AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling C; Vol. 78; N°2; pp 191-209
Submitted Mar. 27, 2017; Revised May 28, 2017; Accepted Jun. 19, 2017

Sedimentary Reflection of Tectonic Activities of Fault Depression Basin-taking Lufeng Depression as an Example

Zhen Zhang*, Jianhua Guo, Wang Yu

School of Geosciences and Info-physics, Central South University, Changsha 410083, China; Key Laboratory of Nonferrous Metallogentic Prognosis, Ministry of Education, Central South University, Changsha 410083, China (Corresponding author's email: slzz0906@vip.qq.com)

Abstract

Lufeng depression is a fault depression basin with abundant petroleum resources. It's of significance to analyze the structure and sedimentary situation of the study area. 11 third-order seismic sequence boundaries are identified in Wenchang Formation of fault-depression period and Enping Formation of fault-sag period and 10 third-order sequences of type- I are divided based on the seismic data. According to the features of seismic facies and log facies, the sedimentary facies of fault depression period include fan delta, sublacustrine fan, lacustrine facies, delta facies, etc. Delta facies and lacustrine facies were found in the fault sag period. Wenchang Formation deposited during fault depression period and Enping Formation deposited during fault sag period both can be subdivided into initial fault depression period, rapid fault depression period, intensive fault depression period and fault depression shrinking period. However, there is obvious difference between the sedimentary characteristics of Wenchang Formation and Enping Formation. Ancient landform of Wenchang Formation at the depositional stage features large terrain elevation difference, deep water bodies and rich types of sedimentary facies, while the landform of Enping Formation features flat terrain, shallow waters, and rather simple sedimentary facies types. The change rules of fan bodies in fault depression period and in fault sag period are consistent. The fan bodies all advance towards the basin, except the one in the intensive fault depression period, which flinches towards the provenance.

Key words

Fault depression basin, Episodic activity, Fault depression period, Fault sag period, Sedimentary reflection.

1. Introduction

The fault depression basin is rich in oil and gas resources and is an important exploration area in the oil and gas field in eastern China. The fault depression period of the basin is the main period for hydrocarbon source rock development, and the reservoir and caprock are widely developed in the fault sag period, so the fault basin can form a complete oil and gas system.

The depositional filling of the fault basin is controlled by the episodic activities of the boundary faults, and the type and distribution range of the sedimentary facies vary greatly in different faulting period. The sedimentary facies features manipulate the type and distribution of the oil and gas reservoir. Therefore, the analysis and comparison of the depositional filling of fault basin can effectively guide the oil and gas exploration in the fault basin. Many studies have been done on the tectonic evolution of the fault basins, especially on the palaeogene fault basins in East China [1-2]. However, the studies are all focused on the analysis of tectonic evolution and sedimentary response of the fault-depression period, while there are not many studies of tectonic evolution and sedimentary response of the fault-sag period. And comparative study on the tectonic evolution and sedimentary response of the two periods are much less. It is particular important to note that the fault-sag period is the main stage for reservoir development. The study of sedimentary evolution in the fault-sag period will help to guide the oil and gas exploration in the faulted basin.

Lufeng Depression is located in the northeastern part of Pearl River Mouth Basin (Figure 1) [3]. It can be divided into five north north-east trending sags [4-5]. The basements of the sags are Mesozoic strata or Yanshanian volcanic rocks [6-7], while the sags are filled with Cenozoic strata. Three stages are divided based on the basin evolution process, namely, faulting period, fault-depression transforming period and the depression period.

This paper focuses on the tectonic-sedimentation characteristics and differences of the basins in the faulted period and fault-depression transforming period. The Palaeogene Wenchang Formation sediments were found in the faulting period, and Enping Formation sediments were found in fault-depression transforming period. For both Wenchang Formation in the faulting period and Enping Formation in the fault-depression transforming period, four stages can be divided as per the activity routines of boundary faults, namely, initial fault depression period, rapid fault depression period, intensive fault depression period and fault depression shrinking period. The activity rules of the boundary faults control the sediment filling process. The sedimentary reflection of the tectonic evolution can be analyzed based on the study of the tectonic evolution, sequence stratigraphy of the target stratum, sedimentary facies and depositional evolution sequence [8-11].

2. Division of Succession of Strata of Fault Basin

Seven seismic sequence boundaries can be identified in the study area of Wenchang Formation: Tg, T85, T84, T83, T82, T81 and T80. The Tg boundary in Lufeng area is characterized by a typical angle unconformity surface, truncation surface and onlap surface. What is beneath the boundary is the disorder parallel-sub-parallel reflection structure with medium and strong amplitude. Above the boundary is the disorder progradation reflection structure with medium-weak amplitude, so the seismic facies above the boundary and below the boundary are significantly different. The T85 boundary presents as a truncation surface and an onlap surface. What is beneath the boundary is a disorder progradation reflection structure with medium-weak continuity and medium-strong amplitude and what is above the boundary is a disorder progradation reflection structure with medium-strong amplitude. T84 boundary is widely distributed in Lufeng area, which presents as a truncation surface and onlap surface in the seismic section. What is below the boundary is the subparallel, disorder progradation reflection structure with medium-weak continuity and medium-strong amplitude and what is above the boundary is the subparallel, disorder progradation reflection structure with medium-strong continuity and medium-strong amplitude. T83 boundary presents as truncation surface and onlap surface in the seismic section. What is beneath the boundary is the subparallel, disorder progradation reflection structure with medium-strong amplitude and medium-strong continuity, and what is above the boundary is the parallel progradation reflection structure with strong amplitude and high continuity.

