68. BROADBAND DOWNHOLE DIGITAL SEISMOMETER EXPERIMENT AT SITE 794: A TECHNICAL PAPER[1]

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ABSTRACT

A broadband seismic observation was made for the first time in a competent rock section beneath sediments of an ocean. A digital broadband (DC-30 Hz) seismometer was successfully emplaced in Hole 794D in the Japan Sea during Leg 128 by *JOIDES Resolution.* The installation did not require any tools not standard in ODP drilling. The seismometer capsule about 3 m long was clamped within basaltic rock section at 714.5 mbsf at a water depth of 2807 m.

Its three-component data are telemetered via the logging cable to a shipboard real-time recording device or to a seafloor off-line digital data recorder. Real-time recording allows full recovery of six-channel data (two gains per component, 16-bit each) at 80 Hz/channel sampling rate. A controlled source seismic experiment was conducted during this phase (about 60 hr) to obtain detailed local crustal structure.

In an attempt to observe deep and teleseismic events, a seafloor recorder package was deployed together with a lead-acid battery power supply by a supporting vessel. This first-design package operated for about 1.5 months to record 60 Mbytes of data in two modes: (1) event detection and (2) time window. It was retrieved about 8 months after the deployment.

INTRODUCTION

In fall 1989, we successfully installed an ocean broadband downhole seismometer (OBDS) in Hole 794D during Leg 128 (Ingle, Suyehiro, von Breymann, et al., 1990). Our specific aim of installation was to better image the laterally heterogeneous crust-mantle structure beneath the Japan Sea, backarc of the northern Japan subduction zone, from a permanent seismic station previously nonexistent in conjunction with existing land stations (Fig. 1).

It has long been considered a major step forward in observational seismology to develop a permanent seismic station that operates on the seafloor. But there seems to be no single path to this goal. System requirements vary among different objectives. There is no consensus on what environment, whether seafloor, or within competent rock, or in between, should give "sufficient" signal-to-noise (S/N) ratio. Technical difficulties regarding power supply and data retrieval have been pointed out (e.g., COSOD II, 1987). Leveling and stabilizing the sensor is another problem. More importantly, broadband observational data scarcely exist for assessment (Sutton et al., 1965).

To date, there have been a number of seismic observations of frequency band above about 1 Hz utilizing the drilled holes. Vertical seismic profiling or oblique seismic experiment have been carried out to study detailed upper crustal structure taking advantage of a fixed coordinate, variable depth observation (e.g., Stephen et al., 1980; Stephen et al., 1983). But the presence of mechanical noise from the ship and drill string and limited observation time prohibit global seismology type studies.

The University of Hawaii group (HIG) has made four seismic experiments to seek quiet environment at four sites on Legs 65, 67, 78A, and 88 (Lewis, Robinson et al., 1983; Aubouin, von Huene, et al., 1982; Biju-Duval, Moore, et al., 1984; Duennebier, Stephen, Gettrust, et al., 1987). Navy Ocean Research and Development Activity (NORDA) has conducted three experiments on Legs 78B, 88, and 91 (Hyndman, Salisbury, et al., 1984; Duennebier, Stephen,

Gettrust, et al., 1987; Menard, Natland, Jordan, Orcutt, et al., 1987). Results from these experiments in comparison with simultaneous ocean bottom seismometer (OBS) measurements showed improvements in S/N ratio for downhole instruments. Also, later phases were also better identified for borehole instruments as they are less affected by boundary layer waves (Stoneley waves).

Decrease in noise level between about 2 and 20 Hz compared to seafloor observation was about 20 dB for vertical component and 30 dB for horizontal component, which further decreased 10 dB after 9 months of installation in the successful fourth experiment (OSSIV) by HIG (Duennebier, Stephen, Gettrust, et al., 1987). It was 10–15 dB and 25–30 dB improvement over OBS observation for vertical and horizontal components, respectively, in the band 0.6–4.5 Hz in the successful third deployment (MSS) by NORDA (Menard, Natland, Jordan, Orcutt, et al., 1987).

These findings and our wish to install a broadband instrument coupled directly to the basement rock lead to our utilizing an ODP drilled hole. We here describe our OBDS system and its operation during Leg 128 and the data recovery in May 1990. Its performance is described in a separate paper (Kanazawa et al., this volume). Results on detailed crustal structure and anisotropic characteristics revealed from a controlled source seismic experiment are presented in separate papers (Hirata et al., this volume; Shinohara et al., this volume).

SYSTEM OUTLINE

We have designed our system to be installed through the drill string in ODP holes without modification to the string or any special equipment. While there are developments for independent installation from scientific drilling operations such as by using a submersible or by wireline reentry (e.g., Legrand et al., 1989), which gives the opportunity of utilizing previously drilled holes and greater flexibility in scheduling, this installation required the drilling vessel to clean the hole and to guide down the instrument.

