Study on gravity anomaly changes and crustal structure characteristics in Weihe Basin

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Abstract. Based on the Earth Gravitational Model (EGM2008) and the global terrain model (ETOPO1), we calculate and obtain the free air gravity anomaly and Bouguer gravity anomaly in the Weihe Basin. The wavelet multi-scale analysis method is used to decompose the Bouguer gravity anomaly with 1st to 5th order wavelet detail and wavelet approximation. At the same time, based on the logarithmic power spectrum method, the average depth of the field source corresponding to the 1st to 5th order wavelet detail and approximation is calculated. The research results show that: (1) the wavelet approximation of Bouguer gravity anomaly of order 1st to 5th in the Weihe Basin corresponds to a field source depth of 12 to 84 km. From the wavelet approximation images, the basic pattern of different tectonic units in the study area can be clearly seen. (2) The field source depth corresponding to the wavelet detail of the 1st to 5th order Bouguer gravity anomalies in the Weihe Basin is 3 to 49 km. From the wavelet detail images, the characteristics of different tectonic divisions and fault distribution in the study area can be clearly seen. (3) Gravity anomaly gradient zones often correspond to relatively large-scale faults, such as the Longxian-Baoji fault, the northern Qinling fault, the Weihe fault, and the Huashan piedmont fault. In addition, from the wavelet detail images, the main structural units such as the Baoji uplift, the Xi’an sag, the Lishan uplift and the Gushi sag can be identified.

1. Introduction

55 to 50 Ma ago, the subduction and collision of the Indian plate and the Eurasian plate caused western China and the entire east Asia to undergo the strongest structural deformation since the Cenozoic [1]. The Himalayan movement not only caused the rapid vertical uplift of the Qinghai-Tibet plateau, but also caused a large amount of material within the Qinghai-Tibet plateau to flow eastward, and the Gansu-Qinghai block produced eastward movement, forming a compression on the western part of the Weihe Basin and making a left-handed strike-slip along the fault zone at the northern margin of the Qinling mountains [2-3]. For activities, the fault zone at the northern margin of the Qinling orogen was generally regarded as a left-handed strike-slip fault. Under the combined action of the high angle upthrust collision of the Philippine sea plate and the significant back arc expansion of the Ryukyu Archipelago arc, the north China and south China blocks in the eastern part of China have a SE trending pushing effect. In addition, the horizontal migration velocity of south China block to SE was obviously stronger than that of north China block, and accompanied by the drag of deep mantle small-scale convection in the Basin, thus forming a NW-SE extensional environment between the Ordos block and south China block [4]. In addition, the differential uplift of the Qinling orogenic belt resulted in the formation of a deeper Weihe Basin between the Qinling orogenic belt and the Ordos block [5-6]. The complex crustal tectonic environment and geodynamic evolution process of the Weihe Basin have made this area as a hotspot for scholars at home and abroad (as shown in Figure 1). From the Eocene to the...
In the Oligocene, by tracing a series of preexisting faults near east-west, it was discovered that the Weihe Basin expanded south and north, forming a nearly east-west faulted Basin. In the mid-Miocene, the Weihe Basin strengthened its rifting and accepted sedimentation again. At the same time, the sedimentary range expanded from north to south, and the Basin expanded to the south near the north piedmont fault of the Qinling orogen. During this period, the whole Weihe Basin was in the NEE direction, and at the same time, a normal fault system with NEE syncline series began to appear in the northern margin of the Weihe Basin. The late Miocene was an important stage in the tectonic evolution of the Weihe Basin, with the intensification of the fault-depression structure, the uplift area in the western part of the Weihe Basin began to rift and accept sedimentation. The northern boundary of the Basin also extended to the Liquan-Pucheng fault and moved eastward. The sedimentation of the Weihe Basin's fault depression extended to the Yuncheng Basin. In the early Pleistocene of the quaternary, the western part of the Weihe Basin gradually uplifted and there were sedimentary discontinuities. The Weihe Basin was generally deep in the east and shallow in the west, and the deposition center moved to the east [7-9].

