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Sandstone bodies distribution in sequence stratigraphic framework of Jurassic Sangonghe formation in Moxizhuang area, Junggar basin

Based on Vail's classical sequence stratigraphy theory, the sequence stratigraphy framework of Jurassic Sangonghe formation in Moxizhuang area is studied by using outcrop, logging and logging data. The first flooding surface (FFS) and the maximum flooding surface (MFS) at both sequence boundary and sequence interior are identified.The Sangonghe formation is divided into 2 third-order sequences to identify the low stand systems tract (LST), transgressive system tract (TST) and high stand systems tract (HST). Due to the mutual cutting and superimposition of multi-stage channel sand bodies, the connectivity of subaqueous distributary channel sand bodies in SQ2 sequence of Sangonghe Formation is good, especially in the sedimentary period of fan delta front in the LST of SQ2 sequence. JSQ1 sequence is mainly the development of meandering river point bar sand bodies; The sand bodies in the LST of JSQ2 sequence are mainly developed in the subaqueous distributary channel of the fan delta front. The HST of JSQ2 sequence is mainly the development of sand bodies in shallow lakes and bars. According to the development and evolution of sand bodies in the two sequences of the Sangonghe formation, places atwells Z101 - Z105, Z3 - Z5 and Z102 - Z103 are areas where sand bodies are developed intensively.

Keywords: *Junggar basin; Moxizhuang area; Sangonghe formation; sequence stratigraphic framework; system tract; sandstone bodies distribution.*

Introduction

The Jurassic Sangonghe formation in Moxizhuang area of the central Junggar basin is the main exploration formation of Shengli oilfield in the deep layer of western basin. Since the discovery of oil and gas in 2002 in this area, rich oil and gas shows have been obtained from more than 20 exploratory completed wells with the accumulated and proved geological reserves up to 10 million tonnes, thus it has good prospects for oil and gas exploration [1-2]. With the constantly deepening of exploration and development work, the strong heterogeneity of reservoirs makes the distribution law of oil and gas complex in space, with no ideal development effect and generally low oil and gas production. Among them, the sand bodies of the reservoir changes frequently in the lateral direction, with obvious spatial heterogeneity, causing unclear understanding of genetic types and distribution characteristics of the oil-bearing sand bodies, which seriously restricts the exploration and development process of Moxizhuang oilfield. To this end, the authors have carried out the detailed geological research on sedimentary reservoir in Moxizhuang area in response to the above problems so as to make the distribution characteristics of genetic sand bodies in each reservoir clear under the constraints of isochronous sequence stratigraphic framework and provide technical support for the exploration and development of similar reservoirs.

1. Regional geological background

The Junggar basin is located in the core stable zone of the Junggar-Tuha block. It is a composite superimposed basin in the continental plate developed from the Late Carboniferous System in the Quaternary. The central exploration area of the Junggar Basin mainly includes the main part of central uplift, central depression, Luliang uplift and Ulungur depression. The study area is located in the southeastern part of the depression to the west of Well Peng-1 at the central depression zone of the Junggar basin and is adjacent to the Maqiao convex in the east [3-4] (Fig.1).

As the target formation of the study, the Sangonghe formation is the largest sedimentation in the transgression period of the Jurassic in the basin. It is dominated by gray mudstone, argillaceous siltstone and marl and mixed with yellow-green medium and fine sandstones that are generally 100-700 m thick and integrated with and contact the underlying Badaowan formation. The Sangonghe formation is widely exposed at the basin margin. The profile of the Sangonghe formation at the southern margin is composed of 4 sets of extremely thick gray-green, yellow-green block sandstones and large sets of dark gray, gray-green silty mudstones, as well as gray-yellow, gray-green medium-thick layered fine siltstone interbedding, in which the upper and

