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BGS Oriented Seabed Rockdrill (BRIDGE Drill) - Engineering Report for scientific cruise JR63

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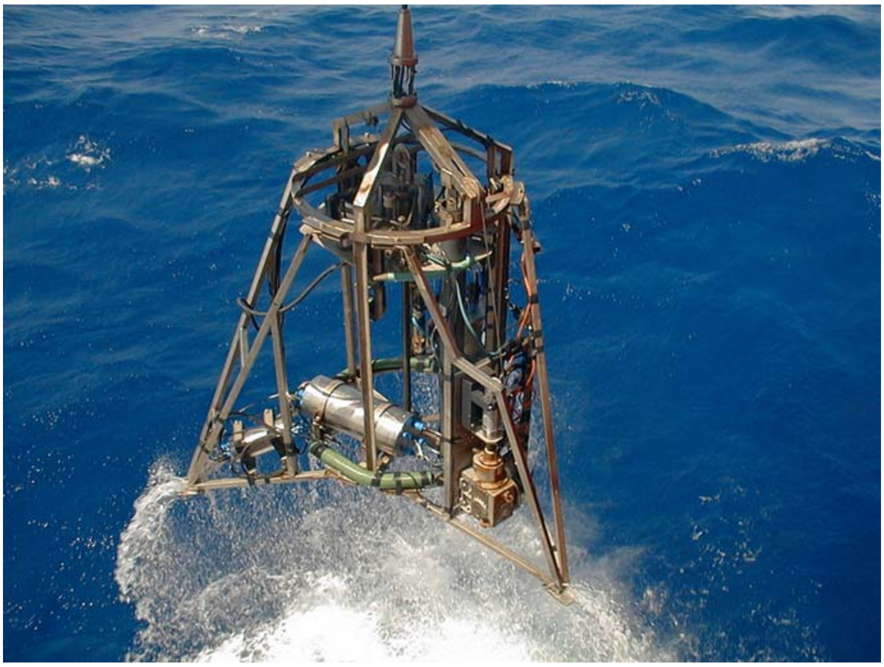

BRITISH GEOLOGICAL SURVEY

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Smith, D.J., Brett, C.P., Wallis, D.G., Derrick, J.F.

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Recovery of Oriented Drill on RRS James Clark Ross.

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Specific to this report

Marine Operations and Engineering, 2A Nivensknowe Road, Loanhead, Midlothian EH20 9AU

☎ 0131-448-2700 Fax 0131-448-2545
e-mail: djsm@bgs.ac.uk

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
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☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS

☎ 028-9066 6595 Fax 028-9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

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Summary

This report describes the building up, testing, calibration and operation of the BGS BRIDGE drill system whilst on scientific cruise JR63. The location was in the vicinity of 15 45N, 46 55W, the fifteen-twenty fracture zone of the Mid-Atlantic Ridge. This cruise was in support of a scientific award from a proposal by Prof Joe Cann, Leeds University, Dr. Chris McCleod, Cardiff University and Simon Allerton (formally Edinburgh University). Whilst other equipment was taken and used, (TOBI, swath, dredging etc), during the cruise, the primary system on which the proposal was based was the oriented drill.

After solving various problems in almost all aspects of the system, during the initial period of swath, dredging and TOBI, the drill operated with no significant down time throughout the operational period. Twelve days of operations resulted in 73 sites drilled with core recovery from 63 bringing the total number of sites for this drill to 90. Maximum operating water depth was 4520m; maximum drilled inclination was 42 degrees from the vertical. A total of 320 seabed landings were made and seabed photographs taken. On a further 87 attempted landings the drill rig fell over and had to be picked up again.

The drill operated successfully at its maximum design depth of 4500m.

It is believed that a few records have also been broken, namely the only drill able to produce scribed core and oriented to a known reference. Deepest water depth (4520m) drilled utilising remote drilling techniques and possibly only beaten by ODP type drilling.

Since the prototype had been designed, built and tested in 1998 on JR36, there has been little or no development of the system. Development would improve reliability of certain components and ease of use or would enhance the system's capability making it more useful for this particular application and other types of marine science. A series of recommendations are described to address ease of use, improved performance, reliability and client requests.

1 Introduction

The BGS Bridge drill is designed to take oriented hard rock cores and is so named because the original development of the drill was funded by the NERC, BRIDGE programme in 1996-98. All subsequent development, including the provision of a second drill rig complete with a full set of spare components has been funded by the BGS directly.

The prototype drill had undergone successful trials in 1998 on Atlantis Bank, from the RRS James Clark Ross (cruise JR36), when 16 sites were cored, to a maximum water depth of 800m. This was to be only the second utilisation of the system and the main target water depths were in the 1500-2500m range. It was also intended to carry out deeper attempts at the end of the planned programme of sites.

The objective of this report is to document the events, successes and failures of the utilisation of the oriented drill system on cruise JR63. This report also provides analysis and recommendations for future use of the system.

The principle scientific objective of cruise JR63 was to conduct detailed geological investigations in the area around 15 45N, 46 55W that is in fifteen-twenty fracture zone of the Mid-Atlantic Ridge.

Previous swath mapping of the area had revealed four anomalous shallow massifs rising to 1540m below sea level. These and other such massifs have been interpreted as surface expressions of low angle detachment faults. The principle aim was to test this hypothesis.

2 The Drill System

The drill is designed to be deployed from an armoured coaxial power and hoist cable such as the 17.5mm diameter one available on the James Clark Ross, using the vessel's main traction winch. All power, communications commands and data are transmitted via this coaxial cable.

The drill takes a 35mm diameter core using a standard twin barrel system. The core is cut by the outer, rotating barrel and is scribed along its length with a single reference line as the core enters the inner, non-rotating, barrel. During drilling, water is continuously flushed between the two barrels to cool the bit and to flush away the rock cuttings or any sediment. The scribed line is referenced to magnetic north using two flux gate compasses mounted on the drill rig. Where possible, the drill rig is constructed from low-magnetic stainless steel to minimise its magnetic signature. The compasses have an auto-compensation routine that allows them to compensate for the magnetic signature of the drill rig. The operation of the drill is monitored by a subsea computer, which sends data from the suite of sensors on the drill to a computer on the surface for display to the operator. The same subsea computer receives operator commands via the surface computer enabling the drilling operation to be controlled in real time.

There is a monochrome stills camera on the drill rig, which is used to transmit seabed pictures back to the surface. This allows the site to be selected or rejected prior to coring and also provides a visual record of the site for archiving purposes.

Limitations imposed by the use of coaxial cable dictate the use of limited single-phase power, onto which all data and communications have to be transmitted. Through the use of modern, compact, motor controllers the drives for rotation, retraction and water flushing are driven directly from 3 phase AC motors, providing a high degree of control and efficiency.

The original design of the drill permitted a maximum core length of 1100mm. However, based on the Atlantis Bank experiences, modifications have been made to improve the stability of the rig and to give the drill bit/barrel more protection when landing on an irregular seabed. This has involved re-siting the main subsea electronics bottle to the bottom of the rig to lower the centre of gravity, reducing the maximum travel of the drill table. The overall length of the barrel has been reduced so that, on deployment, the drill bit does not extend as far below the centre of the rig frame, making it less likely to hit an irregular seabed on landing. The combination of these two adjustments has reduced the maximum drill bit travel, resulting in a maximum possible core length of 770mm, when the drill is standing on a flat, level seabed.

3 Mobilisation of The Drill System

3.1 11TH TO 28TH APRIL

Wednesday April 11th

The drill container arrived on the vessel at 16:30. The container was positioned on the Port side of the after deck; just clear of the main 'A' frame. Evidence was found to suggest that the container had suffered large shocks during transit, several stays had come out, and water had entered. The main drill surface computer hard disk had failed, though the spare computer was operational.

Initial building of the two drill frames was a quick and easy process; only one leg from each rig had been removed for containerisation. The main drill system was run up and compasses calibrated on the dockside, see orientation section for detailed description.

Thursday April12th

Continue with compass calibration.

Friday April 13th

Orientate scribe, compasses, pitch, roll and camera with respect to leg 2, the reference for the rig. The compasses are internally offset, through firmware, to provide the bearing of leg 2. The scribe was adjusted to align with leg 2.

