direct potential-field interpretation towards subsurface geologic maps. In this way, potential-field data could gain the kind of credibility accorded to seismic reflection data, because the seismic data are presented to look like geologic cross-sections.

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Keep in mind that seismic anomalies are indicative of vertical changes in rock properties, whereas potential-field anomalies are indicative of lateral changes in rock properties. Indeed, assumptions related to processing seismic data actually suppress identification of these lateral changes, such as: The Earth is made up of horizontal layers of constant velocity, the source waveform is known, noise is predictable, the wavelet is minimum phase, etc.

Seismic data, unlike potential-field data, can't always tell what is happening geologically in a lateral sense.

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Aeromagnetic Constraints on the Basement Structure of the Tunghai Shelf and the Okinawa Trough in the East China Sea

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EDITOR'S NOTE: *Depth-to-basement inversions are fairly routine in regional scale exploration. It is important to note that relatively simple modeling assumptions can yield valuable constraints on basement structure.*

Remanant magnetization "relaxes" over geologic time. Precambrian granites worldwide seem to display only induced magnetization and can be modeled effectively without a remanant effect.

Introduction

Aeromagnetic surveys offshore the western Nansei Islands, Japan, were conducted by the Geological Survey of Japan (GSJ) from 1982 to 1989 (Okuma et al., 1991). The surveys cover the area from the Tunghai Shelf in the East China Sea to the Okinawa Trough west of the Nansei Islands (Ryukyu Arc) (Figures 1 and 2). Although the area, especially the Tunghai Shelf, was regarded as a potential field for hydrocarbon resources, few explorations were conducted in the area. The aeromagnetic surveys, therefore, were conducted. Then we performed a 3-D, two-layer magnetic modeling to obtain further detailed information about the basement structure of the area. This paper outlines the results of the modeling and describes characteristics of the magnetic anomalies in the area.

Geology

In the study area, two major geologic structures are known for having hydrocarbon potential—the Tunghai Shelf and the Okinawa Trough (Figure 2).

Wageman et al. (1970) suggested the existence of a large sedimentary basin, the Taiwan Basin, in the Tunghai Shelf, which is bounded on the northwest and southeast by the Fukien-Ryeongnam Belt (Fukien-Reinan Massif) and Goto-Senkaku Belt (Taiwan-Sinzi Folded Zone), respectively (Figure 3). Since then, the basin has been regarded as a potential field for oil and gas resources. The Taiwan Basin is divided into three basins: the Goto Basin, the Tokai Basin, and the Senkaku Basin from northeast to southwest (Kizaki, 1986; Figure 3). Thick sediments have been deposited almost continuously since the Paleogene, with a hiatus in the Middle Miocene (Aiba and Sekiya, 1979). Recently, hydrocarbon explorations such as seismic reflection surveys and drilling have been conducted, mainly in the Goto Basin and the Tokai Basin, resulting in shows of oil and gas. Oil and gas shows also have been confirmed in several drill holes close to the continent in the East China Sea (Guangding, 1989). However, the detailed basement structure of the area, especially the Senkaku Basin, remains unclear because of insufficient explorations.

The Goto-Senkaku Belt lies along the outer edge of the Tunghai Shelf between Kyushu Island and Taiwan and consists of two parts, the Goto Belt and the Senkaku Belt (Aiba and Sekiya, 1979; Figure 3). The Goto Belt comprises Paleogene to Early Miocene sediments associated with welded tuff and granitic rocks of Miocene age, and it is overlain mostly by Pliocene sediments (Kizaki, 1986). Miocene granitic rocks also are exposed in the Senkaku Islands (Matsumoto and Tsuji, 1973). The Goto-Senkaku Belt was uplifted in the Middle Miocene and, in some parts, to Pliocene time and dammed flows of sediments from the continent.

The Okinawa Trough is a back-arc basin associated with northwestward subduction of the Philippine Sea Plate at the Ryukyu Trench (Figure 2) and is bounded on the northwest and southeast edges by the Goto-Senkaku Belt and the Ryukyu Arc, respectively (Figure 3). The bathymetry of the trough becomes deeper toward the southwest and exceeds 2000 m offshore northern Ishigaki Island (Figure 2). Hydrocarbon explorations have been conducted mainly in shallow-water areas—the northeastern part of the trough and the Ryukyu Arc area (Aiba and Sekiya, 1979). Geologic and geophysical investigations (e.g., Oshima et al., 1988) also have been conducted to reveal the origin of the trough. Many step faults and their resultant roll-over anticlines commonly are observed on seismic profiles in the west flank of the trough north of Okinawa Island (Aiba and Sekiya, 1979). Covering the trough are thick Pliocene and Pleistocene sediments, and the maximum depth of acoustic basement exceeds 5000 m.

Characteristics of Magnetic Anomalies

Previous magnetic data in the East China Sea are mainly from widely spaced ship-track data (e.g., Wageman et al., 1970). The aeromagnetic surveys by GSJ were flown at an elevation of 460 m (1500 ft) above sea level with line spacing of 5 km, especially 2.5 km over the Senkaku Islands (Okuma et al., 1991). Therefore, our new magnetic data (Figure 4) are more detailed than the previous ones.

