POLISH MARITIME RESEARCH Special Issue 2015 S1 (86) 2015 Vol. 22; pp. 100-105
10.1515/pomr-2015-0040

STRUCTURAL INTERPRETATION OF THE QINGDONG AREA IN BOHAI BAY BASIN FROM SHIPBORNE GRAVITY DATA

Chunguan Zhang[a]
Jingguo Chen[b]
Mingyi Song[c]
Jinkuan Wang[b]
Bingqiang Yuan[a]
[a]School of Earth Science and Engineering, Xi'an Shiyou University, Xi'an 710065, Shaanxi, China
[b]Huabei Department, BGP Inc. of CNPC, Renqiu 062552, Hehei, China
[c]Geological Exploration Institute of Nonferrou Metal Geological Exploration Bureau of Guangdong Province, Guangzhou 510080, Guangdong, China
School of Earth Science and Engineering, Xi'an Shiyou(Petroleum) University, No. 18 East Section, Xi'an Dianzi 2 Road, Xi'an, China

ABSTRACT

The Qingdong area, located in Bohai bay basin, was suspected good exploration prospects. In order to study tectonic features and find out favourable petroleum prospects in the area, the gravity data at a scale of 1:50,000 were interpreted. This paper, through data processing and synthetic interpretation of the high-precision gravity data in the area, discusses characteristics of the gravity field and their geological implications, determines the fault system, analyses features of the main strata, divides structure units and predicts favourable petroleum zones. The results showed that the faults controlled the development of the Mesozoic and Cenozoic strata and the distribution of local structures in this area. The study revealed that the Qingtuozi uplift and the Kendong uplift in the north were formed in Mesozoic, and the Qingdong depression in the middle was the rift basin in Mesozoic and Cenozoic. Thicker strata in Mesozoic and Cenozoic developed in the Dongying depression and the Qingdong depression, so there is abundant hydrocarbon in these two depressions, and then the Guangligang rise-in-sag and the Qingdong rise-in-sag developed in the center in these two depressions are also favorable places for prospecting

Keywords: gravity anomaly, seismic profile, rise-in-sag, structure Unit, the Qingdong depression

INTRODUCTION

In recent years, small and medium basins in the eastern China have been paid more attention for hydrocarbon exploration by geologists. Several pools in the Changling rift of Songliao basin and the Nanpu depression and the Bozhong depression of Bohai bay basin have been explored with potential exploration prospects. Since 1990th, a lot of works have been done in the Qingdong depression by Shengli Oilfield, SinoPec, especially focused on Cenozoic evolution [4,13,15], reservoir conditions and potentiality of hydrocarbon resources [3,12], and then good exploration prospects was suspected in the Qingdong depression. However, affected by Tancheng-Lujiang fault [2,6], the structures are complicated in this area, and the depression is located in a shallow sea and other factors, more work in details need to be done for properties of basement, structures and sedimentary evolution in the Qingdong depression.

The authors studied the features of gravity anomaly in Qingdong area, quantitatively fitted and comprehensively interpreted two gravitational profiles, discussed the characteristics of basement and sedimentary rules of the Mesozoic and Cenozoic strata. The structural framework was determined, tectonic units were divided and the favorable places for prospecting were discussed in this paper.

GEOLOGICAL BACKGROUND

The Qingdong area is situated in Bohai bay basin. Like a square in its shape, the study area has a 39 km long southern boundary and a 60 km long eastern boundary. The total area in survey is about 2,430km^2 (Fig. 1). The study area is located in Laizhou bay with sea area in the east and larger slope for the sea floor. There is smaller area in which water depth is less than 2 m and most area ranges in 4-8 m. Within the east edge of this area and the Yellow River estuary, the water depth is more than 10m. Near the Yellow River estuary, there is a unique transition zone characterized with shallow water and thick mud.

