Yamazaki et al. Earth, Planets and Space (2016) 68:174
DOI 10.1186/s40623-016-0561-7

Earth, Planets and Space

LETTER Open Access

Paleomagnetic inclination variations during the last 200 kyr in the Okhotsk Sea and their relation to persistent non-axial-dipole field

Toshitsugu Yamazaki[1,2,3*], Takaya Shimono[3,4] and Seiko Inoue[3]

Abstract

Studies on geomagnetic paleointensity using marine sediments revealed that intensity fluctuations contain variations with timescales of 10^4 years and longer. In contrast, directional secular variations of such timescales were far less studied. In this paper we study inclination variations of longer than a millennial timescale using sediment cores at nine sites in the Okhotsk Sea. Relative paleointensity and magnetic susceptibility variations were used for inter-core correlations and age estimations. The average inclinations of individual cores were close to those of the geocentric axial dipole (GAD) field at the site latitudes. A stacked inclination curve for the last 200 kyr showed intervals of shallower inclinations at about 25–45, 75–90, 110–135, and 185–200 ka. These are synchronous with inclination shifts toward negative previously reported in the western equatorial Pacific, and temporally coincide with paleointensity lows in general. Both the Okhotsk Sea and western equatorial Pacific are within a region of outward directed flux in the persistent non-axial-dipole (NAD) field, and the synchronous inclination shifts may have been caused by a larger contribution of the NAD field when the GAD was weaker.

Keywords: Paleomagnetism, Inclination, Paleointensity, Non-axial-dipole, Okhotsk Sea, Western equatorial Pacific

Introduction

Continuous records of past geomagnetic intensity variations during the last few million years recovered from marine sediments revealed that paleointensity fluctuations between polarity reversals contain variations with timescales of 10^4 years and longer (e.g., Guyodo and Valet 1999; Yamazaki and Oda 2005; Valet et al. 2005; Channell et al. 2009; Tauxe and Yamazaki 2015). It is expected that paleomagnetic direction also has secular variations of such timescales. However, discussion on directional secular variations has mostly been for centennial to millennial timescales utilizing datasets during Holocene (e.g., Korte and Constable 2005; Lund et al. 2006; Yang et al. 2009; Constable and Korte 2015). Directional secular variations of 10^4 or longer timescales, if exist, would have an amplitude of ~5° or smaller, similar to differences between the time-averaged field during the last few million years and the geocentric axial dipole (GAD) field. Such variations are close to sampling and measurement errors for studies using sediment cores, and not easy to be detected. To enhance signal-to-noise ratios, precise inter-core correlations among many cores are required, which is also not easy to be performed.

Occurrence of inclination variations with timescales of 10^4 years and longer was previously reported using sediment cores from the western equatorial Pacific (Yamazaki and Ioka 1994; Yamazaki and Oda 2002; Yamazaki et al. 2008). Using a continuous inclination record for the last 2 m.y., a possibility of orbital influence on inclination variations was argued (Yamazaki and Oda 2002; Roberts et al. 2003). Correlation between paleointensity and inclination was also investigated using some records from this region, and a model explaining

*Correspondence: yamazaki@aori.u-tokyo.ac.jp
[1] Atmosphere and Ocean Research Institute, University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa, Chiba 277-8564, Japan
Full list of author information is available at the end of the article

the correlation was proposed (Yamazaki and Oda 2002, 2004; Yamazaki 2002). For better understanding of the geomagnetic field behavior of 10^4 year and longer timescales, further accumulation of datasets with global site distribution is required. It is also necessary to understand long-term secular variations for tectonic application of paleomagnetism assuming the GAD field; we need to know a period of time required for averaging out secular variations in order to detect differences of several degrees in paleolatitudes.

In this paper, we present inclination variations during the last 200 kyr recorded in sediment cores from the Okhotsk Sea. Three piston cores and nine gravity cores adjacent to each other were used for stacking. We show that synchronous inclination shifts occur in the Okhotsk Sea and western equatorial Pacific and that the inclination variations may correlate with paleointensity. We then present a model for the coherent variations.

Samples and methods

Three piston cores of about 20 m long were obtained from the central part of the Okhotsk Sea during the *R/V Mirai* MR06-04 cruise in 2006, and nine gravity cores of about 6 m or less in length were obtained from the same area during the *R/V Yokosuka* YK07-12 cruise in 2007 (Fig. 1; Table 1). Three gravity cores out of nine were reoccupation of the three piston-core sites to make up for disturbed surface sediments. Composite core sections, GC1 + PC7, GC8 + PC6, and GC9 + PC5, were established at the three sites (Yamazaki et al. 2013). Discrete samples for paleo- and rock magnetic measurements were taken sequentially from the half-split core surfaces using plastic cubes of 7 cm^3 each.

