An Attempt to Detect a Long-Term Change of Geomagnetic Total Force at Fixed Observation Stations on the Sea Floor

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Since 1987 we have been working with the establishment of the sea floor observation stations in order to detect long-term geophysical changes. Study of the changes of geomagnetic field is one of the most important works to be carried out on the station. The sea floor observation station is a fixed and non-magnetic platform installed firmly on the sea floor, which is easily accessible by manned submersibles. We have installed three such observation stations in the Sagami Bay which is close to Tokyo. The operation and observation were carried out with the aid of the Japanese Submersible SHINKAI 2000 every year. Measurements were made four times in the last four years. Duration of the measurement was from 1 hour to 25 hours depending on the conditions of the submersible.

The equipment used to measure the geomagnetic total force is a proton magnetometer specially designed for the sea floor. The sensor is a toroidal coil dipped totally in Kerosene oil which is pressure-balanced by means of Beryllium-Copper bellows. The magnetometer is installed on the platform exactly in the same fashion every time. Transportation and installation are made by the submersible using manipulators. By comparing the data from the sea floor with those of the land geomagnetic stations, we confirmed the feasibility of detecting changes of geomagnetic total force on the sea floor.

1. Introduction

In 1987 a Proton Magnetometer for sea floor use was developed and its performance was tested in success through the measurement of 77 days at a depth of 4000 m (Koizumi et al., 1989). The objectives of the development were two-fold: (1) Verification of the magnitude of drift of the Fluxgate Magnetometer for sea floor use. (2) Detection of the secular change of geomagnetic total force on the sea floor.

In 1989 the first measurement of geomagnetic total force was made on a fixed sea floor observation station in the Sagami Bay (35°00'.84N, 139°16'.13E, 1359 m). A submersible SHINKAI 2000 was used to support installation. The measurement proved to be a failure, however, because of the magnetic effect from an acoustic transponder attached to the sea floor station, which should have been removed in case of measurement and yet could not be removed actually due to the reason mentioned at the later part of this paper. In 1990 a reliable measurement of absolute magnetic force was made for 25 hours on the same fixed sea floor observation station in the Sagami Bay. In the following two years magnetic measurements under the exactly same condition were repeated on the fixed sea floor observation station. Using two measurements of 1990 and 1991, the annual change of absolute magnetic force was first inspected by comparing the data on the sea floor with the data at five land geomagnetic stations, Kakioka, Matsuzaki, Omaezaki, Kanoya and, additionally, Kanzoan. The last measurement made in 1992 was also used by comparing with the Kakioka data. Although the results seem to be still tentative, they suggest the possibility of detecting a real secular change of geomagnetic field in near future by the method proposed in this paper.

2. Instrumentation

The sea floor observation station is a non-magnetic concrete block made of concrete re-enforced by
carbon fibers. It is 1,100 mm by 1,100 mm in area and 500 mm in height, with the weight 800 kg in air and about 400 kg in water (Fig. 1). There is a vertical through-hole with the diameter of 160 mm in the middle of the block, which is prepared for the magnetometer to be inserted into. There are some metallic parts attached to the concrete block for convenience of installing it on the sea floor from a ship. The metal is totally pure titanium which is non-magnetic as well as very resistive against corrosion. Installation of the concrete block on the sea floor was made using a wire extended down from the ship’s winch. In this installation the LBL (Acoustic Long Base Line positioning) subnavigation technique was applied (Fujimoto et al., 1992) using acoustic transponders and pingers. Positioning of the station is as accurate as ±2 m relatively as far as the acoustic positioning is concerned. The absolute position relative to world geodetic system depends on the accuracy of the GPS positioning.

The sea floor station lies on the sea floor sediment directly, so that some amount of sink or inclination may be suspected. The sediment of the middle Sagami Bay is of course very soft, but, when the concrete block 400 kg in weight was dropped vertically at 3-m high, it sank by a depth of 25 cm leaving the upper 25 cm above the sea floor.