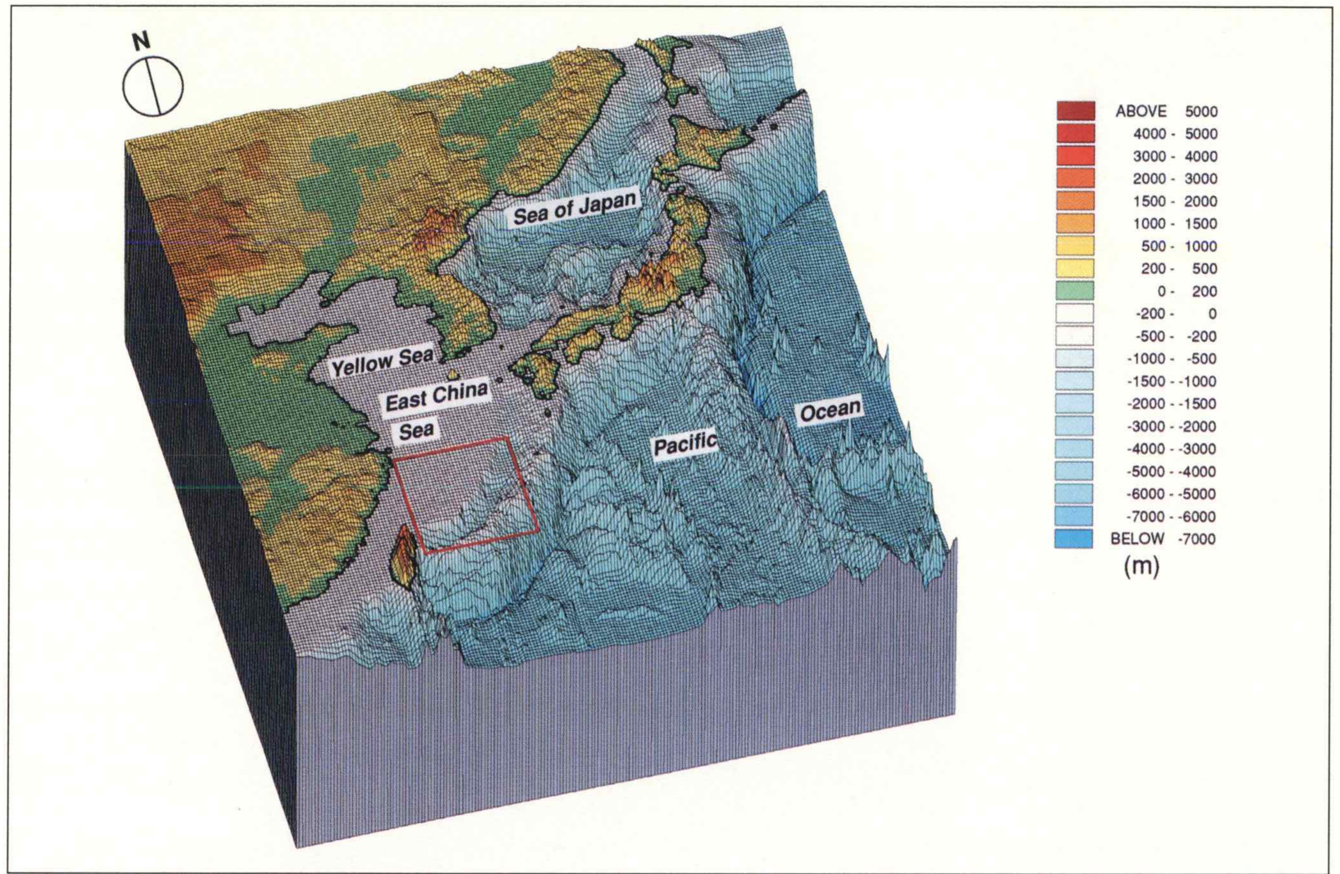

__Figure 1.__ Location of the study area. The area bounded by solid red lines shows the study area. Vertical exaggeration is 12.5:1. Topography data were compiled from the terrain data "KS-110" by Geographical Institute of Japan, bathymetry data by the Hydrographic Department, Maritime Safety Agency, Japan, and ETOPO5 data by NOAA.

