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Stratigraphic Correlation Division Algorithm Based on Log Curves Filter Synthesis and Similarity Measurement

Mengxin Song, Chengci Wang, Hongping Miao (Research Institute of Petroleum Exploration & Development, CNPC)
Yu Ren (Beijing YueXin Times Technology Co., Ltd.)

ABSTRACT

The results of fine stratigraphic correlation affect the accuracy of understanding the distribution of oil and gas reservoirs. In the development stage, numerous development wells formations need to be finely divided into small layers, but this work often consumes a lot of research time, needs to rely on the subjective experience and understanding of researchers, and it is difficult to compare the reservoirs less than 10m at present. In this paper, a combined optimization model based on curve filtering synthesis and similarity measurement is proposed to compare and divide thin layers. The specific method is to select characteristic curves, marker wells and marker strata through mean similarity, variance similarity and morphological similarity; Based on the curve similarity and SNR energy maximization, weighted fusion of each selection curve was carried out to obtain a filtered synthetic curve, which was used to mark the formation division; Continuous stratigraphic division is carried out through sliding window detection. Finally, this combined optimization algorithm can realize the division of the marker stratum with a thickness of about 2m. The efficiency of the whole process is 92% higher than that of manual work. Through the artificial stratification comparison results, the accuracy of 85% drilling formation division reaches more than 95%.

Key Words：Stratigraphic correlation Division; Log Curves Filtered Synthesis; Similarity Measurement; Sliding Window Detection; Combinatorial Optimization

EXTENDED ABSTRACT

Introduction

Fine stratigraphic correlation and division is an important basic work in petroleum geology research, and is the premise of studying reservoir and spatial distribution. Its accuracy determines the correctness of understanding of underground reservoirs. When the oil field enters the development stage, it is necessary to divide the reservoir formation into small layers or even single sand bodies. The results provide a basis for the study of small layer microstructure, sedimentary microfacies, heterogeneity and remaining oil distribution. In the past, researchers used to divide small layers manually, which resulted in heavy workload, long time, and depending on the experience, knowledge and understanding of professionals. Different researchers often had large differences in the division results and could not establish a unified comparison standard.

In recent years, a large number of scholars at home and abroad have begun to study intelligent stratigraphic correlation and division, which has reduced the problems of inconsistent correlation standards and uncertain stratigraphic interfaces in the process of correlation, and greatly improved the work efficiency. Yongshi and [1] put forward the method of combining intraformational difference method with cluster analysis to stratify logging curves. Hawkins and Merriam [2] proposed to use the optimal segmentation method to layer a single curve, and then studied a variety of curve methods that can handle discrete [3]; Liu Jiajin [4] et al. used the optimization principle to establish the recursive operation model of range stratification, and determined the optimal number of layers and corresponding layering points. Zhu Jianbing [5] proposed that by analyzing the nature and geological significance of logging curve activity, it is found that the interface of quasi sequence unit can be identified by using the unity of activity curve (natural potential, resistivity, natural gamma) and combining with practice. Xue Bo [6] proposed to weaken the factors hindering layering with morphological filtering in the wavelet transform layering method, effectively reducing the pseudo stratigraphic division, so that the final layering result is closer to the real stratigraphic interface. Wang Ping [7] et al. used Walsh change method to automatically separate logging curves. Xu Chaohui [8] and others have realized automatic stratigraphic division and correlation based on convolution neural network algorithm widely used in depth learning and logging data in dense well network area.

In this paper, the method of curve filtering synthesis and stratum similarity measurement is proposed to carry out intelligent stratum fine correlation and division, more finely divide the stratum less than 10m, and give a clear method to determine the stratum boundary point, which is convenient for industrial production. The data involved include 20 kinds of logging data, including drilling coordinates, well deviation and lithology series curves, porosity series curves, resistivity combination curves, microelectrode curves, etc. The main process includes six steps, including data preprocessing, model training, layering scheme design, marker stratum division, continuous stratum division, and fault correction through wells.

Methodology

Data Processing

The research area has selected an oilfield development block in China, which has been developed for many years. The basic well pattern and infill well pattern have been deployed successively. The drilling and logging data are complete, and the layered data have been tested by years of development practice, with high reliability. The test area with an area of $40km^2$ is selected. There are nearly 200 development wells in the area. The sedimentary environment is meandering river and river delta front. The reservoir is mainly channel sand body. The reservoir rock types are mainly siltstone and sandstone. The thickness of single sand layer is 1.8m~10.2m, and the thinnest sand layer is only about 2m.

