УДК 550.3+551.21(265.72)

DISTRIBUTION OF ERUPTIVE VOLCANIC BASALT IN THE SOUTH CHINA SEA AND ADJACENT AREAS BY INTERPRETING GRAVITY, MAGNETIC AND SEISMIC DATA

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Поступила в редакцию 20 мая 2015 г.

Volcanic basalt eruption activity in the South China Sea and adjacent areas occurred strongly in Cenozoic E ra. However, it is difficult to define their ranges and spatial locations.

This paper presents the methods of reduction to the magnetic equator in low latitudes to bring out a better correlation between magnetic anomalies and their causing-sources; high-frequency filtering is to separate gravity and magnetic anomalies as well as information about the volcanic basalts in the upper part of the Earth's crust; 3D total gradient is to define the spatial location of high density and magnetic bodies. The distribution of eruptive volcanic basalt is determined by multi-dimensional correlation analysis between high frequency gravity and magnetic anomalies with weighted total gradient 3D.

The results from the above-mentioned methods have shown that the distribution of the eruptive volcanic basalt is mainly concentrated along the South China Sea's seafloor-spreading axis, transitional crust, Manila trench and some large faults zone. These results are improved by existing boreholes and seismic data in the study area.

Key words: **South China Sea, distribution of eruptive volcanic basalts, interpreting of gravity and magnetic anomalies.**

INTRODUCTION

The South China Sea formed from the collision between the Indian and the Eurasian plates. The opening process of South China Sea leads to sea-floor spreading to form the basins. Some of them were opened by pull-apart mechanism resulting in lithospheric rift and separating of sub-continent as well. It is said that the spreading process terminated in the Late Miocene after the collision among North Palawan formation and West Philippine Arc; Taiwan Island and Chinese mainland. The initiate phase of lithospheric rift is often accompanied by magmatic activities (eruption and intrusion). Volcanic activities are quite strong after sea-floor spreading and the magmatic eruption occur not only in the South China Sea, but also elsewhere in the Southeast Asia. The magmatic activity cut-through the ocean floor, sub-continent such as Paracel and Spratly Islands, Reed Bank forming the extrapolate basalt layers in the region. Many suggested that, the opening process of the South China Sea is more complex than the existing document. Researching results from the geothermal and gravity methods show that either the rate of subsidence extremely slow or the intrusion rate of heat flow come up so high. The relationship of the time and space of magmatic field after rift is unclear and inconsistency geophysical data lead to the question, that is, main motion for the magmatic field: the mantle uplift or the lithospheric rift? [11, 14].

The volcanic activities occur in multi-phases and basalt eruption develops largely in the South China Sea and continental margins. In the Late Mesozoic, the eruptive volcanic basalt is main granite distributed in the northern margin of the South China Sea, Indochina continental shelf and Paracel and Spratly islands. In the Cenozoic, types of volcano are main basalt eruption, concentratd commonly in the continental margins and oceanic crust areas. In general, the distributive characteristics of eruptive volcanic basalt have a close relationship with the geotectonic activities of the South China Sea [1, 10, 14].

In the ocean, eruptive volcanic basalt is the main source of the local gravity and magnetic anomalies. Based on the difference of density and magnetic between volcanic basalt and sediment rock, some geoscientists have used the geophysical methods such as gravity, magnetic and seismic to determine the

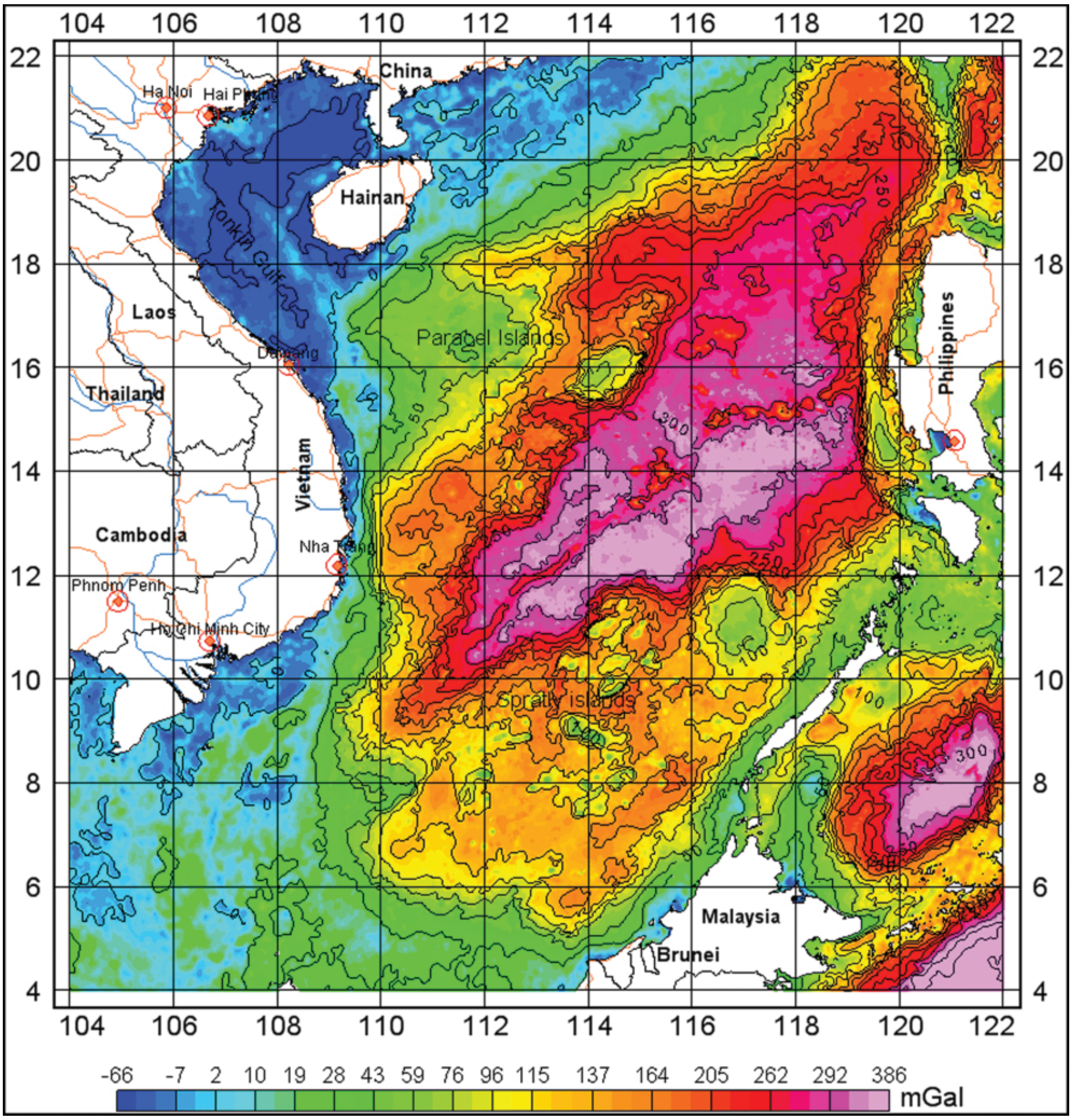

Fig. 1. Complete Bouguer gravity anomaly.

location of eruptive volcanic basalt. However, due to the complex tectonic activity, the difference of the Earth's crust structure, the diversity of rock types, variations of the geophysical anomaly at low latitudes, then the application of an individual geophysical method will not be able to bring out good results. Therefore, it is necessary to apply the interpretative methods of gravity, magnetic with seismic and drilling data in combination [10, 15].