We have so far installed three observation stations in the Sagami Bay. The first one was installed in 1987 which is named OBB No. 1, and two other stations (OBB No. 2 and 3) were installed in 1988 and 1989 one by one. These stations have been observed every year from the submersible SHINKAI 2000, in order to check the posture of the station. It is true that the concrete block may sink with time to some extent. The oldest OBB No. 1 appeared in the case of 1992 dive (five years after installation) to have been buried to some extent. But, this does not seem totally due to sinking but fall of sediment, because the sediment deposited largely on top of the station.

Figure 1 also shows the sensor unit of the proton magnetometer mounted on the concrete block. A toroidal coil sensor dipped in Kerosene oil is fixed to the top of a pipe made of polyvinyl chloride 600 mm high and 140 mm in diameter. The lower part of the pipe is inserted to the hole of the concrete block, and pressed down by a lead weight 10.4 kg. In this configuration the center of the sensor is to be fixed at 515 mm above the plane of the station. This kind of operation is conducted using a manipulator of SHINKAI 2000.

Figure 2 shows the sensor unit of the proton magnetometer. A Beryllium Copper bellows and two 1-pin connectors are attached to compensate for water pressure and apply excitation electric current.

Figure 3 is a view of the proton magnetometer when the installation is completed. The proton sensor
An Attempt to Detect a Long-Term Change of Geomagnetic Total Force

is connected by a water-proof cable 3-m long to a pressure-tight aluminum vessel in which the amplifier, recorder and batteries are housed. Although the electronics unit is magnetic its effect on the sensor at a 3-m distance proved to be smaller than 1 nT by a test conducted at a land geomagnetic observatory. In the case of measurement on the sea floor the submersible which is also magnetic moves away from the station by a distance longer than 50 m. The measurement was made in normal cases every 1 min with the resolution of 0.5 nT. In a special case which will be referred to in the later section it was 20 sec. The quartz crystal clock used as a time base was calibrated to the precision of $10^{-6}$. Temperature change of the clock has been checked over a range from 1°C to 40°C.

Fig. 2. A pressure-compensated proton sensor. A toroidal coil is housed in the polyvynil chloride vessel filled with Kerosene, which occupies most part of the Beryllium Copper bellows. Two 1-pin non-magnetic and water-proof plugs are attached to the vessel which are connected to the toroidal coil.

Fig. 3. A photograph of proton magnetometer installed on the sea floor which was taken by a still camera of the submersible. The sensor is installed on the concrete platform and it is connected by a cable to the cylindrical aluminum pressure-tight vessel for the electronics unit. The aluminum vessel is placed by about 3 m apart from the sensor.
Exact estimation of the local change of geomagnetic total force requires a strict control of the measurement. Gradient of geomagnetic field at the point of measurement may be one of those of which particular care must be taken. The place where the observation stations are located is covered with sediments thicker than 1 m. The sea floor stations (OBB's) made of concrete blocks and pure titanium have a specific magnetization with the intensity of about $10^{-2}$ A/m, which has been verified by the measurement of magnetization as to a cubic sample. Considering this status of measuring environment, we think that the magnetic gradient at the observation station may be normal. Although we should inspect the magnetic gradient by actual measurement sooner or later (this may be a tough work, though), we do not think at this moment that the magnetic gradient is problematic in our experiment.

3. Measurements

Location of measurement is shown in Fig. 4. The three sea floor stations concentrate at the northern tip of the Sagami Trough. The OBB No. 1 which is the station used throughout the present experiment is located on a comparatively flat shoulder area west of the trough. The Sagami Bay area is characterized by the Sagami Trough, the Oshima active volcano and the seismically active fault running south-to-north along the western rim of the bay. These tectonic settings suggest the possibility of magnetic change in the area due to volcanic lava and crustal stress. The experiment to detect secular magnetic change is being made on the Izu-Peninsula nearby (Sasai and Ishikawa, 1991). The data on the sea floor will be useful as the data for comparison.

