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GEOMAGNETIC SURVEYS ON SEA BY AIRCRAFT AND SHIP*

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Abstract

In accordance with the resolution adopted at the XIth General Assembly of I. U. G. G., 1957, the program of magnetic surveys on sea has been progressed in Japan.

For the aeromagnetic survey on sea, an airborne magnetometer with saturable inductor was developed by the Tohoku University team of the writers, and was put to practical surveys in Boso-district in February, 1958, around O Sima Island (Izu) area in July, 1958, and in the Izu Syoto (Islands) in August, 1959. The results of the first and second surveys were reported previously. The third survey was carreid out by "Beachcraft No. 502" of the Maritime Safety Board, with flight elevation of 3000 m above the sea level, measuring the vertical component of the earth's magnetic field to clarify that the most remarkable anomaly was associated with volcanoes on the Izu Syoto.

For the magnetic survey at sea surface, a shipborne magnetometer, designed by the Tohoku University team of the writers, was employed on a survey ship *Takuyo* of the Hydrographic Office around the Sagami Nada near Izu Hanto (Peninsula), in January, 1960.

The heart of this magnetometer is a saturable inductor mounted on a gimbal system. In order to avoid the magnetic disturbance by the vessel, the instrument was hung at about 40-meter depth beneath her body. From results of the survey, two remarkable anomalies were observed around Ito and Okinoyama, respectively. It is found that the anomalous anomaly Near Ito is associated with submarine volcanoes, and the anomaly around Okinoyama belongs to the submarine topographic configuration.

We also studied the magnetism of a steel vessel. In this paper, the general feature of magnetic fields around an iron ship is investigated, especially, from the

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standpoint of detecting it magnetically. Magnetic moment of the steel vessel *Takuyo* was obtained from the results of magnetic survey around her body by assuming the vessel as a uniformly magnetized prolate spheroid.

Introduction

In order to investigate the terrestrial magnetism and to promote the safety of navigation the magnetic survey over all Japan has been carried out on land by the Hydrographic Office since 1912. The magnetic survey on sea was difficult, because we could not build non-magnetic vessel and instrument measuring the earth's magnetic field at sea. Therefore, we could not prepare the real magnetic chart for sea area.

The aeromagnetic survey has been developed recently in U. S. A; at first, total intensity was observed in north-eastern Umnak, Alaska, and afterwards, extensive surveys were made in some parts of the main land of U. S. A., Alaska, Canada, Mexico, and the Pacific Ocean.

The magnetic survey at sea was carried out from 1912 to 1927 by a non-magnetic vessel *Carnegie* designed in U. S. A.

At the XIth General Assembly of the International Union of Geodesy and Geophysics held at Toront, Canada, 1957, the cooperation of the world magnetic survey, especially on sea, was proposed and adopted. At present, magnetic surveys on sea are being carried out by a non-magnetic survey vessel *Zaya* of U. S. S. R., and by the aircraft "R5D" with the NOL Vector Airborne Magtetometer by U. S. A.

In Japan, after the resolution adopted at the Toront Assembly, the program of magnetic survey on sea has been progressed by the World Magnetic Survey Committee of the Science Council of Japan, and the Hydrographic Office has planned the schedules of aeromagnetic survey on the adjacent seas of Japan. Following this plan, the aeromagnetic surveys were carried out on Boso-district, around O Sima Island (Izu) area and the Izu Syoto (Islands) by the cooperation of the Hydrographic Office and Tohoku University. Thus, the first magnetic chart for sea in Japan was prepared. The results of these surveys were reported partly in the previous papers (Kato, Matuo et al. 1958, 1959), and the result of the survey on the Izu Syoto is discussed in detail in the present paper(Part I).

Magnetic survey at sea surface was held on the survey ship *Takuyo* (771 tons) of the Hydrographic Office in Sagami Nada. The instrument employed in this survey is a latest type of shipborne magnetometer equipped with a saturable inductor, electronic oscillators, amplifiers, recorder and gimbal. The instrument was produced by the Tohoku University team of the writers. From the results of survey two remarkable anomalies were found near Ito and Okinoyama, and several interesting facts were also discovered (Part II).

We measured a magnetic field around *Takuyo* with the shipborne magnetometer (Part III).

Part I

Magnetic survey on sea by means of an airborne magnetometer

1. Planning.

The first magnetic survey was held on Boso-district in February, 1958, and the second around O Sima Island area in July of the same year. From the results of these surveys, it was clarified that there were remarkable anomalies near Ito, and that they were associated with a volcano. The third survey was carried out on the Izu Syoto in August, 1959. The Izu Syoto are composed of a number of volcanic islands including active, dornant, and extinct quaternary volcanoes.

2. Instrument.

The airborne magnetometer to measure a vertical intensity of the earth's magnetic field consists of a detecting mechanism, electoronic oscillators amplifiers, recorder, gimbal system and a vertical gyroscope. The heart of the airborne magnetometer is a saturable inductor. This inductor consists of a core of easily saturable ferromagnetic material of high permeability (a very thin strip of permalloy) with an external winding coil to which is applied an alternating current by means of electronic oscillator. By a coaxially wound secondary coil around the saturable core, vertical intensity of the earth's magnetic field is measured. Because the saturable core inductor can measure the external field parallel to its axis, it can be used to measure the vertical component of the earth's magnetic field by setting an axis of saturable core parallel to the vertical direction. In our instrument, attempts have been made to use a vertical gyroscope to orient the detector so as to measure the vertical component in aircraft. The gyroscope determines the true vertical in a moving vehicle. This system in aircraft can keep the vertical within the accuracy of about 10 minutes of arc, when the aircraft flies at high altitude of about 3000 meters in smooth air.

The airborne magnetometer enabled us to make measurements of vertical component quite easily, and instrumental error never exceeded 50 γ which assured sufficient accuracy for the survey on sea. The detail on this airborne magnetometer is shown in the following.

If an external magnetic field Z, which we must measure, is applied to the core, the field is increased during one half of the cycle and decreased during the other half.

Then, the amplitude of the wave form of flux density becomes asymmetry, because so called B—H curve of the ferro-magnetic core has a character of point symmetry. In other words, there is a proportional relation between the intensity of the magnetic field (Z) and the amplitude difference between positive and negative amplitudes of flux density. When suitable and saturable alternating magnetic field (hereafter it is called "carrier") is driven to the primary coil of the ferro-magnetic core, the output voltage of secondary coil is proportional to the differetiated value of flux density with respect to time. The output electromagnetic-motive force of an integral circuit in an electrical device has a similar wave form for the time as that of above mentioned flux density.

But the constant term in the wave form of flux density is eliminated at the output of the secondary coil, for the output voltage is given as the differentiated value of the flux density with respect to time. Then, the output voltage of the integral circuit does not contain this constant term, therefore, it shows similar wave form to that of flux density with respect to time. Then, it is considered that there is always proportional relation between the magnetic field and the difference in positive and negative pulse amplitudes of output electromagnetic-motive force of the integral circuit. Therefore, we used the alternating pulse wave whose width is enough narrow compared with its period as a carrier wave in order to obtain the best sensitivity.

