PS Application and Extension of Fine Fault Recognition Technology in Surrounding Area of Penglai 19-3 Oilfield, Bohai Bay Basin, Eastern China*

Xugang Ma[1], Donghong Zhou[1], Dingyou Lv[1], Dayong Guan[1], and Hongguo Zhang[1]

Search and Discovery Article #20436 (2018)**
Posted July 16, 2018

*Adapted from poster presentation given at 2018 AAPG Annual Convention & Exhibition, Salt Lake City, Utah, May 20-23, 2018

[1]China National Offshore Oil Corporation (CNOOC) Limited, Tianjin, China (maxg@cnooc.com.cn)

Abstract

At present, the main exploration target in Bohai Oilfield is still structural traps, but with the increase of exploration degree, large-scale traps have become less and less, so the fine fault interpretation is important in searching for new structural traps and improving the success rate. Penglai A structure is located in the east of Penglai 19-3 Oilfield, which is a complicated fault block trap formed by controlling large boundary faults and strike-slip faults. The position of the structural area is at the confluence of the Tancheng-Lujiang Fault and Zhangjiakou-Penglai Fault, where faults are very developed with varied lateral trends, stress properties and structural orders. We could not deploy appraisal wells in the lower parts of the trap as most of the trap area was invalid.

In view of this problem, a comparative analysis was carried out based on the conventional methods of faults identification, and finally, a high-precision coherency cube and fault likelihood attribute technique based on construction-oriented filtering technique were used to identify fine faults. The strike-slip faults in the lower part of Penglai A-3 structure are recognized by using high precision coherence cube, and then found and implemented on Penglai A-2 structure was a new subtle strike-slip fault located on the west side of PLA-2-2 well, discovered based on the fault likelihood attribute technique. The successful drilling of PLA-2-6 well deploying at its lower levels upgraded 6.48 million tons of proven oil reserves.

Furthermore, the Penglai A-4 structure was discovered in the western lower part of Penglai A-2 structure by this method, and the trap area was increased by 9 km^2, which laid out a good foundation for the further exploration. The combination of high precision coherence cube with fault likelihood technique can identify faults at different scales, which is the key to fine fault interpretation. With the development of fine fault recognition technique, a number of new structural traps will be discovered in Bohai Oilfield.

Application and Extension of Fine Fault Recognition Technology in Surrounding area of Penglai 19-3 Oilfield , Bohai Bay Basin, Eastern China

Xugang Ma, Donghong Zhou, Dingyou Lv,Dayong Guan,Hongguo Zhang

(Bohai Oilfield Research Institute, CNOOC Ltd. _Tianjin, China)

Abstract: At present, the main exploration target in Bohai Oilfield is still structural traps, with the increase of exploration degree, large-scale traps have become less and less, so the fine fault interpretation is an important guarantee for searching new structural traps, and improving the success rate of exploration. Penglai A structure located in the east of Penglai 19-3 Oilfield, Which was a complicated fault block trap formed by controlling large boundary faults and strike-slip faults. The position of structural area is at the confluence of the Tancheng-Lujiang fault and Zhangjiakou-Penglai fault, where faults are very developed with varied lateral trends, stress properties and structural orders.We couldn't deploy appraisal wells in the too lower part of the trap, most of the trap area was invalid. In view of this problem, a comparative analysis was carried out based on the conventional methods of faults identification, and finally, a high-precision coherence cube and fault likelihood attribute technique based on construction oriented filtering technique were used to fine identification faults. The strike-slip faults in the lower part of Penglai A-3 structure are recognized by using high precision coherence cube, and then found and implement Penglai A-2 structure ; a new subtle strike-slip fault located on the west side of PLA-2-2 well is discovered based on the fault likelihood attribute technique , the successful drilling of PLA-2-6 well deploying at its lower levels upgraded 6.48 million tons of proven oil reserves.Furthermore, Penglai A-4 structure was discovered in the western lower part of Penglai A-2 structure by this method, and the trap area was increased by 9km^2, which laid out a good foundation for the further exploration. The combination of high precision coherence cube with fault likelihood technique can identify faults at different scales, which is the key to fine interpretation. With the development of fine fault recognition technique, a number of new structural traps will be discovered in Bohai Oilfield.