The first measurement on OBB No. 1 (35°00'.84N, 139°16'.13E, 1359 m) was carried out on 27 October 1989 (Koizumi and Segawa, 1990). Measurement continued for about 2 hours and the magnetometer was retrieved by the submersible soon after the measurement. A problem in this measurement was that the acoustic transponder which was attached to the station for the sake of the initial location had a strong magnetic effect on the magnetic sensor. At this time we tried to pull out the transponder, but, failed. So, the measurement started with the transponder nearby. The proton magnetometer itself worked well. The result showed that the magnetic field on the station went down by several tens of nT due to the magnetic effect of the transponder.

![Fig. 4. Bathymetry of the Sagami Bay and location of the sea floor observation stations (OBB No. 1, 2, 3). OBB No. 1 is the site where magnetic measurements were made.](image)
An Attempt to Detect a Long-Term Change of Geomagnetic Total Force

The second measurement was conducted on 7 and 8 November 1990. The measurement continued for 25 hours. The acoustic transponder was removed before the measurement. As for the magnetization of the concrete block itself, it was confirmed to be less than $3 \times 10^{-2}$ A/m. We think that the magnetization of such an amount is of the same order as that of the sea floor sediment or soil, so that it may be an inevitable situation.

In the upper parts of Figs. 7 through 10 are plotted the raw data of magnetic total force from 1990 and 1991 measurements denoted by OBP to be compared with four land measurements at Kakioka, Matsuzaki, Omaezaki, and Kanoya. The raw data from 1992 measurement also denoted by OBP is separately shown in Fig. 11 to be compared with the measurement at Kakioka. It is seen that the data generally show clear daily variations synchronous with the data on land. One problem observed from the sea floor data is that there are short period fluctuations with the data on the sea floor with the amplitude of $\pm 3$ nT which the Kakioka data are void of. Although several reasons may be considered for this, we think that the artificial magnetic noise propagating from the industrial zone around the Sagami Bay may be most responsible.

The measurement in 1991 was made for about 2 hours on 25 November. This measurement was at the interval of 20 sec unlike the previous case. This was done because we intended to clarify the reason for data fluctuations on the sea floor. It proved to be effective because, as seen from Fig. 5, it was found that the fluctuations of data which appeared random in the 1990 data were actually sinusoidal and continuous variations. The measurement in 1992 was also made on 24 November at the interval of 20 sec.

4. Comparison of Geomagnetic Field

The total magnetic forces measured on OBB No. 1 in the Sagami Bay were compared with the data at the Kakioka, Matsuzaki, Omaezaki and Kanoya geomagnetic observatories which all belong to the Japan Meteorological Agency. We made an additional comparison also with the data of the Kanozan Observatory. The geography of these observatories are shown in Fig. 6. The comparisons are demonstrated in Figs. 7 through 10. The measurement of 1992 was compared with the data at Kakioka only and the comparison is shown in Fig. 11 separately. The reason why the Kakioka data only were compared in this study is because the data from 1990 and 1991 were not available.
Fig. 6. Distribution of land geomagnetic observatories Kakioka, Matsuzaki, Omaezaki, Kanoya and Kanozan (Mark •) and the sea floor station OBP (Mark ▼).

Fig. 7. Comparison of total magnetic force observed on the sea floor in 1990 and 1991 (OBP), and those at the land station Kakioka observed at the same time (KAK). \( \Delta \text{KAK} = \text{OBP} - \text{KAK} \) are also plotted for 1990 and 1991, respectively. The abscissa is local time and the ordinate is nT.
An Attempt to Detect a Long-Term Change of Geomagnetic Total Force

Fig. 8. Comparison with the land station Matsuzaki (MAT). See Fig. 7 for the other legends. Beware that the scale in the ordinate is shifted.