Continue to harness up the rig and perform H.V. and communication tests connected to the 9.5km vessel's co-axial cable. Motors briefly powered up and camera tested with photo of the deck.

Saturday April 14th

Sailed 15:00.

Sunday April 15th to Saturday April 28th

With the initial mobilisation complete, the next two weeks were taken up with looking at every aspect of the drill system, while waiting for the window of coring operation. The vessel sailed north past the equator to the work area and commenced the science operations with swath bathymetry followed by dredging and TOBI.

The compensator bottle for the retract winch gearbox was found to be leaking oil. It was replaced with one from the spare rig.

When the drill was operated, noise was seen on the RPM sensor data. This was traced to sensor and power cables (non screened) being in close proximity to each other. The cables were resited.

Various communication and control operation problems were encountered. These it is believed were traced to the ship's dirty 240VAC supply and poor earth. This had not been a problem in Recife when the main engines were not running. The system functioned correctly after changing the supply and providing a bond between the outer armour of the co-axial cable and the drill frame. It was not established if the vessel's impressed current had been switched off in port.

NOTE: System works with or without an earth connection to the surface 1500VAC transformer.

Further measurements were taken of the rig to calculate the table travel distance, penetration, echosounder position etc. that had not been carried out since changing the barrel length and reducing the travel distance due to the repositioning of the subsea electronics bottle.

Rig 1 transformer was removed from the rig to allow a drain plug to be fitted to the base. This allows easy removal of oil and more importantly inspection of saltwater contamination. The transformer on rig 2 was subsequently modified. The transformer was remounted and filled with approximately 15 litres of oil. A standard 1 litre compensator was re-mounted flush with the base of the transformer and completely oil filled. Additional fittings were installed for a second BGS manufactured compensator. This second compensator was mounted approximately 200mm above the top of the transformer and half filled with oil. The air temperature during this time was 30+ degrees C.

The drill drive gearbox was topped up with oil. The attached 0.5 litre compensator was ¾ filled.

The retract winch compensator was leaking and assumed to have failed. A replacement 1.0 litre compensator from the 2nd rig was used and filled to ¾ full.

3.2 MOTORS

A new motor and pump assembly was used for the water flush. A new motor was used for the drill motor. This motor was a replacement for the retract motor that failed in 1998. The original motor used as the drill motor for the 17 sites on the Atlantis Bank cruise in 1998 was used for the retract winch.

From experience gained using the motors and possible causes of failures, each motor electrical connector was sealed with self-amalgamating tape where the tail emerges from the top of the connector. In addition a thin layer of Vaseline was applied to the neoprene part that seals against the motor body. This technique was applied to all motors used on the rig.

3.3 BARREL ASSEMBLY

A barrel assembly was made up and fitted to the rig. A spreadsheet of all the drill bits and their internal dimensions was made, see appendix 3.

Checks were made of the clearances of the inner and outer barrels and it was established that in there was less than 1mm gap between the ID of the drill bit and ID of the inner barrels for most of the barrels.

3.4 INCLINATION SPREADSHEETS

To aid both the calculation of the resultant inclination from the pitch and roll data and the rotation of this inclination with respect to the rig reference (leg 2), two spreadsheets were made. The resultant lookup tables were used throughout the operation.

3.5 SPARE RIG BUILD UP

The remaining few days prior to commencing operations of the drill was taken up with building up the spare rig. This was never completed for two reasons.

- There was insufficient time
- To do so beyond a certain point would have jeopardised the use of the spare components for the main rig.

During this second build a new type (to BGS) of subsea electric motor was installed. Prior to installation an investigation was carried out into the best use of them for our application of deep-water operation. The motors are oil filled with the windings open to the oil and consequently the internal large compensator (compared with the existing motors) is designed primarily for oil expansion due to oil heating during operation. This differs to other types of borehole motors including the motors previously used in two ways

- Oil filled instead of glycerine/water filled
- Windings open to the oil instead of potted and sealed.

Further investigation found that these oil filled motors had a small air space, i.e. the cylinder was not completely filled. It was thought that the best way to use these motors to greater depths than the manufacturers specification was to:

- Eliminate the air gap
- Slightly inflate the rubber diaphragm to allow for any oil compression whilst also leaving enough compensation for oil expansion due to heat.

Both these where done by the addition of extra oil. An additional 90ml of oil was included after the air gap had been filled. The oil used was standard hydraulic oil that was found to mix well with the existing ESSO MARCOL 172 oil inside the motors, prior to filling, this was confirmed by Millers Oils technical department.

Two motors were compensated in this manner. Both were initially mounted on the spare rig, which provided confirmation that they would fit into the same area despite being physically larger and utilising different mounting threads. It was noted that if one of these motors had to be fitted to the primary rig, then a modification to the rig would be required to accommodate the extra length of these motors.

During this time the second (spare) camera subsea electronics was built. This was bench tested with the spare camera and light. The light failed to operate and was traced to a broken bulb. This appears to be another example of the rough treatment the container took during transit.

3.6 ORIENTATION: BGS BRIDGE DRILL COMPASS CALIBRATION

This procedure, called calibration by the manufacturer, is strictly speaking a compensation procedure by the compass for the ferrous material to be found as part of the drill structure. It should be carried out in a relatively constant magnetic environment without any severe magnetic gradients.

The manufacturer has evolved three methods whereby the compass may be calibrated. The first method involves knowing exact headings and as such is not considered suitable for the BGS Bridge drill. However both of the other methods have been used successfully to calibrate the drill compasses, as they do not require an exact knowledge of heading at the calibration site. The method used prior to the Atlantis Bank project was the ‘eight point’ calibration and involved use of a forklift truck. However, this was not felt suitable for the mid-Atlantic preparations in Recife where the quayside space was limited.

In Recife the ‘Circular’ method was chosen as it appeared better suited to the situation. The circular method requires the compass mounted on the drill rig to be rotated through 360° over a period of between one and two minutes. During this period the compass collects data through the complete rotation and using proprietary routines provided by the manufacturer, is able to compensate the compass readings for the presence of magnetic or ferrous material on the vehicle.

Due to the design of the drill electronics, normal communications from the compasses are routed through the main electronics processor. However for calibration this is not adequate to the task and a direct link between each compass and an external computer must be established. Once this link is made, to each compass in turn, then the procedure is carried out for that compass before control is once again returned to the main processor.

The process starts with a command to the main seabed processor to connect the compass receive and transmit lines directly through the frequency shift keying (FSK) modulator to the surface control PC. Meanwhile the seabed processor is monitoring the receive line for the signal to retake control of the communications. Once a direct connection is made to the compass, the data rate is reduced from 9600 Baud, which is too fast for reliable data transfers, to 4800 Baud, more suited for error free operation. At that point the proprietary software is invoked, with the first act being to confirm the serial number and the current configuration settings held in the compass firmware.

Next, the calibration procedure is called up from within the software package and the compass is rotated through 360° slowly. At the dockside, this was carried out by suspending the drill from the aft crane some two metres above the ground, where it was then rotated by hand. Lifting the rig to the height resulted in a stable magnetic environment. Presumably the quayside contained a substantial amount of iron.

At sea it was noticed that the drill naturally spun slowly in the water as it was deployed or recovered. It was possible to make use of this fact during deployment or recovery to recalibrate the drill at sea. The differences between the compass readings changed with use at sea. It is believed that this is due to an effect caused by the considerable pitch and roll values whilst the drill was positioned on the seabed, the compass calibration not taking into account the possibility of the drill being on an uneven surface.

At the end of the calibration procedure the compass software itself produces two figures, the noise score and the magnetic environment count. The noise score is a guide to overall accuracy and should be 8 or 9 and the magnetic environment figures show the quality of the magnetic environment and should exceed 5, any lesser values would indicate the need to repeat the calibration. A score of 8 or 9 gives an expected accuracy of 1° or better.

4 Daily Operations Log 28th April to 11th May

All times quoted are GMT

Saturday 28 April

Received access to the cable in the early evening on completion of TOBI operations. Mechanical and electrical terminations completed and the pot allowed to cure overnight.