1. Geological Setting

- The Tanlu fault zone runs through the Bohai Bay basin, and the multi-stage tectonic movement makes the structure of Bohai Oilfield very crushed.In the other hand, the north west trending Zhangjiakou-penglai fault makes the eastern structure more fragmented.The imaging quality of seismic data in fault zone is poor, and it is difficult to interpret faults (Figure 1).
- Even though, we have found many oilfields(Figure 2), with exploration becomes more difficult, Fairways, fisheries, military exercises are all in the sea.How to find large-scale oil and gas reservoirs is a huge challenge.
- The Penglai 19-3 Oilfield is the world famous oilfield, but its surrounding structures are complex, the fault is developed and the exploration degree is low, so we carried out the research on the Penglai A structure in the east (Figure 3).
- It can be seen from the coherent slice (Figure 4) that in the shallow stratum,different fault systems are very developed. Related structural studies are very difficult.

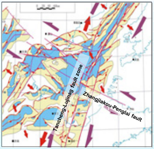


Figure 1. Bohai sea and surrounding area Paleogene tectonic dynamic pattern

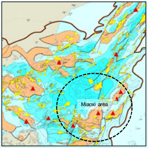


Figure 2. Bohai Sea exploration situation map

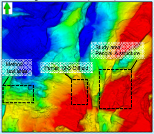


Figure 3. Location of study area

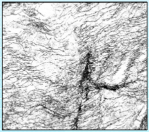


Figure 4.Penglai 19-3 Oilfield and surrounding area coherent slice(1000ms)

20-23 May 2018 • Salt Lake City, Utah
AAPG ACE 2018 ANNUAL CONVENTION & EXHIBITION

Application and Extension of Fine Fault Recognition Technology in Surrounding area of Penglai 19-3 Oilfield , Bohai Bay Basin, Eastern China

Xugang Ma, Donghong Zhou, Dingyou Lv,Dayong Guan,Hongguo Zhang
(Bohai Oilfield Research Institute, CNOOC Ltd. _Tianjin, China)

2. Key Technologies

2.1 Structure oriented filtering

Usually the filtering is used to improve the SNR of seismic data, structure oriented filtering without destroying the fault section, remove the interference noise in seismic section, so that the fault profile for easy identification.After the structure oriented filtering treatment, the SNR of seismic section is improved obviously, and the fault feature is more obvious (Figure 5).After the structural oriented filtering, the seismic coherence profile (Figure 6b) shows the fault are more clear and accurate, and the SNR is relatively high.

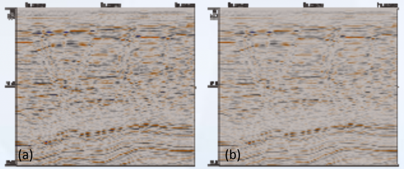


Figure 5. Seismic sections before （a） and after （b） processed with structure-oriented filter

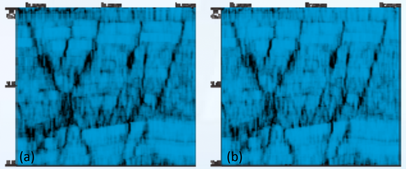


Figure 6. Coherence seismic sections before （a） and after （b） processed with structure-oriented filter

2.2 Forward modelinging analysis

Assuming geological conditions are ideal, forward modelinging analysis can theoretically guide structural interpretation.The object of this analysis for the micro faults, due to the limited resolution of seismic data, micro faults are difficult to be identified clearly, combined the guidance of the theoretical model with a variety of seismic attributes to explain the micro faults.When the wave frequency is constant, fault distance is larger, more easy to identify; from the distance of different faults in the forward modeling of different frequency fields (Figure 7), it can be seen that when the fault distance is constant, the greater the wavelet frequency, the higher the resolution of the fault.

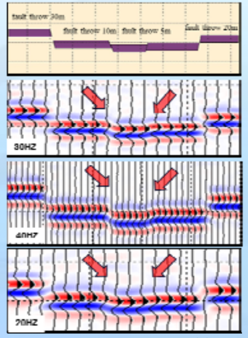
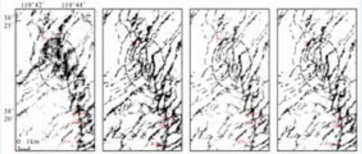