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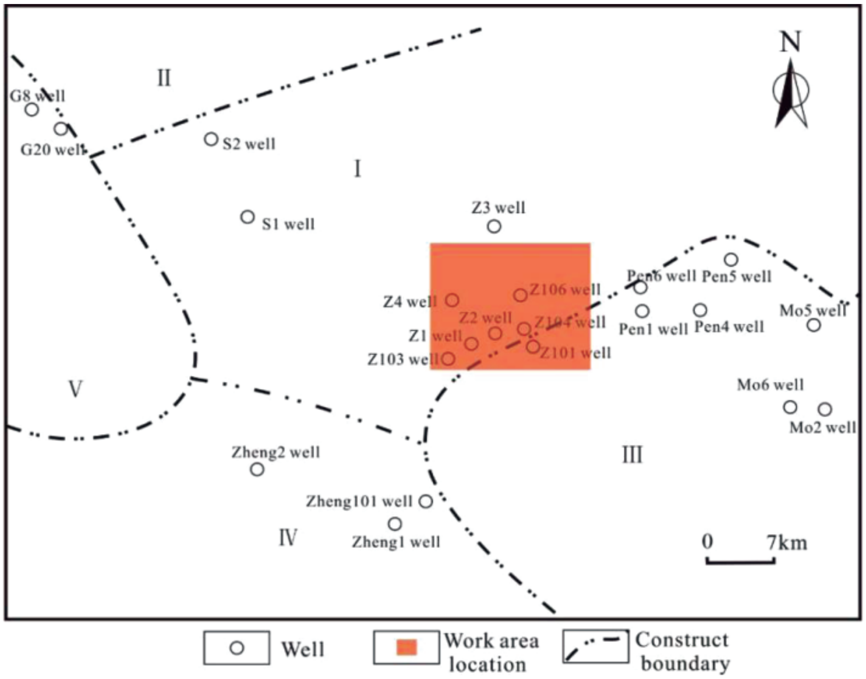

I - Pen 1 well west depression; II - Dabason bulge; III - Maqiao bulge; IV - Changji depression; V - Zhongguai bulge

Fig.1 Location of the studied area

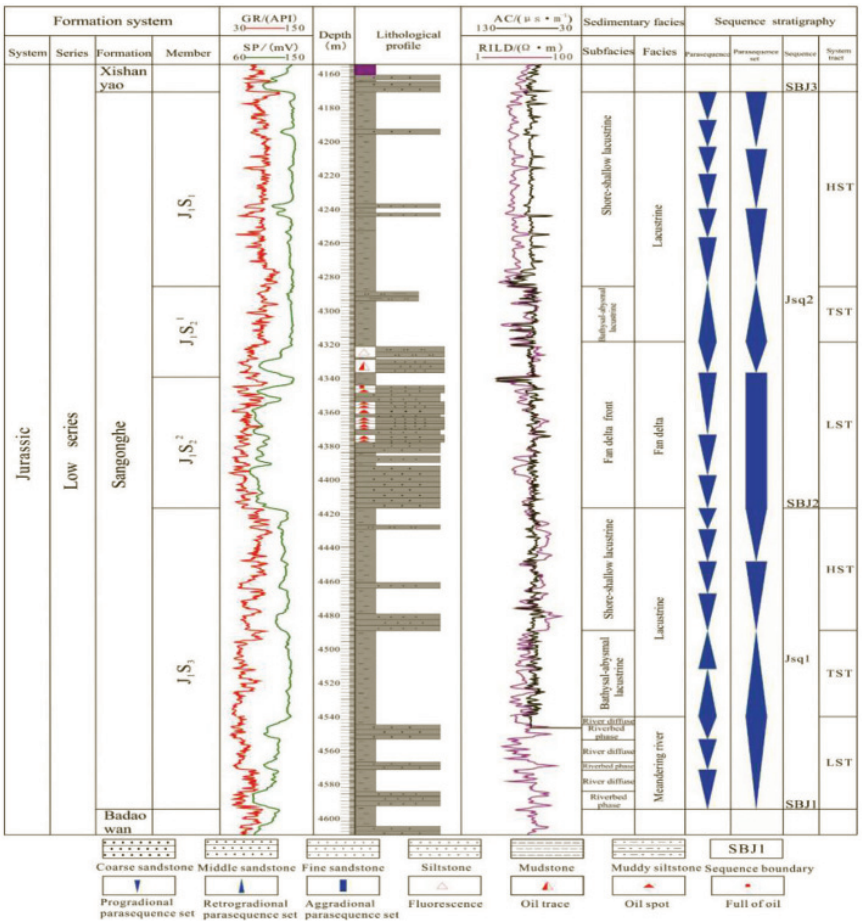

Fig.2 Synthetical histogram of stratum of Jurassic sangonghe formation in zhuang 2 well, moxizhuang region

lower 2 sets of fine-grained sediments are mixed with gray-black carbonaceous mudstone or coal streak. Generally, the fluvial-delta – lacustrine facies sedimentary deposits are the main formations, with no trace of industrial coal seams. In the Sangonghe-Manas river and most areas under the well in the basin, the Sangonghe formation can be divided into three members according to its lithology: Sangonghe Section 1 (J1s1), Sangonghe Section 2 (J1s2) and Sangonghe Section 3 (J1s3) [3,5-6].