In order to eliminate the inaccuracy of magnetic anomalies at low-latitudes, which caused by magnetic declination and inclination angle, some scientists have presented the methods of reduction to the magnetic equator or pole in the spatial and frequency domain [3, 5]. The application of low/high frequency filters allows determining the local/regional gravity and magnetic anomaly. Here, the high-frequency anomalies are used to explain and determine the distribution of eruptive volcanic basalt [8, 10]. 3D total gradient method is often used to determine the spatial location of the blocks of eruptive volcanic basalt [13].

DATA USED

The main gravity, magnetic and seismic data sources in the South China Sea are from the marine surveys of the Russian, Vietnam, French, German, United States and Japan geophysical companies. In the Vietnam Marine Research Programs, which carried out by the Institute of

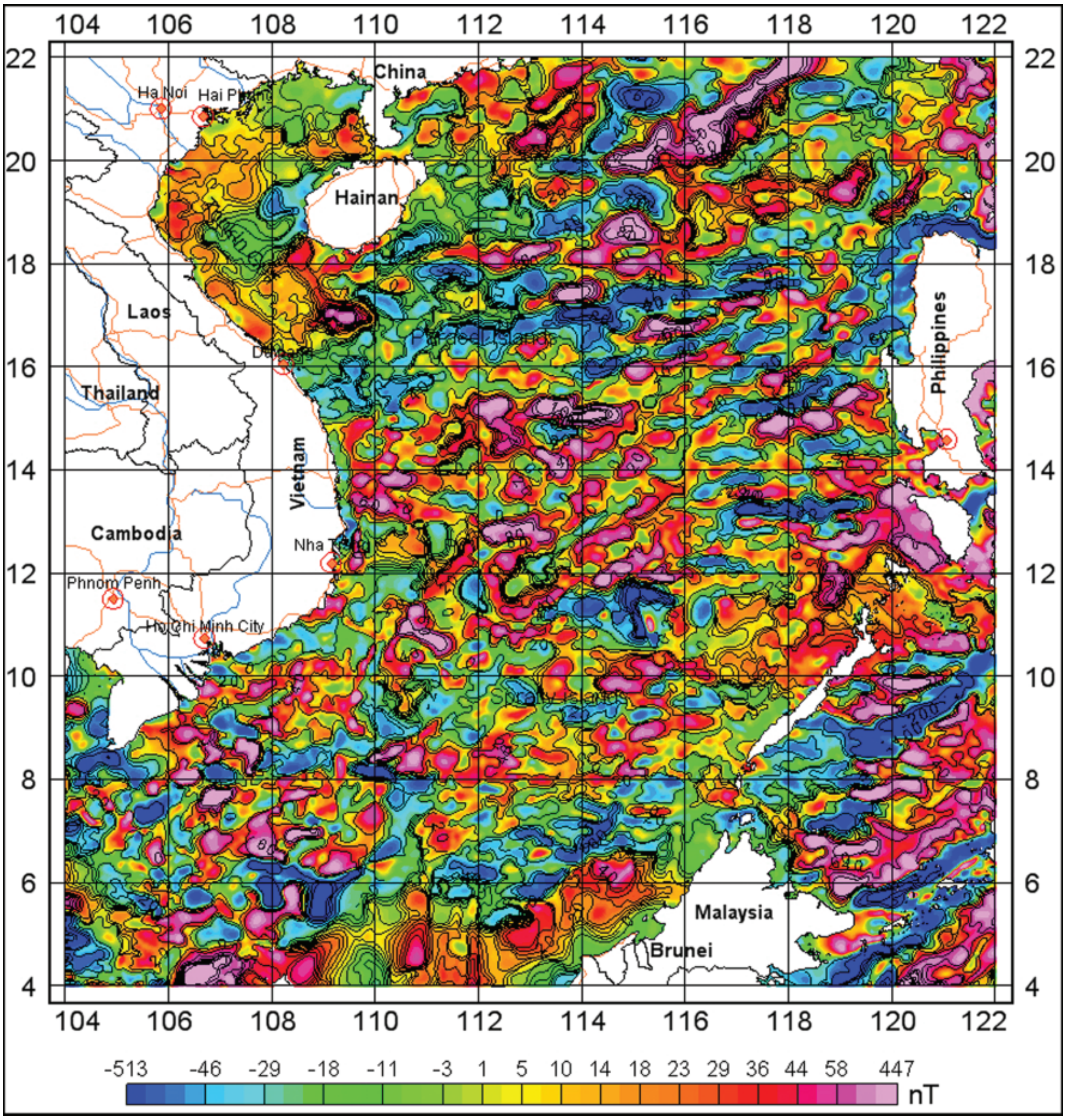

Fig. 2. Magnetic anomaly ΔTa.

Marine Geology and Geophysics in recent years, such as KHCN-06-12, KC-09-02, KC09-11/11-15 are also collected, interpreted and added the new research results and the valuable geophysical data in the South China Sea and adjacent areas [11], [15].

In this paper, the authors have combined the satellite gravity and magnetic with shipboard data in order to bring out a data set of the satellite-shipboard-derived, which have a higher accuracy and uniform resolution, in the South China Sea. In recent years, United State scientists have built a new gravity, bathymetry grid with interval of 1′×1′ (David Sandwell V21.1) [12], (Figure 1, 2, 3). The magnetic data (EMAG2) is get from the NOAA's National Geophysical Data Center. EMAG2 is a global Earth Magnetic Anomaly Grid that compiled from satellite, shipboard, and airborne magnetic surveys. That is the result of global cooperative projects on geophysical data, which are frequently added and updated. One can say that, it is the geophysical data sources with the most uniform resolution, wide coverage, suitable accuracy and cost to use effectively for research the geological structure in the South China Sea [12, 16].

In addition, this study also refers and usies the seismic data from the oil and gas exploration surveys that carried out by the geophysical companies inside and outside Vietnam, as projects VOR93, TC93, PK08… [15]. The research area was selected within 104°–122°E and 4–22°N.