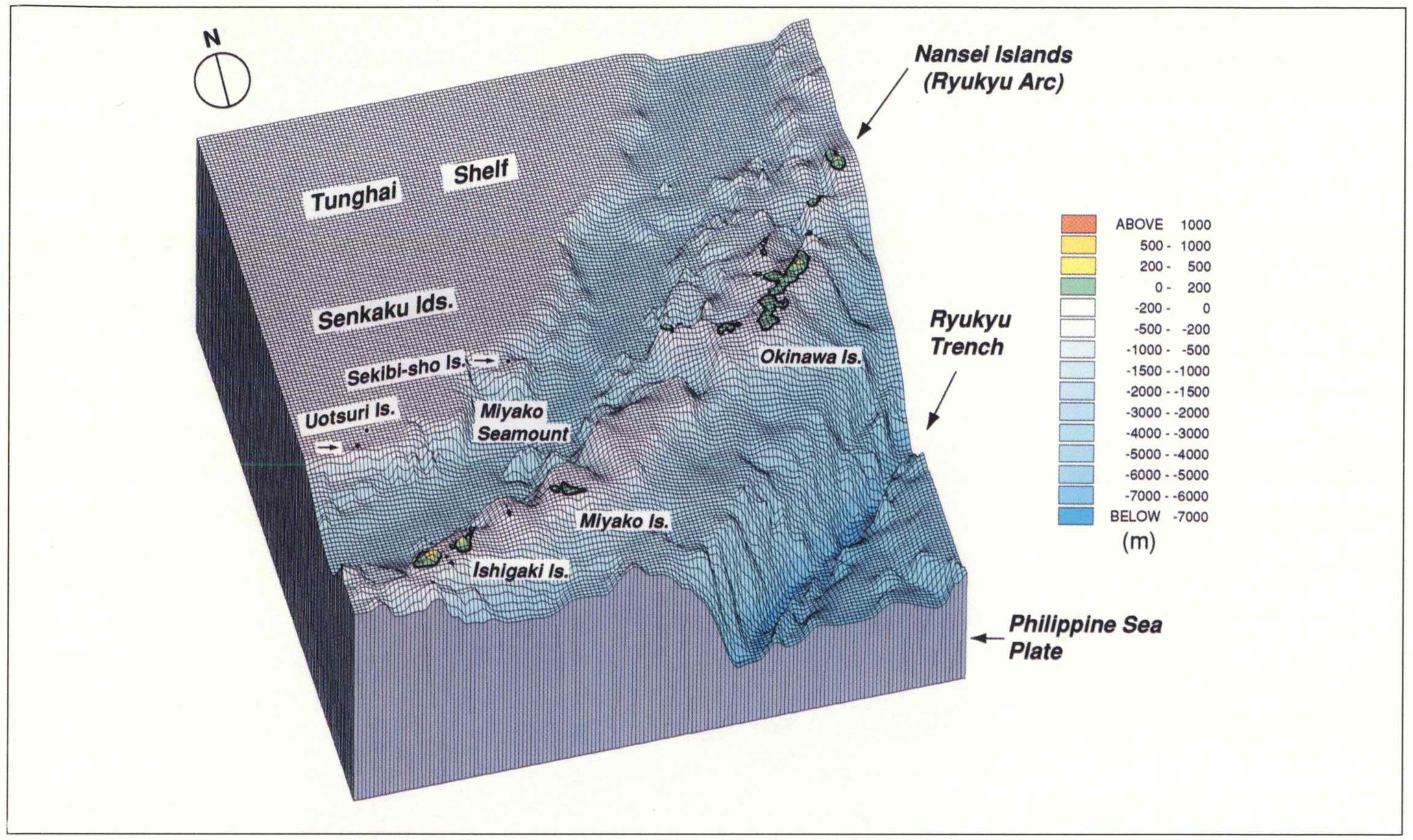

__Figure 2.__ Bird's-eye view map of the topography of the study area. See also Figure 1.

Generally, magnetic anomalies trend northeast to southwest along the topography (Figure 4). Magnetic anomalies, which have long wavelengths of more than several tens km and small amplitudes of less than 50 nT, are distributed predominantly in the Tunghai Shelf and west flank of the Okinawa Trough. From the total-intensity magnetic anomalies (Figure 4), a reduction-to-the-pole anomaly map was made through a method in frequency domain (Figure 5). This map clearly shows a correlation between the bathymetry and magnetic highs at the margin of the Tunghai Shelf. A large number of magnetic highs (H2) are dominant over the Goto Belt, whereas few intense anomalies are obvious over the Senkaku Belt, except in and around Sekibi-sho Island. This implies a difference in past volcanic activities between the Goto Belt and the Senkaku Belt, with more intense activities on the Goto Belt. Magnetic lows (L1) lie west of the Goto-Senkaku Belt in the shelf, where the Tokai and Senkaku basins are located. A magnetic high area (H1) is distributed north of Uotsuri Island in the shelf, which is inferred to correspond to local uplifts of the basement of the Senkaku Basin.

A magnetic low area (L2) ranges along the west flank of the Okinawa Trough but is limited to the areas from the northeastern edge of the survey area to the northwest of Okinawa Island.

Magnetic highs (H3, H4) can be observed in the Okinawa Trough near the southwestern and northeastern edges of the survey area. Some of these anomalies at the axis of the trough correspond to knolls which are assumed to be magnetized in the direction of the present Earth's magnetic field (Oshima et al., 1988).

