—Report—

Physical and magnetic properties of piston core samples collected from the Japan Trench before the 2011 Tohoku earthquake

Kiichiro Kawamura1,2,4* Toshiya Kanamatsu2, Masayuki Oishi3, and Makoto Yamano4

We report in detail deep-sea sediments around the Japan Trench. We have collected core samples using a piston corer system and a MBARI type corer during the cruises KH-05-3 and KH-07-3 by R/V Hakuho-maru and KR04-08, KR08-10, KR09-16 and KR10-12 by R/V Kairei of Japan Agency for Marine-Earth Science and Technology. We recovered totally sixteen piston core samples and two MBARI type core samples in these cruises before the 2011 Tohoku earthquake. Fourteen coring sites are located on the outer rise on the Pacific plate, and 4 sites are on the landward trench slope. The core sediments are predominantly composed of diatomaceous silty clay interbedded with volcanic ash layers. Physical and magnetic properties of the core sediments, and lithological characteristics of tephras such as the refractive indices of volcanic glass and phenocrysts are reported as well.

Keywords: vane shear strength, anisotropy of magnetic susceptibility, physical properties, time-marker tephra

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1. Introduction

Sixteen piston core samples were collected from deep sea floor in the northern Japan Trench area off northeast Japan (Table 1; Figs. 1 and 2) using a 4-m-piston-corer system during six research cruises of KR04-08, KR08-10, KR09-16 and KR10-12 by R/V Kairei and KH-05-3 and KH-07-3 by R/V Hakuho-maru. Only one core of KR10-12 PC01 was sampled using a 6-m-piston-corer system. Two MBARI core samples were collected during the research cruises of KR08-10 and KR09-16. These cores were collected before the 2011 Tohoku earthquake.

In this paper, we describe in detail these sediment cores and report physical, mechanical, magnetic properties and volcanic glass indices in the samples as a data report. Core photos and lithological columns are shown in this paper as well. These core samples record the sedimentary structures before the earthquake. According to Ikehara (2012) and Arai et al. (2013), sandy sediments were transported from an area shallower than several hundred meters in water depth and deposited on seabed of several thousand meters in water depth after the earthquake. This deposition might be a key to understanding paleo-earthquake events and/or paleo-tsunami events in marine core samples. We think that these core samples before the earthquake play an important role in comparison studies between core samples before and after the earthquake.

2. Core descriptions

For onboard treatments of the piston core samples, we have processed as follows: 1) Cut the whole core by 1 m section, 2) Split the whole core into working and archive halves, 3) Measure thermal conductivity, 4) Describe the cores by naked eyes and smear slides following the ODP technical note (Mazzullo and Graham, 1988), and take photographs, 5) Measure shear strength of the core samples using a vane shear tester, 6) Take samples successively using 7-cc-plastic-cubes for measurements of physical and magnetic properties. Although we reported already the core description in detail in cruise reports of KR08-10, KR09-16 and KR10-12 (Yamano, 2008; 2009; 2010), we describe briefly them in this paper as follows.

2.1 Cruise KR04-08

We recovered one piston core of PC01 in the cruise KR04-08 (Fig. 2). PC01 of 349.5 cm long was recovered from an outer rim of a moat (~80 m deep and ~2 km wide) around a knoll on the Pacific plate (Figs. 3 and 4). The dominant lithology is diatomaceous silty clay, which is olive brown (2.5Y4/3) at 0–5 cm below seafloor (hereafter cm-bsf) and olive black (7.5Y3/1) at 5–349.5 cm-bsf. It

Table 1. Location of coring sites. WD = water depth, CL = core length.

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Fig. 1. Topography in the Japan Trench and location of study area
is interbedded with three olive gray (2.5GY6/1 or 7/1) volcanic ash layers at 113–115 cm-bsf, 203.5–207.5 cm-bsf and 222.5–225.5 cm-bsf showing normal grading.

2.2 Cruise KII-05-3

Three piston cores of HP-1, -2, -3 were recovered in the cruise KH-05-3 (Fig. 2). These cores were collected from a flat floor on the outer rise on the Pacific plate. These cores are composed of predominantly diatomaceous silty clays (Figs. 3 and 4) as described in detail below.

HP-1 of 66.0 cm long is composed of diatomaceous silty clay. We observed a brown layer at 0–6 cm-bsf. The color changes from brown to yellowish olive at 6 cm-bsf, and to olive at 10 cm-bsf. An ash layer is at 62–65 cm-bsf.

HP-2 of 259.5 cm long is diatomaceous silty clay. The color changes from brown to yellowish olive at 1 cm-bsf, and to olive at 4 cm-bsf. An ash layer is at 254.5–259.5 cm-bsf.

