Control of Anticline Crest Zone on Depositional System and Its Geological Significance for Petroleum in Changshaling, Ying-er Sag, Eastern Jiuquan Basin

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ABSTRACT: Yinger (营尔) sag is the main petroleum generative sag in eastern Jiuquan (酒泉) Basin, and only the Changshaling (长沙岭) oil resource has been found after 60 years prospecting. Changshaling anticline crest zone was formed above the regional uplift, and was slightly affected by over thrust during Tertiary Period. The anticline crest was identified as a structural transposition zone. Based on analysis of seismic facies, logging facies and seismic inversion technique, it has been demonstrated that anticline crest zone conducts drainage entering basin and dominates sedimentary detritus further dispersing, and the anticline crest zone controls the distribution of sand bodies and the development of sedimentary system consequently. The sequence stratigraphic patterns of multi-step fault belt in Member 3 of Xiagou (下沟) Formation in Lower Cretaceous in the anticline crest zone is composed of the...
development of sedimentary facies in plan and distribution of multi-step fault belt sand bodies in spatial. This research investigates the sand-control models and sequence patterns, and finally a model of reservoirs in anticline crest zone is identified.

KEY WORDS: anticline crest zone, reservoir sand body, multi-step fault belt, Member 3 of Xiagou Formation, Yinger sag.

INTRODUCTION

A theory of oil and gas accumulation has been developed to account for the relations among stratigraphy and structure in the oil fields that produced from Paleozoic reservoirs in the Big Horn Basin of Wyoming (Stone, 1883). Especially, the anticline zone is always the area where major accumulations of oil developed. Complicated tectonics and fault systems provided favorable channels and trap condition for significant oil and gas production which occurs in anticline crest zone generally. One of the most abundant trap types is the anticline that is affected by multi-period tectonic movement and mechanical mechanism of continental basins in China, which provides favorable geological structure for lithologic and stratigraphic oil and gas reservoirs. At this stage, the research about anticline crest zone is aimed at the qualitative study of origin and its relationship with hydrocarbon enrichment. There are several major genesis types of anticline zone: inherited anticline zone, differential compaction anticline zone and fault associated anticline zone (Ming et al., 2005; Zhong et al., 2005; Wang et al., 2003). In addition, the previous research confirmed that hydrocarbon accumulation and distribution are communicated by special migration pathway in anticline crest zone based on the methods of oil-source correlation, reservoir model construction and typical oil reservoirs dissection (Fu and Wang, 2008; Xiang, 2005).

However, less analysis aimed at the effects on the depositional process and factors of production of anticline crest zone reservoirs, which became complicated due to secondary faults. Reservoir sands sometimes formed along the uplift such as transversal convexity, anticline crest zone and rolling anticline, and not always formed along the fault-break zones where big fault displacement occurs (Wang et al., 2011, 2008). Therefore, it can be perceived that anticline crest zone propagate with a relation to depositional process and reservoir, and more attentions should be paid in various basin types for the various structures controlling sand bodies. Significant oil and gas production occurs at Changshaling anticline crest zone in Yinger sag, Ji- uquan Basin. Several wells in Changshaling anticline crest zone have obtained high production; almost all high yielding wells of Yinger sag are located in Changshaling anticline crest zone (Han et al., 2003). Therefore it can be identified that, Changshaling anticline crest zone is the most favorable region for future exploration due to its profitable structure conditions and beneficial reservoir conditions. The purpose of this article is to discuss the characteristics of anticline crest zone and to analysis the controlling on drainage entrance, sand transport path and its correlationship with sedimentary facies in Changshaling, Yinger sag, Ji- uquan Basin.

GEOLOGICAL BACKGROUND

Jiuquan Basin is a Meso–Cenozoic superposed basin is composed of fault-subsidence and depression stages, which is located at the intersection portion of NEE Altyn Tagh structure belt and NWW North Qilian Mountains structure belt. Jiuquan Basin experienced Yanshan Movement in Late Cretaceous epoch, Himalayan Movement in Cenozoic since the Early Cretaceous epoch, whose tectonic style is very complicated. It can be divided into two sub-areas: West Jiuquan depression and East Jiuquan depression. Yinger sag is a secondary tectonic unit of eastern Jiuquan Basin. It appears a NE trend and is bordered by Wenshu Mountain in the west, facing Qingshui salient in the east, jointing with Qilian Mountains in the south, and attaches the Tianquansi salient in the north. The Yinger sag is 1 400 km² in area (Fig. 1). Yinger sag is the maxium sag which has a high degree of prospecting and has the best hydrocarbon potential in eastern Jiuquan Basin. It appears a NE trend and is bordered by Wenshu Mountain in the west, facing Qingshui salient in the east, jointing with Qilian Mountains in the south, and attaches the Tianquansi salient in the north. The Yinger sag is 1 400 km² in area (Fig. 1). Yinger sag is the maxium sag which has a high degree of prospecting and has the best hydrocarbon potential in eastern Jiuquan depression. The boundary fault developed all around the sag, which includes the west Shangba fault, south Shuangerjin fault, and east Xiaheqing fault (Pan et al., 2006; Wang et al., 2005).

