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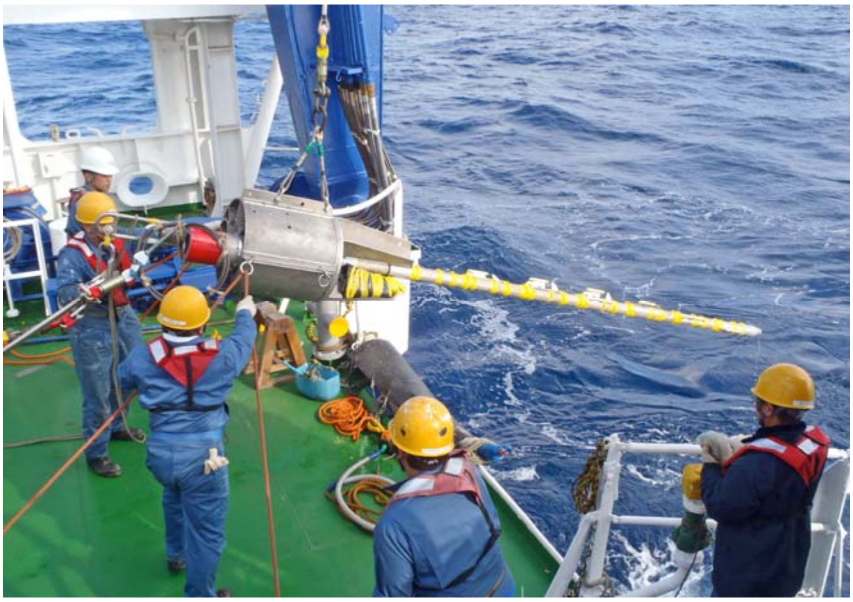
NATSUSHIMA Cruise Report

NT11-23

Thermal structure of forearc areas of the southwest Japan and Kanto subduction zones and its relation to seismic activity



Nankai Trough area

December 16, 2011 – December 26, 2011

Japan Agency for Marine-Earth Science and Technology
(JAMSTEC)

Contents

1. Cruise Information

Cruise number:

NT11-23

Ship name:

R/V NATSUSHIMA

Title of the cruise:

2011 Deep Sea Research
Research cruise with NATSUSHIMA

Title of proposal:

S11-51
Thermal structure of forearc areas of the southwest Japan and Kanto subduction zones and its relation to seismic activity

Cruise period:

December 16, 2011 – December 26, 2011

Port call:

2011	Dec. 16	Dept. from Yokosuka (JAMSTEC)
	Dec. 25	Arriv. at Yokosuka (JAMSTEC)

Research area:

Nankai Trough area

Research map:

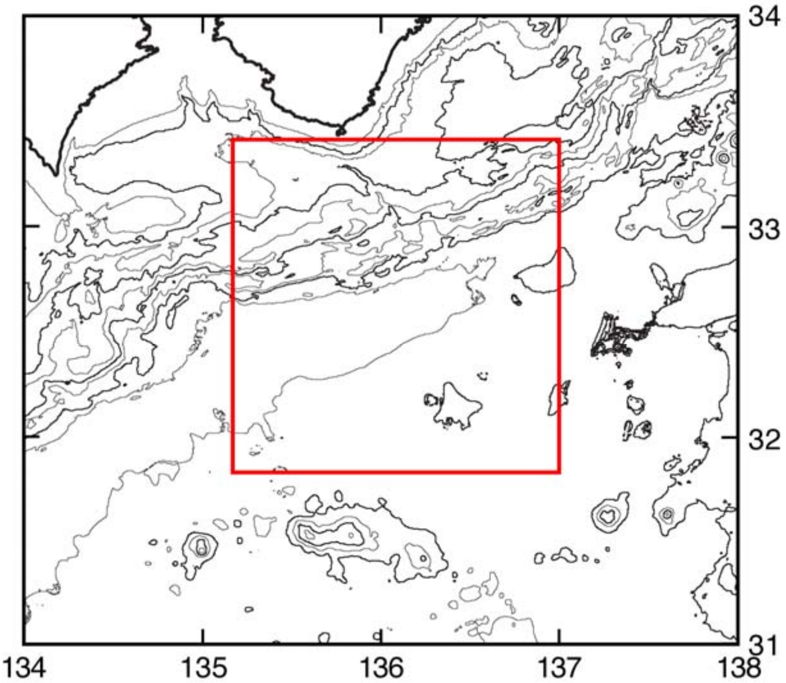


Figure 1-1. Survey area of NT11-23 cruise.

Ship track and observation points are shown in 3.2.3.

2. Researchers

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3. Observation

3.1. Introduction

The temperature structure of the subducting oceanic plate, generally determined by the seafloor age, is one of the most important factors controlling the subsurface thermal structure of subduction zones. In the Nankai subduction zone, the age of the subducting Philippine Sea plate (Shikoku Basin) significantly varies along the trough in a range of about 15 to 30 m.y. (e.g., Okino et al., 1994). The thermal structure of the plate interface and the overriding plate should accordingly vary along the trough. Surface heat flow observed on the floor of the Nankai Trough is, however, not consistent with the age of the Shikoku Basin, indicating that the temperature structure of the Shikoku Basin lithosphere may be different from that expected from the seafloor age. Off eastern Shikoku (off Muroto), the mean of heat flow on the trough floor is extremely high, about 200 mW/m^2, twice as high as the value corresponding to the age (15 m.y.) considering the effect of sedimentation (Yamano et al., 2003). In contrast, the values observed in the area southeast of the Kii Peninsula (off Kumano) are around 100 mW/m^2, close to the value estimated from the age (20 m.y.) with the sedimentation effect (Hamamoto et al., 2011). It is important to investigate what is the cause of this difference for studies of the thermal structure of the Nankai subduction zone.

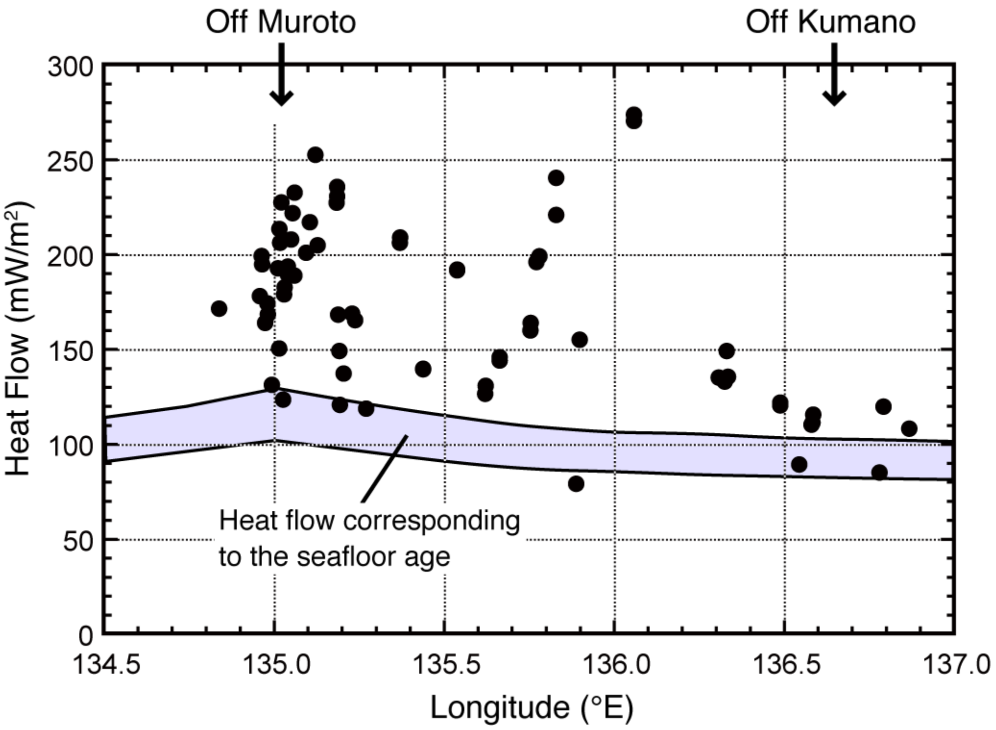

Figure 3.1-1. Heat flow data on the floor of the Nankai Trough plotted versus the longitude. Compared to the value estimated from the age of the subducting Shikoku Basin, heat flow is anomalously high off Muroto, while it is normal off Kumano.