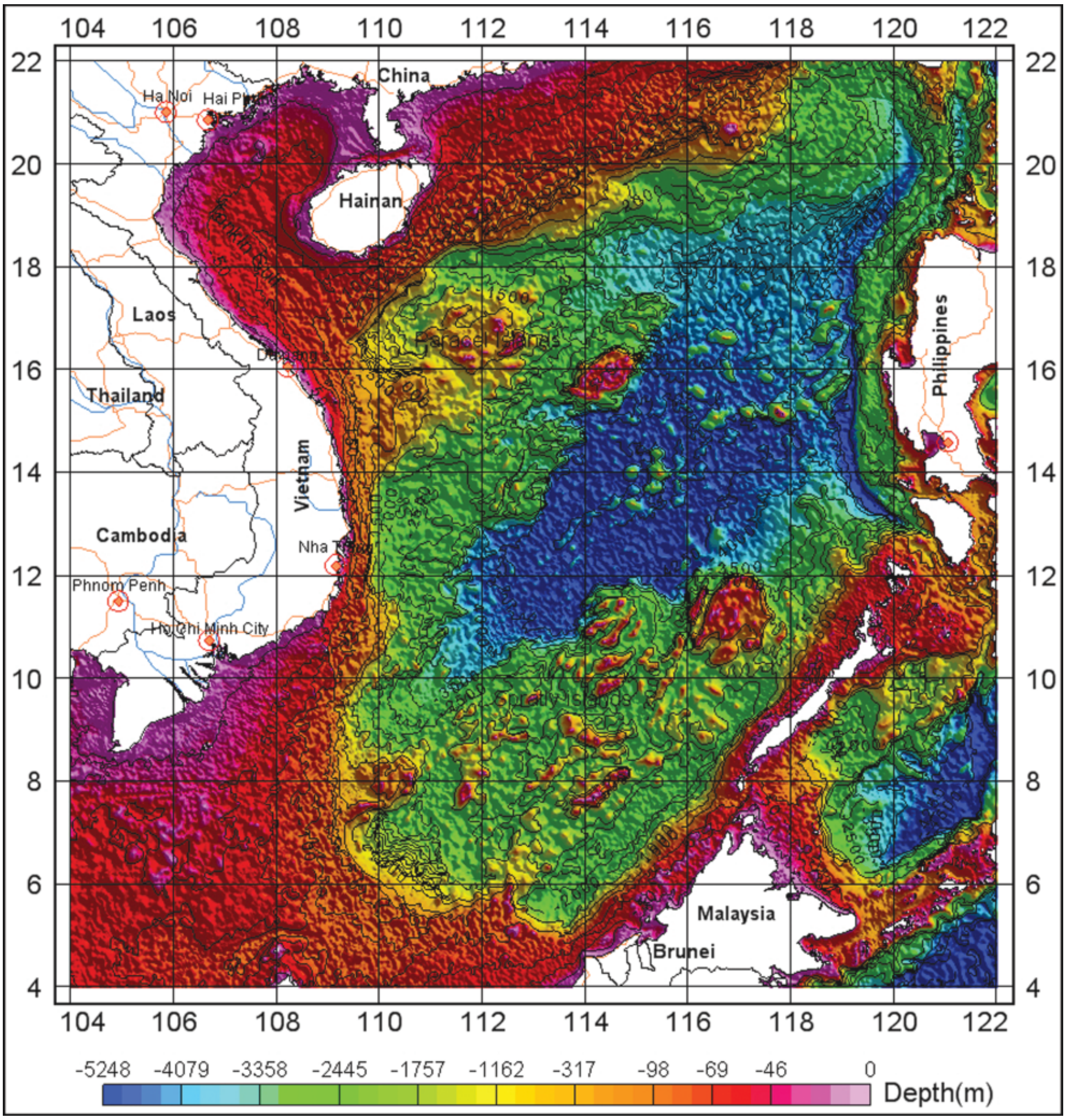

Fig. 3. Bathymetry.

METHODS APPLIED

Research and determination of the distribution of eruptive volcanic basalt (including eruption or intrusion) in the South China Sea is a complicated problem that cannot be solved only by a single method. The researchers must have an overall view on geological structure and relationship between them and the eruptive volcanic basalts in different phases. Therefore, it is necessary to apply a combinative geophysical methods to adjust the magnetic anomalies with their causing-source locations; to separate the anomalies, which could cause by eruption volcanic basalts in the near Earth's surface, from the observed gravity anomaly; to determine the ranges and spatial locations of the anomaly-causing sources. This paper presents some methods as follows.

Reduction to the magnetic equator

The quantitative analysis on magnetic data in the low-latitudes region is encountered a difficult problem causing by magnetic inclination, that is, the anomaly locations and their sources are not coincident. Meanwhile, the study area is located in the low-latitudes near the equator where magnetic anomalies have a poor correlation with anomaly-causing geological objects. As results, the reduction to the magnetic equator method is used to solve the above-mentioned problem. This is a new method applied to the low-latitudes region to adjust the magnetic anomaly