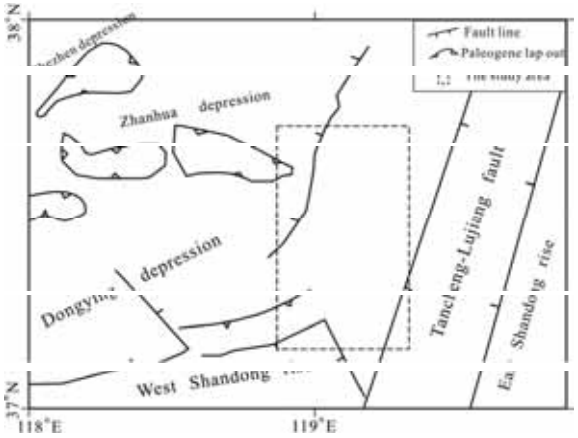

Fig. 1. The regional location of the study area (modified after Li et al. (2008))

Based on well data from Well Qing 1, Well Lai 101, Well Yanggu 1, Well Kendong 3, Well Qingdong 2 and Well Qingdong 4, the stratigraphic pattern includes Taishan group, Cambrian, Ordovician and Carboniferous - Permian, Jurassic - Cretaceous, Paleogene (Kongdian group, Shahejie group and Dongying group), Neogene (Guantao group and Minghuazhen group) and Quaternary (Plain group).

This study area is located in the connection zone of the Jiyang sag and Tancheng-Lujiang fault [2]. It is complex for the distribution of basement and seals that are Taishan group or Cambrian without Paleogene and in which Neogene layers overlain the basement of Mesozoic - Neopaleozoic. The thicker Shanhejie – Kongdian groups develop in the Qingdong depression while Dongying groups and Shahejie groups are in the Zhanhua depression.

The Qingdong depression was deposited fast and stable in Paleogene [2,6]. Shahejie group was found when Well Qingdong 4 was drilled 828m, in which Member 3 and 4 of Shahejie group are the dominant source rocks. Well Qingdong 5 has 3 oil formations in Member 3 of Shahejie group and 4.37t oil could output per day.

DATA PROCESSING METHOD AND TECHNIQUE

Three methods of sliding trend analysis, regularized filtering and extraction of vertical second derivative were applied to separate the gravitational anomalies. Through strict comparison for the results obtained from the above methods, those results better fitting the regional geology (especially the sedimentary cover) and seismic data were selected to be the reliable reference maps. The normal methods for detecting boundary of potential field source mainly are directional derivative, vertical derivatives, extreme points or null points of horizontal gradient [8,11]. In this study, for extracting the information of fault structure, the horizontal total gradient of gravitational anomaly has been used in computation. In addition, we applied 2.5-D interactive forward fitting software in processing gravitational data. The software is to simulate the deep geological structure using 2.5-D model and through comparison between the theoretic gravity anomalies generated by the model and the measured anomalies. To modify the geology-mathematics model step by step to fit the actual anomaly for inversing the geometry shape and define the physical properties of geologic bodies at depth.

Densities were measured from the rock samples, and they identically reflect that a sufficient density difference exist between the Pre-Mesozoic basement and the overlying strata. Moreover, the densities show that obvious density difference is still present in between the Tertiary and Mesozoic layers, which means that certain density interfaces exist in the several main sequences overlying the Pre-Mesozoic basement. Thus, there is the geophysical basis for calculating the interface depths using the gravity data.

For the consideration of the regional geology and stratigraphic formations in this area, the arithmetic mean values of the densities from the sample measurement were used in the quantitative fitting calculation of gravity. And the density mean values for different strata are: the Quaternary-Tertiary strata, 2.19×10^3 kg/m^3; the Mesozoic strata, 2.50×10^3 kg/m^3; the Pre-Mesozoic strata, 2.70×10^3 kg/m^3.