We decided to make the long-term observation by a seafloor recording unit with a power supply, which is cable linked to the borehole sensor package. This means that visits to site are necessary to recover data and to recharge power. It has basically the same layout as the ocean sub-bottom seismometer systems (OSS) built by the University of Hawaii (Duennebier, Stephen, Gettrust, et al., 1987) (Fig. 2). Other possible methods were: (1) cable link to land, (2) cable link to surface buoy, and (3) acoustic link to ship. The first method
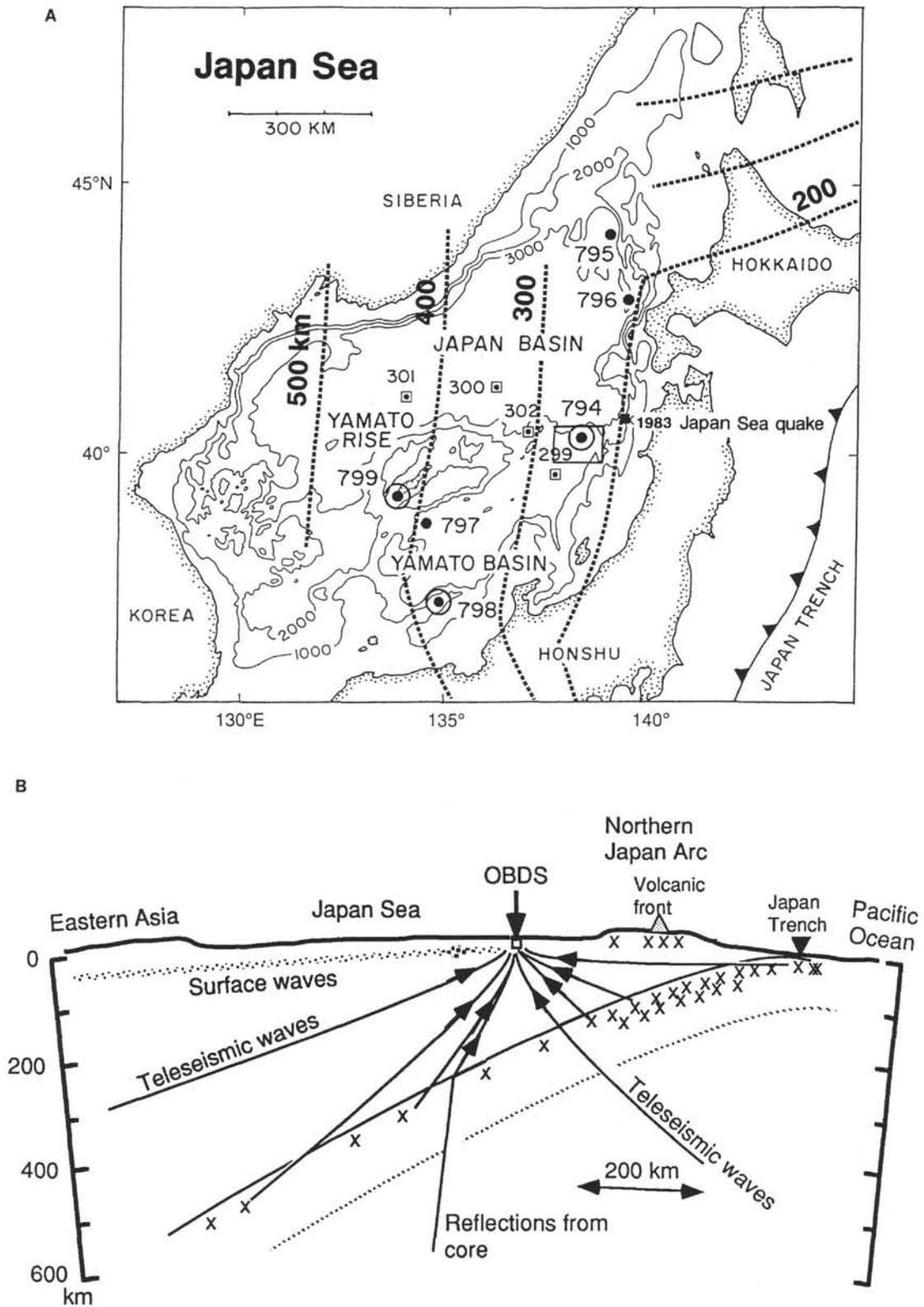
Figure 1. **A.** Location of downhole seismometer (OBDS) at Site 794 in the Japan Sea. Water depth is 2807 m. Wadati-Benioff zone is indicated by depth contours in broken lines. Location of 1983 Japan Sea earthquake is also shown. Enlargement of area in small rectangle appears in Figure 8. **B.** Vertical cross section in approximate east-west direction showing various seismic waves from regional earthquakes (crosses) and teleseismic events. Pacific Ocean Plate subducts beneath Japan Island Arc, Japan Sea, and East Asia spanning about 1500 km horizontally. There have been no seismic stations within Japan Sea.
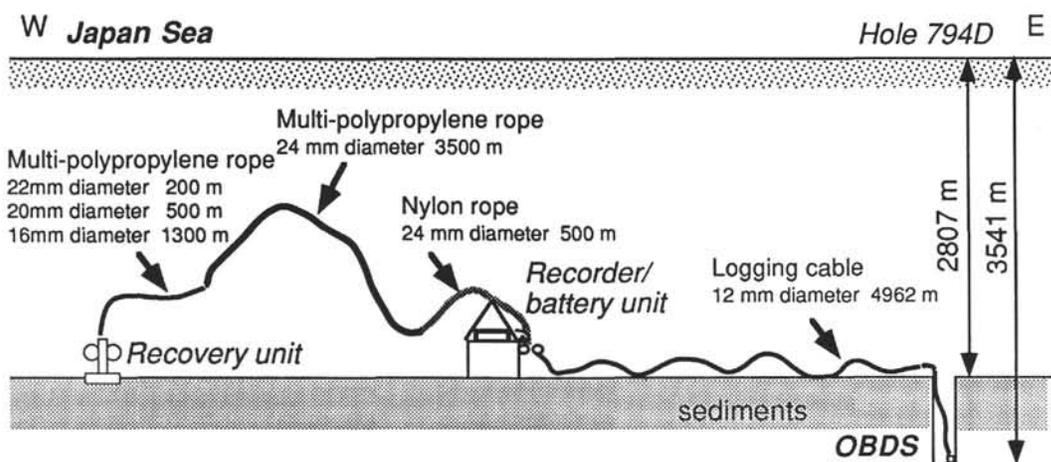
Figure 2. Layout of the OBDS system at off-line observation phase. A recorder/battery unit on the seafloor supplies power to and receives data from OBDS near bottom of Hole 794D via seven-conductor logging cable. Recovery unit releases from its weight by acoustic command from a ship and floats up to surface. Then, a 6000 m long rope is spooled to retrieve data without stressing the OBDS.

was not feasible costwise since the nearest land was 160 km away and also because the cable would have to be buried at least part of the way to avoid damage from trawl net fishing. The second method would require a major technical development for a stable operation over a year. The third method is a strong future candidate for data recovery, but cannot supply power.

We proceeded with this design because of our regionally specific objective rather than aiming at routine observation. We started constructing the system in 1987 aiming at using the state-of-the-art technology.

The sensor package including the digital data transmission electronics are housed in a stainless steel tube. The inner diameter of the drill pipe, which is nominally 4 in. (~10 cm) in diameter, and the scheduled hole depth of about 4000 m delimited the actual sensor diameter to be less than 75 mm. This pressure housing can be clamped within the open hole section which would be about 10 in. (~25 cm) in diameter in competent rock.

The installation procedure is similar to logging measurements. A standard electromechanical cable for logging was to be used for lowering the instrument and for data/power link (Table 1). The cable would be spliced once in order to pull out the drill pipe.

Table 1. Logging cable specifications.

Cable weight	502 kg/km (340 lb/kft)
Cable diameter	12 mm (0.464 in.)
Strength	7.7 ton
Electrical resistance	34 ohm/km (10.4 ohm/kft) (center)
	36 ohm/km (10.9 ohm/kft) (outer)
	4.3 ohm/km (1.3 ohm/kft) (armor)
Insulation	>> 49 Gohm/km (15 Gohm/kft)
Capacitance @ 1 kHz	1.3 pf/m (40 pf/ft) (armor to outer conductors)
	1.4 pf/m (42 pf/ft) (armor to center conductors)

A digital telemetry technique was adopted to send the data. Real-time observation can be made aboard a vessel provided the other end of the cable is connected to a modem and a personal computer with a large data storage. The logging cable is about 5000 m length in about 2800 m water depth, so that accidentally pulling the borehole instrument could be avoided.

Much longer time than real-time observation time is required to record natural earthquakes of interest, which, in our case, are events that provide information on the heterogeneity of the Japan Sea upper

mantle. Because of limited data capacity, a continuous recording was not possible. This part of the system is retrievable and, hence, improvements in data storage and power consumption will be sought. Presently, the data recorder and battery pack unit weighs most (about 1.5 tons) in the system. Still, its deployment could be made from a supporting vessel (50 m length class), which also meant maximizing drilling time for the drill ship.

DOWNHOLE PRESSURE HOUSING

The pressure housing is schematically shown in Figure 3. The overall length is about 300 cm. The outside diameter of 98 mm (3.86 in.) was constrained by the drill pipe inner diameter. The sensors and electronics are placed in the top half.

The extension pad and its motor are housed in the bottom half, which can be remote-controlled through logging cable. Single pad (32 cm long × 8 cm wide) retracts to 98 mm diameter or extends up to 27.2 cm diameter (10.7 in.) inside the 10 in. diameter open hole. The outer surface of the pad has grooves cut in to grip the hole wall.

