



Vietnam Academy of Science and Technology

Vietnam Journal of Marine Science and Technology

journal homepage: vjs.ac.vn/index.php/jmst



Forecasting zonation of oil-gas prospects in the sedimentary basins of the Northeast Vietnam continental shelf based on gravity and borehole data

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Received: 5 October 2021; Accepted: 10 March 2022

ABSTRACT

This study used the 2D and 3D normalized total gradient (NTG) method of gravity anomalies to detect the gravity anomalies caused by oil-gas reservoirs. The NTG of gravity anomalies can be associated with known oil-gas reservoirs, and most of them seem to be a good coincidence with the reservoirs. The closed minima of the NTG of gravity anomalies indicate the existence and locations of the density deficient anomalies closely related to the possible oil-gas reservoirs. The reliability of the NTG method depends mainly on the Fourier-developed coefficient N . Here, N is optimally selected by the borehole data. The 2D, 3D normalized total gradient method is applied in the sedimentary basins of the Northeast Vietnam continental shelf. Borehole data confirm the results of the method.

Keywords: Normalized total gradient, oil/gas prospect, Fourier developed coefficient.

Citation: Tran Tuan Duong, Tran Tuan Dung, Tran Trong Lap, Tran Hoang Tam, Pham Le Hoang Linh, and Nguyen Van Thanh, 2022. Forecasting zonation of oil-gas prospects in the sedimentary basins of the Northeast Vietnam continental shelf based on gravity and borhole data. *Vietnam Journal of Marine Science and Technology*, 22(2), 155–164. <https://doi.org/10.15625/1859-3097/17234>

ISSN 1859-3097/© 2022 Vietnam Academy of Science and Technology (VAST)

INTRODUCTION

In marine research, the interpretative method of gravity anomalies plays a crucial role in many fields such as tectonic structure, oil and gas exploration, etc. The densities of oil and gas reservoirs are lower than that of the surrounding environment. The gravity anomalies caused by the mass of density

anomalies related to oil-gas reservoirs can be detected using gravity data analysis. Interpretation of gravity anomalies of possible oil-gas reservoirs is often carried out during the initial exploration period. It has a practical significance in discovering sedimentary basins, local structures, and areas with an oil-gas potential [1, 2].