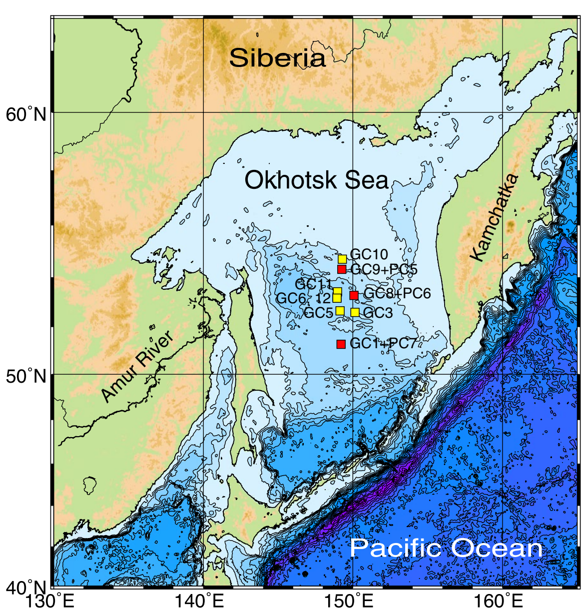

Fig. 1 Locations of cores used in this study. *Red* composite sites of piston and gravity cores, *yellow* gravity-core sites

Relative paleointensity and magnetic properties of the three major sites, GC1 + PC7, GC8 + PC6, and GC9 + PC5, were already reported by Inoue and Yamazaki (2010) and Yamazaki et al. (2013). The procedure of paleo- and rock magnetic measurements of other gravity-core sites, GC3, GC5, GC6, GC10, GC11, and GC12, was the same as that of Inoue and Yamazaki (2010) and Yamazaki et al. (2013). Stepwise alternating-field (AF) demagnetization showed univectorial behavior in general except for a soft secondary component that was removed at AF of 10 mT or less. Most samples have maximum standard deviation (MAD) of <10° at principal component analysis (Kirschvink 1980); a small number of samples with MAD >10° were discarded. For relative paleointensity estimation, anhysteretic remanent magnetization (ARM) was chosen as a normalizer of natural remanent magnetization (NRM) for compensating differences in NRM acquisition efficiency, and NRM and ARM intensities after AF demagnetization at 30 mT were used for calculating relative paleointensity.

Inter-core correlation and age assignment

The scheme of inter-core correlations is shown in Fig. 2. Correlations and age estimations of the three major sites, GC1 + PC7, GC8 + PC6, and GC9 + PC5, were based on relative paleointensity, which was tied to the PISO-1500 curve of Channell et al. (2009), as presented in Yamazaki et al. (2013). The cores of the three sites cover the last 360–520 kyr with the average sedimentation rates of 37–59 m/m.y. The age model based on the oxygen-isotope ($\delta^{18}O$) stratigraphy at Site GC1 + PC7 well agrees with that of relative paleointensity (Yamazaki et al. 2013). Coincidence of the relative paleointensity records of the three major sites is generally good (Fig. 3a), although relatively large temporal and spatial lithological changes in the Okhotsk Sea sediments (Nürnberg and Tiedemann 2004; Yamazaki et al. 2013) are not ideal for relative paleointensity estimations, and thus, the records may partly be influenced by lithological changes (Tauxe and Yamazaki 2015).

Other short gravity-core sites were, on the other hand, tied to the Site GC1 + PC7 or GC9 + PC5 based on inter-core correlation using magnetic susceptibility (Fig. 2). We chose magnetic susceptibility for the correlation rather than relative paleointensity because the number of conspicuous features that can be used for correlation is larger in magnetic susceptibility for the cores that cover a relatively short period of time. The Site GC10, the northernmost site, was tied to Site GC9 + PC5, whereas other southern sites are correlated