SENSORS

No sensors other than a set of three-component seismic sensors were included in order to minimize complication of the system and to consume less power. A feedback type accelerometer was considered to achieve broadband response. On land, many stations had been making broadband high-quality observations using those sensors (e.g., Romanowicz and Dziewonski, 1986). On the other hand, there were no models available for seafloor downhole observations (e.g., Purdy and Dziewonski, 1989).

We selected Guralp's modified CMG-3 (Table 2). Its vertical component consists of a horizontal boom supported by a triangular leaf spring. The natural period of the pendulum is about 0.4 s. The horizontal movement is sensed by an inverted pendulum with similar period as the vertical component. The boom position is sensed by a differential capacitive displacement transducer. The feedback is applied by an electrodynamic transducer.

These masses can be locked upon installation by micromotors. The vertical sensor is designed to operate normally up to 5° tilt. ODP holes are expected to be less than 3° from vertical (G. Foss, pers. comm., 1989). The leveling of a horizontal component is achieved by a motor-driven sensor base (Pl. 1).

Figure 3. Pressure housing of downhole seismometer (left) and internal sensor package (right). Extension pad is retracted when inside the drill pipe and extends out by pad motor housed near bottom to clamp itself in open hole. A three-axis feedback-type accelerometer constitutes the heart of OBDS. Observed signals are amplified, filtered, digitized, and telemetered uphole.

The three-component sensors are stacked to fit in the pressure housing (Pl. 1). A wide dynamic range is achieved by dividing the signals into two gains. The high-gain channels are amplified by a factor of 6 and low-cut-filtered (Table 2). The feedback sensor package mates directly to the broadband digital telemetry package (BDTS) via a 32-pin connector (Fig. 3).

DATA/POWER LINK

Figure 4 shows the data and power transmission diagram. Data consist of commands sent downhole and digital seismic signals with replies to commands. There are two electronic boards that constitute the BDTS. One is the A/D converter and the other is the telemetry unit (Table 3). Its test was made by inputting calibration signals of different levels to confirm linear response. As the sensors must

withstand forces exerted during installation and because there is no way to check the system other than via the logging cable after installation, sensor controls and checking the state of health (SOH) must be included in the system.

We tested the system with a simulated cable based on logging cable specifications (Table 1). A DC-DC converter requiring two lines for power did not work well when there was considerable impedance before power supply. We increased this to three lines and changed it to regulate with Zener diodes and power regulator IC's. The armor was used to ground the power line. Final test was made aboard *JOIDES Resolution* through 10 km of logging cable and a simulated cable. For the case of seafloor observation, the cable length would be

Table 2. Guralp sensor specifications.

Type	Guralp DT008A slimline CMG-3 Three-axis feedback accelerometers		
Sensor mass	160 g		
Sensitivity	Vertical	Horizontal 1	Horizontal 2
Low-gain (DC 30 Hz)	2566	2700	2854 Vm/s^2
High-gain (0.01–30 Hz)	15396	16200	17124 Vm/s^2
Resolution (LSB)	0.346 mV		
Dynamic range	16-bit (96 dB) each gain; (112 dB total)		
Leveling control	Vertical: mass centering by command-driven motor Horizontal: mass centering by command-driven motor and sensor base levelling (accommodates 5° of tilt)		
Power	±12V ±15 mA (including feedback and filter electronics when quiet)		
Sensor package	525 mm length, 75 mm diameter		
Input/Output	32-pin circular connector (12 pins for 6-channel signals; 11 pins to command lock, center, calibrate each component; 3 pins for power)		

Table 3. BDTS specifications.

A/D converter Crystal Semiconductor CS501 6: 16-bit, 150 mW, non-linearity 0.001% maximum

Digital telemetry	Communication rate	Modulation
Downhole	150 bps	FSK (frequency shift key)
Uphole	19,200 bps	DPSK (differential phase)

Data packet: 15-byte	Bytes	Content
	1–2	Vertical low gain
	3–4	Vertical high gain
	5–6	Horizontal-1 low gain
	7–8	Horizontal-1 high gain
	9–10	Horizontal-2 low gain
	11–12	Horizontal-2 high gain
	13	State-of-health (SOH)
	14–15	status

Available commands	
	Get values from SOH 8-bit A/D's
	Get internal variables, e.g., lock status
	Set internal variables
	Automatic centering of mass of each component
	Mass locking/unlocking of each component
	Base locking/unlocking of each horizontal component
	Start/stop automatic centering mode (automatic centering every 11 min)
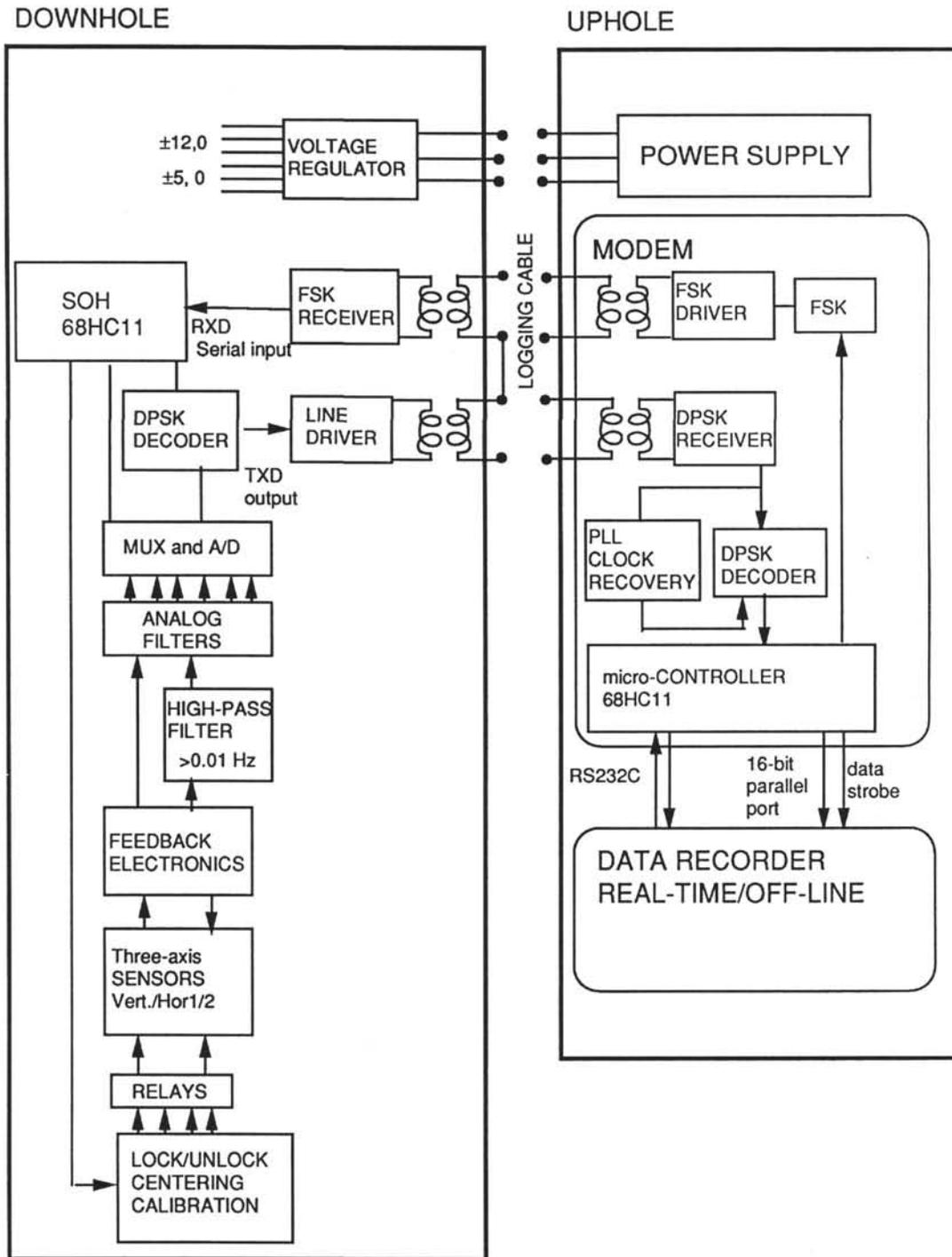
Figure 4. Data and power link between downhole unit and uphole. Power is sent via #2 (+48 V), #5 (−48 V), and #1 armor (GND) of seven-conductor double armored logging cable. Data are transmitted uphole (#4; #6 common) and commands sent downhole (#3; #6 common). Pad motor uses #7 and GND (not shown).