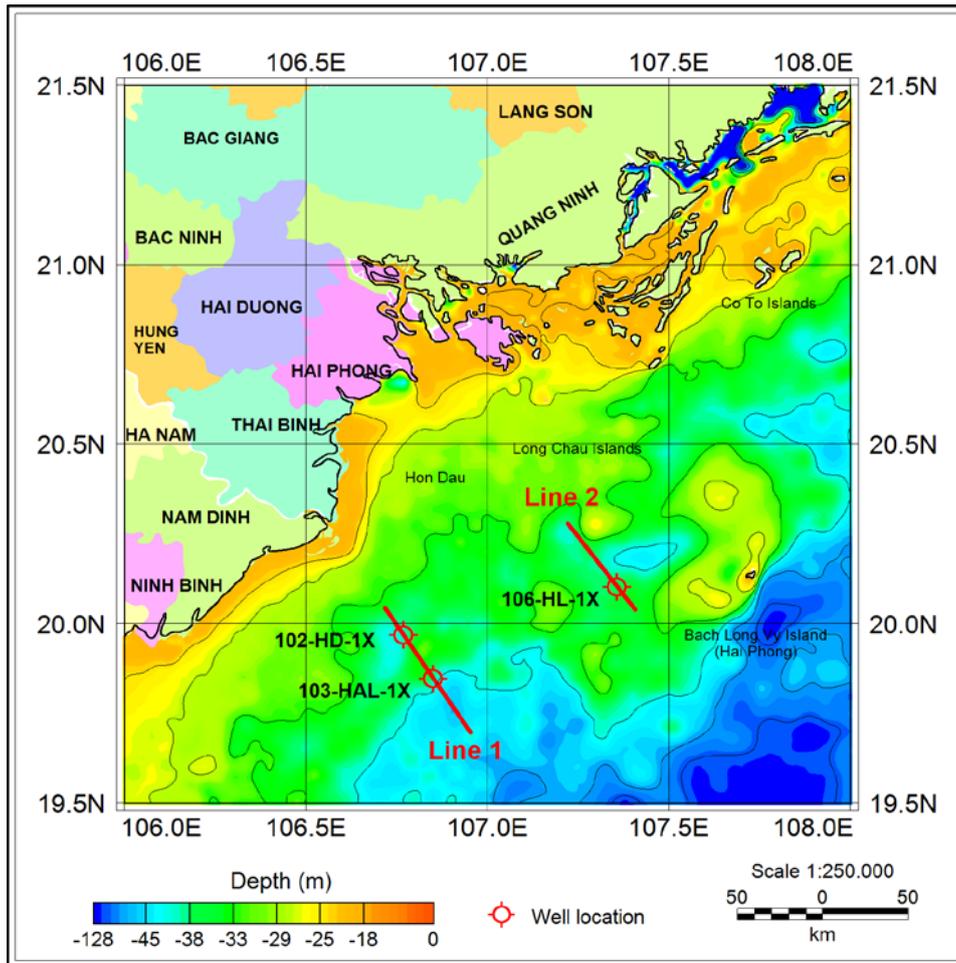


Figure 1. Location of study area (19.5°–21.5°, 106°–108°)

The gravity anomalies of the oil-gas reservoirs are small. Although it is possible to recognize from the observed gravity anomalies, the gravity effects of the oil-gas reservoir are much smaller than that of regional structures. The separation of the local gravity anomalies attributed to oil-gas reservoir from the total observed anomalies is a challenging problem. The separation of the

local and regional gravity anomalies is performed by many methods such as analytical continuation, regression, modeling, filtering, etc.; the attained results are entirely dependent on the concrete applied methods. Many studies have shown that gravity anomalies need to be transformed to other forms to detect the oil-gas reservoirs more accurately. The NTG of gravity anomalies at different levels of analytical

downward continuation allows for determining the singular points that related to the sources of anomalies.

Utilization of normalized total gradient of gravity anomalies to discover oil-gas reservoirs was shown, and its theory was developed more by Berezkin, W. M., in 1973 [1]. After that, Cianciara, B., and Marcak, H., (1977) [3] presented a variant of the singular points method to overcome some defects of the normalized total gradient method, then proposed a new trend to locate the faults and lithological boundaries.

Moreover, Chinese geophysicists such as Hualin Zeng et al., (2002) [2] have used a model of an inhomogeneous density anticline [1] with a supposed reservoir in its upper part to study the relationship between the minima of the NTG of gravity anomalies and the oil-gas reservoirs. The achieved results have proved the stability and accuracy of the method in detecting oil-gas reservoirs.

Applying the methods in combination to improve the accuracy and reliability in separating gravity anomalies, which are possibly caused by oil-gas reservoirs, is a concerning problem for geologists and geophysicists. In this paper, the author applies the 2D, 3D NTG method along with standardization and filtering of the observed data to detect and delineate the oil-gas potential areas in the sedimentary basins of the Northeast Vietnam continental shelf. The standardization of observed data has been used to maximal decrease Gibb's effect. The filtering reduces the distortion that caused by the fictitious sources during the analytical downward continuation.

In Vietnam, Tran Tuan Dung (2005) has applied the NTG method in determining the oil and gas reservoir in the Nam Con Son basin; Nguyen The Hung et al., (2005) [4] applied the NTG method in assessing the potential of oil-gas in the Tien Hung formation of the Red river basin; Tran Van Kha (2014) used the NTG method in forecasting structural zones with oil and gas prospect in Xuan Truong district, Nam Dinh province and adjacent areas [5].

This paper only focuses on researching the sedimentary basins of the Northeast Vietnam

continental shelf, shown in Figure 1. There have been many oil-gas exploration boreholes done in this area. According to seismic, geochemical, and boreholes data, some oil reservoirs developed in Eocene-Oligocene rocks and early Miocene rocks of marine origin, but most of them were formed and developed in the pre-Cenozoic fractured basement [6, 7]. The borehole documents also show that in the Red river basin area, many oil and gas traps are located at different depths and connected horizontally [8].

METHOD

Normalized Total Gradient method (NTG)

The NTG method was first proposed by Berezkin [1] and developed by Hualin Zeng (2002) [2], who designed to calculate the NTG anomaly from a convex lens model with the upper part considered an oil reservoir. Research results from the model show that the NTG minimum anomaly is closely related to oil and gas aquifers (Figure 2). For two cases: a model with a uniform density and a model with a heterogeneous density.