Sunday 29 April

The drill was connected to the cable in the early morning (08:00GMT) and initial on- deck tests carried out. From the outset there was a considerable problem with electrical noise generated in the coaxial cable. The main consequences of this were difficulty in communicating with the camera and the surface control programme, resulting in programme lock up, forcing a reboot of the control computer. The drill was deployed into the water and the problems persisted, with the camera communication being very poor. All other drill functions appeared to operate normally, and continued to do so on the occasions when the surface programme locked up. The drill was recovered and the camera bottle exchanged for the spare. At the same time a large steel hawser was bolted to the deck and streamed over the stern to improve the ship's earth. The drill was re-deployed to a depth of 50m and communication to the camera was improved but far from perfect. The surface programme continued to lock up intermittently, but all other functions appeared to be working. The drill was lowered to the seabed in a water depth of 1620m for the first site JR63-BR21, landing at 15:51 and photograph taken. The drill table was lowered and the drill penetrated some 400mm into the seabed. However on preparing to drill it was found that the flush pump was not working. The drill was recovered to deck. During the lift up through the water column the compass auto-compensation routines were both run as the drill turned slowly in the water. The lower compass achieved a score of 9, 7, and the upper one, 9, 8. On recovery a small sample of sediment and pebbles was recovered. It was found that the flush pump motor had failed and was replaced with one of the new oil compensated motors. The drill re-deployed at 18:50 for site JR63-BR22. The photograph taken on landing revealed too much sediment and the vessel was moved 20m to find a more suitable site. This sequence was repeated once more before an acceptable site was found. On starting drilling the surface programme locked up. On restarting, viewing the information in the terminal programme suggested the drill was working correctly. The operation continued in this 'manual' mode just leaving the drill running, being able to monitor it and changing the settings, but using minimum commands. When it appeared that no further penetration was being achieved the main programme was started to turn the drill off and recover it. The programme operated for long enough to affect particular commands, but not long enough to drill the site without locking up. On recovery it was found that the drilling had been successful, with 210mm of peridotite recovered, complete with scribe mark. The drill was deployed again at 23:11 for site JR63-BR23 and landed on the seabed at 23:49.

Monday 30 April

Drilling continued overnight in with sites BR23 and BR24 being completed by 06:05 in much the same way, 'manually', monitoring progress using the terminal programme. As this happened efforts were being made to address the noise problem which was overcome by a combination of hardware and software changes. The gain in the communications signal line was reduced and various changes were made to the software in the main surface control programme to make it less sensitive to noise events. A better routine of commands to the camera to take photographs was developed, resulting in much more consistent camera function. The drill was deployed for site BR25 at 06:57, by which time the main drill programme was much more stable and was used to control the drilling. For the first time it was possible to log the drilling progress on the surface computer at this site and this, and subsequent operations, went more smoothly. By this stage a fairly standard routine of operation had been established. The drill would be lowered to the seabed and, on a successful landing, a photograph was taken and transmitted up the cable to the surface computer as a .jpg file. If the site was suitable then drilling commenced, and if unsuitable the drill was lifted and moved and the operation repeated until a suitable site was found. All .jpg photographs were retained and renamed as BRxx_1.jpg, BRxx_2.jpg and so on. On completion of the site and during the recovery of the drill from the sea bed, the last photograph of the site, was transmitted up the cable as a higher resolution binary file, this transmission taking about 15 minutes. A routine on the surface computer converted this binary file to a .tif file for viewing and archiving purposes.

Drilling continued throughout the remainder of the day with the surface programme hanging occasionally. The first attempt to drill BR27 was abandoned when the drill table could not be lowered. On recovery it was found that the table safety locks were still in place. They were taken off and the drill re-deployed with compass auto-compensation routines being run as the drill was being lowered to the seabed. Scores of 9, 9 and 9, 8 were achieved for the lower and upper compass respectively. Sites BR26 to BR29 were completed when the latter was terminated due to loss of DGPS signals and the drill recovered to deck at 23:25.

Tuesday 1st May

Coring operations continued throughout the 24-hour period with sites BR30 to BR36 being completed without serious disruption. A further modification to the surface control programme appeared to completely cure the problem of occasional programme locking. Site BR32 was terminated when DGPS signals were lost. After difficulty with landing on a very steep seabed requiring six attempts, site BR35 was drilled with the rig at the extremely steep inclination of 36^{o} and drilling was terminated early to prevent possible damage to the barrel. A good, short (100mm) core was recovered.

Wednesday 2nd May

Site BR37 was completed without incident at 02:53. During the course of site BR38, after spending some time trying to find a suitable site, the ship's winch failed with the rig on the seabed. It was only able to pay out cable and not haul in and too much cable was paid out - as witnessed on the seabed photograph which clearly showed several coils of cable on the seabed. It took approximately two hours for the fault (a blown fuse in the control system), to be found and rectified. The drill was then recovered to deck at 09:09 to assess if any damage had been done to the cable or drill rig. No damage was apparent and the drill was re-deployed for site BR39. This site and the following two (BR40 and BR41) were completed without incident by 16:38. During operations on site BR42, the drill rig was lifted off the seabed and moved on several occasions as normal. However on one lift, the weight came onto the cable lifting the rig clear of the seabed but with pitch and roll indicators showing that the rig was very steeply inclined. This indicated that the cable had snagged on the rig, which was gently lowered back to the seabed. On lifting off again the cable came clear of the rig, which was once again hanging vertically in the water column. It was decided to commence drilling at the next landing of the rig, despite having a poor seabed photograph. This was interpreted as the camera having been moved out of alignment by the cable snag. However, on lowering the drill table it simply continued travelling down until it reached the bottom stops, leading to speculation that the drill barrel had been lost. The drill was recovered to deck at 19:14 and was found to be intact, undamaged and with the camera in its correct position. It had been a sediment site after all. The cable was inspected and, despite having a noticeable kink in it, no strands of the armouring had been broken and were considered usable. Site BR43 was then completed without incident and the drill was deployed for site BR44 at 23:17.

Thursday 3rd May

At site BR44, again the drill table lowered to the bottom stops through sediment without drilling. BR 45 was completed by 03:55 with more success, the drill penetrated nearly to the lower stops. The exact position was unsure because, as the drill table neared the lower stops, the echosounder readings became extremely noisy and unreliable. This was thought to be due to sediment in the water column thrown up by the action of the flush pump. Whilst steaming towards site BR46, the two small magnets at the bottom of the sensor panel were moved up by 50mm. This ensured that the proximity sensors on the drill table detected them reliably when the table reached the bottom stops. In this way, in situations where the echosounder had become noisy, reaching the end stops was observed on the surface control display by the signal from the proximity sensors operating the appropriate set of lights.

Sites BR46 and BR47 were completed without incident at 08:46 and 12:31 respectively. On the move between the two, a litre of oil was added to the subsea transformer bottle compensator. This was to compensate for the operating temperature being lower than when the compensators were originally filled. The drill barrel bottom bush was also opened out by 2mm diameter to make rotation of the barrel easier. Whilst lowering the drill on site BR47, the flush pump was tested at different speeds, and the rates of flow and motor current recorded.

At site BR48, the drill jammed at the seabed when attempting to start it. This was at first thought to be due to the very steep angle of the rig and so the rig was picked up and landed again. The drill was then tested in the water before lowering the drill table towards the seabed and it was found that the drill would not start. On recovery it was found that the drive mechanism had shed a few split rings and one of them had jammed the drive mechanism. The drive mechanism was replaced with a spare. Thereafter site BR49 was completed without incident at 19:44 and site BR50 was commenced and required 10 landings before finding a suitable site for drilling. On one of these landings the drill table had been lowered to the seabed but had penetrated to the lower stops without drilling. It was retracted with the flush pump still running and then spun briefly in the water, to ensure no sediment remained, before moving to the next landing. Drilling on a suitable site finally commenced at 23:08, almost three hours after deployment.