Magnetic Modeling

As we described before, long-wavelength and small-amplitude magnetic anomalies are distributed predominantly in the Tunghai Shelf and west flank of the Okinawa Trough. These anomalies may correspond to uplift and subsidence of the geologic basement, composed probably of granitic rocks. Therefore, we applied a 3-D, two-layer model inversion (Gerard and Debeglia, 1975; Okuma et al., 1989) to interpret magnetic anomalies of the study area. First, an average depth of the interface, 3.9 km below sea level, between the nonmagnetic upper layer and magnetic basement was estimated from a slope of radially averaged power spectrum of the reduction-to-the-pole anomalies (Figure 5). Then the deviation from the average depth (i.e., magnetic basement depth) was calculated over the survey area by an iterative convergence method, using pseudogravity and reduction-to-the-pole anomalies. We assumed the magnetic basement is magnetized in the direction of the present Earth's magnetic field (inclination = 38.5°N, declination = 4°W) in the area, with a uniform magnetization intensity. We employed 2.0 A/m for the magnetization intensity, taking account of magnetic anomalies caused by volcanic rocks in the Goto-Senkaku Belts and the Okinawa Trough in addition to those caused by granitic rocks. As magnetization intensities of rocks actually vary from point to point, resultant magnetic basement depths in this study do not always coincide with the acoustic basement. In our case (Figures 6 and 7), the magnetic basement in the southern Okinawa Trough is deeper than the top of the 4.5–6.0 km/s layer, the acoustic basement of a multichannel seismic reflection profile, and shallower than the top of the 6.0–6.4 km/s layer (Hirata et al., 1991), probably a granitic layer.

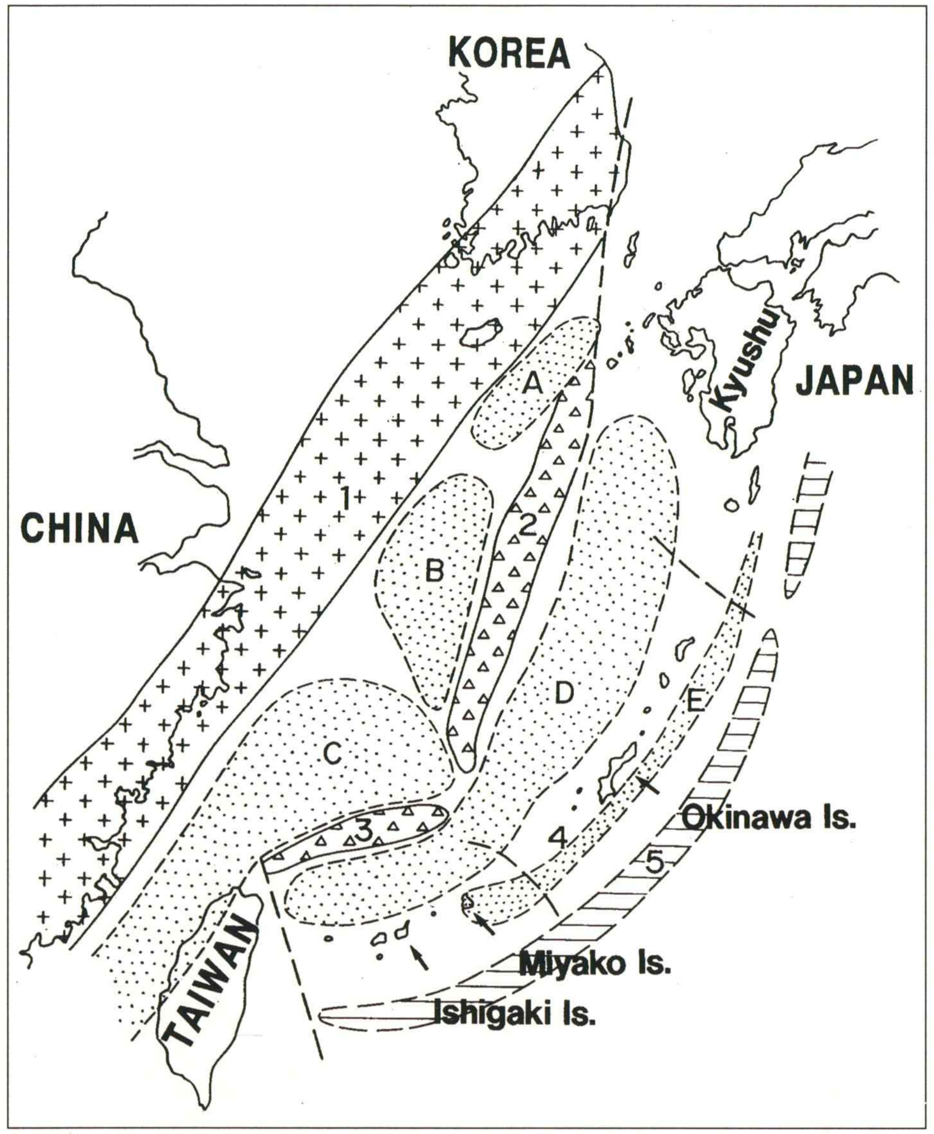

Figure 3. Outline of the geologic structure in and around the East China Sea (after Japan Natural Gas Association and Japan Offshore Petroleum Development Association (1982): (1) Fukien-Reyongnam Belt; (2) Goto Belt; (3) Senkaku Belt; (4) Ryukyu Geanticline; (5) Ryukyu Trench; (A) Goto Sedimentary Basin; (B) Tokai Sedimentary Basin; (C) Senkaku Sedimentary Basin; (D) Okinawa Trough; (E) Ryukyu Fore-arc Sedimentary Basin.