2. Sequence strata division and comparative analysis

2.1 Recognition of sequence boundaries

On the basis of digesting and absorbing the regional sedimentary evolution law, and referring to the data of logging in the area and outcrop in the field, the sequence boundary of Sangonghe formation in Moxizhuang area is identified and divided by using Vail's classical sequence stratigraphy theory and method [7-8].

Three types I sequence interfaces (S BJ1~S BJ3) have been identified in the Sangonghe formation in Moxizhuang area from bottom to top, all of which have obvious sedimentary discontinuities and exposure signs. The rapid decline rate of the lake plane exceeds the sedimentation rate of the "sedimentary shoreline slope break zone", which affects the formation of sequence boundarie. It is usually manifested as the transformation interface of sedimentary facies associations, with the logging curve changing from low amplitude straight to saw toothbox or bell shape abruptly.

Boundary of SBJ 1 is the interface between Badaowan formation and Sangonghe formation. Dark gray and gray black mudstone is distributed on the top of Badaowan formation, and the natural gamma value is obviously higher, while meandering river point par sandstone is distributed at the bottom of the second member of Sangonghe formation, and the natural gamma curve is toothed box type, as shown in Fig.2.

Boundary of SBJ 2 is located at the bottom of the second member of

Sangonghe formation, which is a sedimentary transformation surface. The gray-black mudstone of coastal lake facies is distributed under the interface, while the large overlapping sandstone of underwater distributary channel in fan delta front is above the interface. The natural potential curve changes from straight below the interface to box-shaped negative anomaly above the interface, as shown in Fig.2

Boundary of SBJ 3 is the interface between Sangonghe formation and Xishan Kiln formation, which is also the sedimentary transformation surface. Gray-black mudstone of shallow lake facies is distributed in the lower part of the interface, while meandering river facies point bar sandstone is located in the upper part of the interface. Natural gamma shows a high value below the interface and a dentate low value above. Similarly, the natural potential curve also abruptly changed from a straight high value below the interface to a box-shaped low value above the interface, as shown in Fig.2.

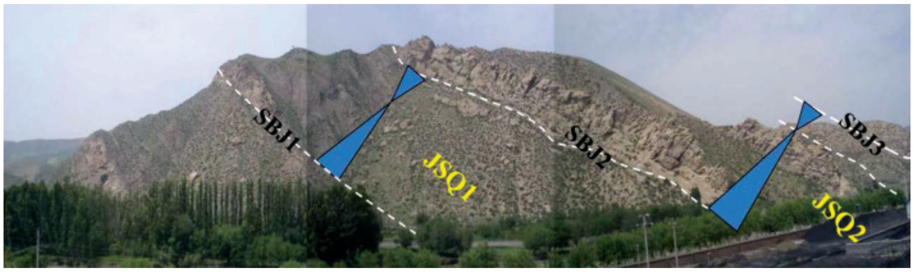

Fig.3 Section of Sangonghe formation in Sangonghe township, fukang city

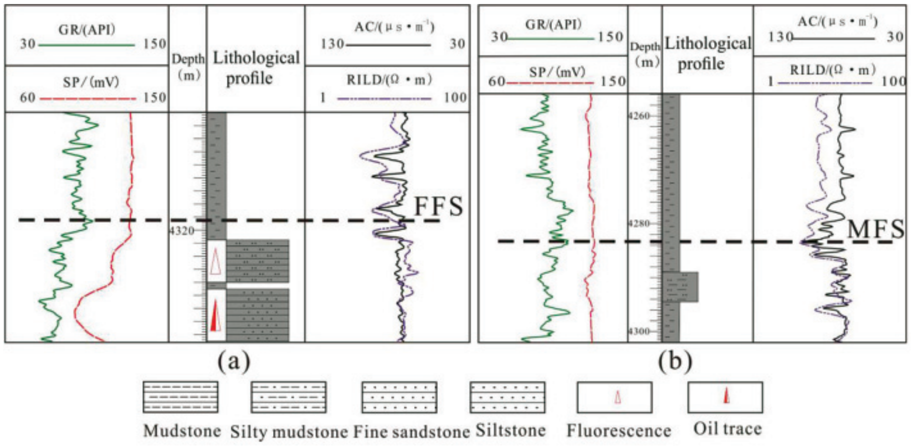

Fig.4 Drilling identification marks of FFS and MFS of Jurassic Sangonghe formation in Moxizhuang area

The field profile has a good correlation with the sequence in hinterland of the basin. Taking the Sangonghe section in Fukang as an example, the Sangonghe formation in this section can also identify two third-order sequences, and the lithologic association has a good correspondence with the underground, as shown in Fig.3.