about 5 km. Power supply tests indicated that in order to receive data, +48 V and −36 V were the minimum required.

SEAFLOOR UNIT

Seafloor Data Recorder

We have made a re-use of the cylinder pressure vessel originally developed by Nagumo et al. (1970). It was tested to pressure equiva-

lent to 4000 m water depth. The only modification was to attach a connector to couple the logging cablehead. This vessel was attached on top of the battery unit with care to avoid electrical corrosion by allowing no direct metal contacts.

Inside this housing are a modem, data logging controller, and recorder (Fig. 5, Table 4). The recorder is a self-contained package communicated through an RS-232 interface. A cartridge tape runs in start-stop mode to store up to 60 Mbytes, which can operate up to
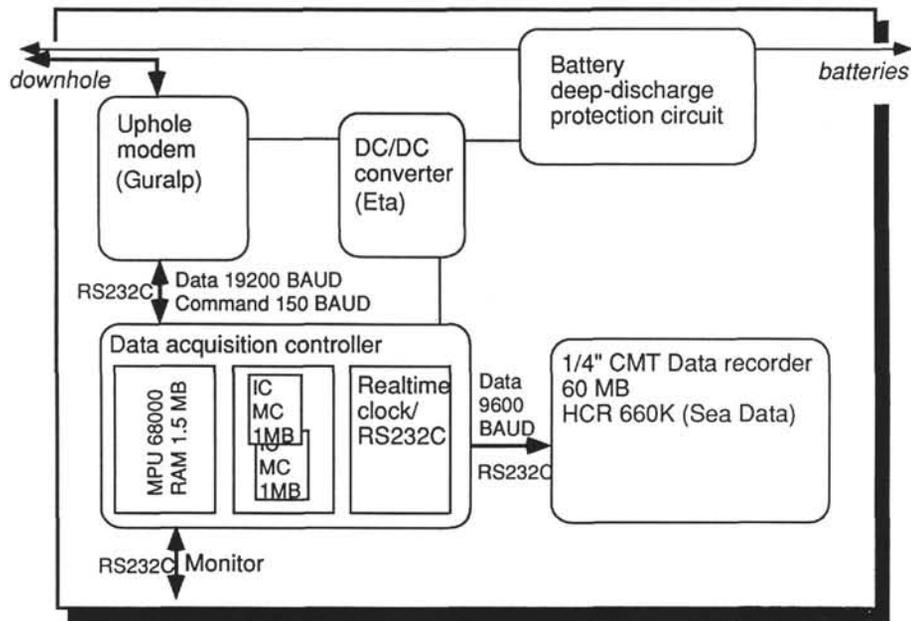
Figure 5. Block diagram of seafloor data recorder. Data are stored digitally in a 60 Mbyte cartridge disk. Two IC memory cards are for data buffering.

about a year. The data acquisition controller does data selection in two modes: (1) event detection mode and (2) time window mode (Fig. 6; Table 4). It buffers data onto two 1 Mbyte IC memory cards before outputting to the recorder.

The event detection mode uses an algorithm of triggering by setting a STA/LTA (short term average/long term average) threshold. Aiming at moderate to large earthquakes, two sampling rates were selected; 20 Hz and 1 Hz. The former is called SP (short period), and recording is made for 40 min. The latter is called LP (long period) and will record for 2 hr per event. Both are triggered independently where STA means taking an average of 10 samples and LTA, of 1000 samples; that is, the amplitude changes at two different frequency bands are monitored. Two threshold levels may be selected, and in the case where the first threshold level fails to trigger any event, the second level is adopted. In this experiment, we chose four and two in that order. No detection takes place while data are being recorded.

A time window recording was incorporated to study the background noise level. Three different frequency bands and time dura-

Table 4. Data recording scheme.

Real-time recording
  Modem: Guralp
  Time: Time code generator corrected against Japan Standard Time
  System A (with time stamping):
    Compaq 386-40, 80 MB HD, 40 MB Irwin mini-data cartridge back-up
    Data packet: 15-byte packet + 1 byte time

System B (no time stamping):
  Toshiba J-3100-GT, 20 MB HD, 600 MB SONY Magneto-optical disk
  Data packet: 15-byte packet

Off-line seafloor recording (Fig. 5):
  Modem: Guralp
  Real time clock TCXO: Vectron CO-252
    Temperature stability: $\pm 1 \times 10^{-7}$(0°–50°C)
    Aging: 5×10^{-7}/yr
    Short-term: 1×10^{-9}
  Data acquisition controller: Akashi
    RAM: 6×256 KB; ROM: 2×256 KB; IC memory card: 2×1 MB
  Recorder: Sea Data HCR66OK; 60 MB cartridge tape recorder; 20AH battery
  Battery deep-discharge protection: Cut line if voltage drops below 75%

tions were set up as shown in Figure 6. This mode has lower priority than the event detection mode, so that interruption may occur.

Power Supply

Power requirements for this experiment are shown in Table 5. It can be seen that the logging cable itself is a major power dissipator, and it is far more than an all-in-one OBS with a passive sensor system. We chose to use lead-acid batteries with nonliquid electrolytes in pressure-compensated housings, similar to the type used by deep submersibles. The lead-acid type was selected over Ag-Zn or Ni-Cd type, the energy density of which are superior but much more costly. Since the electrolyte is solid, the batteries may be placed upside down upon deployment.

Table 5. Power requirements.

Downhole via logging cable:	–48 V, –148.5 mA, 7.1 W
	+48 V, 200 mA, 9.6 W
BDTS demodulator	–12 V, 26 mA, 2.3 W (48V equiv = 6.5 mA)
	+12 V, 96 mA, 0.6 W (48V equiv = 24 mA)
Akashi controller	1.92 W (+24 V, 80 mA) (48V equiv = 40 mA)

Twenty batteries are put together inside an aluminum frame, making this part the heaviest (about 1 ton in air) component of the seafloor unit (Table 6). This can be serviced by a vessel larger than about 50 m length without heave compensation.