The gravity anomalies $\Delta g(x, z)$ are determined by Laplace's equation as follows [1, 2]:

$$\Delta g(x, z) = \sum_{n=1}^N B_n \sin \frac{\pi x}{l} e^{-\frac{\pi z}{l}}$$

where: l is the observed length; B_n is a coefficient determined from boundary condition:

$$B_n = \frac{2}{l} \int_0^l \Delta g(x, 0) \sin \frac{\pi x}{l} dx$$

However, the field distortion will appear during the calculating processes. The elimination of the distortion on the edges of study area is carried out by a smooth function as follows [1]:

$$q_m = \left(\frac{\sin \frac{\pi x}{N}}{\frac{\pi x}{N}} \right)^m$$

In oils and gas exploration, coefficient $m = 2$.

Finally, applying equations:

$$\Delta g(x, z) = \sum_{n=1}^N B_n \sin \frac{\pi n x}{l} e^{-\frac{\pi n z}{l}} e^{-\frac{\pi^2 n^2 z^2}{\beta^2 N^2}} \left(\frac{\sin \frac{\pi n}{N}}{\frac{\pi n}{N}} \right)^m$$

$$G_H(x, z) = \frac{\sqrt{V_{xz}^2(x, z) + V_{zz}^2(x, z)}}{\frac{1}{M} \sum_{n=1}^M \sqrt{V_{xz}^2(x, z) + V_{zz}^2(x, z)}}$$

The so-called 2D NTG of gravity anomalies as follows [1]:

Modification of 3D NTG of gravity anomalies is introduced by [9]:

$$G_H(x, y, z) = \frac{\sqrt{V_{xz}^2(x, y, z) + V_{yz}^2(x, y, z) + V_{zz}^2(x, y, z)}}{\frac{1}{M} \sum_{n=1}^M \sqrt{V_{xz}^2(x, y, z) + V_{yz}^2(x, y, z) + V_{zz}^2(x, y, z)}}$$

where: $G_H(x, y, z)$ is the NTG anomaly at position (x, y, z) ; V_{xz} , V_{yz} , V_{zz} are the first derivatives in x, y, z direction of gravity

anomalies Δg ; N is the developed coefficient of Fourier series; M is the number of observed stations. The $G_H(x, y, z)$ is dimensionless.

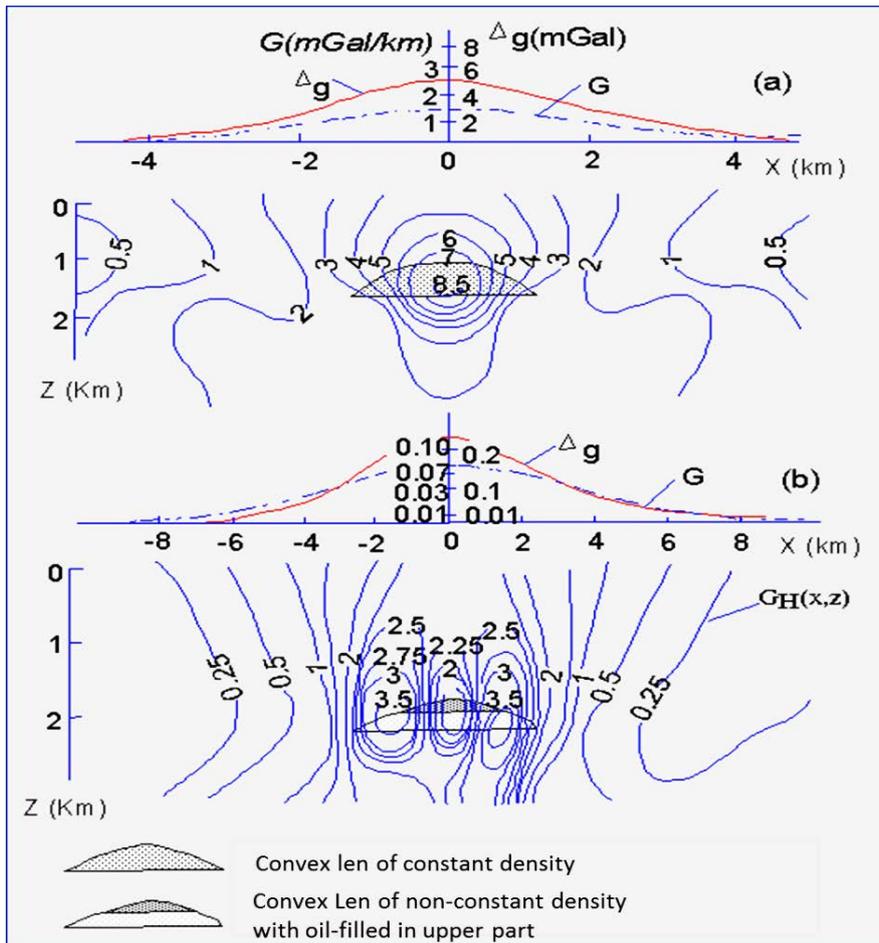


Figure 2. Section $\Delta g(x, 0)$; $G(x, z)$ và $G_H(x, z)$: a) Through a convex lens of constant density; b) Lens of non-constant density with oil-filled in upper part [1]