Friday 4th May

Sites BR50 - BR53 inclusive were completed by 14:15 without incident. On site BR54 the DGPS signals were lost shortly after starting to drill. The drill was retracted and lifted clear of the seabed, with the distinct possibility that no core had been recovered. Rather than use up time bringing the drill back to deck and re-deploying, the drill was lowered onto the seabed again (at the request of the PSO) when the DGPS had stabilised and another hole drilled. On recovering the drill to deck at 17:55 it was obvious from the core that there were two distinct samples so the second attempt was treated as a new site and renamed as BR55. Whilst moving to the next site, the plastic, protective hose on the last six metres of cable was pulled back to inspect the cable and check for broken strands of armouring. None were found and the hose was replaced. Site BR56 was completed shortly before midnight with no further incident.

Saturday 5th May

Coring operations proceeded with little incident throughout the 24 hour period. Sites BR57 - BR62 were completed with BR61 requiring ten landings before a suitable sight was found. The drill was deployed for BR63 shortly before midnight.

Sunday 6th May

Sites BR63-BR65 were completed without incident by 09:21. However, on site BR66 it became noticeable that the focus of the camera had deteriorated. Having selected a drilling location for site BR66, the rig fell over when paying out cable on the retract winch to lower the drill table to the seabed. As there was the possibility of damage to the retraction wire in this situation, the drill rig was recovered to deck at 14:11 for inspection. In fact, the retraction wire had suffered damage by running over the edge of one of the pulleys and the wire was replaced. At the same time the camera was exchanged for the spare. A photograph on deck with the new camera confirmed the better focus. It was thought that the probable cause of the loss of focus were the repeated knocks to the camera on occasions when the rig fell over on landing. Sites BR67 and BR68 were completed without further incident at 17:49 and 21:32 respectively, and operations at site BR69 started at 22:18.

Monday 7th May

Sites BR69 and BR70 were completed by 07:00. At this last site it was very difficult to take photographs, the operation of the camera being very intermittent and with degraded quality. On recovery the camera bottle was replaced by the original bottle, which had been repaired since its earlier failure. On trying to take a test photograph on deck this second bottle failed immediately. The root cause of the problem was then traced to the lamp, which was found to have a cracked lens and had suffered water ingress. The lamp was replaced with the spare. The immediate failure of the camera bottle in the deck test was traced to a blown fuse. This was replaced and this camera bottle re-installed on the drill rig. All these changes were carried out between sites and no significant time was lost. The camera bottle, which had failed on the seabed, was examined and repaired whilst drilling operations proceeded. Site BR71 was completed at 12:28 and the core barrel assembly was changed prior to BR72, using an impregnated G9 drill bit. Site BR72 was then completed without incident at 16:58, the G9 bit appeared to drill faster than the surface set diamond. During the deployment at site BR73, compass auto-compensation routines were run. Compass 2, the top one, was fine with a score of 9, 7. However compass 1, the lower one, failed to calibrate and communication to it was lost. The site was completed using the top compass only. The lower compass is housed within the main subsea electronics bottle and, on recovery on completion of site BR73 at 21:28, the main electronics bottle was changed for the spare (S/N 1004). During deployment at site BR74 several attempts to calibrate the new compass (S/N 9100026) were made. The best score being achieved was only 6, 7 indicating an accuracy of only 4^{o}. The top compass remained good.

Tuesday 8th May

Site BR74 was completed successfully at 07:24 after requiring 15 attempted landings and 14 photographs to select a suitable site. However, on recovery, it was found that the drill bit was broken, having completely lost one section of the impregnated head. It was thought this was probably caused by the bit hitting the seabed on one of the many attempted landings at this site. The bit was replaced with another G9. On the next site, BR75, it was noticed that the retraction seemed to be very slow. On recovery at 11:10 it was found that the retraction motor was almost seized. This was a Franklin motor and it was replaced with a Lowara motor. Thereafter, sites BR76 and BR77 were completed without incident by 20:29 and BR78 started. Further attempts to calibrate the lower compass resulted in similar values, or failed altogether. Use had been made of the natural rotation of the cable as it was hauled out and hauled in. This rotation diminished over a period of deployments. It was felt that the rig was not rotating fast enough in the water.

Wednesday 9th May

Sites BR78 to BR80 were completed without incident by 07:55. On routine inspection of the drill rig at the end of site BR80 it was decided to replace the drive chain, removing the tensioner at the same time. Sites BR81 and BR82 were then completed but, on recovering the drill from this last site at 15:45 there appeared to be damage to the cable several hundred metres up from the drill. After recovery some 400m of cable was flaked out on the deck for inspection. One strand of armouring had sprung out of alignment, though no actual break in any of the armouring strands could be seen. After some debate it was decided to continue with the cable and keep a close eye on it to see if the problem continued to move up the cable. After so many landings it was good that the cable had lasted so long without requiring a re-termination. It may well be that a swivel is required for further, extended periods of use on such a cable. At the next site, BR83, it proved very difficult to land the drill, but four hours after deployment the rig finally settled onto a suitable location, having made 15 attempted landings and taken 10 photographs. Drilling was started, but did not appear to get very far at all. On recovery it was found that the bit head had been broken off completely and it had been trying to drill on the steel collar. The bit was replaced with an impregnated G10 on and the drill re-deployed at the same location for site BR 84 at 23:04

Thursday 10th May

The difficulties in landing the rig at this location continued. It fell over six times and on two occasions it was briefly stuck on the seabed, the vessel moving to free it. The site was abandoned as being too difficult and the drill was recovered to deck at 01:59. On recovery it was found that the new bit was broken - even before it had drilled a single hole. The bit was replaced by the surface set diamond one which is more robust. The next site, BR84, was successfully cored with the surface set bit, but the drilling was very slow and on recovery at 06:29 the bit was, again, exchanged for an impregnated G9 one. Sites BR86 and BR87 were completed without incident at 10:24 and 13:14 respectively. However, at site BR88, the drill jammed shortly after starting. On recovery at 16:50, it was found that the drill bit had, again, been broken in collision with the seabed. The bit was replaced by the surface set diamond one. Sites BR89 and BR90 were completed by 23:33 and the drill deployed for site BR91 at 23:56.

Friday 11th May

Site BR91 was completed at 06:25 after a total of 29 attempted landings, of which 20 successfully resulted in photographs being taken. This marked the completion of the planned sites for the project in water depths between 1500-2500metres and the vessel moved to deeper water for deep-water deployment trials. The drill was deployed at site BR92 at 08:19 in 3968m of water. This served several purposes:

- Test the drill at it's designed maximum working depth;
- Provide evidence of a working drill system in deep water for future scientific proposals;
- Find the maximum water depth the RRS James Clark Ross cable hauling system can deploy the drill to.

The lowering was stopped with the drill at 3000m and all functions tested successfully. Lowering was again stopped at 3500m where, again, all functions tested correctly. The drill was then lowered to the seabed where the first photograph revealed a suitable site on pillow lavas. A core was successfully taken and the drill recovered at 11:53. The vessel then moved to a deeper site at 4520m and the drill deployed for site BR93 at 13:48. Three landings were made, with all of the photographs revealing sediment cover. As no further time could be devoted to further deep trials the drill table was lowered and the drill run at this depth for 40 minutes, before recovering to deck at 19:20. No core was recovered, but a sediment sample was recovered from the hollow legs of the drill rig. This marked the completion of the BGS Bridge drill operations.

5 Recommended Modifications and Upgrades:

This section is divided into four sections:

- ease of use;
- improved performance;
- reliability;
- client request.

5.1 EASE OF USE

5.1.1 Software

The drill system was made to function in a productive manner. However, there are aspects of the system that either did not function consistently or are inefficient. This frustrated both the operators and the client.

5.1.1.1 SURFACE CONTROL SOFTWARE

- Some aspects of the surface software require cleaning up, in addition modifications would improve ease of use. These include:
- Resultant inclination should be displayed and ideally the angle of the inclination with respect to the scribe;
- Displays of digital readout would benefit from enlarging;
- Facility to print out graph display data, either from the main program or spreadsheet;
- Ability to scroll through the graph data and expand and contract the time axis;

5.1.1.2 SUBSEA SOFTWARE

The subsea software proved very reliable. Whilst certain aspect would benefit from cleaning up, there is not an immediate requirement.