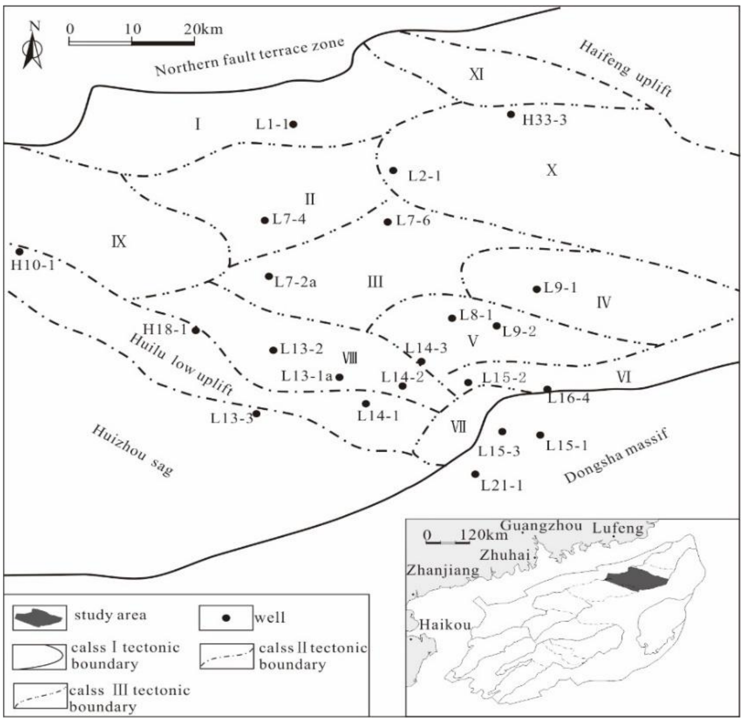

Fig.1. Location of Study Area

T82 boundary presents as truncation surface and onlap surface in the seismic section. What is beneath the boundary is the parallel progradation reflection structure with strong amplitude and high continuity, and what is above the boundary is the parallel-progradation, subparallel-wormlike reflection structure with medium amplitude and medium-weak continuity. T81 boundary features the onlap surface in the seismic section and truncation surface can also be found at the edge of partial depressions. What is beneath the boundary is the progradation-wormlike reflection structure with medium amplitude and medium-weak continuity and what is above the boundary is the parallel, sub-parallel-progradation reflection structure with medium amplitude and medium-weak continuity. The T80 boundary is a regionally comparable unconformable surface, featuring truncation surface. It also presents as onlap surface. T80 boundary is the division surface of Wenchang Formation and Enping Formation and the regional unconformable surface formed by the two scenes of Zhuqiong movement after going through uplift erosion. What is beneath the boundary is the parallel, sub-parallel progradation reflection structure with medium amplitude and medium-weak continuity. What is above the boundary is the parallel, sub-parallel-progradation reflection structure with medium amplitude and medium-weak continuity and beneath the boundary is a parallel-sub-parallel reflection structure with medium-strong amplitude and medium continuity.

T73, T72, T71 and T70 seismic sequence boundaries can be identified in Enping Formation. T73 boundary is only distributed in Lufeng No.13 Depression and it presents as truncation surface at the edge of the depression. Below T73 is a parallel, sub-parallel reflection structure with medium-strong amplitude and medium continuity, and above T73 is a parallel-subparallel reflection structure with medium amplitude and medium-strong continuity. T72 boundary is composed of onlap surface and truncation surface. Beneath the boundary is a parallel-sub-parallel reflection structure with medium amplitude and medium-strong continuity and above the boundary is a parallel-sub-parallel reflection structure with medium-strong amplitude and strong continuity. T71 boundary is characterized by onlap surface and downlap surface. Below the boundary is a parallel-sub-parallel reflection structure with medium-strong amplitude and strong continuity and above the boundary is a parallel-sub-parallel reflection structure with medium-strong amplitude and medium continuity. T70 boundary was formed in the period of South Sea movement. The early deposited stratum underwent erosion effect due to the tectonic uplifting, so a large amount of erosional unconformities were developed in the structural high part. Below the boundary is a parallel-sub-parallel and progradation reflection structure with medium-strong amplitude and medium continuity, and above the boundary is a parallel reflection structure with strong amplitude and high continuity.

Based on the 11 seismic sequence boundaries identified in Wenchang Formation and Enping Formation, 10 third-order sequences can be marked out, including 6 in Wenchang Formation and 4 in Enping Formation. Low system tract, lacustrine transgressive system tract and high stand system tract can be recognized in each sequence.

3 Features of Sedimentary Facies in Fault Basin

3.1 Types of Sedimentary Facies in Faulted Period

The sedimentary facies types in the faulted period cover fan delta, lacustrine facies, sub lacustrine fan and delta facies.

Fan delta: It is mainly distributed in the low system tract and lacustrine transgressive system of each sequence. Mainly consisting of sandy conglomerate and granule conglomerate, the fan delta develops erosion surfaces and large-scale cross bedding. In the seismic section, the fan delta mainly has a disorder progradation reflection structure with medium-weak amplitude and weak continuity. Fan delta spreads over the downthrown side of the boundary faults in the fault basin, and changes gradually into semi-deep lake-deep lake sub-facies towards the internal of the depression.

Lacustrine facies： It mainly consists of mudstone, silty mudstone, siltstone and fine sandstone sediments, and develops level stratification, wavy bedding and ripple cross lamination. Burrow pores and bioturbation structure are frequently seen in the sandstone. Lacustrine facies are mainly distributed in the center of depression sedimentary facies and shore shallow lake and semi-deep lake-deep lake facies can be identified. The shore shallow lake mainly consists of siltstones, fine sandstones, and argillaceous sandstone sediments with ripple cross lamination and wavy bedding, while semi-deep lake-deep lake mainly contains mudstone and silty mudstone with level stratification.

In the seismic section, the shore shallow lake features the worm-like reflection structure with medium amplitude and medium-weak continuity, while the semi-deep lake-deep lake is characterized by parallel-sub-parallel reflection structure with medium-strong amplitude and high continuity.

Sublacustrine fan facies: They are distributed in low stand system tract and lacustrine transgressive system of SQ3 and SQ4, mainly consisting of coarse sandstone, medium sandstone and fine sandstone. Section B, C and D of Bouma sequence can be seen here, but section A is rare. Sublacustrine fan provenance mainly comes from the fan data and is mainly deposited in the semi-deep lake and deep lake. In the seismic section, the sublacustrine fan is lenticular reflection structure with medium-weak amplitude and weak continuity (Figure 2). The bottom of the lenticular reflection structure is the sequence boundary, above which is the parallel reflection structure with strong amplitude and high continuity.

