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Submarine cable OBS using a retired submarine telecommunication cable: GeO-TOC program

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Abstract

In order to study the Earth's structure and subduction zone tectonics, seismic data from the oceanic region are extremely important. The present seismograph distribution in the oceanic region, however, provides a very poor coverage. To improve this poor seismic coverage, a cable OBS system using a retired submarine telecommunication cable is proposed. The GeO-TOC cable runs from Ninomiya, Japan, to Guam through the Izu-Bonin forearc and the Marina Trough. The total length of the cable is 2659 km. An OBS, IZU, using the GeO-TOC cable, was successfully installed at the landward slope of the Izu-Bonin Trench in January 1997. The IZU OBS is located approximately 400 km south of Tokyo. The installation method is similar to repair work on submarine cables. The IZU OBS is equipped with three accelerometers, a hydrophone, a quartz pressure gauge, and a quartz precision thermometer with a few temperature sensors to monitor overheating of the internal electronics. After installation, the voltage increase is 90 V when the current is maintained at a constant 370 mA. Data from accelerometers are digitized by 24-bit A/D converters and sent to Ninomiya at 9600 bps for each component. Hydrophone data are sent to Ninomiya as analog signals using the AM (Amplitude Modulation) method for safety reasons. Hydrophone data are digitized at the shore station. Other slow-rate data are multiplexed and sent to the shore at 9600 bps. The instrument can be controlled by a shore computer. All data will be transmitted from Ninomiya to Tokyo and combined with other existing seismic data.

Keywords: Ocean Bottom Seismometer; Submarine cable; Submarine volcano; Hydrophone; Izu-Bonin trench

1. Introduction

Seismic waves are the most powerful tool to study the Earth's structure. Although roughly two thirds of the Earth's surface is covered by ocean, the distribution of seismic stations in the oceanic area is extremely poor. This poor coverage affects accuracy and resolution of the Earth's structure, particularly, in the Pacific Ocean. Even when using a $20° \times 20°$ mesh on the Earth's surface, there are many areas with no seismograph stations (e.g., Montagner and Rommanowicz, 1995).

Oceanic seismic stations are important not only for the global seismic studies, but are also important for local seismic studies. Seismic hazards are among the most urgent topics in countries such as Japan. In particular, the Japanese islands are surrounded by

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seismically very active trenches such as the Kuril Trench, the Japan Trench, the Izu-Bonin Trench, the Nankai Trough, and the Ryukyu Trench. The Sagami Trough and the Suruga Trough are short, but they also have high seismic risks. The Japan Trench and the Nankai Trough can be monitored by several existing and planned cable OBS's, such as the JMA (Japanese Meteorological Agency) off-Omaezaki seismic cable, the JMA off-Boso seismic cable, the ERI (Earthquake Research Institute) off-Sanriku seismic cable, the NRIESDP (National Research Institute for Earth Science and Disaster Prevention) Sagami-Bay seismic cable, and the JAMSTEC (Japan Marine Science and Technology Center) off-Muroto seismic cable. However, there are no permanent OBS stations along the Izu-Bonin Trench and the Mariana Trench.

There are a few different ways of performing seismic observations in the oceanic region: land stations using oceanic islands, real-time OBS by tethered-buoy and satellite telemetry, stored OBS by pop-up or tethered using off-line recording, and real-time OBS using submarine cables. Although many institutions including ERI have developed advanced free-fall/pop-up OBS (e.g., Jacobson et al., 1991; Shinohara et al., 1993; Kasahara et al., 1995b, 1997), they have weaknesses in terms of quick data retrieval, large power supply requirement for a long period of observations and scheduling and cost of vessels for deploying and retrieving instruments. Real-time data retrieval is mandatory for seismic hazards mitigation. Among the above seismic observations, a submarine cable OBS system can be the most reliable system because of the excellent techno-

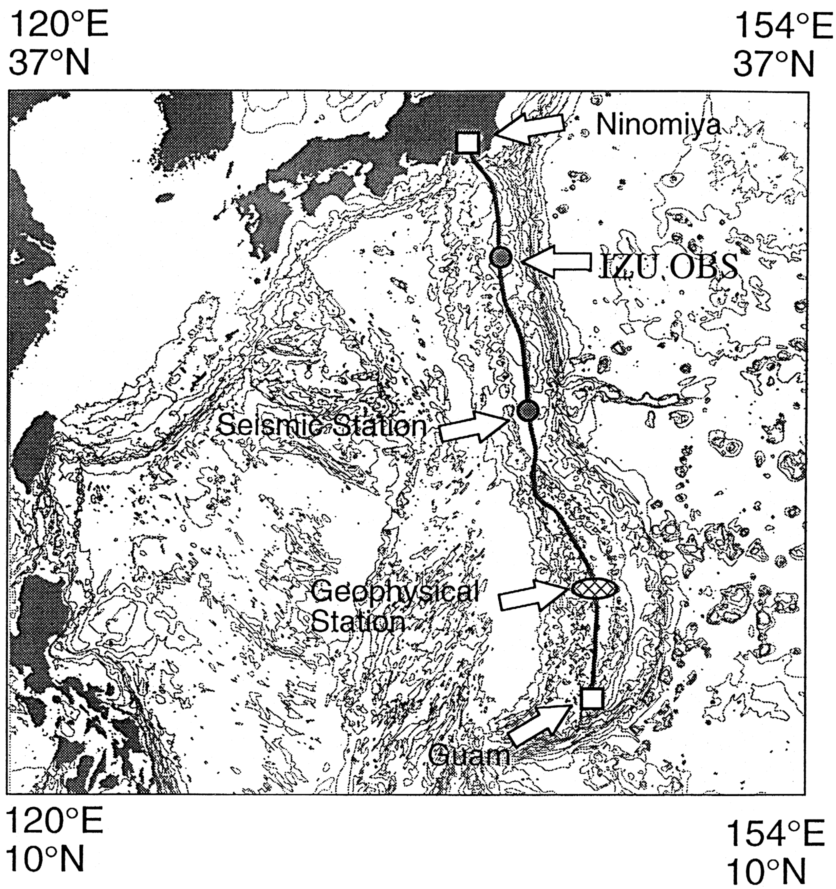

Fig. 1. Location of IZU OBS and two other planned locations.

logical expertise in the telecommunication world. In addition to its high reliability, the most significant advantages of a submarine cable system are real-time data telemetry and available electric power for the equipment through the cable. In contrast to these advantages, the high construction cost is a drawback of a submarine cable system, especially for observations at long distances from the shore. Multi-national submarine telecommunication cables often pass through important seismological regions. If we can use these submarine cables, it would reduce the construction costs of a real-time seismic station in the ocean. Due to technological progress in optical fibers, submarine optical fiber cables have replaced coaxial submarine cables. Optical fiber can bring order of magnitude more telephone channels than coaxial cable. In 1989, the first optical fiber submarine cable between Japan and US, called TPC-3 (Trans Pacific Cable-3), was deployed by international telephone companies. TPC-3 connects Japan, Guam, Hawaii and the US west-coast, and replaced the TPC-1 (Trans Pacific Cable-1) and HAW-2 (Hawaii 2) submarine cables, which were the first Japan–US submarine telecommunication cables. With the installation of TPC-3, the TPC-1 and HAW-2, coaxial cable systems were retired from commercial use in 1990.

