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[2] Determination of structural lineaments of Northeastern Laos using the LTHG, EHGA methods

Abstract

The LTHG and EHGA methods are enhancement versions of the gradient amplitude and can outline the border of shallow and deep anomalous bodies simultaneously.[2] Recently, these techniques have been used in approximating the borders of gravity and magnetic data.[2] In this paper, we apply the LTHG and EHGA methods to the gravity dataset from the global gravity model WGM2012 to extract structural features of Northeastern Laos that appear as lineaments on transformed data maps.[2] We also apply the tilt depth method to this dataset to estimate the depth of these lineaments.[2] The findings showed that most of structures identified in Northeastern Laos are trending in the ENE-WSW, NE-SW, E-W, WNW-ESE and N-S directions with the depth ranging from 1.3 to 2.1 km.

Keywords: gravity, WGM2012, LTHG, EHGA, Northeastern Laos.

1. Introduction

One of the classic applications of gravity and magnetic methods is to outline lineaments in observed field using various filtering techniques (Pilkington and Tschirhart, 2017; Castro et al., 2018; Sehsah et al., 2019; Eldosouky et al., 2020a, b, c; Oksum et al., 2019). This process is important since the determined border generally correspond to the lateral changes of the geological structures (Eldosouky, 2019; Pham 2020, 2021). Many border approximation techniques are developed to interpret potential field anomaly (Ferreira et al., 2013; Narayan et al., 2016; Nasuti et al., 2019; Pham et al., 2018a, b; 2021a, b).[2] The total horizontal gradient method (THG) is a conventional detector commonly used for edge estimation (Cordell, 1979).[3] The analytic signal is another popular technique used to detect the boundaries of subsurface structures (Nabighian, 1984).[2] Although these conventional techniques are prevalent detectors used to interpret potential field anomaly, they also have limitations (Le et al., 2020, Pham et al., 2021c, d, e, f).[2] To overcome the limitations of these traditional techniques, researchers proposed several new approaches based on the potential field gradients.[2] For instance, Miller and Singh (1994) used the inverse tangent function of the ratio between the vertical derivative and THG.[3] Fedi and Florio (2001) introduced an enhanced version of the THG based on sum of the vertical gradients. Verduzco et al.[3] (2004) suggested a detector using the amplitude of gradient of the tilt angle. Wijns et al.[2] (2005) proposed the theta technique that normalizes the total gradient by the amplitude of gradient.[2] Cooper and Cowan (2006) used a normalized version of the gradient amplitude. Ferreira et al. (2013) presented another enhanced version of the THG method. Pham et al. (2019, 2020a) presented the LTHG and EHGA methods that employ respectively the logistic and inverse sine functions to improve the THG method. Apart from the techniques mentioned above, many other methods in the studies also rely on potential field gradients. (Fedi, 2002; Cella et al., 2009; Tatchum et al., 2011; Pham et al., 2020b; 2021g; Oksum et al., 2021b; Melouah and Pham, 2021).

Gravity data and subsurface structures of Northeastern Laos (Fig. 1a) have not been studied in the past. Several global gravity models have been developed according to new data sets to improve the understanding of the geodynamical and geological processes of the Earth (Bonvalot et al. 2012; Sandwell et al., 2014). The new gravity models with high accuracy can be used for detection of structural features of Northeastern Laos.[5]

In this paper, the LTHG, EHGA and the tilt depth techniques have been applied to gravimetry data from the high-resolution global gravity model WGM2012 to outline the geological features of Northeastern Laos. The findings bring a better understanding of structural features of Northeastern Laos.

2. Geological setting

As shown in Fig. 1b, northeastern Laos is existing in different period ages of metamorphic rocks such as Cenozoic metamorphic, Jurassic- Cretaceous to Triassic, Devonian to Permian, Cambrian to Silurian and Pre-Cambrian ages, while some parts of the area found Cenozoic granitoides, Jurassic- Cretaceous granitoides, Permo -Triassic granitoides, and Early-Midle Paleozoic granitoides (Fyhn et al., 2019). The Proterozoic rocks found in the Song Ma massif are located in northeastern Laos. These rocks comprise arenites, schists and marbles that are considered to be lower Paleozoic age. The ultramafic rocks appear in some areas of an ophiolite belt near the Sam Neua district of Houaphanh province where the main suture is situated parallel to the NW to SE striking the Song Ma.

3. Data

The gravity dataset of Northeastern Laos was generated from the WGM2012 model (Fig. 2). [5] The WGM2012 is a global gravity field model with high resolution, which contains data from EGM2008 and DTU10 models (Bonvalot et al. 2012). The Bouguer data of Northeastern Laos range from -58 mGal to 93 mGal, with high amplitude signals appearing in the eastern part (Fig. 2). Recently, the use of gravity data from the WGM2012 model in detecting geological structures has shown great success (Kahveci et al., 2019; Eldosouky et al., 2021; Elmas and Karslı, 2021).

4. [6] Methods

The THG is one of the most commonly used detectors for extraction of the borders of the geology structures. This detector is formulated as follows (Cordell, 1979):

$$THG = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2}, \quad (1)$$

The THG is less effective when the anomalous bodies are interfered by nearby sources. Pham et al. [6] (2019) proposed the LTHG method for improving the performance of the THG method:

$$LTHG = \left[1 + exp\left(\frac{-\frac{\partial THG}{\partial z}}{\sqrt{\left(\frac{\partial THG}{\partial x}\right)^2 + \left(\frac{\partial THG}{\partial y}\right)^2}}\right)\right]^{-\alpha} \quad (2)$$

where α is a constant between 2 and 10 (Pham et al., 2019).

