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Application of improved parabola-based method in delineating lineaments of subsurface structures

Abstract

Nam Dinh province (Vietnam) is obscured by Quaternary sediments. The informartion of the lateral boundaries of the subsurface structures in this area is of crucial interest in many applications of geoscience. Notably, gravity methods have been introduced to determine lineaments of subsurface structures. However, in this study, we applied the improved parabola-based method to extract lineaments of subsurface structures of Nam Dinh province, and the interpreted results show northwest-southeast trending structures for study area. These results gave us insight to new information that will help us to better understand the structural framework and tectonic setting of Nam Dinh province.The success of this study suggests that the improved parabola-based method is a useful tool for delineating the lateral boundaries of the subsurface structures from gravity data.

Keywords: Gravity data,Lateral boundaries, Improved parabola-based method,Nam Dinh province.

1. Introduction

The gravity method is one of the oldest methods used in geophysics exploration (Elhussein, 2021). The gravity exploration programs began from the first and third of the 20th Century and continues to this day as a small but significant element in several exploration areas (Nabighian et al., 2005). Interpreting the gravity anomalies can bring information on the depths and edges of the subsurface structures (Pham et al., 2020a, b, 2021a, b). Understanding the edges of gravity sources has an important effect on mapping the geology map. Several methods have been developed to extract the edges of the gravity data. Interestingly, notable authors (e.g. Miller and Singh, 1994; Wijns et al., 2005; Nasuti et al., 2018; Zareie and Moghadam, 2019) have gone ahead to introduce balanced methods for the extraction of the boundaries of the deep and shallow structures simultaneously. However, these methods only produce the secondary structures in edge maps (Pham et al., 2021 c, d). Using the amplitude-based methods, this problem can be solved. These methods have been developed by Nabighian (1972), Cordell (1979), Fedi and Florio (2001), Beiki (2010), among others. Although the amplitude-based methods can avoid bringing false structures, they are dominated by the large-amplitude signals due to the shallow structures (Pham 2021). Some authors have developed peak locating methods to overcome this problem. The use of these methods has shown great success in determining the lateral boundaries of the subsurface structures in many areas (Paoletti et al., 2004; Nasuti et al. 2012; Tschirhart and Morris, 2014; Phillips et al., 2007; Fofie et al. 2019). The parabola-based method is the first method, developed by Blakely and Simpson (1988) to determine the peaks of the signals. Kha et al. (2018) improved the parabola-based method to bring more detail to the peak. However, both methods cannot detect all peak's locations. Another method, introduced by Phillips et al. (2007), is based on fitting a quadratic surface to the transformed anomalies in the 3 × 3 window.[31] This method can be used to determine all peaks, but it produces false information around deep souces (Pham et al., 2021e). Recently, Pham et al. (2021f) have been introduced an improved method for locating the signal peaks. The method determines the peaks by fitting a parabola to three successive data points.

Nam Dinh province is located in the southeastern part of the Song Hongdelta, Vietnam (Fig. 1). It is obscured by Quaternary sediments, and so it is not observed on the surface. Subsurface geological structures of the area can be determined quickly and economically by assessing gravity data.

In this paper, we show the results of the improved parabola-based method (Pham et al., 2021f) applied to gravity data from Nam Dinh province (Vietnam) to extract lineaments. These results bring new information that is essential to improve the understanding of the structural framework and tectonic setting of the areas.

2. Geological setting

Nam Dinh province is located in the Northern region of Vietnam (Fig.[12] 1) which is known as a significant part of the Tethyan orogenic belt, and is located between the Cenozoic Indochina and South China blocks (Hieu et al. 2012). It is bordered on the southeast by the Gulf of Tonkin, on the northwest by Ha Nam province, on the northeast by Thai Binh province, and on the southwest by Ninh Bình province. Nam Dinh province is a part of the Song Hong delta that is known as one of Asia's largest deltas (Tue et al., 2019; Pham, 2020).[67] The delta is formed during the Holocene as a result of the Red River sediment discharge into the East Vietnam sea (Tanabe et al., 2006). It is underlain by Cainozoic extensional basins (Fyhn and Phach, 2015) (Fig. 1).[12] The location of the study area is shown in Fig. 1. This area extends from longitude 105°54'32" to 106°26'19" and latitude 20°6'59" to 20°31'35". It is covered by Quaternary sediments with a maximum thickness of 180 m (Phach et al., 2020).