We have been conducting heat flow measurements on the floor of the Nankai Trough between the off-Muroto and off-Kumano areas (south of the Kii Peninsula) in order to examine the transition from high to normal heat flow for investigation of the cause of the high anomaly and the thermal structure of the Shikoku Basin lithosphere. The obtained data show that extremely high heat flow is observed in the area west of 136°E, where heat flow is highly variable and the mean value is comparable to that in the off-Muroto area (Fig. 3.1-1). The boundary between the western high heat flow area and the eastern normal heat flow area is not clear partly because the data is still rather sparse. The transition zone around 136°E is close to the rupture segmentation boundary between the 1944 Tonankai and the 1946 Nankai earthquakes, across which seismicity on the landward side of the trough conspicuously changes (Mochizuki et al., 2010). It indicates a relationship between the thermal structure of the subducting plate and the seismic activity. For further investigation of this relationship, more detailed heat flow survey and thermal modeling based on the heat flow distribution are necessary.

A possible cause of the anomalous high heat flow in the western area is advective heat transfer by hydrothermal circulation in the oceanic crust of the Shikoku Basin. The uppermost

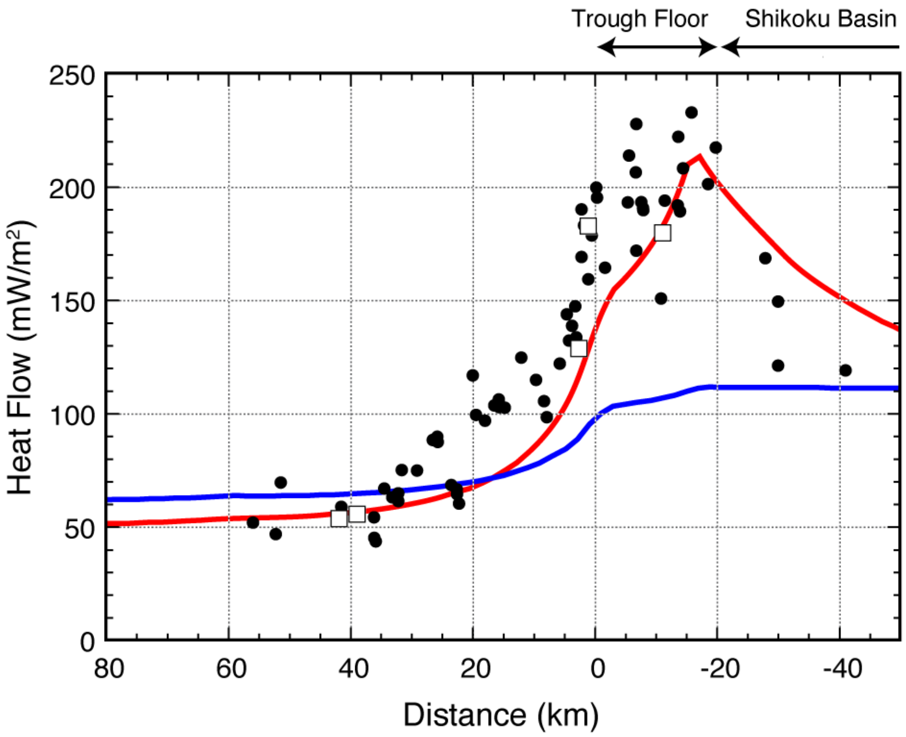

Figure 3.1-2. Heat flow profile across the Nankai Trough off Muroto (Yamano et al., 2003). The horizontal axis is the distance from the deformation front (positive landward). Red and blue curves are surface heat flow calculated with the model of Spinelli and Wang (2008) with vigorous fluid circulation in the subducting crust and with no circulation respectively.

several hundred meters of the basaltic basement of the oceanic crust generally has high permeability and allows extensive pore fluid flow (e.g., Fisher, 2005). Hydrothermal circulation may therefore be occurring in a high permeability layer just below impermeable sediments in the Shikoku Basin crust as well, influencing the temperature structure of the upper part of the plate and surface heat flow (Yamano et al., 1992). For example, sharp landward decrease in heat flow in the frontal part of the accretionary prism off Muroto (Fig. 3.1-2) cannot be caused by a conductive process and must be associated with some advective heat transfer.

Spinelli and Wang (2008) proposed the following model to explain the high heat flow anomaly off Muroto. The topmost part of the Shikoku Basin oceanic crust retains high permeability even after subduction and allows vigorous hydrothermal circulation which efficiently transfer heat along the plate interface from deeper part of the subduction zone. The upward advective heat transfer results in high heat flow on the Nankai Trough floor (Fig. 3.1-2) and cool down the plate interface (seismogenic zone of great subduction thrust earthquakes). If we apply this model to the heat flow distribution on the trough floor, the transition from the high heat flow off Muroto to the normal heat flow off Kumano may correspond to variation in vigor of hydrothermal circulation, which should be related to variation in permeability of the subducting oceanic crust. Heat flow measurements in the northernmost part of the Shikoku Basin (seaward of the trough floor) will enable us to test the validity of the model by comparing the calculated heat flow with the observation (Fig. 3.1-2).

3.2. Summary of the Cruise

3.2.1. Research items

(1) Heat flow measurement (HF)

Measurement of temperature profiles in surface sediment with ordinary deep-sea heat flow probes for determination of terrestrial heat flow.

(2) Long-term temperature monitoring on the seafloor (PWT)

Long-term monitoring of the bottom water temperature using a pop-up type instrument for evaluation of influence of water temperature variation on heat flow measurement.

(3) Sediment core sampling with heat flow measurement (HFPC)

Sampling of surface sediments with a piston corer and heat flow measurement at the same site using small temperature recorders mounted on the core barrel.

(4) Bathymetry survey

Bathymetry mapping with a multi narrow beam system.

3.2.2. Cruise schedule and operations

Date	Events, Operations
Dec. 16	Leave Yokosuka (JAMSTEC) Transit to the survey area
Dec. 17	Wait for the sea condition to recover in the survey area
Dec. 18	Arrive in the survey area Heat flow measurement (HF01)
Dec. 19	Piston core sampling with heat flow measurement (HFPC01)
Dec. 20	Piston core sampling with heat flow measurement (HFPC02) Heat flow measurement (HF02)
Dec. 21	Heat flow measurement (HF03) Heat flow measurement (HF04)
Dec. 22	Bathymetry survey Deployment of a pop-up water temperature monitoring system (PWT01) Take refuge from rough sea (Atsumi Bay)
Dec. 23	Take refuge from rough sea (Atsumi Bay)
Dec. 24	Transit to Yokosuka
Dec. 25	Arrive at Yokosuka (JAMSTEC)

Detailed cruise log is given in 7.1.

