Installation of Borehole Geophysical Observatories in the Western Pacific by Ocean Hemisphere Project

Masanao SHINOHARA
mshino@eri.u-tokyo.ac.jp
Earthquake Research Institute, University of Tokyo, Japan

Eiichiro ARAKI
araki@jamstec.go.jp
Japan Marine Science & Technology Center, Japan

Toshihiko KANAZAWA
kanzawa@eri.u-tokyo.ac.jp
Earthquake Research Institute, University of Tokyo, Japan

Kiyoshi SUYEHIRO, Hitoshi MIKADA
suyehiro@jamstec.go.jp, mikada@jamstec.go.jp
Japan Marine Science & Technology Center, Japan

Selwyn SACKS, Alan T. LINDE
sacks@dtm.ciw.edu, linde@dtm.ciw.edu
Carnegie Institution of Washington, United States

Masashi MOCHIZUKI
mm@eri.u-tokyo.ac.jp
Earthquake Research Institute, University of Tokyo, Japan

Kenji HIRATA, Yuka KAIHO
hiratak@jamstec.go.jp, kaihoy@jamstec.go.jp
Japan Marine Science & Technology Center, Japan

Abstract. Ocean Hemisphere Project (OHP) planned to install four ocean floor borehole geophysical observatories in three areas of the western Pacific. The main objective of installation of borehole stations is to obtain high quality data for a high-resolution image beneath the western Pacific. Two borehole geophysical observatories (JT-1 and JT-2) on the landward slope of the Japan Trench were successfully installed in July and August, 1999. In addition, installation of a seismic observatory (WP-2) in the northwestern Pacific Basin was completed in August, 2000. From the preliminary data of JT-1 and WP-2, we found that boreholes at the sea floor provide quiet environments for seismic observation. For completion of the network construction, installation of a seismic station in the Philippine Basin is scheduled in April, 2001 during ODP Leg 195.

1. Introduction

Tomographic studies using earthquake waves propagating through the Earth's interior have revolutionized our understanding of mantle structure and dynamics. A great limitation on existing tomographic images of the Earth's interior is the uneven distribution of seismic stations, especially lack of stations in large expanses of ocean such as the Pacific. The scientific importance of establishing long-term geophysical stations at deep ocean sites has been

acknowledged by the earth science communities and is detailed in various reports. The objective is to understand the processes driving Earth's dynamical system from a regional to global scale by imaging the Earth's interior with seismic waves. Unfortunately, few seismometers are located on the 71% of the Earth's surface covered by oceans. The asymmetry and non-uniformity of the seismic station distribution makes high-resolution imaging of some parts of the mantle nearly impossible. Many ocean bottom geophysical sensors, whose locations have been carefully selected to optimize imaging, are needed around the world to attain the goals of the international geoscience programs. Ocean Hemisphere Network Project (OHP) has selected the western Pacific area for installation of ocean-bottom sensors because it is ideal for addressing problems related to plate subduction. As the results of previous studies about borehole seismometers, it is becoming clearer that emplacement of seismometers into the igneous crust inside a borehole can provide low noise environments. OHP planned to install four borehole geophysical stations at three sareas (Fig.1). At present, three borehole geophysical stations were established and one borehole seismic station is planned for installation in April, 2001.

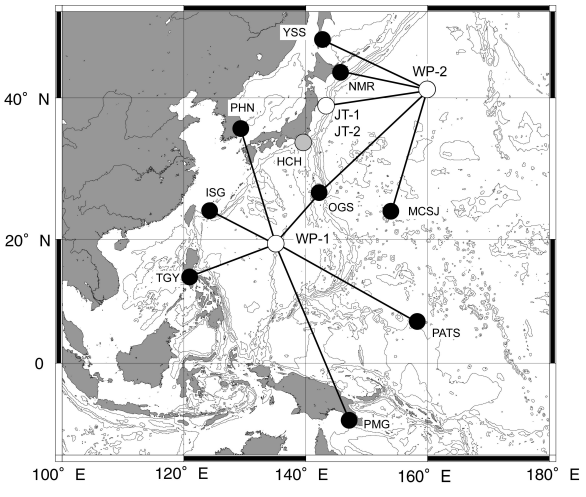

Fig.1. Map of western Pacific area showing borehole geophysical sites. Solid circles indicate land seismic stations, whereas open circles are current and proposed seafloor borehole observatories. A few borehole stations effectively complement and expand the existing network.

2. Site

The sites WP-1 and WP-2 are effectively located to complete a 1000-km span network in the western Pacific area. Two stations (JT-1 and JT-2) are located immediately above the inter-plate earthquake generation zone on the landward side of the Japan Trench.