5.1.1.3 CAMERA SOFTWARE

The interaction of using this software with the main drill surface control program, resulted in an acceptable method of operation, i.e. it performed it's purpose, though as the programmes could not be run together the operation involved opening and closing at least three programs (more if the camera failed to operate first time). Some thought on the operational use of the drill and camera system would benefit this process.

Note: Consideration of this must be taken in conjunction with any development of a continuous or near continuous video imaging upgrade.

5.1.2 Seabed Camera

The camera system is an essential part of the oriented drill system. Two of the limitations of the drill system are the available electrical power and hence drilling torque and the stroke of the drill barrel. Both these factors limit the use of the drill system to exposed or near exposed rock drilling. These engineering limitations and the fact that the client would prefer to drill on exposed rock as they can view it, make the camera system a pre-requisite of the system.

5.1.2.1 Seabed Camera Operation

The current camera system is an innovative method of attaining a B&W image of the seabed for site selection and performs to the original specification.

The operation is not 100% reliable in operation. The present system would benefit from further software development.

A more fundamental issue is the overall method of operating the drill and hence the camera operation. The 400+ landings of the rig for 73 sites highlight the problem in site selection. It became clear during this operation that the most efficient method for selecting suitable drill site would be to have a photographic survey of the area. This was achieved on the Atlantis Bank project utilising the first leg of the cruise and an ROV. This obviously takes up valuable survey time and equipment. Two alternatives methods to achieve this and would be a more efficient use of survey time are:

- Use a small (approx. 0.5m sq) AUV developed by the USA that takes seabed pictures while following a preset track. This could be used simultaneously with drilling operations.
- Develop the drill to be able to provide, ideally continuous colour video or at least slow frame B&W pictures (min update rate 5sec).

It could be argued either way, which of the two suggestions is the most cost efficient, depending how the costs are evaluated.

The first suggestion whilst theoretically available (this cruise tried to obtain it), in practice, appears only available for US projects. The second suggestion it is believed possible if, either using a fibre optic coaxial cable (RRS Darwin, R/V Sonne) or modifying the method of attaining seabed photographs.

The coaxial cable on the JCR was found to suffer severe bending (kinks of diameter 150mm were observed) due to repeated seabed landings. Whilst fibre optics are very robust there would be a possible unreliability built into the system. This coupled with the fact that the only DP vessel available at present in the NERC fleet does not have a fibre optic coaxial cable and the UK (UKORS) swivel arrangement required for power and fibre optic is very costly and physically large would favour pursuing an approach that utilised existing standard coaxial cables.

There is a severe limitation in the data rate that can be achieved when AC power is used on the coaxial cable compared with DC power. This is currently 4800 baud. As taking seabed pictures and drilling are separate activities, a hybrid system could be developed that switches off the AC power when seabed photographs/video are taken. The camera system could either operate by switching in a DC power system or utilise a battery pack to power the light and camera.

An alternative method of data transfer would be to use an acoustic data link thereby eliminating the cable completely for data transmission.

NOTE: Aberdeen University has received a NERC JIFF award to develop benthic seabed landers and house other marine facilities e.g. 500Bar pressure vessel testing. This facility also includes a development to transmit colour video up a 10km coaxial cable utilising compression techniques.

5.1.2.2 OTHER CAMERA ENHANCEMENTS: TWIN/TRIPLE LASERS TO GIVE PICTURE PERSPECTIVE

This simple idea comes from Javier Escartin who has seen this work on some of the Woods Hole camera equipment. The aim is to give seabed pictures, especially those that look sideways a method of calculating scale against distance. The solution is to mount three lasers in a triangle around the camera, these lasers will provide three parallel lines, and hence any object can be scaled. Whilst an example has not been viewed, a possible practical solution would be to mount three pen lasers in a steel ring that slides over the camera.

It is recommended that any future cruise proposal include development funding to achieve continuous or slow scan seabed video.

5.1.3 Surveyed orientation alignment on rig

If proved difficult and time consuming (at least a day) to align the rig components, pitch, roll, upper and lower compasses and scribe up to leg 2 (the rig reference) and thus overall accuracy of orientating the core to a world reference was reduced.

The ease of alignment and accuracy would be greatly improved if:

- Each rig had scribe lines marked at appropriate positions on the metal frame;
- Where appropriate build alignment jigs to be used for this purpose, e.g. an insert into the bush to align the barrel screw and hence the scribe;
- Essential mechanical components were positioned at sensible reference locations, e.g. the subsea electronics and upper compass.

5.1.4 Removing/installing subsea electronics on rig

Prior to the dispatching of the rigs to Brazil it was noticed, at the first fitting, that the removal of the new larger and hence heavier subsea electronics was difficult to mount in position on the frame without a crane. This is true for both the main tube and the individual end flanges, which require a set procedure for removal.

This could be improved by various measures:

- Taking to sea and using a small hand operating lifting trolley, similar but smaller that green lifting trolley at BGS Loanhead;
- Block and tackle arrangement connected to the drill table;
- Allow the mounting bracket arrangement for the electronics to slide out on rollers through the frame and onto a small trolley which could them be wheeled into a lab. This bracket arrangement could also double up as a way to accurately position the electronics to a sensible reference for orientation purposes.

Whilst the above are suggestions to be independent of possible other shipboard facilities, the subsea electronic packages were easily manoeuvred on this project with the aid of the large aft crane and the calm weather.

5.1.5 Mechanical termination of co-axial cable

The top hat mechanical termination works well. The Wirelok termination was found to rotate inside the top hat due, i.e. there was no bond between the stainless steel and the Wirelok.

During mobilisation BGS were asked whether the coaxial cable, once terminated, would fit through the JCR's cabling system to allow the vessel's cable hauling system to perform sequential tasks, with different cables, without the requirement to chop the mechanical termination, e.g. dredging and drilling operations. The present mechanical termination was found to be too large in diameter to fit through the system.

The following two recommendations address these issues:

- Put lip, bolt or other protrusion on the inside of the mechanical termination to stop the Wirelok termination rotating;
- Redesign the termination (top hat) to be slimmer in diameter.

5.1.6 Manuals

The system would benefit from updating the manuals to include every aspect of the system. This would allow ease of operation and maintenance and also hopefully allow the system to be operated by marine staff other than the engineers that designed and built it.

5.2 IMPROVED PERFORMANCE

5.2.1 Temperature sensors

The various temperature sensor's data suffered from noise. The likely cause is the lack of a separate power supply line to sensors. Modification to the electronics is required.

5.2.2 Proximity sensors on sash weight

Additional sensors near the top and bottom of the sash weight tube would provide the operator with warning prior to the end of travel. This was initially suggested (John Derrick) to know, 'on retraction', when the retraction cable is close to position when the core is pulled out of the seabed. This would enable the operator to slow down the retraction winch prior to breaking the core out of the seabed. Discussions upon returning to BGS have indicated that pull out from the seabed is best accomplished at speed with a good yank to use the friction created to tighten the core spring. A slow withdrawal may allow the core to slide out of the barrel before the core spring tightened. This did occur on one occasion.

In light of this there may be no pressing reason to provide additional sensors.

5.2.3 Electrical power

The system has enough power to drill well if the seabed is bare rock, which it has been designed for. The drill struggles when there is sediment cover. This is not normally a problem as it is bare rock that is the usual requirement for a suitable drill site. There were a few occasions when the drill was operated with 30cm+ sediment cover, when the system failed to have enough torque to drive the drill.

It was noted that the system could not usually use the electronic speed controllers on their maximum output power; this is due to the volt drop down the cable. As more power is demanded the voltage seen subsea drops. The voltage was not allowed to drop below 200VAC. If the voltage could be maintained at 240VAC more power would be available for the controllers.

The transmission voltage down the cable could be increased from 1500VAC to 2000VAC. This would allow the present controllers to operate at their maximum output (and hence faster drilling speeds) and provide more system torque.

Alternatively the weight on the bit could be reduced. Whilst this would provide a faster rotational speed it would not increase the overall power and hence torque.

5.2.4 Water depth rating

Future proposals are likely to require the oriented drill to operate to 5500m. It would be sensible to establish what components would not operate at this depth and address what would need to be done to achieve a working system that operates to 5500m. All future purchases for this system should be investigated with a view to operate to 5500m.