3.Methodology

Consider a 3×3 moving window consisting of a central grid point and its eight nearest neighbors in four directions (Fig. 2). If this window contains a maximum, it must satisfy at least one of the four following conditions:

$$\begin{cases} G_{i,j} \frac{G_{i-1,j}+G_{i+1,j}}{2} \text{ and } \left|\frac{-b}{2a}\right| \leq d, \\ G_{i,j} \frac{G_{i,j-1}+G_{i,j+1}}{2} \text{ and } \left|\frac{-b}{2a}\right| \leq d, \\ G_{i,j} \frac{G_{i-1,j-1}+G_{i+1,j+1}}{2} \text{ and } \left|\frac{-b}{2a}\right| \leq d, \\ G_{i,j} \frac{G_{i+1,j-1}+G_{i-1,j+1}}{2} \text{ and } \left|\frac{-b}{2a}\right| \leq d. \end{cases} \quad (3)$$

A counter N is increased by one for each satisfied inequality. For each condition met, the value and location of the peak are found by fitting a quadratic polynomial moving within three consecutive data points. For the condition given below:

$$G_{i,j} \frac{G_{i-1,j}+G_{i+1,j}}{2} \quad (4)$$

the value of the peak is calculated by:

$$G_{max} = a x_{max}^2 + b x_{max} + G_{i,j}, \quad (5)$$

where

$$a = \frac{1}{2d^2}\left(G_{i-1,j} - 2G_{i,j} + G_{i+1,j}\right),$$

$$b = \frac{1}{2d}\left(G_{i+1,j} - G_{i-1,j}\right), \tag{6}$$

d is the grid intersections distance and the peak location is given by:

$$x_{max} = -\frac{b}{2a} \tag{7}$$

If number of satisfying inequality N is greater than 1, the location of the largest G_{max} located inside the central grid cell (the box of size Δx×Δy) is assigned as a maximum of the window.[38] If N is equal to 1, an acceptance criterion that is based on the curvature of the parabola at the maximum location and the maximum of the data were considered. The criterion is given by:

$$k = \frac{\frac{2a}{[1+(2ax_{max}+b)^2]^{3/2}}}{max(G)} \text{ or } k = \frac{2a}{max(G)}. \tag{9}$$

The acceptance criteria k is decided by the researcher. In general, k ≤ -0.04 will yield the best results.

Fig. 3a and 3b show the 3D view of synthetic model that includes two prisms and its gravity anomalies. Fig. 3c shows the gradient amplitude of the data in Fig. 3b. The maximum locations of the gradient amplitude are fully detected by the improved parabola-based method (Fig. 3d). The method brings all information on the source edge locations.

3. Results and discussions

The gravity data used for extracting subsurface structures of this area were collected in 2011 by Department of Geology and Minerals of Vietnam (DGMV, 2011) (Fig. 4). In order to reduce the effect of high frequencies, an upward continuation of 1 km to the gravity data of Nam Dinh province was applied. Fig. 5a shows the upward continued Bouguer gravity map of the area. The gravity anomaly trends in Fig. 5a are varying NW–SE direction in the study area. The data varies from −17 to 16 mgal with the appearance of a dominant NW–SE anomaly trend in the map. Fig. 5b shows the horizontal amplitude map of the gravity data. This map shows the presence of a dominant NW–SE structural trend, but it does not yield sharpened responses at the geology contacts. For this reason, the use of the peak locations of the horizontal amplitude brings a better estimation of lateral boundaries of the geological bodies than itself. Using the improved parabola-based method, the maximum locations of the horizontal amplitude are detected and shown in Fig. 5c. These maximum locations show subsurface structures of the study area. Fig. 5d shows the superposition of these locations on a gray-scale horizontal amplitude map. Obviously, this method can determine all peak locations of the amplitude of the horizontal gradient, and thus can be seen that most of the extracted structures are NW–SE trending lineaments.[9] These trending lineaments are parallel to the structural trend in the Song Hong fault zone and the Red River basin (Fyhn and Phach, 2015). The results demonstrate the existence of many lineaments which are not outlined by geological mapping alone. The existence of the NE-SW trending lineaments in the map of maximum locations indicates that the Red River basin appears to extend farther southeast beyond the border of the study area. The obtained results can bring some references for further study within geology aims in Nam Dinh province.

5. Conclusions

The improved parabola-based method has been applied to gravity dataset from Nam Dinh province (Vietnam) to detect lineaments of subsurface structures in the area. We have detected the maximum locations of the gradient amplitude of gravity data, which deal with lineaments of density structures. This study finds new information on the lineaments of subsurface structures of the study areas. The structures in Nam Dinh are characterized by northwest-southeast tectonic trends. The results determined by the improved parabola-based method can bring some references for further study within geological aims in Nam Dinh province. The improved parabola-based method thus offers great promise for rapid mapping of subsurface structures without the assumptions on density contrasts.

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