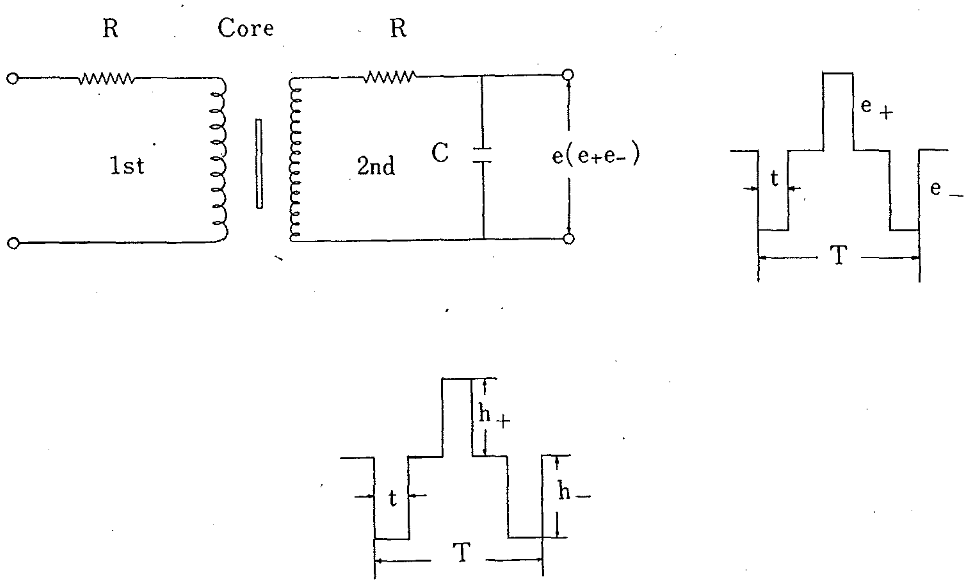


Fig. 1. Schematic Diagram of Operation of Saturable Inductor for Airborne Magnetometer.

The simple circuit for the principle is shown in Fig. 1. The wave form of carrier is illustrated in Fig. 2, where T is the period of alternating pulse wave, and τ and h are the width and the amplitude of it, respectively. Now, it is assumed that there is no hysteresis on the B—H curve of the ferromagnetic core, and magnetic characters of this magnetic core are represented approximately by so-called three straight line segments:

$$B=\mu H \quad \text{for} \quad |B| \leqq B_m,$$
$$B=\pm B_m \quad \text{for} \quad |B| \geqq B_m,$$

where

$\omega CR \gg 1$	is the condition of integral circuit,
μ	is the effective permeability,
B_m	is the flux density at saturation,
H_m	is the minimum field intensity which gives the saturate flux density (B_m) in the core,
$e(e_+ \cdot e_-)$	is the output voltage of integral circuit,
S	is the effective area of the core,
N	is the total turns of secondary coil, and
k	is 10^{-8} SN/CR volt.

In Fig. 2 are illustrated the general characteristics of the wave form of the flux density and the output voltage of an R—C integrator, when the carrier of pulse wave, by which the flux density produced in the ferromagnetic core becomes at saturation, is driven to the core and when an external magnetic field ($\varDelta H$) is superposed on it.

As shown in Fig. 2, the change of flux density with respect to time is expressed as follows. If we take the line X—Y as the time axis,

$$B(B_+B_-)=B_0+\sum_0^\infty B_n(n\omega t+\varphi n),$$

it follows that

$$|B_+| \sim |B_-| = 2\mu |\varDelta H|,$$
$$kB_0 = k\frac{1}{T}\int_0^T Bdt$$

The difference of two amplitudes of positive and negative in the output voltage of integral circuit becomes

$$|e_+| \sim |e_-| = 2k\mu(1-2\tau/T)|\varDelta H|,$$

then

$$|e_+| \sim |e_-| \fallingdotseq 2k\mu|\varDelta H|$$

where $2\tau/T \ll 1$.

This expression shows that the alternating pulse wave, whose width is narrow enough in comparison with its period, should be given as a carrier wave.

The value of $2\tau/T$ may be taken

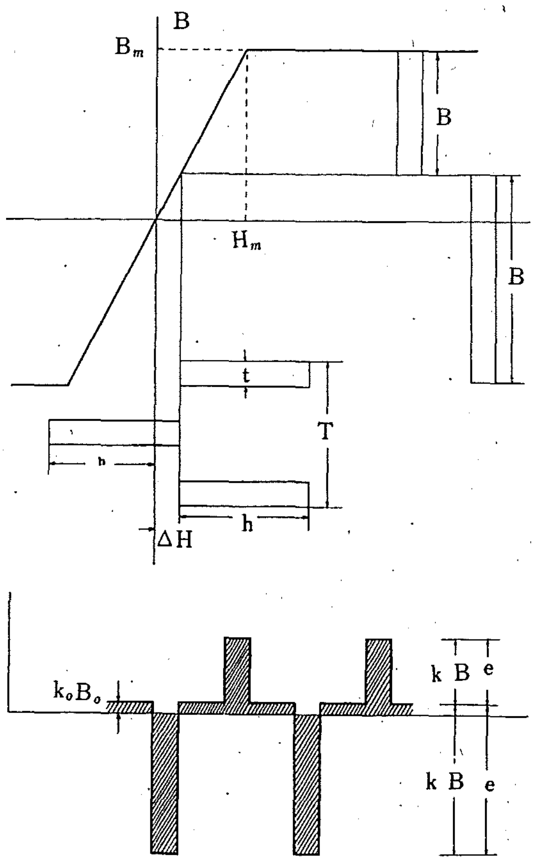


Fig. 2. B—H Curves of Ferro-Magnetic Core.

practically,

$$2\tau/T \doteqdot 1/10.$$

The block diagram of the special type variometer is illustrated in Fig. 3. In this variometer, two essentially identical ferromagnetic cores are fixed geometrically in parallel each other and the external winding connected differentially in order to eliminated odd harmonics of fundamental frequency and to improve the moduration in the magnetic detecter. Even when there was no external magnetic field, the unnecessary outputs voltage would be generated by the unbalances in the amplitude and in the phase of these cores.

It is clear that the unnecessary output voltage generated by the amplitude unballance at outputs of external windings of these two cores must be taken much larger than by the phase difference. The primary and secondary coils are wound around the ferro-magnetic core whose diameter is 1 mm and length is 10 cm.

The ferro-magnetic core consists of a strip of Mo-permalloy of 0.005 cm thick and 0.5 cm wide. The strip is rolled into a tubular form about 0.1 cm in diameter and 10 cm in length.

The eddy-current losses in the core become significant when the driven frequencies of the pulse become to about 1 kc. In order to feed the driving current to the primary coil, the pulse oscillator of the 120 cycles is used. The output voltage of the magnetic detector is transferred to the integral circuit and then the integrated voltage is amplified by the amplifier in the next stage.

In the differential detector, the output voltage of the amplifier is converted to direct current which is proportional to the difference in positive and negative pulse amplitudes. The output of the differential detector is translated into an alternating voltage of 50 cycles by an additional modulator which drives a servomoter only when the difference in positive and negative pulse amplitudes exists. In other words, the servomoter, by which the contact brush of the potentiometer is moved, can not be driven by the output of modulator when there is no signal in the system.

A part of the voltage in the potentiometer is fed back to the compensating coil as shown in Fig. 3, then the external magnetic field ($\varDelta H$) and the magnetic field generated by the current which follows through the compensating coil are always canceled each other autmatically by this servomoter. And, the intensity of the external magnetic field can be recorded visually on the recording paper by the recording pen which is moved autmatically in connection with the contact brush of the potentiometer.

