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5. ENGINEERING REPORT ON THE EXTENDED CORE BARREL (XCB-124E)[1]

David P. Huey[2]

INTRODUCTION

The extended core barrel (XCB) coring system has been in a state of constant development since its earliest attempted uses during DSDP Leg 18. Each version of the tool since its first truly successful deployments during Leg 90 has been an improvement, yielding a more useful and reliable tool for acquiring samples of soft and hard sediments. With its improvements has come popularity within the science community and, consequently, more requests for its use in increasingly more challenging downhole environments. These challenges have dictated a continuing need for evaluation at sea followed by design improvements and revised, upgraded versions of the tool.

The latest version was timed to be made ready for Leg 124E after having been revamped since field testing during Leg 121. It was intended that the 124E version would get enough downhole time to verify that the system was operational and a significant improvement over previous versions. The 121 and 124E versions are the same in concept as their operational predecessor (101C version) but had been improved to provide more flow to the cutting shoe, better control over extension and flow parameters, a greater and more economical variety of cutting shoes, and significant improvements in the strength of several areas of known mechanical weakness, especially the threaded core-barrel connections. All of the above problem areas had limited the usefulness and range of acceptable lithologies for XCB deployments in the past.

During Leg 124E, 11 cores were taken with the new XCB in Hole 772A, and 5 other deployments were made in Holes 773A, 773B, and 775A. The results were sufficient to demonstrate that the latest version of the tool was capable of replacing the 101C version. Further testing at Site 777, the prime site for both XCB and navidrill core barrel (NCB) testing, was intended to demonstrate whether or not the desired levels of ruggedness had been achieved in the new XCB design by subjecting it to interbedded chert and softer sediments, the most difficult and damaging lithologic sequence routinely encountered when using the older XCB versions. In addition, new diamond-enhanced cutting shoes had been developed which were expected to survive chert-coring conditions more successfully than the earlier, hard-faced steel models. One piloted, diamond-impregnated cutting-shoe style was included in the Leg 124E XCB inventory specifically for the chert beds at this site. It was anticipated long before the voyage that the XCB would probably not be adequate for producing high-quality cores of scientific value in the most severe forms of chert-interbed coring. Despite this caveat, it was worthwhile to test the system to find out what limitations were present in the latest version in order to ascertain what, if any, upgrades could be made in the future to assist in the very difficult chert-coring assignments anticipated in the Western Pacific science operations soon to come.

Operational plans for the XCB-124E at Site 777 included intentionally repeated cores in parallel holes through troublesome chert intervals to observe the effects on core recovery of changing coring parameters (weight on bit, rpm, cutting-shoe type, and flow rate). At the same time, wear and breakdown of the XCB coring equipment when the chert became uncorable would be diagnostic for future engineering and science planning.

XCB FLOW TESTS

En route to Site 777 a series of flow tests for the XCB system were conducted. Partial bottom-hole assemblies (BHA's) and XCB core barrels were devised in which the lower ends of both assemblies were simulated to allow for controlled flow measurements. Seawater was pumped into the top of the mini-BHA and allowed to divert partially to the XCB cutting shoe and partially to the XCB core-bit jets just as it would behave downhole. Both the total flow through the entire system and the portion of the flow diverted to the cutting shoe on the core barrel were measured. The tests were repeated, varying the port sizes on the inlet subs, which was expected to control the percentage of the total flow allowed to reach the cutting shoe. Different types of cutting shoes (with different outlet hole configurations) and different total-flow rates were also used. In all, 38 test runs were conducted. At higher flow rates (e.g., 400 gpm total flow) the velocity and energy of the flow emerging from the XCB cutting-shoe ports in the open air was impressive to observe.

Although it was hoped that the percentage of flow diverted to the cutting shoe could be varied from about 5% to 40%, it was found that the inlet sub ports did not offer the range of control desired. The flow to the cutting shoes was found to be variable from 7% to 24% of the total. It was felt from past experience that sticky clay formations would cause the lower extremities of the XCB to become clogged with cuttings if the flow percentage could not be improved over this limit. The chert interbeds at Site 777 did not present this problem, however, since the amount of sticky clay in the interval cored was either very small or nonexistent.

The effect of the size of the outlet holes in the cutting shoes was more dominant than expected. The percentage of flow diverted to the cutting shoe tended to be approximately a linear function of the cross-sectional area of the outlet holes in the cutting shoe. This is unfortunate, because the velocity of the flow out the cutting shoe holes will theoretically be inversely proportional to the cross-sectional area of the holes. The highest possible velocity is desired but is not as effective if it comes at the expense of flow volume. The apparent reason for the inability to control diverted flow to the cutting shoes as expected, using the inlet ports, was a greater than anticipated flow resistance in the flow annulus between the inlet subs and the outlet holes in the cutting shoes. This annulus had been opened to the maximum possible size without either an unacceptable loss in strength of the mechanical components from wall thinning or an equally unacceptable decrease in core diameter by borrowing space from the inside of the assembly. These results have effectively dictated the limit of XCB flow control using the current parallel-open-path concept for the XCB system. A more com-

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[2] Shipboard engineering and scientific parties are as given in the listing of participants preceding the contents.

plex back-pressure-controlled parallel path system would be required if the measured limitations turn out to be unacceptable after sufficient operational experience in a variety of XCB-coreable lithologies.