In addition, the Weihe Basin is also an important seismic activity zone in our country. There have been many earthquakes above M6.0 in history. Among them, the Huaxian M8.0 earthquake had occurred at the year of 1556, which killed more than 800,000 people. However, in recent years, the seismic activity of the Weihe Basin has been weak, especially the central part of the Basin has been in a quiet period of earthquakes for a long time. This is extremely inconsistent with the strong background of the surrounding faults since the late quaternary. Therefore, the study of the characteristics of the crustal structure in the Weihe Basin is very important to grasp the deep structure and judge seismic risk of study area. At present, the research on the characteristics of the crustal structure in the Weihe Basin mainly relies on geological exploration, seismic deep reflection profile and other methods, and relatively few studies are carried out using gravity and magnetic data [10-12]. Generally speaking, the Bouguer gravity anomaly reflects the total effect of gravity anomaly of different depths, scales and densities of the crust. It not only reflects the vertical stratification of geological bodies, but also reflects the lateral density heterogeneity of the crustal medium. The gravity field is closely related to geological structure, crustal deformation and deep material migration, which can intuitively reflect the distribution of geological bodies, deep crustal structure and fault structure distribution, and provide an important scientific basis for the study of the earth's internal structure and geodynamics [13-15]. Traditional gravity data processing methods can only simply decompose gravity anomalies into local and regional fields. But gravity anomaly is formed by the superposition of underground anomaly with different depths and scales, so the traditional methods cannot clearly distinguish more detailed parts of the structure in different horizontal and vertical scales. In recent years, the wavelet analysis method has been widely used in the field of geophysical signal processing. Based on the gravity anomaly, geoscientists have done a lot of meaningful exploration and research. Hou et al [16] used wavelet multi-scale analysis method to analyze the Bouguer gravity anomaly in China mainland, and achieved good results. Yang et al [17] applied wavelet multi-scale analysis method to separating and processing of gravity anomaly, and proposed a new way for the separation of gravity anomaly. The basic principle of wavelet multi-scale analysis method is that, it can decompose the signal into multiple scale components that are woven together, and use the corresponding size of the spatial domain sampling step to obtain different details of the research object, so as to achieve the purpose of field separation [18-19].

Therefore, this article first calculates free air gravity anomaly and Bouguer gravity anomaly based on the EGM2008 global gravity field model. On this basis, the wavelet multi-scale analysis method is used to separate the field source of the Bouguer gravity anomaly. Then we study the characteristics of gravity field anomaly at different scales in the Weihe Basin, and analyze the crustal structure characteristics of the Weihe Basin, so as to provide reference information for researching the deep structure of the area's seismic risk.
Figure 1. Structural features and faults distribution in Weihe Basin. The topographic figure is drawn based on the topographic data of ETOPO1. The red line represents the boundary of the first-level block in mainland China, and the blue line represents the boundary of the second-level block in mainland China. The block border data comes from https://gmt-china.org/data/. The black line indicates the main fault structure in the study area, and the fault data refers to the research results of Deng and others. The structural division of the study area mainly refers to the research results of Li [10] and others.

2. Data and methods

2.1. Research data

This paper mainly uses the EGM2008 (http://icgem.gfz-potsdam.de/) gravity field model data. The establishment of the EGM2008 earth gravity model based on multiple sources of gravity data such as GRACE satellite tracking data, satellite altimetry data, and ground regional average gravity data, as well as high-resolution global topographic data. The spherical harmonic coefficient of EGM2008 global gravity field model is up to 2160 orders, and the spatial resolution is about $5^\prime \times 5^\prime$. This model can provide information about gravity anomaly with a wavelength of about 10 km [20-21]. The free air gravity data comes from EGM2008 gravity field model, the highest order is 2160, and the reference system of the free air gravity data is WGS84. The weighted root mean square (WRMS) error of the data is 3.59 mGal. The digital terrain model data used for terrain correction is ETOPO1. The ETOPO1 data model is distributed by the National Geophysical Data Center (NGDC) in August 2008. Its spatial resolution is $1^\prime \times 1^\prime$. ETOPO1 (https://www.ngdc.noaa.gov/mgg/global/etopo1sources.html) data covers land and oceans around the world. Based on the free air gravity anomaly (as shown in Figure 2a) and ETOPO1 data, we obtained the Bouguer gravity anomaly through terrain correction and height correction (as shown in Figure 2b). In order to increase the calculation speed on the basis of ensuring the calculation accuracy, the terrain is divided into three areas, distant zone, intermediate zone and inner zone. In each zone, we use the different calculation scheme, the expression presented for the attraction
produced by a right rectangular prism. In the distant zone the grid step is 4 km, in the intermediate and inner zone the grid step is 2 km respectively. The limit of the intermediate zone is 20 km, the limit of the distant zone is 167 km, and the crustal reduction density is 2670 kg/m\(^3\). In this article, the terrain correction procedure mainly refers to the literature of Fullea et al. [22-23]. In this paper we mainly study the Weihe Basin and its adjacent areas, which the range of longitude is from 106° E to 111° E, the range of latitude is from 33° N to 36° N.