The idea of using a global submarine cable network for global seismic observations was first proposed by Dr. S. Nagumo around 1980. Mr. K. Kobayashi, who was Vice-president of KDD, proposed the idea to ERI of using TPC-1 for scientific purposes before installation of the TPC-3 system. The importance of reusing retired cables has been discussed by many authors (Nagumo and Walker, 1989; Kasahara, 1990; Walker, 1991; IRIS Steering Committee for scientific use of submarine cables, 1992; Kasahara et al., 1995a). The TPC-1 Ninomiya–Guam section connects Ninomiya near Tokyo and Guam along the Izu-Bonin Trench and the Mariana Trough (Fig. 1). TPC-1 also connected from Guam and Hawaii through Wake island and Midway island in the Pacific Ocean. TPC-1 follows a route not only good for global seismology, but is also extremely useful for the geophysical studies of the Izu-Bonin subduction zone and the Mariana backarc rift zone. ERI, the University of Tokyo, and the IRIS Consortium in the United Sates, jointly obtained the TPC-1 Guam–Ninomiya section in 1990, following its donation by KDD and AT&T.

Compared to the total capacity of commercial telecommunication lines, seismic data need only a small portion of their total capacity. The frequency band-width of TPC-1 is more than enough for seismic measurements, and by using a retired cable, the construction cost of seismic stations in the ocean can be sharply reduced. There were two choices for data retrieval: to telemeter the data to either Ninomiya or Guam. It was decided to supply a positive DC voltage to the OBS and cable systems from Guam station and to get data at the Ninomiya station.

2. Description of GeO-TOC (Guam–Ninomiya section of the former TPC-1) and its geophysical significance

2.1. Specification of the former TPC-1 Guam–Ninomiya section (KDD, 1964; U.S. Department of Commerce, 1991)

In order to understand the engineering works for the submarine cable OBS, it is necessary to briefly describe the structure of the cable system. The TPC-1 (Trans Pacific Cable-1) submarine cable was constructed in 1964 by AT&T, KDD, and other international telecommunication companies, as a part of the first submarine telecommunication cable between Japan and USA. This cable connected Makaha, Oahu, in Hawaii, USA and Ninomiya, Japan through Guam, Wake and Midway islands. It was connected to the HAW-2 (Hawaii 2) submarine cable at Makaha and enabled direct tele-communication between Japan and the USA. The length of the Makaha–Guam and Guam–Ninomiya cables are 7128 km and 2659 km, respectively. The GeO-TOC (Geophysical and Oceanographysical-Trans Ocean Cable) program uses only the Guam–Ninomiya section of TPC-1. In Section 2.2, the authors only discuss the Guam–Ninomiya section of TPC-1.

The TPC-1 submarine telecommunication cable system used 1 in. (25.4 mm) diameter coaxial cables, 74 repeaters and seven equalizers. An equalizer was installed at every 10 repeaters. The distance between two adjacent repeaters is approximately 37.08 km (20 NM). The repeaters use vacuum tubes because of the necessity for the highest level of reliability in 1964, even though transistors were easy to use at that time. The equalizers are composed of passive electronic devices. Each repeater has dual circuits for redundancy. The pressure cases of a repeater and an equalizer were made of Beryllium–Copper. The coaxial cable is the ‘SD type’ developed by AT&T. The SD coaxial cable has a steel wire at the center surrounded by a copper tube (1-mm thick) as the main conductor with an 8-mm diameter. The main conductor is covered by a thick polyethylene insulator and a thin (0.3-mm thick) copper tape as the outer conductor with a 25.4-mm (1 in.) outer diameter. The outer conductor is covered with a 2.54-mm (0.1 in.) thick polyethylene jacket. Near shore and at great depths, double or single armoured cable was used. Due to the shortage of SD cable storage, ‘SF type’ cables with 1.5-in. cable were used for splicing cables during installation of the IZU OBS.

The voltage drop at each repeater is approximately 43 V. The voltage drop for the coaxial cable between Guam–Ninomiya is approximately 902 V in total. Before installation of the IZU OBS unit, +4080 V DC had been supplied to the cable from Guam and the DC section of the Ninomiya cable connected to the sea earth. The high-frequency components from the landing cable at Ninomiya are fed to the ‘Directional Filter’ and the ‘High-Frequency Line’ equipment. The supply voltage was changed due to some cable repairs since 1964, but the supply current has been kept constant at 370 mA. Because the maximum voltage to the cable system was designed to be 6000 V, the maximum power allowance is 1920 V × 370 mA = 710 W. Because the IZU OBS system needs only 33 W, 710 W is more than enough for one OBS system. The frequency band-width of the TPC-1 is 1 MHz. The frequency band between 108 kHz and 504 kHz is called low-band and is used for the communication from Guam to Ninomiya. The frequency band between 660 kHz and 1052 kHz is called high-band and is used for communication from Ninomiya to Guam. The frequency band between 1080 kHz and 1092.5 kHz is called ‘crystal gain’ to check the status of the electronics in each repeater. The attenuation is 1.31 dB/km at 1 MHz and equals 50 dB between two adjacent repeaters (20 NM distance). An amplifier in a repeater compensates for this cable gain–loss. The total quantity of amplification between Guam and Ninomiya equals 3000 dB. An equalizer compensates for the frequency misalignment over a distance of 370.8 km (200 NM). TPC-1 had been used for 138 channels of telephone lines with a 3-kHz band-width for each phone in both directions, although most of present telephone lines use the 4-kHz band-width. In the GeO-TOC program, the 4-kHz band-width is used instead of the original 3-kHz band-width. According to AT&T and KDD engineers (personal communication), the target life of the total TPC-1 system is more than 25 years. After 25 years, system reliability would decrease to half of its initial reliability, but it still seems to maintain a high enough level for scientific purposes. The retirement of TPC-1 in 1989 was mainly due to the appearance of a high-capacity, new fiber-optic cable. The life of a submarine cable is expected to be more than 30 years as shown from cables retrieved during actual deployment in 1997, as mentioned below.

2.2. Geophysical significance

The TPC-1 cable leaves Ninomiya shore station and passes through the Sagami Bay south of Tokyo. The cable runs along the landward slope of the Izu-Bonin Trench and enters the Marian Trough. At 18°N, the cable approaches the hydrothermal area in the Mariana Trough rift zone. Finally, the cable lands on the western shore of Guam. Hereafter, we call the TPC-1 Guam–Ninomiya section GeO-TOC cable.