FEATURES OF GRAVITY ANOMALIES AND STRUCTURAL INTERPRETATION

FEATURES AND GEOLOGIC IMPLICATION OF GRAVITY ANOMALIES

The map of Bouguer gravity anomaly of the Qingdong area, with the scale of 1:50,000, shows that the dominant trend of gravity anomaly is NNE trending which shows the main structural direction is NNE trending, and the gravitational field is characterized with clear zoning (Fig. 2). From northwest to southeast, the Bouguer gravity anomaly indicates double "highs" and "lows" (low–high–low–high) in this work area, the gravity low of Yellow River Farm in northwest corner, the gravity high of Qingtuo-Well Qingdongxie 6 in northwest, the gravity low of Guangli–Well Qingdong 2–Well KL20-1-2 in the middle and the gravity high of Yangjiaogou–Well KL20-3-1 Southeast in south. These gravity highs indicate the basement uplift in northwest corner and the center, while these gravity lows indicate the basement sag in northwest and south in this work area.

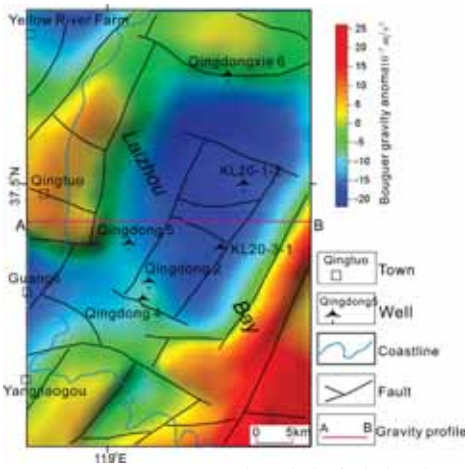

Fig. 2. Bouguer gravity anomaly with the fault distribution

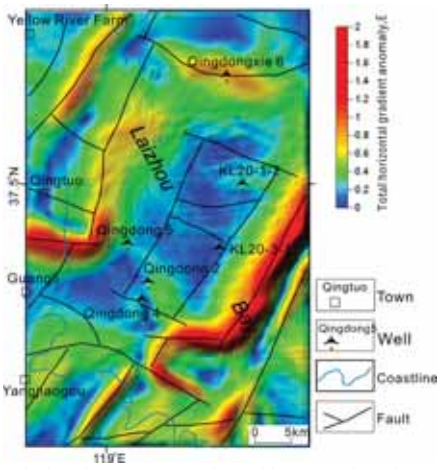

Fig. 4. Fault distribution map with total horizontal gradient anomaly

The gravity low of Well Qingdong 2–KL20-1-2 with NNE trending is the Qingdong depression which has the complete form of Bouguer gravity anomaly. The gradient changes gradually in the middle and largely in the edge. Many gradient zones of gravity anomaly developed in this area, which indicates the complex structure. There are a lot of faults in Qingdong area, and these uplifts contact these depressions by faults.

The regularized filter is applied for calculating the local gravity anomaly, where the wavelength of filter is 15km. The map of local gravity anomaly of the Qingdong area shows that the dominant trend of local gravity anomalies is also NNE trending which is consistent with the trending of Bouguer gravity anomaly that indicates the distribution of local structures is NNE trending in Qingdong area (Fig. 3). There are some gravity highs with different magnitude and ranges in the local gravity anomaly map shows the features of local rise in the middle of these depressions, while these areas show gravity lows in the Bouguer gravity anomaly map, such as the gravity low of Yellow River Farm, Guangli – Well Qingdong 2 and Well Qingdong 2 – KL20-1-2. On the contrary, there are some gravity lows with different magnitude and ranges in the local gravity anomaly map shows the features of local low in these uplifts, while these areas show gravity highs in the Bouguer gravity anomaly map, such as the gravity high of Qingtuo – Well Qingdongxie 6 and Yangjiaogou –Well KL20-3-1 Southeast.