DATA USED

The data of three 102-HD-1X, 103-HAL-1X, and 106-HL-1X, performed in the northeast Vietnam continental shelf (Figure 1) is used as a priori information, as a source of standard data to determine the basic characteristic parameters in the calculating the NTG of gravity anomalies. The depth of the three boreholes is 1,189; 834; and 1,517 m, respectively. The NTG anomalies have been calculated on cross-sections: Line 1 and Line 2; The location of the two cross-sections can be seen in Figure 1.

This paper uses the complete source of gravity anomaly data from previous work by Bui Cong Que (2005) and Tran Tuan Dung (2019) [10] and together with a new gravity data [11].

In the area, the gravity anomalies have been measured rather detailed with high accuracy. In Figure 3, the variety range of the gravity anomalies is from -64.4 mGal to +22.4 mGal. The negative gravity anomalies are credited to accompanying sedimentary materials of the basins, peaking in the coastal areas of Ninh Binh, Nam Dinh, and Hai Phong provinces. Interspersed with regions with positive gravity anomalies are regions with negative gravity anomalies. Interspersed with regions with positive gravity anomalies are areas with negative gravity anomalies located in the southeast and southwest of Bach Long Vi island. Some bands of strong gravity gradient are also observed here in Northeast, Northeast-Southwest direction, with some hundreds of kilometers long in the area.

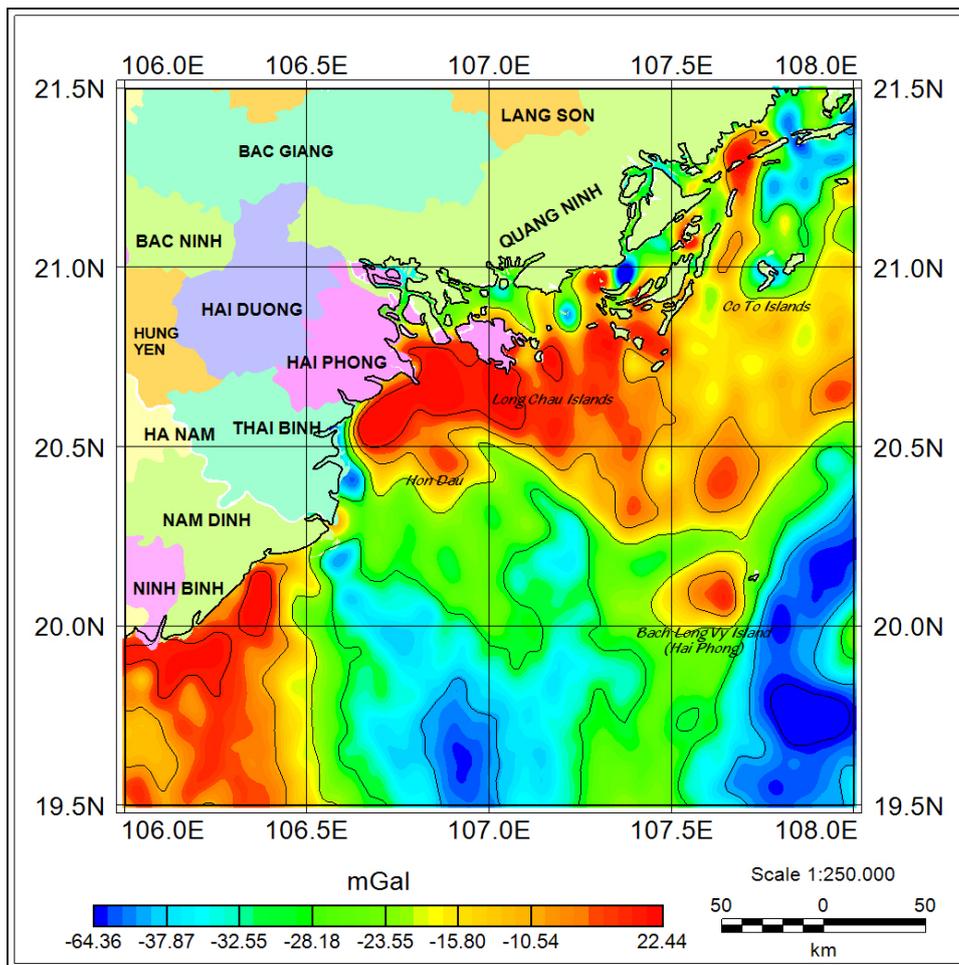


Figure 3. Complete Bouguer gravity anomaly [11]

