DCS system and API top drive are then installed.

3. Once all systems are connected, and the API drill string is returned to bottom under full compensation, the DCS system becomes fully operative and runs its own 10-ft rods to the base of the API borehole for spud-in. Only at this stage, and after the secondary heave compensation is switched on and activated, is the secondary string in full compensation and in a similar condition to the other "piggy-back" strings.

Table 1. Time-utilization analysis of main activities on *Bucentaur* in 1988.

	Moere/Troendelag		Barents Sea	
No. of holes	6		8	
Water depth (m)	204–243		264–409	
Overburden (m)	3–68		7–75	
Diamond drilling (m)	14–127		22–181	
Activity	Relative time consumption (%)			
[a]General	[b]4–14	[c]11	4–45	15
[d]API	17–40	25	6–35	22
HR running of pipe	7–17	9	5–11	7
HR drilling	27–60	49	11–71	50
Logging	4–11	6	2–9	6

[a] Includes detailed positioning at site, rigging of equipment, running of seabed template, and repair of any equipment involved.
[b] Range for all holes in area.
[c] Average for whole area.
[d] Includes all running and drilling with API pipe.

COMPARISONS AND GENERAL OBSERVATIONS: ODP DCS SYSTEM AND OTHER SYSTEMS

The technical differences between the ODP and the IKU/*Bucentaur* diamond coring systems are listed in Table 2. *Bucentaur* is used in the comparison as being the most up to date and therefore incorporates lessons and techniques learned from the other systems.

The differences in the main drilling equipment on board *Resolution* and *Bucentaur*, together with the coring requirements of both vessels, have operational implications. There are benefits and drawbacks in both working environments.

Regarding the two vessels, the smaller size and weight capability of the derrick on *Bucentaur* limits the total length of API string that can be run to a maximum of about 1000 m compared with a 9000-m rating for the *Resolution*. Furthermore, only single API joints can be run on *Bucentaur* at any time, compared with triples on the larger vessel. However, the "piggy-back" platform hanging in the derrick of *Bucentaur* does not limit its ability to run or handle API pipe significantly, although there is very little space left in the derrick for running pipe, whereas the present configuration of derrick handling on the *Resolution* does not allow for the DCS to be present while the API string is being handled.

A seabed template is deployed from *Bucentaur*. That acts as a reentry tool for API drilling and coring when simply set at the

Table 2. Comparisons of ODP and IKU/*Bucentaur* diamond coring systems.

	ODP	IKU/*Bucentaur*
Hole size (in.)	4.0 (H and N)	3.78 (H) 2.96 (N)
Bit size (in.)	3.96 OD, 2.4 ID (H) 3.96 OD, 1.875 ID (N)	3.76 OD, 2.27 ID (H) 2.96 OD, 1.74 ID (N)
Core size	2.4 in. (× 5 ft or 10 ft) 1.875 in. (× 10 ft)	2.27 in. (× 10 ft) 1.74 in. (× 10 ft)
Top-drive rpm (range, m)	0–1800	0–900
Top-drive torque (max., ft-lb)	6000	4000
Weight on bit (range, lb)	0–12,000	0–33,000
Drill-rod string (in.)	Hydril 500 tubing 3.5 OD, 2.942 ID (external upset)	HDBGR drill rods 3.5 OD, 2.79 ID (internal upset) NDBGR drill rods 2.756 OD, 2.157 ID (internal upset)
Maximum single length deployed from platform	Single 10-ft tube	Single 10-ft rod
Maximum string length (ft)	12,000	3300 (H) 4950 (N)
Length of DCS platform (ft)	41	25
Weight of DCS platform (lb)	40,000	23,000
API size (in.)	5.5 S-140	5 modified (4 ID)
Derrick height (ft)	147	85