Recovery Unit

Based on experiences from years of using tethered OBS, nylon and polypropylene rope amounting to 6000 m length were used to connect the recorder package and acoustic release system (Fig. 2). Upon data recovery, the release system is first recovered and then the rope is wound onto a winch to retrieve the data package. We estimated maximum tension to be less than about 3 tons. A nylon rope was used near the recorder. Small-diameter (16 mm) rope is used near the float for less friction.

STA/LTA event detection

Second-order
high-cut
digital filter

STA/LTA = average of 10 samples / average of 1000 samples
Threshold = 4; if no event for 10 days, then = 2

All → | 10 Hz |

SP
20 sample/s
40 min /event

2 B/sample 576,000 bytes

All → | 0.5 Hz |

LP
1 sample/s
2 hr/event

2 B/sample 86,400 bytes

Time window

All →

NOISE
80 sample/s:
1 min x 10 times

2 B/sample 57,600 bytes

Low-gain → | 8.33 mHz (120 s) |

Long period
1 sample/min x 45 days

2 B/sample 38,880 bytes

Low-gain → | 138.9 mHz (2 hr) |

Very long period
1 sample/hr x 180 days

6 B/sample 77,760 bytes

DATA FORMAT

1 File/Component/Event

| BOF | DATA | ⌇⌇ | DATA | EOF |

BOF: 512 B Header/Directory/Start time Filename/Null
EOF: 512 B filled with 0x0003

Figure 6. Data selection scheme. Event detection mode and time window mode are available. An event trigger occurs if short term average (STA) and long term average (LTA) ratio exceeds a preset value, in which case, short period (SP) and long period (LP) recordings are made. Time window mode is meant for noise level recording. All samplings are made after appropriate anti-alias filtering.

The acoustic recovery system consists of two 17 in. glass spheres for buoyancy and an acoustic releaser placed in the middle with a lifetime of 1 year (extendable) suspending the weight (Pl. 2). The release mechanism is an exploding bolt operated by acoustic command. If this fails to operate, the polypropylene part of the rope system would be picked up.

INSTALLATION

The original plan was to drill and case Hole 794C on Leg 127, and reuse the hole for our seismic experiment. This would give about 2 months of time to allow the hole to stabilize itself as much as possible before installation. Unfortunately, Hole 794C became unusable when a BHA was left inside the hole during Leg 127. Our attempt to fish this BHA out on Leg 128 failed, and hence, it was quickly decided to drill Hole 794D for the experiment. Two other supporting ships for the geophysical experiments were on tight schedules, and thus little change in timing of the experiment was possible despite these last minute changes.

Table 7 shows the summary of Hole 794D. The casing of the hole through sediment section was important because of swelling clay instantly obstructing the hole for reentry. Logging information was vital to determine that the final position of the borehole instrument was within competent rock section. Figure 7 shows the logging record and the final position of the instrument.

Table 8 shows the sequence of installation operation. It was necessary to lower the drill pipe to near-bottom so that our instrument, much lighter than logging tools, would not be obstructed. The logging cable was

Table 6. Battery specifications and wiring.

Single lead-acid battery: Length 46 cm, width 31 cm, height 31.5 cm
    Battery: Matsushita LCR (lead-calcium rechargeable)
    Weight: 49 kg (in air); 19.1 kg (in water)
    Case: Molded polyethylene
    Diaphragm: Molded polyether urethane
    Pressure compensating fluid: Inert oil
    Electrical: 24 V, 38 AH
    Maker: DEEPSEA Power & Light

Configuration:
    Number of batteries: 20
    Y-splicing: Ten sets of two batteries connected in series by diode protected Y-splice
    Controller unit: Ten outputs from Y-splices are gathered into two sets connected in parallel to supply ±48 V with two 5A fuses protection.
    Battery frame: 6061-T6 Al welded with #5356 Al rod; stainless steel (316) isolated from noncoating Al frame; zinc used for anodic protection. 148 cm long × 140 cm wide × 97.3 cm high

Table 7. Hole 794D.

Position: 40°11.366′N, 138°13.944′E
Water depth: 2807 m
Penetration: 733.5 m
Sediments: 542.2 m
Hard rock:
    Depth (mbsf): 573.0
    Nature: Olivine dolerite
    Measured velocity: 5.4 km/s
Drilling dates:
    4–13 September: drilled to 666 mbsf and cased through 560 mbsf
    22–29 September: deepened to 733.5 mbsf and logged
Instrument depth: 714.5 mbsf

reheaded and connected to the downhole seismometer. A final test was made to check the clamping device. Then, the instrument was lowered to and first clamped at 718 mbsf. Incoming data were saturated by noise, so we judged from the command performance of the leveling motors for horizontal components, which did not seem to indicate normal function. We decided to reclamp the instrument above the initial position at 714.5 mbsf. This time, the leveling functioned, and the mass on each sensor was swinging between positive and negative maxima.

The next step was pipe stripping. The cable was cut at the rig floor and the pipe stripping proceeded as illustrated by Byrne et al. (1980). We did not retract the pad during this procedure. Two stands of drill-pipe were left to protect the logging cable suspended through the moon pool as the ship would move away from the hole. "Torpedo" splicing was made applying "ScotchKote" at seals for longer duration, and the real-time recording began. One horizontal component was found to be malfunctioning for unknown reason.

The *JOIDES Resolution* was offset by 1536 m in 180° direction while paying out 1353 m of logging cable to prepare for real-time observation. The offset direction was determined from the OBS array geometry and sea currents (Fig. 8).

REAL-TIME EXPERIMENT

The real-time experiment lasted for about 60 hr starting from the time of cable splicing until the cutting of the cable to pass to the supporting vessel, *Kaiko-maru 5*. Digital recordings were continuously made during this period onto two personal computer systems (Table 4). The automatic mass centering mechanism was activated during this phase, which meant that the masses would be automatically centered every 11 min.

Two recording systems ran in parallel dedicated to data retrieval for safety. Both should record exactly the same digital signals. One system would put a time stamp when storing data onto a hard disk while the other magneto-optical disk storage system could not. Since the data transmission uphole must maintain 19,200 bps in order to send six channels of 80 Hz sampling 16-bit data, special coding was necessary to capture and store the data at this rate.

We conducted a controlled source seismic survey during this time to obtain the local crustal structure and to find the azimuths of horizontal sensors. *Tansei-maru* of Ocean Research Institute, University of Tokyo, shot air guns as a signal source and also deployed nine OBS's for a high-resolution study (Shinohara et al., this volume; Hirata et al., this volume). Two vessels independently corrected time against Japan Standard Time (JJY radio signal).

DEPLOYMENT OF SEAFLOOR UNIT

After passing the cable to *Kaiko-maru 5*, a final electrical connection test was made. The clock was started and the data controller power was set. Figure 9 shows a schematic view at the deployment of the seafloor unit. Great care was taken so that no excess tension was applied to the cablehead. The package was lifted over the aft end of the ship by the

Table 8. Downhole seismometer installation.

