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Initial exploration of Hydrocarbon resources by gravity data: A case study in the south of Qom province, Iran

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ABSTRACT

Geophysical methods widely used in oil and gas exploration. Modeling of gravity data is used extensively to illustrate the geometry and interface between the sediments and bedrock. Which can help the salt dome, anticline folds, dome-shaped uplift of the continental platform and reef masses to be identified. There are various methods to illustrate the bedrock topography, and we will describe one of these methods in present paper. Using the upward continuation, we extract the residual gravity anomaly which in fact shows the local effect of bedrock gravity on the observed gravity. Then, according to the Oldenburg – Parker method, the residual gravity data are inversed and finally the 3D geometry the bedrock is illustrated. It should be noted that some software's like Surfer and Excel are used in this research but the program main code is written using Matlab programming.

Introduction

Estimating the bedrock depth is one of the main aims of geophysics that is used in engineering and explorations, extensively. Since there is always a density contrast between bedrock and h the upper layers, the gravimetry method used to examine these gravity changes could be significantly helpful to determine the bedrock geometry. The gravimetry includes measuring and studying the earth gravity field. These studies play a significant role in geologic sciences and constitute a base for geodesy studies that without their exact mappings a correct image of the earth situation could not be obtained. In exploration geophysics, study and investigation of the gravity anomaly (Bouguer) have been used for oil exploration and mining for a long time, but it has been less implemented in water investigations, geotechnics and engineering. The gravity studies in exploration are based on local heterogeneity of minerals and rocks density. In petroleum exploration studies, due to the high volume of salt domes, the gravity anomalies up to tens of mGals can be expected, while for the low volume of mineral veins and masses, these anomalies are just few tenths mGals or less and they could seldom reach to a few mGals. Several authors have presented different algorithms to compute the geometry of a density interface related to a known gravity anomaly. Some of them (e.g. Cordell and Henderson [1]; Dyrelius and Vogel [2]; Rao and babu [3], among others) use an approximation to the perturbing body by means of several rectangular prisms of constant density. The gravity effect for each prism is calculated and then, the total gravitational field is determined by adding the effect of all prisms. Tsuboi [4] gave a simple but efficient method based on equivalent stratum technique to compute 3D topography of a density interface. Another algorithm (e.g. Oldenburg [5]) is based on the rearrangement of the forward algorithm by Parker [6]. The Parker's scheme is based on the Fourier transform of the gravitational anomaly as a result of the sum of the Fourier transforms of the powers of the surface causing the anomaly. Oldenburg [5] demonstrated that Parker's expression could be rearranged in order to determine the geometry of the density interface from the gravity anomaly.

The upward continuation method to extract residual gravity from regional gravity

For decades, separating regional and residual fields has been a vital subject in gravimetry and magnetism. A proven process for separating regional and residual fields is through convolution with what is called "separation filter". The term "residual" is used for the modeling field with shallow to intermediate scattering source and the term "regional" is implemented for the field with a deeper area [7]. In other words, the observed field f_0 is the summation of the regional field f_{reg}, residual f_{res}, and noise f_{noise} fields:

$$f_0(r) = f_{reg}(r) + f_{res}(r) + f_{noise}(r) \quad (1)$$

Suppose that the source of anomaly in our case, forms half of the underground space from z=0 to $z\rightarrow\infty$. Consider the residual field originating from the upper levels of z_0 and the regional field originating from lower levels of z_0. After a series of mathematical relationships we will have:

$$P_{res}(k) = S_0(k)\left[1-\exp(-2kz_0)\right] \quad (2)$$

Where $S_0(k)$ is Bouguer anomaly, k is the wave number and z_0 is the upward distance in upward continuation.