RESEARCH RESULTS

Selecting the Fourier developed coefficient N

The relationship between the NTG of gravity anomalies and the Fourier-developed coefficient N is very close. How to determine accurately N is a very significant problem. The $G_H(x, y, z)$, as well as Fourier developed coefficient N , depend effectively on the length of profile and dimension of the study area. Berezkin, W. M. (1973, 1978) and Hualin Zeng et al., (2002) pointed out that if the size of the profile is too short, then the NTG of gravity anomalies are moved up, high frequency components increase, the Fourier developed coefficient N becomes smaller, the minima of NTG of gravity anomalies appear shallower [2]. Therefore, the solution of the NTG method is less practical. The studies have revealed that the length of the profile and dimension of the area should be 10 times greater than the study-expected depth to get suitable results.

Borehole data constrain the NTG of gravity anomalies. The authors have used the borehole data undertaken in the sedimentary basins of the Northeast Vietnam continental shelf (Figure 3) as a priori information and datum source in order to identify the specific source parameters in calculating the NTG of gravity anomalies. The depths of boreholes vary and penetrate the different geological formations up to 1,517 m. Among them are several discovered oil and gas; others are dry. The NTG of gravity anomalies are calculated at different values of N , and then which one with the minima of the G_H best coincides with the known reservoir will be selected.

Two cross-sections through the boreholes 103-HAL-1X; 102-HD-1X; 106-HL-1X are introduced here (Figure 1). According to the above boreholes data, the depth to the center of the two known oil-gas reservoirs are about 1,189; 834; and 1,517 m, respectively.

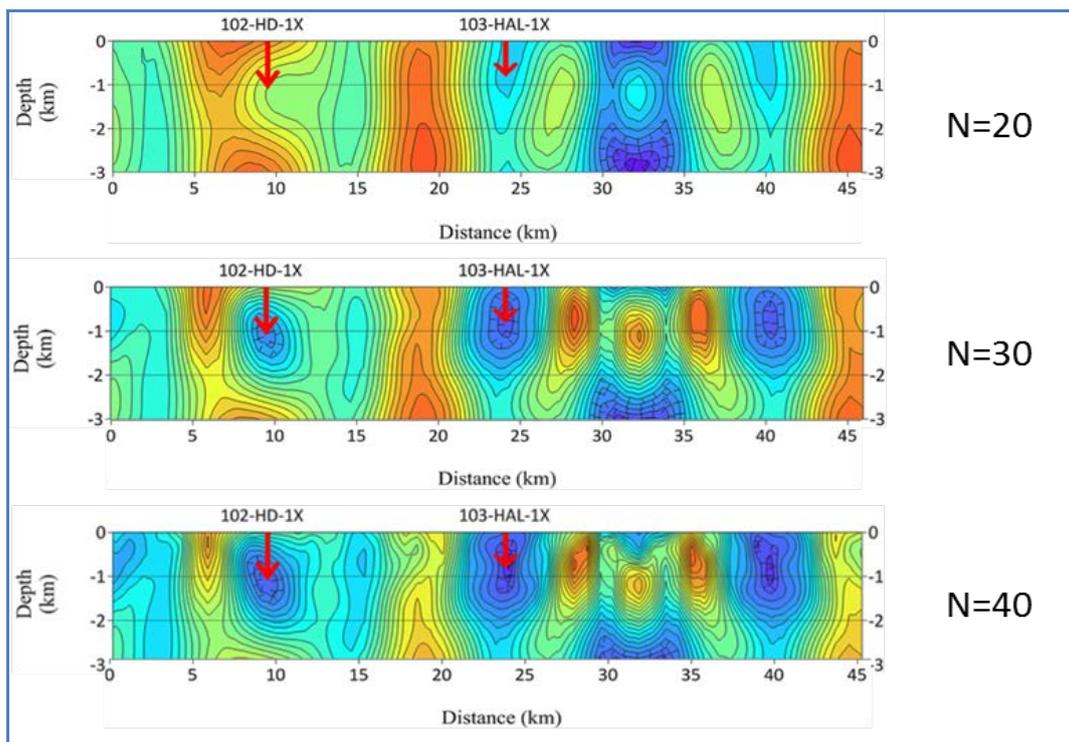


Figure 4. Normalized total gradient of gravity anomalies on a Line 1 through borehole 102-HD-1X and 103-HAL-1X with Fourier developed coefficient $N = 20$, $N = 30$ and $N = 40$