HP-3 of 222.0 cm long is an olive diatomaceous silty clay layer interbedded with ash layers at 23–31, 75–76, 106–109 and 114–121 cm-bsf and pumiceous sandy layers at 155–162, 182–203 and 208–222 cm-bsf.

2.3 Cruise KII-07-3

One piston core of PC-1 was collected on the outer rise nearby the trench axis during the cruise KH-07-3 (Fig. 2). PC-1 of 236.5 cm long is composed of diatomaceous silty clay, which is an olive gray (5Y3/2) at 0–18 cm-bsf and an olive black (5GY2/1) at 18–236.5 cm-bsf. We observed an olive gray (5Y4/1) volcanic ash layer at 209.5–210.5 cm-bsf and an olive gray (5Y3/2) siliceous ooze layer at 210.5–211.5 cm-bsf.

2.4 Cruise KR08-10

Six piston cores of PC01, 02, 03, 04, 05 and 06 were recovered in the cruise KR08-10 (Fig. 2). Three coring sites of PC01, 02 and 03 were located on the outer rise on the Pacific plate, and the other three coring sites of PC04, 05 and 06 were on the landward trench slope. In addition, we recovered a push core by remotely operated vehicle (ROV) Kaiko 7000 II (sample of 7K#430 C-1) from a flat floor near the Hokkaido Rise (outer rise on the Pacific plate). These cores are described in detail as follows (see Figs. 3 and 4).

PC01 of 307.0 cm long is predominantly olive black (10Y3/2) clayey silt to silty clay with diatoms, which is composed of mostly siliciclastic grains, diatoms, volcanic ashes and pumice.

Fig. 2. Coring sites of piston core samples in this study. Radial black bars show rose diagrams of corrected Kmax directions (see text). Arrows indicate bottom current directions as reported by previous studies.
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Fig. 3. Photographs of the core samples.
Fig. 4. Lithological columns of the core samples. Magnetic susceptibility (MS) in $10^{-5}$ SI and porosity (PO) in percent are shown by solid circle and open square plots, respectively.
glass and clay particles. The clayey silt has pyritized burrows filled with grayish mud in places. The silty clay is interbedded with dark greenish gray (10GY3/1) faint laminae in places. Grayish volcanic ash layers are seen at 112–116 cm-bsf and 300–307 cm-bsf. Just below the bottom of the core, two lapilli-sized pumices are in the core catcher (but most of the material in the core catcher were lost during the operation).

PC02 of 155.0 cm long is predominantly olive black (7.5Y3/2) silty clay including volcanic glasses. Two gray (7.5Y4/1 or 5/1) volcanic ash layers are seen at 12–13 cm-bsf and 80–84 cm-bsf.

PC03 of 161.5 cm long is olive black (10Y3/2) silty clay with diatoms. Two volcanic ash layers are seen at 24.5–26.5 and 118.5–126.5 cm-bsf. A rounded pebble-sized mudstone is at 51.5 cm-bsf, which is probably a drop stone.

PC04 of 188.0 cm long is predominantly olive black (7.5Y3/2) sandy clay with diatoms. The sediments contain many volcanic glasses. Two pumiceous volcanic ash layers are seen at 47–49 and 156–164 cm-bsf.

PC05 of 243.0 cm long is predominantly olive black (7.5Y3/2 or 10Y3/2) silty clay with diatoms. The sediments contain many volcanic glasses. A gray (5Y4/1) volcanic ash layer is seen at 58–60 cm-bsf. A drop stone of a rounded pebble-sized gabbroic rock is seen at 197.5 cm-bsf.

PC06 of 245.0 cm long is composed of predominantly olive black (7.5Y3/2 or 10Y3/2) silty clay with diatoms. The sediments contain many volcanic glasses throughout the core. Two volcanic ash layers are seen at 80–86 and 230–233 cm-bsf. At 185–230 cm-bsf, the core sediments are sandy clay with forams and/or diatoms. In the sandy clay, normal grading is seen at 185–199, 199–217, and 217–230 cm-bsf.

The core 7K#462 C-2 of 27.5 cm long was collected from the flat mud surface. It is composed of mainly olive black (7.5Y3/2) diatom silty clay. The surface oxidized layer is dark olive brown (2.5Y3/3) diatom silty clay.

2.6 Cruise KR10-12

We recovered three piston cores of PC01, 02 and 03 in the cruise KR10-12 (Fig. 2). Two coring sites of PC01 and 02 were located on the outer rise on the Pacific plate, and one coring site of PC03 was located on the landward trench slope. These cores are described in detail as below (see Figs. 3 and 4).