3.2.3. Ship track and observation points

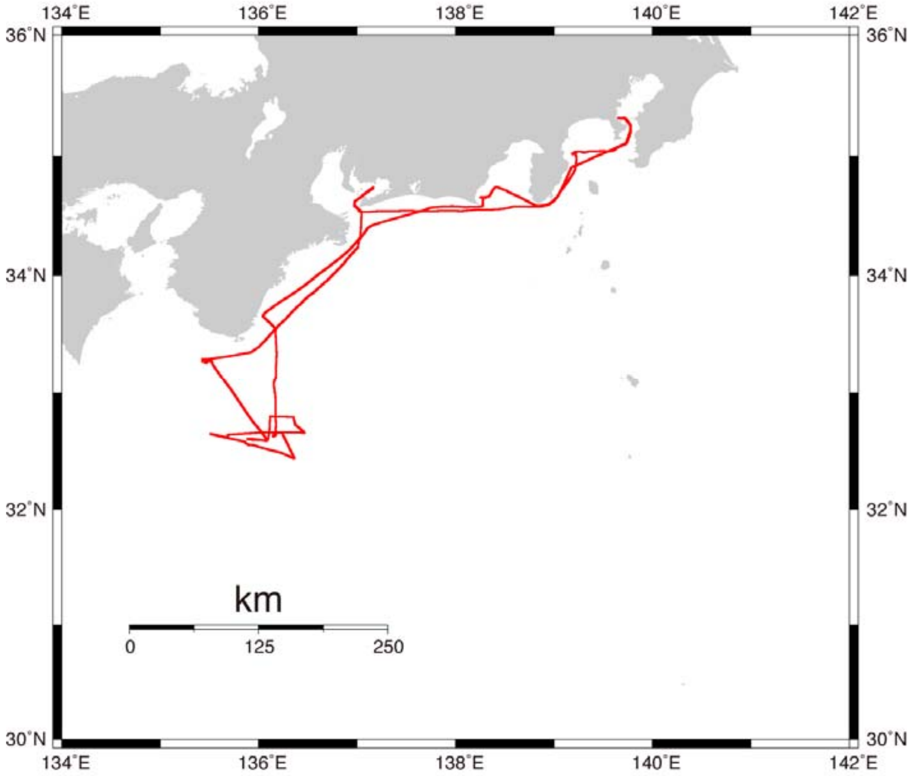

Figure 3.2-1. Ship track of NT11-23 cruise.

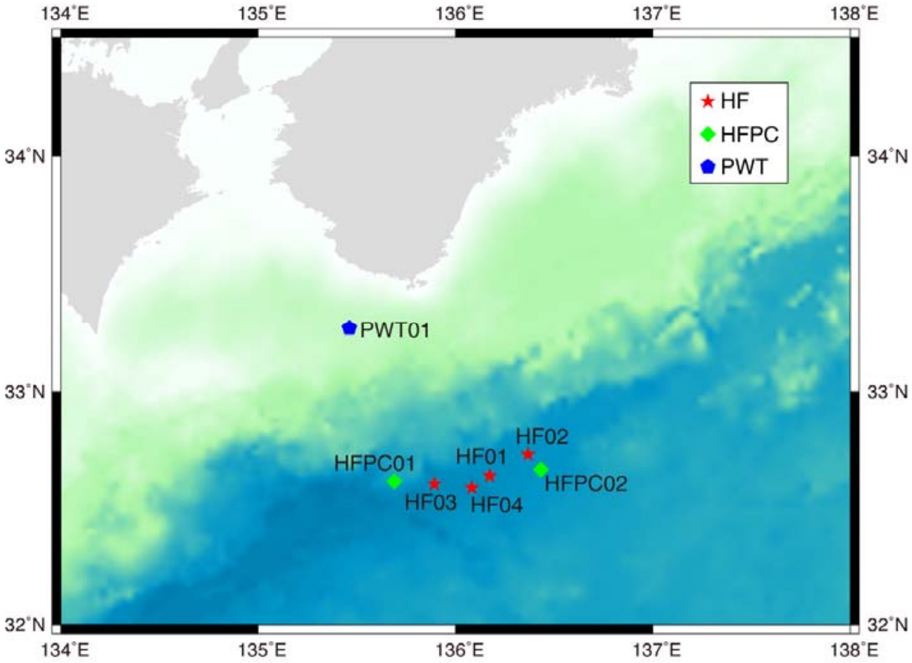

Figure 3.2-2. Measurement and sampling stations on NT11-23 cruise.

3.3. Research Objectives

We conduct heat flow measurements in the Nankai Trough area south of the Kii Peninsula in order to know detailed heat flow distribution, especially transition of heat flow on the trough floor from high values off Muroto to normal values off Kumano. Based on the obtained data and through numerical modeling, we investigate along-arc variation in the temperature structure around the subduction plate interface (seismogenic zone) associated with variations in the age and crustal structure of the subducting Philippine Sea plate and examine its relation to seismic activity and deformation process.

Surveys in trench areas south of Kanto were also planned in the research proposal. On this cruise, however, we concentrated on surveys in the Nankai Trough area.

Specific objectives of this research cruise

(1) Heat flow measurement on the Nankai Trough floor

We investigate the transition from anomalously high heat flow off Muroto to normal heat flow off Kumano through detailed measurements on the floor of the Nankai Trough south of the Kii Peninsula, mainly around 136°E (cf. Fig. 3.1-1). The result will be compared with along-arc variations in other geophysical features of the Nankai subduction zone, e.g., seismicity (Mochizuki et al., 2010), slow earthquakes (Obara, 2011), age and crustal structure of the subducting Shikoku Basin (Okino et al., 1994; Kodaira et al., 2006; Ike et al, 2008), and magnetic anomaly (Kido and Fujiwara, 2004).

(2) Bottom water temperature monitoring in the forearc area

We deploy instruments for long-term monitoring of bottom water temperature in a forearc basin between the Nankai Trough and the Kii Peninsula, where the water depth is relatively shallow, less than 2000 m. The obtained temperature record for about one year will be used for determination of heat flow by removing the influence of bottom water temperature variation. Surface heat flow data in the forearc area is important as constraint on frictional heating and temperature distribution along the plate interface (Hamamoto et al., 2011).

(3) Heat flow measurement in the Shikoku Basin

To test the model proposed by Spinelli and Wang (2008) on advective heat transfer by hydrothermal circulation in the subducting crust, we conduct heat flow measurements in the northernmost part of the Shikoku Basin off Muroto. The obtained data can be compared with surface heat flow calculated with the model, which enables us to evaluate and improve the model (cf. Fig. 3.1-2).

Measurements for this purpose could not be made on this cruise because of rough sea conditions.

(4) Measurement of physical properties of sediment core samples

We take sediment core samples using a piston corer and measure physical properties of core samples. Measurement of thermal conductivity of sediment is particularly important for determination of heat flow. Information on sedimentation rate and depositional environment deduced from samples is also useful for interpretation of the obtained heat flow values.

3.4. Instruments and Operation Methods

3.4.1. Deep-sea heat flow probe

Heat flow is obtained as the product of the geothermal gradient and the thermal conductivity. We measured the geothermal gradient by penetrating an ordinary deep-sea heat flow probe or a heat flow piston corer (HFPC, cf. 3.4.2) into seafloor sediments.

[Specification of tools]

The deep-sea heat flow probe (Fig. 3.4-1) weighs about 800 kg and has a 3.0 m-long lance, along which seven compact temperature recorders (Miniaturized Temperature Data Logger, ANTARES Datensysteme GmbH; Fig. 3.4-2) are mounted in an outrigger fashion (Ewing type). A heat flow data logger (Kaiyo Denshi Co., DHF-650) placed inside the weight head (cf. Fig. 3.4-3) was used for recording the tilt and the depth of the probe. Tilt and depth data were sent to the surface with acoustic pulses so that we can monitor the status of the probe on the ship.