Changshaling structure is located in the west slope
zone of Yinger sag, and it is a large anticline crest zone which has been cut into a series of complex fault blocks by different levels of faults (Fig. 2a). Anticline crest overlies the top of Mesozoic basement, and developed Chijinpu Formation, Xiagou Formation and Zhonggou Formation from the bottom to the top of Lower Cretaceous. The basin sedimentary evolution process is divided into three stages: initial rift stage, fault expansion stage and downwarp filling stage. Xiagou Formation is the major oil bearing strata which is in fault expansion stage (Fig. 3). Xiagou Formation overlaps the Chijinpu Formation and consists in ascending order of Member 1 of Xiagou Formation (SQK$_1^{g1}$), Member 2 of Xiagou Formation (SQK$_1^{g2}$) and Member 3 of Xiagou Formation (SQK$_1^{g3}$) from the bottom to the top. Xiagou Formation mainly develops fan deltas and lacustrine sedimentary systems. Statistics of strata thickness shows that the strata is thicker in the eastern area than the western (Li et al., 2006; Lou, 2005; Ren et al., 2000; Xu, 1994).

**ANTICLINE CREST ZONE FEATURE**

Yinger sag can be divided into four secondary tectonic units including Yingbei fault step belt, north sub-sag, Changshaling anticline crest zone and South sub-sag from north to south, and formed “uplift within the sag” structure style. Anticline crest zone is located at the middle of Yinger sag. In Yinger sag, almost all the intra-basinal faults oriented to SE, NE or WE directions, and the NE trending fault shaped in the largest scale (Fig. 2a). Anticline crest zone has been cut into multiple fault blocks by NE trending faults such as Heiliang fault and Chang 2 fault, and formed multi-step fault belt in section map (Fig. 2c).

The previous studies indicate that Changshaling structure zone has taken shape before the Xiagou deposition period, while the anticline, which is inherited, developed on the regional paleo uplift and was controlled by underlying basement strata (Fig. 2b). At late stage, it has been transformed by different compact effects under the influence of later sedimentary filling (Lou, 2005; Xu, 1994).

As Jinfosi granite rock exists in the southern margin of Yinger sag and the northern margin of Qilian orogenic belt, anticline crest zone is not influenced apparently by thrust nappe movement of Qilian orogenic belt in Cenozoic (Zhao et al., 2004; Chen and Huang, 1995).

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**Figure 1. The regional location of Yinger sag, Jiuquan Basin.**
Figure 2. Structural framework of anticline crest zone in Changshaling, Yinger Sag (a); the plan map of Changshaling anticline crest zone; (b) section A-A’, cross-section of anticline; (c) section B-B’, length-section of anticline.
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Figure 3. Generalized stratigraphy and tectonic events of Yinger sag, eastern Jiuan Basin. HST. highstand system tracts; EST. expanding system tract; LST. lowstand system tract.
ANTICLINE CREST CONTROLS ON SAND BOIDES

According to the previous research of Bohai Bay Basin (Wang et al., 2010; Feng, 2006; Lin et al., 2000), basin-filling accommodation space is controlled by the structural slope break zone which formed a long term synsedimentary faults activity. The structural slope break zone plays an vital role on controlling function on the development of sedimentary system and the distribution of sand bodies. Nevertheless, in recent years, researches on sand bodies controlled by structure have provided a new thought for the prediction of petroleum reservoirs, and large scale sand bodies were usually found on the uplifts in Cenozoic continental faulted basins of eastern China (Wang et al., 2011, 2008). Beside the boundary fault, anticline services an elevation at the footwall of Shangba fault, and produces a relative lowland which makes the drainages converge disperse on anticline crest zone. In conclusion, the entrance of material source depends on the characteristics of structure in a basin.