1. Reentry to Hole 794D and RCB coring (JR: 22 September, 2033 hr to 23 September, 23 hr)
2. Logging runs (JR: 24 September, 1500 hr to 25 September, 1900 hr)
3. OBS deployment (TM: 24 September, 1445 hr)
4. Reheading logging cable (JR: 25 September, 1850 hr to 26 September, 0050 hr)
5. Seismometer run in hole. Lock all components before descent. Because the tool is light it cannot be detected at the drum winch room. Pumping is done to push down the tool. Stop winch at 11,600 ft depth reading. (JR: 26 September, 0214 hr to 0346 hr)
6. Clamp and test seismometer. (JR: 26 September, 0351 hr to 0545 hr)

0351 hr	Test the tool. First clamping attempted.
0545 hr	Power off. Vertical component was left at unlocked position. Horizontal 1 component locked. Slacken the wire and cut at the rig floor.

7. Drill pipe stripping. (JR: 26 September, 0545 hr to 1620 hr)

1530 hr	Drill pipes nearly out.
1620 hr	Lower pipe for logging cable protection during shift.

8. Splice cable (JR: 26 September 1652 hr to 1910 hr)

1652 hr	"T-bar" and pipe set. Start cable splicing
1830 hr	Test
1910 hr	Slack >>12 m from "T-bar." "Torpedo"splicing. In the "clamshell" is silicon grease. Taped and shrink-tubed and taped again.

9. Real-time experiment/air gun shooting (JR, TM: 26 September, 2130 hr to 29 September, 0602 hr)

2218 hr	Offset 1536 m to 180° direction. Cable 1353 m paid out.
2232 hr	Air gun shooting from 2232.05 hr.
28 September	(storm weather)
29 September, 0602 hr	Power off.

10. Cable passing from JR to KM (29 September, 0649 hr to 1400 hr)

0649 hr	Turn JR for bringing drill pipes up without damaging the cable.
0700 hr	Pipe recovered. Total length of the logging cable is 4965 m.
0730–0840 hr	Attach cablehead.
0904 hr	Cable out of moonpool.
1120 hr	Use crane to pull up the wire. Repeat pull and cut some length.
1400 hr	Complete passing the cable from starboard side. Four people transfer to KM for modem boards transfer and final checking.

11. Seafloor unit deployment (29 September, 1400 hr to 30 September, 0020 hr)

1833 hr	Checking at KM.
2200 hr	Battery unit and recorder into water.
2315 hr	JR ready for next operation.
30 September	(very good weather)
0020 hr	KM deployed acoustic transponder. End of operation.

(time in UT: add 9 hr for JST)

JOIDES Resolution (JR): Downhole seismometer installation
Tansei-maru (TM): Air-gun shooting and OBS array observation
Kaiko-maru (KM): Seafloor unit deployment

recovery rope which ran through a sheave on an A-frame. After lowering the package into the sea, the ship drifted while the crew was paying out the rope system. Several hundred kilograms of tension was maintained during this operation to pull the cable and rope.

RECOVERY

In May 1990, we revisited the site to recover the seafloor system. A chartered ship of about 50 m length was equipped with a winch with a load cell to monitor load during recovery. First, as we approached the site, three transponders were deployed to determine the ship position, in addition to GPS aid. The weight was successfully released by acoustic command and the float was recovered. It took 5 hr from that time to retrieve the seafloor recorder. The rope tension increased eventually to 2.5 ton.

No apparent damage was found to the recorder or to the battery unit. There was no electrical corrosion on the surfaces of these units. Inside, the cartridge tape was advanced only a little. There was no triggering from the event despite the fact that there should have been. The reason for this is probably because of DC offset in the data and telemetry problem. Available data then are from IC memory cards only.

We made an overnight effort to revive the system by trying a real-time observation. It was found that the error rate in data telemetry had increased considerably, the reason of which is under investigation. We redeployed only the recovery unit, which took 3 hr. The data recorder and the battery unit were brought back for closer inspection and for modification and recharging.

Hole 794D
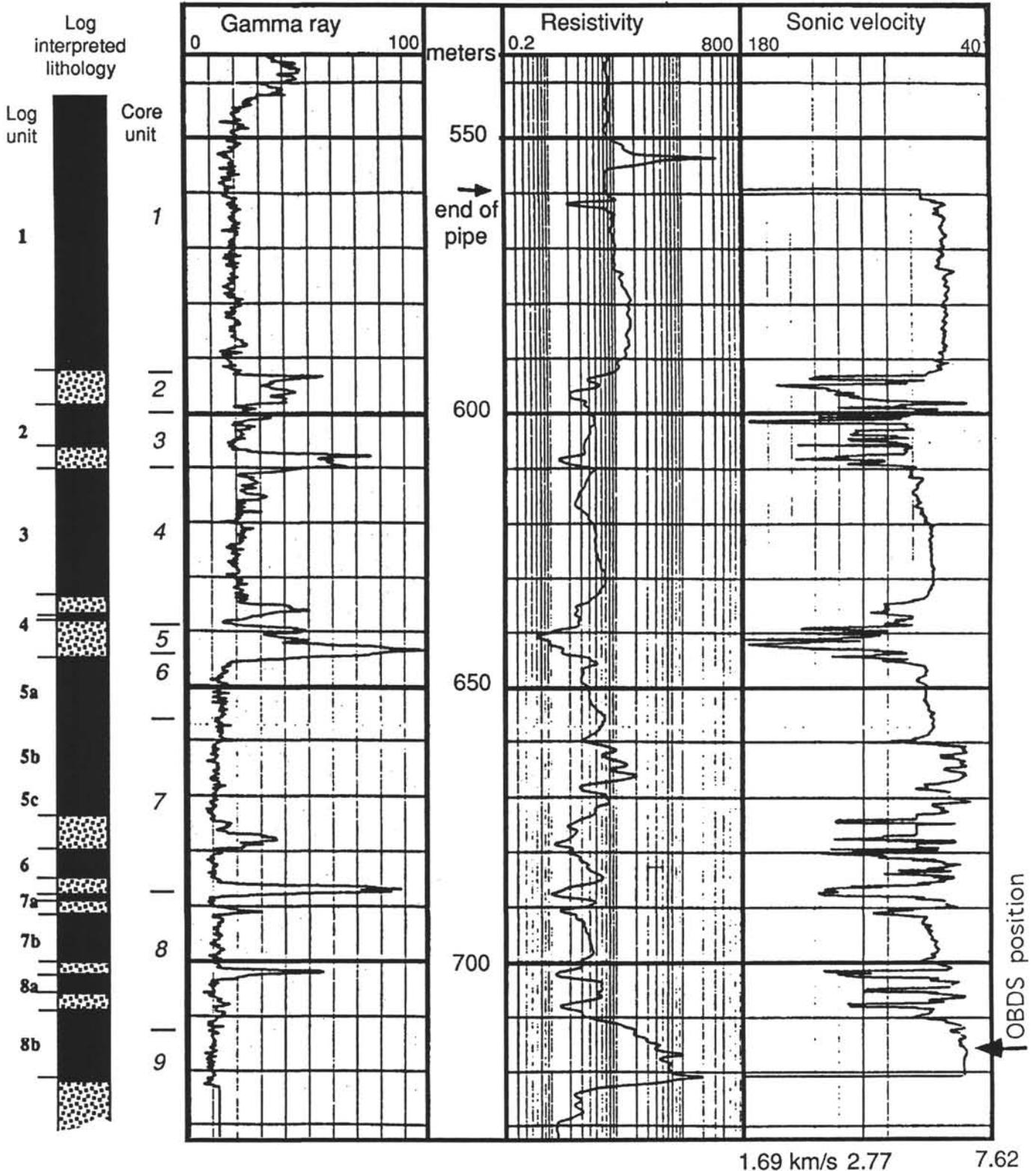
Figure 7. Seismic stratigraphy combination log record. Column 1 is interpreted lithology (see Ingle, Suyehiro, von Breymann, et al., 1990). Logging records are, from left, total gamma rays (0–100 API units), resistivity (phasor induction medium, 0.2–800 ohm-m), and sonic traveltime (180–40 μs) (velocity indicated below). An arrow at lower right shows the position of seismic sensor within low gamma ray, high resistivity, high velocity medium at 714.5 mbsf or 3522 m from surface.