seabed, and as a downhole stabilizer and seabed-to-ship string tensioner when additionally clamped around the API pipe. The seabed template, in conjunction with the BHA and the API string, can be configured to accommodate the Fugro Wison System, which is a real-time umbilical-connected wireline system for CPT measurements. During the *Bucentaur* operation for IKU, this system was used as a tool carrier for *in-situ* temperature and heat-conductivity measurements. An important spin-off from the heat-flow measurements was the possibility of monitoring movements of the API bit. Measurement would include any friction created by pipe movement and penetration resistance as the 4-mm (OD) temperature probe pushed into the undisturbed sediments below the API bit. These measurements proved that no movement of the API bit occurred when the template was clamped to the API pipe. Television monitoring of the API drill pipe within the template also showed that only a few centimeters of movement occurred around the unclamped drill pipe, even at low bit weight (0.5–1.0 metric tons) and high ship heave (4–5 m), provided that the "hard-tie" system was activated between the template and drilling compensators.

The most negative factor of the diamond drilling system on *Bucentaur* is its total handling capacity of approximately 1000 m of H drill rods and the constraint of being able to run only single 3-m lengths. On the other hand, no decoupling of the "piggy-back" platform is necessary between mobilization and demobilization. All API pipe handling and API wireline operations can be done through the "piggy-back" and API power swivels simultaneously. The combination of an efficient main compensator, a seabed template, and, if available, a "hard-tie" system between the main compensator and the seabed-template compensator precludes the need for an extra compensator for the "piggy-back" drill string. That may not hold true, however, for longer drill strings with a more significant differing stretch factor between the two drill strings. The "piggy-back" rods are connected and disconnected by a hydraulic coupling system. To reduce the weight on the derrick of the *Bucentaur*, the hydraulic power is provided by motors under deck and supplied to the pumps on the "piggy-back" platform via umbilical hydraulic hoses.

During development of the IKU/*Bucentaur* method, several general and operational principles have been adhered to, all of which have contributed to the present operational success:

1. When possible, use standard, readily available equipment. This has been done in order not to change the mining-type drilling equipment proved efficient on land. No modifications have been made either to the core barrels or to the wireline system.
2. Try to control the different forces acting on the system. The aim at each site has been to have a outside seal on the API bit before the diamond coring has started. The main reason for this has been to avoid possible erosion of the API hole. When that seal has been broken, the leakage outside the API string and into the main borehole has been accepted, since rotation and attempts to reseal the API bit have been regarded as more damaging to the "piggy-back" borehole than allowing the leakage. Loss of seal has occurred frequently but has not resulted in any noticeable borehole-stability problems in either the API or the "piggy-back" boreholes.
3. Execute detailed site surveys prior to the final site selection. The site surveys serve two main objectives: to give input to the geoscientific evaluation of the site, and to act as a basis for the technical evaluation of the drilling solution for each site. High-resolution seismic surveys tied to known geology can provide conclusive information on what coring method or bit type to choose (both for the API string and the "piggy-back" string) and may also contribute to the mud program for the borehole. A good prognosis of the expected drilling conditions at each site helps the driller react meaningfully when encountering different drilling responses. In order to extrapolate technical experience, high-resolution seismic surveys can also provide continuity from one area to another.

Although API borehole instability and the lack of a proper basement rock in which to evaluate the DCS coring did not allow as full a test of the ODP DCS system as was planned, it was demonstrated that the ODP diamond coring system proved capable of maintaining good control over bit weight in adverse weather conditions when using the computer-controlled secondary heave compensation, and also that the system was capable of collecting core from soft sedimentary-rock formations when run under this system. Equally important was the demonstration that, using the manual mode and with an experienced driller, proper rotation and coring without secondary heave compensation was not possible without excessive bit weight occurring and the mud flow blocking off.

Generally bad weather throughout the trial helped to prove the robustness of the DCS but may have contributed to the lack of API-borehole stability, which was never good at any of the attempted locations, even during the drilling of the API borehole. It cannot be overemphasized that API stability is the single most important factor if DCS coring is to become a reality. While casing the hole is an option, it is yet another time-consuming exercise and rather defeats the object of wireline coring where the DCS should simply take over from the API systems to continue advancement of the borehole.

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