PC01 of 274.5 cm long is predominantly olive gray (7.5Y4/1) diatom silty clay, which is composed of mostly diatoms, siliciclastic grains, clay particles, and volcanic glasses. At 247–274.5 cm-bsf, the diatom silty clay is interbedded with dark greenish gray (10GY3/1) faint laminae in places. Olive black (7.5Y3/2) medium to fine volcanic ash layer with normal grading is seen at 105–107 cm-bsf. A light gray (5Y7/1) fine volcanic ash layer is at 139–144 cm-bsf.

PC02 of 287.5 cm long is predominantly olive black (10Y3/2) diatom silty clay including volcanic glasses. Three black (7.5Y2/1 or 3/1) scoriaceous volcanic ash layers are seen at 80–81, 184.5–185.5 and 224.5–225.5 cm-bsf.

The core 7K#462 C-2 of 27.5 cm long was collected from the flat mud surface. It is composed of mainly olive black (7.5Y3/2) diatom silty clay. The surface oxidized layer is dark olive brown (2.5Y3/3) diatom silty clay.

2.5 Cruise KR09-16

We recovered two piston cores of PC01 and 02 in the cruise KR09-16 (Fig. 2). In addition, we recovered a push core sample of 7K#462C-2 from a flat floor on the outer rise on the Pacific plate. These cores are described in detail as below (see Figs. 3 and 4).
3. Methods

For these cores, we measured physical and magnetic properties and volcanic glass indices using the following methods.

3.1 Physical and mechanical properties

Void ratios and porosities were calculated from volume, wet and dry weights of sediments as shown in Ikehara (1989). The sediments were packed in a plastic cube (7 cm$^3$ = sample volume) for every 2 cm interval, and we measured the void ratios and porosities using the cube samples by every 4 cm interval.

Undrained shear strengths of the core samples were measured by the laboratory miniature-vane-shear apparatus. The vane-shear test was performed following the Japanese Geotechnical Society (2000) standard, using a torque driver with a 20-mm high and 10-mm diameter vane. The measurements were conducted as follows: 1) the whole wings of the torque driver were penetrated directly into the split surface, 2) the torque driver was rotated slowly at a rotation rate of ~90°/min, 3) record the maximum torque force. The shear strength is calculated from the shear friction working during rotation.

3.2 Magnetic properties

Samples were packed in 7 cm$^3$ plastic cubes for AMS (anisotropy of magnetic susceptibility) and paleomagnetic measurements using KLY-3 and -4 anisotropy magnetic susceptometers (AGICO Co. Ltd., Czech) and a 2G-Enterprise superconducting magnetometer (2G-Enterprises, CA, USA), respectively.

The AMS results are geometrically expressed by an ellipsoid with three principal axes: maximum (Kmax), intermediate (Kint), and minimum (Kmin) magnetic susceptibilities. It is generally accepted that the ellipsoid is controlled by arrangement patterns of magnetic particles in sediments (Tarling and Hrouda, 1993).

The northern magnetized direction in the samples, which deviated during core sampling, was determined by paleomagnetic declinations and was used to correct the AMS orientations. Because the declination data are rotated gradually downward due to twist during coring within one core, magnetic north was calculated accordingly by the least-squares method. A correction to magnetic north is applied.

Because all the minerals in marine sediments contribute to the AMS to various degrees, it is important to define the kind of mineral most responsible for the measured magnetic fabric. This was conducted by following a magnetic hysteresis analysis using a MicroMag AGM2900 Model (Princeton Co. Ltd., UK). The MicroMag measures susceptibility in high magnetic fields (K$_{hf}$) of 500–900 G. The K$_{hf}$ is generally a result of mainly paramagnetic minerals rather than ferrimagnetic minerals (Housen and Sato, 1995; Housen, 1997). Low-field susceptibility (K$_{lf}$) in the sediments measured at 0.4 G using the KLY-4 can be subdivided into components that are contributed by both ferrimagnetic and paramagnetic minerals (Housen and Sato, 1995; Housen, 1997). The ratio of K$_{hf}$/K$_{lf}$ is inversely proportional to the relative contribution of ferrimagnetic minerals to the K$_{lf}$ (Housen and Sato, 1995; Housen, 1997).

3.3 Refractive indices

For the purpose of identification of the time-marker tephras, we analyzed refractive indices of some pumiceous deposits and deposits consisting of fine volcanic glass. Samples were washed in the laboratory, and volcanic glass and orthopyroxene and hornblende phenocrysts were gathered by hand-picking. Heavy minerals were crashed to be easy to observe, using agate mortar. These particles were enclosed within the glass cell with immersion oil. We measured using a Refractive Index Measurement System (RIMS 2000; Kyoto Fission-Track Co., Ltd.; Danhara, 1991). More than thirty points were measured in each sample.

4. Results

Measurement results of physical, mechanical and magnetic properties are shown in Appendix 1.