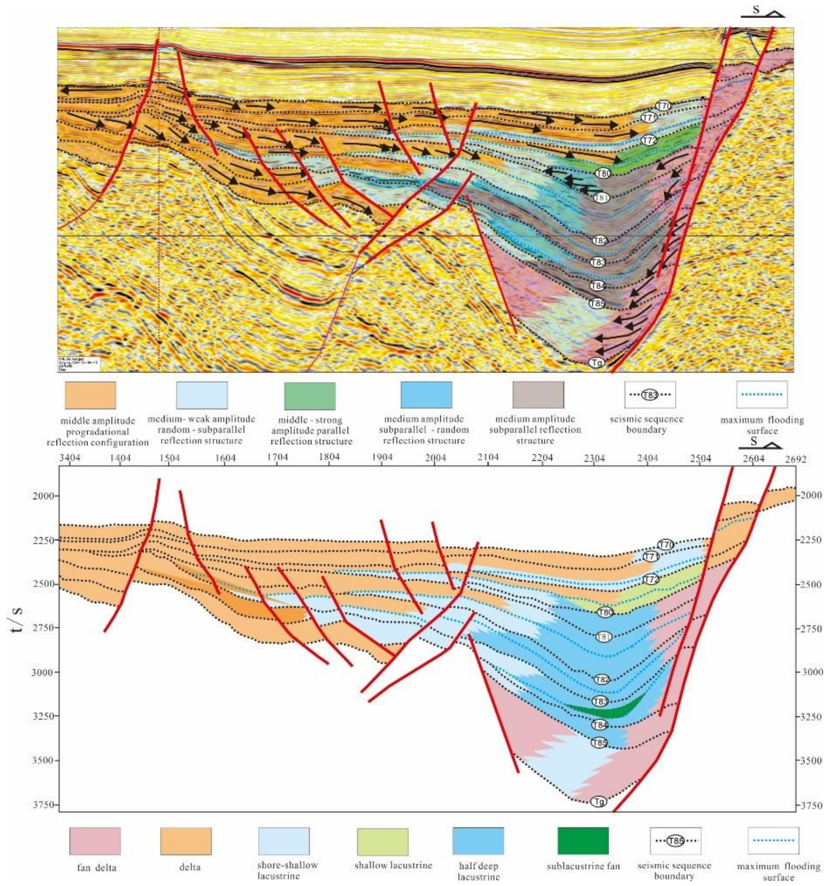

Fig.2. Reflection Features of Seismic and Facies of Wenchang And Enping Formation

Delta facies: They are distributed in high stand systems tract of each sequence in braided river delta and meandering delta. The braided river delta is mainly distributed in SQ1, SQ2, SQ3 and SQ4 sedimentary sequences in the initial fault depression period, rapid fault depression period, and intensive fault depression period. The meandering delta is mainly distributed in the gentle slope belt of the fault basin in the weak fault depression period and depression shrinking period. Braided river delta mainly composes of gravelly coarse sandstone, gritstone and medium sandstone, with a small shale content, while meandering delta mainly contains fine sandstone and siltstone, with high shale content.

3.2 Types of Sedimentary Facies in Fault-sag Period

The fault-sag period is featured by Enping Fomration. The delta facies and lacustrine facies can be identified based on the lithofacies and log facies.

(1) Delta Facies

They are mainly distributed in the high stand system tract of each sequence. Delta plain, delta front and prodelta parfacy can be identified based on the core information.

Delta Plain: With relatively complicated lithology, the delta plain features grey sandy conglomerate, gravel sandstone, coarse sandstone, carbonaceous mudstone, coal seam, and coal lines. The delta plains have different lithologic combinations at different tectonic stages. In the early period of the fault-depressed basin in Enping Formation, the coarse-grained sediments such as fine-grained conglomerates, sandy conglomerates, gravel sandstones and coarse sandstone are often deposited due to the steep terrain at the edge of the basin or due to the development of sedimentary slope belts and tectonic slope belts in the basin. This type of delta plain has developed erosion filling structure, and braided river course, so it can be commonly seen that the sandy conglomerate at the scour surface and above the scour surface present a positive rhythm in the core (Figure 3). In addition, large parallel bedding and oblique bedding are also developed in the sandy conglomerate (Fig. 3).

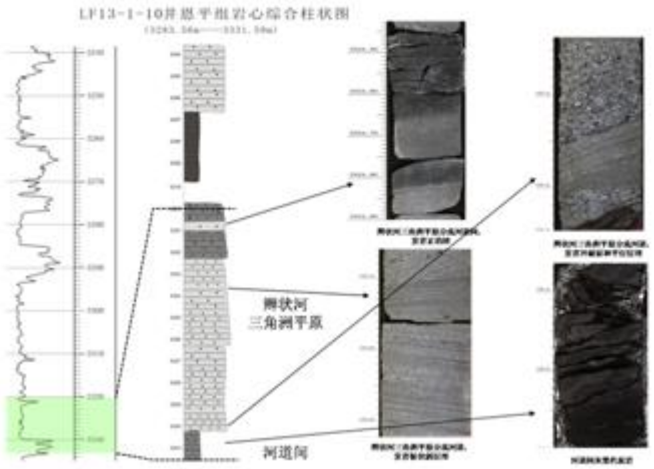

Fig.3. Deposition Characteristic of Delta Plain of Enping Formation In Lufeng Area

In addition to large-scale parallel bedding and oblique bedding with strong hydrodynamic forces, boulder clay is also developed in the coarse sandstone. Presenting as a long strip, this kind of boulder clay is distributed disorderly in the sandstone, indicating that the sandstone transport distance is short. It is judged that it is a delta plain deposit from the lithologic and sedimentary structural features. In the longitudinal direction, the bottom of the braided channel holds abrupt contact relationship with the mud rock instead of gradient contact relationship, signifying strong erosion effect of the river sandstone on the substrata. In addition, the deposition velocity is fast and the hydrodynamic condition is strong and stable. In terms of well logging curve, this kind of delta plain presents as jugged box shape and jugged bell shape in the Gamma Curve. The gamma average is 78API. In longitudinal direction, the box-shaped sandstone with low gamma value has abrupt contact relationship with the mud rock with high gamma value on the substrata and the boundary is clear. The box-shaped curve is often upwards combined with the bell curve. This kind of sedimentary association shows that the deposit granularity is tapering upwards and the hydrodynamic condition weakens. The sedimentary facies also change from riverway to marginal bank or flood plain, delta front or even shore-shallow lake and semi-deep lake-deep lacustrine sediment.