2.2. Wavelet multi-scale analysis method

The wavelet multi-scale analysis method can decompose the Bouguer gravity anomaly into approximation and detail fields. The approximation fields are the reflection of regional Bouguer gravity anomaly information, which mainly reflect the large-scale low frequency anomaly information caused by deep field sources. The detail fields are the reflection of local Bouguer gravity anomaly information, which mainly reflect the small-scale high frequency anomaly information caused by shallow field sources. Among them, low-level details represent shallow geological body anomaly, and high-level details represent deep geological body anomaly [14-19]. The basic expression of the wavelet multi-scale analysis method is that: the signal \( f(x) \in R \) with a resolution of \( 2^{-j} \), using \( A_j f(x) \) represents the low frequency approximation part in the space of \( V_j \), \( D_j f(x) \) represents the high frequency details in the space of \( W_j \), then we can get [24]:

\[
A_j f(x) = A_{j+1} f(x) + D_{j+1} f(x) \quad (1)
\]

It can be further written as:

\[
P_{N_j} f(x) = A_N f(x) + \sum_{j=1}^{N} D_j f(x) \quad (2)
\]

Where, \( P_N f(x) \) indicates that the function of \( f(x) \) is mapped to the subspace of \( V_N \), \( N \) is the maximum order of wavelet decomposition, for gravity anomaly \( \Delta g(x) \), suppose it is decomposed into the space of \( N = 4 \), formula (2) can be simplified as [24]:

\[
\Delta g(x) = A_4 G + D_4 G + D_3 G + D_2 G + D_1 G \quad (3)
\]

Where, \( A_4 G \) represents the 4th order wavelet approximation part, \( D_1 G \) to \( D_4 G \) represents 1st to 4th wavelet details. For 2D plane function \( f(x,y) \), need using 2D wavelet transform for analysis. For 2D gravity anomaly, wavelet multi-scale decomposition can also be performed [24]:

\[
\Delta g(x,y) = A_4 f(x,y) = A_4 f(x,y) + \sum_{j=1}^{4} (D_j^h f(x,y) + D_j^v f(x,y) + D_j^d f(x,y)) \quad (4)
\]

Where, \( D_j^h f(x,y) \), \( D_j^v f(x,y) \), \( D_j^d f(x,y) \) represents the high-frequency details in the horizontal, vertical and diagonal directions in the space of \( W_j^2 \), respectively.

2.3. Logarithmic power spectrum method

The Logarithmic power spectrum method is a gravity and magnetic field analytical processing method first proposed by Spector and Gant [25]. On the basis of wavelet multi-scale analysis method, the power spectrum method is used to calculate the equivalent depth of the field sources. The power spectrum method, as an auxiliary method of the wavelet multi-scale analysis method, adds a quantitative estimate of the average depth of field sources at different depths. The combination of power spectrum analysis and wavelet multi-scale analysis method is beneficial to the deeper and more reasonable crustal structure explanation [26-29]. Consider the spectrum of the gravity anomaly of the ball in the simplest case, the power spectrum expression in polar coordinates is that [25]:

\[
E(r) = |S(u,v)|^2 = A^2 e^{-2hr} \quad (5)
\]

Take the logarithm of both sides, we can get formula \( \ln E(r) = \ln A^2 - 2hr \), \( \ln E(r) \) is called the radial logarithmic power spectrum of the anomalous spectrum, \( A \) is the size factor, \( r \) is the circular
frequency or wave number, \( h \) is the depth of the field source. The radial logarithmic power spectrum has a linear relationship with the radial frequency, and the slope of the straight line is \(-2h\). According to the slope of the straight line, the depth of the field source can be calculated as [25]:

\[
h = \frac{\ln E(r_2) - \ln E(r_1)}{2(r_1 - r_2)}
\]  