2.2 Recognition of the first flooding surface(FFS) and the maximum flooding surface (MFS)

The first flooding surface is the surface that begins to return quickly after the lake level drops to its lowest point. It is formed when the formation datum or lake level starts to rise again and the sediment supply rate is less than that of the available space. The first lake flood surface in Moxizhuang area is developed in both sequences, showing the transition from meandering river channel beach deposit or fan delta underwater distributary channel deposit to semi-deep lake mudstone when the accommodation space is low. Mudstone, carbonaceous mudstone and isolated natural dike sand body deposits above the channel deposit can be used as identification marks for the first lake flood surface.The logging curve shows a sudden change from progradation or aggradation to mudstone baseline (Fig.4a).

The maximum flooding surface is a relative equilibrium surface when the lake level rises to the maximum, and in continental basins it is mainly a set of quasi-sequence deeper-water deposits advancing toward the land and away from the land bank when the supply of terrigenous debris is insufficient [9]. The MFS deposits are found in both sequences in Mosizhuang area,which were composed of mudstone, silty mudstone, etc. From the perspective of the evolution of sediment grain size, the MFS is located at the position with the the most fine-grained size, its lower grain size tends to be finer upward, and its upper grain size tends to be coarser downward. From the view of the formation stacking pattern, the MFS is at the position where the retrogradation stacking pattern changes to the progradation or the accretion, and that is within the mudstone baseline of the large section of the natural potential curve and the peak position of the natural gamma curve on the logging curve (Fig.4b).

2.3 Recognition of parasequence and parasequence set

2.3.1 The recognition of parasequence

Parasequence is a stratigraphic unit composed of several strata or rock formations that are related in origin, and the stratigraphic scale is equivalent to six levels of sedimentary cycles. Each parasequence generally has the characteristic of gradually shallowing-upward sedimentary water body, which is characterized by the upward thinning of grain size in the study area and mainly develops in the beach-flood beach microfacies of the third member of Sangong river and the underwater distributary channel-inter-channel microfacies of the second member of Sangonghe fan delta.

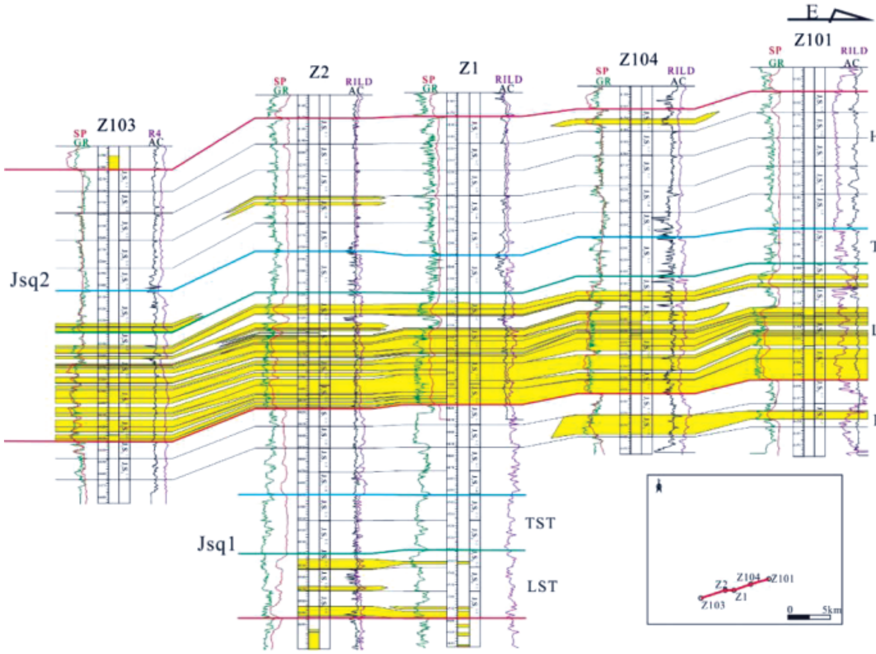

Fig.5 Comparative profile of sand bodies in Sangonghe formation of Well Zhuang 103 - Zhuang 101 in Moxizhuang area