Another detector for approximating of the border is also developed by Pham et al. [2] (2020), which is based on the asin function and the THG derivatives. The detector is given by: [31]

$$EHGA = R\left(asin\left(p\left(\frac{\frac{\partial THG}{\partial z}}{\sqrt{\left(\frac{\partial THG}{\partial x}\right)^2+\left(\frac{\partial THG}{\partial y}\right)^2+\left(\frac{\partial THG}{\partial z}\right)^2}}-1\right)+1\right)\right), \quad (3)$$

where p is a constant greater or equal to 2 (Pham et al., 2020).

5. Results

We generated a gravity model (Fig. 3a) to evaluate the applicability of the THG detector and its enhanced versions. The gravity anomalies of the model are shown in Fig. 3b. Fig. 4a displays the THG of the anomaly data in Fig. 3a. It is observed from this figure that the THG method brings clear images for the edges for the source D, but responses from the bodies A, B and C are blurred. Fig. 4b displays the edges estimated from applying the LTHG method to the anomaly in Fig. 4a. It is seen that the maxima of the LTHG are located directly over the source borders, and the results are more sharp-cut responses over the source boundaries than those from the THG method. Fig. 4c displays the edges determined from using the EHGA technique. Similar to the LTHG detector, the EHGA detector equalized the anomalies of shallow and deep bodies. This method provided a boundary map having a higher resolution than the THG method.

Fig.[4] 5a displays the boundaries determined by applying the THG detector to the gravity of Northeastern Laos.[4] In the THG filter result, it is seen that the borders of the more significant amplitude anomalies prevailing in the eastern and southern regions of the area are prominent.[4] The THG method cannot balance gravity different anomalies, making it less effective in approximating the borders of the deep structures. Fig. 5b shows the edges outlined by applying the LTHG method to gravity data. As shown in the model example, the peaks of the LTHG function are located directly over the boundaries of geological structures. It is seen from this figure that a large number of boundaries are delineated by this method. The method emphasizes shallow and deep surface features with different wavelengths. Fig.[4] 5c illustrates the map obtained by applying the EHGA technique to the Bouguer gravity data. It is observed from this figure that the method provides a uniform gain for all transformed data, and they represent the signatures of geology due to density variations.

6. Discussion

It is clearly seen from Fig. 5a that the THG emphasizes shallow geological features with relatively short wavelengths. The reason is that this technique uses the gradient amplitudes of gravity anomaly.[4] The LTHG and EHGA techniques are based on the ratio of the derivative amplitudes of data, therefore they can emphasize both short and long wavelengths. In other words, the LTHG and EHGA methods are effective in balancing different anomalies, and they provide clearer geological features than the THG. It can be noted that the LTHG and EHGA methods provided more sharp-cut responses over the borders of geology structures compared to the THG and other methods. Since the LTHG and EHGA methods produced clearer images than those from the THG method, we used these methods to determine the lineaments of Northeastern Laos. Fig. 5d shows the lineaments extracted from the LTHG and EHGA maps (Fig. 5b and 5c).[34] The major structural features in Northeastern Laos are oriented in the NW-SE, E-W, WNW-ESE and ENE-WSW directions with the predominant trend being the NW-SE.

To detect the depth of the lineaments, we used the tilt depth method (Salem et al., 2007). Fig.[4] 6 shows the result of application of the tilt depth method to the Bouguer gravity data. Fig.[9] 7 shows the histogram of the depth estimates obtained from the tilt depth method.[17] It can be seen from Fig.[9] 6 and 7 that the depth of most of the lineaments varies from 1.3 km to 2.1 km. For comparison, the lineaments in Fig. 5d are superimposed on the tilt depth map. We can see that the majority of solutions are trending in the NW-SE, E-W, WNW-ESE and ENE-WSW directions. Clearly, the positions of source points are mostly correlated with the lineaments determined by the LTHG and EHGA methods. The presence of the gravity lineaments in the eastern and southern parts of Northeastern Laos (Fig. 5d) is verified by the signals of the THG (Fig. 5a). We can see that many gravity lineaments match with geological features of Northeastern Laos. The lineaments illustrate a-good-correlation-with-the NW-SE trending-faults-in-the-northern and southeastern parts-of-the area. The lineaments also coincide with some E-W trending-faults-in-the southwestern-part-of the-area. We anticipate that the dominant NW-SE trending boundaries determined by the edge filters-are-related-to the same tectonic activity that might be originated due to the collision-of-Indochina-and-South China.

7. Conclusions

The LTHG and EHGA methods-were-applied-to gravity data to outline structural features of Northeastern Laos. The tilt depth technique was also used to detect the depth of gravity lineaments. Various-structures were identified in the Northeastern Laos by the interpretation results of Bouguer anomaly.[7] Our findings showed that most of the lineaments outlined in the Northeastern Laos are trending in the ENE-WSW, NE-SW, E-W, WNW-ESE and N-S directions with the predominant trend being the NW-SE. The depth of these lineaments ranges from 1.3 to 2.1 km. The obtained lineaments match with geological features of Northeastern Laos and provide valuable information for geophysicists to better understand the subsurface geological structures of the area.