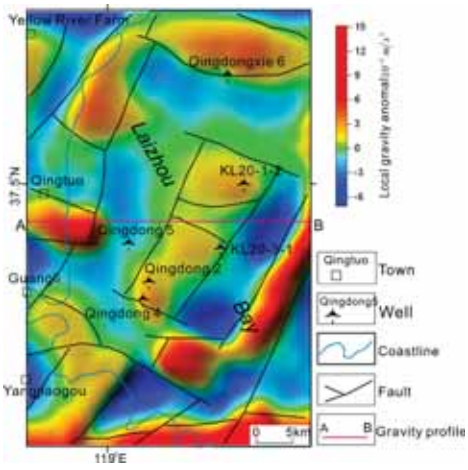

Fig. 3. Local gravity anomaly with the fault distribution

FAULT STRUCTURE SYSTEM

To determine the fault structure system, we first identified and marked the different linear structure from the maps including the Bouguer gravity anomaly map, the local gravity anomaly, and the horizontal total gradient map (Fig. 4), and then compared them with structures from the regional geology and the inferred faults from certain seismic profiles. On the basis of the above work, the fault structure system in this area has been established.

From Fig. 1 to Fig. 4, it can be seen that the faults are well developed and the structures are complicated in this area. The faults can be divided into NE (NNE)-trending and NWW-trending groups and the former group is dominant and has a strike consistent with the regional fault structure.

As the basement faults control the boundaries of the structure units in the study area, most NE (NNE)-trending faults on a large-scale stretch a long distance and have a large fault throw and deep cut, while the NWW-trending faults, developed in the sedimentary cover, are on a small-scale and cross cut the NE (NNE)-trending faults in most cases. Due to the faulting, the fault blocks are well developed. In general, the framework of the study area is characterized with East-West zoning and South-North blocking. The NE-trending depressions and uplifts were alternatively distributed. This pattern may have been the strike slip motion of the Tancheng-Lujiang Fault. On the one hand, thus, the strike slip motion could have produced the NE (NNE)-trending faults. On the other hand, it probably caused the development of the NWW-trending faults along the weak structure bands. The NE- and NWW-trend faulting acted together and forged the structure framework of East-West zoning and South-North blocking.

INTERPRETATION OF GRAVITATIONAL PROFILE

In order to study the structural characteristics and determine the distribution of main sedimentary stratum and the contact between tectonic units in Qingdong area, gravity anomaly profiles were used for quantitative interpretation combined

with seismic data and well data. These chosen profiles should perpendicular to the main tectonics of this work area [1,14]. In this paper, A-B profile were chosen to carry out quantitative interpretation.

The A-B profile passes through the middle of the study area with an EW trending. From west to east, this profile starts at the Qingtuozi uplift, and the western part of the A-B profile coincides with the 1094 offset seismic profile. Across the middle of the Qingdong depression, this profile arrives at the Weibei uplift. The 1094 profile shows that the quality of the seismic data is poor in the deep and better in the superficial part, which indicates obvious fluctuation in the Cenozoic. From west to east, the Bouguer gravity anomaly displays high-low-high features (Fig. 5). In the western part of the A-B profile, the Qingtuozi uplift, the maximum value of Bouguer gravity anomaly displays 8×10^{-5} m/s^2. In the middle of the Qingdong depression, the value of Bouguer gravity anomaly decreases to -18×10^{-5} m/s^2, with a decrease of 26×10^{-5} m/s^2. In the eastern part of this profile, the Weibei uplift, the value of Bouguer gravity anomaly increases to 9×10^{-5} m/s^2. The east-west changes of Bouguer gravity anomaly indicate the features of basement relief in this area.

Combined with seismic data and well data, the A-B profile was quantitatively fitted and comprehensively interpreted, and the results are shown in Fig. 5. The results of quantitative interpretation show that the basement rises up in the western part of the A-B profile, and the basement depth is more than 1,400m in the Qingtuozi uplift while less than 5,500 m in the Qingdong depression. In the Weibei uplift, the basement depth rises rapidly to less than 500 m, with the lifting amplitude of 4,500 m. In the middle of the Qingdong depression, the lifted block developed in Mesozoic.