Table 1 Positions of coring sites and summary of inclination data

Site	Latitude (N)	Longitude (E)	Depth (m)	GAD *I*	Mean *I*	Δ*I*
GC1 + PC7	51°16.5′	149°12.5′	1253	68.2	71.2	3.0
GC3	52°36.1′	150°08.3′	1048	69.1	69.9	0.8
GC5	52°39.6′	149°08.8′	1084	69.1	75.0	5.9
GC6	53°13.5′	148°56.5′	1456	69.5	64.6	−4.9
GC8 + PC6	53°16.9′	150°04.7′	1145	69.5	69.2	−0.3
GC9 + PC5	54°19.0′	149°16.1′	828	70.2	70.9	0.7
GC10	54°43.0′	149°17.9′	513	70.5	70.8	0.3
GC11	53°25.7′	148°58.3′	1381	69.6	68.8	−0.8
GC12	53°10.4′	148°56.5′	1299	69.5	74.2	4.7

I inclination, *GAD* geocentric axial dipole, Δ*I* inclination anomaly (observed inclination minus GAD inclination)

to Site GC1 + PC7 (Fig. 2). This is because environmental changes and thus magnetic property changes including magnetic susceptibility were asynchronous between the northern and southern parts of the Okhotsk Sea (Yamazaki et al. 2013); this is why relative paleointensity was used for the correlation of the three major sites. The southern part (Sites GC1 + PC7 and GC8 + PC6) was in mobile sea-ice conditions even in full glacials, and accumulation of ice-rafted debris (IRD) increased in glacial and deglacial periods. This was succeeded by extremely enhanced ocean productivity induced by nearly ice-free conditions in early interglacials. The northern part (Site GC9 + PC5) was, on the other hand, covered with perennial sea ice in glacials, and IRD accumulation was low in glacials and increased in early interglacials. Succeeding ocean-productivity enhancement was delayed compared to the southern part (Yamazaki et al. 2013).

The correlation between Site GC3 and Site GC1 + PC7 is shown in Fig. 4; the correlations of other sites are presented in Additional file 1, Additional file 2, Additional file 3, Additional file 4, and Additional file 5. A constant sedimentation rate was assumed between tie points. The inter-core correlations using magnetic susceptibility yielded relative paleointensity variations consistent with each other. Estimated ages of the bottom of the gravity cores range from about 57 (Site GC11) to 197 ka (Site GC3). Age–depth curves of individual cores are shown in Additional file 6. The average sedimentation rate is from 21 (Site GC5) to 92 m/m.y. (Site GC6), which corresponds to time intervals of 1100 and 250 years for each discrete sample, respectively.

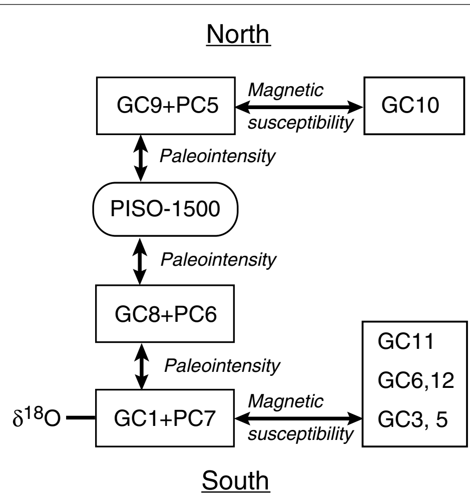

Fig. 2 Scheme of inter-core correlation and age assignment

Results and discussion

Inclination records of the three major sites are shown in Fig. 3, which suggests that variations of a timescale of a few tens of 1000 years occur in common. Inclination records of each gravity-core site are presented in Fig. 4 and Additional file 1, Additional file 2, Additional file 3, Additional file 4, and Additional file 5 together with the records of the target sites of the inter-core correlations with magnetic susceptibility. The agreement of inclination records between the coupled sites is generally good. Inclination data of all nine sites are superimposed in Fig. 5a. Inclination variations with a timescale of a few tens of thousand years are visible. Sudden inclination decreases were observed at about 28, 35–40, 64 85, 113, and 188–195 ka in two or more cores. Part of them are close in age to known geomagnetic excursions, the Mono Lake excursion at ~33 ka, the Laschamp at ~41 ka, the Blake at ~120 ka, and the Iceland Basin at ~188 ka (Roberts 2008), and they may have recorded the excursions. On the other hand, low inclination spikes at about 128 and 180 ka, which were recorded in only one core (Site GC9 + PC5), may not be of geomagnetic origin.