Fig. 9. Comparison with the land station Omaezaki (OME). See Fig. 7 for the other legends. Beware that the scale in the ordinate is shifted.

case is that, in the previous results of comparison, the comparison with the Kakioka data gave an unusually large value, and that the data of Matsuzaki and Omaezaki for 1992 were not available because of the system change at the Geomagnetic Observatory, Kakioka. The scheme of comparison is as follows: If the data at the sea floor, Kakioka, Matsuzaki, Omaezaki and Kanoya are denoted by OBP, KAK, MAT, OME and KNY, respectively, then the comparison is made as, for instance;

\[ \Delta KAK(90) = OBP(1990) - KAK(1990), \]  \hspace{3em} (1)

\[ \Delta KAK(91) = OBP(1991) - KAK(1991), \]  \hspace{3em} (2)
Fig. 10. Comparison with the land station Kanoya (KNY). See Fig. 7 for the other legends.

Fig. 11. Comparison of total magnetic force observed on the sea floor in 1992 (OBP). KAK is the measurement at Kakioka in 1992.

\[ \delta \text{KAK}(91, 90) = \Delta \text{KAK}(91) - \Delta \text{KAK}(90). \]  

Among these formula, \( \delta \text{KAK}(91, 90) \) means an apparent annual change of geomagnetic total force on the sea floor between 1990 and 1991, provided that there is no anomalous secular change at the Kakioka geomagnetic observatory. Similar formulation can be made for the other land stations. It is worth mentioning that the magnetic data at the Matsuzaki and Omaezaki observatories fluctuate as much as the data on the sea floor. This is also caused by the artificial noises because these observatories are not so remote from the urban zones. Figure 12 shows a summary of \( \Delta(90) \) and \( \Delta(91) \) values corresponding to 4 land observatories. \( \Delta(92) \) is handled for Kakioka only. The horizontal bars drawn in the middle of dots of data show the averages of the measurements. \( \delta(91, 90) \)'s or \( \delta(92, 91) \)'s are obtained by taking the
Fig. 12. Plots of $\Delta$(KAK), $\Delta$(MAT), $\Delta$(OME) and $\Delta$(KNY) for 1990, 1991 and 1992 measurements shown as a summary. The mean values of $\Delta$ represented by horizontal bars with each year, when there are two measurements, are taken graphically by eye, and their difference $\Delta(91) - \Delta(90)$ or $\Delta(92) - \Delta(91)$ are evaluated from the means. Beware that the scale in the ordinate is shifted in some place for readability. As for the cases of Omaezaki (OME) and Matsuzaki (MAT), the horizontal bars to show the averages of $\Delta$ (solid lines) are shifted by 10 nT to match the scale for 1990 (dotted lines) for easy comparison by eyes.

In this study, however, since the data on the sea floor in 1991 and 1992 were obtained at the daytime only, we were obliged to do the estimation from the daytime data. The differences of the sea floor data from the data at the land observatory show sometimes large variations as seen from the data of 1990 in Fig. 12. This is because of the phase differences in daily variations caused by longitude differences. This difference is particularly large for the case of Kanoya observatory. With all the difficulties encountered in the estimation, we dare to take the average changes of geomagnetic total force using the data available at present. This estimation has resulted in the following values as annual changes: Between 1990 and 1991 the total magnetic force on OBB No. 1 decreased by 7 nT relative to Kakioka, increased by 1 nT relative to Matsuzaki, increased by 3 nT relative to Omaezaki and increased by 3 nT relative to Kanoya. Between 1991 and 1992 the total magnetic force on OBB No. 1 did not change at all relative to Kakioka. This is really rough estimation just made graphically. The results are also shown in Table 1.
Table 1. Evaluation of geomagnetic changes on the sea floor station (OBP) in comparison with the measurements at Kakioka (KAK), Matsuzaki (MAT), Omaezaki (OME), and Kanoya (KNY). \( \Delta KAK = OBP - KAK \), \( \Delta MAT = OBP - MAT \), \( \Delta OME = OBP - OME \), \( \Delta KNY = OBP - KNY \). \( \delta KAK = \Delta KAK(1991) - \Delta KAK(1990) \) or \( \Delta KAK(1992) - \Delta KAK(1991) \). \( \delta MAT \), \( \delta OME \) and \( \delta KNY \) mean similarly. Marks — mean no data available, because of the policy change of data distribution in the side of geomagnetic observatory.