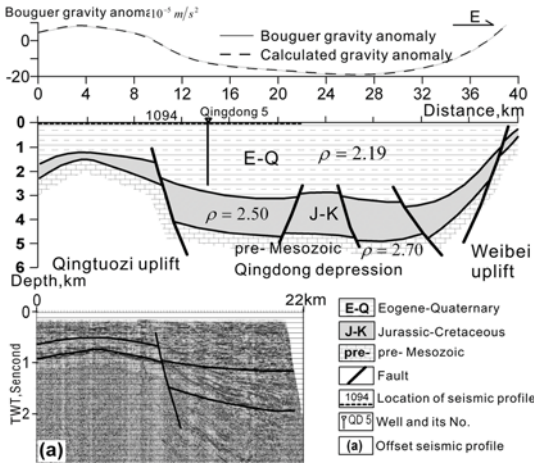

Fig. 5. Map of integrated interpretation on the A-B profile

TECTONIC FEATURES

Coupling the gravity-seismic-well integrated interpretation and the previous study of regional structural background [5,7,10] with the above study of the gravitational field and the fault system, the Qingdong area can be divided into the following eight tectonic units (Fig. 6): the Zhanhua depression, the Kendong uplift, the Qingtuozi uplift, the Qingdong depression, the Dongying depression, the Guangrao uplift, the Weibei uplift, and the Laohe depression.

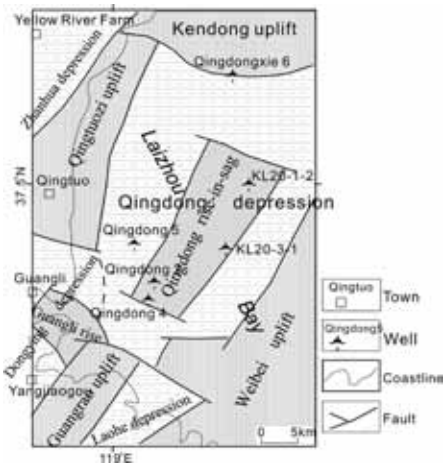

Fig. 6. Map of tectonic units

The Qingdong depression is the main body of the study area and a Mesozoic-Cenozoic depression. Its north, west, southwest and southeast portions contact the Kendong uplift, the Qingtuozi uplift, the Guangrao uplift and the Weibei uplift by faults, respectively. In the Qingdong depression, the Bouguer gravity anomaly displays a NNE trending gravity low with a large area. The gravitational value changes gradually in the middle of the gravity low and gravity gradient zones change largely in its southeast, west and north. These features of the gravitational field indicate that the Qingdong depression is controlled by faults in its southeast edge, west edge and north edge, and a large difference of basement depth between the Qingdong depression and its surrounding uplifts. The depression is basically a Mesozoic and Cenozoic basin with thick Mesozoic and Cenozoic deposit. Because of faulting, the depression can be further divided into some sub-depressions and the Qingdong rise-in-sag. The Qingdong rise-in-sag is located in Well Qingdong 2 – KL20-1-2 area, with a NE trending. Obviously, the Qingdong rise-in-sag is a lifted block, and the conditions of migration and accumulation are better.