Another kind of delta plain was developed at the end of the depositional stage of the fault-depressed basin, featuring the development of fine-grained sediment and coal bed, such as SQ10 sequence in Enping Formation. The fault-depressed basin of this period is relatively flat, with undeveloped slope break belts in the lake basin and weak lake hydrodynamic conditions. The sediments were transported to the distant areas of the lake basin under the action of the river and were seldom deposited at the edge of the basin. Therefore, in humid climate conditions, the coal lines, coal bed and flooding sand shale constantly deposited at the edge of the flat basin, that is, lake basin swampiness. This type of delta plain presents as tooth profile, finger shape, and funnel shape on the logging curve. In general, the particle size of the sediment in this type of delta plain is much smaller than that of the first kind, and the delta plain features interbedded deposition of the sand shale. The sandy ground was low, and was characterized by the development of coal lines and coal beds.

(2) Delta front: The lithology is characterized by gravel-bearing coarse sandstone, coarse sandstone, medium sandstone, siltstone and mudstone. The sorting features of the sandstone is poor and the roundness is featured by subangular and sub-rounded shapes. The sandy ground of the delta front is lower than that of the delta plain, which can be reflected clearly from the logging curves. The logging curves of the delta front are of jagged funnel-shape, jagged bell-shape and asymmetric tooth profile and finger shape, while the logging curves of the delta plain are mainly of box or bell shapes. The core information also indicates that the deposit granularity at the delta front is smaller than that of the delta plain. The sub-facies of the delta front feature by medium-coarse sandstone, and parallel bedding and oblique bedding were developed in the sandstone. Burrow pores and bioturbation structure are developed in the silty sandstone and argillaceous silt with fine particle size.

The logging curves of the sub-facies of the delta front are dominated by bell shapes and funnel shapes (Fig. 4). Both the bell-shape logging curve and the funnel-shape logging curve have many jags, because the mud rock of the flooding system tract was deposited among the sandstones due to the impact of the seasonal rivers.

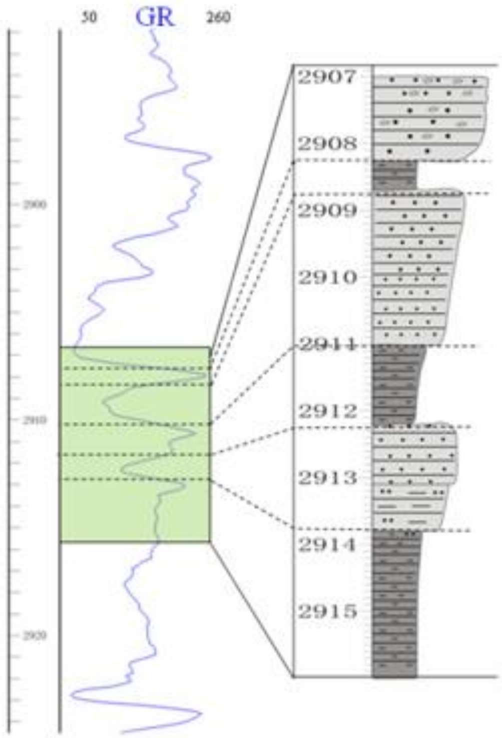

Fig.4. Deposition Characteristic of Delta

Whether it is bell-shaped or funnel-shaped tooth formation is more serious, mainly due to the impact of seasonal rivers, in the sandstone deposition between the flood period of mudstone. The bell-shaped logging curve represents the fine grain size of the sediment, the weakening of the hydrodynamic conditions, and the gradual deepening of the water body, so the bell-shaped logging curve often represents the underwater distributary channel deposition. The funnel-shaped logging curve represents the gradual increase of the granularity of the sediment, the hydrodynamic condition is gradually increased, and the water body gradually becomes lighter, so the funnel-shaped logging curve is a typical representative of the delta front estuary sand dam. The dentate funnel-shaped curve represents the sandstone interbedded in the flood season.

The bell-shaped logging curve represents that the grain size of sediment is large at the lower part and small at the upper part. The hydrodynamic.

conditions of sedimentation weaken upwards, and the water is getting shallower, therefore the funnel-shaped logging curve is a typical example of the entry sand bar in the delta front. The jagged funnel-shape curve represents the interbedding of the sand-shales deposited in the seasonal rivers in multiple flooding periods.

Lacustrine faces

Lacustrine faces are the main type of sedimentary facies in Enping Formation of the study area. Based on the core and logging curve features, the shallow lake sub-facies and lake sub-facies can be identified.

The lithology of the shore shallow lake sub-facies is mainly composed of gray, light gray siltstone and argillaceous siltstone, and a lot of ripple cross lamination, wavy bedding, burrow pores and bioturbation structure (Fig. 5).