The bedrock topography Inversion, supposing a uniform density difference

The inversion procedure uses the equation described by Parker [6] to calculate the gravity anomaly caused by an uneven, uniform layer of material by means of a series of Fourier transforms. This expression, in its one-dimensional form, is defined as:

$$F\left[\Delta g(x)\right] = -2\pi G\rho e^{-|k|z_0}\sum_{n=1}^{\infty}\frac{|k|^{n-1}}{n!}F\left[h^n(x)\right] \quad (3)$$

where $F(\Delta g)$ is the Fourier transform of the gravity anomaly, G is the gravitational constant, ρ is the density contrast across the interface, k is the wave number, h(x) is the depth to the interface (positive downwards) and z_0 is the mean depth of the horizontal interface. Oldenburg [5] rearranged this

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equation to compute the depth to the undulating interface from the gravity anomaly profile by means of an iterative process and is given by:

$$F\left[h(x)\right] = -\frac{F\left[\Delta g(x)\right]e^{|k|z_0}}{2\pi G\rho} - \sum_{n=2}^{\infty}\frac{|k|^{n-1}}{n!}F\left[h^n(x)\right] \quad (4)$$

This expression allows us to determine the topography of the interface density by means of an iterative inversion procedure. In this procedure we assume the mean depth of the interface, z_0, and the density contrast associated with two media, ρ. The gravity anomaly is first demeaned prior to the calculation of the Fourier transform. Then, the first term of equation 4 is computed by assigning h(x)=0 [5] and its inverse Fourier transform provides the first approximation of the topography interface, h(x). This value of h(x) is then used in equation 4 to evaluate a new estimate of h(x). This process is continued until a reasonable solution is achieved.Following Oldenburg [5], the process is convergent if the depth to the interface is greater than zero and it does not intercept the topography. Further, the amplitude of the interface relief should be less than the mean depth of the interface.As the inversion operation (equation 5) is unstable at high frequencies, a high-cut filter, HCF(k) is included in the inversion procedure to ensure convergence of series. This filter is defined by:

$$HCF(k) = \frac{1}{2}\left[1+\cos\left(\frac{k-2\pi WH}{2(SH-WH)}\right)\right] for WH < k < SH$$
$$HCF(k) = 0 for SH < k \quad (5)$$
$$HCF(k) = 1 for WH > k$$

is used to restrict the high frequency contents in the Fourier spectrum of the observed gravity anomaly. The frequency, k can be expressed as 1/λ; λ being the wavelength in kilometers. The iterative process is terminated when a certain number of iterations has been accomplished or when the difference between two successive approximations to the topography is lower than a pre-assigned value as the convergence criteria. Once the topographic relief is computed from the inversion procedure, it is desirable to compute the gravity anomaly produced by this computed topography [8]. In general, this modeled anomaly must be very similar to the one used as input at the first step of the inversion process.

