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Characteristics of abnormal high pressure in Linnan Sag and its formation mechanism

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Abstract:The Linnan Sag is located in the west of Jiyang Depression in the Bohai Bay Basin, and its Shahejie Formation has developed significant abnormal high pressure. Based on logging data and measured pressure data, this paper discusses the development characteristics of abnormal high pressure; clarifies the cause mechanism of abnormal high pressure; the study found that abnormal high pressures are generally developed in the the Es3z and Es3x and the Es4s in the depression area, and the pressure coefficient is 1.1~1.4, and the development of abnormal high pressure in the center of the depression is particularly remarkable, and the remaining pressure is above 20MPa. The central uplift belt and southern slope in the northeastern part of the study area showed a normal pressure state as a whole, and isolated small abnormal high pressure systems developed locally. The most important cause of the abnormal high pressure in the Shahejie Formation may be the transmission of overpressure caused by the undercompaction of mudstone, and on this basis, the pressurization caused by hydrocarbon generation and dehydration of clay minerals is superimposed.

Key Words: Abnormal high pressure; controlling factors; development characteristics; Shahejie Formation; Linnan Sag

After years of research by domestic and foreign scholars , the causes of abnormal high pressure mainly include physical, chemical, and geological dynamic factors[1-5]. Formation pressure prediction can be divided into prediction methods using seismic data, drilling data analysis methods and geophysical logging methods[6,7].

After years of oil and gas exploration and development, the oil and gas resource potential of the middle and shallow layers is declining, which is difficult to meet the needs of production. The characteristics of the abnormal high pressure developed in the Shahejie Formation and its genesis are still unclear, which hinders Further deepening of exploration work. The research on the development characteristics and genetic mechanism of abnormal high pressure will guide the future exploration in depth.

1 Regional geology

The Linnan Sag is located in the Huimin Sag in the southern part of the Bohai Bay Basin. The overall shape of the Linnan Sag is wide in the west and narrow in the east, with a slightly inclined trapezoid, with a total area of about 1,300km2. The northwestern part of the Linnan Sag is adjacent to the central uplift zone, the southeast part is adjacent to the Qudi Horticultural Zone, and the south part is the Luxi Uplift (Figure 1)[8-10]. The Linnan Sag experienced the fault depression period of the Paleogene and the fault depression period of the Neogene, and deposited the Shahejie Formation (Es), Dongying Formation(Ed), Guantao Formation (Ng), Minghuazhen Formation (Nm)and the fourth series(Q). Among them, Shahejie is composed of the Es1, the Es2, the Es3, and the Es4. The lithology is mainly sandstone and interbedded sand and mudstone, and the stratum thickness is about 1800m.