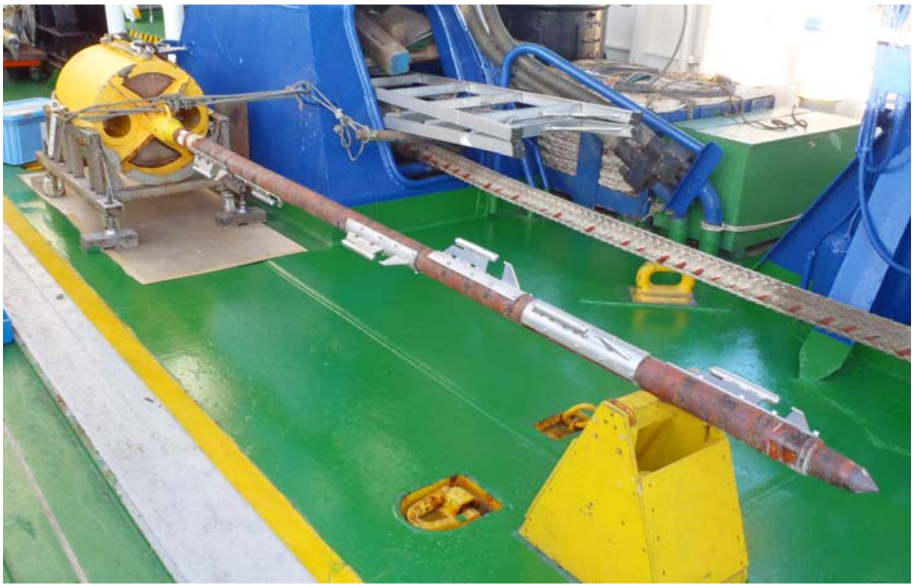

Figure 3.4-1. Deep-sea heat flow probe.

Figure 3.4-2. ANTARES Miniaturized Temperature Data Logger (MTL).

Specifications of the heat flow data logger and the ANTARES Miniaturized Temperature Data Logger (MTL) are summarized below:

Heat Flow Data Logger DHF-650 (Kaiyo Denshi Co.)
  Pressure case: titanium alloy
  Case length: 725 mm
  Maximum diameter: 145 mm
  Pressure rating: 7000 m water depth
  Tilt: two-axis, 0 to ±45°
  Data-cycle interval: 30 sec
  Pinger frequency: 15.0 kHz (or 12.0 kHz)

Miniaturized Temperature Data Logger (ANTARES Datensysteme GmbH)
  Pressure case: stainless steel
  Case length: 160 mm
  Diameter: 15 mm
  Pressure rating: 6000 m water depth
  Number of temperature channel: 1
  Temperature resolution: 1.2 mK at 20°C, 0.75 mK at 1°C
  Sample rate: variable from 1 sec to 255 min.

[Operations]

A 15 m long nylon rope was inserted between the heat flow probe and the winch wire rope in order not to kink the wire rope during probe penetrations. An acoustic transponder was attached about 120 m above the probe for precise determination of the position of the probe (Fig. 3.4-3).

Multi-penetration heat-flow measurement operations were conducted following the procedures described below.

1. Measure water temperature about 50 m above the seafloor for calibration of temperature recorders.
2. Lower the probe at a speed of about 1 m/sec until it penetrates into the sediment.
3. Measure temperatures in the sediment for about 15 min. Monitor the wire tension and pay out the wire when necessary to keep the probe stable.
4. Pull out the probe.
5. Move to the next station keeping the probe about 1000 m above the seafloor.
   or
   Keep the ship position and allow the probe to move above the seafloor for 5 to 10 min.
6. Repeat penetrations.

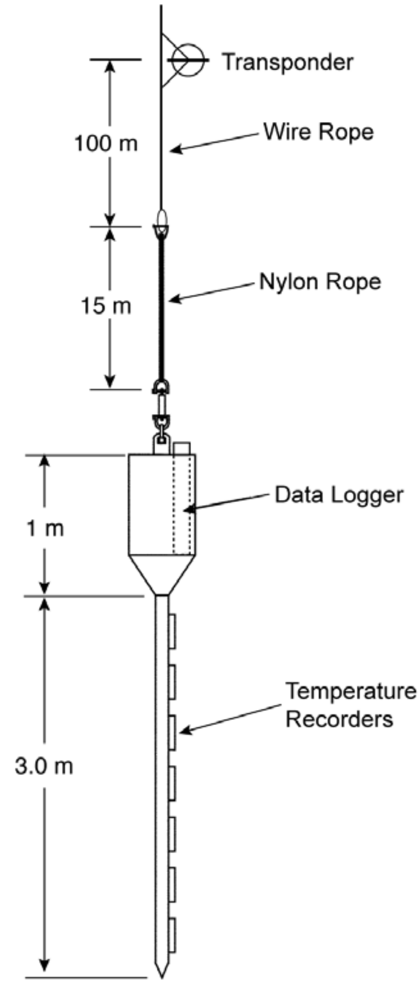

Figure 3.4-3. Configuration of the heat flow measurement system using a deep-sea probe.

3.4.2. Heat flow piston coring system

[Specification of tools]

During this cruise, sediment core samples were taken with the heat flow piston coring system (HFPC) (Fig. 3.4-4). This coring system was used for combined operation of measuring heat flow and recovering sediments. The general outline of the system is shown in Fig. 3.4-5.

A stainless steel barrel was attached to a piston core head of 800 kg weight. The core head has a space for mounting the heat flow data logger to record the temperatures of thermistor sensors mounted along the barrel. On this cruise, seven ANTARES MTLs (cf. 3.4.1) were mounted helically on the outside of barrel, between the base of the weight stand and the core catcher bit. A transponder was also mounted on the winch wire to obtain the depth and position of this equipment. The stainless steel barrel with this system is 4 m in length and liner is used for recovering sediments. The balance and pilot corer are the same as ones for ordinary

Figure 3.4-4. HFPC with compact temperature data loggers (MTLs).

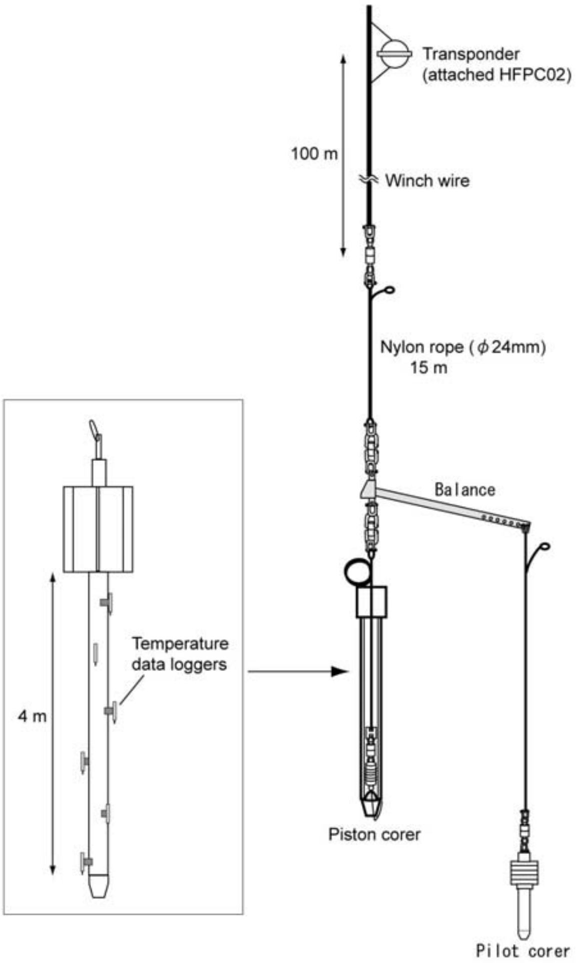

Figure 3.4-5. Configuration of the heat flow piston coring (HFPC) system.

piston core systems. 24 mm nylon rope was placed between the balance and winch wire for additional wire out and/or increased tension after hitting sea bottom. Because the system must be kept in the sediment for 15 minutes to obtain stable temperature, additional wire out is necessary for avoiding pulling the barrel out of the sea floor by either heaving or drifting of the ship during the measurement.