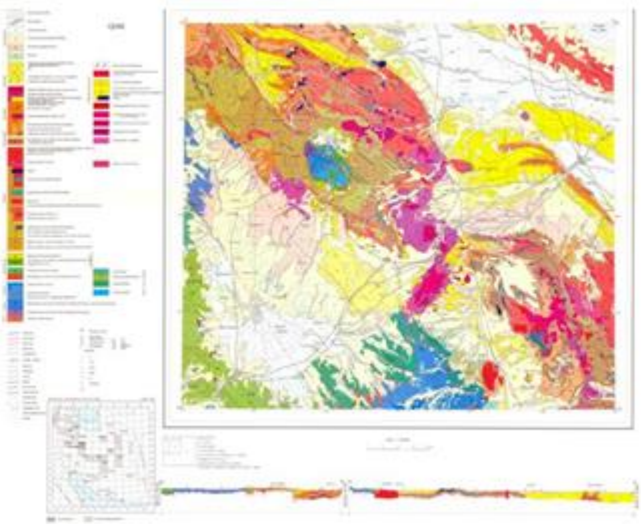

Figure 1. Geological map of the Qom Formation

Geological information about the studied field

Geological structure Qom shows good potential for oil and gas production in this province there. Tectonic motions cause unbalanced and the creation of marine sediment strata Kulob is ponds. There are basic volcanic rocks in the Miocene. Thickness of limestone and marl varies in the southern half of the sheet, the maximum expansion. Qom Formation is the oldest layers in the mountain region south and west of Kashan the fossiliferous green shale's appear in the Lower Red Formation conglomerate layer interlayer mode, but the side is converted the Qom Formation.In east central Iran, Qom formation of a layer of reddish diagnosis is difficult in the North West region of Hamedan andSaveh and the fact that its thickness is measured from 500 to 2,300 meters. The Qom Formation Tekab area, Miane can be seen in and around Lake Urmia.

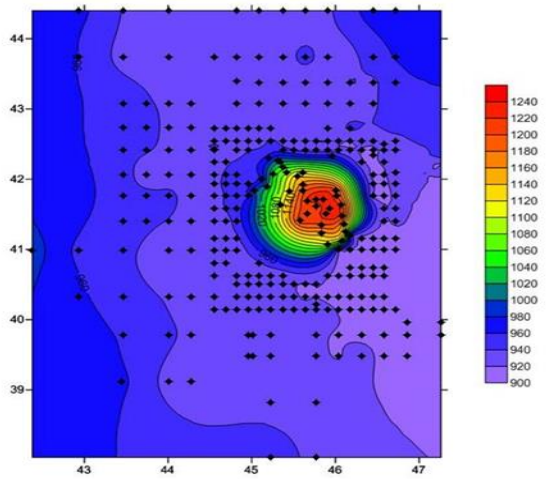

Figure 2. Topographic map of the area and the location of gravity stations

Applying the upward continuation to separate the local field from regional field

The upward continuation method transfers measured data from the measuring level to a higher level. This data transfer to higher level (levels) is performed by mathematical tools and numerical calculations [12]. This transfer weakens the anomalies with shorter wavelength. These anomalies are related to surface effects and/or the noise existed in gravity anomaly maps. So with this transfer, the anomalies related to shallow surfaces will be weakened or vanished, and the anomalies related to wider and deeper sources appear clearly. Regional and residual anomalies integration is in fact a mixture of effects of two resources which one is located under the other. And if these anomalies are not completely separated from each other, the regional anomaly that is the purpose of exploration can't show itself as a closed contour and the desired anomaly is poorly understood. If more upward continuation is required, the desired anomalies would be removed and if less upward continuation is required, anomalies can't be accurately detected. After necessary corrections, first we get Bouguer anomaly [13]. Then, using the upward continuation the residual anomaly which indicates the local field is extracted from Bougueranomaly. According the equation 2,the most important factor in upward continuation is the distance of travel, meaning that what distance should be used such that the residual anomaly could completely show the bedrock topography. It needs to select a profile from the region. Then, the various continuation distances should be applied on that profile and then the two-dimensional shape of each of the residual anomalies should be compared with Bouguer anomaly of that profile. Each continuation distance which makes more similarities with Bouguer anomaly, is in fact our desired continuation distance and the residual anomalies for whole points should be calculated using this. As we shall see, the two-dimensional form of residual gravity for a selected profile with 42 stations with the distances 250, 500, 3000, 5000 and 7000 meters are drawn and compared with the two-dimensional form of the Bouguer anomaly of the same profile. As can be seen in illustrations, the 2-D figures of upward continuation of 5000 meters are more similar to the Bouguer anomaly of the profile. Therefore, to determine the residual anomaly of all points, the upward continuation of 5000 meters is used [14] (Figures 3-9).

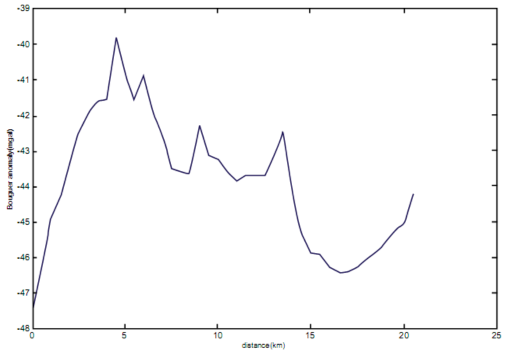

Figure 3: Complete Bouguer anomaly of a profile of the region.