XCB DEPLOYMENTS—SITES 772 THROUGH 775

The first deployment of the XCB-124E tool came at Hole 772A. The plan for the hole was to use the XCB and new pressure core sampler (PCS) to core a hole through the sediment overlying basement in preparation for testing the new diamond coring system (DCS). The actual depth at which basement would be encountered was unknown; thus the coring sequence entailed coring and washing to greater depths in order to arrive at basement quickly. XCB cores 124E-772A-6X to -11X were taken from the interval 35.4–92.4 meters below the seafloor (mbsf). Recovery ranged from 0 to 9.79 m and averaged 6.86 m per core. The hard-faced, soft-formation steel cutting shoes were used exclusively. For the most part the formation was unconsolidated silty clays, which were not a particularly representative test for XCB coring since such sediments ordinarily would be cored with the hydraulic piston corer. Five additional XCB cores were cut in the hole, at 130.1, 168.0, 173.7, 275.5, and 361.0 mbsf. For the last two cores, the six-bladed, impregnated diamond-insert cutting shoes were tested. Again, the results varied from 0 to 5.38 m recovery of core. As with the earlier versions of the XCB, the percentage of recovery seemed to be dominated more by the formation's physical characteristics and less by the core-barrel setup or the driller's technique.

A total of five cores were cut with the XCB in Holes 773A, 773B, and 775A, all in preparation for planned DCS coring in the same hole. The recoveries ranged from 0.35 to 7.86 m per core. In two of the five core runs the six-bladed diamond-impregnated cutting shoes were tested. The net result of the preliminary testing of the XCB at these "DCS sites" was as follows:

1. The formation cored dominates the results when using the XCB-124E just as it did with earlier versions of the tool. Increased control over core blocking, plugging of cutting-shoe jets, or washing away soft materials was not achieved as desired. The XCB-124E behaved in this regard virtually identically to its predecessors.
2. The cutting shoes and core catchers of the XCB-124E version were a great deal easier to clean and keep clean.
3. The mechanical ruggedness and reliability of the XCB-124E appeared to be noticeably superior to the previous versions, although the true test of that would come at the chert sites.
4. The new-style cutting shoes were as good or better than any previously devised. The soft-formation sawtooth shoes were identical in coring performance with their predecessors but were easier and less expensive to manufacture. The all-new impregnated insert shoes were the best diamond-enhanced type yet tested. They showed no signs of catastrophic failure typical of earlier versions.

XCB DEPLOYMENTS—SITE 777

The XCB was deployed seven times at Site 777. After a single piston core to establish the mud line at Hole 777A, five XCB cores were attempted. Two were cut in very soft sediment that was suitable for piston coring but was too soft for effective XCB usage; thus the recovery was only 2.07 m over the 17.6-m interval cored, with the remainder most likely having been washed away. On the third XCB core the anticipated chert zone was encountered. The rate of penetration dropped to about 10 m/hr over the last 4 m of the cored interval. The recovery was poor owing, first, to washing away of the soft sediment overlying the chert/porcellanite, and then, to jamming of the cutting shoe with chert fragments after encountering the hard zone. Cores 124E-777A-4X and -5X experienced the outcome common to XCB coring in chert-dominated sediments: the cutting shoes failed owing to abrasion and broke down under the influence of the hard, broken chert fragments, which neither could be cored smoothly nor removed completely from the vicinity of the cutting shoe. On each core the cutting shoe had to be retired, as all of the diamond-impregnated cutting structure was worn away. Material recovered for both cores was a few chunks of recently fractured chert. Further attempts to legitimately core the chert/porcellanite interval were not attempted with the XCB because it was obvious that the XCB would not be suitable for coring this type of lithology. Further attempts to force the issue would only have resulted in the unnecessary destruction of more of the limited XCB cutting-shoe inventory, which would be needed for more suitable coring environments on upcoming science legs.

The XCB was deployed twice more, however, to prepare Holes 777C and 777E for navidrill coring. In Hole 777C a well-used diamond-impregnated cutting shoe was used to wash (at high flow rates) 10 m into the chert zone to make a suitable starting hole for the navidrill core barrel (NCB). The shoe was worn to near destruction as before, and no core was recovered. In Hole 777E a single XCB core was cut 9.5 m into the upper layer of the chert zone using a piloted (stepped), fully impregnated diamond cutting shoe. Recovery was 0.41 m of fractured chert fragments varying in size from BB's to golf balls, but only one or two pieces showed any signs of actual smoothly cut surfaces that could be attributed to the action of the cutting shoe. The cutting shoe itself was worn to the point of doubtful reusability but did not suffer catastrophic breakdown of the crown matrix, as had been the common result with similar shoes tested during Leg 121.