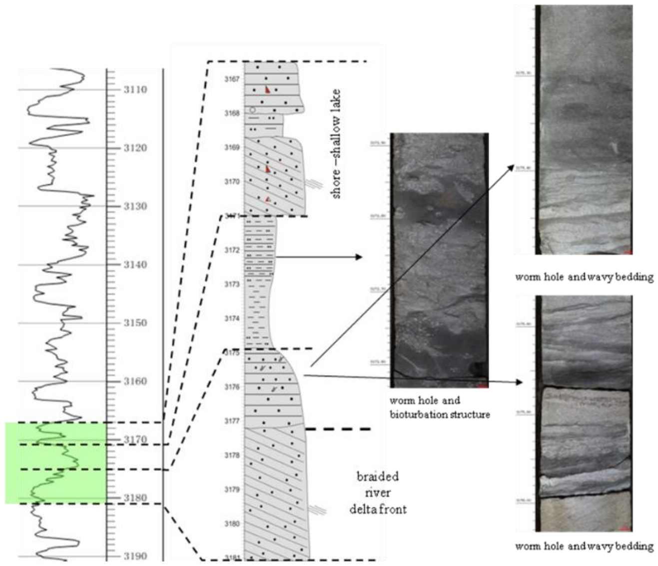

Fig.5. Deposition Characteristic of Shore and Shallow Lake of Enping Formation in Lufeng Area

The sandstones in the shore shallow lake present as a finger shape or as a dentation in the logging curve. In longitudinal direction, the finger-shaped sandstone in the lacustrine facies is often quite low and plenty sandstones carried by the delta were deposited in the shore shallow lake. Therefore, the frequent alternation between the flood period and the dry season is the root cause of the interbedding of the finger-shaped sandstone and mudstone. The sediments of the shore-shallow lacustrine are mostly developed in the transgressive system tract and high stand system tract, while this kind of sediments were seldom seen in the low stand system tract.

4 Episodic Activity of the Fault Basin

4.1 Episodic Activity in the Fault-depression Stage

The fault-depression stage can be further divided into initial fault depression period, rapid fault depression period, intensive fault depression period and fault depression shrinking period. Different fault basins at different fault depression stages have different types of sedimentary combinations (Figure 6).

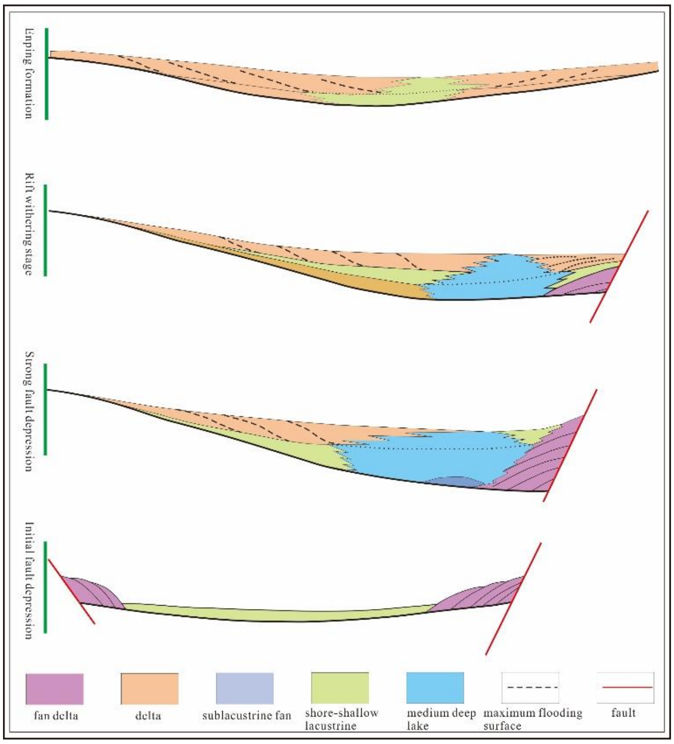

Fig.6. Deposition evolution of Wenchang and Enping formation in Lufeng area

Initial fault-depression stage: It is the period of the controlled depression. The sedimentary range of this period is very limited, and the offshore submarine fan and shore-shallow lake sediments are mainly deposited, and the fan delta and the coastal subsea apron are distributed at the downthrown side of the controlled depression.

Rapid fault-depression stage: It is the period of the controlled depression with relatively rapid activity speed. The types of sedimentary facies changed mainly into fan delta, braided river delta, semi-deep lake and shore shallow lake. The fan delta is mainly distributed at the downthrown side of the controlled depression. Due to the rapid decline of the boundary faults, the center of subsidence of the basin was rapidly formed, and was characterized by the deposition of dark fine granules in the semi-deep lake. In the area with gentle slope belt of the fault basin, due to the abundant supply of provenance, the braided river delta was widely developed.

Intensive fault depression period: It is the period when the activity speed of the controlled depression is the largest. At this period, the lacustrine levels were most widely distributed and the water was the deepest, so the semi-deep lakes were extensively developed and the thickness of the source rock is the largest (Figure 6 and Figure 7). The side of the steep slope of the depression was dominated by the fan delta. At the side of the gentle slope belt, the braided river delta and shore shallow-lake sediments were seen.

Formation	Fault depression stages	Fault depression	Sequences division	System tract	Base face	Sedimentary facies types	Sediment type
Wenchang Formation features	Fault depression stages II	Depression shrinking period	SQ6	HST		Delta facies、Shore shallow lake、Deep lake	Mainly medium grained sediments, minor source rock.
			T81	LST-TST			
			SQ5	HST		Delta、Shore shallow lake、Deep lake、Fan delta	Primarily medium and fine grained sediments, secondly source rock.
			T82	LST-TST			
		Intensive fault depression period	SQ4	HST		Deep lake、Delta、Shore shallow lake、Deep lake、Fan delta、Sublacustrine fan	Primarily source rock, secondly medium grained sediments.
			T83	LST-TST			
	Fault depression stages I	Intensive fault depression period	SQ3	HST		Fan delta、Shore shallow lake、Delta、Deep lake、Sublacustrine fan	Primarily medium and coarse grained sediments, secondly source rock
			T84	LST-TST			
		Rapid fault-depression stage	SQ2	HST		Fan delta、Delta、Shore shallow lake、Deep lake	Mainly corse grained sediments with certain amount of source rock.
			T85	LST-TST			
		Initial fault-depression stage	SQ1	HST		Fan delta、Shore shallow lake、Deep lake、Sublacustrine fan	Mainly corse grained sediments, minor surce rock.
				LST-TST			

Fig.7. Fault Depression Stages and Corresponding Deposition Features of Wenchang in Lufeng Area

Depression shrinking period: It is the period when the activity speed of the controlled depression is relatively small. The steep slope of the fault basin at this period featured by braided river delta, while the gentle slope of the fault basin was dominated by meandering deltas and shore shallow lakes. The semi-deep lakes were distributed in the center of subsidence in an obviously shrinking distribution range.