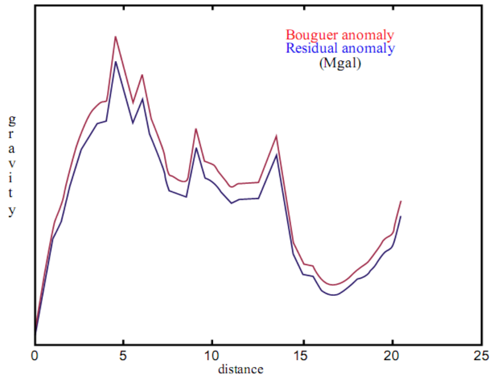

Figure 4: Comparing the profile Bouguer anomaly with residual anomaly of the same profile for the 250 meter continuation distance.

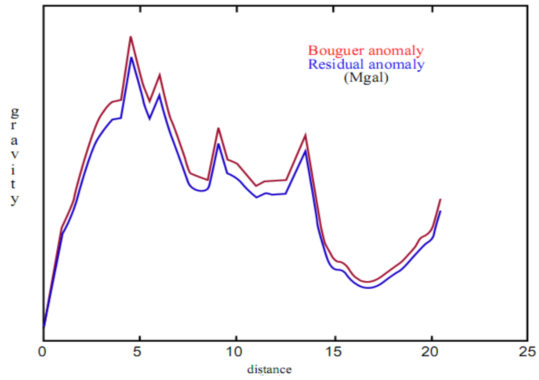

Figure 5: Comparing the profile Bouguer anomaly with residual anomaly of the same profile for the 500 meter continuation distance.

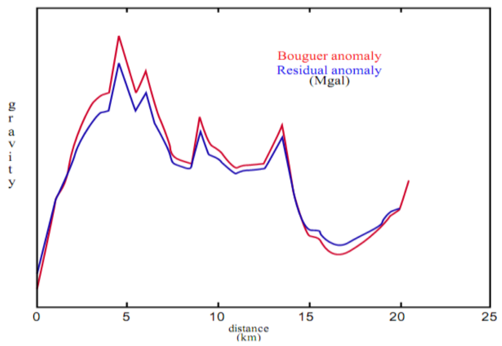

Figure 6: Comparing the profile Bouguer anomaly with residual anomaly of the same profile for the 3000 meter continuation distance.

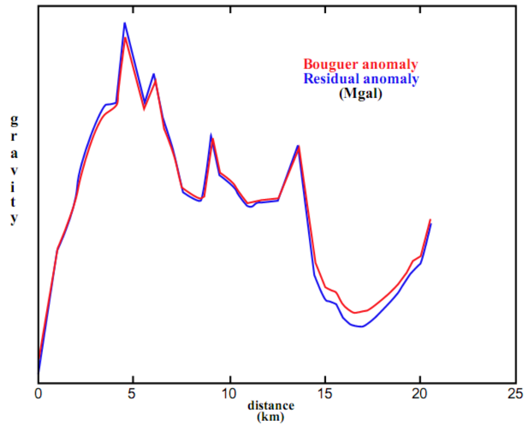

Figure 7: Comparing the profile Bouguer anomaly with residual anomaly of the same profile for the 5000 meter continuation distance.

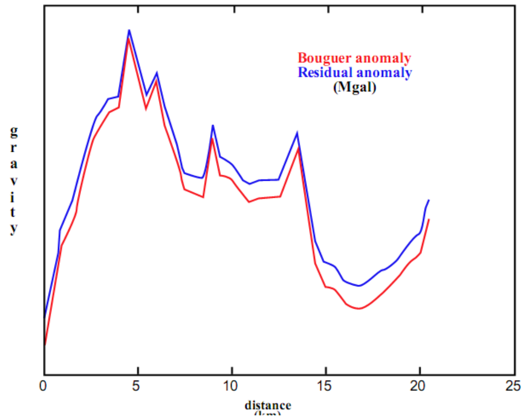

Figure 8: Comparing the profile Bouguer anomaly with residual anomaly of the same profile for the 7000 meter continuation distance.