We constructed a stacked inclination record of the Okhotsk Sea. The age interval of the stack was limited for the last 200 kyr because the number of available cores

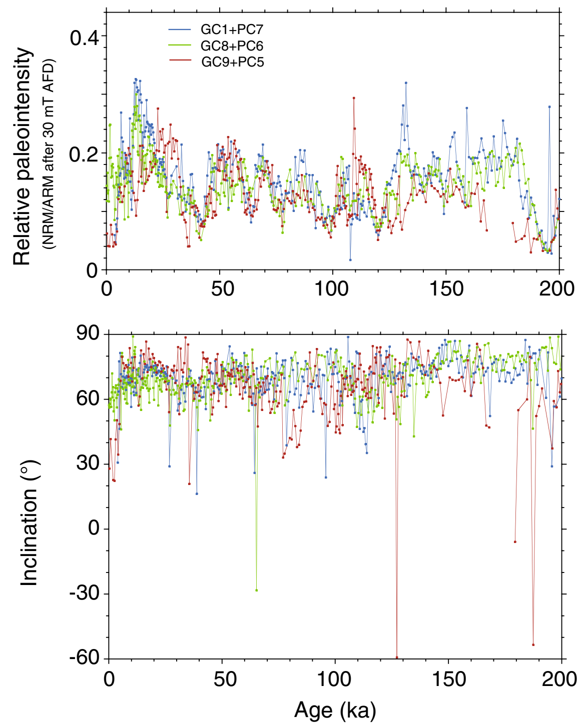

Fig. 3 Relative paleointensity and inclination of the three composite core sites. Relative paleointensity (*upper*) and inclination (*lower*) records of individual sites are superimposed. Paleointensity records are after Yamazaki et al. (2013). *Blue* Site GC1 + PC7, *green* Site GC8 + PC6, *red* Site GC9 and PC5

for older ages is small, three or less. First, the mean inclination of each site was calculated between 0 and 100 ka (Table 1). Inclination data from the uppermost 20 cm of each core were removed because of possible physical disturbance of surface sediments during coring. For calculating the mean inclination, incfish.py of the pmag.py programs for inclination-only data (Tauxe 2010) was used. Inclination anomaly (ΔI) of each site, which is defined as observed mean inclination minus GAD inclination, ranges from −4.9° to 5.9° (Table 1), and the mean ΔI of the nine sites is 1.0° ± 3.2° (the mean ΔI is 2.1° ± 1.7° when calculated between 0 and 200 ka for four sites that cover this time interval). Next, we chose Site GC1 + PC7 as a representative location, and differences in inclinations expected from the differences in site latitudes were corrected using GAD inclinations. In addition, inclinations of each site were shifted slightly so that the ΔI of each site becomes zero. Then, the mean and standard deviation were calculated at 1-kyr intervals after resampling of each record (Fig. 5b). Long-term inclination variations are visible on the stacked record; intervals of shallower inclinations occur at about 25–45, 75–90, 110–135, and 185–200 ka in the Okhotsk Sea.

We then compare the inclination stack from the Okhotsk Sea with the stacks of relative paleointensity and inclination from the West Caroline Basin in the western equatorial Pacific (Yamazaki et al. 2008; Fig. 5). The inclination records of the two regions show parallel variations,