CONCLUSIONS

The XCB-124E version of the extended core barrel system was declared operational as a result of the trials on Leg 124E and replaced the previous (101C) version. Although the XCB is not suitable for chert or chert/sediment interbedded coring, it is highly appropriate as a routine coring tool in many other lithologies commonly encountered in ODP operations. In testing in chert-dominated formations at Site 777, it was effectively given a severe trial. All identified areas of mechanical weakness were found to be improved over the previous design, as hoped. No mechanical failures occurred except for severe wear of the cutting shoes in those cases where chert overpowered the mechanical durability of the diamond-bearing matrix. In particular, the tendency toward catastrophic failure of the cutting-shoe box connection has been eliminated by new connections throughout the XCB with greatly improved torque strength. No connection failures were evident, despite coring conditions that destroyed the best available diamond cutting shoes. The new-style cutting shoes also provided enhanced cleanout capabilities when sediment managed to get in and clog the flow passages. There was not sufficient opportunity to evaluate how much of the clogging problem has been eliminated with the new, enlarged flow passages to the cutting shoes, but the results of the on-deck flow tests suggest that the problem will persist.

The attempts to core the chert beds with the XCB system were unsuccessful. A few pieces of chert were recovered, with partially trimmed surfaces matching the cutting-shoe inner diameter, but the trimming operation was never completed because the chert layer apparently fractured before a full cylinder could be produced and "fed" into the core receptacle past the core catchers. This all-pervasive fracturing problem is thought to be caused by excess energy stemming from the proximity of the roller-cone bit and is endemic to the XCB system. In fact, this particular limiting characteristic of the XCB was one of the original factors that prompted development of the navidrill coring system. Although the cutting shoes, threaded connections, and latch assembly now used on the XCB (previous areas of mechanical vulnerability) all held up to the severe demands of chert-bed coring, the basic coring action of the XCB appears to be inadequate to core very hard/soft interbeds owing to uncontrollable fracturing of the hard layers and washing away of the soft material.

FUTURE PLANS

It is not intended that the XCB system should be an endless development project. Its role is to acquire cores in those sedimentary formations too stiff for piston coring but not lithified enough to require rotary core barrel (RCB) coring, although it has been used successfully to take rock cores in a few limited cases. At the very least it provides a means to continue coring in a hole started with the advanced hydraulic piston corer (APC) without requiring a round trip of the drill string for an RCB core bit and a BHA. The XCB also has the potential to capture core from formations where any other type of rotary coring using roller-cone bits would wash away significant portions of the sought-after lithology. Hard-soft interbeds, in particular, represent a recurring scientific target which only the XCB has any real chance of recovering with high percentages in routine coring operations. (Success with the NCB or DCS developmental tools may change this.)

In order to achieve these modest goals, the XCB must be the most versatile of all the ODP coring tools. Past models, though capable of producing high-quality cores in the right lithologies, proved vulnerable to mechanical failures and displayed excessive tendencies toward plugging and core blocking. The XCB-124E is stronger in all of the areas of known mechanical weakness but shows no vast improvement in terms of preventing core blocking or plugging. To solve these problems, and gain the resulting benefits of more core from a wider variety of downhole environments, would require significant reformulation of the XCB equation. One possibility for achieving greater control over nozzle plugging and core jamming is a controlled-back-pressure scheme. In that concept the parallel flow path to the roller-cone-bit jets would be controlled by the core barrel itself. The back pressure to drive the amount of flow desired out the XCB cutting-shoe jets would be achieved by modulating the flow to the bit jets via check valves or variable orifices. Before such a system could be developed and tested, a better theoretical understanding of the flow and pressure regime around the bit and cutting shoe will be required. The flow tests conducted on Leg 124E (and similar tests done on Leg 121) are the first step in that process.

Cutting shoes represent the highest cost item in the XCB inventory because of difficult fabrication requirements and the need for frequent replacement. Improvements in the design of the shoes to make them easier to fabricate, and therefore less expensive, will continue to be made.

The most common cause for missed core when using the XCB is core jamming. Industrial coring equipment used by the mining industry now sometimes includes mechanical anti-jam devices that act like little jars inside the core barrel. Such devices will be examined for applicability to the XCB coring system. Another means of coping with core jams is to have real-time knowledge of the problem as it occurs. To do this will require that development of the sonic core monitor system be continued. The ultimate system is seen as an XCB with a real-time core-entry monitor system that would allow the driller to make proper adjustments to coring parameters immediately as core blocking begins. The sonic core monitor was included in the variety of tools slated for testing on Leg 124E but did not get deployed because the opportunity for suitable testing conditions did not arise.

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