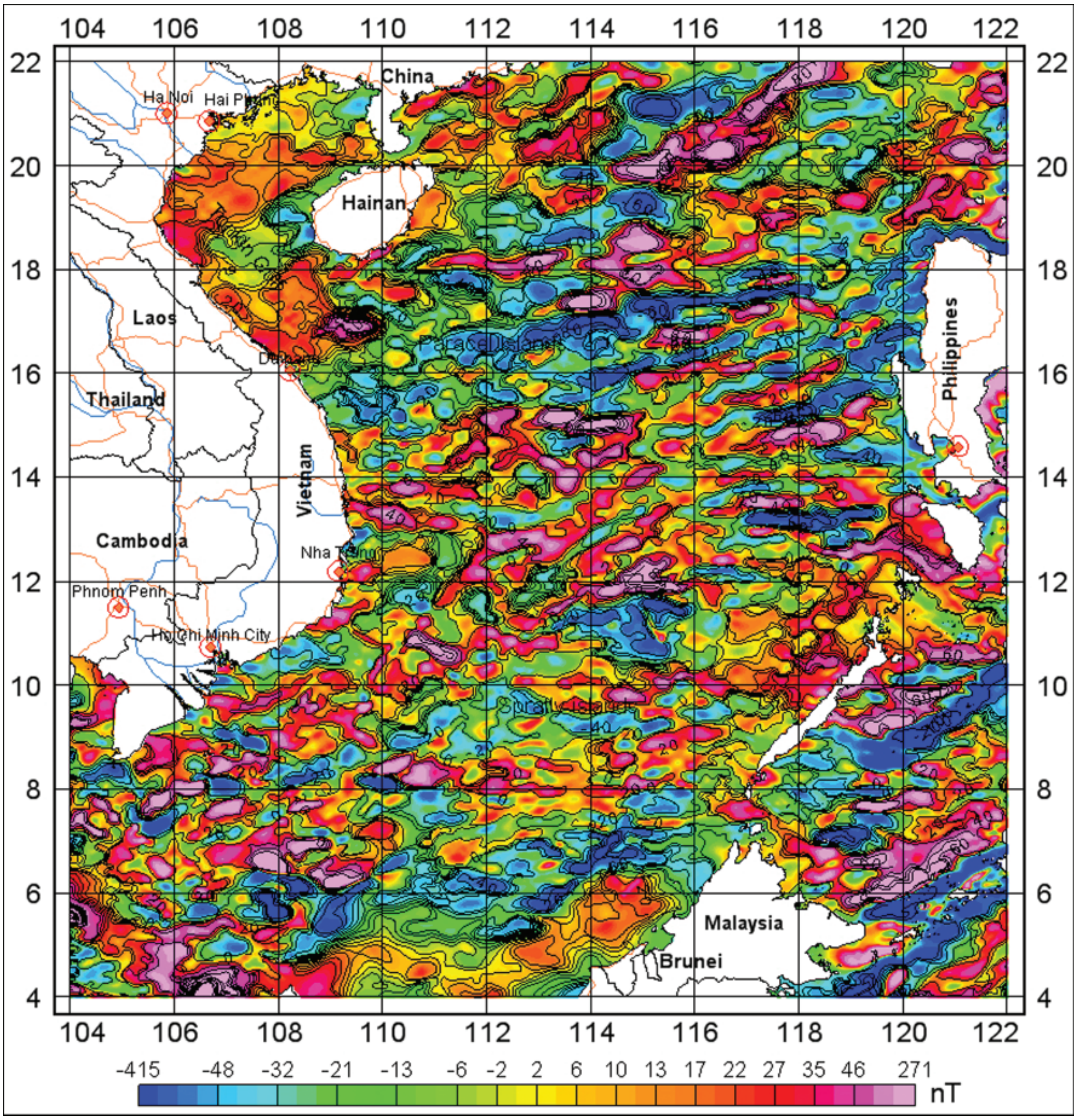

Fig. 4. Magnetic anomalies after reduction to the equator ΔTa.

locations to a best coincidence with their sources. It makes the interpretation of magnetic data more easier, which without losing their geophysical significance [5, 6, 13].

The method of reduction to the magnetic equator that presented in the researches [3], [13] is applied in this paper. Magnetic deviation and magnetic inclination angle will be calculated for the center point of the research area [4].

Reduction to the magnetic equator is represented by the following formula:

$$F\{\Delta T\alpha_{Eq}(x, y)\} = F\{L(x, y)\}\, F\{\Delta T\alpha(x, y)\} \quad (1)$$

Where: F{} is Fourier transform; $\Delta T\alpha_{Eq}(x, y)$ is reduction to the magnetic equator with $L(x,y)$ operator; $\Delta T\alpha(x, y)$ is observation magnetic data; $L(x, y)$ is operator of reduction to the magnetic equator.

The operator of reduction to the magnetic equator is calculated [3, 13]:

$$L(x,y) = \frac{\left[\sin(I) - \cos(D-\theta)\right]^2}{[\sin^2(I\alpha) + \cos^2(I\alpha)\cdot\cos^2(D-\theta)]} \times$$
$$\times \frac{[-\cos^2(D-\theta)]}{\sin^2(I) + \cos^2(I)\cdot\cos^2(D-\theta)]}. \quad (2)$$

Where: D is magnetic deviation angle; I is magnetic inclination angle; θ is wave direction; $I\alpha$ is correction angle of magnetic inclination.

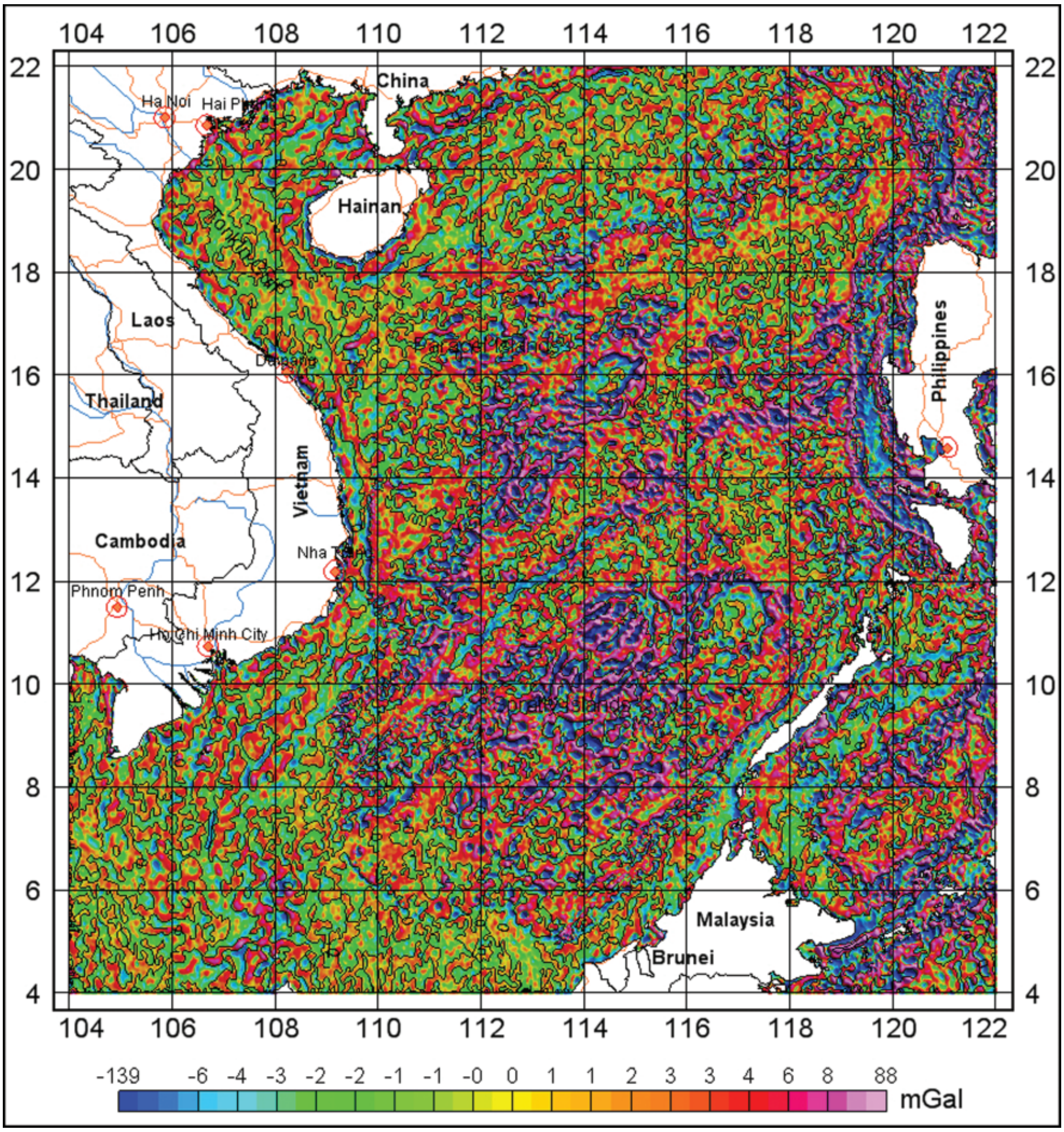

Fig. 5. Residual gravity anomaly at filtering wavelength λ = 50 km.