The 2D NTG of gravity anomalies are selectively calculated at different values of N , but here presented only the results that correspond to three values of the Fourier

developed coefficient N . The selected N is 20, 30, 40. When $N = 30$, the closed minima of the NTG of gravity anomalies best coincided with the center of the known oil-gas reservoir. Figures 4, 5 manifest visibly that with $N = 40$, the depth of the closed minimum anomalies is deeper than the depth of the reservoirs; with $N = 20$, the closed minimum anomalies are shallower.

The borehole data play a critical role in calculating the NTG of gravity anomalies and selecting the Fourier developed coefficient N . The value N can be applied to the investigative area. The estimated depth to the reservoirs depends mainly on the Fourier developed coefficient N . But its horizontal locations are highly reliable and could be seen clearly on the vertical cross-section.

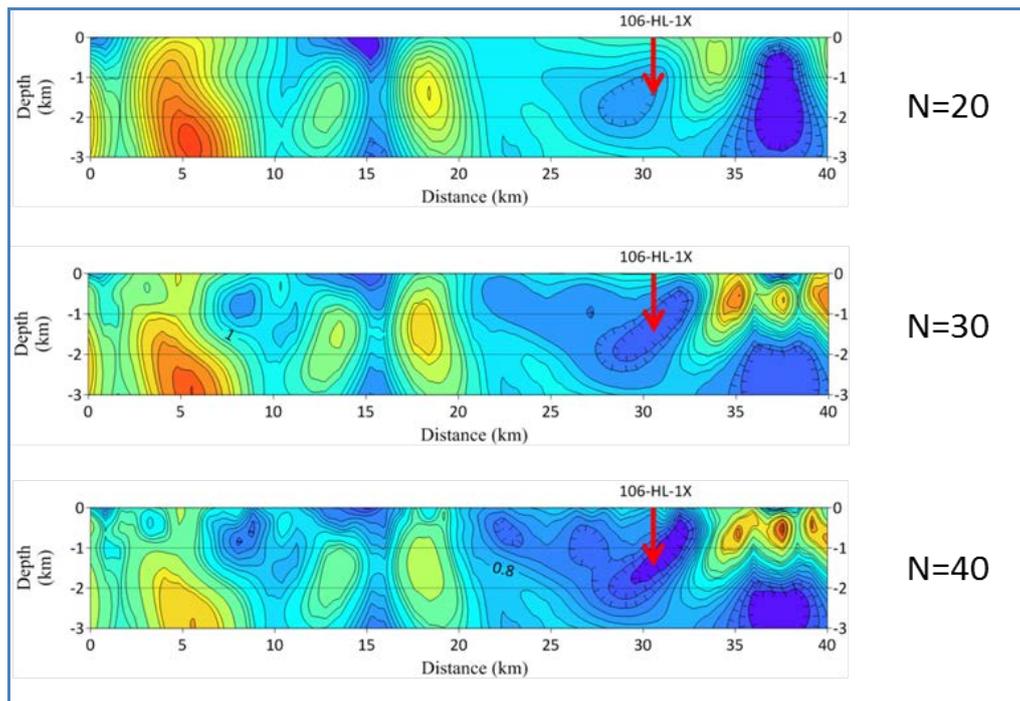


Figure 5. Normalized total gradient of gravity anomalies on a Line 2 through borehole 106-HL-1X with Fourier developed coefficient $N = 20$, $N = 30$ and $N = 40$

3D NTG of gravity anomalies

In the area, the author only concentrates on determining and delineating the potential oil-gas areas with the depth up to 3,000 m. The 3D NTG of gravity anomalies $G_H(x, y, z)$ is calculated from the above equations based on the gravity anomalies (Figure 3). Regarding the geological formation and the boreholes taken in the area, the depth levels at 750; 1,500; 2,250; and 3,000 m are selected for calculating the NTG of gravity anomalies. The optimum Fourier developed coefficient $N = 30$ is applied for all depth levels mentioned above. In this case, the closed minima of the NTG of gravity anomalies are indicated as an existence of the

density deficiency anomalies that are closely related to the possible oil-gas reservoirs. Figures 6a–6d shows undoubtedly that the spatial distribution of the minima of the NTG of gravity anomalies (hatched area) depends on the depth studied. In other words, it is caused by the spatial variation of the rock density of subsurface geological formations. In the figures, the closed minima with contour value less than 0.5 are considered areas with high oil-gas potential.