3. Magnetic survey.

The third aero-magnetic survey was carried out on the Izu Syoto with the

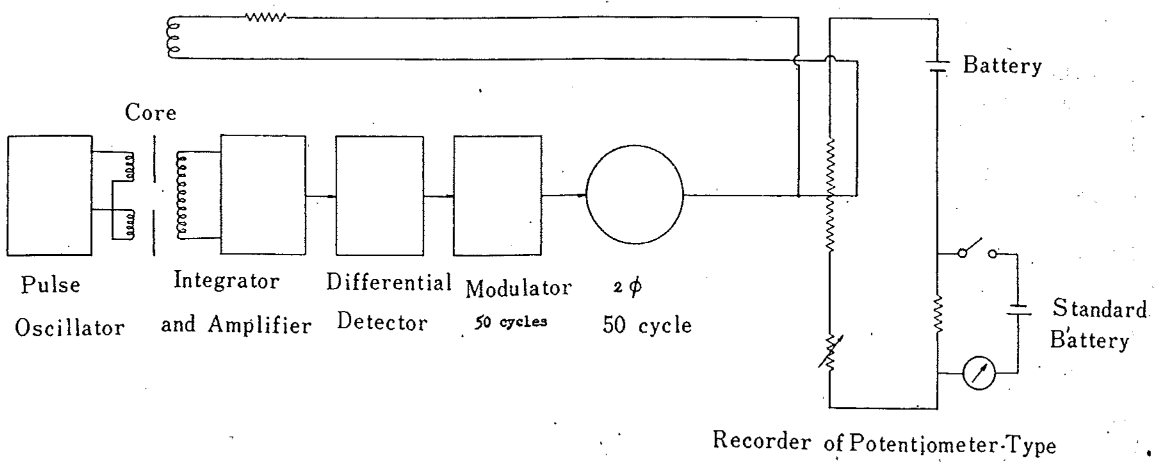


Fig. 3. Schematic Diagram of Airborne Magnetometer.

airborne magnetometer by airplane "Beachcraft No. 502" of the Maritime Safety Board from August 16 to 20, 1959. Flight pattern of aero-magnetic survey is shown in Fig. 4. The flight elevation in this aero-survey was about 3000 meters above the sea level. The aircraft could fly smoothly, because of good condition of air in that height. The pilots were guided on these flight pattern by an electronic indicator, Radio Beacon, that showed the position of the plane with respect to the present course. The altitude of aircraft was determinde by a barometric altimeter. The instrument measures the height above the sea level. The feature of vertical intensity obtained in this survey is shown in Fig. 5.

As can be seen in Fig. 5, it was found that there exists an area of remarkably large anomaly in the south-eastern area of Ito city. This anomaly is considered to be due to the submarine volcanoes. The detailed description of this anomaly is shown from the results of a magnetic survey by ship-borne magnetometer in the following chapter.

Then, the normal values of the vertical intensity on the Izu Syoto is obtained from the magnetic chart No. 6024 of the Hydrographic Office for 1955.0. We can get the intensity of a magnetic anomaly from Fig. 5, by using the normal value around the Izu Syoto.

Thus, local magnetic anomalies closely related to the structure of volcanoes have been found on many volcanic islands and on a marine volcano. It is seemed that these volcanic islands is constructed from the basaltic rocks. Then, regarding to geomagnetic surveys on volcanes, one of the writers (Y. Kao, 1956) carried out a magnetic survey at Miyake Sima Island on land. In this time, authors carried out a aero-magnetic survey on the island. Using the results of these magnetic surveys, we evaluated a depth

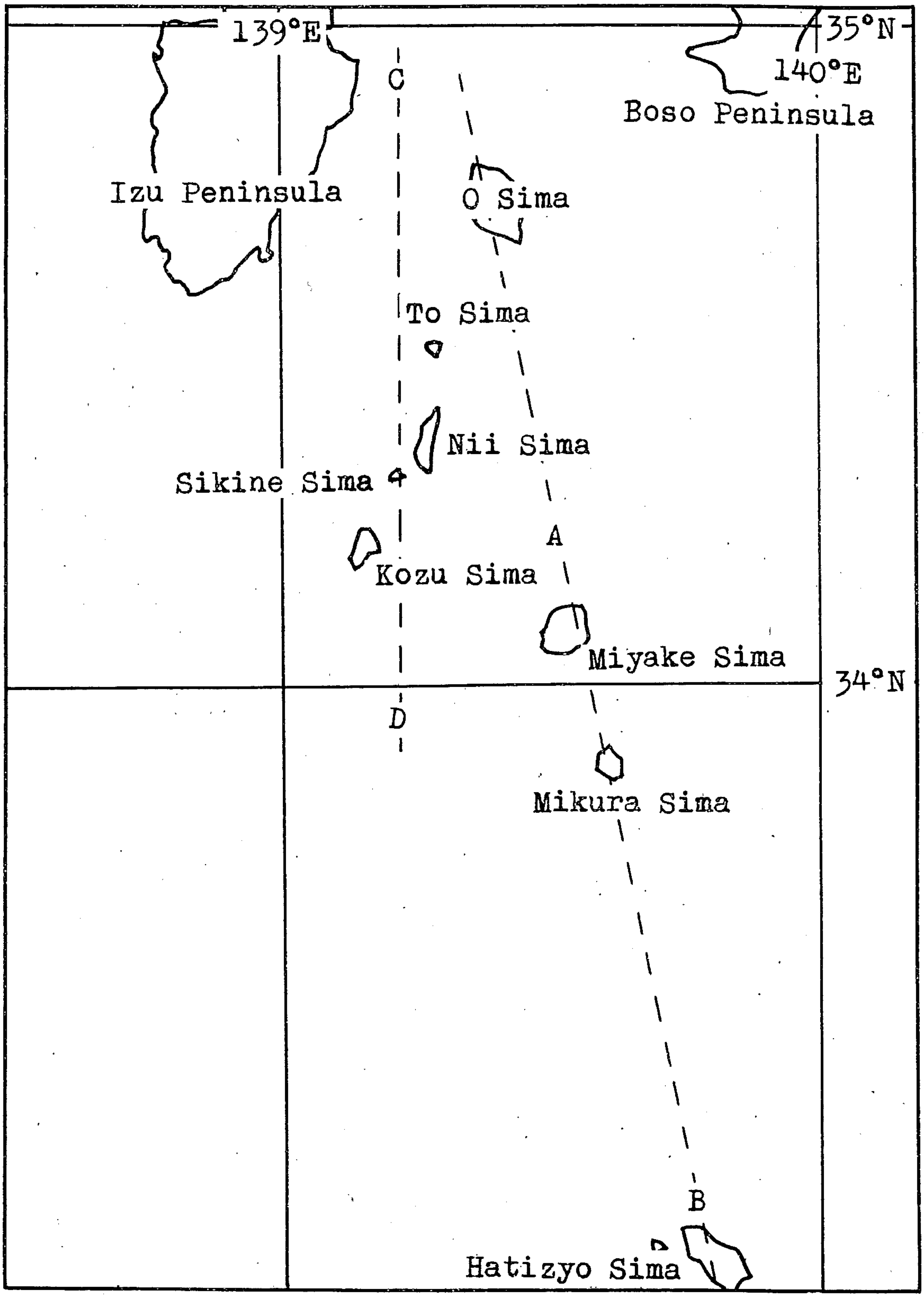


Fig. 4. Flight Pattern of Aeromagnetic Survey.