The study area relates only to a part of the Fulin sub-depression, which is a negative tectonic unit in the southeast of the Zhanhua depression. The Bouguer gravity anomaly displays an open-to-north gravity low, and there is a gravity gradient zone between the Zhanhua depression and the Qingtuozi uplift and the Kendong uplift, which indicates that the Zhanhua depression contacts these two uplifts by faults in its southeast. The Dongying depression is located in the southwest corner of the Qingdong area and a Mesozoic-Cenozoic rifted basin. The study area relates only to a part of the Qingnan sub-depression and the Guangli rise-in-sag, which are subset tectonic units in the east of the Dongying depression. In the Dongying depression, the Bouguer gravity anomaly displays an open-to-west gravity low. The gravitational value changes largely in the north edge and gradually in the south, indicating that the Dongying depression is faulting in the north and overlapping in the south. The Laohe depression is located in the southwest corner of the study area, retained by the Guangrao uplift and the Weibei uplift. In the Laohe depression, the Bouguer gravity

anomaly displays a complete gravity low and the gravitational value changes largely in the northwest and northeast edge and gradually in the southeast, indicating that the Laohe depression is faulting in the north and overlapping in the south and the basement rises gradually from north to south.

The Kendong uplift is a Mesozoic uplift, located in the northeast of the study area. In the Kendong uplift, the Bouguer gravity anomaly displays an open-to-north gravity high, and gravity gradient zones change largely in its south and west, indicating a large difference of basement depth between the Kendong uplift and these two depressions. Obviously, the Kendong uplift is a lifted block. The Qingtuozi uplift is also a Mesozoic uplift, located in the northwest of the study area. In the Qingtuozi uplift, the Bouguer gravity anomaly displays an open-to-southwest gravity high, and gravity gradient zones change largely in its south, east and northwest, indicating that the Qingtuozi uplift contacts the surrounding units by faults. The Guangrao uplift is located in the southwest corner of the study area and the Bouguer gravity anomaly displays an open-to-southwest gravity high. The gravitational value changes largely in the southeast edge and gradually in the north and northwest, indicating that the Guangrao uplift contacts the surrounding units by faults. The Weibei uplift is located in the southeast of the study area and the Bouguer gravity anomaly displays an open-to-east and open-to-south gravity high with a large area and a NNE trending. The gravitational value changes largely in the northwest edge, indicating that the Weibei uplift contacts the Qingdong depression and the Laohe depression by faults and these faults is the west branch of the Tancheng-Lujiang fault. Because of faulting, the Weibei uplift is also a lifted block.

CONCLUSIONS

1. The macro-distribution of the faults in Qingdong area is consistent with the areal structure of the study area. These faults constitute the boundaries of these tectonic units and control the development of Mesozoic and Cenozoic stratum, the formation of the lifted blocks and graben blocks and the distribution of local structures.
2. The Qingdong area can be divided into the following eight tectonic units: the Zhanhua depression, the Kendong uplift, the Qingtuozi uplift, the Qingdong depression, the Dongying depression, the Guangrao uplift, the Weibei uplift and the Laohe depression. The Qingtuozi uplift were formed Mesozoic, and the thickness of the Mesozoic and Cenozoic strata is less than 2,000m. The basement depth of the Weibei uplift is less than 1,000m. The Qingdong depression is a Mesozoic and Cenozoic rift and develops thicker Mesozoic and Cenozoic strata and its thickness more than 5,000m.
3. The Guangli rise-in-sag and the Qingdong rise-in-sag are the favorable places for prospecting. Development of thicker Mesozoic and Cenozoic strata, abundant hydrocarbon and rise-in-sags in the Dongying depression and the Qingdong depression, the Guangligang rise-in-sag and the Qingdong rise-in-sag are also the favorable places for prospecting.

ACKNOWLEDGEMENTS

This work is supported by the Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No. 14JK1579), China. Thanks should be given to Professor Li Jiuliang for instructions in the study, especially discussions on geological interpretation.