The oil-gas prospect areas are predicted and clearly expressed in Figure 6. The obtained result in Figures 6a–6d is a product of combination of the intermediate results at

different depths, shown in Figures 6a–6d using GIS technology. Herein, the contour value of 0.5 is also used for separating the deficient density anomalies. Based on the comparison of the calculated results and borehole data, the author realized that the correlation between them is very close and understandable. Almost all of the known oil-gas discovered areas coincide with the minima of the NTG of gravity anomalies (Figure 7a). However, some

oil-gas discovered regions that do not well coincide with the minimum anomaly range; these may concern the inhomogeneous density in the deeper layer (Figure 7b).

Concerning previous studies and the results of this paper’s work, we can say that the 3D NTG of gravity anomalies is more reliable than the 2D one. Moreover, it can give us a look more detailed into oil-gas exploration (Figure 7b).

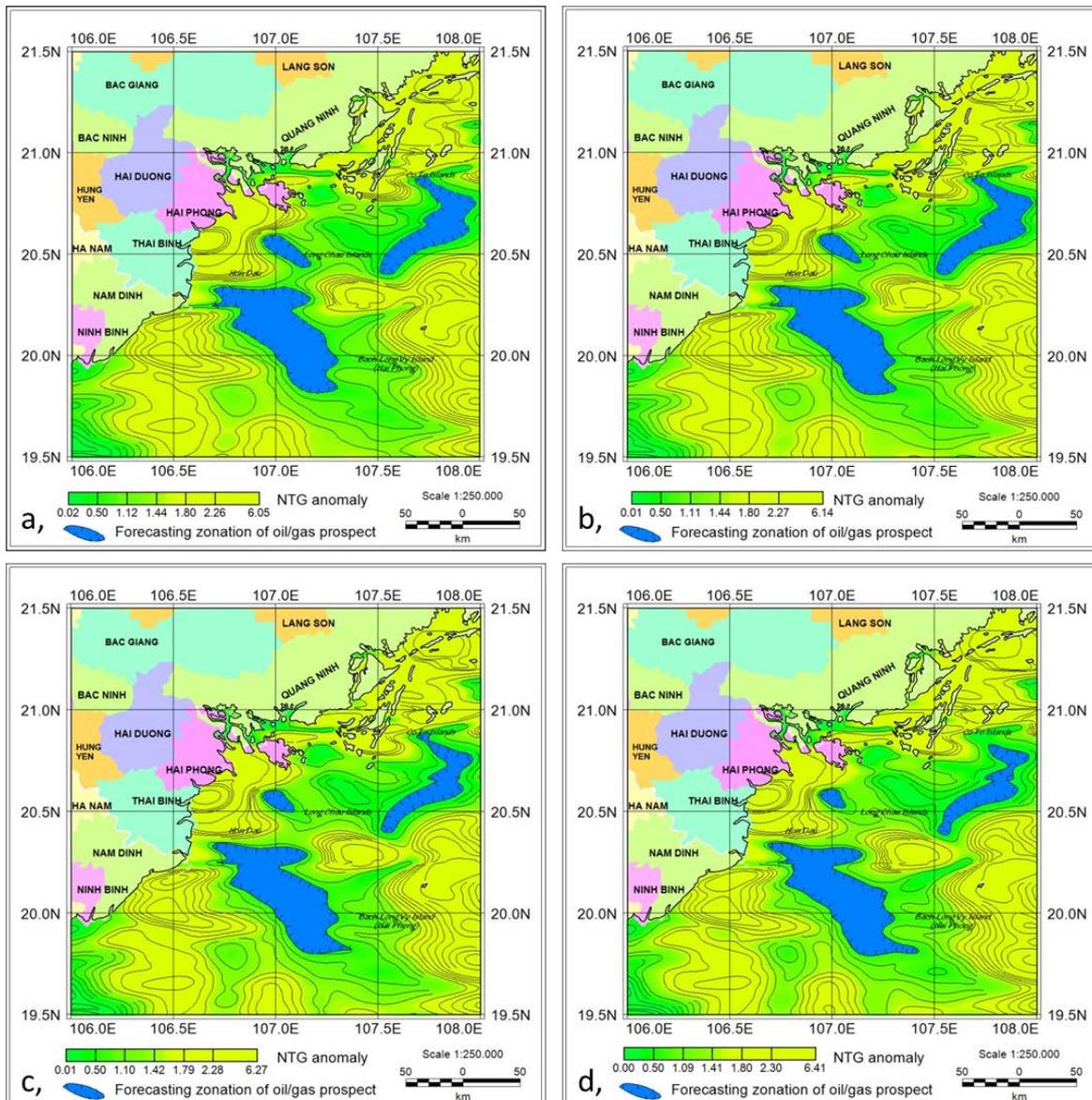


Figure 6. Showing normalized total gradient of gravity anomalies at different depths on figures: a) 750 m; b) 1,500 m; c) 2,250 m; d) 3,000 m

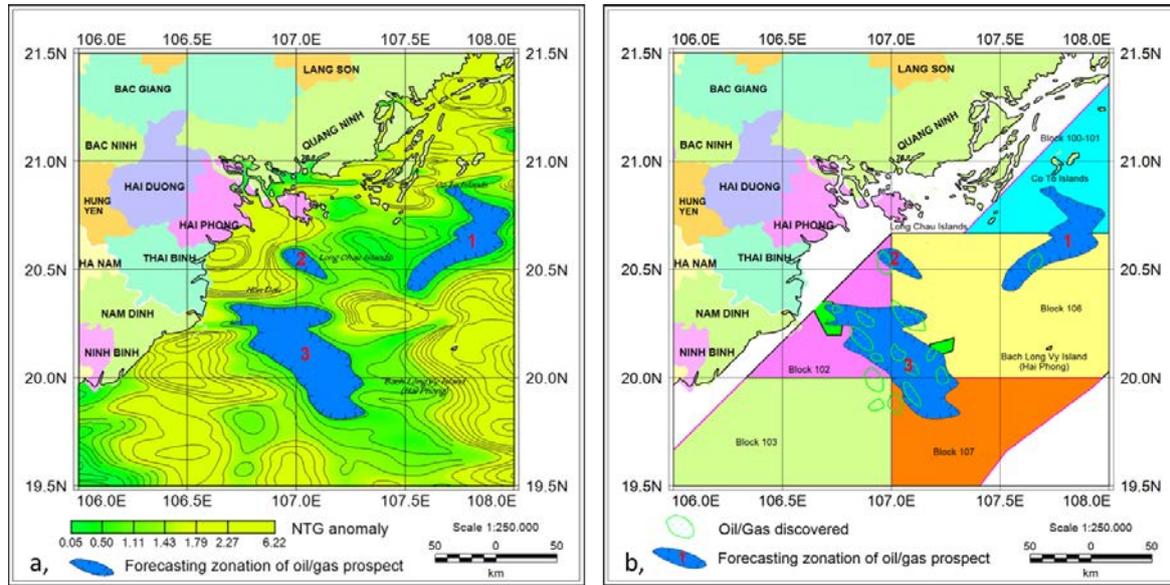


Figure 7. Showing oil-gas prospect in the sedimentary basins of the Northeast Vietnam continental shelf: a) The obtained results of the 3D NTG and borehole data in combination; b) Compare with previous research results from oil-gas companies

CONCLUSIONS

Application of the 2D, 3D normalized total gradient method, standardization of the observed data, and combined analytical continuation filtering will significantly reduce Gibb's effect, eliminate the fictitious sources, and allow detection of the singular points related to sources of anomalies.

Borehole data have a real significance, and these are the datum for optimal selection of the based parameters to increase the accuracy and resolution and decrease the multi-solution of the normalized total gradient method. In this study, the optimal Fourier developed coefficient N value was determined based on comparing and associating the NTG anomaly with borehole data. Here, $N = 30$ has been selected for the sedimentary basins of the Northeast Vietnam continental shelf.

The method can be used to delineate the oil-gas potential areas and find the explorative borehole in the oil-gas investigation. The 2D and 3D NTG of gravity anomalies have reliability in detecting and locating density deficiency anomalies associated with possible oil-gas reservoirs. The 3D NTG of gravity anomalies is more reliable than 2D in oil-gas exploration.

Acknowledgments: The authors wish to thank the VAST Project UQĐTCB.02/21–22 for funding this research.

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