2.1 Japan Trench (JT-1, JT-2)

The Japan Trench area is where a great deal of efforts has been made for monitoring seismic and geodetic motions on land for many years. To monitor strain and seismic activity continuously to understand how plate motion is accommodated across a subduction zone. Two stations were constructed for monitoring the ongoing tectonic processes as well as to confirm detail previous findings in the deep sea terrace on the landward slope of the Japan Trench (Fig2). In the plate boundary off Sanriku, moderately large seismic events occur frequently and aseismic slips (slow earthquakes) with comparable or larger magnitude are expected to occur even more frequently. It has long been a source of concern that seismic coupling efficiency of the subduction zone off Tohoku appears so low, maybe only 25%. This means that of the total Pacific motion expected to being subducted, only a quarter is seen as stick-slip motion leading to thrust-type earthquakes. One possibility is that the rest of motion is released as slow earthquakes which are not observed on a seismometer. Any data leading to better understanding of the partitioning of strain release into damaging "fast" events and slower events will be extremely valuable and may lend further insight into the whole earthquake process. JT-1 was located above the active portion of the seismogenic zone where large interplate thrust earthquakes recur and JT-2 is positioned above an aseismic portion of the seismogenic zone. JT-1 and JT-2 greatly improve source location, focal mechanism, and rupture process determinations of the earthquakes near the Japan Trench. JT-1 and JT-2 also make a dense seismic network of 50 - 100 km scale with the land broadband seismometers on the Japanese islands. Therefore, this network will provide data to

improve the structural image of the plate boundary.

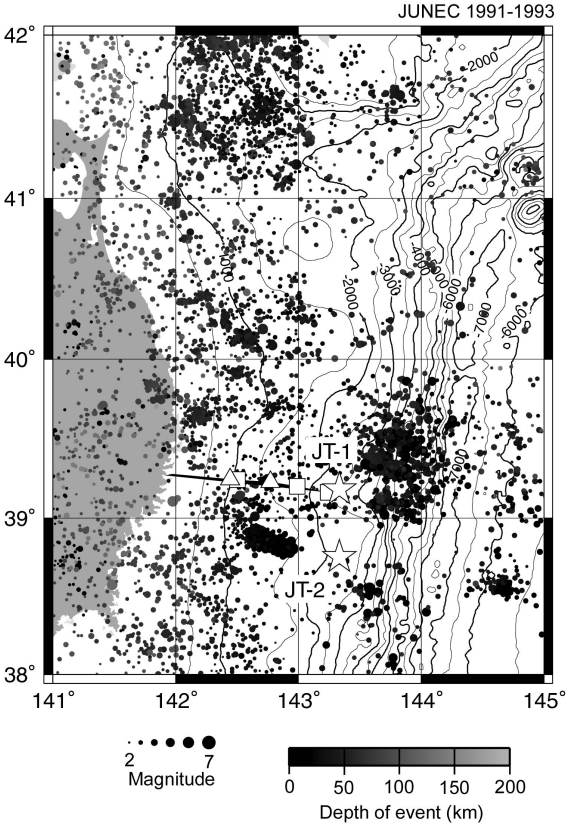

Fig.2. Map of Japan Trench area with seismicity. There is a difference of seismicity between JT-1 and JT-2. The area around JT-2 has low seismicity.

2.2 Northwestern Pacific Basin (WP-2)

The WP-2 station is situated on a normal oceanic Mesozoic crust in the northwestern Pacific Basin. This station is neighbored by Petropavlosk to the north, by many Japanese stations to the west, by Minami-Torihima to the south, and Midway to the east. WP-2 has the scientific importance, since no other land site can replace this site. This site also provides unique seismic observations on the seaward side of the trench. Accumulation of broadband seismic data from within basin part of the Pacific Plate will help us to obtain detailed lithosphere and asthenosphere structure of the Pacific Plate.

2.3 West Philippine Basin (WP-1)

WP-1 site is in the west Philippine Basin west of the Kyushu-Palau Ridge, and is more than about 1000 km away from land stations. A seismic station at the center of the Philippine Sea plate is an essential addition to the surrounding stations and will bring about following crucial information in understanding the global dynamics operating in the western Pacific together with existing land stations. The observations of seismic surface waves as well as various phases of body waves from earthquakes at the Philippine Sea plate margins will provide sufficient data to map differences in plate structures among different basins comprising the plate. Site WP-1 will be a crucial network component in determining whether the Pacific plate is penetrating into the lower mantle in the Marianas Trench but not in the Izu-Ogasawara (Bonin) Trench.