In the figure 4 is picture of the magnetic anomaly after reduction to the magnetic equator. Comparing the magnetic data in the figure 4 with the initial data in the figure 2, it can see that the magnetic anomalies after the reduction have strongly changed in the both direction and magnitude (figure 4).

Frequency filtering

The frequency filtering separates out the gravity and magnetic anomalies caused by the shallow geological objects from the total observed anomalies in order to determine the ranges and the spatial locations of the eruptive volcanic basalts, which are formed in the upper part of the Earth's crust.

Low-pass filters of gravity anomalies are calculated by the following formula:

$$F\{\Delta g_{LF}(x, y)\} = F\{H(x, y)\}\, F\{\Delta g(x, y)\} \qquad (3)$$

Where: F{} is Fourier transform; $\Delta g_{LF}(x, y)$ is low frequency anomalies that filtered with $H(x, y)$ operator; $\Delta g(x, y)$ is complete Bouguer gravity anomaly; $H(x, y)$ is the low-pass filter operator.

The Gaussian low-pass filter operator as follows:

$$H(x, y) = e^{-D(x,y)^2/2\lambda^2} \qquad (4)$$

Where: $D(x, y)$ is the distance between point (x, y) on the gird and the center of filtering window; λ is cutoff wavelength.

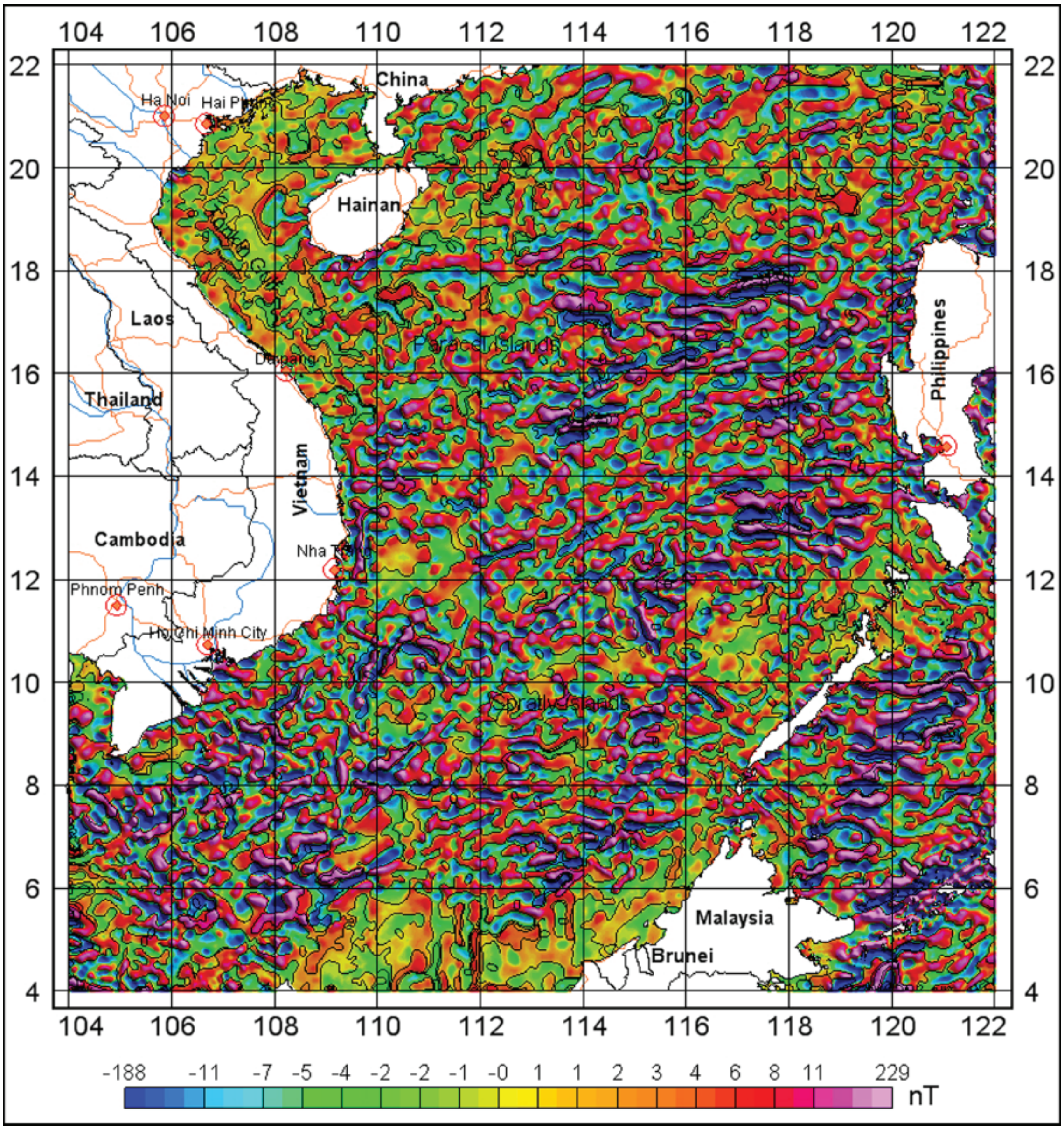

Fig. 6. Residual magnetic anomaly at filtering wavelength λ = 50 km.

In the next step, residual gravity anomalies are calculated:

$$\Delta g_{HF}(x, y) = \Delta g(x, y) - \Delta g_{LF}(x, y). \quad (5)$$

After doing low-pass filter with different wavelength λ, the gravity, magnetic anomalies that correspond to these wavelength will be used to calculate and interpret geological structures at different depths.

Here, the high frequency gravity and magnetic anomalies are calculated for the whole area with the Gaussian low-pass filter, which was introduced in [3], with the filter wavelength λ. For each wavelength λ, it will bring out a distribution of geophysical anomalies at different depths. After comparing the results from the filtering in certain above-mentioned wavelengths λ, it can be seen that, the residual gravity, magnetic anomalies corresponding to the wavelengths λ = 50 km (figures 5, 6) have a good correlation with the shallow geological objects. As a result, they have been applied to build the 3D total gradient model (gravity and magnetic anomalies) to determine the locations and ranges of the eruptive volcanic basalts.