The magnetic basement attains a depth of less than 2 km below sea level on the Goto Belt (Figure 6 and cross-sections C-D and E-F in Figure 8). The result implies the existence of magnetized bodies near the sea bottom in this area. They may be related to Middle Miocene volcanic and intrusive rocks of the Goto Belt. Around Sekibi-sho Island, the magnetic basement also rises to a depth of shallower than 2 km below sea level (Figure 6 and cross-section G-H in Figure 8). However, the uplifted area is limited to near the island, compared with the one in the Goto Belt. This result suggests a difference in geology between the Goto and Senkaku Belts.

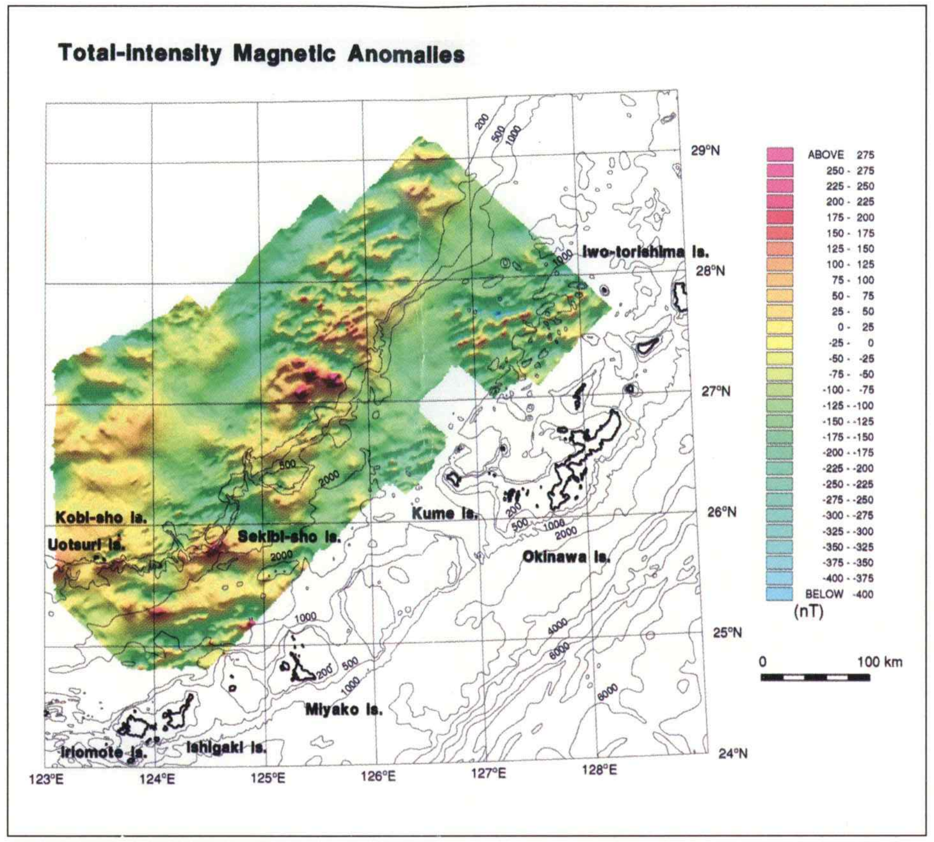

Figure 4. Shaded-relief map of IGRF-residual total-intensity aeromagnetic anomalies of the study area. The aeromagnetic surveys by GSJ were flown along northwest-southeast flight lines at an altitude of 460 m above sea level and spaced 5 km apart, especially 2.5 km apart over the Senkaku Islands (Okuma et al., 1991). Contour interval is 25 nT. Bathymetric contours are in meters. Inclination of the light source, 45°; declination, 0°.

The magnetic basement is situated at a depth of 1 km below sea level to the north of Uotsuri Island in the Tunghai Shelf (Figure 6 and cross-section G-H in Figure 8). This magnetic basement high corresponds to one of the large anticlinal structures with gentle dips in the Senkaku Basin, suggested by seismic reflection data (Tokai Univ., 1969). Hydrocarbon accumulations are expected in those structures, but intensive seismic investigations are necessary to confirm more detailed structures in this area.

The magnetic basement also rises up to near the sea bottom along the east flank of the Okinawa Trough, especially offshore northern Okinawa Island (cross-section C-D in Figure 8) and near the Miyako Seamount (cross-section G-H in Figure 8). They correspond to volcanic knolls and intrusive rocks beneath the sea bottom.

The magnetic basement subsides mainly in the Tunghai Shelf and the west flank of the Okinawa Trough (Figure 6). A magnetic basement low extends in the north-northeast–south-southwest or northeast-southwest direction at a maximum depth of 10 km below sea level in the Tunghai