Figure 7. Characteristics of fault displacement in different frequency

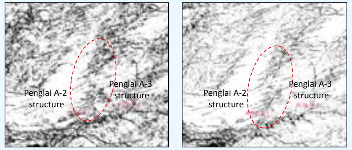
2.3 High-precision coherence cube

We select the same complex structural region in the west of Penglai 19-3 Oilfield (Figure 3), compared and analysed the conventional coherent methods, good fault recognition result can be obtained by the StructureCube module. This module was studied deeply, and the process of high-precision coherence cube summarized with good result (Figure 8). The strike-slip faults in the lower part of Penglai A-3 structure are recognized by using this method, and then found and implement Penglai A-2 structure (Figure 9).



a.PF b.Dip c.PF-Dip d.10-30Hz PF-Dip

Figure 8. Comparison of different application effects based on the StructureCube(1000ms)



a.Conventional coherence b. high precision coherence

Figure 9. Comparison of different methods in Penglai A area(1000ms)

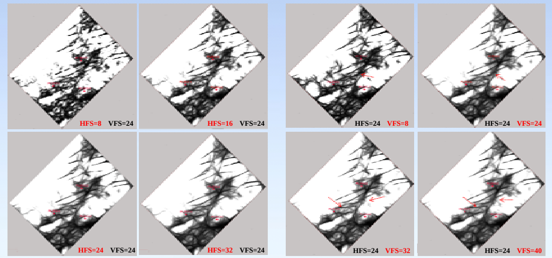
2.4 Fault likelihood attribute

Although the method of high precision fault identification has obviously improved the speed and effect of identifying conventional fault. However, the fault recognition is not good for the fault with small fault displacement. Through literature research investigation,the fault likelihood attribute identify fault with better results.That alignment requires prior estimates of reflection slopes, given estimates of reflection slopes, we might define structure oriented semblance as(1)

$$\text{semblance}=\frac{\langle \text{image} \rangle_s^2}{\langle \text{image}^2 \rangle_s} \quad (1)$$

$$F=1-\text{Semblance}^n \quad (2)$$

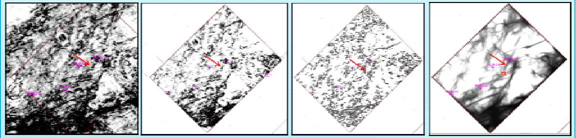
where, for each semblance value, $\langle \cdot \rangle s$ denotes a structure oriented averaging of whatever is inside the brackets. To highlight these features, Hale (2013) define an attribute fault likelihood F by(2). The choice of power n is somewhat arbitrary; it increases the contrast between samples with low and high fault likelihoods, enhance visibility of unfaulted seismic reflectors.



a. HFS b. VFS

Figure 10. Parameters test of HFS and VFS(1000ms)

We select the complex structure of Penglai A area to conduct parameters test.First, set the VFS samples to 24, and HFS for different samples,It is found that, with the increase of the number of samples, the noise interference decreases, and the recognition effect improves gradually, and the effect of 24 and 32 is not very different. Therefore, it is considered that the HFS samples are 24 can get good results.The main frequency of the target layer is about 30hz, the apparent cycle is about 33ms, and HFS is better when it is 1.5 times apparent cycle. Then, it is considered that the VFS samples are 32 can get good results,about 2 times apparent cycle (Figure 10).



a.Conventional coherent b. high precision coherence c.Curvature attribute d.Likelihood attribute

Figure 11. Comparison of multiple fault identification attributes(1200ms)

Through the comparison of multiple fault identification attributes including: coherence、high precision coherence、curvature , the fault is clear and continuous with fault likelihood identification. In particular,the newly subtle strike-slip fault F1 discovered in Penlai A Oilfiled (Figure 11).

Application and Extension of Fine Fault Recognition Technology in Surrounding area of Penglai 19-3 Oilfield , Bohai Bay Basin, Eastern China

20-23 May 2018 • Salt Lake City, Utah
AAPG ACE 2018 ANNUAL CONVENTION & EXHIBITION

Xugang Ma, Donghong Zhou, Dingyou Lv,Dayong Guan,Hongguo Zhang
(Bohai Oilfield Research Institute, CNOOC Ltd. _Tianjin, China)

2. Key Technologies

2.1 Structure oriented filtering

Usually the filtering is used to improve the SNR of seismic data, structure oriented filtering without destroying the fault section, remove the interference noise in seismic section, so that the fault profile for easy identification.After the structure oriented filtering treatment, the SNR of seismic section is improved obviously, and the fault feature is more obvious (Figure 5).After the structural oriented filtering, the seismic coherence profile (Figure 6b) shows the fault are more clear and accurate, and the SNR is relatively high.