The parasequence is a stratigraphic unit composed of multiple rock formations or rock formation groups related to genesis. The stratigraphic scale is equivalent to the Grade VI sedimentary cycle. Each parasequence has the characteristics of gradually shallowing-upward sedimentary water body. In the study area, the parasequence present significantly that its grain size become finer upward, and they mainly develop in the meandering river beach – floodplain microfacies of Sangonghe Member 3 and the underwater distributary channel-inter-channel microfacies of fan delta of Sangonghe Member 2.

2.3.2 Recognition of parasequence set

The parasequence set is a succession of genetically related parasequences, which form a distinctive stacking pattern that is bounded, in many cases, by marine flooding surfaces and its correlative surfaces. The stacking pattern of the parasequence is controlled by the ratio of the sediment replenishment rate to the new accommodation space rate.

In the Sangonghe formation of the Moxizhuang area, there is a parasequence set consisted of two parasequences vertically in different stacking patterns (Fig.5): (1) Aggradation parasequence set: It is vertically superimposed by a series of similar parasequences. There is no obvious change in the thickness of the parasequence and the sand body vertically. It is mainly located in the Sangonghe Member 2. The reaction water body is relatively stable. The sediment supply rate is approximately equal to the rate at which the new accommodation space is formed. (2) Retrogradation parasequence set: The parasequence gradually moves toward the land. The upward sand body becomes thinner. The water in the lake basin gradually becomes deeper. The sedimentation response of the logging curve is in normal graded bed sequence. Sangonghe Member 3 is visible, and the sedimentation rate of reactive sediments is less than the rate of new accommodation space. (3) Progradation parasequence set: The parasequence gradually migrates to the center of the basin and can be found in the upper part of the Sangonghe Member 1 and Member 3. It mainly deposits mud-rich fine-grained materials due to insufficient supply of sand bodies, without obvious reverse grain sequence characteristics.

2.4 Identification, Division and Characteristics of Sedimentary Systems Tract

The systems tract is a collection of a series of simultaneous sedimentary systems. Each systems tract is considered to be related to a specific section of the global lake surface changing curve. Therefore, it is necessary to use the lake surface rise change as an important basis for dividing the systems tract, and the intuitive sedimentary systems tract trichotomy shall be used [10]. According to this, the sequence of the Sangonghe formation in Moxizhuang area is divided into LST, lacustrine transgressive systems tract and high stand systems tract.

2.4.1 LST (LST)

The LST is formed in the early stage of sequence development at the bottom of Jsq1 and Jsq2 sequences. The bottom boundary is consistent with the bottom boundary of the sequence, and the top boundary is the FFS. The main facies association is the point bar sandstone and the fan delta front underwater distributary channel sandstone. The logging curve is in the form of a zigzag box or a bell and consists of one or several aggradation parasequence sets vertically (Fig.5).

2.4.2 Lacustrine transgressive system tract (TST)

The TST is formed in the middle stage of each sequence development, and the bottom and top boundaries are the first flooding surface and the maximum flooding surface respectively. The formation period is the expansion period of the lake. The sedimentary water body becomes deeper, and the area is enlarged. The new accommodation space is larger than the sediment supply volume, forming a sedimentary system characterized by lakeshore onlap. The facies association is characterized by the development of semi-deep lacustrine facies mudstones. The logging curve appears that