As described in Section 1, the IZU OBS can give additional data to the present global seismic network for study of seismic structure of subduction zone along the Izu-Bonin Trench and the structure of Philippine Sea plate. The Wadati-Benioff zone along the Izu-Bonin Trench shows deep earthquake occurrence down to 600 km. The Izu-Bonin arc system shows different morphological shape of the Wadati-Benioff zone from one for the NE Japan (Honshu) arc system (e.g., Kasahara and Tanaka, 1986). Although the Japan Trench is one of the best seismologically studied areas in the world, the Izu-Bonin Trench, which is also close to Honshu, Japan, has been less seismologically studied because of lack of good islands to install an array of land seismic stations. An addition of the IZU OBS to the present land seismic network of Japanese Universities can provide improvement on detectability and precision for source parameters of small earthquakes. In addition to the above, seismic waves travelling along the subduction zone will give good quality data for a high Q zone study.

West of the GeO-TOC cable, there are distinctive volcanoes, at Myojin-Sho reef (31°57′N, 139°58.5′E) and Sumisu island (31°30′N and 140°02′E). Myojin-Sho frequently erupts nearly every year. Myojin-Sho island has repeatedly emerged and submerged due to submarine volcanic activity. Among the many large submarine eruptions, the eruption in 1952 is distinct (Ossaka, 1991). Following the eruption in 1952, an island 100 m width × 150 m length and 30 m high appeared. During eruptions, one survey vessel of the Maritime Safety Agency, Japan, was lost, possibly due to the submarine eruption of Myojin-Sho. Thirty-one lives including some scientists were lost in this accident. Sumisu island has also showed volcanic activity. On the landward slope of the Izu-Bonin Trench at 30°55′N, 141°52′E, there is a serpentine diapir (Torishima Forearc Seamount). The serpentine diapir seems to have been produced by hydration of peridotite and upwelling of weathered light materials due to their buoyancy.

The OBS location (31°23.445′N, 140°54.81′E, 2750 m deep, see Fig. 1) was decided due to the geophysical significance and the distance limitations of a cable ship and depth limitations of the OBS pressure case. The site is approximately 80 km from Sumisu island and 100 km from Myojin-Sho.

3. Engineering problems when reusing retired submarine telecommunication cables

Because deployment of OBS seems to be similar to repair work on a submarine cable, existing technology can be used (Suzuki, 1990). There are some engineering problems involved in using a submarine cable for scientific purposes. One problem was the slow power-on-rate to the cable due to the characteristics of the repeaters. This was solved by designing a special power unit in the IZI OBS. Another problem is the splice itself.

Usually, some extra cables are inserted at the point of repair. The splicing on the main cable is called ‘M–M (Main–Main)’ splicing. M–M splicing is a very delicate work and requires special skills. When the inserted cable is long, the gain loss from the inserted cable will either lie within the allowance of repeater gain or need to be compensated for. The IZU OBS has no circuits for gain–loss compensation and just adds the seismic signals to the high frequency line. Considering this factor, the cable loss should be minimal. Twice the water depth, or approximately 6 km of cable, can be within the allowance for gain–loss.

Due to the shortage of ‘SD’ cable storage, which is the same for TPC-1, the ‘SF’ cable developed by AT&T has to be used for the inserting cables during installation. The length of ‘SF’ cable would be approximately twice the water depth of the deployment point. Insertion of ‘SF’ cables into ‘SD’ cables requires splicing two cables with different diameters, for example, 1-in. cable and 1.5-in. cable. The electrical characteristics satisfy this splicing. The problem of mechanical strength was solved using a special splicing tool developed by KCS.

4. Specification of IZU OBS

The outside appearance of the pressure case of the IZU OBS resembles a submarine cable repeater (Fig. 2). Using the repeater shape for the OBS pressure case, all of the equipment on the cable ship can be used without any modifications. However, this may lose some properties of the seismic response of the OBS system. The OBS pressure case made by stainless-steel is 325 mm in outside diameter and 1350 mm in length without couplers, as shown in Fig. 2. The total length of OBS including cable couplers on both ends is 3620 mm. The coupler has a 30-m leading cable on each side and is designed to connect to the 1-in. coaxial main cable and the coaxial cable from the pressure case, and to be able to flex when the OBS unit turns on a cable engine (3.3 m in diameter) on the cable shipboard (Fig. 2). The pressure case is made of stainless-steel. To avoid corrosion of the pressure case, it was wrapped with a 2-mm thick heat-shrunk poly-ethylene tube. The maximum water depth of the pressure case is 3000 m. A quartz pressure/temperature sensor and a hydrophone are attached on the outside of each endcap.

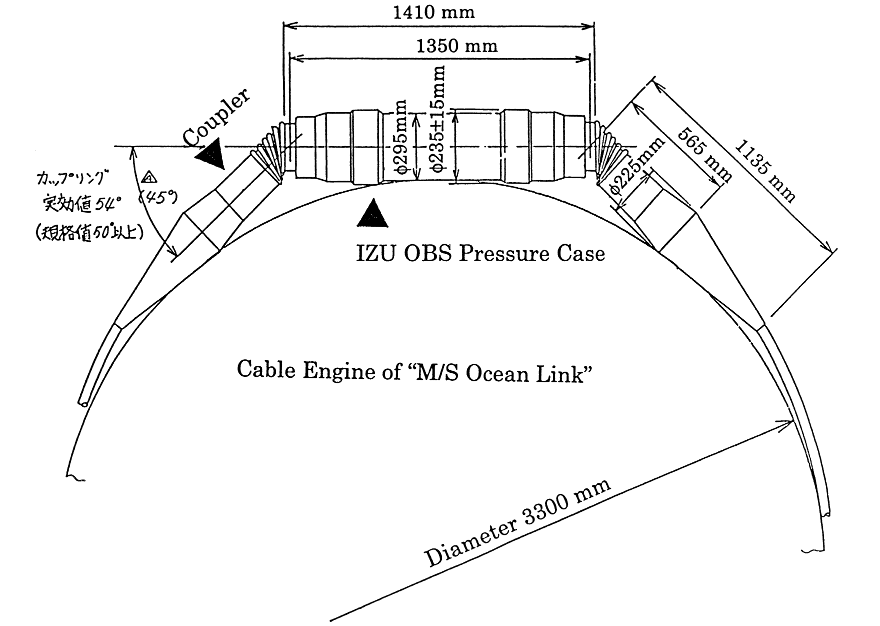

Fig. 2. Pressure case of IZU OBS with a coupler at each end on ship cable engine.