Collate 194 drilling data(Figure 1), including well location coordinates, well deviation, various logging curves and existing drilling layering data, conduct deviation correction for deviated well sounding, and preprocess the curves, including longitudinal curve splicing, deletion of invalid values, curve normalization, etc., to eliminate the impact on formation division in the later period.

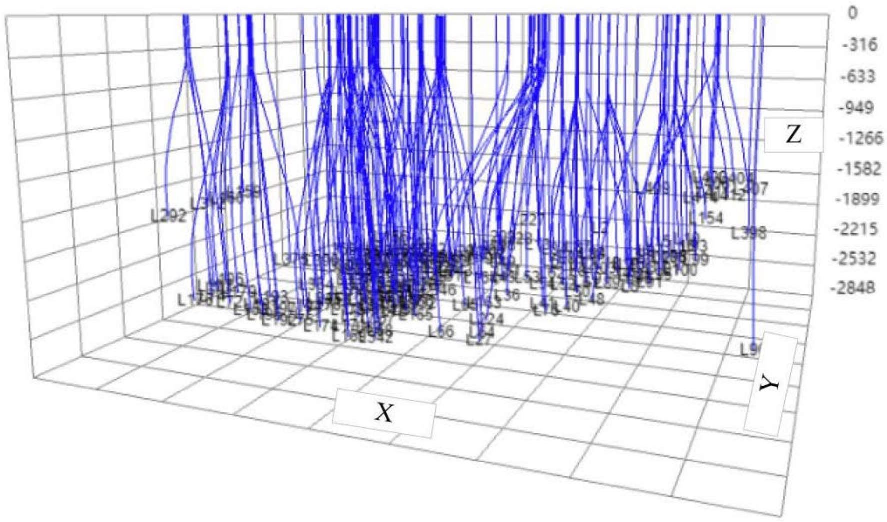


Figure 1 Spatial Distribution of Drilling

Model training

The main target interval in the study area is T1~T10, which is subdivided into 10~14 small layers with thin stratum thickness. In order to divide each small layer in detail, the above small layers are listed as key target strata for research.

Through model real-time training, curve selection, marker well selection and marker stratum selection are carried out for the study area to select the curve, marker well and marker stratum with higher curve consistency and more obvious characteristics.

The selected method is to calculate the similarity, which requires comprehensive consideration of mean similarity, variance similarity and morphological similarity.

The mean similarity refers to the average value of the same type of curve value of the corresponding interval at all observation points extracted according to the existing stratum layers for similarity comparison, that is, the smaller the mean difference, the higher the similarity of the same stratum in different wells. The study of variance similarity is consistent with the principle of mean similarity. Compare the variance of curve values between different wells on the same type of curve in the same formation. The smaller the variance similarity value, the higher the similarity of the corresponding formation of the two wells. The research on the form similarity is to study the form similarity of the same kind of logging curve of the corresponding formation of each two wells through the algorithm, and calculate the distance between the observation points of the corresponding formation of the two wells. The smaller the value of the form similarity, the higher the similarity of the corresponding formation of the two wells.

When measuring the shape similarity, the difference of formation thickness between the two wells is considered: when the formation thickness is different, the length of the two logging curves is different, and the points used to calculate the similarity are not one-to-one corresponding; When the stratum thickness is the same and affected by the geological structure, the points of the data form of the two curves on the depth axis are not aligned. Therefore, a similarity measurement method based on optimal path planning is used to measure the morphological similarity.

Based on the above model training process, model training is conducted for all data in the study area. According to the characteristics of logging curves in the study area, in order to ensure the accuracy of final stratification, as many drilling wells with high similarity will be selected as possible in the selection of marker wells. Through comparison and inspection of the results of manual stratification, 83 marker wells will be finally selected. The selected curves include neutron porosity curve (CNL), natural gamma curve (GR), density curve (DEN), acoustic transit time curve (AC) and natural potential curve (SP) are combined characteristic curves.

Determination of layering scheme

On the basis of determining a large number of marker wells and their marker strata, the top boundary depth and bottom boundary depth of the regional marker strata can be roughly determined. A section covering the whole well is made at the highest top depth interface and the lowest bottom depth interface, with an increase of 50m above and below each, to ensure that the marker horizon is within the target range. The upper and lower plane range is the final candidate area for marker strata.