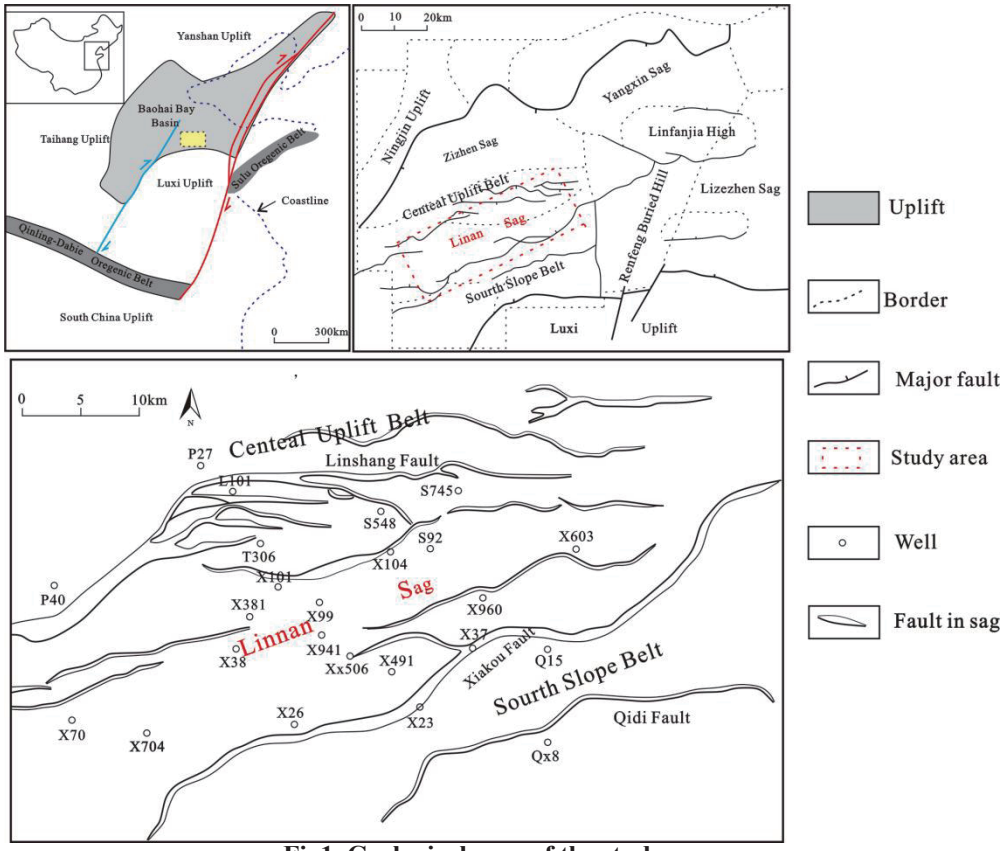

Fig1. Geological map of the study area

2 Developmental characteristics of abnormal high pressure

2.1 Single well development characteristics

According to the measured data of the drill pipe test,The formation pressure of X941 at a depth of about 3840m is about 70MPa, the overpressure is about 30MPa, and the geological horizon is Es3x. After predicting the formation pressure of Well X941 according to the balanced depth method, it is found that the abnormal high pressure develops significantly below the depth of 3000m , and the geological horizon is Es3z and Es3x . The sensitivity response of the abnormally high pressure section to the compensation neutron and density logging curve further confirms the correlation between the hypersonic jet lag and the abnormal high pressure. The Es3x and Es4s are the geological horizons with significant development of abnormal high pressure. The excess pressure is generally 5 ～ 20MPa.

2.2 Plane development characteristics

The results show that with the increase of burial depth, the formation pressure in the Es3x increased sharply, and the development range of abnormal high pressure also further increased. The vicinity of Well X381 is the center of abnormal high pressure development, with a pressure coefficient of more than 1.45. In addition, small-scale abnormalities of high pressure also developed in the eastern part of the sag center. Around X48 is the center of abnormal high pressure, with a pressure coefficient of over 1.25. The central uplift belt in the northeastern part of the sag and most of the southern slope show normal pressure .

3 Causes of abnormal high pressure

3.1 Mudstone undercompaction

The Linnan Sag deposited thick clastic rocks during its geological evolution. Among them, the thickness of the Shahejie Formation, where the abnormally high pressure is developed, is about 1800m, and the lithology is mainly sandstone and interbedded sand and mudstone. During the Es3 , the internal water body of the Linnan Sag was deeper in the north and shallow in the south, and the settlement center was near Linyi in the northern part of the depression. During this period, semi-deep lakes and deep lake deposits dominated by large sets of oil shale and dark mudstone developed. Among them, the Es3z and Es3x are under-compensated deposits due to strong faults. Deep lacustrine mudstones are widely developed and distributed in a region. The buried depth is generally greater than 2500m, the average thickness is about 196m, and the maximum thickness is 420m (Table 1). Starting from the upper part of the fourth section of the Shahejie Formation, the depressions and depressions have entered a new developmental period. Due to the adjacent peripheral uplift and sufficient source replenishment, the sedimentation rate is about 200m/Ma; the basin rifting during the sedimentary period of the third member of the Shahejie Formation is enhanced, and the sedimentation rate is as high as 400-600m/Ma. The above-mentioned geological conditions are entirely possible to cause under-compaction of mudstone in the Linnan Subsag, and thus the formation of abnormally high pressure in the Shahejie Formation.

Table1: Mudstone thickness table of Shahejie Formation in Linnan Sag

Level		Es1	Es2	Es3s	Es3z	Es3x	Es4
Mudstone Thickness/m	Average	95	136	169	196	70	79
	Maximum	217	356	408	420	160	123

3.2 Hydrocarbon generation

The source rocks in the Linnan Sag are widely developed. Among them, the sedimentary period of the middle Es3 sub-member has the widest water area and the deepest water body. The upper part is dark gray mudstone with oil shale, the middle part is dark mudstone and oil shale concentrated section, and the lower part is the interbedded dark mudstone and oil shale. Oil shale and dark mudstone have the largest thickness, with an average thickness of about 196m and a maximum thickness of 420m. The Es3z is the most important high-quality source rock in the Linnan sag.