(6)

3. Characteristic analysis of gravity anomalies in Weihe Basin

3.1. Characteristics of the free air gravity anomaly

The free air gravity anomaly in the Weihe Basin (as shown in Figure 2a), shows obvious topographical-related features. In the whole Weihe Basin the free air gravity anomaly changes mainly in negative values, and in the Zhouzhi area in the middle section of the Weihe Basin, the free air gravity anomaly is at the lowest value, about -150 mGal. The free air gravity anomaly in the Liupanshan area shows a positive change, with a maximum value of 60 mGal, forming a gravity gradient zone with the adjacent north margin of the West Qinling. The free air gravity anomaly changes smoothly in the western area of the southern margin of the Ordos block, basically changing around 0 mGal. Local positive changes occur in the Xunyi-Zhengning area in the central part and the Huanglong area in the east of Weihe Basin, and the maximum values are 20 mGal and 50 mGal, respectively. The free air gravity anomaly in the Qinling orogenic belt changes mainly is positive values, with a maximum value of about 120 mGal. The gravity anomaly changes drastically between the Qinling orogenic belt and the Weihe Basin, forming a very significant gravity gradient zone. However, the change of gravity anomaly between the Shangxian-Danfeng suture zone in the northern margin of the Qinling Mountains and the Mianxian-Lueyang suture zone in the south is relative consistent. In addition, the Qinling orogenic belt shows Basin-ridge-mountain structural characteristics obviously.

3.2. Characteristics of the Bouguer gravity anomaly

The Bouguer gravity anomaly is obtained after the free air gravity anomaly which was corrected by mesosphere and topography [29-30] (as shown in Figure 2b). Compared with Figure 2a, there is a weak correlation between Bouguer gravity anomaly and topography, but there is an obvious mirror relationship between Bouguer gravity anomaly and Moho interface depth (as shown in the last figure). The Bouguer gravity anomaly in the Liupanshan tectonic area shows a wide range of negative change. Especially the triangular area bounded by the Longxian-Baoji fault and the Chengxian-Taibai fault is the lowest Bouguer gravity anomaly zone in the entire study area, with the smallest value which reaches -240 mGal. The southern margin of the Ordos block is bounded by Xunyi-Zhengning. The Bouguer gravity anomalies in the east and west are obviously different, indicating that there are significant differences in the crustal structure and the crustal medium density between these two regions. The Weihe Basin is bounded by the longitude of 109°, with obvious differences of the Bouguer gravity anomalies from east to west. There may be two reasons for the differences of the gravity anomaly: on the one hand, it may be related to the deep crustal structure and medium density, such as upwelling of mantle material, uplift of Moho surface, difference of rock density, and so on. On the other hand, it is related to the long-range comprehensive effect of NE pushing of Indian plate and SW pushing of Pacific plate.

In addition, in the eastern part of the Weihe Basin, there are obvious the Bouguer gravity anomaly change gradient zones near Huashan Piedmont fault, Shuangquan-Linyi fault, Hancheng fault, Zhongtiaoshan fault, and so on. From north to south of these areas, the Bouguer gravity anomaly appears alternately with high value and low value. The Bouguer gravity anomaly in the Qinling orogenic belt has obvious segmentation and zoning features. In particular, the Bouguer gravity anomalies of West, Mid and East Qinling bounded by Chang’an-Lintong fault are obviously different. In addition, taking the Mianxian-Lueyang suture zone as the boundary, there are obvious differences in the Bouguer gravity anomalies between the north and south sides. From the Bouguer gravity anomaly image, the main structural units in the Weihe Basin and adjacent areas can be identified clearly, such as the first-level
structures of the Weibei Uplift (correspond the high gravity anomaly area), the Liupanshan structural area (correspond the low gravity anomaly area), and so on; such as the second-level structures of the Baoji Uplift (correspond the high gravity anomaly areas), the Xi’an Sag (correspond the low gravity anomaly area), the Lishan Uplift (correspond the high gravity anomaly area), the Gushi Sag (correspond the low gravity anomaly area), and so on. The Bouguer gravity anomaly is a superimposed field that reflects the information of different deep field sources. Due to the mutual interference of different signals, the definition of geological structures and faults distribution characteristics are not enough, and the information of different field sources needs to be separated using the wavelet multi-scale analysis method.