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<th>Omaezaki</th>
<th>Kanoya</th>
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<td>682 nT</td>
<td>324 nT</td>
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<td>+3 nT</td>
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<td>327 nT</td>
<td>30 nT</td>
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<tr>
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<td>0</td>
<td>+1 nT</td>
<td>+3 nT</td>
<td>+3 nT</td>
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<td>( \Delta OME )</td>
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5. Discussion and Conclusion

The land measurements of geomagnetic total force related to this study are those made in the eastern Izu Peninsula (Sasai and Ishikawa, 1991; Oshiman et al., 1991). These measurements are for the area around Ito City including Hatsushima Island, which is tectonically very active with seismic and volcanic activity and the active fault running along the eastern margin of the Izu Peninsula. It is well known that there was a volcanic eruption in 1989 at the shelf close to Ito City (submarine eruption of Teisi volcanic knoll). The long-term changes of total magnetic force in this area reported so far show a few nT in the amplitude. It is anticipated that the magnetic change may be smaller as the distance from this active spot becomes larger. The OBB No. 1 station is about 10 km east of the Hatsushima Island, so that the effect from the tectonic change at the Izu Peninsula might fade away. However, we do not think that there is any positive reason for it, rather, we think we might find magnetic change of another type in the Sagami Bay. In any case, it is important to our experiment that the changes in magnetic total force observed between 1990 and 1991 were a few nT in magnitude: If this had been much larger, we should have to reconsider the method of experiment employed. There is no guarantee that the magnetic force at land geomagnetic stations is stable. Annual change of the sea floor data obtained relative to Matsuzaki and Omaezaki stations (1 nT and 3 nT, respectively) may be reasonable. This result may suggest that, in the area from the Sagami Bay over to the Omaezaki Peninsula through the Izu Peninsula, no locally anomalous change in geomagnetic field took place in 1990 and 1991. Comparison with the Kanoya observatory which is about 850 km apart from the Sagami Bay is less persuasive, and yet the result does not seem so extraordinary, showing the change of 3 nT. What is most mysterious is the result from the comparison with the Kakioka observatory. The result shows a decrease of 7 nT on the sea floor station, which is quite the reverse compared with the other cases. The data at Kakioka is the highest in quality and nothing has been reported as to particular behaviour of the magnetic field in the area.

The measurement made in 1992 is useful to evaluate the measurement of 1990. The result that there is no change of magnetic field on the sea floor between 1991 and 1992 suggests the abnormality of the measurement in 1990. This is further confirmed by the comparison, additionally made, with Kanozan observatory (KNZ) at the Boso Peninsula, as shown in Fig. 13. The differences \( \Delta (KNZ) = OBP - KNZ \) between the geomagnetic total forces on the sea floor and at Kanozan are about 520 nT. These differences decrease gradually from 1990 to 1992. The double difference between 1990 and 1991, i.e., \( \delta (KNZ)(91, 90) \) is about -2 nT, suggesting that it is impossible for the sea floor data to vary locally by as much as 7 nT from 1990 to 1991.

One possibility for artificial changes in magnetic field on the sea floor observation station is that the submersible affects the magnetometer to some extent if the distance from the sea floor station is not long.
Fig. 13. Plots of $\Delta(KNZ) = OBP - KNZ$ for 1990, 1991 and 1992 measurements. This is an additional comparison to Fig. 12. The differences $OBP - KNZ$ are close to 520 nT for all the years, so the scales in the ordinate are shifted by 10 nT for 1991 and by 20 nT for 1992 relative to 1990. Although the horizontal bars to indicate the averages are not drawn in this case, it can be found that $\delta(KNZ(91, 90))$ is less than 2 nT and that $\delta(KNZ(92, 91))$ is also less than 2 nT.

enough. We usually shift the submersible away from the station by more than 50 m, but the distance measurement is not so reliable in such a case, leaving room for suspicion that it may be shorter. We need to repeat the measurement many more times to make our experiment convincing.

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