The electrical block diagram is shown in Fig. 3. The electronics, hydrophone and outside appearance with couples are shown in Fig. 4. The high-frequency carrier and signals are superposed on a high voltage in the center conductor of the coaxial main cable. The PSF (Power Separation Filter) splits the DC and the high-frequency carriers. Although the voltage at the IZU OBS is approximately +900 V DC, the

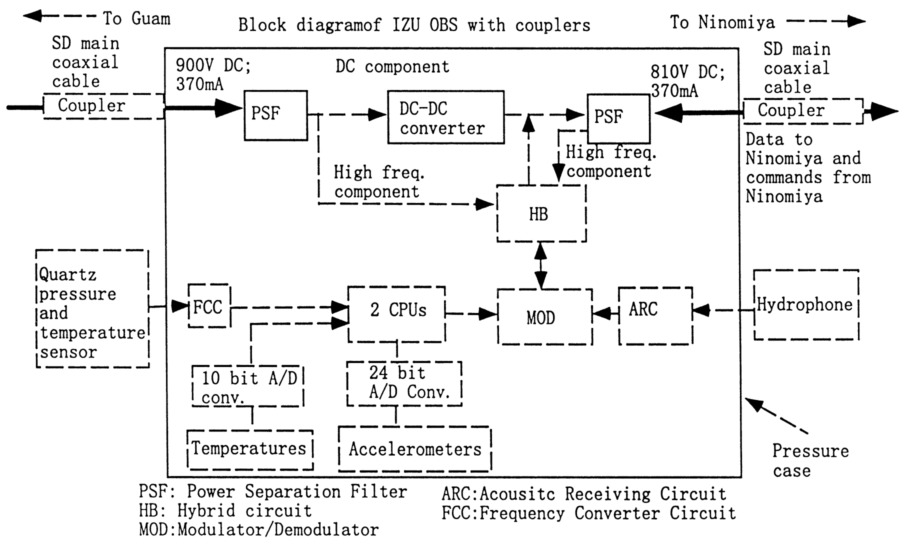

Fig. 3. Block diagram of electronics of IZU OBS.

Table 1
Specification of IZU OBS

Sensor type		Model	Comp.	Freq.	Freq. sensitivity	A/D	Sampling (Hz)	Cent. f (kHz)	Max. bps	Gain (dB)	Min. resol.
Seismometer	Accelerometer										
		JA-5V-IIIA	*X*	DC-60 Hz	4 V/G	24 bits	62.5/125	422	9600	0 or 50	10–0.2 μG
		JA-5V-IIIA	*Y*	DC-60 Hz	4 V/G	24 bits	62.5/125	426	9600	0 or 50	10–0.2 μG
		JA-5V-IIIA	*Z*	DC-60 Hz	4 V/G	24 bits	62.5/125	430	9600	0 or 50	10–0.2 μG
Hydrophone	Pressure	ITC-1010		DC-1 kHz	(−)190 dB			400	AM1kHz	0–30	
Pressure	Quartz sensor	PaloScience 8B7000-15	P				0.1	418	9600		10 cm water
Temperature	Quartz sensor	PaloScience 8B7000-15	T				0.1	418	9600		0.001°C
	solid device	AD592	A/D-*X*		100 mV/°C	10 bits	0.1	418	9600		0.01°C
	solid device	AD592	A/D-*Y*		100 mV/°C	10 bits	0.1	418	9600		0.01°C
	solid device	AD592	A/D-*Z*		100 mV/°C	10 bits	0.1	418	9600		0.01°C
	solid device	AD592	board		100 mV/°C	10 bits	0.1	418	9600		0.01°C
	internal	JA-5V-IIIA	Acc. *X*		10 mV/°C	10 bits	0.1	418	9600		0.01°C
	internal	JA-5V-IIIA	Acc. *Y*		10 mV/°C	10 bits	0.1	418	9600		0.01°C
	internal	JA-5V-IIIA	Acc. *Z*		10 mV/°C	10 bits	0.1	418	9600		0.01°C
CPU Reset								698	300		
Commands								694	300		

system is designed for +4500 V DC. The 90 V DC voltage drop with a 370 mA constant current was used to obtain the system DC power supply. The system is composed of sensors, A/D converters (24 bits and 10 bits), two CPUs and RS-232C transmitters–receivers, modulators, PSFs, and a DC power supply.

The specifications of sensors, frequency bands, and data-transmission rate are summarized in Table 1. Three component accelerometers (JA-5 V-III-A, JAE) were used as seismometers. The sensitivity of accelerometers is 4 V/G for all components. The resolution of this accelerometer was found to be approximately 100 nG over the frequency range of 0.05–100 Hz (Katao et al., 1990). The resolution of the seismometer is worse than broadband seismometers such as STS-2 and Guralp CMG-3T, which are not durable enough to resist shocks during installa-

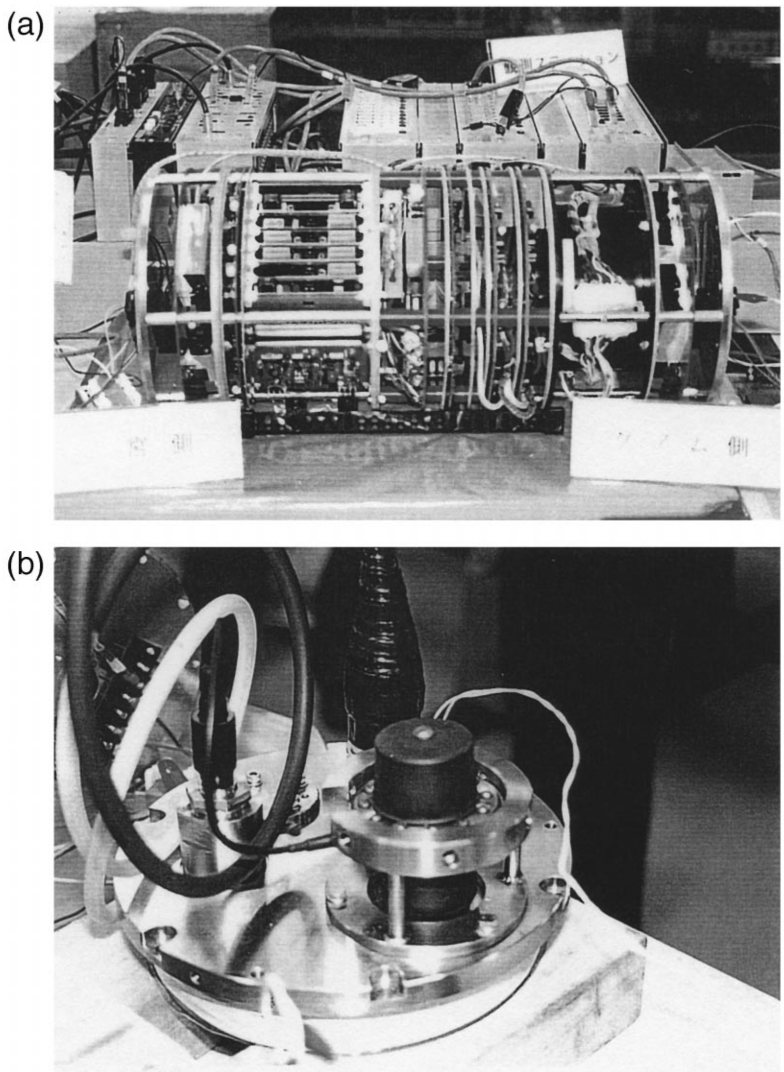

Fig. 4. Photographs of (a) electronics, (b) hydrophone at pressure case end cap, (c) exterior view of pressure case with couplers and (d) exterior view of IZU OBS. The pressure case is wrapped in a heat-shrunk poly-ethylene tube.