[Operations]

Preparation for the piston coring

After barrels are attached to the head (weight stand), the main wire is connected, through the barrel, to the piston at the bottom of the barrel. The core catcher and bit are then attached. The balance is connected to the end of the main wire. The entire assemblage is carried under the A-frame using a cart and is lifted over the edge of the deck by the winch. The pilot core and its wire are then connected to the balance. The system is then lowered through the water to the seafloor.

Hit the bottom and off the bottom

The piston core system starts lowering at a winch speed of 20 m/min, which gradually increases to a maximum 50 m/min. The piston core is stopped at a depth about 100 m above the sea floor for 5 minutes to reduce any pendulum motion and to calibrate the temperature sensors on the outside of barrel.

After 5 minutes, the wire is lowered at a speed of about 20 m/min., at the same time carefully watching the pen recorder of the strain gauge tension meter. When the piston core hit the bottom the tension will abruptly decrease by the amount of the piston core weight. Therefore, it is easy to detect the bottom hit.

After the recognition of hit the bottom, add 5 m to wire out, stop and keep the position for 15 minutes. And then, rewinding of the wire is started at a dead slow speed (~20 m/min.) until the tension gauge indicates that the core has lifted off the bottom. The tension meter shows a small increase in tension when the core is being pulled out of the sea floor and then a steady value. After we can recognize absolutely that the piston core is above the sea floor, the winch speed is increased to 60 m/min., and then gradually to maximum speed.

3.4.3. Long-term temperature monitoring system

At stations with relatively shallow water depths (e.g., less than 2500 m), temporal variation of the bottom water temperature significantly disturbs the temperature profile in surface sediment, making it difficult to measure heat flow with ordinary deep-sea probes. One method to determine heat flow at such shallow sea stations is long-term monitoring of temperatures in surface sediment (Hamamoto et al., 2005). We can analytically remove the influence of the bottom water temperature variation from the long-term sediment temperature records. Another possible method is to conduct temperature profile measurement with a deep-sea probe after monitoring the bottom water temperature for a certain long period. We may be able to determine heat flow by analyzing the temperature profile combined with the water temperature record for the preceding period.

We have been using a pop-up water temperature measurement system (termed PWT below) in order to obtain long-term bottom water temperature records (Fig. 3.4-6). PWT consists of an acoustic releaser, weights, floats (glass spheres), and a small water temperature recorder (NWT-DN, Nichiyu Giken Kogyo Co.) (Fig. 3.4-7). For deployment, the whole system is released at the sea surface and it sinks freely down to the sea floor. The system is recovered by activating the acoustic releaser with a command sent from a surface ship.

Figure. 3.4-6. Pop-up water temperature measurement system (PWT).

Specifications of the water temperature recorder (NWT-DN) are summarized below.

Pressure case	titanium alloy
Case length	212 mm
Diameter	41 mm
Pressure rating	6000 m water depth
Number of temperature channel	1
Temperature resolution	1 mK
Sample rate	variable from 2 sec to 1 day

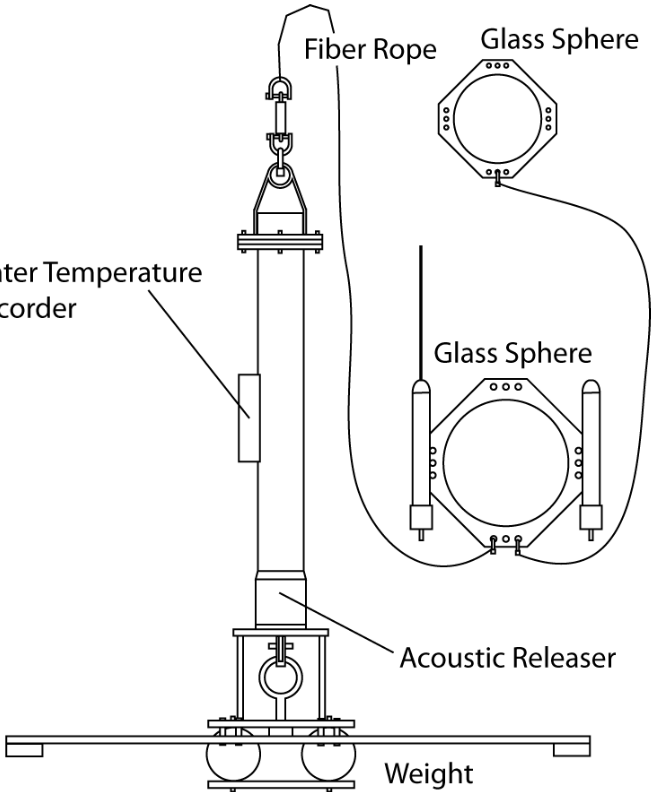

Figure 3.4-7. Schematic drawing of PWT.

3.4.4. Physical properties of core samples

[Thermal property]

Thermal properties (thermal conductivity, heat capacity, and thermal diffusivity) of earth materials are important parameters for calculating heat flow, modeling the thermal structure and transport of heat and fluid under the ground. For thermal conductivity measurements, we used two instruments. One is Model QTM-500 (Kyoto Electronics Manufacturing Co., Japan; Fig. 3.4-8). This instrument measures thermal conductivity of sediment with a half space box-type probe (Sass et al., 1984). Measurements with this instrument were made on split core samples (Fig. 3-4-8). The other is KD2 Pro Thermal Properties Analyzer (Decagon Devices, Inc., USA) with a single needle probe sensor (KS-1 probe) (Von Herzen and Maxwell, 1959). The probe was inserted into split core samples. For measurements of thermal conductivity, heat capacity, and thermal diffusivity, we used KD2 Pro Thermal Properties Analyzer with a dual needle probe (SH-1) (Ochsner et al., 2001; Fig. 3.4-9). The probe was inserted into split core samples.

Figure 3.4-8. Thermal conductivity measurement on the sample NT11-23 PC01 with QTM-500.

Figure 3.4-9. Thermal conductivity, heat capacity and thermal diffusivity measurements on the sample NT11-23 PC01 with dual probes of KD2 Pro.

[Shear strength]

In order to understand shear strengths of core samples under the undrainage and unconsolidation (UU) conditions, we conducted vane shear test. The shear strength is measured using four-wing-bearing torque driver of 2 cm in height and 1 cm in width. Measurements were made as follows; 1) the whole wings of the torque driver were penetrated directly into the split-core surface, 2) the torque driver was rotated slowly, 3) record the maximum torque force. The shear strength is calculated from the shear friction working during rotation of the driver as:

$$C = \frac{M_{t\max}}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)}$$

where C is the shear strength (kg/cm^2), $M_{t\max}$ is the torque moment (kg cm), H is the wing height (cm), and D is the total wing width (cm).

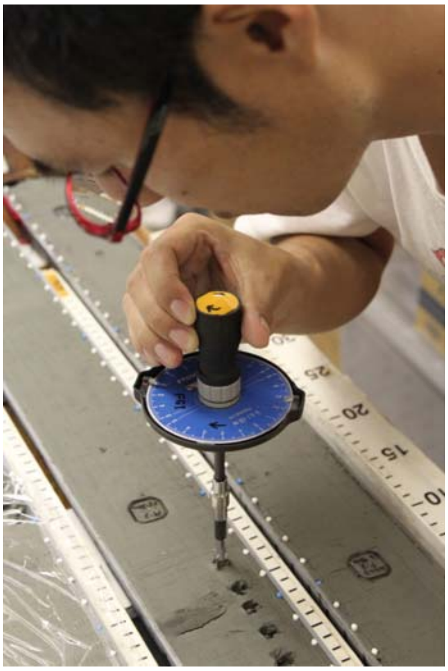

Figure 3.4-10. Vane shear test (Photograph was taken during the KH-10-3 cruise of R/V Hakuho-maru. The tester is Mr. Otsuka from AORI, University of Tokyo.)