Figure 2. Gravity anomaly in Weihe Basin (a) Free air gravity anomaly; (b) Bouguer gravity anomaly.

4. Characteristics of crustal structure in Weihe Basin
The Bouguer gravity anomaly data is decomposed by wavelet multi-scale of order 1st to 5th, and the wavelet approximation and detail images of order 1st to 5th are obtained. The approximate images of wavelet transform reflect the regional Bouguer gravity anomaly information, which mainly reflect the large-scale low-frequency anomaly information caused by the deep field sources. The gravity anomaly components include the interface depth change of the upper mantle top, the density change of the lower, the middle and the upper crust [16-18, 24, 26-29]. The wavelet transform detail images are the reflection of the local field Bouguer gravity anomaly information, which is mainly reflected the reflection of small-scale high-frequency information caused by shallow field sources. On this basis, the logarithmic power spectrum method is used to calculate the approximate field source depth corresponding to the 1st to 5th order wavelet approximation and detail images. Since the detail images of the 1st order wavelet transform mainly reflect the density changes of the sediments near the surface [28-29], as the same, the depth of the field source corresponding to the approximation images of 1st and 2nd order wavelet is basically the same, so this paper only analyze the features of deep crustal structure revealed by the detail and approximation images of the 2nd to 5th order.

4.1. Characteristics of the Bouguer Gravity Wavelet Approximation
These are 2nd to 5th wavelet approximation images of Bouguer gravity anomaly in the Weihe Basin [22, 30] (as shown in Figure 3). Table 1 shows that the equivalent field source depth corresponding to the 2nd to 5th order wavelet approximation, the range of the equivalent field source depth is from 15 to 84 km. Although the depth of the gravity field reflected in the image of each order of wavelet approximation is different, however the 2nd to 5th order wavelet approximation images can clearly identify the basic pattern of different tectonic units in the study area. With the increase of the wavelet approximation order, the local anomaly information of gravity anomaly in different structural units and large faults has been better suppressed, and the regional anomaly information has become more prominent. The basic pattern of major tectonic units and their distribution characteristics of Bouguer gravity anomaly are becoming
more apparent. The characteristics of gravity anomaly belts distributed in different regions are different in their directions, shapes, and gradient changes, which are actually manifestations of geological differences.

![Figure 3](image-url)  
Figure 3. Wavelet approximation of Bouguer gravity anomaly in Weihe Basin.  
(a) 2nd order; (b) 3rd order; (c) 4th order; (d) 5th order

| Order  | Equivalent field source depth (km) | Order  | Equivalent field source depth (km) |
|--------|-----------------------------------|--------|-----------------------------------|
| 1st order | 12                               | 1st order | 3–5                             |
| 2nd order | 15                               | 2nd order | 5–6                             |
| 3rd order | 31                               | 3rd order | 10                             |
| 4th order | 51                               | 4th order | 24                             |
| 5th order | 84                               | 5th order | 49                             |
This is 2nd order wavelet approximation image of the Bouguer gravity anomaly in the Weihe Basin (as shown in Figure 3a), Figure3a presents obvious zoning characteristics: taking the Xunyi-Xi’an as the boundary, the gravity anomaly in eastern and western of study area has obvious differences. The Bouguer gravity anomaly in the Liupanshan tectonic area appears low value. The Bouguer gravity anomaly gradually increases from west to east of the study area, and the variation range is from -240 to -80 mGal. Taking the Xunyi-Xi’an as the boundary, there are significant differences of the gravity anomalies from south to north in the western part of the study area. Comparison of the southwestern margin of the Ordos block and the Qinling orogenic belt with the Weihe Basin, the Bouguer gravity anomaly in the first two regions is slightly larger, but the internal gravity anomaly has little different, showing obvious horizontal density uniformity. The boundary of gravity anomaly difference has obvious consistency with the geological structure boundary, and the deep and large faults, structural units and the distribution of gravity anomaly have a good corresponding relationship. The Bouguer gravity anomaly in the eastern part of the Weihe Basin is relatively complex, and two relatively low value areas of Bouguer gravity anomaly appear the areas of Dali and Hancheng. The Bouguer gravity anomaly in the central part of the Weihe Basin changes relatively smoothly, indicating that the gradient of the topographical change is relatively slow. The Bouguer gravity anomaly on the southern margin of Ordos gradually increased from west to east, but the magnitude was lower than that of the Weihe Basin. In the east and west of the Qinling orogenic belt, the Bouguer gravity anomaly is significantly different. The south of Huaxian and north of Luonan is also known as the small Qinling tectonic belt [5-6], the Bouguer gravity anomaly value reaches -100 mGal, which is nearly 100 mGal different from the West Qinling orogenic belt. Further observation reveals that the NEE trending Chang’an-Lintong fault seems to be the dividing line between the eastern and western Qinling orogenic belts, which further shows that the EW direction of the Qinling orogenic belt is not continuous, and its orogenic formation mechanism and orogenic period is not the same [31].