3D total gradient

Method of 3D total gradient of gravity, magnetic anomalies is applied to determine the locations, ranges and depth of the anomaly-causing objects. However, this study refers only to their locations and ranges. There have been many studies on this problem, though, the method

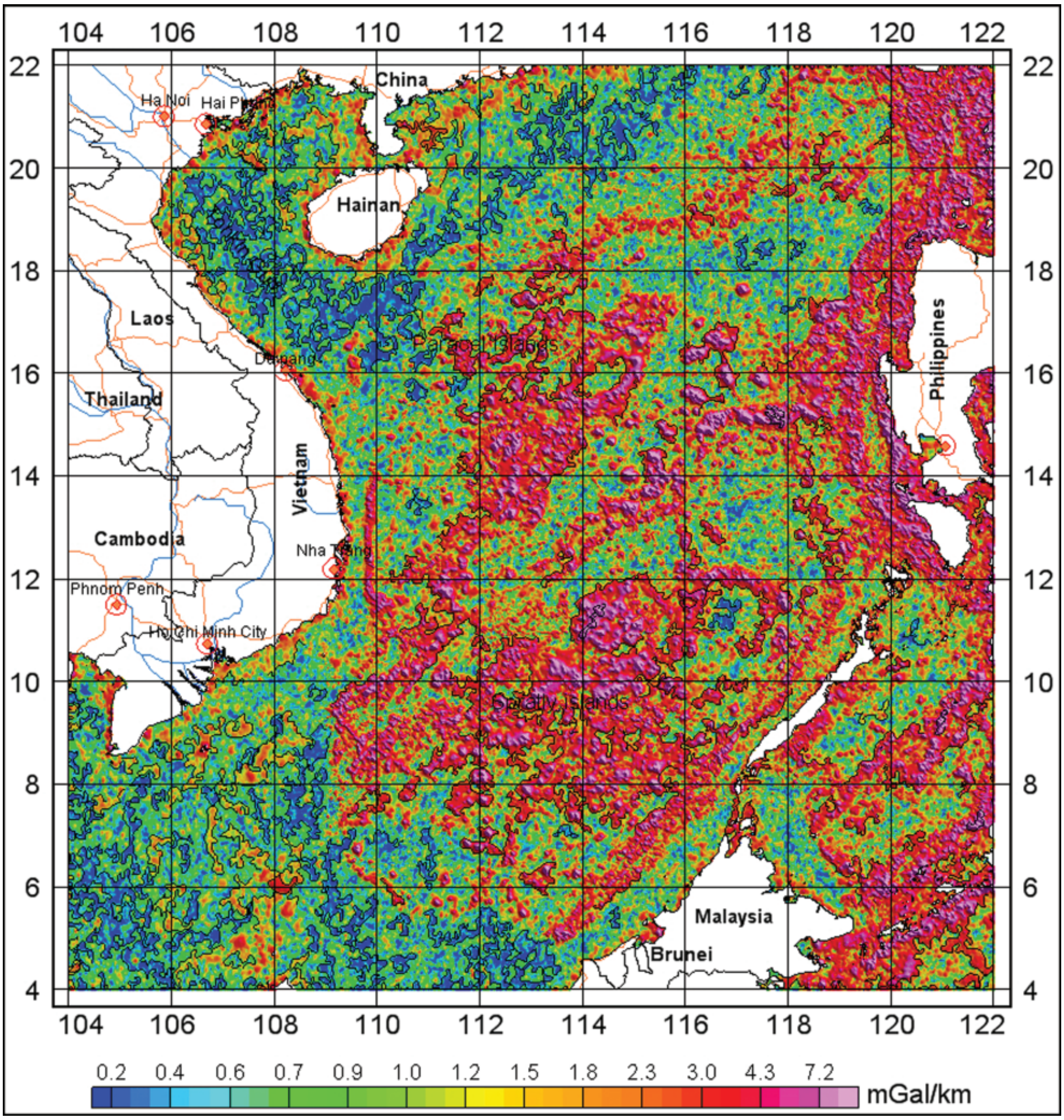

Fig. 7. 3D total gradient of gravity anomaly.

that presented in [3] is choose to calculate the 3D total gradient of gravity, magnetic anomalies in the area. The formula for calculating 3D total gradient as follows:

$$Gra(x,y)=\sqrt{\left(\frac{dA}{dx}\right)^2+\left(\frac{dA}{dy}\right)^2+\left(\frac{dA}{dZ}\right)^2}, \quad (6)$$

where: A is gravity or magnetic anomalies.

The 3D total gradient of gravity, magnetic anomalies bring out a clear picture on the spatial distribution of the eruptive volcanic basalt (in the upper part of the Earth's crust). However, to reduce the multi-solutions and improve the reliability of the method, it should have an overview analysis in combination with others geology-geophysics documents (seismic, drilling data..). Calculated result of the 3D total gradient is showed in figure 7, 8.

RESULTS AND DISCUSSION

In the area, the eruptive volcanic basalts have higher density and magnetism than surrounding rocks. The eruptive volcanic basalts that have different components, then also have a relative change in density and magnetism value. Throughout the analysis and comparison with others data sources from the researches [6, 8, 10, 16], it has been found that in the area the eruptive volcanic basalts have a density range from 2.73 to 2.87 g/cm^3 and the magnetism range from +50 to +170 nT, respectively.