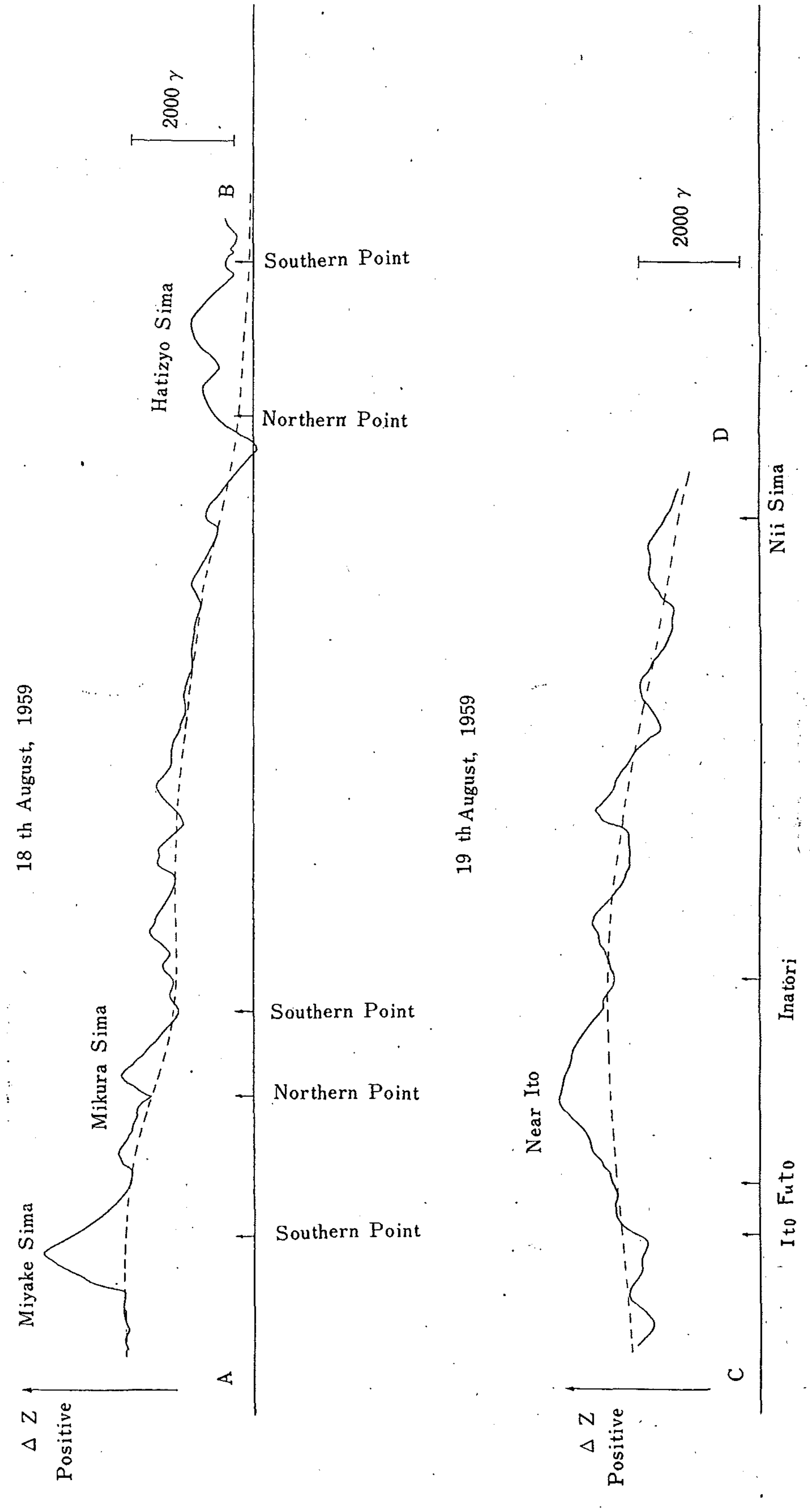


Fig. 5. Results of Aeromagnetic Survey in Izu Syoto Area.

of dipole on Miyake Sima to conclude that the depth is about 5 km.

In future, the aero-magnetic survey over all adjacent seas of Japan will be held by the Hydrographic Office forming a link in the chain of the program of the world magnetic survey of I. U. G. G.

Part II

Magnetic surveying at sea by means of ship-borne magnetometer

1. Planning.

It has been established that the magnetic survey by means of a ship-borne magnetometer at sea is very useful to investigate marine volcanoes and magnetic anomaly at sea. It is clear that local magnetic anomalies at sea are closely related to the structure of volcanoes. As it was clarified that there were a anomalous local magnetic anomaly near Ito district by the air-borne magnetic survey in 1959, the first magnetic survey by the ship-borne magnetometer was carried out near Ito district in January, 1960.

The magnetometer, all transistorized, was especially designed by the research group on ship-borne magnetometer of the Tohoku University. The details of the magnetometer are described in the following section. Also, the magnetic survey at sea was carried out around Okinoyama in Sagami Nada by *Takuyo*.

The portable ship-borne magnetometer enables us to make measurements of vertical intensity quite easily. Many good measurements can be performed in a short time.

2. Instrument.

The recent development of the saturable core magnetometer contributes the major advances in geomagnetic survey. The heart of the ship-borne magnetometer is the saturable inductor. The earth's magnetic measurement by the saturable inductor is independent of the velocity and acceleration of the vehicle. This consists of a core of easily saturable ferromagnetic material of high permeability (permalloy) with an external winding to which is applied an alternating current producing a magnetic field that drives the core cyclically through saturation.

If an external magnetic field, H is applied also to the core and if the permeability, μ, of the core is high, the magnetic flux density, μH, produced in it by the external field is an appreciable part of the flux density at saturation, B_m. Owing to this effect of the core, the output electromagnetic-motive force of the coil will be distorted and will have an asymmetrical wave form containing both even and odd harmonics of the driving frequency. Schematic diagram of operation of saturable inductor is shown in Fig. 6. Both even and

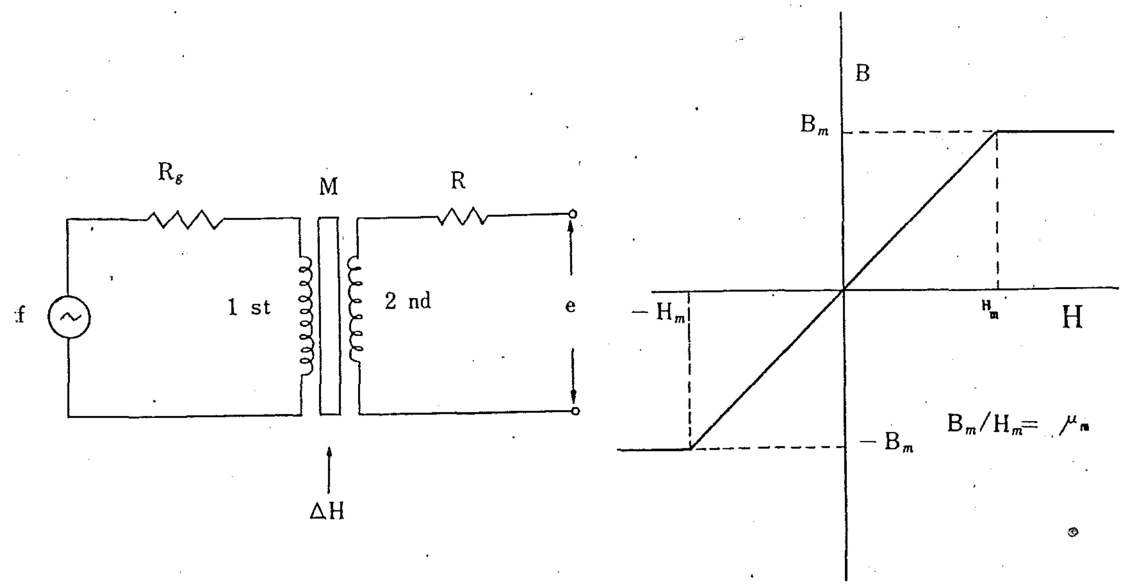


Fig. 6. Schematic Diagram of Operation of Saturable Inductor for Shipborne Magnetometer.

odd harmonics are functions of the external field, H, but only the even harmonics are sensitive to its sign and vanish when it equals zero.
Therefore, measurement of one or more of the even harmonics of the output emf provides a means of measuring the external field. In this case, the only one harmonic system was employed to measure a external magnetic field. Diagram of this system is shown in Fig. 7.