We plotted the void ratios versus vane shear strengths (Fig. 5). The void ratios of all the sediments range from ~5.0 to ~1.1, and vane shear strengths are from ~0 to ~29 kPa (Fig. 5). Porosity values decrease constantly from 90 to 40% throughout the cores (Fig. 4). These changes of the physical and mechanical properties result from burial consolidation.

The magnetic susceptibility values range from ~0 to ~15 × 10$^{-3}$ SI (Fig. 4). Most of the spike peaks of the magnetic susceptibility correspond to the volcanic ash layers (Fig. 4). The corrected Kmax directions are projected by a
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Fig. 5. Vane shear strength (VSS) versus void ratio (VR).

Table 2. Measurement results of MicroMag AGM2900 Model. Hcr = remanent coercivity, Hc = coercivity, Mr = magnetic remanance, Ms = saturation magnetization, Khf, Klf = high and low field magnetic susceptibility (see text), KHF/KLF = ratio of high and low field magnetic susceptibility

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<th>Sec.</th>
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<th>Hcr</th>
<th>Hc</th>
<th>Mr</th>
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Table 3. Results of refractive index analysis (n of volcanic glass, y of orthopyroxene, n² of hornblende phenocrysts). The type of volcanic glass: bw = bubble wall type, fi = fiber type, jc = junction type, pm = pumiceous type. Minerals: cpx = clinopyroxene, ho = hornblende, opx = orthopyroxene.

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rose diagram on the topographic map as shown in Fig. 2. The Kmax directions are sub-parallel to bottom current directions as shown by Owens and Warren (2001).

Magnetic hysteresis data were measured in 10 samples of diatomaceous silty clay (Table 2). Paramagnetic fraction is less than 10% in most of the samples, but a sample of KR08-10 PC06 shows more than 50% (Table 2). These results indicate that the ferrimagnetic mineral grains (e.g. magnetite) should align sub-parallel to the bottom currents.

The results of refractive indices of volcanic glass and orthopyroxene and hornblende phenocrysts in 12 tephra samples are shown in Table 3. We estimated that the samples of KH-07-3 PC01 209.5–210.5 cm-bsf, KR08–10 PC01 109–113 cm-bsf, PC02 13–19 cm-bsf, PC03 24.5–26.5 cm-bsf, PC04 47–49 cm-bsf, PC05 58–60 cm-bsf, PC06 84–86 cm-bsf would be correlated to To-HP tephra (15 ka; Machida et al., 2003). Based on the result, the sedimentation rates of all the cores are 3–10 cm/kyr on average, although there might be large variation of the sedimentation rates under the local topographic effects. On the other hand, the tephra samples containing fine bubble wall glass shards (KR08-10 PC01 84–91 cm-bsf, PC02 4–17 cm-bsf, PC03 56–64 cm-bsf, and PC06 85–88 cm-bsf) and the tephra of KR08-10 PC04 72–78 cm-bsf could not be correlated to wide spread tephra. Therefore, we have to analyze in detail such as chemical composition for more certain identification of each tephra layer. This work will enable us to determine the ages and sedimentation rates of deposits with a high degree of accuracy.

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References


Supporting Online Material

https://www.jstage.jst.go.jp/browse/jamstecr

Supplemental table: Physical, magnetic and mechanical properties of core collected during cruises KR04-08, KH-05-3, KH-07-3, KR08-10, KR09-16 and KR10-12. Each cruise data set is shown in each sheet. Cube# = sample name of 7 cm$^3$ sample, Cruise = cruise name, PC No. = core number, W/A = working or archive halves, Sec. = section number, depth = sediment depth below seafloor, MS = magnetic susceptibility (SI unit), K1, K2, K3 = intensity of maximum, intermediate, minimum magnetic susceptibility, L = magnetic lineation degree (Kint/Kmin), F = magnetic foliation (Kmax/Kint), P = anisotropy degree (Kmax/Kmin), P' = corrected P, T = shape parameter, q = shape parameter for unconsolidated sediments, K1(2,3)a = Kmax (int, min) azimuth (0 is north, clockwise is positive), Cor. K1(2,3)a = corrected Kmax (int, min) azimuth by paleomagnetic north, K1(2,3)d = Kmax (int, min) dip angle (0 is horizontal, down is positive), AF = alternating field demagnetization (AFD) degree by paleomagnetism, Unit is Gauss. Int. = paleomagnetic intensity after 200 G AFD, Dec. = paleomagnetic declination by 200 G AFD, C. Dec. = calculated declination (see text), Inc. = paleomagnetic inclination by 200 G AFD, Ww = wet weight of 7 cm$^3$ sample, Dw = its dry weight, WBD = wet bulk density, WC = water content, PO = porosity, VR = void ratio, VSS = vane shear strength.