tion work. There are two options for accelerometer amplifications; namely, one and 50 times. The frequency characteristics are flat for DC to 50 Hz. Accelerometers are mounted in dual-axes gimbals. The DC offset of the X-axis (perpendicular to the cable elongation) and the Y-axis (parallel to the cable elongation) due to the Earth's gravity are cancelled manually by gimbals controlled from land. The DC offset of the Z-axis is at maximum when DC components on the X-axis and the Y-axis are at minimum. The DC offset on the Z-axis is cancelled by subtraction of DC voltage from the sensor output. Due to this offset subtraction, the final digitizing resolution of the Z component is one or two bits worse than those for the X and the Y components.

The ITC-1010 model is used for the hydrophone; model 8B7000-15 (Palo Science) is used for the quartz pressure/temperature sensor. Accuracy is approximately 10 cm by water depth and 0.001°C, respectively. The frequency outputs of the quartz sensor are sent directly to the serial port of the CPU. There are other temperature sensors to measure the system. Seven thermometers are used: three for the A/D converters, one for the circuit board (AD592, Analog Device), and three for the accelerometers (internal). These outputs are digitized by 10 bit A/D converters. The accuracy of temperature measurements is 0.1°C.

The outputs of amplifiers for accelerometers with anti-alias filters are digitized by three sets of independent Δ-Σ-24-bit-A/D converter and digital-filter (CS5322/5323, Crystal Semiconductor). The final resolution of digital data is approximately 20 bits for the X and Y components and 18–19 bits for the Z

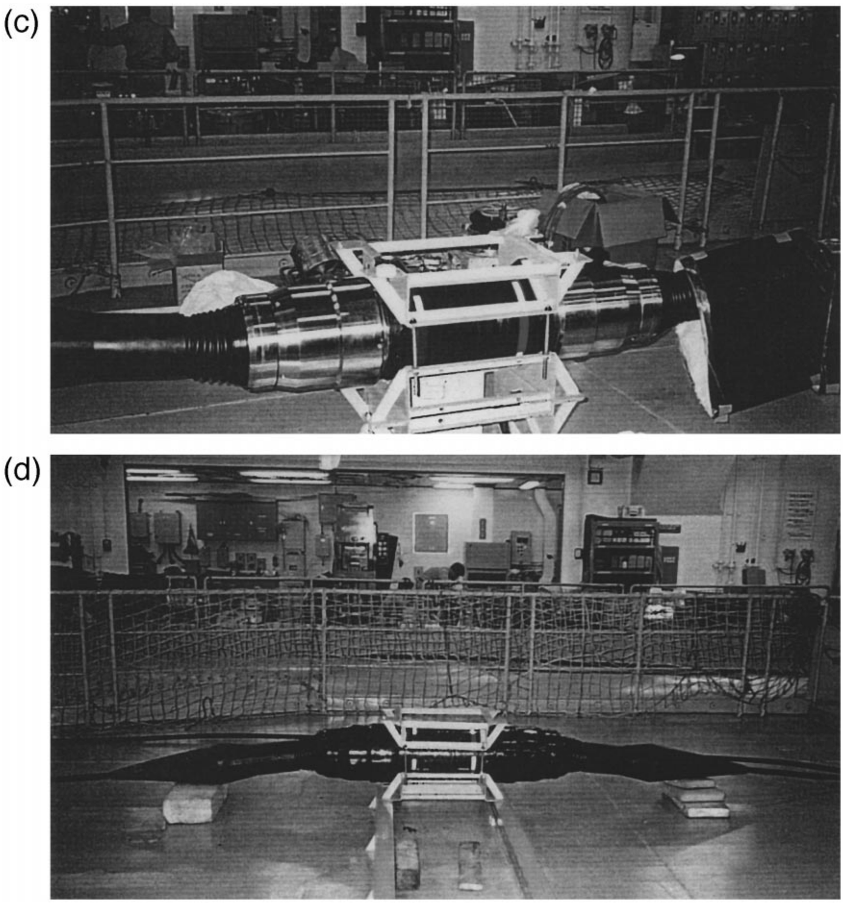

Fig. 4 (continued).

component. This is due to jitters in the sampling clock, DC–DC power supply noise (60 kHz), CPU clock noise, and fluctuations of the reference voltage to the A/D converter. The sampling rate for accelerometers can be chosen from 62.5 Hz or 125 Hz. This can be controlled by a land computer. Two 16 bit CPUs (H8 series, HD6475348CG, Hitachi) are used to increase reliability. One CPU takes care of *X* and *Y* component data and the second CPU handles *Z* and other slow-rate data such as pressure and temperature. The second CPU also controls gain setting of amplifiers, level setting of modems and rotation of gimbals. There are two telemetry methods: multiplexing for time using the entire frequency band and frequency division multiplexing. The first method seems to be more advanced, but the latter has advantages in terms of ease of design of IZU internal modems and the use of receiving–transmission equipment at the shore station. In the IZU OBS, data telemetry is FDM (Frequency Division Multiplexing). Each unit of data is transmitted at a center carrier frequency with a 4-kHz band-width in the low-band. The command signals are sent in the high-band. The digital data from one accelerometer are sent to the Ninomiya station at a data rate of 2400–9600 bps using 4-kHz band-width. Temperature and pressure data are sampled every 10 s, time-multiplexed and sent to Ninomiya at 2400–9600 bps. The data transmission rate can be changed depending on variations of noise level on the line. The hydrophone output is transmitted to Ninomiya in analog form using the AM mode for reliability. Even if the digital system malfunctions, we can still obtain hydrophone data. The amplifier has flat frequency characteristics over DC to 400 Hz. However, the gain change of the hydrophone amplifier is achieved digitally.

All signals are fed to modulators, which have several carrier bands with 4-kHz band-widths in the low-band of the cable. The control signals from the land computer use the high-band and are demodulated in the OBS. The CPUs can be reset by a land computer. The frequency range of 416–432 kHz is used for digitized output data and 399–403 kHz for hydrophone analog data. The command signal and the CPU reset signal from shore are sent at 692–696 kHz and 696–700 kHz, respectively. The total power dissipation in the OBS is 90 V at 370 mA. The DC–DC power supply in the OBS system is specially designed for a slow increase of supply voltage. The power-on-rate of the GeO-TOC is slow, roughly 15 min, and the usual switching regulator cannot be operated correctly at such a slow power-on-rate.