3.5. Preliminary Results

3.5.1. Heat flow measurement

We carried out heat flow measurements at four sites with the deep-sea heat flow probe (Fig. 3.5-1) and at two sites with the HFPC (Table 3.5-1; Fig. 3.2-2). At three sites (HF01, HF03, and HF04), multiple penetrations were made for examining local variability of heat flow. The coordinates of the stations listed in Table 3.5-1 are the positions of the acoustic transponder attached above the probe or HFPC determined with the SSBL system of the ship, except HFPC01 for which the position of the ship is shown because the transponder was not used at this site. The water depth in the table was determined from the pressure measured with the DHF-650 heat flow data logger (cf. 3.4.1) while the probe or HFPC were on the seafloor.

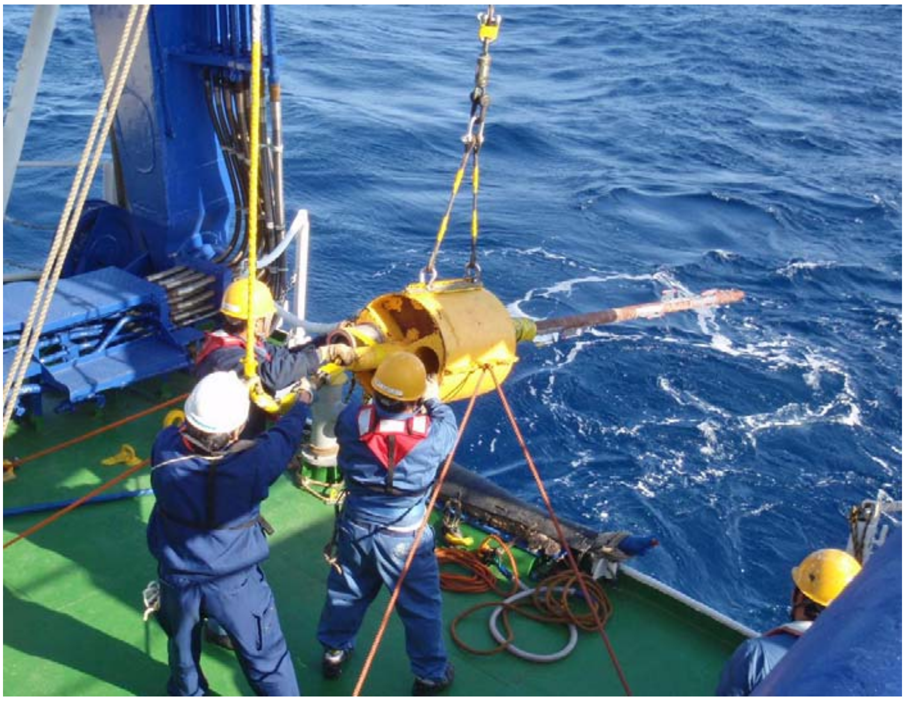

Figure 3.5-1. Heat flow measurement operation.

All of the six sites are located on the floor of the Nankai Trough south of the Kii Peninsula between 135°40’E and 136°30’E (cf. Fig. 3.3-2), which seems to be a transition area from the high heat flow off Muroto to the normal heat flow off Kumano. Although the trough floor is generally flat and covered by soft sediment, heat flow measurement can be made only in very limited spaces because of densely laid submarine telecommunication cables, in the vicinity of which we cannot penetrate probes or corers. During this cruise, tuna fishing activity imposed additional constraints on measurement locations.

At HF03A and HFPC02, the heat flow probe and the piston corer fell down right after hitting the seafloor probably due to hard bottom sediment (sandy layers) and we could not obtain sediment temperature data and core sample. At the other stations, the probe or corer fully penetrated into sediment and temperature gradient data of good quality was obtained. Results of these measurements provide valuable information on the high to normal heat flow transition on the floor of the Nankai Trough.

Table 3.5-1. Results of heat flow measurements

Date	Station	Latitude (N)	Longitude (E)	Depth (m)	N
Deep-sea heat flow probe					
Dec. 18	HF01A	32°38.46'	136°10.57'	4610	7
	B	32°38.22'	136°10.12'	4605	7
	C	32°38.07'	136°09.87'	4605	7
	D	32°37.95'	136°09.62'	4605	7
	E	32°37.75'	136°09.31'	4610	7
Dec. 20	HF02A	32°44.00'	136°22.14'	4545	7
	HF03A	32°36.48'	135°53.67'	4665	fell
	B	32°36.47'	135°53.64'	4665	7
	C	32°36.48'	135°53.62'	4665	7
Dec. 21	HF04A	32°35.51'	136°05.13'	4760	7
	B	32°35.50'	136°05.14'	4760	7
HFPC					
Dec. 19	HFPC01*	32°37.03'	135°41.39'	4720	7
Dec. 20	HFPC02	32°39.97'	136°26.11'	4540	fell

N: number of temperature sensors used to obtain temperature profile in sediment.

*: position of the ship.

Heat flow values will be obtained by combining the measured temperature profiles with thermal conductivity of surface sediment. Thermal conductivity at each site needs to be estimated from the values measured on piston core samples (cf. 3.5.3) and the existing data at nearby stations.

3.5.2. Long-term temperature monitoring

We deployed one pop-up water temperature measurement system (PWT; cf. 3.4.3) at a station in a forearc basin between the Nankai Trough and the Kii Peninsula (PWT01; Table

3.5-2; Figs. 3.2-2 and 3.5-2). The station was selected based on a detailed bathymetry map obtained with the multi narrow beam system of the ship (cf. 3.5.4). After the system had landed on the seafloor, the position was precisely determined by acoustically measuring slant ranges at three locations. The PWT will be recovered about one year after deployment.

We planned heat flow measurement and piston coring in the vicinity of PWT01, but could not conduct them due to rough sea conditions.

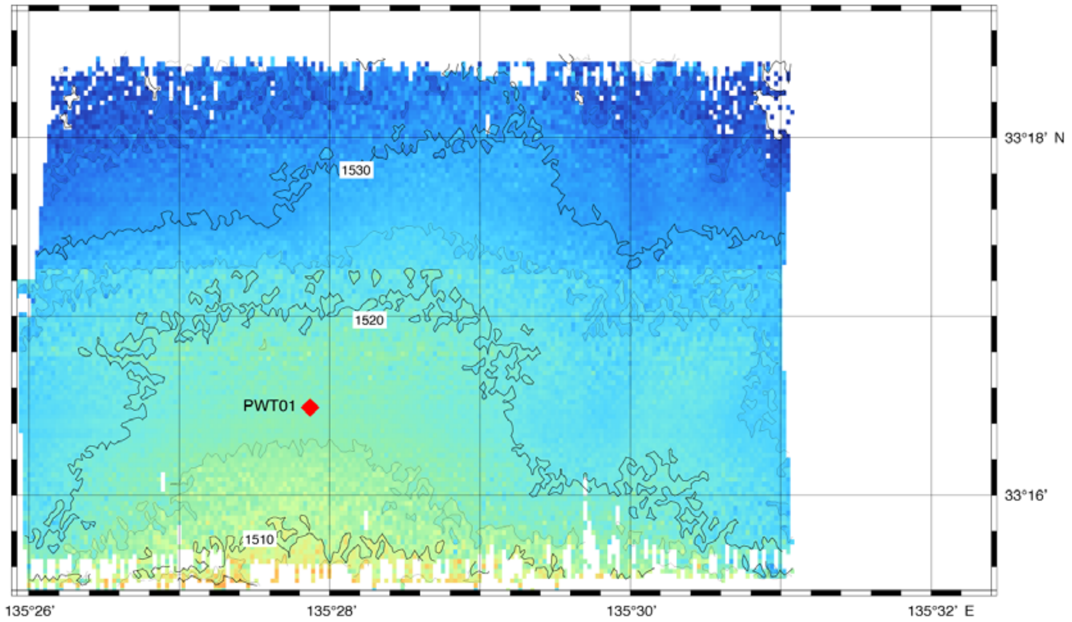

Figure 3.5-2. Location of PWT01 shown on a multi-narrow-beam bathymetry map (cf. 3.5.4).