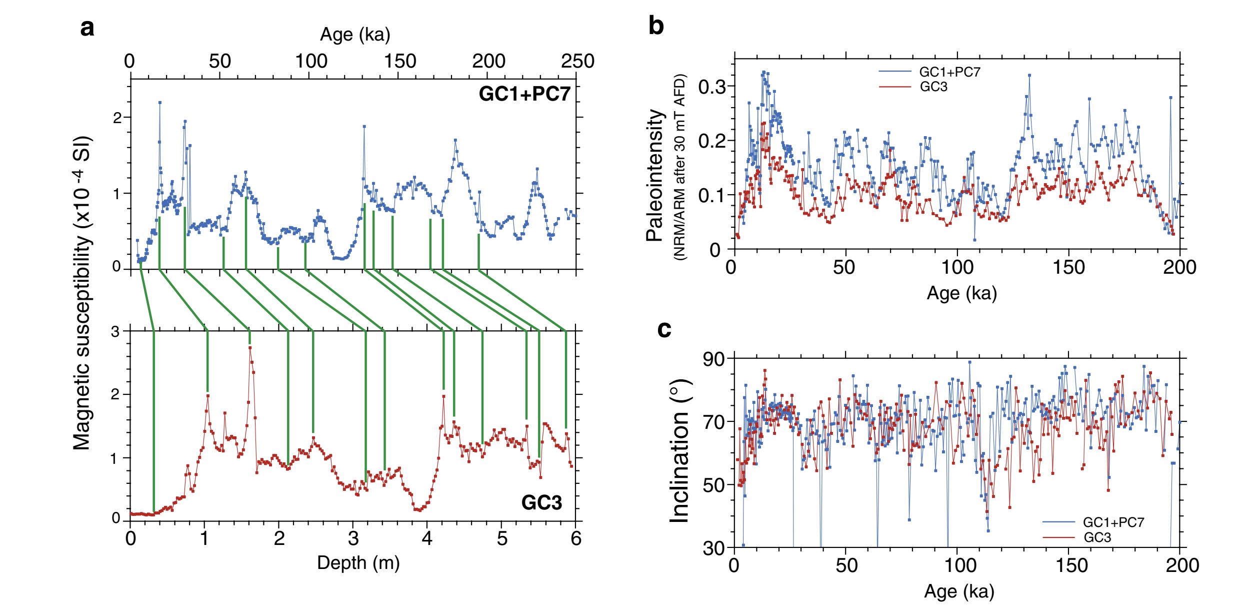

Fig. 4 Inter-core correlation between Sites GC1 + PC7 and GC3. **a** Correlation and age estimation using magnetic susceptibility, **b** comparison of relative paleointensity records after the correlation, and **c** corresponding inclination records