Taking the abundance of organic matter in the Es3z as an example, the organic carbon content is relatively high, ranging from 0.4 to 7.1%, with an average of 1.55%. Most of the source rock organic carbon is greater than 1.0%, and the deposition center is greater than 2.0%. The organic carbon content of the oil shale in S744 well is as high as 7.10%. The average organic carbon content in the Es3x is 1.39%. On the plane, the organic carbon value of each layer is higher in the north and lower in the south, and high-quality source rocks are widely distributed. The content of chloroform asphalt "A" in the Es3z and Es3x is relatively high, and the content of chloroform pitch "A" in the the Es3z and Es3x is between 0.02 and 1.61%, with an average of 0.4196%. On the plane, the "A" value of chloroform pitch is higher in the north and lower in the south. Most of the chloroform pitch "A" value is greater than 0.2%, and the deposition center can reach 0.3%, for example, the S51 well reaches 0.7%. The content of chloroform asphalt "A" in the Es3x is high, with an average of 0.1989%.The hydrocarbon generation potential measured by the pyrolysis method has a good correlation with the organic carbon content, and the hydrocarbon generation potential of the Es3z and Es3x is higher. The hydrocarbon content increases with the degree of thermal evolution, and the content of the the Es3z and Es3x is high, reaching 50% to 65% of the chloroform pitch "A".The main source rock section of the Linnan sag is mainly composed of type II kerogen, which has a great potential for hydrocarbon generation. Among the organic microscopic components of the butterroot samples, the stable components (the saprolite group and the chitin group) are absolutely dominant, the vitrinite group content is low, and the inert group content is extremely low. This indicates that the type of hydrocarbon-generating parent material is good, mainly oil-type kerogen(Table 2).

Osborne and Swarbrick believe that the abnormal high pressure is affected by the type, abundance and thermal

evolution of organic matter[11]. Kerogen, which accounts for 10% of the volume of the source rock, can generate a pressure of about 10Mpa during thermal evolution. Organic matter hydrocarbon generation, especially cracking and gas generation, and the accompanying large amounts of CO2 and CH4 dissolving carbonate rocks and forming barriers are important mechanisms for the formation of abnormal high pressures. The approximate depth of the source rocks in the Linnan sag entering the mature stage is about 2500m, and the geological horizon is in the Es3s; the hydrocarbon generation peak is 3000-4200 m, and the geological horizon is in the Es3z and Es3x and Es4s. Due to the overlap between the hydrocarbon generation horizon and the abnormally high pressure development horizon, it can be roughly inferred that the hydrocarbon generation may cause the abnormal high pressure in the Linnan Sag.

Table2: Comprehensive table of organic matter type parameters

Well	Sub-member	TOC %	IH mg/g	IO mg/g	Type	Sapropelinite% %	Exinite%	Vitrinite%	Inertinite% %
X38	Es1	4.87	551		I				
S74	Es2	1.51			IIa	72.00	8.70	18.70	0.70
S641	Es3s	1.38	327		IIa	55.30	39.70	1.30	3.70
S51	Es3s	1.72			IIa	74.30	7.00	17.30	1.30
X38	Es3z	1.73			IIa	32.70	67.30		
L82	Es3z	2.01	335		I				
L86	Es3z	2.24			I				
X38	Es3z	1.14	188		I				
L80	Es4	0.97	204	84	IIa				

3.3 Clay mineral dehydration

There are a large number of clay minerals such as illite and Imonite mixed layers in the Shahejie Formation of the Linnan Sag. During the diagenesis process, the conversion of montmorillonite to illite will release a large amount of interlayer water and adsorbed water, which is sealed the formation caused an increase in interlayer pressure, and it can be inferred that the dehydration of clay minerals assisted the formation of abnormal high pressure

4 Conclusion

(1)Abnormal high pressure is generally developed in the Shahejie Formation of Linnan Sag. The abnormal high pressure in the center of the depression is particularly significant, and the pressure gradually weakens to normal pressure from the center of the depression to the surrounding slope and uplift areas. The horizons appearing on the top surface of abnormal high pressure in different areas of the depression are roughly located in the middle and lower sub-members of Shahejie Formation. The excess pressure is generally between 5 and 20 Mpa, and the pressure coefficient is between 1.1 and 1.4.

(2)The strong rifting in the sag resulted in the rapid deposition and burial of argillaceous sediments. The undercompaction of mudstone formed the background of the abnormally high pressure in the Shahejie Formation. The organic matter type, abundance and maturity of the two main source rocks in the Es3x and the Es4s determine the significance of hydrocarbon generation on pressurization.The dehydration of clay minerals promotes the development of abnormal high pressure.

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