Vicinity of Site 794
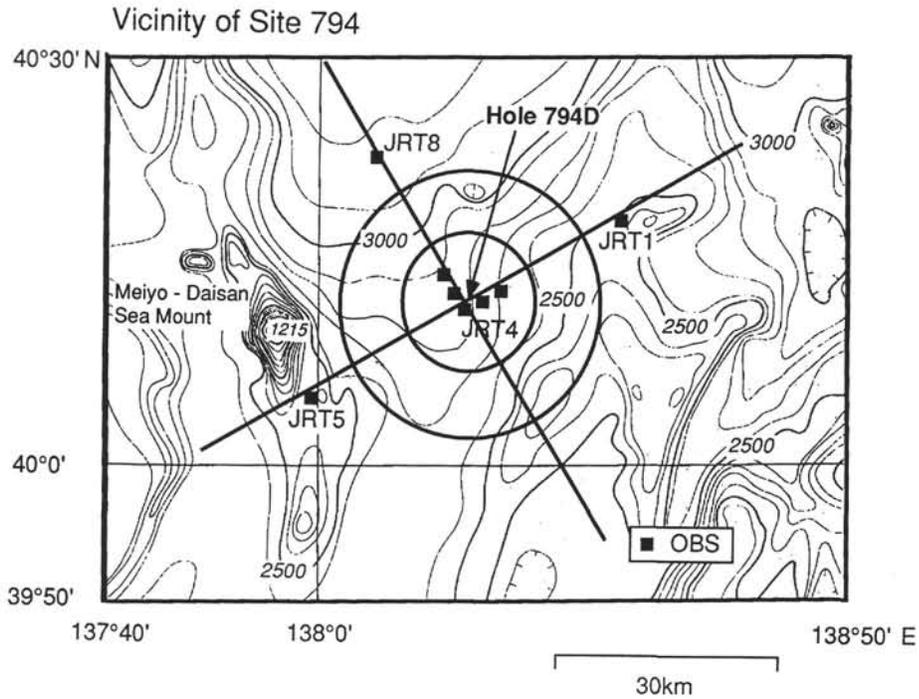
Figure 8. Detailed map of Site 794 vicinity. OBS-array location and air-gun profiles in solid lines are shown. Seafloor recorder unit and recovery unit lie westward of Hole 794D.

SUMMARY

In summary, we have constructed a digital downhole seismometer system with broadband and wide dynamic range response (OBDS) to be installed in an ODP hole. Its installation was attempted in the fall of 1989 on ODP Leg 128 in the Japan Sea and was successful. The OBDS was emplaced at a depth of 714.5 mbsf within basaltic rock section at Site 794. Sixty hours of real-time digital recording was made from *JOIDES Resolution* through the logging cable, including controlled seismic source signals, for the first time in broadband. Two components of the feedback-type accelerometers operated normally.

A support vessel brought the seafloor recorder unit to be connected to the cable and deployed the unit to capture deep or teleseismic events
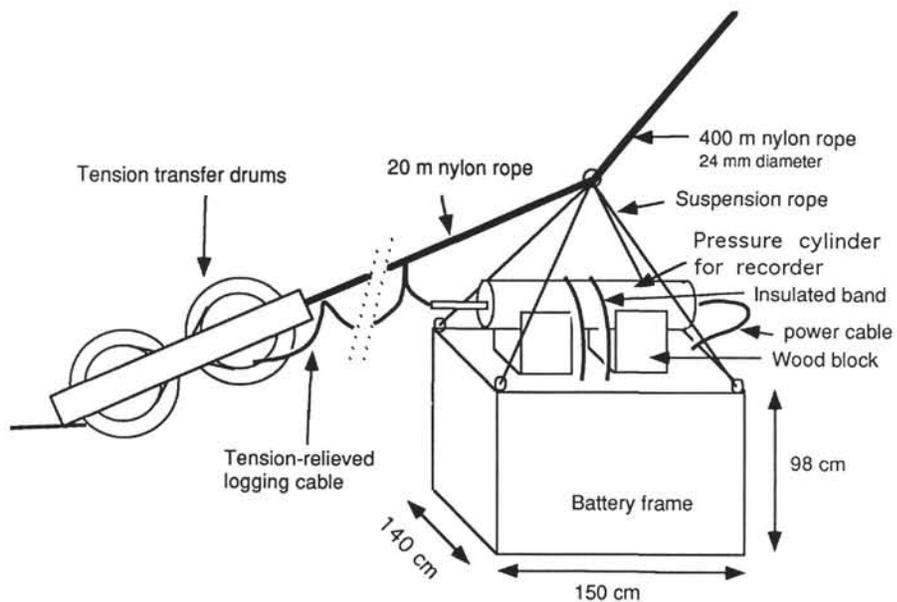
Figure 9. Deployment of seafloor unit. Cylinder is the pressure housing of data recorder attached without direct metal contacts to aluminum battery frame. Tension of the logging cable is transferred to rope, so that little tension applies to cablehead. The unit was put into water by an A-frame from aft of *Kaiko-maru 5*.

together with ambient noise. Pressure-compensated lead-acid batteries were configured in an aluminum frame as the main power supply, which also holds the cylinder vessel with the data recorder on its top. A rope system of 6000 m length is attached with the recovery unit at the end (Fig. 2).

The seafloor unit was recovered after about 8 months underwater without any electrical or mechanical damage. Unfortunately, the event detection had not functioned, although there were a number of large events worldwide including the Loma Prieta earthquake.

Modifications can be made only for the seafloor units. Plan is underway to improve the system as there is no definite evidence that the downhole instrument has irreversibly gone wrong. The present system allows only about 1.5 months of operation. We are considering alternate power sources, such as fuel cells or isotope cells, for the future to prolong life to years. The data capacity should also be increased. We are currently developing a digital audio tape-based seafloor data recorder, which can store 1 Gbyte of data in a much smaller size and with less power consumption than our present system.