It is normally known that Changshaling anticline crest zone should be rich in sand bodies due to abundant supplication of Wenshushan uplift sources (Lou, 2005; Xu, 1994). Present explorations proved that sand bodies are mainly distributed at anticline crest zone. The sand content and sandstone thickness figures show that the sand thickness trends to reduce along the ridge of crest and it has two different maximum value centres on the opposite sides of Chang 2 fault (Fig. 4). Supplied by a northwestern margin fault source, the sediments transport from the basin edge to its center for a long distance. The intersection of Shangba fault and high area of anticline crest dominated the entrance of river system, and NE trending fault such as Heiliang fault and Chang 2 fault controlled the transportation and distribution of the sand bodies to deep lake.

According to the virtue of drilling and logging data, seismic data, seismic wave inversion, the analysis of residual thickness, as well as the topographic feather, depositional systems was identified in Yinger sag, which includes fan delta, braided river delta, deep-lacustrine and turbidite deposits in Member 3 of Xiagou Foramaion. All fan-delta and braided river delta are located adjacent to the boundary faults of Yinger sag. Among them, fan-delta deposits developed mainly at the SE, NE, and SW direction of the sag, and braided river delta deposits developed at the NW direction of the sag in Changshaling anticline crest zone exactly (Fig. 5). Braided river delta was characterized by channelized alluvial deposition and that was in response to the expansion of drainage area in the sag. And due to further distance away from the material source than fan delta deposits, braided river delta deposits are significantly finer grained than fan delta. The wells data revealed that Member 3 of Xiagou Formation in K4 is mainly composed of thinly interbedded fine-grained sandstones and siltstones. Funnel-shaped log curves show that Well K4 developed in several upward coarsening associations, which suggested the braided river delta front subfacies. In Well K5, Member 3 of Xiagou Formation is composed of interbedded of dark gray mudstone and light gray sandstone, and developed slump structure. It was identified as turbidite fan facies in the relative deep lake (Fig. 6).

In conclusion, it can be suggested that anticline crest zone had obviously dominated the development of reservoir sands, especially influenced the material source entrance and the transportation in the basin: (1) Anticline, which is approximate like uplift, relatively shorten the distance from hanging-wall. So source drainages converge at the relative low part and then disperse on anticline crest; (2) Along both side of anticline crest, which was steep gradient background, relative short sedimentary transport process and rapid sediments discharge, are not favorable for the transportation of clastic materials but for quick deposition (Fig. 7); (3) Instead, a gentle slope background provided by anticline crest along the strike direction, combining with the NE trending multi-step fault (Heiliang fault, Chang 1 fault and Chang 2 fault) is beneficial for long-distance transportation for sediments (Fig. 6). Each fault not only supply transport path from the source to the depression center for sediments but also provide accommodation space for fan bodies; (4) The depositional system is affected by many factors such as paleostructure, paleodrainage system and paleo-geomorphology. However, in this research area, paleogeomorphology is the dominated influence factor in the distribution of sedimentary (Fig. 5). Different
from other fan delta sedimentary systems that developed in Yinger sag, the anticline crest has provided favorable conditions for the development of braided river delta, therefore a certain transporting distance from source area to depositional area where braided river delta deposits downloaded and sedimentary detritus formed (Fig. 7).

**SEQUENCE PATTERN OF ANTICLINE CREST ZONE**

The multi-step fault belt which developed in the anticline crest zone was controlled by a number of NE

![Figure 4. Sand content and sandstone thickness map of Member 3 of Xiagou Formation in Changshaling anticline zone, Yinger sag. (a) Sand content map; (b) sandstone thickness map.](image-url)
trending synsedimentary faults. All these fault planes were parallel or oblique to each other. With regular changes in the lake level, different fault-terrace belts controlled the distribution of different facies belt and thus controlled the spatial distribution of sand bodies (Huang et al., 2012). Clastic material typically deposited at the foot of each level of the step-fault from lake edge to center basin. Furthermore, each level of the step-fault also makes up the delivery path for detritus transportations.

Based on depositional environment and sedimental features, braided river delta which developed in anticline crest zone can be divided into delta plain sub-facies and delta front sub-facies (Fig. 8). As a whole, Heiliang fault dominated the distribution of delta plain sub-facies, Chang 1 and Chang 2 faults controlled the distribution of delta front sub-facies.

During lowstand system tract (LST), lake level declined and the lake shrunked. The delta front sub-facies of LST system was mainly deposited on the root fault of Chang 1 fault which formed the lowstand wedge. The slumping of braided river delta fronts and the turbidite fans formed lenticular sand bodies in deep lake. Incised valley formed based on the development of river plain channels which provide the delivery path for the sedimentary detritus to center.

During the lacustrine expanding system tract (EST), the lake level rose, which signals the end of LST deposition period. When the sedimentation rates are smaller than tectonic subsidence rates, a great quantity of mudstone with a wide distribution of deep lacustrine sedimentary developed. It provided a favorable condition of cap rocks and source rock for underlying low stand sand bodies. Because of the thick mudstone developing in EST, we combined LST and EST sedimentary facies in plane map (Fig. 8b).