This is 3rd order wavelet approximation of the Bouguer gravity anomaly in the Weihe Basin (as shown in Figure 3b), it can be seen that along with the depth of the field source continues to increase, the regional characteristics of the Bouguer gravity anomaly in the Weihe Basin become more obvious, reflecting the basic characteristics and distribution characteristics of deep structures. In particular, some local gravity anomaly in the southern margin of the Ordos block and the Qinling orogenic belt disappeared. The boundary characteristics of the secondary block structure are more obvious, the gravity anomaly in the west of the Weihe Basin has a large-scale consistency. On the contrary, the difference in the Bouguer gravity anomaly in the east of the study area is quite obvious, showing obvious differences in deep density. The structural features of depression and uplift are obvious. From the wavelet approximation of Bouguer gravity anomaly in the Weihe Basin (as shown in Figure 3c, 3d), the gradual increase of Bouguer gravity anomaly from west to east becomes more obvious with the further deepening of the source depth.

4.2. Characteristics of the Bouguer Gravity Wavelet Details

Figure 4 shows the 2nd to 5th order wavelet detail images of the Bouguer gravity anomaly in the Weihe Basin. Table 1 shows the depth of the field source corresponding to the wavelet details is from 5 to 49 km. The 2nd order wavelet detail of the Bouguer gravity anomaly in the study area (as shown in Figure 4a) reflects the diverse and complex field source information, which mainly reflects the lateral anisotropy of the sedimentary layer and upper crust density. The long axis of the abnormal trap has a good corresponding relationship with the distribution of faults and the main structures. The gravity anomaly in the Ordos block is basically concentrated between -4 and 4 mGal, the gravity anomaly range is small and the amplitude is low, showing a single crustal structure with obvious stable cratonic characteristics. The gravity anomaly between the Ordos block and the Qinling orogenic belt presents obvious zoning and block characteristics. The gravity anomaly trend gradually changes from NW to NE in the west and east of the Weihe Basin, and the magnitude of the change is more than that in the Ordos block, the increasing trend basically changes between -10 and 10 mGal. The gravity anomaly changes in the Qinling orogenic belt is the most intense, with the largest scale and amplitude.
According to the equivalent field source depth, the 3rd order wavelet details of gravity anomaly in the Weihe Basin (as shown in Figure 4b) mainly reflect structural information at the depth of about 10 km. Compared with the 2nd order details of gravity anomalies (as shown in Figure 4a), the local small-scale gravity anomalies are significantly reduced. The Ordos block presents a wide range of low-value gravity anomalies, and the cratonic characteristics are further reflected. The gravity anomaly in the Weihe Basin presents a narrow strip with multiple associated gravity cascades. The distribution of faults and structural zoning is becoming more and more obvious. The boundaries of the positive and negative changes of gravity anomalies often correspond to relatively large-scale faults, such as the Longxian-Baoji fault, the Shuangquan-Linyi fault, the Huashan Piedmont fault, the Chang’an-Lintong fault, and so on. In addition, the main structural units such as the Baoji Uplift, the Xi’an Sag, the Lishan Uplift and the Gushi Sag can be identified based on the distribution characteristics of gravity anomalies. The gravity anomaly in the Qinling orogenic belt alternates with positive and negative changes, with obvious Basin-ridge structural features [5-6, 10].