REFERENCES

4. Bauer C., and Fichler C., *Quaternary lithology and shallow gas from high resolution gravity and seismic data in the central North sea*, Petroleum Geoscience, Vol. 8, pp. 229-236, 2002.
5. Cao Z., *Calculation of extension and subsidence of the Cenozoic pull–apart and rift basins along the Yingkou-Weifang fault zone*, Chinese Journal of Geology, Vol. 43, pp. 65-81, 2008.
6. Carolyn Lampe, Guoqi Song, Liangzi Cong, and Xing Mu, *Fault control on hydrocarbon migration and accumulation in the Tertiary Dongying depression, Bohai Basin, China*, AAPG Bulletin, Vol. 96, pp. 983-1000, 2012.
7. Guo X., He S., Liu K., Song G., Wang X., and Shi Z., *Oil generation as the dominant overpressure mechanism in the Cenozoic Dongying depression, Bohai Bay Basin, China*, AAPG Bulletin, Vol. 94, pp. 1859-1881, 2010.
8. Hao F., Zhou X., Zhu Y., Bao X., and Yang Y., *Charging of the Neogene Penglai 19–3 field*, American Association of Petroleum Geologists, Vol. 93, pp. 155-179, 2009.
9. Li C., Xin R., and Li J., *Controls of Tancheng-Lujiang fault on Paleogene depositional system in Qingdong sag*, Xinjiang Petroleum Geology, Vol. 29, pp. 209-213, 2008.
10. Li J., Tian B., Wang W., Zhao L., and Yao Z., *Lateral variation in the sedimentary structure of west Bohai bay basin inferred from P–Multiple receiver functions*, Seismological Society of America, Vol. 97, pp. 1355-1363, 2007.
11. Li L., *Improved edge detection tools in the interpretation of potential field data*, Exploration Geophysics, Vol. 44, pp. 128-132, 2013.
12. Li L., Zhong D., Yang C., Shi X., and Gong H., *The decollement structures in Jiyang depression, Bohai bay basin, China*, Chinese Journal of Geophysics, Vol. 51, pp. 521-530, 2008.
13. Li X., Liu B., Zhao Y., Liu C., and Wu J., *Late Pleistocene–Holocene submarine active structures in the Bohai Sea*, Acta Oceanologica Sinica, Vol. 32, pp. 52-59, 2010.

14. Ma G., *Edge detection of potential field data using improved local phase filter*, Exploration Geophysics, Vol. 44, pp. 36-41, 2013.

15. Shi P., Fang X., Chen T., Fu Z., and Zhang Z., *Petroleum geologic characteristic and prospecting target in Qingdong sag*, Journal of Southwest Petroleum University (Science & Technology Edition), Vol. 31, pp. 43-48, 2009.

16. Wang S., Zhang X., Fang S., Zhang C., Wang F., Zhao J., Zhang J., Liu B., Pan S., and Huang C., *Crustal structure and its features in the northwest margin of Bohai bay and adjacent areas*, Chinese Journal of Geophysics, Vol. 51, pp. 1451-1458, 2008.

17. Wei Y., and Yang Z.J., *The application of combined gravity and seismic data formation separation for revealing deep structure*, Applied Geophysics, Vol. 3, pp. 255-259, 2006.

18. Yang G., *Structural framework and evolution of Qingdong sag, Bohai bay basin*, Petroleum Geology and Recovery Efficiency, Vol. 18, pp. 7-10, 2011.

CONTACT WITH THE AUTHORS

Chunguan Zhang[a]
Jingguo Chen[b]
Mingyi Song[c]
Jinkuan Wang[b]
Bingqiang Yuan[a]

[a]School of Earth Science and Engineering, Xi'an Shiyou University, Xi'an 710065, Shaanxi
China
[b]Huabei Department, BGP Inc. of CNPC, Renqiu 062552, Hehei
China
[c]Geological Exploration Institute of Nonferrou Metal Geological Exploration Bureau of Guangdong Province, Guangzhou 510080, Guangdong
China
School of Earth Science and Engineering, Xi'an Shiyou(Petroleum) University, No. 18 East Section, Xi'an Dianzi 2 Road, Xi'an
China
Postcode: 710065
tel: +86 158 0925 2583, fax: +86 29 8823 4429
e-mail: chunguan-zhang@163.com