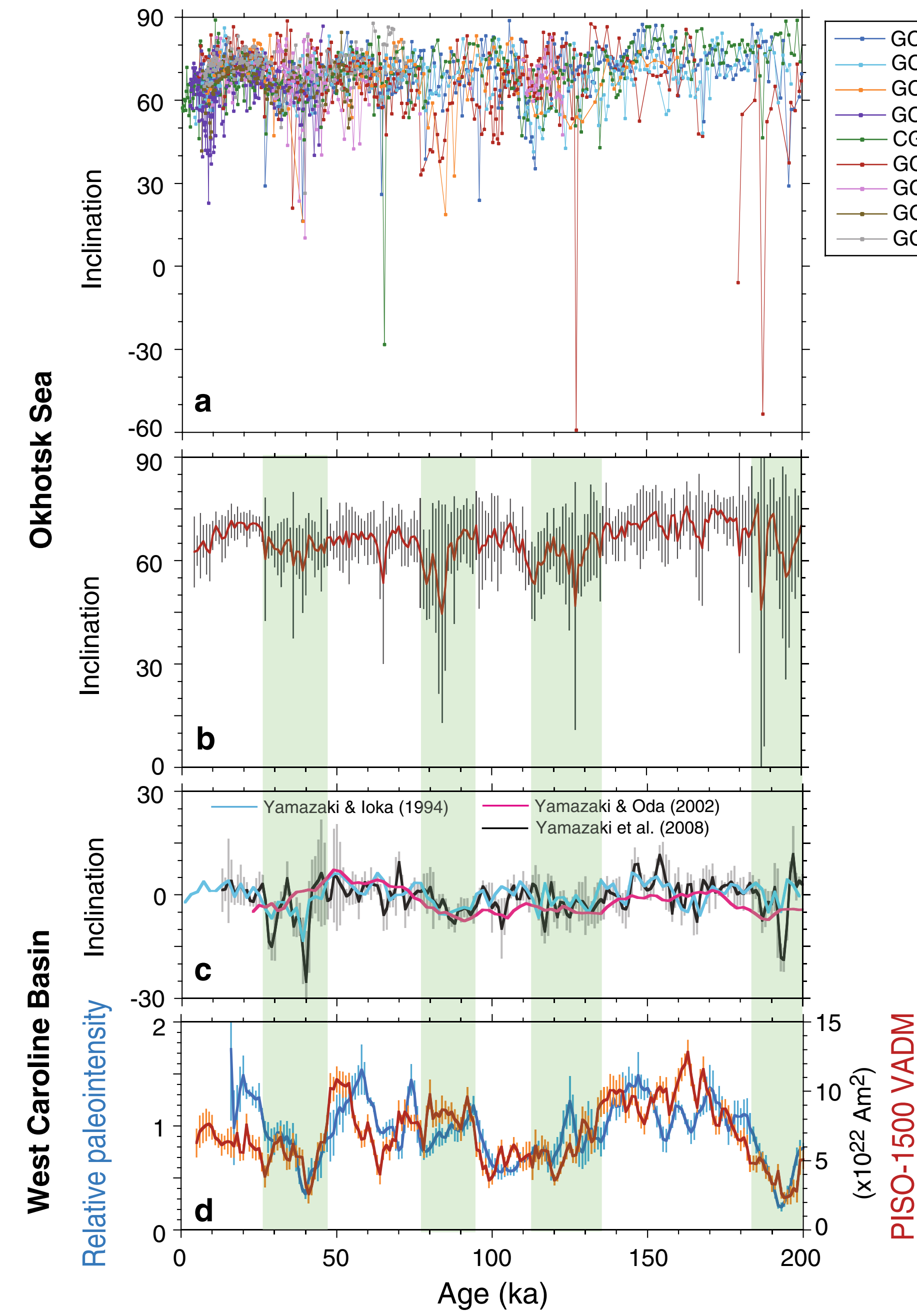

Fig. 5 Inclination stack of the Okhotsk Sea and comparison with the western equatorial Pacific. **a** Individual and **b** stacked inclination records at the nine sites in the Okhotsk Sea during the last 200 kyr, **c** inclination stacks [*blue* Yamazaki and Ioka (1994), *black* Yamazaki et al. (2008), note that the average inclination of each core was set to zero for stacking] and a inclination record of Yamazaki and Oda (2002) (*red*) from the West Caroline Basin in the western equatorial Pacific, and **d** relative paleointensity stacks of Yamazaki et al. (2008) from the West Caroline Basin (*blue*) and the PISO-1500 paleointensity stack of Channell et al. (2009) (*red*). *Light green* bands indicate periods of shallower inclinations in the Okhotsk Sea and coeval steeper negative inclinations in the West Caroline Basin in the western equatorial Pacific

although the two regions are about 5000 km apart; the periods of shallower inclinations in the Okhotsk Sea at about 25–45, 75–90, 110–135, and 185–200 ka coincide with those of negative steeper inclinations in the West Caroline Basin. These inclination shifts are synchronous with relative paleointensity lows in general (Fig. 5), as pointed out in the West Caroline Basin by Yamazaki and Oda (2002) and Yamazaki et al. (2008), although a period of paleointensity low around 100 ka contradictorily has steeper, but not shallower, inclinations in the Okhotsk Sea.

Yamazaki and Oda (2002, 2004) and Yamazaki et al. (2008) explained the inclination and paleointensity variations observed in the western equatorial Pacific that relative contribution of a persistent quadrupole component increased when the strength of the GAD field decreased. The western equatorial Pacific is known to have a large ΔI associated with a quadrupole component, and the sign of ΔI flips with polarity reversals (Johnson and Constable 1997). From sediment cores in the West Caroline Basin, ΔI of $-6.5° \pm 2.8°$ ($N = 13$) in the Brunhes Chron was reported (Yamazaki et al. 2008). The phase of the paleointensity–inclination correlation also flipped with polarity reversals, in-phase in the Brunhes Chron and anti-phase in the Matuyama Chron (Yamazaki and Oda 2002). The coeval inclination variations observed in the Okhotsk Sea, however, cannot be explained by this model because ΔI in this area is near zero, as observed in our cores.

Hoffman and Singer (2008) proposed that a magnetic field at Earth's surface during polarity transitions and excursions is dominated by a field generated only in the shallower part of the core, designated the SCOR field. They also proposed that the SCOR field is represented by persisting higher-degree terms other than the GAD field and lasts for a timescale of ~10^6 years. Both the Okhotsk Sea and western equatorial Pacific are within a region of outward directed flux in the 1590–1990 time-averaged non-axial-dipole (NAD) field, which extends from Europe and Asia to the south of Australia (Hoffman and Singer 2008; Constable and Korte 2015). Thus, the observed inclination shifts around excursions, shallower in the Okhotsk Sea and deeper toward negative in the western equatorial Pacific, may be explained by a larger contribution of the SCOR field when the GAD was weak. In the western North Atlantic, the 1590–1990 time-averaged NAD field has opposite inward flux. In this region, periods of steeper inclinations than the site averages, in which rapid excursional directional swings are intercalated, were observed near the Laschamp excursion (Lund et al. 2001, 2005) and "excursions 13a, 15a, and 17a" (~510, ~573, and ~666 ka, respectively; Lund et al. 2001). This may support the SCOR field model. The coherent shifts in inclinations among the Okhotsk Sea, western equatorial Pacific, and North Atlantic may also be explained by hypothetical dipole wobbles. However, the correspondence of the inclination shifts to paleointensity lows prefers the SCOR field model.