In addition, the type of rocks deposited in different subsidence periods is also different (Figure 7). At the initial fault depression period, the sediments mainly include near-shore submarine fans and fan-delta sandy conglomerate. Because the sedimentary area is close to the source and the sediment transport distance is short, the coarse sediments with poor sorting features and roundness were dominant.

At this stage, the steep slope zone mainly consisted of the fast accumulated near-source coarse sediments, while the gentle slope zone is mainly the coarse sandstone, and gravel-bearing coarse sandstone whose sorting features and roundness were superior to those of the steep slope.

The intensive depression period is the period with the largest range of lacustrine levels. At this period, the distance from the provenance to the depositional district is the furthest, so the sorting features and roundness of the sediments in the gentle slope belt were sound. The center of subsidence was dominated by the semi-deep lake dark shale deposits.

In the fault depression shrinking period, the lake basin range dwindled and the sediments in the gentle slope belt were dominated by fine sand shales from the shore shallow lakes and deltas. The granularity of the sediments was fine, and the sorting features were mediocre. The roundness is featured by sub-roundness and sub-angular shape.

4.2 Episodic Activity of the Fault-sag Period

The fault-sag stage can also be divided into initial fault depression period, rapid fault depression period, intensive fault depression period and fault depression shrinking period. The activity velocity of the boundary faults at the initial fault depression period was small, so the sag sediments were very limited, which were dominated by the delta and shore shallow lakes. In addition, semi-deep lake sediments were developed in regional areas (Figure 8). In the rapid depression period, the activity velocity of the boundary faults quickened obviously and the sedimentary area of the sag also increased, which was dominated by the delta and shore shallow lakes. The activity velocity of the boundary faults reached its maximum in the intensive depression period, and the lacustrine levels also reached its maximum. The sedimentary facies types were mainly consisted of delta and shore shallow lakes. The activity velocity of the boundary faults slowed down gradually in the fault depression shrinking period, but the sedimentary area of the lake basin did not dwindle. At this period, the delta and shore shallow lake sediments were dominant (Figure 8).

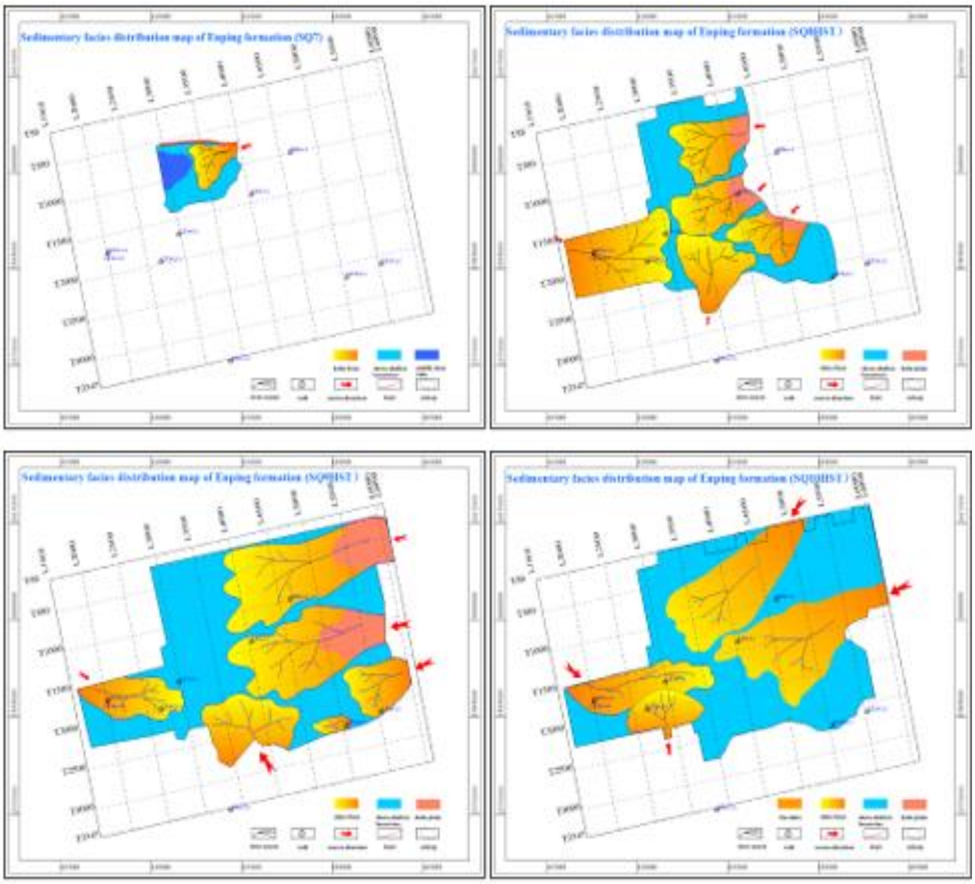

Fig.8. Facies Distributions of Enping Formation in Lufeng Area

5 Sedimentary Reflection at the Fault-depression Stage

The tectonic activity has obvious control effect on the sedimentary facies [12-15]. The sedimentary characteristics can also reflect the tectonic evolution features, for example, during different fault depression periods, the fan body types and their distribution types are significantly different. The variation rule of the fan body range can also reflect the characteristics of the episodic activity of the fault depression.

5.1 Fault-depression Period

There are a variety of fan types at the fault depression period, including developed fan delta, nearshore underwater fan, sublacustrine fan, braided river delta and meandering river delta. The fan delta and nearshore under fans were mainly distributed in the downthrown side of the boundary fault, which were extensively developed during the initial fault depression period, rapid fault depression period and intensive fault depression period. The sublacustrine fan was widely distributed in the semi-deep lake and deep lake at the rapid fault depression period and the intensive fault depression period. The braided river delta was mainly distributed in the gentle slope belt of the faulted basin, and was extensively developed during the initial fault depression period, the rapid fault depression period and the intensive fault depression period. The meandering river delta was mainly developed in the gentle slope belt of the faulted basin, and was extensively developed in the fault depression shrinking period.