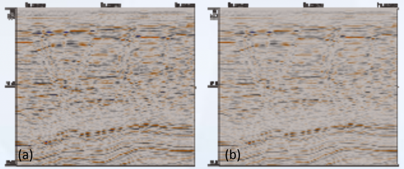


Figure 5. Seismic sections before （a） and after （b） processed with structure-oriented filter

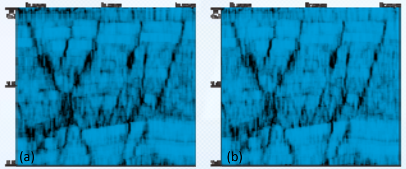


Figure 6. Coherence seismic sections before （a） and after （b） processed with structure-oriented filter

2.2 Forward modelinging analysis

Assuming geological conditions are ideal, forward modelinging analysis can theoretically guide structural interpretation.The object of this analysis for the micro faults, due to the limited resolution of seismic data, micro faults are difficult to be identified clearly, combined the guidance of the theoretical model with a variety of seismic attributes to explain the micro faults.When the wave frequency is constant, fault distance is larger, more easy to identify; from the distance of different faults in the forward modeling of different frequency fields (Figure 7), it can be seen that when the fault distance is constant, the greater the wavelet frequency, the higher the resolution of the fault.

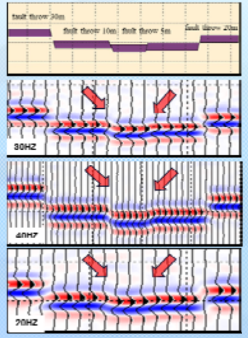


Figure 7. Characteristics of fault displacement in different frequency

2.3 High-precision coherence cube

We select the same complex structural region in the west of Penglai 19-3 Oilfield (Figure 3), compared and analysed the conventional coherent methods, good fault recognition result can be obtained by the StructureCube module. This module was studied deeply, and the process of high-precision coherence cube summarized with good result (Figure 8). The strike-slip faults in the lower part of Penglai A-3 structure are recognized by using this method, and then found and implement Penglai A-2 structure (Figure 9).

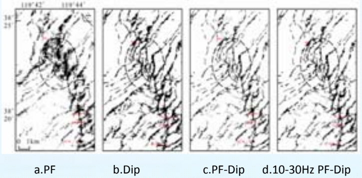


Figure 8. Comparison of different application effects based on the StructureCube(1000ms)

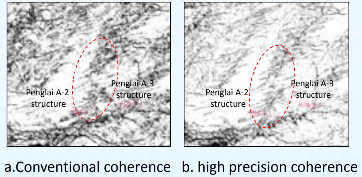


Figure 9. Comparison of different methods in Penglai A area(1000ms)

2.4 Fault likelihood attribute

Although the method of high precision fault identification has obviously improved the speed and effect of identifying conventional fault. However, the fault recognition is not good for the fault with small fault displacement. Through literature research investigation,the fault likelihood attribute identify fault with better results.That alignment requires prior estimates of reflection slopes, given estimates of reflection slopes, we might define structure oriented semblance as(1)

$$\text{semblance}=\frac{\langle \text{image} \rangle_s^2}{\langle \text{image}^2 \rangle_s} \quad (1) \qquad F=1-\text{Semblance}^n \quad (2)$$

where, for each semblance value, < · > s denotes a structure oriented averaging of whatever is inside the brackets. To highlight these features, Hale (2013) define an attribute fault likelihood F by(2). The choice of power n is somewhat arbitrary; it increases the contrast between samples with low and high fault likelihoods, enhance visibility of unfaulted seismic reflectors.

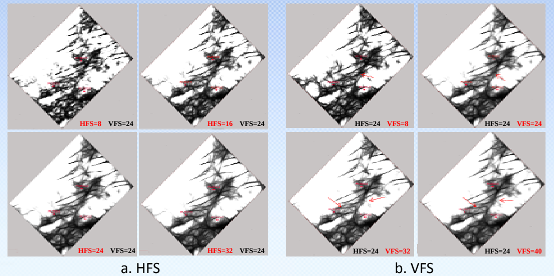


Figure 10. Parameters test of HFS and VFS(1000ms)

We select the complex structure of Penglai A area to conduct parameters test.First, set the VFS samples to 24, and HFS for different samples,It is found that, with the increase of the number of samples, the noise interference decreases, and the recognition effect improves gradually, and the effect of 24 and 32 is not very different. Therefore, it is considered that the HFS samples are 24 can get good results.The main frequency of the target layer is about 30hz, the apparent cycle is about 33ms, and HFS is better when it is 1.5 times apparent cycle. Then, it is considered that the VFS samples are 32 can get good results,about 2 times apparent cycle (Figure 10).