On the basis of determining the candidate area of marker stratum, marker well, marker stratum and characteristic curve combination, in order to accurately divide the remaining wells to be layered, a corresponding marker well, marker stratum and characteristic curve combination are matched for each well to be layered.

Based on the spatial well distribution and the premise of distance priority, find the nearest one or more marker wells corresponding to the wells to be stratified. According to the curves and strata of the marker wells, modify the characteristic curve combination and marker strata obtained from the model training, select the curve combination and marker strata standard corresponding to the matching of the wells to be stratified, and divide the corresponding strata. If there is a plane distribution map of sedimentary microfacies of the marker bed, the marker bed of the same type of microfacies shall also be selected as the basis for division when revising (Table 1).

Table 1—Matching marker well, marker stratum and characteristic curve combination of some wells to be layered

Well to be layered	Marker well	Marker stratum	Characteristic curve combination
L1	L324，L347	T0，T4，T5，T8	AC，SP
L10	L16，L15	T0，T4，T5，T8	GR_1，GR，AC_1，AC，SP
L100	L101，L96，L95	T0，T4，T5，T8	SP，GR
L101	L242，L100	T0，T4，T5，T8	SP，GR
L103	L12，L25，L19	T0，T4，T5，T8	AC，SP，GR
L106	L107，L277，L286	T0，T4，T5，T8	SP，GR
L107	L106，L277	T0，T4，T5，T8	SP，GR
L12	L18，L25，L19	T0，T4，T5，T8	AC_1，AC，SP，GR_1，GR
L13	L84，L88	T0，T4，T5，T8	SP，GR
L14	L9，L92	T0，T4，T5，T8	AC，SP，GR_1，GR
L15	L16，L77	T0，T4，T5，T8	AC，SP，GR
L153	L193，L191	T0，T4，T5，T8	GR_1，GR，AC_1，AC，SP
L154	L398，L48	T0，T4，T5，T8	AC，SP，GR
L156	L177，L167	T0，T4，T5，T8	GR_1，GR，AC_1，AC，SP

L159	L275，L160	T0，T4，T5，T8	AC_1，SP，AC，GR_1，GR

Curve Filtering Synthesis Method Based on Maximizing Curve Similarity and Signal to Noise Ratio Energy

Filter and synthesize multiple curves, select multiple curves with obvious geological characteristics and high curve similarity, and combine them into one logging curve. Eliminate the influence of individual singular data in the data, retain the most significant features of the curve, and merge according to the principle that when the curve features are consistent, the features are enhanced, and when the curve features are inconsistent, the features are weakened.

The curve direction is determined based on the curve coefficient obtained by the method of maximizing the signal to noise ratio energy. Through the combination of the similarity and direction of each logging curve obtained in the model training process, each selection curve is weighted and fused to obtain a filtering composite curve.

As shown in Figure 2, the hb curve is a filtered composite curve, and the three curves on the left, middle and right are respectively the true layering of the wells to be layered, the intelligent layering of the wells to be layered, and the true layering of the marker wells.