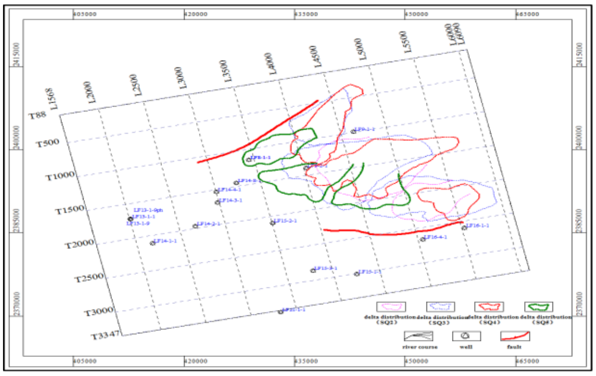

Fig.9. Delta Distribution Scope of Different Stage of Fault Depression in Lufeng Area

There are significant differences in the distribution range of fan bodies during the fault depression period. The fan was mainly distributed in the local area of the sag during the initial depression period. Since the sediment provenance supply was sufficient during the rapid fault depression period, the fan bodies were distributed more extensively. However, their distribution range dwindled during the intensive fault depression period due to the expansion of lacustrine level and insufficient sediment provenance supply. During the weak fault depression period and fault depression shrinking period, the distribution range of the fan bodies expanded thanks to the sufficient sediment provenance and the decline of the lacustrine level (Figure 9).

5.2 Fault-sag Period

The type of fan bodies at the fault-sag period is simple, but the distribution range of the sub-fan bodies vary. The delta was developed in the initial fault depression period, rapid fault depression period, intensive fault depression period and depression shrinking period. But the fan delta was seldom seen. The distribution range of the delta changed greatly during the fault-sag period. The distribution of the delta was quite limited at the initial depression period. The delta was mainly distributed in local area of the sag. However, its distribution range expanded rapidly at the rapid fault depression period due to sufficient sediment provenance. At the intensive fault depression period, the lacustrine level expanded and the sediment provenance was insufficient, so the fan bodies flinched towards the sediment provenance and had a very limited distribution range. At the fault depression shrinking period, the delta distribution range expanded again due to sufficient sediment supply and declining of the lacustrine level.

5.3 Similarities and Differences of Sedimentary Reflection during the Fault-depression Period and Fault-sag Period

There are significant differences in the sedimentary facies types and fan distribution range of the fault basin at the fault-depression period and fault-sag period. There are a variety of fan types at the fault depression period, including fan delta, nearshore subaqueous fan, sub-lacustrine fan and delta, while the fan types were very simple at the fault-sag period when only the delta was developed. The distribution range of the fan bodies was relatively small at the fault-depression period, but the thickness of the fan was larger. The distribution range of the fan bodies was large at the fault-sag period, but the thickness of the fan was relatively small. In addition to the effect of the tectonic activity on the fan features, the ancient landform also had an important impact on the distribution rules of the fan bodies. At the fault-depression period, both of the center of subsidence and the depocenter were located at one side of the boundary fault of the fault basin (Figure 10) and the area of the lacustrine basin was small. The terrain elevation difference was large and the water body depth was large. At the fault-sag period, the center of subsidence of the lacustrine basin was mostly situated in the center of the basin (Figure 9). The area of the lacustrine basin was small, but the terrain elevation difference was small and the water body was shallow.

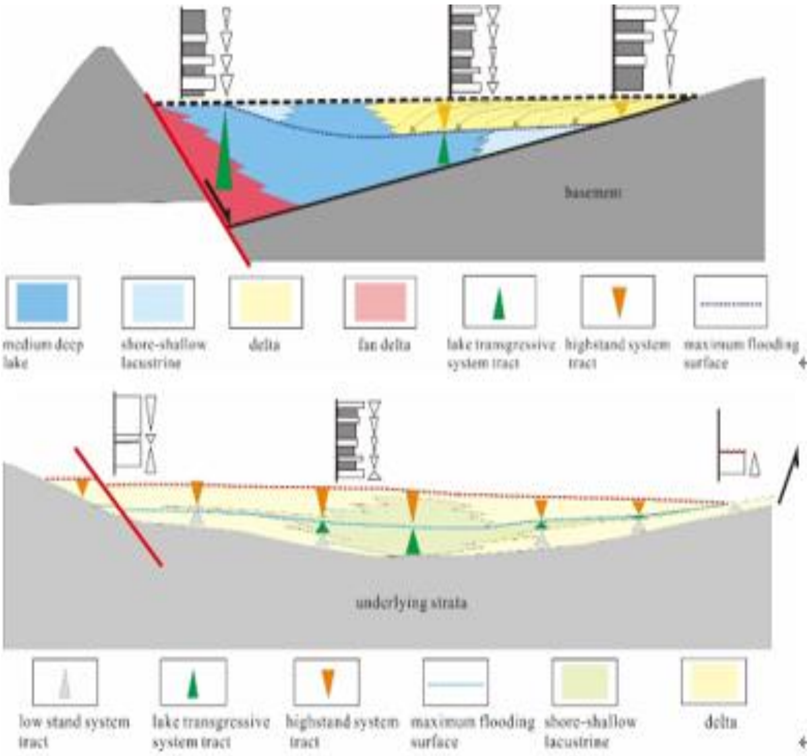

Fig.10. Deposition Feature of Fault Depression(upper) and Fault Sag(below)

Tab.1. Similarities and Differences of the Sedimentary Reflection at Different Stages of the Fault-depression Period and Fault-sag Period