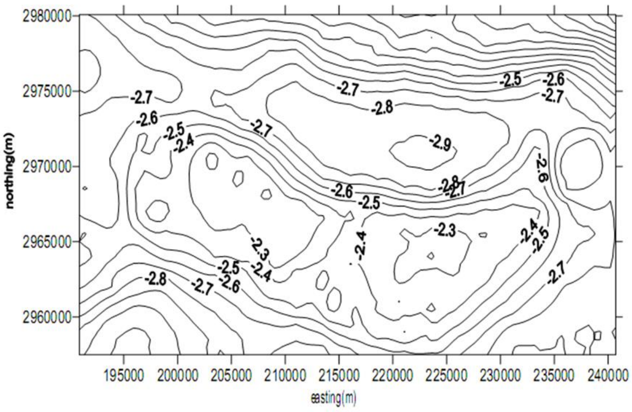

Figure 9: Contouring map of the residual anomaly (the distance between contour lines 0.1 mGal).

Three-dimensional topography inversion

The first parameter we need is the density difference between bedrock and the upper sediments. According to geological mapping and drillings existed in the area, bedrock density is estimated to be 2.9 gr/cm3, and the upper sediments density is estimated to be 2.3 gr/cm3. Thus, the density difference put into calculations is considered to be 0.6 gr/cm3. Also, the basic surface around which the topography is calculated extends to the top of the bedrock and is 800 meters (considering the geology maps and drillings), such that all the bedrock is located under it. Convergence is obtained in second iteration in iterative method which is obtained by the standard deviation (rms error) of about 0.0093 km (convergence criterion in 0.02 km). The maximum depth is obtained around 800 m under reference surface and the maximum height around 550 m above reference surface.

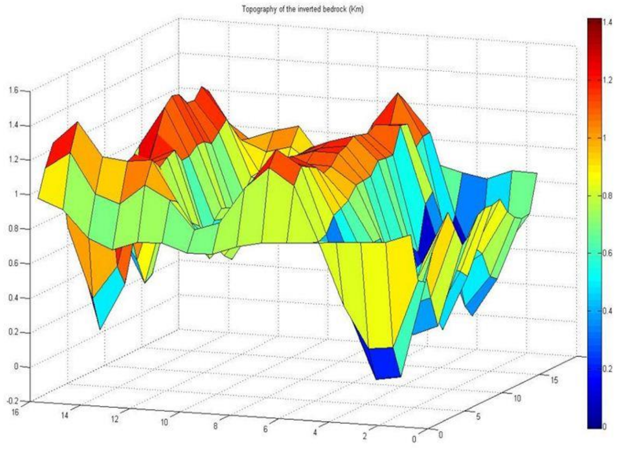

Figure 10: 3D illustration of bedrock topography (km)

Conclusion

Fast Fourier transforms is the basis of this study which is very useful for reducing computational time. For program convergence it is vital to change the filter parameters which are related to bedrock geometry. If the topography to be simulated is located in more depths, a filter that uses longer wavelengths should be designed. Choice of filter parameters and also the bedrock depth should vary from one location to another. Therefore, selection of the depth of reference surface depends on the specifications of the region under study and additional data like geophysical and geological data. Basically, these approaches that make use of fast Fourier transforms are the best methods of calculation. Such that these methods are easily implemented in various methods of geophysical interpretations which require a lot of processing. In a broad range of different densities and different depths, joint studies with other geophysical explorations including seismic profiles to obtain a subsurface structure (eg, bedrock topography) are very useful and important.

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