5. Shore station equipment

The Guam shore station is located in the AT&T cable station. The equipment on Guam is composed of a DC power supply, utilizing the original TPC-1 power supply. This can supply DC voltage up to 6000 V with a constant current of 370 mA. The supply current is monitored in Guam and Ninomiya by a digital multi-meter.

Fig. 5 shows the shore station unit at Ninomiya. The coaxial cable connects to the receiving–transmission (R–T) equipment in the Ninomiya station. Similar equipment to the TPC-1 R–T unit is used except the SG–G–CH equipment defined below. This is a typical R–T unit in coaxial cable receiving–transmission equipment used by telephone companies. All back-panels of the equipment were rewired. The R–T unit is composed of PSF (Power Separation Filter), DF (Directional Filter), HFL (High-Frequency Line) and SG (Super Group), G (Group), CH (Channels), and DM (Demodulator) or Modulator. A SG–G–CH equipment used by domestic telephone system is utilized by GeO-TOC Ninomiya instead of the original TPC-1 SG–C–CH equipment. The PSF outputs a DC component and a high-frequency component. The DC component is connected to the sea-ground as described above. The high-frequency component comes to the DF and the DF outputs a high-band component and a low-band component. The HFL compensates for frequency misalignments over all bands. The SG–G–CH outputs the necessary 4-kHz channels. The CH outputs are transmitted to modems and receiving land computers.

6. Field-work of OBS deployment

Before installation of IZU at sea, three land tests were carried out: a noise test at land seismic observatory, a telemetry test from Guam to Ninomiya using

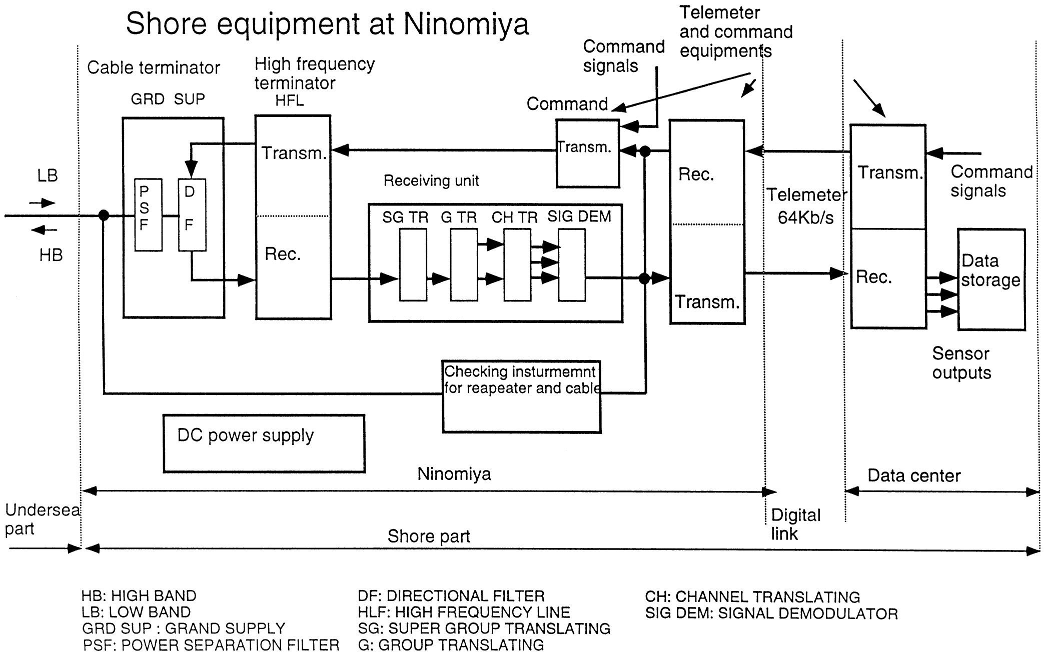

Fig. 5. Block diagram of Ninomiya receiving and transmitting equipment.

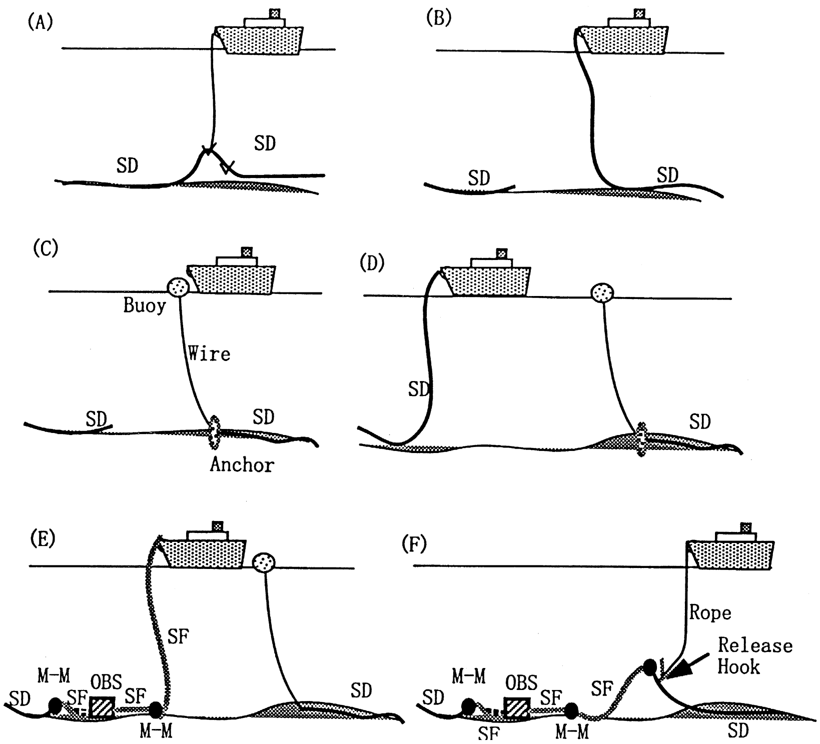

Fig. 6. Scheme for installation work for IZU OBS as described in the text.

the GeO-TOC cable, and a power unit test of IZU OBS at Ninomiya using the GeO-TOC cable power on–off. All tests were satisfactory.