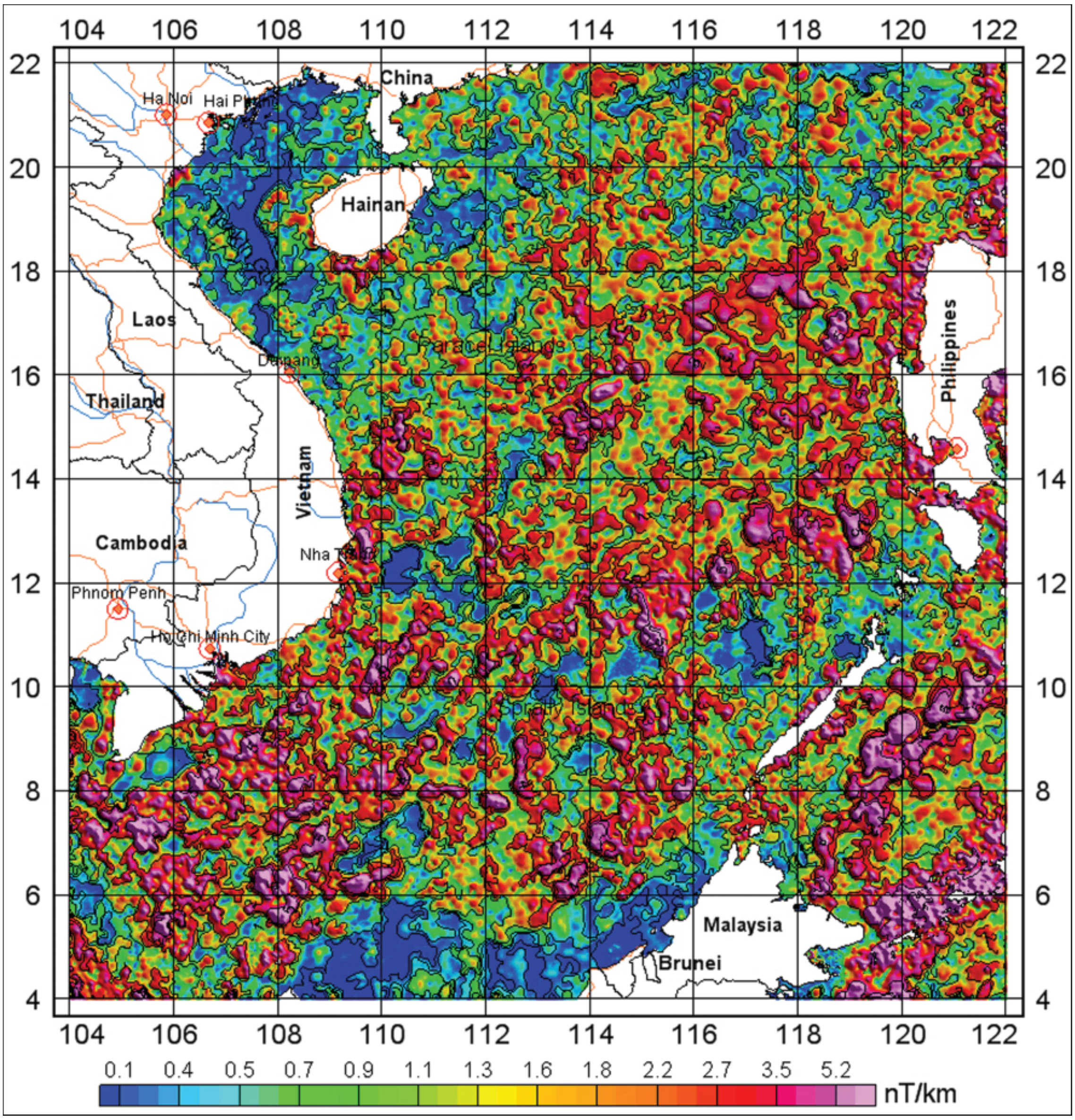

Fig. 8. 3D total gradient of magnetic anomaly.

From achieved results, the multi-dimensional correlation coefficient between the distributive characteristics of the gravity, magnetic anomalies and their total gradient is determined by integrating the 3D spatial information of them. The obtained multi-dimensional correlation coefficients has a variant range from 0.0 to 15.1 (figure 9 a). Based on the above-mentioned multi-dimensional correlation coefficient with the seismic and drilling data from researches [6], [8], [10], [16 (Figure 9b), the authors have evaluated, interrelationship-classified to provide a detailed picture of spatial distribution of the eruptive volcanic basalt in the South China Sea and adjacent areas (figure 10).

Throughout the results of this research, comparing with the results of some previous researches of the eruptive volcanic basalt in the South China Sea, it has been found that there are many remarkable coincidences between them. The results from the above-mentioned methods have shown that the distribution of the eruptive volcanic basalt mainly concentrates along the South China Sea's seafloor-spreading axis, transitional crust, Manila trench and at some large faults zones.

The red-marked circles are the best correlation between the eruptive volcanic basalts and geophysical fields, which have high correlation coefficients, they are supposed to be the spatial locations of the eruptive

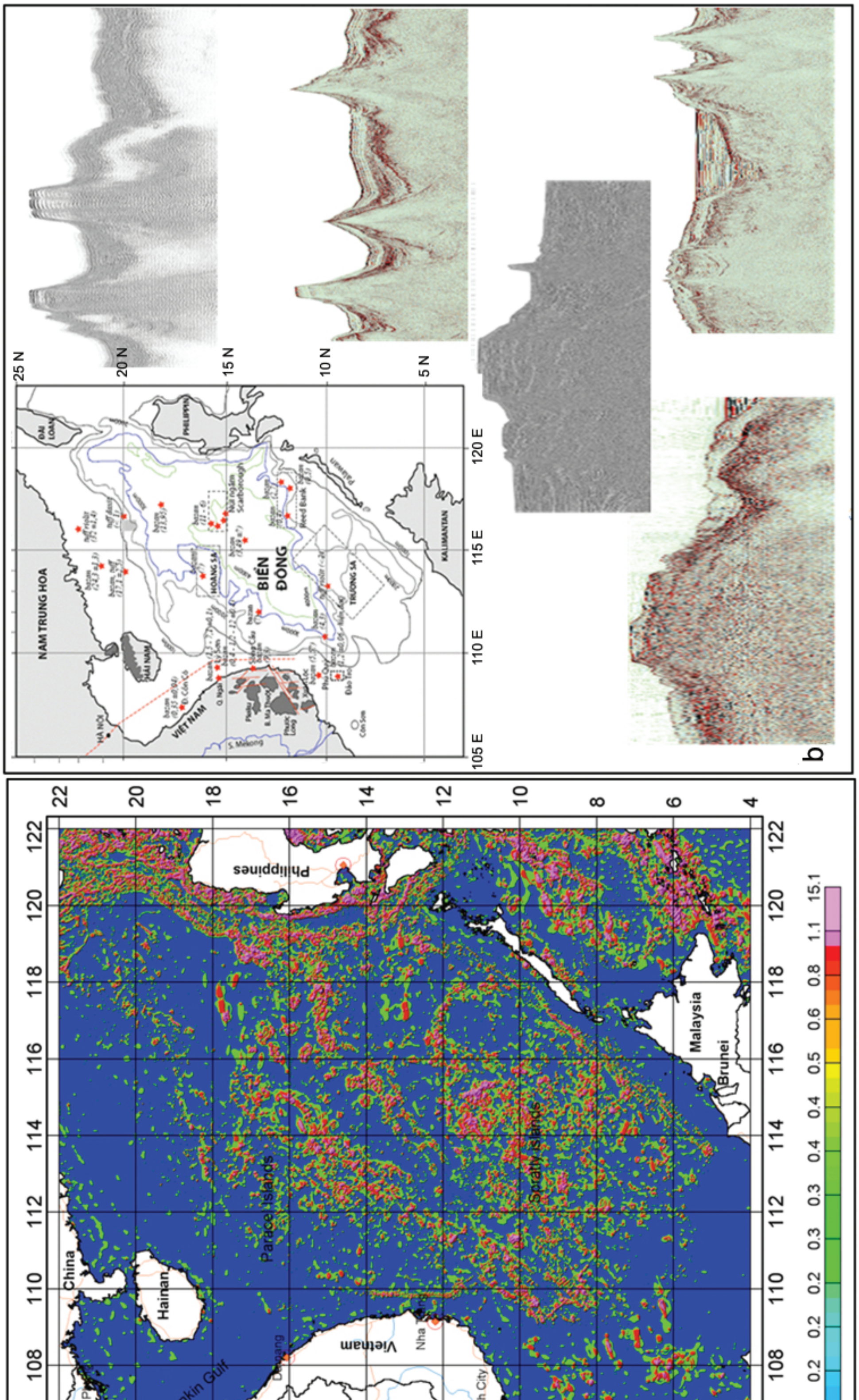

Fig. 9. a – Spatial correlation coefficient between high gravity, magnetic anomalies and their total gradient with distribution of eruptive volcanic basalt; b – eruptive volcanic basalt locations in the known seismic and drilling data.