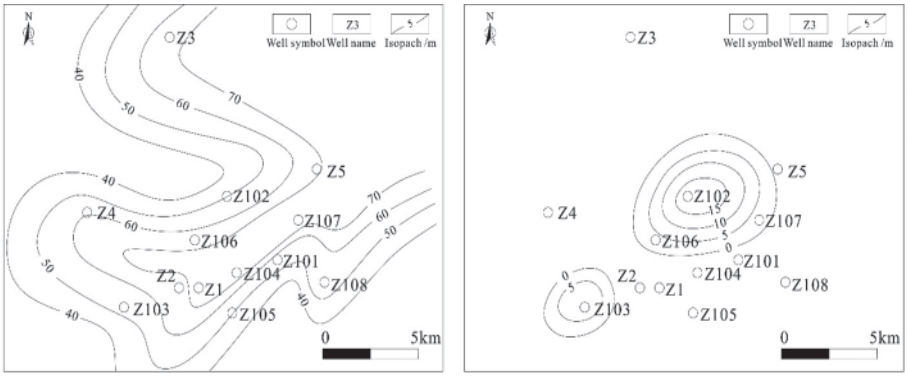

Fig.6 Horizontal distribution of Jsq2 sequence sand bodies in Moxizhuang area

the natural potential curve is straight and natural gamma logging curve has obvious tooth-like high values (Fig.5).

2.4.3 High stand systems tract (HST)

The HST is formed in the late stage of each sequence development. The bottom boundary is the MFS, and the top boundary is the top interface of the sequence. It is formed in the period when the lake begins to shrink and the water body becomes shallow. However, it mainly develops shore-shallow lacustrine facies mudstone and beach bar sand body combination due to the decrease of sediment supply in the study area during this period. The logging curve is a form of toothed funnel or finger (Fig.5).

2.5 SEQUENCE DIVISION AND ITS CONSTITUTION CHARACTERISTICS

The most commonly used data for single well sequence division and comparison are logging curve and lithology logging data 5 wells in different locations in the study area are selected for sequence division to reflect the sequence development characteristics in the area. The division follows the principle of large to small, that is, on the basis of third-order sequence division, the parasequences are divided with third-order sequence boundary as the constraint and the vertical evolution of sedimentary facies as the basis. The well Zhuang 2 is taken as an example to illustrate the sequence division of the Sangonghe formation. It can be seen from Fig.5 that the Sangonghe formation has two developed third-order sequences, including Jsq 1 and Jsq 2.

Jsq 1 has 9 developed parasequences, in which the LST consists of 3 parasequences, and the sedimentary facies are combined into the meandering river beach-flood plain to form an aggradation parasequence set. The TST consists of 2 parasequences, mainly semi-deep lake mudstone sedimentation; the HST consists of 4 parasequences, and the sedimentary facies are combined into the shore-shallow lake mudstone mixed with sand reef and beach bar sand.

Jsq 2 has 10 developed parasequences, in which the LST consists of 4 parasequences to form the aggradation parasequence set, and the sedimentary facies are combined into the superimposed fan delta front underwater distributary channel sand bodies.

2.6 CONNECTING-WELL SEQUENCE STRATIGRAPHIC ANALYSIS

Based on the single well sequence division, the well-connected comparison of sequence strata is carried out. A high-precision sequence stratigraphic framework in the north-south and east-west directions of the study area is established to provide a framework for tracking and prediction of reservoir sand bodies. The most important basis for the division and comparison of the parasequences is that the two adjacent wells have similar characteristics of rock and electricity combination, and the thickness changes smoothly or has a certain change trend.With the profile of Zhuang 103 - Zhuang 2 - Zhuang 1 - Zhuang 104 - Zhuang 101 well which is roughly parallel to the source direction taken as an example, the development characteristics of the sequence are analyzed (Fig.6). Zhuang 103, Zhuang 2, Zhuang 1, Zhuang 104 and Zhuang 101 are 5 wells located from west to east in the approximate east-west direction. Based on the logging curve cycle and lithology cycle analysis of single well, these wells are divided into 2 third-order sequences, 6 systems tracts and 19 parasequences in the Sangonghe formation during the sedimentary period. The parasequence can be compared to in these wells, with little change between wells and strong comparability, which indicates that the sedimentation of the Sangonghe formation is relatively stable during the sedimentary period [11].

3. Distribution law of sand bodies in sequence stratigraphic framework

3.1 CONNECTIVITY OF SAND BODIES

With the promotion of stratified mining technology, in the later development and water injection process, it is often the case that the injected water is not driven along the design horizon. The main reason is that the sand bodies of the designed water injection horizon are not isochronously deposited. For the subsequent development and production needs, it is necessary to study the sand body connectivity in the isochronous stratigraphic framework. According to the development of sand bodies in Moxizhuang area, the authors have prepared the profile map of 2 east-west sand body connectivity and the profile map of 2 north-south sand body connectivity. One of them runs east-west and passes through wells Zhuang 103 - Zhuang 101. the sand body conection profile is shown in Fig.5