The OBS IZU was installed from January 6 to 13, 1997, using the cable ship 'Ocean Link' owned by KCS. The target location of the IZU OBS was located between R14 and R15 repeaters. The fieldwork was very complicated and was composed of 11 major stages (Fig. 6): (1) splicing extra 'SF' cables and 'SD' cable at each end of the OBS couplers. The extra 'SF' cable of the Ninomiya-side was approximately 2.797 km and that of the Guam-side was 15 km at maximum. The length of the Guam side extra 'SF' cable was adjusted by the final splicing before the last deployment. (2) Hooking the main cable and cutting the main cable at the ocean bottom (Fig. 6A); (3) retrieving the Guam-end of the cut-main cable to the ship (Fig. 6B); (4) putting wires at the Guam-end of the cut-main cable and deploying the main cable, wires, and buoy in the sea (Fig. 6C); (5) retrieving

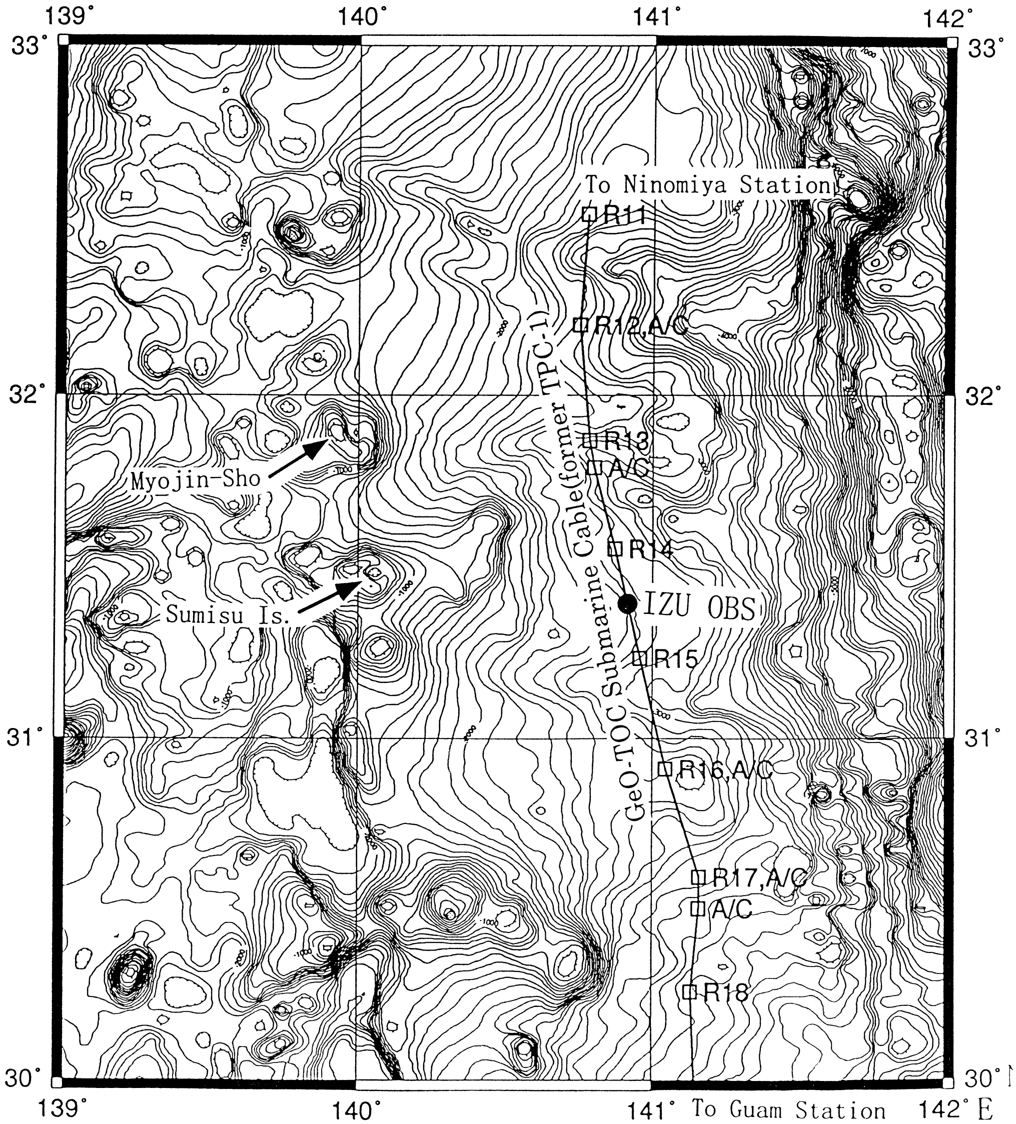

Fig. 7. Map of IZU OBS with water depths.

the Ninomiya-end of the cut-main cable to the ship (Fig. 6D); (6) splicing the ‘SD’ cable of the Ninomiya-side of the cut-main cable and the extra ‘SF’ cables (2.797 km) attached to the OBS; (7) supplying power to the OBS unit through the cable from the Guam-end attached to the OBS unit, and testing the OBS functions at Ninomiya; (8) gradual deployment of the cables in the sea, from the main Ninomiya-end, extra ‘SF’ cables connected to the OBS unit, the OBS unit itself, and the extra Guam-side ‘SF’ cables connected to the OBS unit in the water (Fig. 6E). (9) Retrieving buoy, wires, and Guam-end of the cut-main cable; (10) splicing the Guam-side ‘SF’ cable connected to the OBS, and the Guam side ‘SD’ cable-end of the cut-main cable. The length of the extra ‘SF’ cable was adjusted to the necessary length before final deployment. (11) Deploying the last part of the cable (Fig. 6F).

A detailed map near IZU station is shown in Fig. 7. The final length between repeater R14 and R15 is 41.254 km (22.275 NM) (Fig. 7), which corresponds to the 3.425 km insertion of extra cables. The distance between R14 (Ninomiya side repeater) and IZU is 18.113 km and that between R15 and IZU is 23.140 km. This is within the allowance of repeater gain–loss compensation. With the IZU installation, the 10.274-km long ‘SD’ cable was replaced by a 13.695-km long ‘SF’ cable. Due to the several failures on retrieval of cable cut end from the bottom, three M–M splicing were done during the installation.

There were some key points during installation. The most essential point is splicing the two cable, especially splicing two cables with different specifications. This delicate work was done by engineers on board the cable ship.

Some difficulties were found when retrieving the cut-end of the main cable from the bottom. After several attempts to hook the cable with jamming grapnel anchors, the Guam side was retried on the ship. It was found that the bottom was covered by pumice from Myojin-Sho and Sumisu submarine volcanoes and the pumice prevented the cable from being grabbed by the jamming grapnel anchors. The retrieved cables have the appearance of new cables and no damage was found to the retrieval cable except where hooked. This further substantiates the long life for submerged coaxial cable. The polyethylene insulator of the coaxial cable is only damaged by ultra-violet light from the sun. In deep ocean, coaxial cable seems to maintain its original electrical and mechanical specifications. The examination of insulation of the cable for the Guam direction and the Ninomiya direction showed an extremely high resistance of 100 TΩ.

The other major problem was noise on the cable generated by the DC power supply. When DC power of 910 V and 365 mA was supplied to the cable, the noise generated by the DC power supply was too large to reset the OBS unit. This was solved by a low-pass filer attached to the DC power supply.