This single harmonic system uses a single-element inductor and a narrow band-pass filter that excludes all harmonics but the desired frequency (the second harmonic) of the output emf. The major portion of the earth's field

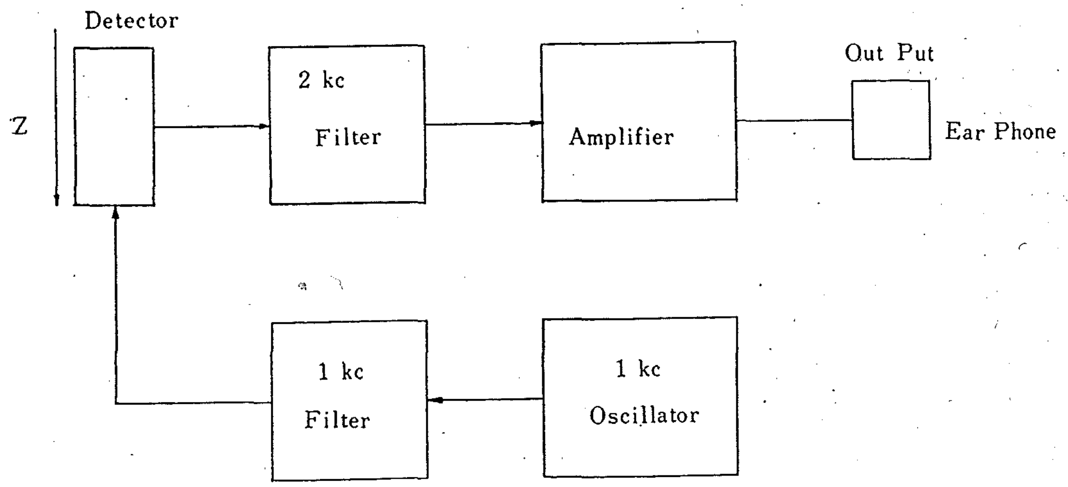


Fig. 7. Schematic Diagram of Shipborne Magnetometer.

acting on the detector coil is nullified by a magnetic field produced by means of a steady direct current flowing through a coaxial secondary winding around the saturable core.

Thus, instead of measuring the earth's vertical field, this equipment measures the intensity of a steady direct current flowing through a nullified coil controlling a electric resistance. Because the saturable inductor measures the external field parallel to its axis, it can be used to measure the vertical component of the earth's magnetic field. In this instrument an attempt was made to use a gimbal system to orient the detector so that the vertical component could be measured at sea.

The gimbal system mounted in the case of magnetometer determines the true vertical line at sea. If the angle for rolling of a ship-borne due to wave is about 20°, the error of measurement never exceeds over 50γ. The detector and gimbal system is set in a bomb-shaped nacelle. This detector mechanism must be located so that it is not affected appreciably by the magnetic material of the ship. A photograph of the shipborne magnetometer is shown in Fig. 8.

This magnetometer may be accomplished by moving the detector mechanism from the ship and hanging it by means of a winch and cable system into the sea. The towing cable consists of the necessary electrical conductors and nylon rope.

3. Associated Equipments.

The shipborne magnetometer measures the magnetic vertical intensity at each point at sea. The position of the ship was fixed by electronic navigation aids, such as loran, or by sextant.

The depth of the shipborne was determined by scale from sea level. The depth of sea bottom at each observed point was measured by an echo sounder. All necessary data to compile a magnetic chart were measured frequently so that the magnetic intensity could be determined at each point.

4. Magnetic Survey.

The most efficient pattern for surveying is a series of parallel traverses taken at right angles to the trend of the major magnetic anomalies. Since this trend is not known until the survey is well under way, and a magnetic anomaly is magnetized to direction of earth magnetic field, so the course measured must be crossed by two traverses, the one parallel to a magnetic meridian and the other perpendicular to it. The observed points are shown in Fig. 9. The survey was carried out on Sagami Nada by *Takuyo* from January 20 to 26, 1960.

Since, in magnetic surveys the effects of the diurnal variation of earth's magnetic field and the instrumental drift are very small, these effects can be negiected to measure a magnetic field within the error of about 50γ. The

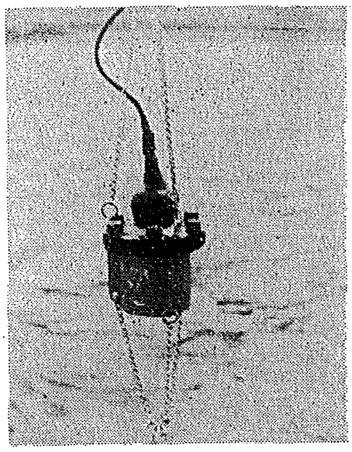


Fig. 8. Shipborne Magnetometer.

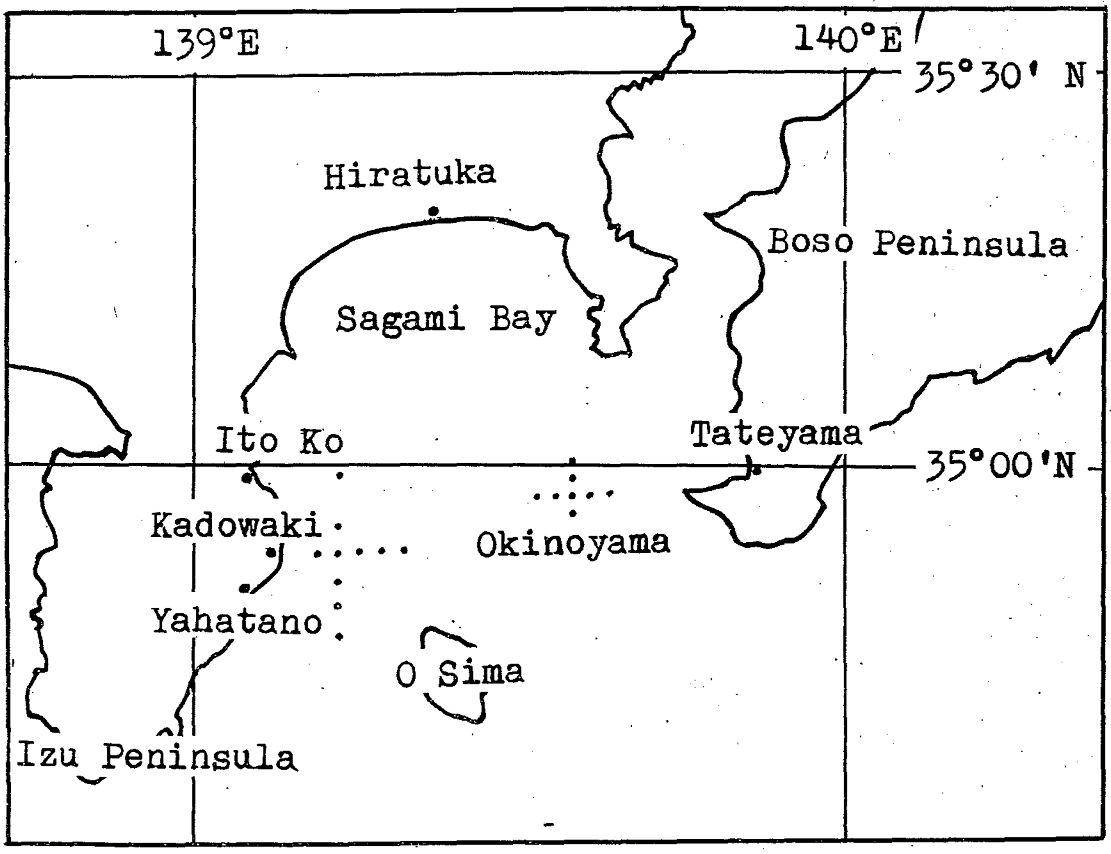
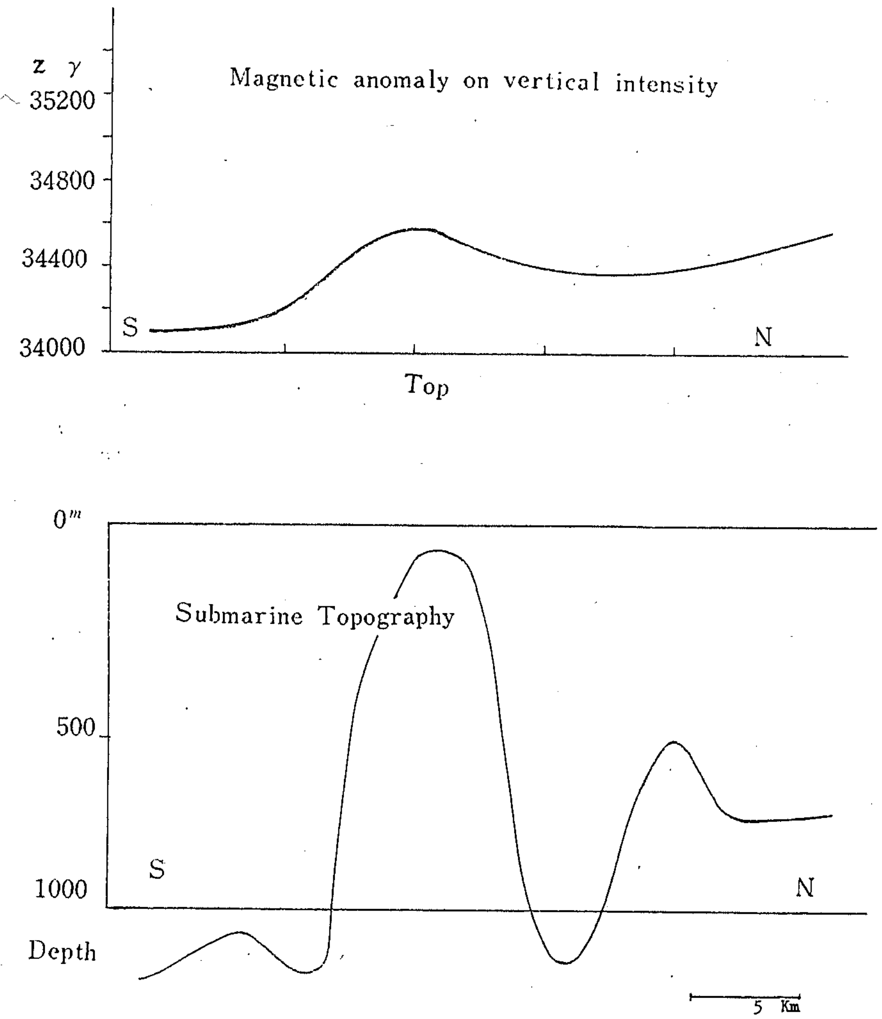