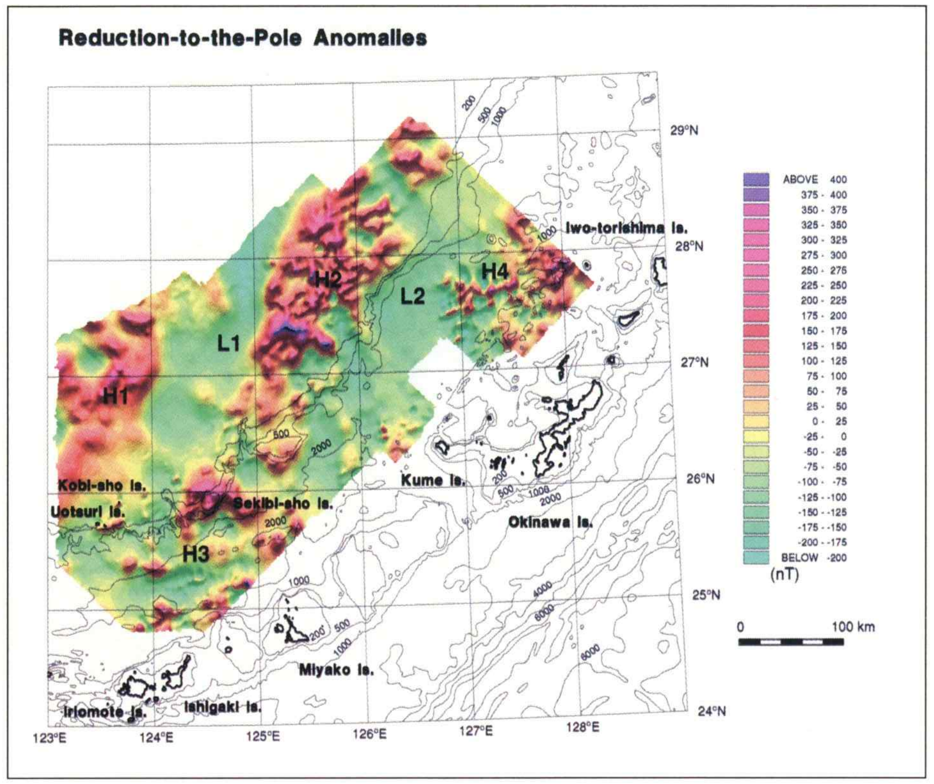

Figure 5. Shaded-relief map of reduction-to-the-pole anomalies, calculated from the IGRF-residual total-intensity aeromagnetic anomalies (Figure 4). H1-H4, magnetic highs; L1-L2, magnetic lows. See also Figure 4.

Shelf (cross-section E-F in Figure 8), although a small magnetic basement high, 100 km north of Sekibi-sho island, interrupts the extension locally. This corresponds to the southern edge of the Tokai Basin and the eastern part of the Senkaku Basin.

The maximum depth of the magnetic basement reaches 10 km below sea level in the west flank of the Okinawa Trough, 150 km offshore northwest Okinawa Island (cross-section E-F in Figure 8). A magnetic basement low traverses the Goto Belt in the northwest-southeast direction and corresponds to a subsidence of the acoustic basement in the northern part of this area, where thick deltaic or submarine fan sediments are deposited (Aiba and Sekiya, 1979). There is a possibility of hydrocarbon accumulations in those thick sediments because of high heat flows, although the sediments seem to be too young to generate them.

Conclusions

A 3-D, two-layer model inversion was applied to analyze magnetic anomalies in the Tunghai Shelf and the Okinawa Trough. The resultant magnetic basement map gave constraints of the basement structure of the area. This map shows the existence of a local uplifted zone in the