Table 3.5-2. Deployment of long-term temperature monitoring instrument

Station	Deployment	Coordinates	Depth (m)
PWT01	Dec. 22, 2011	33°16.49'N, 135°27.87'E	1520

3.5.3. Piston core samples

One piston core sample was collected from the Nankai trough floor, off the Kii Peninsula using a 4-m-piston-corer system operated by Marine Works Japan Co. Ltd. The piston corer system has a pilot corer (so-called a Marine Work 74 Gravity corer), but we could not recover a pilot core sample in this cruise. Seven temperature recorders for heat flow measurements were attached on the core barrel of the piston corer. We call this system as a heat-flow piston corer (hereafter HFPC). Sample name of piston core is NT11-23 HFPC01 in this description, and the formal sample name in the Kochi Core Center is NT11-23 PC01.

The piston core sample was processed as follows;

1) Cut the whole core into 1-m sections.
2) Split the whole core into Working and Archive halves..
3) Working half: take photographs, describe sedimentary structures by naked eyes and smear slides.
4) Measure shear strengths of the core sample at 2 cm intervals using vane shear tester (cf. 3.4.4).
5) Take samples successively for physical and magnetic properties studies.
6) Archive half: measure thermal conductivity using a half-space probe and needle probes (cf. 3.4.4).
7) Pack cores into plastic cases (D-tubes) for storage, then transport to the Kochi Core Center.

The recovered core sample is described in detail below.

[HFPC01]

To measure heat flow on the floor of the Nankai Trough south of the Kii Peninsula, HFPC01 was conducted on the trough floor at 32°37.03’N and 135°41.39’E. The water depth was 4718 m. The longitude and latitude of the coring site are average values of a data set of a GPS system of the ship during the coring operation. The water depth at the coring site was determined from an average value of pressure records in the heat flow system.

The recovered core sample is 181.0 cm long. The piston core sediments are predominantly dark olive gray (2.5GY3/1) clayey silt as turbidite muds. We can divide them into four turbidite units; t1 (0-5 cm-bsf), t2 (5-63 cm-bsf), t3 (63-105 cm-bsf) and t4 (105-163 cm-bsf). These units have four black (2.5GY2/1) medium to very fine sand layers with normal grading at 3-5, 58-63, 97-105 and 158-163 cm-bsf. These are basal sand layers in the turbidite units. Thin very fine sand layers are seen at 24-25, 52.5-53 (having normal grading) and 116.5-117 cm-bsf. Sand lamina are seen at 80-83, 143-145, 147-149, 149-154 and 177-179 cm-bsf. These were probably deposited during the turbidite deposition. Two sand lamina at 147-149 and 149-154 cm-bsf are inclined and seem to be elongated (e.g. slump or coring disturbance). If these deformed structures are formed during coring operation as coring disturbance, all (or most) of the sedimentary structures throughout the core should be deformed. Hence, we think that these are original sedimentary structures as slumping.

Below t4, clayey silt and lamina are seen at 163-181 cm-bsf. This horizon is probably an older turbidite unit (t5) without the basal sand layer.

Shear strengths of clayey silt layers increase successively to about 5 kPa with increase of depth. Several spike peaks throughout the core correspond to sand layers.

Thermal conductivities of sediments were measured with QTM-500 at 10 locations (8 for clayey silt and 2 for fine sand layers) on split core samples of HFPC01. Thermal conductivities were also measured with KD2 Pro with single probes at 10 locations. The measurement points are the same as those for measurement with QTM-500. With dual probes of KD2 Pro, thermal properties (thermal conductivity, heat capacity and thermal diffusivity) were also measured at the same locations.

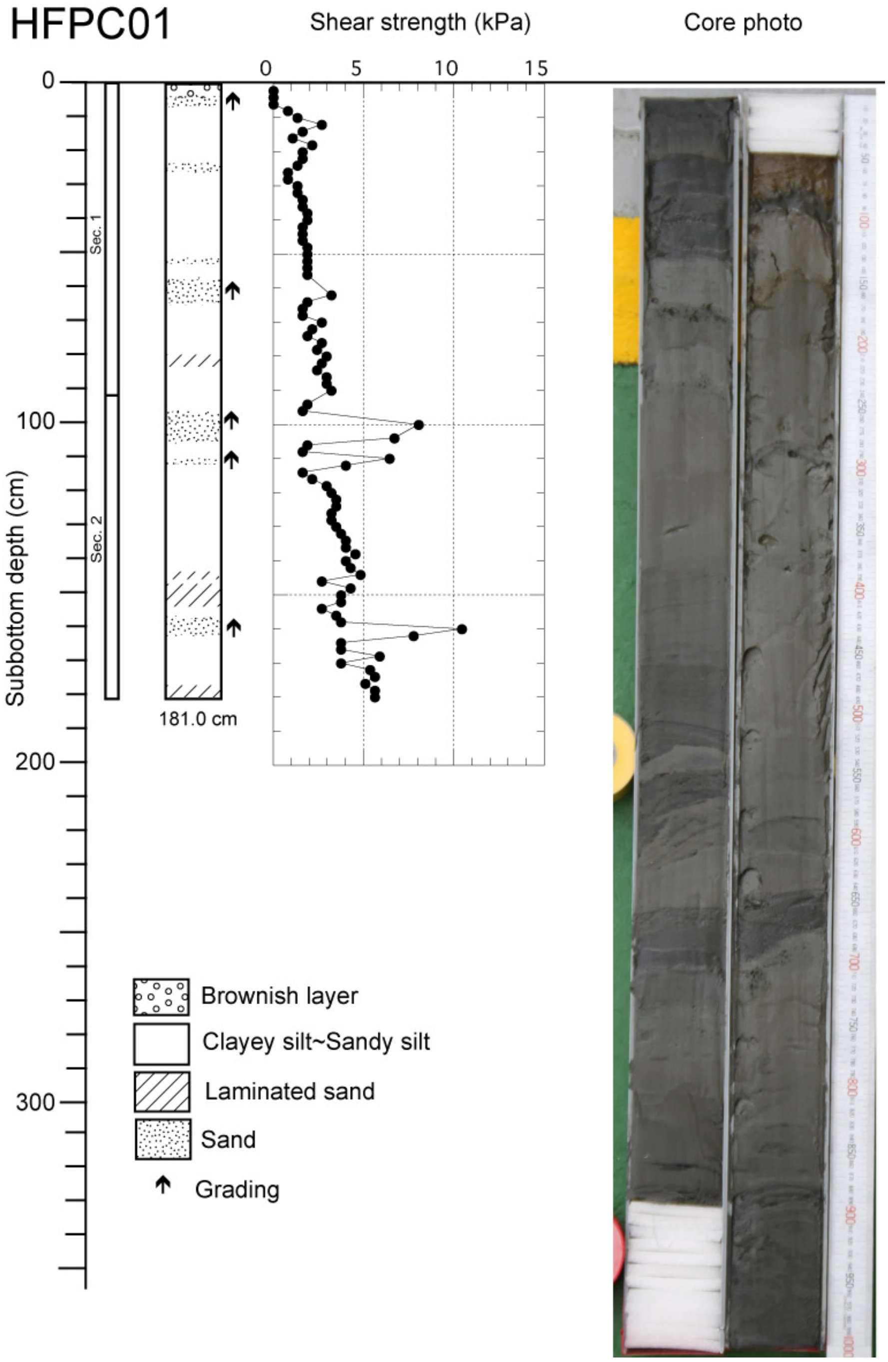

Figure 3.5-3. Summary of HFPC01.