Fig. 9. Distribution of Measuring Points.



Fib. 10–b. Magnetic Anomaly and Submarine Topography at Okinoyama.

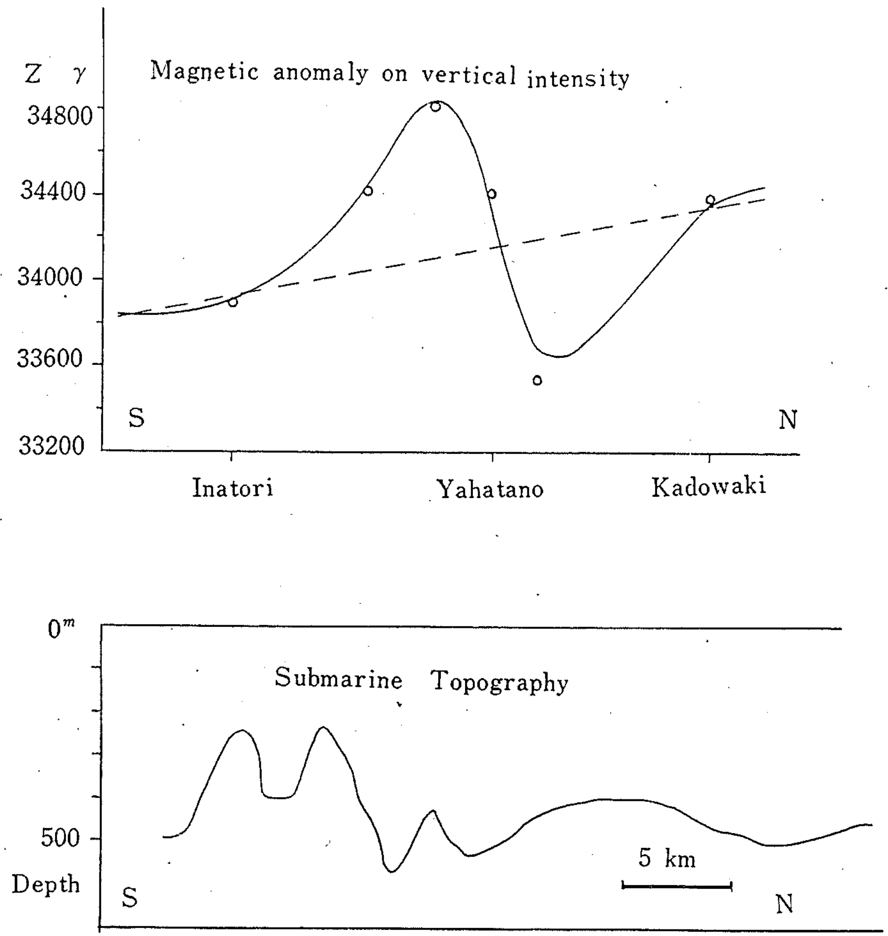


Fig. 10–a. Magnetic Anomaly and Submarine Topography near Ito.

necessary time duration is about 20 minutes to measure a magnetic field at a point, and the measurement is carried out at about 40 meters depth where there are not any influence occurred by a magnetic materials of ship. A morphology of magnetic anomaly is determined by drawing an average smooth curve through the observed values. A smooth curve is calculated by the least squares method.

The results of magnetic survey could be used to supply information which would permit unique or more accurate determination of the depth of the material producing a magnetic anomaly.

Fig. 10. shows the results of this survey, from which it is found that there are two pronounced anomalies, one is near Ito, other around Okinoyama at Sagami Nada. The anomaly near Ito is very great, but the one at Okinoyama is not so great as the one near Ito.

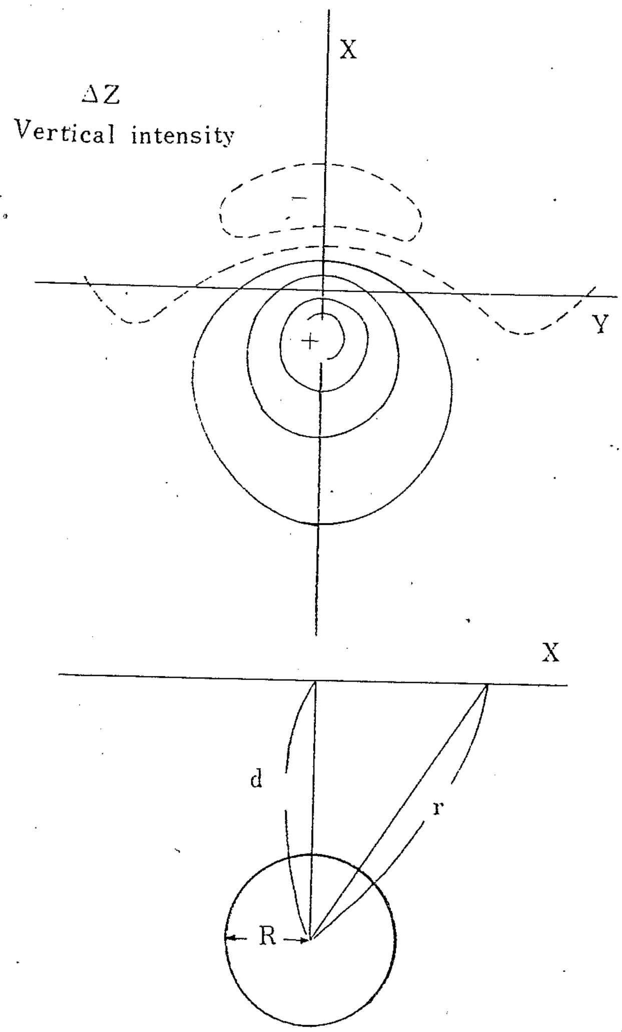


Fig. 11. Distribution of Magnetic Anomaly due to a Under-Ground Dipole.