3. System overview

The observatories are designed to last for many years as a stand-alone system. Although four station has small difference, outline of system configuration is identical. For JT-1 and JT-2, the sensors consist of a strainmeter, a tiltmeter, and two broadband seismometers (Fig.3). Two same seismometers (CMG-1T) are used at WP-2. The sensors reside near the bottom of the hole with each housed in a separate pressure vessel. Separated cables connect the sensors uphole. The signals from CMG-1T are digitized in the sensor packages and sent in digital form to the sea floor packages. The signals from other sensors are sent in analog form. The seafloor package called MEG serves to digitize the analog signals and to combine the digital data from the sensors to a single serial data stream. The data are stored in a digital format in a separate module, called SAM, via a RS232C link. The SAM has four 18-Gbyte SCSI hard disks equivalent to more than 6 channels of one year-long continuous data of 24-bit dynamic range at 100 Hz sampling rate. The borehole sensors are permanently cemented in as required for the strainmeter operation and to assure good

coupling for the other sensors. The SAM provides a communication link to the borehole system.

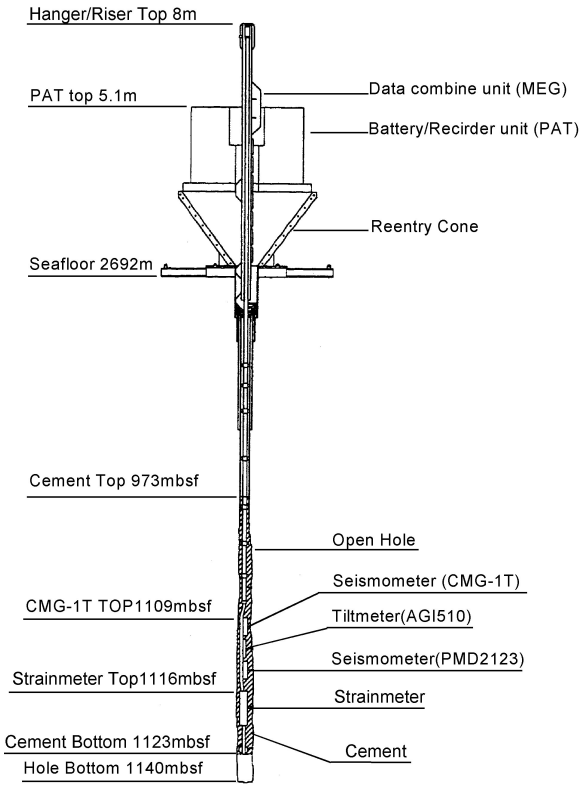

Fig.3. Schematic of equipments used in the borehole installation at JT-1. Other stations have fundamentally the same configuration.

We can make a check of the status of the observatory via a "SAM-ROV interface" or "BOB unit" that enables RS-232C communication between the SAM and the ROV at a ROV visit. BOB unit can extract data through the SAM. Electric power is supplied from the battery system called Sea Water Battery (SWB) or lithium battery unit. Energy of the SWB comes from electrolytic dissolution of the magnesium anode. All the sea-floor instruments, the MEG, the SAM, the magnesium anode of the SWB and lithium battery unit are designed to be replaceable by ROV or submersible.

3. Installation and Activation of System

We have already installed three borehole geophysical observatories, JT-1, JT-2 and WP-2. JT-1 and JT-2 were installed during ODP Leg186 in July and Auguest 1999(Sacks *et al*., 2000, Suyehiro *et al*., 1999). Installation of WP-2 was performed on ODP Leg 191 in August, 2000. (Kanazawa *et al*., 2000) Installation of WP-1 is planned on ODP Leg195 in April, 2000.

The sensors are supported on 4.5" diameter casing pipe which hangs on the base of the reentry cone at the seafloor (Fig.3). The sensors were cemented in the holes to stop fluid motion around the sensors in order to make the noise level lower and to achieve highly sensitive broadband seismic observations and to bond the strainmeter well to the Earth crust. After the cementing, assembly of the battery/recorder unit (PAT) around the drill string. The PAT was lowered and released. The borehole system first requires an electrical connection to be made between the PAT/SAM and the MEG. This must be performed by a ROV or submersible. Once this connection is made, the data from downhole start to flow into the SAM on the PAT. The ROV can also check the status of the system via a RS-232C communication link.

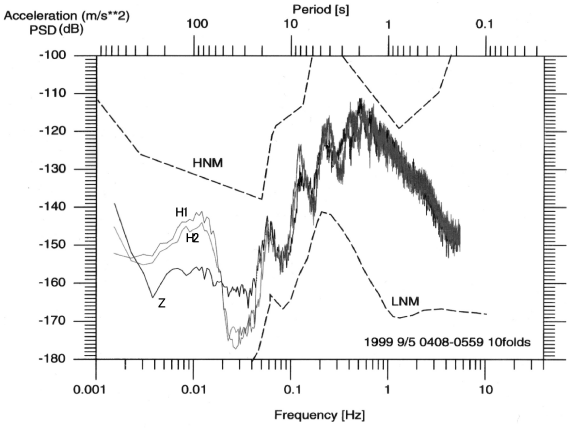

Fig.4. Seismic noise spectra from the borehole seismometers (CMG-1T) at JT-1. The rise of noise around 0.01 Hz is known to be infragravity wave noise induced from a long-period surface wave in the ocean (Araki *et al*., 2000).