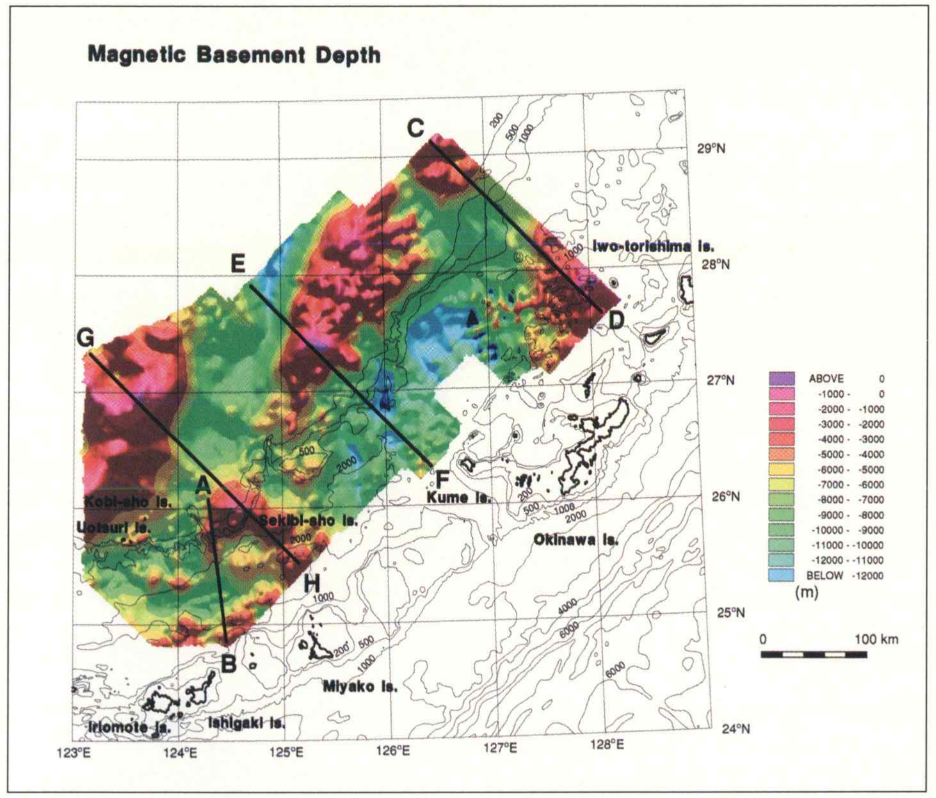

Figure 6. Magnetic basement depth map of the study area, estimated by a 3-D, two-layer model inversion (Gerard and Debeglia, 1975; Okuma et al., 1991). The magnetic basement is assumed to be magnetized in a direction of the present Earth's magnetic field (inclination = 38.5°N, declination = 4°W) in the area, with a uniform magnetization intensity of 2.0 A/rn. The absolute mean error is 14.9 nT. Contour interval is 1000 m. See also Figure 4.

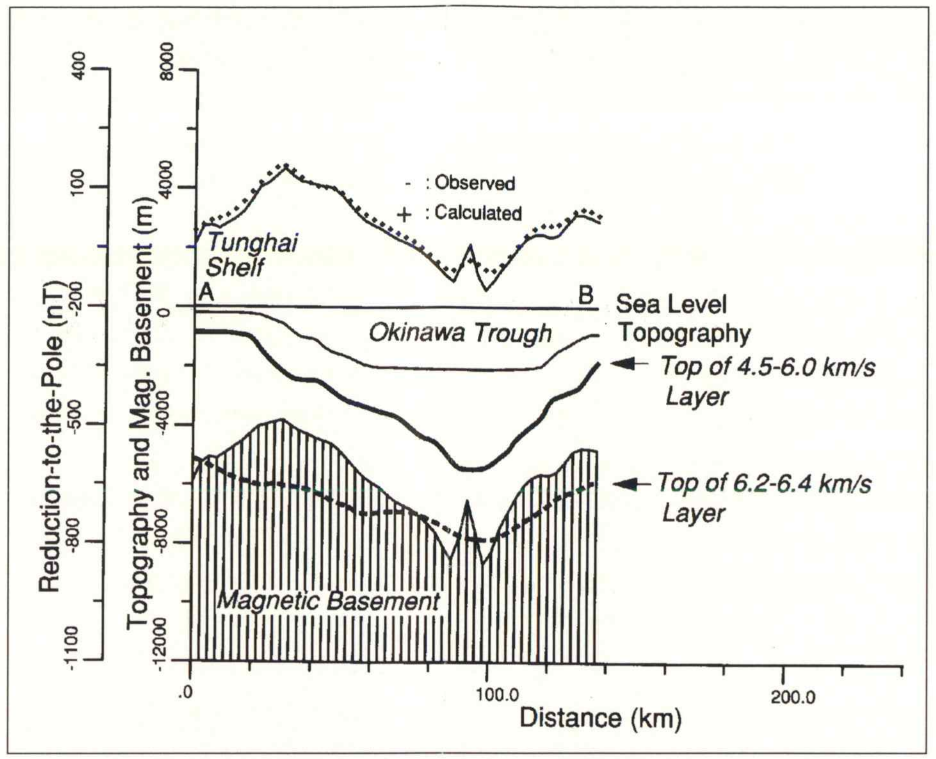

Figure 7. Cross-section (A-B) on the magnetic basement depth map (Figure 6). The 4.5–6.0 km/s layer, corresponding to the acoustic basement of a multichannel seismic reflection profile, and the 6.2–6.4 km/s layer, probably a granitic layer, are from a seismic refraction profile along a 2-D P-wave velocity model (Hirata et al., 1991) of the 1988 DELP cruise.

Senkaku Basin, and magnetic basement depths of 10 km below sea level in the Tokai Basin and in the west flank of the Okinawa Trough north of Okinawa Island.

Acknowledgment

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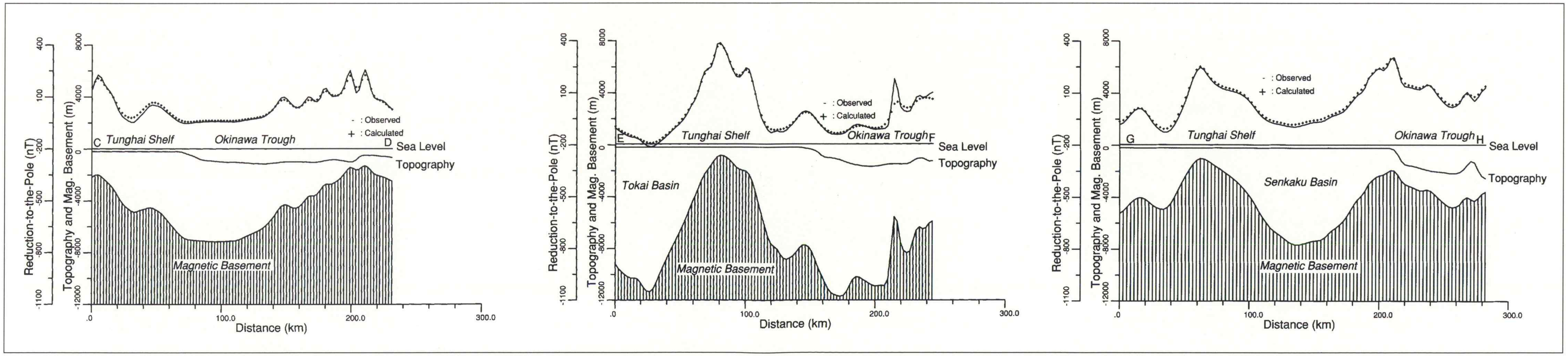