The analysis of these anomaly is shown in the following. Assuming a magnetic field of anomaly occurs by a dipole under the ground, and taking the dipole as the origin of coordinates and its depth as d, we get the vertical component of magnetic anomaly due to the dipole as follows:

$$Z=3\,M_z\left[\frac{-d}{r^5}\left(x-d\frac{Z_0}{H_0}\right)\frac{H_0}{Z_0}-\frac{1}{3r^3}\right].$$

where M_z represents vertical moment of the dipole. The distribution of vertical intensity by the anomaly is shown in Fig. 11, where, magnetic inclination in the adjacent sea of Japan is taken approximately 45°, namely $H_0=Z_0$. Comparing Figs. 10 with 11, we can easily obtain the magnetic moment and the depth of the dipole.

If we assume the dipole to be produced by uniform magnetized sphere of radius R, the effective intensity of magnetization is expressed as

$$M=\frac{4}{3}\pi R^3 J.$$

As shown in Fig. 11, the anomaly shows a large positive anomaly in southern area, and a small negative anomaly in northern area.

In the case of the anomaly near Ito, the depth of dipole is about 2 km and the magnetic moment is 2.4×10^{14} emu. The anomaly near Ito is very anomalous.

Therefore, we can consider that the anomaly may be caused by a large mass of basaltic rock under ground. The intensity of magnetization is listed in Table 1 assuming the dipole to be due to a uniformly magnetized sphere of radius R=2km. It seems that there are no apparent correspondence to the submarine topography near Ito.

This suggests that the magnetic field is more seriously affected by the magnetic properties of materials near the surface of the earth than by the submarine topography. Also, we can consider that this magnetic anomaly is associated with the submarine volcano.

TABLE 1. MAGNETIZATION AND MAGNETIC MOMENT ON AN ANOMALY AT OKINOYAMA AND AN ANOMALY NEAR ITO

Position	J emu/cc	Magnetic Moment	Rock
Near Ito	0.035	2.4×10^{14} emu	Basalt
Okinoyama	2×10^{-5}	5.4×10^{11} emu	Shale

In the case of the anomaly at Okinoyama, we can calculate the magnetic moment by the same method described in case of a anomaly near Ito. The results is tabled in Table 1.

From the chart and a profile of submarine topography as shown in Fig. 10, we can see that Okinoyama has the structure of bank. Therefore, the magnetic anomaly at Okinoyama may be caused due to the remnant magnetization of the mass of bank mainly by the earth's magnetic field. Assuming that the dipole is situated at the centre of the bank, and the anomaly occurs due to the remanent magnetization of the mass of bank, its depth, intensity of magnetization and magnetic moment are able to be calculated as follows. The results is shown in Table. 1, too.

depth .... about 0.6 km
M .... 5.4×10^{11} emu
J .... 2.0×10^{-5} emu/cc

It can be concluded that the anomaly can be interpreted as magnetic anomaly, largely due to the uniform magnetization of the bank under sea level with its intensity of 2.0×10^{-5} emu/cc in the direction of earth's magnetic field. Thus, it is found that the bank of Okinoyama is formed of sedimentary rock.

Part III

Magnetism of a steel vessel

1. Magnetism of a steel vessel.

The detailed measurement and analysis of the magnetic field existing on a steel vessel is studied in this chapter. Magnetism of a steel vessel arises largely from induced and permanent magnetisms on the vessel.

A permanent magnetism can be considered as a concentrated dipole and the intensity depends on the magnetic heading upon which the vessel was built.

An induced magnetism can be treated as if it were concentrated in bares of soft iron, one vertical and the other horizontal. The polarity of a steel vessel depends upon the position of the vessel relative to the earth's magnetic field, and the strength depends upon the strength of the vertical and horizontal components of the earth's field.

Assuming the ship as a uniformly magnetized prolate spheroid, the magnetic fields around an iron ship was calculated by J. Ohshima (1955). From the results, a simplified diagram of the distortion of the earth's field in the vicinity of a steel vessel is shown in Fig. 12. A vessel's induced magnetism varies with heading.

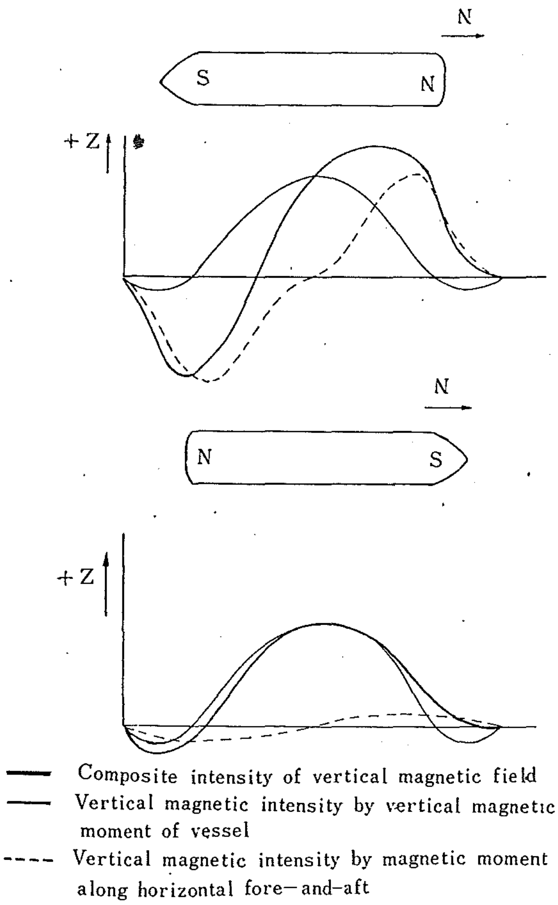


Fig. 12. Theoretical Distribution of Vertical Magnetic Field of Steel Vessel.

The total magnetic moment of vessel is divided into three components: (1) vertical, (2) horizontal fore — and — aft, and (3)

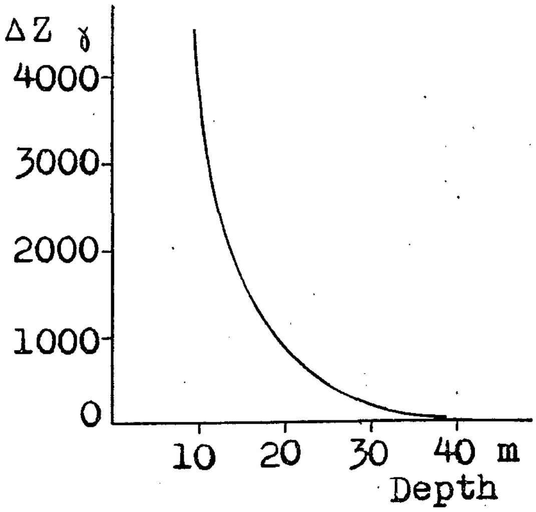


Fig. 13–a. Relation between Magnetic Field due to *Takuyo* and Depth, 1st Point.