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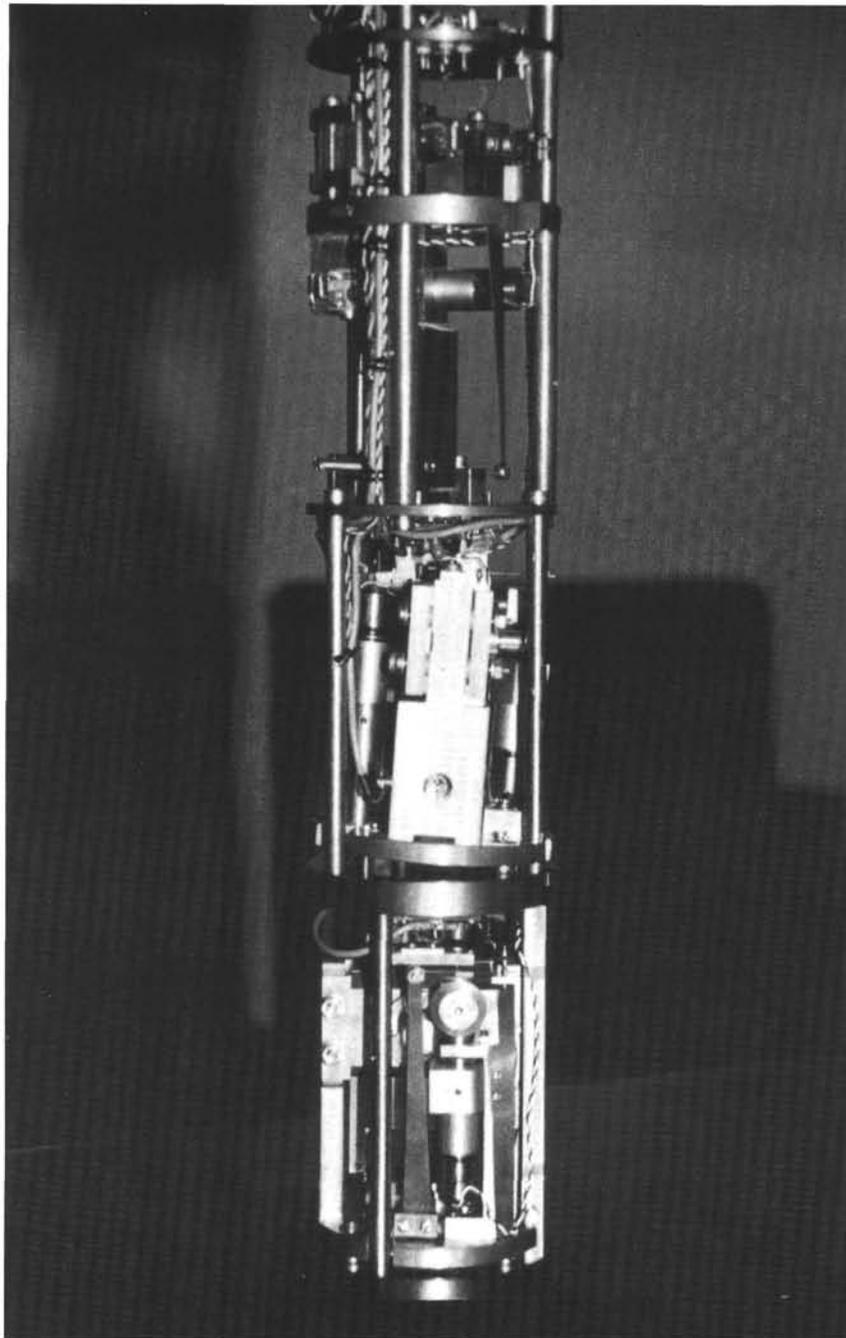
Plate 1.   Guralp three-axis feedback-type accelerometer sensor stack-up. A vertical sensor sits on top of two mutually orthogonal horizontal sensors. Bases of horizontal sensors tilt in the direction of inverted pendulum movement to become horizontal accommodating up to 5° deviation from vertical.
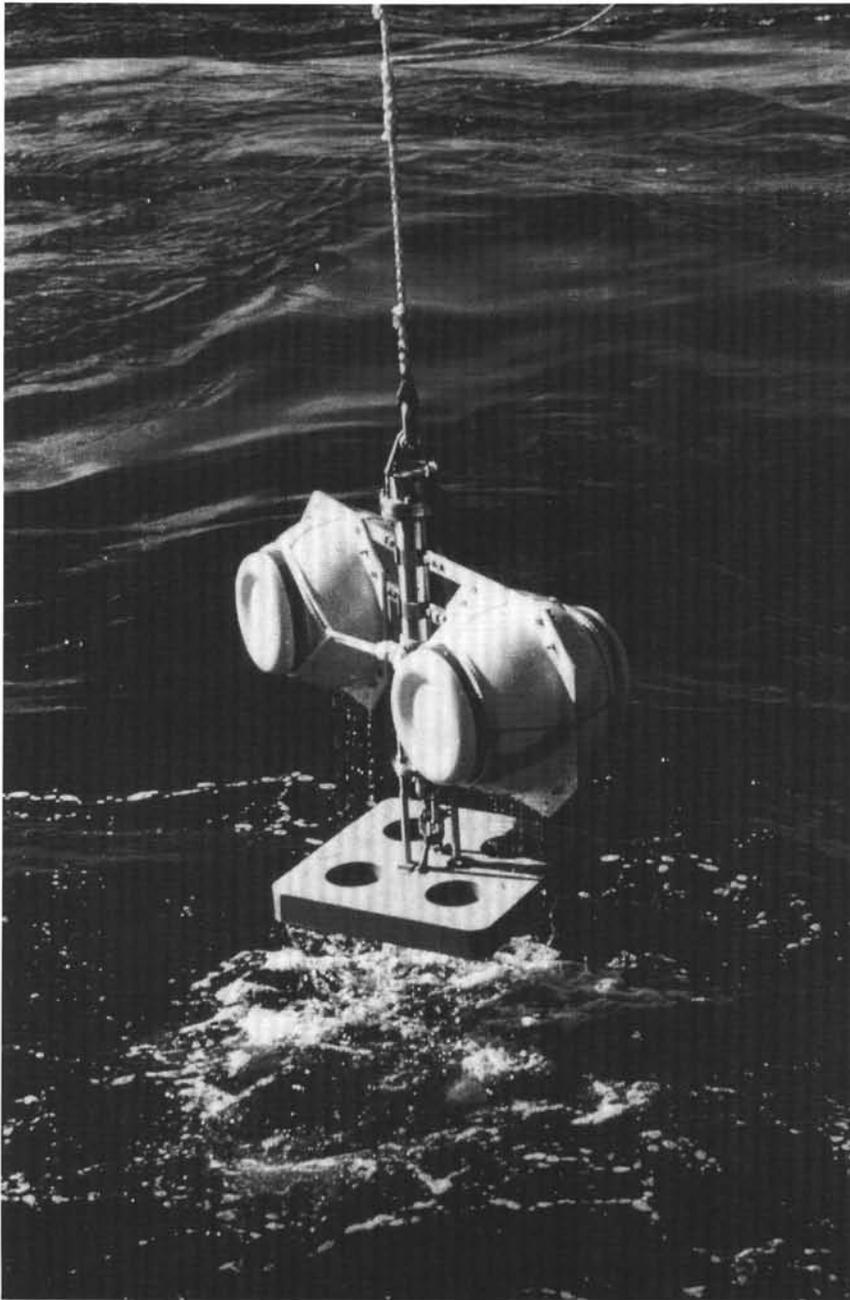
Plate 2.   Acoustic recovery system. Two glass spheres cradle an acoustic releaser suspending a 150 kg iron weight.