5.2.5 Solid-state north seeking gyro

Despite a great deal of effort in aligning and calibration of the compasses, there still remains uncertainty on the overall accuracy of the orientation data. The compasses lost calibration several times and had to be recalibrated. The compass data was also technically invalid on slopes greater than 10 degrees, (the majority of sites), as the rig steel mass, produces a different flux effect when in any orientation other than vertical. This is because the calibration carried has only nulled out the effect of the frame in a vertical plane.

The scientists are also demanding better than 5° accuracy, ideally 1°.

In light of this, it is recommended that any future scientific proposal should include an element for client requests and that a solid state north seeking gyro be purchased.

5.2.6 Bit weight control

There were occasions when the ability to control the bit weight would have been an advantage. These were when there was a layer of sediment, too much bit weight and when there was a large inclination angle, too little bit weight.

Whilst a third motor controller could be used to independently control the drill and retract motors and provide a form of bit weight control, this would take valuable electrical power away from the drill motor. It could also be argued that as the drill has to only core a maximum of 770mm it should be possible to optimise the bit weight for the conditions of the project and an additional function may prove counter productive.

5.3 USER REQUEST

5.3.1 Continuous video camera surveillance

This is requested by the clients to make the system more efficient to them.

‘In terms of development, the biggest development that I can wish for, and that will make the drill a really appealing tool, is a video connection. It would provide a fully autonomous piece of kit to bring along on a ship at a low cost, and to find sites 'on the fly'. Pogoing is both time consuming and rather inefficient, so it either requires time at the expense of reduced number of samples and in poorer sites, or more expensive tools to be brought along for site selection, such as autonomous vehicles, ROVs or camera sledges. Even if these tools are available, at a high cost, the drill would still require multiple deployments at the seafloor to find the right outcrop from the electronic still cameras.’ Escartin (1), a point also made verbally by YaoLing(2).

‘A couple of laser pointers that are visible on the viedeo/photo for scaling purposes.’ Escartin (1).

‘Downward-looking camera.’ Escartin (1).

'The most important, useful improvement, by a long shot, would be the video camera.' Escartin (1).

5.3.2 Swivel

400+m of coaxial cable had to be cut off at the end of the cruise due to one strand coming out of the lay and running back up the cable. This was the result of the rig spinning as the vessel is moved to a new location. The problem occurred when the rig was picked up off the seabed because the site was unsuitable for drilling and the vessel moved to a new position. As the rig moved sideways the rig tended to spin like a propeller, as the structure is not balanced.

This spinning also occurred when the rig was lowered to the seabed from the surface in one movement and reverse spinning when retrieved from the seabed. This was used to calibrate the compasses. It was noticed that the spinning stopped after a number of deployments.

The deck engineer and scientific boatswain on board, Simon Wright and John Summers concluded that any further operation of the BGS Oriented Drill on the JCR that involved moving the vessel once the drill had been deployed would require a swivel.

As any future operation of the drill will require the vessel to be moved whilst the drill is in the water column, a swivel will be required.

5.3.3 Orientation accuracy

Figures of one degree and better than 5 degree overall accuracy for the orientation of the scribe were suggested by the client. An accuracy of better than 5 degrees would be difficult to achieve as it would not only require an increase in accuracy of the rig orientation but also a thinner scribe.

It is recommended as described else where, that a north-seeking gyro be investigated and built into any future proposals for the use of this system.

5.3.4 Increased length of penetration

As is always the case the length of core or penetration is never enough.

'Slightly longer cores (more more more!).' Escartin(1).

5.3.5 Self levelling and seabed movable rig

'Ideally, wheels to REALLY move 2.6 m one way or another plus retractable legs to put it in flatter when the surface is not quite flat (i.e., 78°, which is almost flat).' Escartin (1).

5.4 CAPITALISE ON DIVERSIFICATION OF USE

5.4.1 Alternative uses in the scientific community

In addition to tectonics and structure of oceanic crust, Similar to this project - there are many other areas of scientific interest that could be the target of a BRIDGE drill.

The following contribution is from Escartin (1).

High-resolution volcanism at the ridge axis

The BRIDGE drill would be a useful tool to do high-resolution sampling of lava flows and geochemistry at the ridge axis. It provides the possibility of studying geochemical variability of lavas at scales of <10 m, similar to studies done on land. This is necessary to understand the evolution of magma chambers, the construction of the volcanic layer of the oceanic crust, and the functioning of submarine volcanoes. In addition to precise sampling of volcanic features of interest, the oriented cores could prove useful to obtain information on magma flow directions (e.g., alignment of crystals within the lava flow), paleomagnetic studies, among others. Typical operations would involve identification of very specific targets, such as a volcanic edifice or a series of lava flows, and detailed sampling (at meter-scale) of different parts of the target to study fine-scale spatial variability.

5.4.2 Rotation of microplates / evolution of overlapping spreading centers

At fast-spreading ridges, the interaction of two adjacent segments of a ridge may result in overlap. The portion of oceanic crust caught in between shows rotation structures, as imaged on bathymetry and sonar data. If the area of overlap is large enough, a microplate may form and rotate as spreading goes on. At smaller scales, like overlapping spreading centers, less well-defined structures have been described. The drill may be used to accurately sample different parts of these rotating pieces of oceanic crust, to accurately position rotations in time and space. As these structures are common at fast-spreading ridges like the East Pacific Rise, this type of studies may provide a god understanding of the evolution in time of rotation, and of the mechanisms driving it.

5.4.3 Margins

There are surely different tectonic problems to be looked into but as yet this area is unknown.

6 Conclusions

The operation of the oriented drill was highly successful. This resulted in achieving the scientific objectives. This point cannot be over stressed. Without this drill, this science would not have been possible due to alternative methods being prohibitively expensive and doubtful even then if oriented cores could be achieved. This drill and mode of operation, i.e. used from a research vessel with DP, has achieved science that was previously not possible and at a cost that is permissible.

It is believed that a few records have also been broken, namely:

- The only drill able to produce scribed core and oriented to a known reference.
- Deepest water depth (4520m) drilled utilising remote drilling techniques and possibly only beaten by ODP drilling.
- The sea bed drill has drilled at inclinations of 42 ° from the vertical.

Overall:

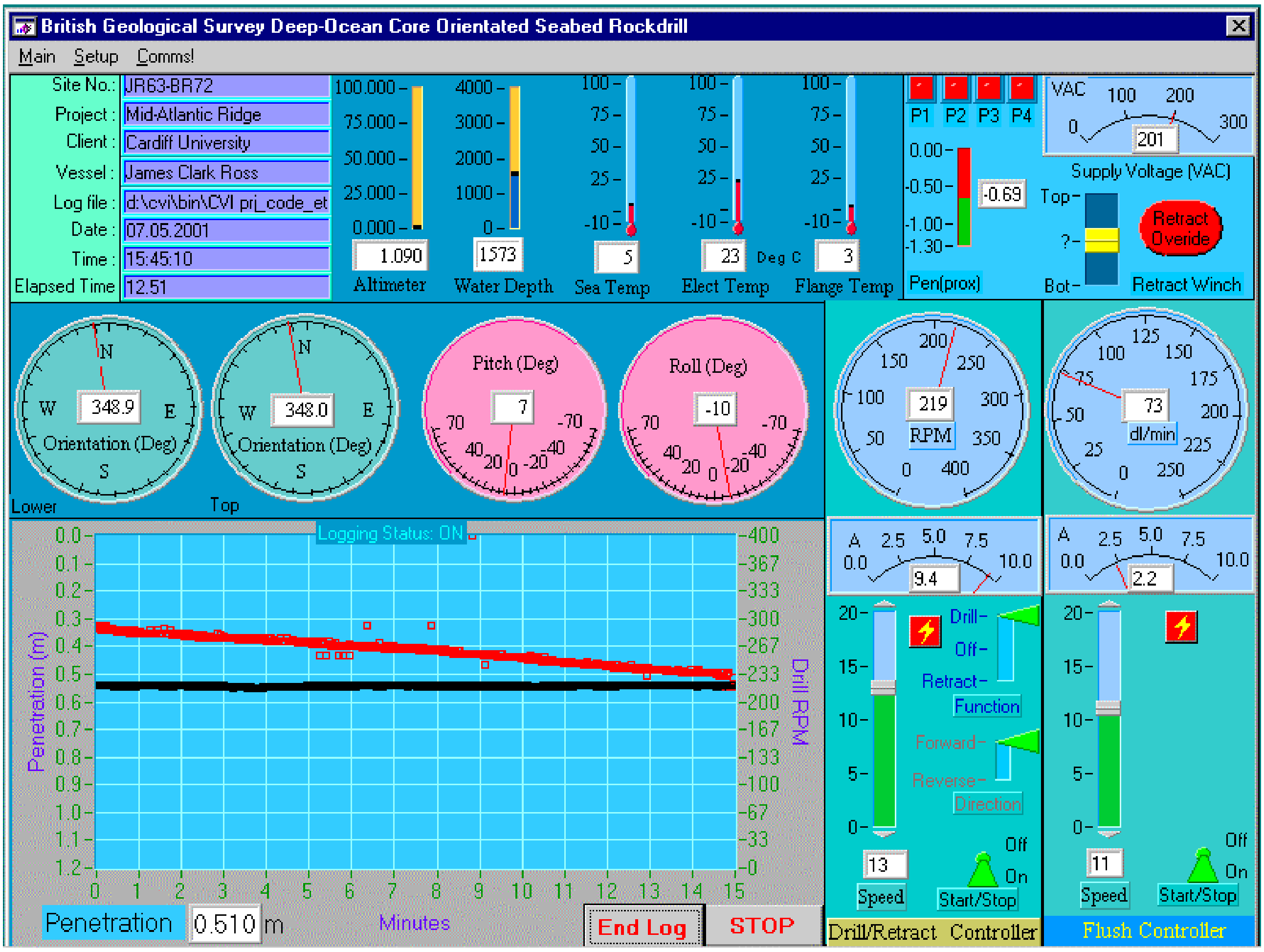
- 73 sites were drilled with core recovery from 63, bringing a total number of sites for this drill to 90.
- A total of 320 seabed landings were made and seabed photographs taken. On a further 87 attempted landings the drill rig fell over and had to be picked up again.
- The drill operated successfully at its design depth of 4500m.

- The BGS BRIDGE drill performance was very successful over a sustained period and the system has definitely progressed from prototype to a working system.

The drill was made to operate in a routine manner and stood up to severe knocks on the seabed. Despite this, the drill is not in a state that could be operated by anyone other than the engineers that designed and built it. A series of recommendations are described to address this and the other issues of: ease of use, improved performance, reliability and client requests.

There are many recommendations and suggestions for further development of this drill. This report realises that any further developments should be through a combination of a BGS funded project on the back of this successful cruise, as part of a NERC facility and funding that has been incorporated into future scientific proposals for future cruises. As such, it is recommended that this report is used as a reference document to aid future developments of the Oriented Rockdrill.