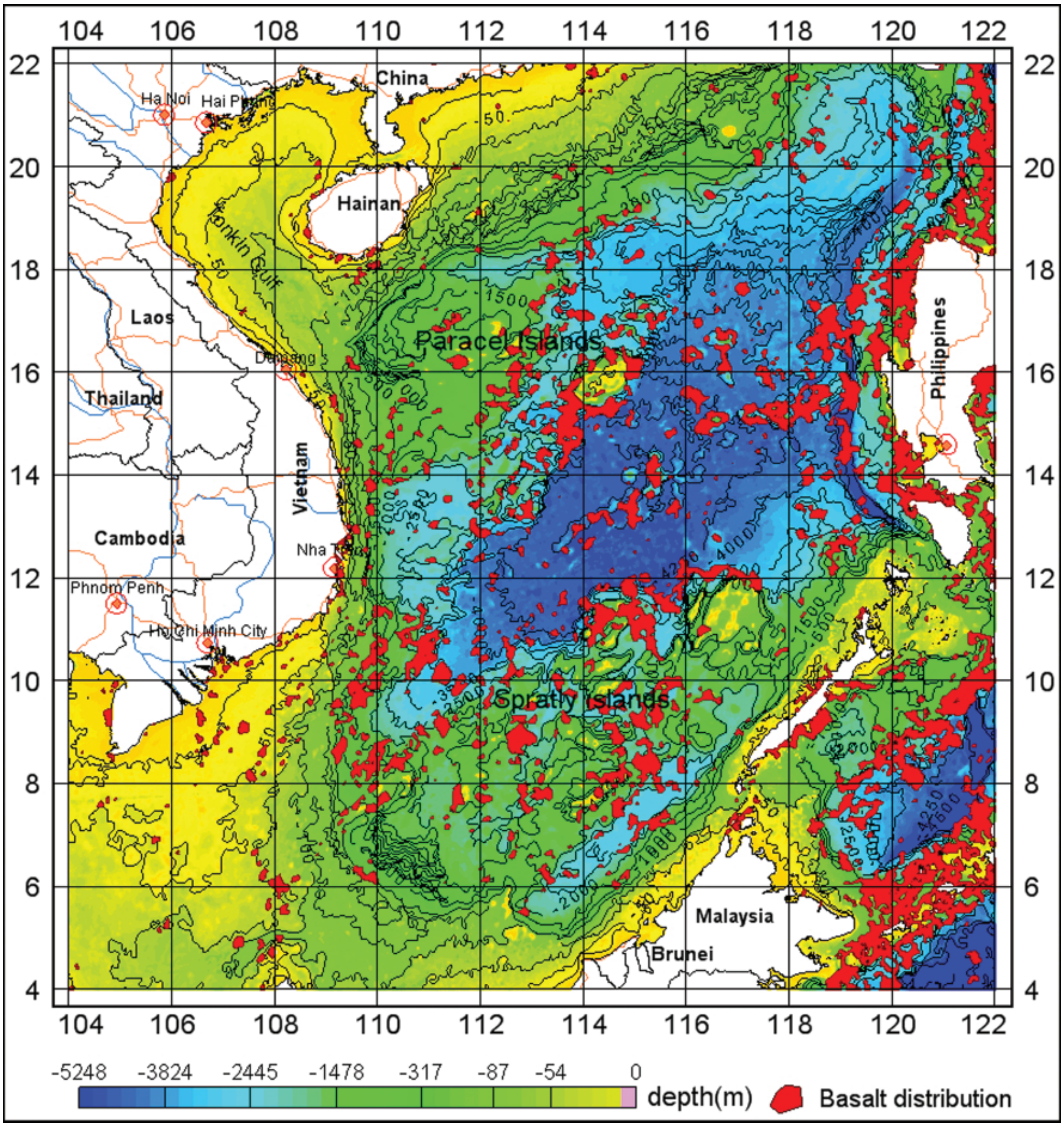

Fig. 10. Distribution of eruptive volcanic basalts in the South China Sea and adjacent areas.

volcanic basalt, and they have high density and magnetism (figure 10).

In addition, throughout spatial analysis of the gravity, magnetic anomalies as well as their correlation with 3D total gradient, faults distribution, it can be seen that the distribution of the eruptive volcanic basalt could be also related to the deep faults.

CONCLUSION

This research has applied an effective geophysical methods in combination to determine the distribution of the eruptive volcanic basalts: Methods of reduction to the magnetic equator in low-latitudes to bring out a better correlation between magnetic anomalies and their causing-sources; high-frequency filtering is to separate gravity and magnetic anomalies as well as information about the volcanic basalts in the upper part of the Earth's crust; 3D total gradient is to define the spatial locations of high density and magnetic bodies.

The method of multi-dimensional correlation analysis between the high frequency gravity, magnetic anomalies with weighted total gradient 3D allows determining quite accurately the ranges as well as the spatial locations of the eruptive volcanic basalts in the South China Sea and adjacent areas.

The diversity of the formation and the complex physical properties of the eruptive volcanic basalt causing the determination of their characteristics more difficulties. In order to determine the distribution of the eruptive volcanic basalts more accurately and efficiently, it is necessary to apply the geophysical methods together with seismic, geochemistry and drilling data... in combination.

Acknowledgments

The authors wish to thank the NAFOSTED's Project (2013-1016) "Study of earthquake, tsunami source model in the Eastern Vietnam Sea and assessment of an earthquake, tsunami hazard and risk in the coastal zone of Vietnam" and VAST's Project (2016–2017) "Study of Cenozoic tectonic evolutionary characteristics in the Spratly Islands area on the basis of geophysical data analysis" for funding this research.

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Рекомендована к печати Р.Г. Кулиничем

Чан Туан Дунг, Буй Конг Куэ, Нгуен Куанг Минь

Распределение эруптивных вулканических базальтов в Южно-Китайском море и прилегающих территориях по результатам интерпретации данных гравиметрии, магнитометрии и сейсмических данных

Активность базальтовых вулканических извержений в Южно-Китайском море и прилегающих территориях полностью проявилась в кайнозойскую эру. Однако существуют трудности в определении их пространственного распределения. Для решения этой задачи в статье приводятся методы и результаты интерпретации данных гравиметрии, магнитометрии и сейсмических работ. Распределение эруптивных вулканических базальтов определено с использованием многомерного корреляционного анализа высокочастотных гравитационных и магнитных аномалий с весовым 3D полным градиентом.

Полученные результаты показывают, что эруптивные вулканические базальты концентрируются главным образом вдоль осей спрединга на дне Южно-Китайского моря, а также в пределах переходной коры, вдоль Манильского желоба и некоторых зон крупных разломов. Эти результаты подтверждаются буровыми и сейсмическими данными, имеющимися в изучаемом районе.

Ключевые слова: **Южно-Китайское море, распределение эруптивных вулканических базальтов, интерпретация данных гравиметрии и магнитной аномалий.**