The position of IZU OBS at deployment was 31° 24.62′N, 140° 54.33′E, 2708-m deep. The precise location can be obtained when we shoot the OBS with airguns. The final power supply to the GeO-TOC system is +4170 V with 370 mA (373.4 mA at Ninomiya) constant current from the Guam station. All of the installation work took 7 days including one and a half days for the round trip between Yokohama and the IZU location. After deployment of the whole unit at sea, the instrument was verified to operate correctly on January 14, 1997.

7. Results and conclusions

The first submarine cable OBS ‘IZU’ using a retired submarine telecommunication cable, the former TPC-1, which spans 2659 km between Guam and Ninomiya, Japan, was designed and installed on the landward slope of the Izu-Bonin Trench in January 1997. The IZU OBS is equipped with three axis accelerometers, a quartz thermometer, a quartz pressure sensor, a hydrophone and additional temperature sensors to monitor the temperature of circuits. Most data other than hydrophone data are digitized and sent to Ninomiya by the FDM method. The hydrophone data, however, are sent to shore by analog AM. The instrument is designed to be controlled from a shore computer in Ninomiya or in Tokyo.

The installation work was similar to cable repair work with some modifications. The submarine cable was cut between two repeaters and the IZU OBS was installed with a spare ‘SF’ coaxial cable, which replaced part of the ‘SD’ coaxial cable. The increased length between repeaters R14 and R15 was 3.425 km. This is within the allowance for gain loss compensation of the repeater. The +4170 V DC is supplied from the Guam station. The voltage increase was 90 V with a 370 mA constant current.

The IZU OBS was installed at approximately 31°24.62′N, 140°54.33′E, 2708-m deep. The precise location can be obtained when we shoot the OBS with airguns. The final power supply to the GeO-TOC system is +4170 V with 370 mA (373.4 mA at Ninomiya) constant current from the Guam station.

The IZU OBS has been working correctly. The ground noise level was approximately 2 μG (> 10 Hz noise), but large low-frequency (approximately several seconds periods and 10–15 μG amplitude) noises are recognized on all three channels (Fig. 8, top). The amplitude of high-frequency noise is approximately at the same level as one in the test at Aburatsubo Geodetic Observatory (Katao et al., 1990), but the low-frequency component is large. This tendency is the same as one obtained by pop-up OBS's (Kasahara et al., 1997). Fig. 8 (bottom) shows an example of an earthquake, which has 7.5-s S-P times. The pressure sensor showed 281.71 kg/mm^2. Using a water density of 1.03, the depth corresponds to 2735 m. The water temperature was approximately 3.5°C and the internal temperature was 12°C.

The installation of the IZU OBS is the world's first attempt to use a retired submarine communication cable for scientific use, and it proved that the technology to reuse retired cables is complete and it is very useful for any submarine scientific research.

Two similar programs to the GeO-TOC projects are ongoing: VENUS (Versatile Eco-monitoring Network by Undersea-cable System) project in Japan and H2O (Hawaii-2 Observatory) project in the U.S.A. The former project (Kasahara and Sato, 1997; Momma et al., 1997; Shirasaki et al., 1997) will use the TPC-2 submarine cable and install many sensors including broadband seismometers. The latter project

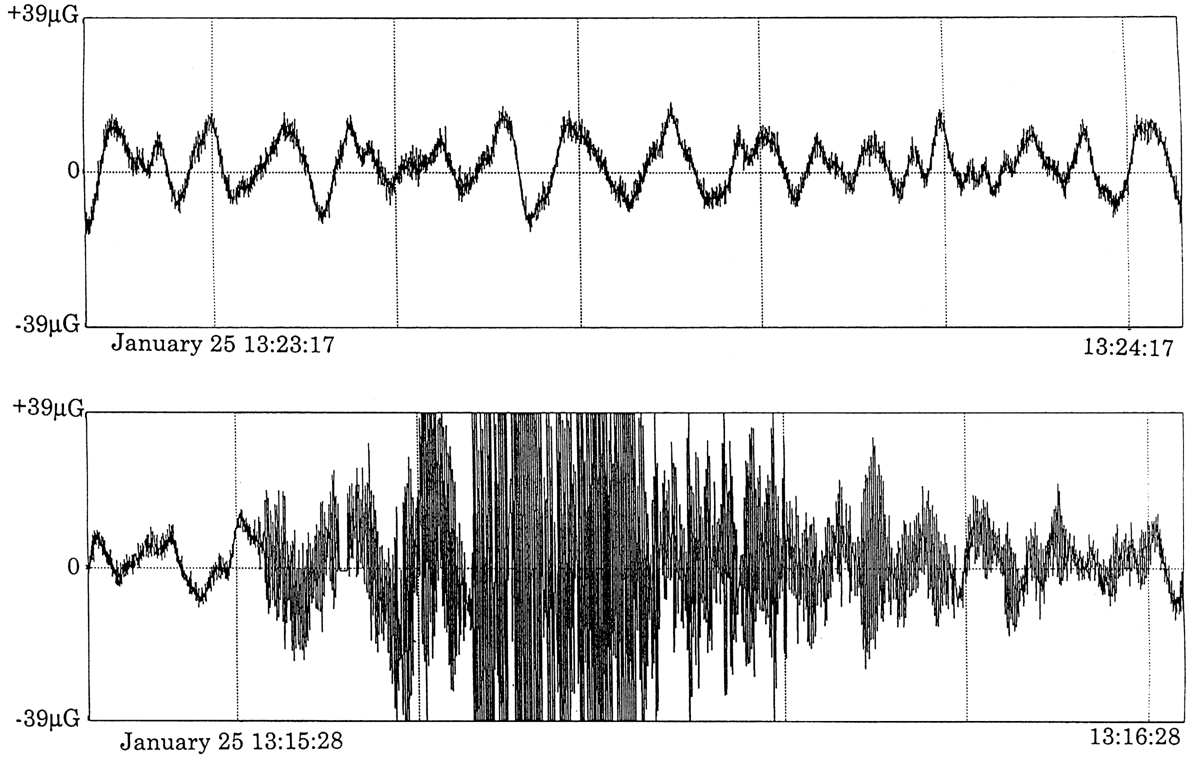

Fig. 8. Examples of *X*-axis (perpendicular to cable) records during 1 min. Vertical scale: ±39 μG. Top: observed ocean bottom noise at 13:16 JST in January 25, 1997. *Y*-axis (parallel to the cable) and *Z*-axis (vertical) components show similar noise (not shown). Bottom: example of an earthquake of January 25, 1997, on *X*-axis during 1 min. Data are recorded full-scale, but are shown clipped on this figure to show detail.

will use HAW-2 submarine cables and install seismometers and magnetic sensors (Chave et al., 1997). The success of GeO-TOC might give excellent guidance for the further work using retired cables.

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