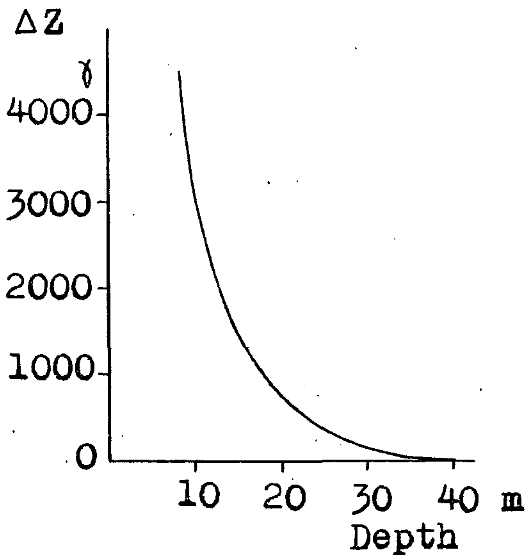


Fig. 13–b. Relation between Magnetic Field due to *Takuyo* and Depth, 2nd Point.

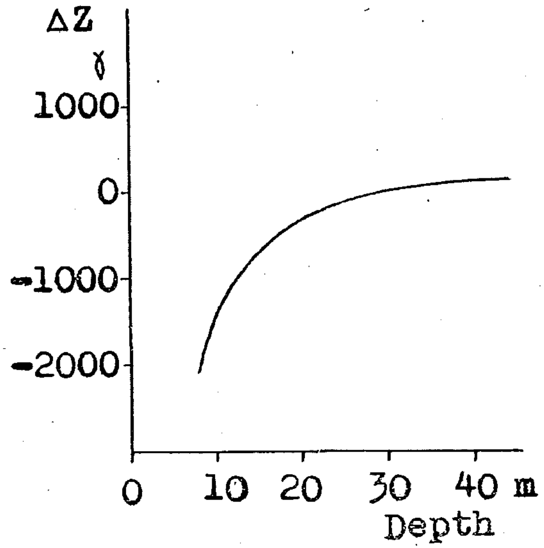


Fig. 13–c. Relation between Magnetic Field due to *Takuyo* and Depth, 3rd Point

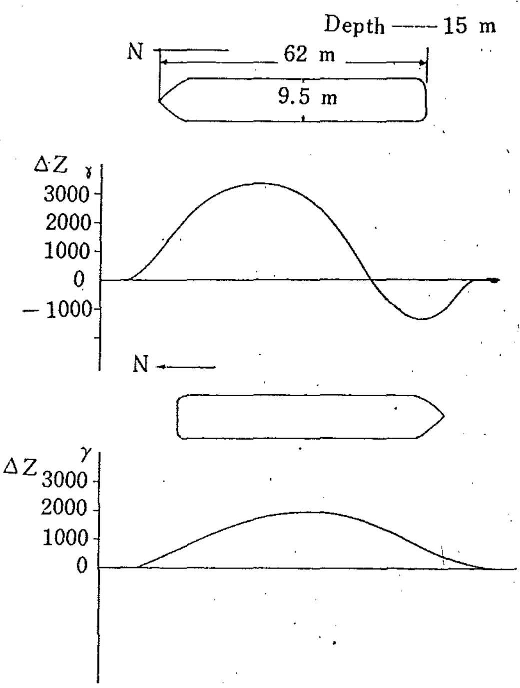


Fig. 14–a. Relation between Magnetic Field due to *Takuyo* and Depth.

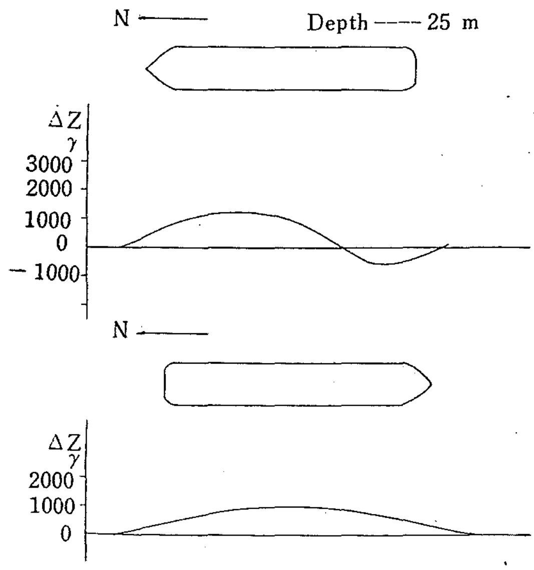


Fig. 14–b. Relation between Magnetic Field due to *Takuyo* and Depth.

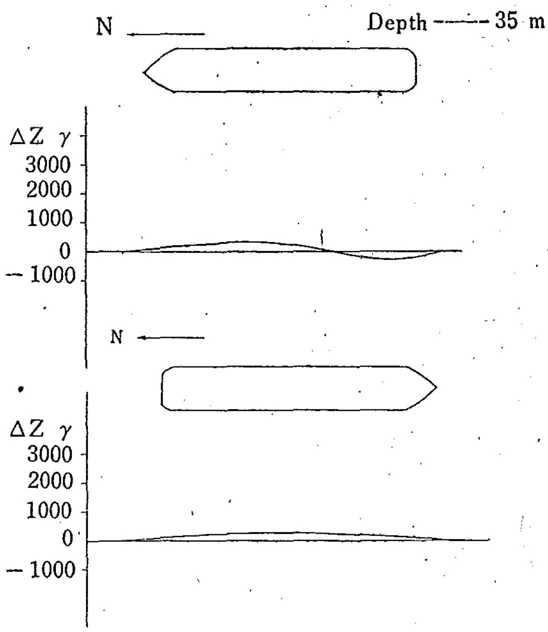


Fig. 14–c. Relation between Magnetic Field due to *Takuyo* and Depth.

horizontal athwartships. The magnetic moment of a steel vessel can be separated into two parts: induced magnetism and permanent magnetism.

2. Measurement of a magnetic field around *Takuyo.*

The magnetic measurement was carried out on *Takuyo*, at Tateyama Bay on January 26, 1960.

At first, the vessel is directed on a heading of magnetic north, and next, on a heading of magnetic south. On such directions of the vessel, vertical component of a magnetic field around the vessel was measured with the shipborne magnetometer along to horizontal fore—and—aft directions of the vessel at each depth under sea level, for example, 15, 20, 25, 30, 35, 40 and 45 meter.

Relation between a vertical intensity of magnetic field due to *Takuyo* and depth obtained from observation is shown in Figs. 13 and 14. Comparing Figs. 12 with 14, we can calculate each component of the magnetic moment of *Takuyo* on a permanent and induced magnetisms, which is listed in Table 2.

TABLE 2. MAGNETIC MOMENT OF *Takuyo.*

Magnetic moment \ component	horizontal fore-and-aft component	vertical component
Permanent magnetic moment	4.2×10^7 emu	5.4×10^7 emu
Induce magnetic moment	4.2×10^7 emu	3.0×10^7 emu
Total magnetic moment	8.4×10^7 emu	8.4×10^7 emu

Conclusion

We carried out geomagnetic survey with the new type magnetometers by means of a aircraft and a vessel on the volcanic island and at sea, and got many interesting results. Also, we measured magnetism of a steel vessel, and calculated each component of the magnetic moment of it.

In future, such magnetic surveys will be held on many areas of the adjacent seas of Japan for the investigation on the terrestrial magnetism and for the promotion of the safety of navigation.

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