Conclusions

In this study, we obtained a stacked inclination record for the last 200 kyr in the Okhotsk Sea. The mean inclination anomaly of nine sites is close to zero. Inclinations shallower than the average occurred at 25–45, 75–90, 110–135, and 185–200 ka. These are synchronous to inclination shifts toward negative reported in the western equatorial Pacific and coincide in general with paleointensity lows. The synchronous inclination shifts associated with decreased paleointensity may be explained by a larger contribution of the SCOR field proposed by Hoffman and Singer (2008) when the GAD was weaker; both the Okhotsk Sea and western equatorial Pacific are within a region of outward directed flux in the persistent NAD field.

Additional files

Additional file 1. Inter-core correlation between Sites GC1 + PC7 and GC5. (a) Correlation and age estimation using magnetic susceptibility, (b) comparison of relative paleointensity records after the correlation, and (c) corresponding inclination records.

Additional file 2. Inter-core correlation between Sites GC1 + PC7 and GC6. (a) Correlation and age estimation using magnetic susceptibility, (b) comparison of relative paleointensity records after the correlation, and (c) corresponding inclination records.

Additional file 3. Inter-core correlation between Sites GC9 + PC5 and GC10 (a) Correlation and age estimation using magnetic susceptibility, (b) comparison of relative paleointensity records after the correlation, and (c) corresponding inclination records.

Additional file 4. Inter-core correlation between Sites GC1 + PC7 and GC11. (a) Correlation and age estimation using magnetic susceptibility, (b) comparison of relative paleointensity records after the correlation, and (c) corresponding inclination records.

Additional file 5. Inter-core correlation between Sites GC1 + PC7 and GC12. (a) Correlation and age estimation using magnetic susceptibility, (b) comparison of relative paleointensity records after the correlation, and (c) corresponding inclination records.

Additional file 6. Age-depth curves of studied cores.

Abbreviations

AF: alternating field; AIST: National Institute of Advanced Industrial Science and Technology; ARM: anhysteretic remanent magnetization; GAD: geocentric axial dipole; GSJ: Geological Survey of Japan; MAD: maximum angular deviation; NAD: non-axial-dipole; NRM: natural remanent magnetization; SCOR: shallow core.

Authors' contributions

TY designed the project, analyzed the data, and wrote the manuscript. TS and SI conducted paleomagnetic measurements and analyzed the data. All authors read and approved the final manuscript.

Author details

[1] Atmosphere and Ocean Research Institute, University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa, Chiba 277-8564, Japan. [2] Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan. [3] Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8572, Japan. [4] Gas Hydrate Research Laboratory, Meiji University, Tokyo 101-8301, Japan.

Acknowledgements

We thank Emi Kariya for help with the paleomagnetic measurements. The paleomagnetic measurements were conducted at the Geological Survey of Japan (GSJ), AIST, when TY was an employee and TS and SI were trainees of the GSJ. The samples used in this study were made available to us by the effort of all personnel related to the *R/V Mirai* MR06-04 cruise (chief scientist: Naomi

Harada) and *R/V Yokosuka* YK07-12 cruise (chief scientist: Tatsuhiko Sakamoto). This paper is based on our presentation at the 2016 Japan Geoscience Union meeting, and we thank Hidetoshi Shibuya for giving us the opportunity of the presentation. The manuscript was greatly improved by comments of anonymous reviewers. Part of this study was supported by a Grant-in-Aid for Scientific Research [(C) 19612002 and (A) 16H02233] from the Japan Society for the Promotion of Science.

Competing interests
The authors declare that they have no competing interests.

Received: 11 August 2016 Accepted: 1 November 2016
Published online: 09 November 2016

