Gravity - Depth Regression Method for 3D Modelling of Basement Geometry

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Abstract. Gravity method is often used to estimate the sedimentary basin configuration at the preliminary stage of oil and gas exploration. This paper aims at the determination of 3D basement topography based on gravity data and known depth at several points. The gravity-depth relationship is used to determine the initial model and to adjust the model iteratively from the residuals. The algorithm is relatively simple and fast, since it does not involve matrix inversion nor multiplication. The proposed method also allows density contrast estimation.

Tests using synthetic data showed satisfactory results in both synthetic model recovery and low RMS misfit after a few iterations.

1. Introduction

The basement geometry or depth estimation is an important phase in hydrocarbon prospecting. Gravity method is of particular interest for mapping basement topography. One of conventional approaches to estimate the basin configuration from gravity data is the well-known Bott’s method [1]. The algorithm employs the Bouguer plate formula to estimate the initial depth model and its iterative modifications from the residuals or misfits. Bott’s method can be applied for both 2D and 3D basement modelling by using relevant gravity model response calculation or forward modelling [2,3].

In Bott’s method, an estimation of the constant density contrast between the basement and the overlying sedimentary rocks has to be assumed. The choice of the density contrast is a critical issue. Erroneous density contrast will give a significantly different model. We followed Florio [4,5] who proposed a similar iterative algorithm incorporating the density contrast estimation. The regression between gravity data and known basement depth at several points is used to convert the gravity anomalies to depths as the initial model. We used the 3D vertical prism model as building blocks of a 3D basin model. The density contrast is estimated from the regression of the observed gravity with the theoretical response of the initial model with a unit density. The model is updated iteratively based on residuals by using the initial gravity-depth relationship. We apply the algorithm to synthetic gravity data associated with a 3D basement model having a constant density contrast.

2. Data and Method

Data

To illustrate and to test the method we used a 3D synthetic basin model that covers an area of 132 x 104 km² discretized into 33 x 26 blocks of vertical prism with 4 x 4 km² in horizontal size. The maximum sediment thickness is around 11 km with a constant density contrast of -0.5 gr/cm³. The theoretical gravity effect at the centre of each grid was calculated by using a 3D forward modelling code modified...
from Blakely [2]. We applied the iterative modelling method to synthetic data without noise and also with Gaussian noise, i.e. zero mean and 0.5 mGal standard deviation.

**Method**

The iterative procedure to obtain the final model is relatively simple as there is no matrix inversion nor multiplication involved. By assuming a constant density contrast, a linear relationship between gravity data and known basement depth at several points (from well, seismic or the other geophysical data) can be used to convert gravity data to basement depth. Since we deal with synthetic data, the regression was done by using basement depths from synthetic model and their associated gravity response. The result of the regression from synthetic data without noise is presented in Figure 1. This linear relationship is used to obtain the initial model by converting the gravity data to basement depth.

The gravity response of the initial basement model is calculated by using a unit density, i.e. $1 \text{g/cm}^3$ or $1000 \text{kg/m}^3$. The linear relationship between observed and calculated gravity data determines the density contrast (see Figure 2). The results for synthetic data with 0.5 mGal Gaussian noise (not shown) are nearly similar to those from noise-free data, since the noise only introduced small alterations in the synthetic data. From both noise-free and noisy data, the density contrasts were estimated to be -0.4844 and -0.4845 g/cm$^3$ respectively, which are very close to the true value of -0.5 g/cm$^3$.

The initial gravity-depth relationship is applied to the residual, i.e. difference between observed and calculated gravity at each grid, to update iteratively the model. The basin depth at $k$-th iteration is formulated by,

$$b^k(x) = b^{k-1}(x) + \left(g_{\text{obs}}(x) - g_{\text{est}}(x, \Delta \rho_{\text{est}}, b^{k-1})\right)m$$

where $g_{\text{obs}}(x)$ is the observed gravity anomaly field at observation points $x_i$, $g_{\text{cal}}(x_i, \Delta \rho_{\text{est}}, b^{k-1})$ is the computed gravity anomaly as function of basement model from previous iteration $b^{k-1}$ and the estimated density contrast $\Delta \rho_{\text{est}}$ and $m$ is the slope of the line that best approximates the gravity-depth relationship. The iteration is stopped when the misfit is less than a threshold value or after a maximum number of iterations. In this case, we performed systematically up to 8-th iteration for all tests without other criteria for convergence.

**Figure 1.** Depth-gravity relationship from the regression between basement depths of the synthetic model and their associated gravity response.

**Figure 2.** The regression between observed and calculated gravity response of the initial model with unit density to obtain estimated density contrast.

### 3. Results and Discussion

The synthetic model and its associated synthetic gravity data are shown in Figure 3a. There are five sub-basins: three of them are in the central part with a NW-SE trend, while two other sub-basins with similar trend are in SW and NE parts of the area. The gravity-depth regression technique was applied to the synthetic data without noise. Figure 3b presents the recovered basin model with calculated gravity anomaly map. A similar set of figures is presented in Figure 4 as profiles crossing diagonally the area.
in SW to NE direction. The initial model from gravity-depth conversion and the model from final iteration are compared with the synthetic model. The recovered and synthetic models are quite similar in both map and mostly in profile representations. The RMS error is 0.396 mGal after 8 iterations.

**Figure 3.** (a) Synthetic model and data without noise, (b) recovered model and calculated gravity.

**Figure 4.** Comparisons of synthetic data and calculated gravity anomaly for profiles crossing diagonally SW-NE the central part of the area shown in Figure 3, (a) for initial model and (b) for final model, both shown at the bottom of the figure compared with the synthetic model.
The second case deals with the same synthetic model where Gaussian noise of 0.5 mGal was added to the synthetic data. The results are presented, with similar set of figures as previously done with noise-free synthetic data, in Figure 5 and Figure 6.

![Figure 5](image5.png)

**Figure 5.** (a) Synthetic model and data with 0.5 mGal Gaussian noise, (b) recovered model and calculated gravity.

![Figure 6](image6.png)

**Figure 6.** Comparisons of synthetic data and calculated gravity anomaly for profiles crossing diagonally the central part of the area shown in Figure 5, (a) for initial model and (b) for final model, both shown at the bottom of the figure compared with the synthetic model.
The recovered model exhibits only minor differences, i.e. only in the central part of the basin model. The RMS error for the final model is 0.5 mGal after 8 iterations. The addition of 0.5 mGal Gaussian noise does not alter much the synthetic data as shown in profiles (Figure 6). In general, tests using both noise-free and noise-added synthetic data resulted in satisfactorily similar recovered models. The misfit of the final model is also in the same level of the noise that was introduced to the synthetic data. However, a higher level of noise may result in more oscillations of the recovered model.

4. Conclusion
The iterative 3D basement modelling based on gravity-depth regression was presented with satisfactory results. The problem of determining the density contrast is also resolved by this method. The algorithm was applied for synthetic data associated with synthetic model having only a constant density contrast for simplicity. In fact, the original algorithm proposed by Florio [4,5] can also be applied for the density contrast varying with depth. In such case, the gravity-depth relationship becomes non-linear.

References
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