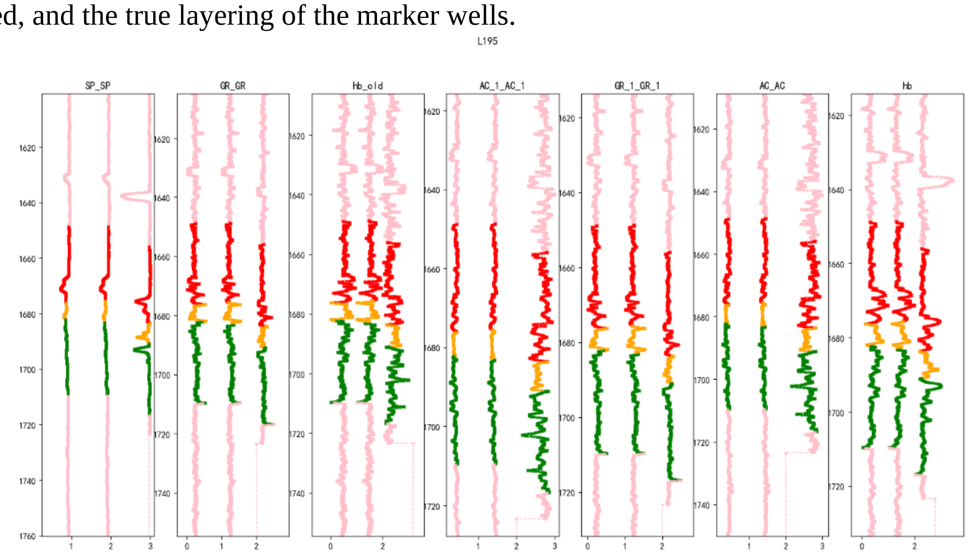


Figure 2 Curve filtering synthesis

Mark stratigraphic division

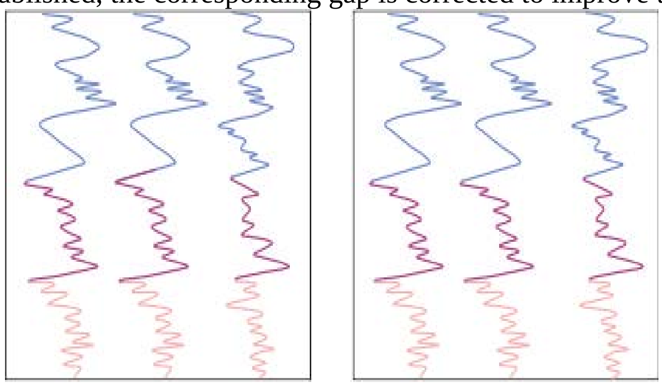
The variable length sliding window detection method is used to select the sliding window data, calculate the similarity between the sliding window data and the corresponding marker bed filter composite curve data of the marker well, extract the candidate stratum according to the limited threshold, and finally determine the final marker bed division result based on the global optimization search idea and inter stratum constraints .

Correction of boundary of marker stratum

On the basis of positioning and dividing the marker bed according to the overall shape of the marker bed, take the curve characteristics of the boundary area of the marker bed of the marker well and the curve characteristics corresponding to the boundary of the marker bed of the well to be layered, and compare the characteristics to achieve the correction of the boundary of the marker bed and improve the division accuracy.

The method of boundary correction also adopts the idea of sliding window detection. Select the boundary of stratum division results, take the upper and lower parts of the boundary as the sliding window detection area, and use the sliding window detection method to correct the boundary of the marker stratum.

As shown in Figure 3, the results before and after the boundary of a marker stratum is established. The curves from left to right are the results of manual division of the wells to be stratified, the results of intelligent division of the wells to be stratified, and the results of manual division of the marker wells. It can be seen that there is a slight deviation between the results of intelligent division of the marker stratum before the boundary is established and the results of the marker stratum division of the reference wells. After the boundary is established, the corresponding gap is corrected to improve the division accuracy.



（a）Before boundary correction （b）After boundary correction

Figure 3 Schematic Diagram of Boundary Correction Results

Continuous stratigraphic correlation division method based on sliding window idea and global optimization

Based on the classification results of target well marker beds, the continuous stratigraphic correlation between marker beds can be achieved.

The sliding window detection method is used to traverse the data of the stratum candidate area, calculate the similarity between the curve segment in the sliding window detector and the corresponding stratum curve segment of the reference well, select several stratum segments with the greatest similarity as the candidate set, and determine the final continuous stratum division result from the candidate set based on the adjacent layer constraints and the global optimization idea.

As shown in Fig. 4, the comparison diagram of continuous stratigraphic division of L195 well based on L153 well is shown. Different colors represent different stratigraphic divisions, and the same color corresponds to the same stratum. The curves from top to bottom are respectively the real stratum division of the marker well L153, the intelligent division result of the well L195 to be layered, and the real stratum division of the well L195 to be layered. It can be seen that the stratum of the well to be layered can be well divided according to the characteristics of the marker well, and the intelligent layering result is ideal.