References
Channell JET, Xuan C, Hodell DA (2009) Stacking paleointensity and oxygen isotope data for the last 1.5 Myr (PISO-1500). Earth Planet Sci Lett 283:14–23. doi:10.1016/j.epsl.2009.03.012
Constable CG, Korte M (2015) Centennial- to millennial-scale geomagnetic field variations. In: Schubert G (ed) Treatise on geophysics, vol 5, 2nd edn. Elsevier, Oxford, pp 309–341
Guyodo Y, Valet J-P (1999) Global changes in intensity of the Earth's magnetic field during the past 800 kyr. Nature 399:249–252
Hoffman KA, Singer BS (2008) Magnetic source separation in Earth's outer core. Science 321:1800
Inoue S, Yamazaki T (2010) Geomagnetic relative paleointensity chronostratigraphy of sediment cores from the Okhotsk Sea. Palaeogeogr Palaeoclimatol Palaeoecol 291:253–266
Johnson CL, Constable CG (1997) The time-averaged field: global and regional biases for 0–5 Ma. Geophys J Int 131:643–666
Kirschvink JL (1980) The least-squares line and plane and the analysis of paleomagnetic data. Geophys J R Astron Soc 62:699–718
Korte M, Constable CG (2005) Continuous geomagnetic field models for the past 7 millennia: 2. CALS7K. Geochem Geophys Geosyst. doi:10.1029/2004GC000801
Lund SP, Williams T, Acton GD, Clement B, Okada M (2001) Brunhes Chron magnetic field excursions recovered from Leg 172 sediments. In: Keigwin LD, Rio D, Acton GD, Arnold E (eds) Proceedings of the ODP Science Results, vol 172. pp 1–18
Lund SP, Schwartz M, Keigwin L, Johnson T (2005) Deep-sea sediment records of the Laschamp geomagnetic field excursion (~ 41,000 calendar years before present). J Geophys Res 110:B04101. doi:10.1029/2003JB002943
Lund SP, Stott L, Schwartz M, Thunell R, Chen A (2006) Holocene paleomagnetic secular variation records from the western Equatorial Pacific Ocean. Earth Planet Sci Lett 246:381–392
Nürnberg D, Tiedemann R (2004) Environmental change in the Sea of Okhotsk during the last 1.1 million years. Paleoceanography. doi:10.1029/2004PA001023
Roberts AP (2008) Geomagnetic excursions: knowns and unknowns. Geophys Res Lett 35:L17307. doi:10.1029/2008GL034719
Roberts AP, Winklhofer M, Liang W-T, Horng C-S (2003) Testing the hypothesis of orbital (eccentricity) influence on Earth's magnetic field. Earth Planet Sci Lett 216:187–192
Tauxe L (2010) Essentials of paleomagnetism. University of California Press, p 489
Tauxe L, Yamazaki T (2015) Paleointensities. In: Schubert G (ed) Treatise on geophysics, vol 5, 2nd edn. Elsevier, Oxford, pp 461–509
Valet J-P, Meynadier L, Guyodo Y (2005) Geomagnetic dipole strength and reversal rate over the past two million years. Nature 435:802–805
Yamazaki T (2002) Long-term secular variation in geomagnetic field inclination during Brunhes Chron recorded in sediment cores from Ontong-Java Plateau. Phys Earth Planet Inter 133:57–72
Yamazaki T, Ioka N (1994) Long-term secular variation of the geomagnetic field during the last 200 kyrs recorded in sediment cores from the western equatorial Pacific. Earth Planet Sci Lett 128:527–544
Yamazaki T, Oda H (2002) Orbital influence on Earth's magnetic field: 100,000-year periodicity in inclination. Science 295:2435–2438
Yamazaki T, Oda H (2004) Intensity-inclination correlation on long-term secular variation of the geomagnetic field and its relevance to persistent non-dipole component. In: Channell JET, Kent DV, Lowrie W, Meert JG (eds) Timescales of the internal geomagnetic field. AGU Monograph vol 145. pp 287–298
Yamazaki T, Oda H (2005) A geomagnetic paleointensity stack between 0.8 and 3.0 Ma from equatorial Pacific sediment cores. Geochem Geophys Geosyst. doi:10.1029/2005GC001001
Yamazaki T, Kanamatsu T, Mizuno S, Hokanishi N, Gaffar EZ (2008) Geomagnetic field variations during the last 400 kyr in the western equatorial Pacific: paleointensity-inclination correlation revisited. Geophys Res Lett 35:L20307. doi:10.1029/2008GL035373
Yamazaki T, Inoue S, Shimono T, Sakamoto T, Sakai T (2013) Sea-ice conditions in the Okhotsk Sea during the last 550 kyr deduced from environmental magnetism. Geochem Geophys Geosyst 14:5026–5040. doi:10.1002/2013GC004959
Yang X, Heller F, Yang J, Su Z (2009) Paleosecular variations since 9000 year BP as recorded by sediments from maar lake Shuangchiling, Hainan, South China. Earth Planet Sci Lett 288:1–9