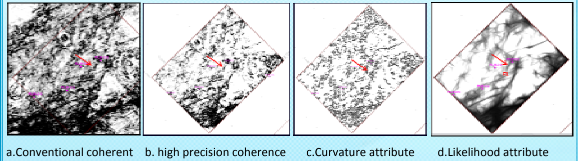


Figure 11. Comparison of multiple fault identification attributes(1200ms)

Through the comparison of multiple fault identification attributes including: coherence、high precision coherence、curvature , the fault is clear and continuous with fault likelihood identification. In particular,the newly subtle strike-slip fault F1 discovered in Penlai A Oilfiled (Figure 11).

Application and Extension of Fine Fault Recognition Technology in Surrounding area of Penglai 19-3 Oilfield , Bohai Bay Basin, Eastern China

Xugang Ma, Donghong Zhou, Dingyou Lv,Dayong Guan,Hongguo Zhang

(Bohai Oilfield Research Institute, CNOOC Ltd. _Tianjin, China)

3. Application examples

In order to verify the reliability of F1 (Figure 12), from south to north, select three sections , overall near the F1 wave group characteristics of the change is not obvious, and there is no obvious slip, section 1 flexure phenomenon is obvious, the others flexural weaker.The existence of F1 is finally determined by considering forward modeling 、 plane attribute and sections. It is because of this new subtle strike-slip fault , we deployed PLA-2-6 well (Figure 13). The drilling of PLA-2-6 well in the lower part shows that the Guantao formation is mostly oil layer, while the PLA-2-2 well for the oil-water layer, also confirmed the existence of micro fault.The drilling of PLA-2-6 well has newly increase proved reserves of 6.48 million tons, providing a solid and reliable basis for the upgrading of reserves in this area.

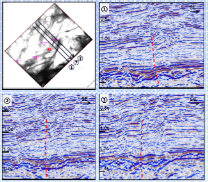


Figure 12. Verify the reliability of F1

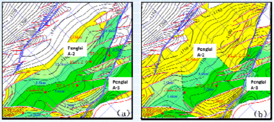
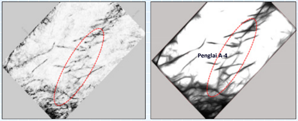


Figure 13. The Guantao formation II oil group structural map comparison of new (a) and old (b) in Penglai A Oilfield



a.Conventional coherent slice （1070ms） b. Fault Likelihood attribute（1070ms）

Figure 14. The application of fault likelihood attribute in the low part of Penglai A Oilfield

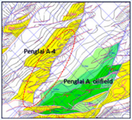


Figure 15. Penglai A Oilfield and surrounding area T_0 structural map

At present,Bohai Oilfield is still the exploration stage with structural traps as its main target. Therefore, fine structure interpretation is an important guarantee for improving exploration success ratio.The combination of structure oriented filtering and fault likelihood attributes can identify faults at different scales, and is the basis for fine interpretation.By using the fault likelihood attribute based structure oriented filtering technology , several subtle strike-slip faults were confirmed. These faults are fuzzy , poor continuity in the commonly used high precision coherent (Figure 14).The interpretation of these faults newly find the Penglai A-4 Structure, increase the trap area 9km^2 (Figure 15),which lays a solid foundation for the overall evaluation of the Penglai A Oilfield.

4. Conclusion

- We have presented a new technique process for detecting and isolating faults from 3D seismic data.This new technique process sets with results that are superior to the coherence、 curvature and other attributes. Using new technique process can identify different types of faults, and the interpretation is more intuitive and precise.
- In Penglai A Oilfield, the successful drilling of PLA-2-6 well in the lower part of PLA-2-2 well, proven reserves of 6.48 million tons, to provide a solid and reliable basis for the upgrading of the district reserves. Furthermore, it has achieved good results in the promotion of other areas (Figure 16).

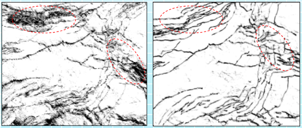


Figure 16. The extension of fine fault recognition technology in BZ16 area(1200ms)