For JT-1 and JT-2, the *Dolphin 3K* of the Japan Marine Science and Technology Center visited and activated the system in September 1999. Preliminary data of 8 hours long were

recovered from JT-1. Seismic data were available from CMG-1T seismometer and PMD seismometer. Noise spectra for the CMG-1T sensor at JT-1 shows that ocean borehole can provide low noise environment (Fig.4) (Araki *et al*., 2000). In addition, there were many seismic events found in the record (Fig.5) (Araki, 2000).

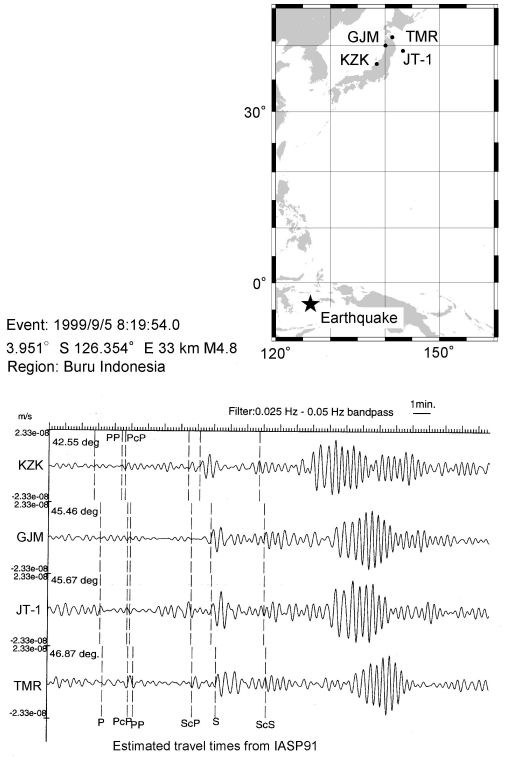

Fig.5. Example of the data recorded by CMG-1T at JT-1 station. The data from nearby land stations are also shown. The component is approximately radial to the hypocenter. The locations of the teleseismic event and the seismic station are also shown.

In October, 2000, *KAIKO*, an ROV belonging to the Japan Marine Science and Technology Center, visited WP-2 to activate the system. During a KAIKO visit, we could confirm the WP-2 system has no problem and KAIKO recovered the SAM on the PAT. Because of only one-day visit of *KAIKO*, the SAM has data from borehole seismometers with 1 hour long. However we found that seismic noise of WP-2 station is also enough low for earthquake observation. Since the seismometers were grouted in the igneous crust, there is no rise of noise around 0.01 Hz, which is induced from a long-period surface wave in the ocean.

5. Conclusion

Ocean Hemisphere Project has a plan to install four ocean floor borehole geophysical observatories in three areas. The main objective of installation of borehole stations is to obtain high-resolution image beneath the western Pacific with seismic waves. Two borehole geophysical observatories (JT-1 and JT-2) on the landward slope of the Japan Trench were successfully installed in July and August, 1999. Installation of a seismic observatory (WP-2) in the northwestern Pacific Basin was completed in August, 2000. From the preliminary data from JT-1 and WP-2, we found that the boreholes at the sea floor provide quiet environments for seismic observation. The installation of WP-1 is scheduled in April, 2001 during ODP Leg 195. After installation of WP-1, the borehole geophysical stations network will provide useful data set for high-resolution mantle structure and understanding the global dynamics operating in the western Pacific.

5. Reference

Araki, E., Geophysical nature of broadband seismic signals in deep oceans, Ph.D. Thesis, Univ. of Tokyo, 2000

Araki, E., H. Mikada, M. Shinohara, K. Suyehiro, Kanazawa, T., Long Period seismic noises in deep ocean borehole and at sea floor, *EOS*, **81**, 48, F838, 2000

Kanazawa, T., M. Shinohara, M. Mochizuki, K. Hirata, E, Araki, and ODP Leg191 shipboard scientific Party, NEREID-191 -New Borehole Seismological Observatory in the Northwestern Pacific Basin-, *EOS*, **81**, 48, F838, 2000

Sacks, I. S., K. Suyehiro, G. D. Acton., *et al*., *Proc. ODP, Init. Repts*., 186 [CD-ROM],2000

Suyehiro, K., S. Sacks, E. Araki, A. Linde, M. Shinohara, Leg186 scientific Party, Monitoring plate subduction in the Japan Trench, *EOS*, **80**, 46, F506, 2000