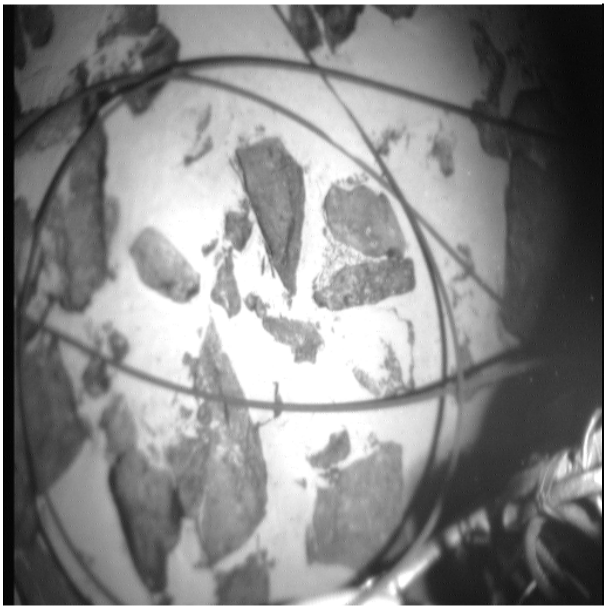
Appendix 1 Example of Control Programme



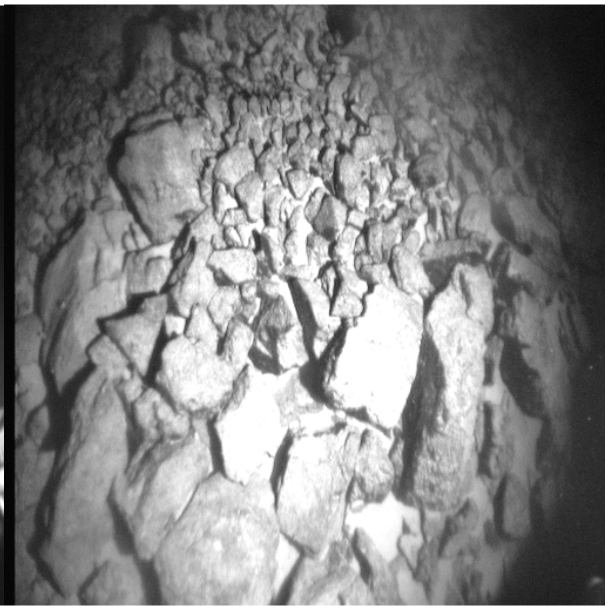
Appendix 2 Example Seabed Photos

BR33

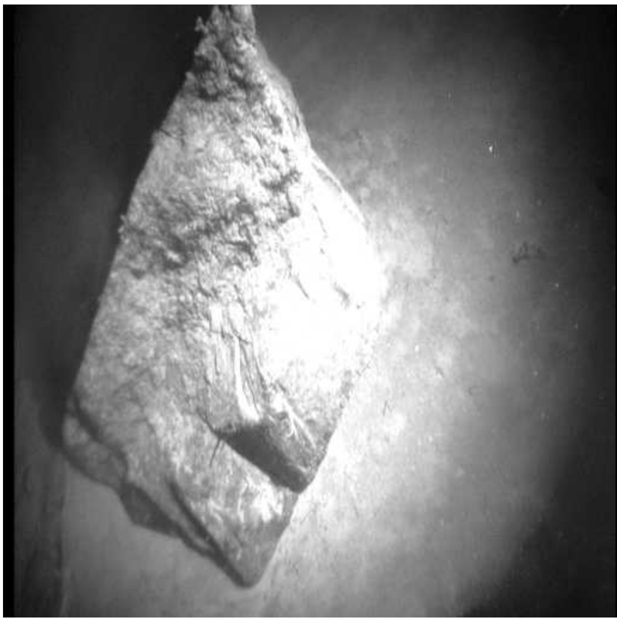
BR35



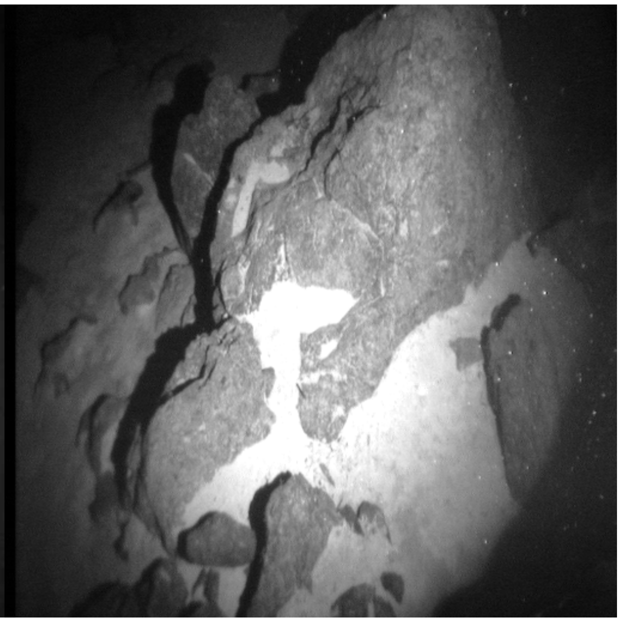
BR38



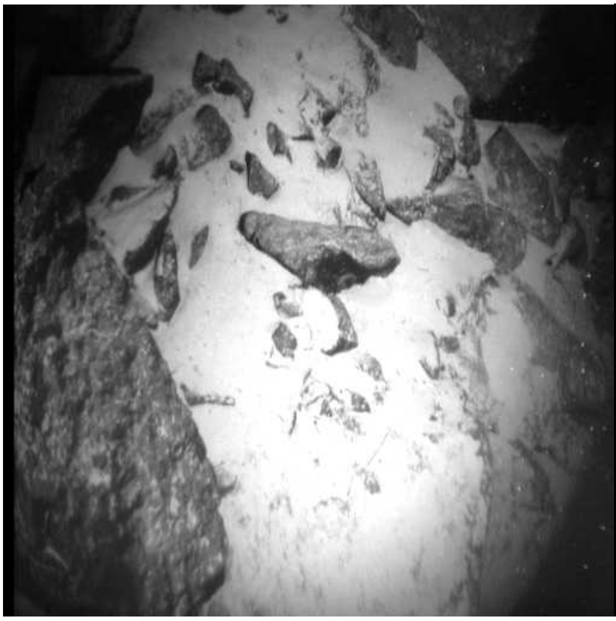
BR69



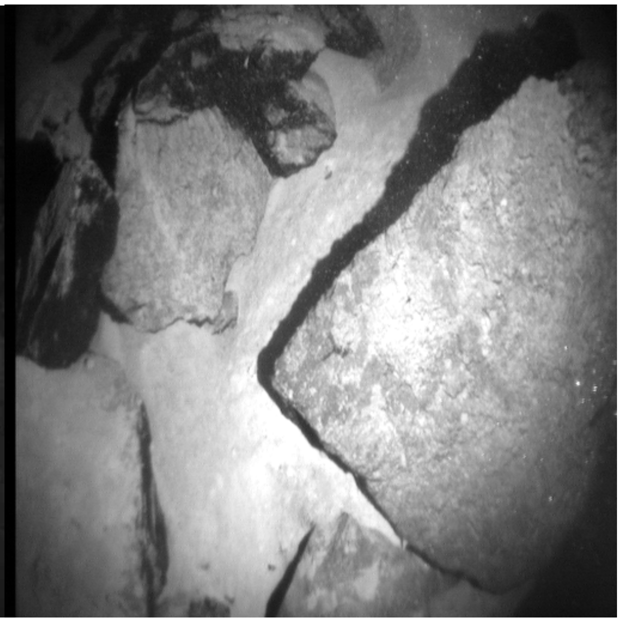
BR74



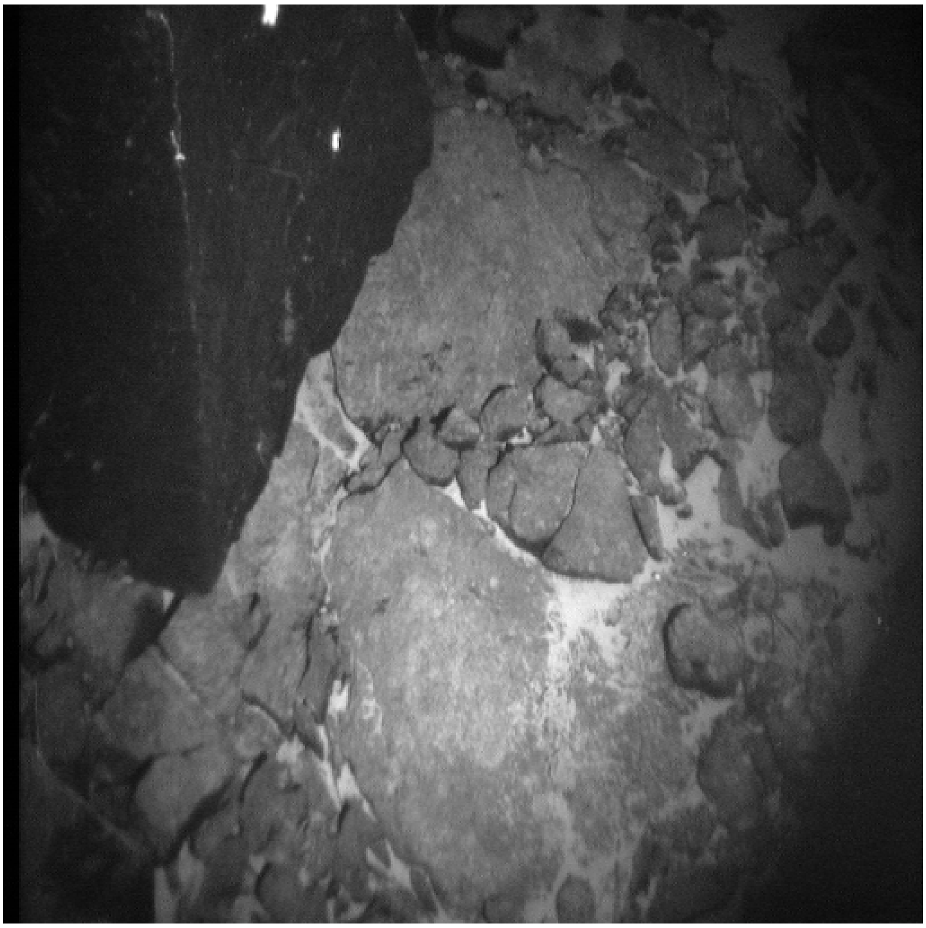
BR81



BE82



BR83



BR85

BR92 (4000m)

Appendix 3 List of Core Bits

BGS Deep-Ocean Oriented Seabed Drill System (BRIDGE) Drill Bit Record										
Project: JR63		Location: Mid-Atlantic Ridge			Vessel: JCR			Date: April-May 2001		
Size	Manufacturer	Type	Stone Size	Matrix Type	Serial No.	Measured ID (mm)	1st Used	1st site	No. of holes drilled	Status
TT46	GeoGem	Surface Set	60/80	N/A	1030	35.3	New			
TT46	GeoGem	Surface Set	60/80	N/A	1030/1	35.3	New			
TT46	GeoGem	Surface Set	60/80	N/A	2561	35.3	New			
TT46	GeoGem	Surface Set	60/80	N/A	2561/1	35.3	29.04.01	BR21		OK
TT46	GeoGem	Surface Set	60/80	N/A	?	35.4	May-98	BR01	13	Worn
TT46	GeoGem	Inpregnated	N/A	G8	1029	34.7	New			
TT46	GeoGem	Inpregnated	N/A	G9	1028	34.5	07.05.01	BR72	2	Broken
TT46	GeoGem	Inpregnated	N/A	G9	2559	35.0	10.05.01	BR86	2	Broken
TT46	GeoGem	Inpregnated	N/A	G9	2559/1	35.0	08.05.01	BR75	0	Broken
TT46	GeoGem	Inpregnated	N/A	G9	2559/2	35.1	New			
TT46	GeoGem	Inpregnated	N/A	G10	1027	34.8	New			
TT46	GeoGem	Inpregnated	N/A	G10	2560	35.0	New			
TT46	GeoGem	Inpregnated	N/A	G10	2560/1	35.0	09.05.01	BR84	0	Broken
TT46	GeoGem	Inpregnated	N/A	G10	2560/2	35.0	New			
TT46	Drill Well	Inpregnated	N/A	SK7	787M01	35.3	New			
TT46	Drill Well	Inpregnated	N/A	SK7	787M02	35.4	New			
TT46	Drill Well	Inpregnated	N/A	SK9	788M01	35.4	New			
TT46	Drill Well	Inpregnated	N/A	SK9	1164204	35.4	New			
TT46	Drill Well	Inpregnated	N/A	SK9	1164206	35.4	New			

Glossary

BRIDGE	British Mid-Ocean Ridge Initiative
DGPS	Differential Global Positioning System
ID	Internal diameter
HV	High Voltage
ODP	Ocean Drilling Programme
PSO	Principle Scientific Officer
RPM	Revolutions per minute
TOBI	Towed Ocean Bottom Instrument
UKORS	UK Ocean Research Services

Related Reports and Documents

The following are papers and documents related to the development and operation of this drill. Though they are not cited in this report the authors acknowledges their relevance to this report.

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