Figure 4. Wavelet detail of Bouguer gravity anomaly in Weihe Basin. 
(a) 2nd order; (b) 3rd order; (c) 4th order; (d) 5th order

Figure 4a and 4b mainly reflect the density structure characteristics of the middle and upper crust. The distribution of gravity anomaly indicates that the crustal density in the study area changes drastically laterally, and the geological body is relatively fragmented. The radial logarithmic power spectrum reflects the field source depth is about 10 km, which is similar to the upper and middle crust depths of the study area [11]. The closeness mainly reveals the variation of the density heterogeneity of the upper and middle crust, and shows the difference in the density structure of the crust in the Ordos block, the Weihe Basin and the Qinling orogenic belt. With the increase of the wavelet detail order, the gravity anomaly becomes extensive and smooth, which mainly reflects the large scale low frequency
anomaly information caused by deep field sources. According to the equivalent field source depth, the 4th and 5th order wavelet details (as shown in Figure 4c, 4d) mainly reflect the density structure of the lower crust and upper mantle. Compared with the 2nd and 3rd order wavelet detail figures, the gravity anomaly distribution and trend characteristics of the 4th and 5th order are quite different. With the disappearance of small scale stripe-shaped and beads-shaped anomalies, it reflects the relatively poor continuity and penetration of the longitudinal density structure in the study area. In addition, the gravity anomaly in the southern margin of the Ordos block is mainly positive and negative low value anomaly, and the depression-uplift structural units are distributed alternately. There is a clear boundary between the Ordos block and the Weihe Basin, while the boundary between the Weihe Basin and the Qinling orogenic belt is not obvious, it can be seen that the basement density of the Weihe Basin and the Qinling Orogenic Belt tends to be the same at the lower crust depth. In particular, in terms of west of the Chang'an-Lintong fault, the gravity anomaly shows a wide range of low-value anomaly, which is consistent with the Weihe Basin's near NS trending extensional structural environment. The 5th order wavelet detail (as shown in Figure 4d) mainly reflects the density structure of the upper mantle. The density difference of the adjacent areas between the Ordos block and the Weihe Basin is obvious, and the position of the gradient zone corresponds to the block boundary. The gravity anomaly between the Weihe Basin and the Qinling orogenic belt is basically the same, indicating that the two areas belong to the same tectonic system in the deep crust. From north to south of the Qinling orogenic belt, the change of gravity anomaly shows a linear trend from negative to positive.

In recent years, relatively few studies have been conducted on the distribution of faults and structural zoning in the Weihe Basin based on gravity and magnetic data, and most of the studies have been based on geological and seismic methods. In this paper, based on the Bouguer gravity anomaly data, the research results obtained by the wavelet multi-scale analysis method are different from the previous research results. Such as the boundary of the structural zone deviates from the existing results, the spread position and cutting depth of the fault are different from the previous results. The reasons for this difference may be: the resolution and accuracy of the Bouguer gravity data is not enough high, and there are differences between geophysical methods and geological and seismic methods. In the future, we will use higher precision and resolution gravity anomaly data and advanced analysis methods to research the tectonic divisions and faults of Weihe Basin [10-13, 32-34].