3.5.4. Bathymetry survey

Bathymetry mapping surveys was made in a small area in a forearc basin between the Nankai Trough and the Kii Peninsula using the multi narrow beam system (SEABAT 8160). The obtained bathymetry map (Fig. 3.5-2) was used for selection of bottom water temperature monitoring site (PWT01; cf. 3.5.2).

4. Notice on Using

This cruise report is a preliminary documentation as of the end of the cruise.

This report may not be corrected even if changes on contents (i.e. taxonomic classifications) may be found after its publication. This report may also be changed without notice. Data on this cruise report may be raw or unprocessed. If you are going to use or refer to the data written on this report, please ask the Chief Scientist for latest information.

Users of data or results on this cruise report are requested to submit their results to the Data Management Group of JAMSTEC.

5. Acknowledgements

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7. Appendices

7.1. Cruise Log

Date	Local Time	Note	Position/Weather/Wind/Sea condition
16.Dec.2011	9:00	Let go all shore line,left YOKOSUKA.Proceeded to research area(NANKAI TROUGH C).	
	10:00-11:00	Education for scientists & boat station drill.	12/16 12:00(UTC+9h)
	18:30	Com'ced proceeding to SURUGA WAN due to rough sea.	35-00.7N 139-28.7E
	22:00	Arrived at off Omaezaki,com'ced heave to due to rough sea.	Fine but cloudy
	23:00	Finished heave to,com'ced drifting.	West-6(Strong breeze)
			4(Sea moderate)
			3(Moderate short)
			Visibly:7
17.Dec.2011	7:30	Finished drifting,then proceeded to research area.	
			12/17 12:00(UTC+9h)
			33-04.5N 135-25.0E
			Fine but cloudy
			NW-4(Moederate breeze)
			3(Sea slight)
			1(Low swell sea)
			Visibly:
18.Dec.2011	5:45	Arrived at research area.	
	5:50	Released XBT at 32-38.4532N 136-10.4266E.	12/18 12:00(UTC+9h)
	7:10	Com'ced heat flow measurement operation.(HF01)	32-38.3N 136-09.8E
	17:55	Recovered heat flow probe & finished above operation.	Fine but cloudy
	18:20	Com'ced proceeding to NANAKAI TROUGH B.	NNE-5(Fresh breeze)
			3(Sea slight)
			3(Moderate short)
			Visibly:7
19.Dec.2011	2:30	Arrived at NANKAI TROUGH B & com'ced heave to.	
	12:53	Hoisted up heat flow piston corer.	12/19 12:00(UTC+9h)
	13:06	Com'ced above operation.(HFPC01)	32-37.9N 135-36.8E
	15:41	Piston corer on sea bottom.	Fine but cluody
	15:57	Piston corer left sea bottom.	NW-4(Moderate breeze)
	18:11	Recovered piston corer & finished above operation.	3(Sea slight)
	18:20	Com'ced proceeding to next area.	3(Moderate breeze)
	21:30	Arrived at NANKAI TROUGH C,com'ced heave to.	Visibly:8
20.Dec.2011	7:10	Hoisted up heat flow piston corer.(HFPC02)	
	7:16	Com'ced above operation.	12/20 12:00(UTC+9h)
	9:29	Piston corer on sea bottom.	32-40.7N 136-25.9E
	9:35	Piston corer left sea bottom.	Fine but cloudy
	11:58	Recovered piston corer & finished above operation.	NW-6(Strong breeze)
	12:05	Com'ced proceeding to next point.	4(Sea moderate)
	13:00	Arrived at above point.	4(Moderate average)
	13:20	Hoisted up heat flow probe.	Visibly:8
	13:24	Com'ced above operation.(HF02)	
	15:22	Heat flow probe left sea bottom.	
	18:53	Recovered heat flow probe & finished above operation.	
	19:00	Com'ced proceeding to NANKAI TROUGH B..	
21.Dec.2011	2:00	Arrived at NANKAI TROUGH B & com'ced heave to.	
	7:00	Hosited up heat flow probe.	12/21 12:00(UTC+9h)
	7:05	Com'ced heat flow measurement operation.(HF03)	32-36.5N 135-53.7E
	9:09	Heat flow probe on sea bottom.	Overcast
	10:14	Heat flow probe left sea bottom.	WNW-2(Light breeze)
	13:46	Recovered heat flow probe & finished above operation.	1(Calm)

	13:55	Com'ced proceeding to next point.	2(Low swell sea)
	14:45	Arrived at above point.	Visibly:7
	14:48	Hoisted up heat flow probe.	
	14:50	Com'ced heat flow measurement operation.(HF04)	
	17:05	Heat flow probe on sea bottom.	
	17:49	Heat flow probe left sea bottom.	
	20:57	Finished above operation.	
	21:00	Com'ced proceeding to NANKAI TROUGH A.	
22.Dec.2011	1:30	Arrived at NANKAI TROUGH A.	
	1:35	Released XBT at 33-16.1616N 135-31.5942E.	12/22 12:00(UTC+9h)
	1:52-3:05	Carried out MBES site survey.	34-00.0N 136-45.5E
	3:57	Deployed pop-up water temperature monitoring system. (PWT01)	Overcast
	4:27-5:06	Carried out calibration of PWT position.	ENE-2(Light breeze)
	5:15	Com'ced proceeding to ATUMI WAN due to rough sea.	1(Calm)
	17:30	Let go anchor arrived at ATUMI WAN.	1(No swell)
			Visibly:7
23.Dec.2011		Anchoring at ATUMI WAN due to rough sea.	
			12/23 12:00(UTC+9h)
			34-44.4N 137-09.8E
			Fine but cloudy
			NW-7(Near gale)
			4(Sea moderate)
			1(Low swell sea)
			Visibly:7
24.Dec.2011	8:00	Clear up anchor & com'ced proceeding to YOKOSUKA.	
			12/23 12:00(UTC+9h)
			34-32.7N 137-41.5E
			Fine but cloudy
			WNW-5(Fresh breeze)
			3(Sea slight)
			2(Low swell long)
			Visibly:7
25.Dec.2011	8:00	Sent out 1st Shore line,then arrived at YOKOSUKA.	

7.2. R/V Natsushima Crew

Captain	EIKO UKEKURA
Chief Officer	AKIHISA TSUJI
2nd Officer	SHINTARO HASHIMOTO
3rd Officer	AKIRA SUZUKI
Chief Engineer	EIJI SAKAGUCHI
1st Engineer	WATARU KUROSE
2nd Engineer	SABURO SAKAEMURA
3rd Engineer	SHOTA NAGANO
Chief Radio Officer	MASAMOTO TAKAHASHI
2nd Radio Officer	HIROKI ISHIWATA
3rd Radio Officer	TATSUHIRO TAKAKUWA
Jr 3rd Radio Officer	YOSHIKAZU KURAMOTO
Boat Swain	KOZO YATOGO
Able Seaman	KUNIHARU KADOGUCHI
Able Seaman	HIDEO ISOBE
Able Seaman	NAO ISHIZUKA
Sailor	HIROTAKA SHIGETA
Sailor	KAZUHO IKEDA
Sailor	HIDEO ITO
No.1 Oiler	KIYOSHI YAHATA
Oiler	KAZUO ABE
Oiler	SHINYA SUGI
Oiler	MASANORI UEDA
Oiler	RYO MATSUUCHI
Chief Steward	RYUEI TAKEMURA
Steward	HIDEO FUKUMURA
Steward	TATSUYA YAMAMOTO
Steward	HIROKI FUKUDA
Steward	KEI ITO