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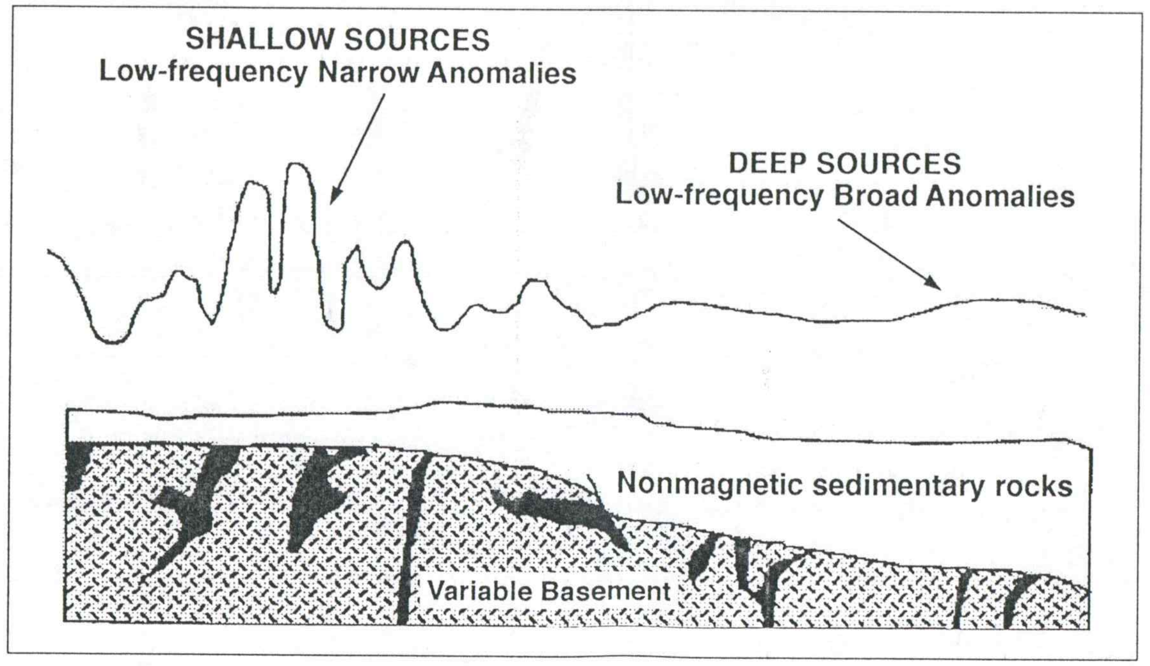
Magnetic Frequency-depth Relationship

Shallow density and susceptibility contrasts produce narrow, or high-frequency, anomalies, while deeper contrasts result in broader, low-frequency anomalies. We can use this characteristic of the gravity and magnetic fields to determine depths to sources, both qualitatively and quantitatively. Because gravity signatures come from everywhere, from the air to the Earth's core, such inferences are often not straightforward or reasonably unique. But most magnetic anomalies come from only a few rock types, such as volcanics, intrusives, and basement rocks. Magnetic data therefore can be used to estimate depth to basement—a classic use for such data. The illustration shows how the anomalies change from narrow over shallow basement to broad over deeper basement.

R. I. Gibson



Aeromagnetic Interpretation of Southwestern Continental Shelf of Korea

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EDITOR'S NOTE: *Baag and Baag show how analysis of even quite old low-quality data sets can provide a powerful tool in tectonic analysis. The work resulted in the prediction of a new sedimentary basin whose origin can be understood in terms of geologic structural elements that are well expressed in the magnetics data.*

Abstract

Analysis of the Project Magnet aeromagnetic data acquired by the U. S. Navy in 1969 permits us to predict a new sedimentary basin, Heuksan Basin, south of the known Gunsan Basin in Block II, offshore South Korea. The basin appears to consist of three subbasins trending north-northwest–south-southeast. The results of our analysis provide not only an independent assessment of the Gunsan Basin, but also new important information on the tectonic origin and mechanism for the two basins as well as for the entire region. The basin-forming tectonic style is interpreted as rhombochasm associated with double-overstepped left-lateral wrench faults. From magnetic evidence, a few northeast-southwest-trending major onshore faults are extended to the study area.

We also interpreted the faults to be left-lateral wrenches. This new gross structural style is consistent with the results of recent Yeongdong Basin analysis (Lee, 1990). The senses of fault movement also are supported by paleomagnetic evidence that the Philippine Sea has experienced an 80° clockwise rotation since the Eocene. Based on a 2.5-D model study, the probable maximum thickness of the sediments in the Gunsan Basin is approximately 7500 m. We believe that the new Heuksan Basin was left unidentified because a high-velocity layer may