4.3. Characteristics of the Moho surface depth
The Moho surface is the interface between the crust and the mantle. Based on the crustal thickness inverted by using the receiver function [35], and on the basis of subtracting the elevation data [36], the real Moho surface depth in the Weihe Basin is obtained (as shown in Figure 5). It can be seen from Figure 5 that the depth of the Moho surface in the study area is from 32 to 50 km, with large fluctuations in the lateral direction. Overall, it shows the characteristics of shallowness and deepness in the east and west of the study area. The Moho undulation and the Bouguer gravity anomaly (Figure 2b) show a "mirror" relationship obviously, which is in good agreement with the research results of Ren et al. [37]. The Liupanshan tectonic area and the Qinling orogenic belt have the deepest depth of the Moho, followed by the western Weihe Basin, and the southern edge of the Ordos block and the middle and eastern part of the Weihe Basin are the shallowest. According to the overall distribution characteristics of the Moho, the whole study area can be divided into four different regions based on the three Moho depth gradient zones, which are the Longxian-Taibai zone, the Tongchuan-Zhashui zone, the Pucheng-Shanyang zone, and the depth of Moho surface in each area presents different characteristics. The area to the west of Longxian-Taibai, which corresponds to the Liupanshan and West Qinling tectonic areas, the depth of Moho surface is from 44 to 50 km. The thickness of the crust gradually becomes thinner from west to east of the study area. The thinning of the thickness is mainly due to the upwelling of asthenosphere material, which causes the stable craton to undergo crustal fold deformation, thinning of the crust, frequent earthquakes, and active magmatic activity. In the middle part of the Weihe Basin and the Mid Qinling Tectonic Zone, the crustal thickness is gradually thinning, the Moho surface
is distributed in a long stripe shape, and the depth is from 36 to 44 km. It is the transition zone between the west and east of the Weihe Basin, and the Moho surface changes relatively smoothly. The depth of Moho surface between the eastern part of the Weihe Basin and the southern margin of Ordos are distributed in a "plow shape" along the EW direction. With Lintong-Weinan as the boundary, the Moho is elliptical, with the long axis in the EW direction and the depth is from 30 to 38 km. It is the place where the depth of the Moho is the shallowest in the entire study area, showing obvious local uplift characteristics [11, 32], which is related to the geological structure evolution process and thicker sedimentary layers in this area. In general, the deep crust structure profile of the study area is closely related to the overlying structure, and can clearly show the following characteristics: The undulation of the Moho surface in the study area reflects the thickening of the crustal thickness from east to west. The block features of deep structures reflected by the depth of Moho surface are clear. The long axis direction of the sag area is mainly NE and NW direction, and the long axis direction of the uplift area is mainly NE and NEE direction.

![Figure 5. Moho surface depth of Weihe Basin.](image)

5. Conclusions

Based on the data of EGM2008 and ETOPO1, we first calculate and obtain the data of free air gravity anomaly and Bouguer gravity anomaly in the Weihe Basin. On this basis, the wavelet multi-scale analysis method is used to decompose the Bouguer gravity anomaly data, and the 1st to 5th order wavelet detail and wavelet approximation data are obtained. At the same time, the logarithmic power spectrum analysis method is used to quantitatively calculate the average depth of the field source corresponding to the wavelet detail and wavelet approximation of 1st to 5th order. Finally, combined with the geological, seismic and other geophysical data of the Weihe Basin, the characteristics of gravity anomaly and crust structures are analyzed, and the following conclusions are obtained:

(1) The resolution and accuracy of the Bouguer gravity anomaly data obtained based on the EGM2008 and the ETOPO1 data are relatively high. Compared with other field source information separation methods, the wavelet multi-scale analysis method is a very effective technical method. According to the results of this paper, this method has obvious advantages for separating gravity anomalies caused by different depths and different scales of geological bodies.
(2) The free air gravity anomaly in the Weihe Basin has a strong correlation with topography, which can reflect obvious regional topographic features. The Bouguer gravity anomaly in the Weihe Basin has a relatively weak correlation with topography, but there is a mirror image relationship with the Moho depth in the area. And according to the characteristics of the Bouguer gravity anomaly, the main structural boundaries and fault distribution locations in the Weihe Basin can be identified.

(3) The wavelet approximation data of Bouguer gravity anomalies of order 1st to 5th in the Weihe Basin correspond to the average depth of the field source at 12 to 84 km, corresponding to the upper crust, lower crust and upper mantle respectively. The wavelet detail data of Bouguer gravity anomalies of order 1st to 5th in the Weihe Basin correspond to field source depths of 3 to 49 km, corresponding to sedimentary layers, upper crust, middle crust, and lower crust, respectively. The basic pattern of different tectonic units in the study area can be clearly seen from the wavelet detail and the approximation images. The boundary of the positive and negative variation of the Bouguer gravity anomaly often corresponds to a relatively large-scale fault. In addition, according to the distribution characteristics of gravity anomalies, major structural units such as the Baoji Uplift, the Xi'an Sag, the Lishan Uplift, and the Gushi Sag can also be identified. The gravity anomaly of the Qinling orogenic belt changes between positive and negative alternately, and the Basin-ridge structure features obvious.

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