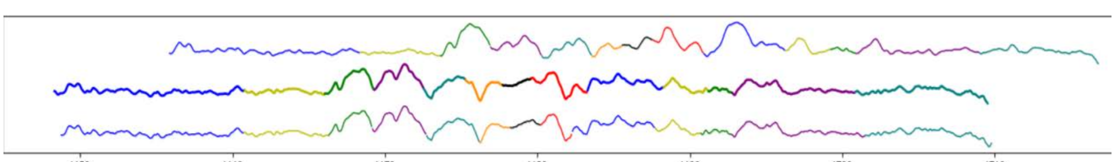


Figure 4 Results of Comparison Chart of Continuous Stratigraphic Division of Well L195-L153

Intelligent layered result verification

In order to obtain an ideal layering result, the results of intelligent layering should be consistent with those of manual layering. Through the above stratigraphic division process, 14 small layers of 194 wells were intelligently compared and divided in the whole process. The results are shown in Table 2. 83 wells had an accuracy rate of more than 95% between the intelligent marker layer division and the artificial marker layer division. The 83 wells were used as the marker wells, and the curve filtering synthesis method was used to divide the marker layers of the remaining wells. In the area where the reservoir changes rapidly, the similarity displayed on the characteristic curve will change, resulting in errors in the determination of the boundary of small layers. The similarity of layer thickness and curve should be fully considered in the division.

When the result of continuous stratigraphic division is not ideal, first adjust the reference marker well of the well, select the well with the same sedimentary microfacies and higher curve similarity for comparison, and then manually intervene and adjust the stratification interface with lower accuracy.

For wells with accuracy less than 50%, after the above analysis, the layering effect is not good, so it is necessary to consider whether there is a fault and add fault data after seismic interpretation for layering correction.

Finally, The thickness of the thinnest marker stratum is divided into 2m, and the efficiency of completing the whole process is 92% higher than that of manual work.Compared with the result of manual correlation, the accuracy of formation classification in 85% drilling is more than 95%.

Table 2—Calculation of accuracy rate of intelligent layering results

	Number of wells with accuracy rate above 95%	Number of wells with accuracy of 95%~85%	Number of wells with accuracy of 85%~75%	Number of wells with accuracy of 75%~65%	Number of wells with accuracy of 65%~50%	Number of wells with accuracy< 50%
Mark layer division	83	21	23	19	27	21
Continuous stratigraphic division(Before manual correction)	102	32	21	17	12	10
Continuous stratigraphic division (after manual correction)	165	9	11	4	2	3

Comparison and division results of corrected drilling with drilled faults

In general, the seismic data interpretation work in the study area will start before the sub layer comparison work, or two work will be carried out at the same time. At the end of the division result, we need to unify with the seismic interpretation results, and use the fault data of seismic interpretation to compare with the layered data. When drilling encounters a fault, there will be stratum duplication or stratum loss, and this well is prone to major classification errors during stratum correlation.

Through fault attribute, combined with the nearest complete marker well layering of the same sedimentary microfacies, the thickness of the repeated formation or the thickness of the faulted formation of the drilled fault well can be calculated, so as to correct the layering of the well and obtain the final layering result.

Results and Conclusions

Based on the methods of well logging curve filtering synthesis and similarity measurement, this paper conducts fine stratigraphic correlation and division for 194 wells in the study area, including data processing, intelligent comparison and division, result correction, and intelligent process, which can help us process data and get results faster. In the comparison process, there are a few wells with poor layering results, which can be attributed to the need for more detailed analysis and corresponding algorithm calculation for different geological phenomena. In the continuous stratigraphic division, the boundary correction is carried out by manual intervention on the sub layer interface with insignificant characteristics. The thickness of the thinnest marker stratum is divided into 2m, and the efficiency of completing the whole process is 92% higher than that of manual work.Compared with the result of manual correlation, the accuracy of formation classification in 85% drilling is more than 95%.

Based on the methods of well logging curve filtering synthesis and similarity measurement, this paper conducts fine stratigraphic correlation and division for 194 wells in the study area , including data processing, intelligent comparison and division, and result correction. Intelligent process can help us process data and get results faster. In the process of comparison, a few wells with poor stratification results, which can be attributed to the need for more detailed analysis of different geological phenomena and the corresponding algorithm calculation. Manual intervention and boundary correction are carried out for the small layer interface with obscure characteristics in continuous stratigraphic division. The thickness of the thinnest marker is divided to 2m, and the efficiency of completing the whole process is 92% higher than that of manual work. Compared with the result of manual correlation, the accuracy of formation classification in 85% drilling is more than 95%.

This method has changed the traditional manual comparison method, eliminated the subjective factors in the research process, and can realize multi task parallel processing in the work process. It can quickly complete the comparison and division of batch wells, greatly improve the work efficiency, and obtain good research results, which is of great significance to the basic geological research.

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