Stages	Similarities	Differences
Initial fault depression period	The fan bodies were small and water was shallow	Wenchang Formation featured fan delta and near-shore submarine fan and was controlled by the faults; Enping Formation featured delta and was slightly affected by the faults
Rapid fault depression period	The fan bodies expanded and moved towards the basin	There were many types of fan bodies in Wenchang Formation. The scale of the delta was small, but the thickness was large. They were controlled by the faults; Enping Formation features delta. The deltas were of large scale and extended far. But the thickness was small and the impact of the faults was small.
Intensive fault depression period	The fan bodies retreated to the provenance direction and the scale dwindled	Wenchang Formation features delta, fan delta and lacustrine fan. The thickness of the fan body was large and the fan scale was small; Enping Formation features delta, and the fan body scale was large, but the thickness was small.
Fault depression shrinking period	The fan bodies moved towards the basin, and the scale enlarged	Wenchang Formation features delta with small scale and large thickness; Enping Formation features delta with large scale and small thickness

Both the fault-depression period and the fault-sag period can be divided into initial depression period, rapid depression period, intensive depression period and depression shrinking period. The sedimentary characteristics of different tectonic activities also have similarities. The distribution range of the fan in the initial fault depression period was small and the grain size of the sediments was coarse. The distribution range of the fan both rapidly expanded and the supply of the provenance was both sufficient at the rapid fault depression period. The area of the lacustrine level expanded and the distribution range of the fan retreated towards the provenance at the intensive depression period. At the fault depression shrinking period, due to the sufficient provenance supply, the distribution of the fan bodies both expanded (Table 1, Figure 8, and Figure 9).

Conclusions

(1) Wenchang Formation features the sediments of the fault basin at the fault depression period and Enping Formation features the sediments of the fault-sag period. Both the fault-depression period and the fault-sag period can be further divided into four stages: initial fault depression period, rapid fault depression period, intensive fault depression period and fault depression shrinking period;

(2) 11 sequence boundaries can be identified in Wenchang Formation and Enping Formation of Lufeng Depression and 10 third-order sequences could be divided, including 6 in Wenchang Formation and 4 in Enping Formation;

(3) The sedimentary facies in Wenchang Formation at the fault depression period include fan delta, lacustrine fan, delta and lacustrine facies; the sedimentary facies in Enping Formation at the fault-sag period include delta facies and lacustrine facies, therefore, Wenchang Formation has richer sedimentary facies compared with Enping Formation;

(4) The distribution range of the delta fan at different stages of the fault depression period and the fault-sag period stage has the same variation rule, that is, the distribution of the fan in the initial fault depression period was limited, the distribution range of the fan expanded at the rapid fault depression period, the distribution range of the fan dwindled at the intensive fault depression period and it expanded at the fault depression shrinking period. At the intensive fault depression period, the fan body retreated to the provenance area.

References

1. S.Q. Hu, W.P. Guo, Discussion on play types and their distribution regularities in steep slope zone of faul-t depressed lacustrine basin, 2002, Geological Journal of China Universit ies, vol. 8, no. 2, pp. 190-195.

2. Q.L. Xin, Z.R. Liu, Q. Jin, Tect onic Facies Analysis in Hydrocarbon- Bearing Basin, 2013, Beijing: Geological Publishing House.
3. S.M. Yu, L.F. Mei, H.S. Shi, Relationship between faults and hydrocarbon accumulation in Panyu low massif and north slope of Baiyun Sag, Pearl River Mouth Basin, 2007, Petroleum Exploration and Development, vol. 34, no. 5, pp. 562-564.
4. S.D. Miao, G.C. Zhang, J.S. Liang, Seismic reflection characteristics and sedimentary environment analysis of Wenchang formation in northern depression of Zhujiangkou basin, 2010, Nature Gas Geoscience, vol. 21, no. 5, pp. 844-846.
5. W.L. Zhu, G.C. Zhang, L. Gao, Geological characteristics and exploration objectives of hydrocarbon s in the northern continental margin basin of South China Sea, 2008, Acta Petrolei Sinica, vol. 29, no. 1, pp. 1-9.
6. C.Y. Liu, P.B. Zhou, Y. Zeng, An analysis of the main controls on Neogene hydrocarbon accumulation in Panyu 4 sag, 2009, China Offshore Oil and Gas, vol. 21, no. 2, pp. 91-94.
7. Q.L. Wei, R.C. Zheng, H.H. Shi, High resolution sequence stratigraphic characteristics of the Paleogene Zhuhai formation in Huizhou depression marine delta, 2008, ACTA Sedimentologica Sinica, vol. 26, no. 5, pp. 744-748.
8. G.J. Chen, C.F. Lu, Y.L. Li, Analysis of the oil and gas-bearing turbidite within Wenchang formation in Enping depression, Pearl River Mouth basin, China, 2008, ACTA Sedimentologica Sinica, vol. 26, no. 5, pp. 744-748.
9. L. Shao, Y.C. Lei, X. Pang, Tectonic evolution and controlling for sedimentary environment in Pearl River Mouth Basin, 2005, Journal of TongJi University (Natural Science), vol. 33, no. 9, pp. 1178-1181.
10. H.Y. Lu, Y.C. Cao, Z.X. Jiang, The basic equation of sedimentation and its application in rift lake basin, 2008, Petroleum Exploration and Development, vol. 30, no. 3, pp. 19-22.
11. R.H. Pu, Advances of sequence stratigraphy for rift lake basin, 2002, Oil and Gas Geology, vol. 23, no. 4, pp. 410-413.
12. Y. Sun, B.Z. Xian, H.X. Lin, Division of sedimentary cycle of sand gravel rock mass in steep slope of faulted lake basin, 2007, Oil Geo physical Prospecting, vol. 42, no. 4, pp. 468-473.
13. S.Q. Hu, W.P. Guo, Discussion on Milankovitch orbit cycle in high frequency sequence of terrigenous sequence in fault depressed lacustrine basin, 2002, ACTA Scientiarum Naturalium Universitatis Sunyatseni, vol. 41, no. 6, pp. 91-93.
14. L.W. Yang, Z.X. Jiang, Y.C. Cao, The accommodation transition in faulted lake basin, 2009, ACTA Sedimentologica Sinica, vol. 27, no. 2, pp. 300-305.

15. Y.L. Ji, S.Q. Zhang, The sequence stratigraphy of terrestrial rift lacustrine basin, 1996, Beijing: Petroleum Industry Press.