The comparison of well-connected sand bodies shows that the Sangonghe formation SQ2 sequence enjoys good sand body connectivity, especially in the sedimentary period of the fan delta front in the LST of SQ2. The sufficient supply of sediment sources and strong hydrodynamic conditions enable the multi-stage channel sand bodies to cut and superimpose each other to form sand bodies that are connected to each other throughout the entire area. Early meandering river point bar of the SQ1 sequence enjoys good sand body connectivity. The sand bodies are not developed, with poor connectivity, due to the impact of combined action of source supply and lake level uplift in the middle and late stages. The beach bar sand bodies of the SQ2 sequence TST and HST are less developed, with poor sand body connectivity, and they are separated each other and distributed lenticularly.

3.2 Plane Distribution Characteristics of Sand Bodies

The reservoir properties of sand bodies mainly depend on the sedimentary environment in which the reservoir sand bodies are located and the location in the sequence stratigraphic framework [12-14]. The source of sedimentation of the Sangonghe formation is mainly from the northeast, and most sand bodies are produced in northeast bands and block mass.

In the Jsq 1 sequence, only Zhuang 1 and Zhuang 2 are completely drilled. From the drilling situation of such two wells, the sand bodies along the meandering river beach are mainly developed.

There are several relatively developed areas of sand bodies in the LST of Jsq 2 sequence, including Zhuang 3 - Zhuang 4 well area in the southwest, Zhuang 103 - Zhuang 106 - Zhuang 102 well area in the middle and Zhuang 105 - Zhuang 101 - Zhuang 107 well area in the northeast. The accumulated sand bodies in these well areas are thicker, generally 50-62 m, and the thickest one can reach 73.2 m, such as Z1 well area (Fig.6a). The lithology is mainly composed of light gray fine sandstone, medium sandstone and medium-fine grain sandstone. It has multiple inverse rhythm of lower fine and upper coarse and develops plate-shaped cross-bedding, massive bedding and parallel bedding. The sand body developed mainly in the subaqueous distributary channel deposits at the fan delta front.

During the sedimentary period of the HST of Jsq 2 sequence, the thickness of the sand body is obviously reduced. Most of the wells have no sandstone distribution. The sandstones relatively concentrate only in Zhuang 102 and Zhuang 103 and distributed lenticularly (Fig.6b). They are mainly composed of gray, light gray siltstones and argillaceous siltstones and develop wavy cross-bedding and horizontal bedding, with the main sand body development of shore-shallow lake sand bar.

Because the study area is far away from the source, the sand bodies of the HST of Jsq 2 sequence are less developed, only the beach bar sand bodies are locally developed, separated each other and distributed lenticularly.

To sum up, from the view of the development and evolution of the sand bodies in 2 sequences of the Jurassic Sangonghe formation, places at Wells Z101 - Z105, Z3 -Z5 and Z102~Z103 have sand bodies developing for a long time and are the areas where the sand body development is concentrated in the study area.

4. Conclusions

Outcrop, mud logging, well logging and other data are used to identify sequence boundaries, the MFS and FFS. The sequence stratigraphic framework of the Jurassic Sangonghe formation in Moxizhuang area has been established and divided into two third-order sequences, identifying LST, HST and HST.

The Sangonghe formation SQ2 sequence enjoys good sand body connectivity, especially in the sedimentary period of the fan delta front in the SQ2 LST. The sufficient supply of sediment sources and strong hydrodynamic conditions enable the multi-stage channel sand bodies to cut and superimpose each other to form sand bodies that are connected to each other throughout the entire area. Early meandering river point bar of the SQ1 sequence enjoys good sand body connectivity. The sand bodies are not developed, with poor connectivity, due to the impact of combined action of source supply and lake level uplift in the middle and late stages. The beach bar sand bodies of the SQ2 sequence LST and HST are less developed, with poor sand body connectivity.

JSQ1 sequence is mainly the development of meandering river point bar sand bodies; the developed sand bodies in the LST of Jsq 2 sequence is mainly found in the subaqueous distributary channel of fan delta front; The LST of Jsq 2 sequencemainly includes the developed sand bodies of shore-shallow lake sand bar. From the view of the development and evolution of the sand bodies in 2 sequences of the Sangonghe formation, places at Wells Z101-Z105, Z3 - Z5 and Z102~Z103 are the areas where the sand body development is concentrated in the study area.

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