During the highstand system tracts (HST), lake level reached the maximum value. Sedimentation rates are greater than tectonic subsidence rates and the accommodation space declines. The delta front sub-facies was mainly accumulated on the root of Heiliang fault, and slump fans of delta front and deep lake turbidite fans of HST system were developed on the hanging-wall of Chang 2 fault.

Based on above analysis, multi-step fault belt in anticline crest zone mainly dominates the distribution...
of delta plain sub-facies, delta front sub-facies and turbidite fans. Sedimentary system varied from delta plain sub-facies in sag margin to delta front sub-facies and turbidite fans in lake center. Moreover, it has a sufficient scale of fans with a long transport distance to deep lake in the lowstand system tract. With a relative short distance of transportation and a relative small scale of sand bodies, the deposition in highstand system tracts (HST) is characterized by deposition which is relative closeness to the material source (Fig. 9). This feature is determined by the condition of lake level in LST and HST, i.e., multi-step fault belt not only controls the distribution of the sedimentary facies, but also controls the spatial distribution of sand bodies in LST and HST.

THE POOLING MODEL OF ANTICLINE CREST

According to the above studies, the multi-step fault belt which is one of the structural slope break zone influenced the accommodation space of the basin and the spatial distribution of sedimentary system. Especially the LST and HST within each sequence, the structural slope break zone is the sharply favors parts of oil and gas reservoir that affected the carried bed, scale of reservoirs, physical parameters of reservoirs and scale of source rock directly (Lu et al., 2009; Lin et al., 2000). And it controlled formation of multiple accumulation models.

Oil & Gas Accumulation Favorable Conditions

(1) Oil source condition: Comparing with other layers, source rock in Zhonggou Formation has maximum abundance of organic material content in Lower
Cretaceous. It also has high organic material content but with limited distribution in Chijinpu Formation. The organic material content in Xiagou Formation is lower than organic material content in Zhonggou Formation, but it has a high conversion of hydrocarbons and content of carbonate (Chen and Huang, 1995).

(2) Reservoir condition: The reservoir mainly developed at the foot of each level of the step-fault with a large sandstone thickness. Clastic system provides large deposit to the basin along the strike direction of multi-step fault belt (Feng, 2006). Controlled by multi-step fault belt, braided river delta that developed on anticline crest zone can be regarded as favorable reservoirs: both the basin floor fan and slope fan in LST and early HST, mudstone deposited in the slope breakzone which provided both excellent cap rock and high and slump turbidite fans were the advantageous parts.

(3) Cap rock characteristics: At the stage of EST quality source rock, inactive faults also have sealing ability and formed favorable fault traps.

(4) Carrier system: Anticline crest was cut by numerous NE-trending normal faults which are the main transporting pathway of oil and gas. The process of oil migration is from higher potential belts to lower ones which has ladder-shaped characteristics. Besides, Zhang (2006) put forward the concept of “fractures hydrocarbon conducting system”. It means that part of the oil and gas from source rock migrated to surrounding reservoirs by fractures or cracks. Fractures hydrocarbon conducting system mainly distributed in deep lake deposits where abnormal high fluid pressure occurred and “self-generation, self-reservoir and self-seal” pool-forming types of reservoirs developed. It is beneficial for the development of fractures hydrocarbon conducting system as abnormal high pressure zones developed better in Yinger sag (Kou et al., 2007; Chen and Huang, 1995).

(5) Trap condition: the traps provide accumulation space for hydrocarbon and the place where oil and gas are barred from further movement. It consists of three parts which are reservoir, cap rock as well as the reservoir and barrier. First, traps developed at the
Figure 8. Syndeposition section of K1-K2-K3-K4-K5 and the plan distribution of sedimentary of LST and HST in Member 3 of Xiagou Formation at Changshaling anticline crest zone, Yinger sag. (a) Syndeposition section of K1-K2-K3-K4-K5; (b) LST and EST sedimentary facies distribution; (c) HST sedimentary facies distribution.
background of anticline crest that has a familiar fold shape and provided stratum-structure composite traps. Second, fault-controlled lithologic traps often developed at the root of fault in multi-step fault belt which developed in anticline crest zone. Moreover, the lenticiform lithologic traps often developed in the slumping of braided river delta fronts or in deep lake deposits. At last, stratigraphic-lithologic traps and up-dip pinchout traps also developed in Yinger sag.

**Typical Reservoir Profile in the Anticline Crest Zone**

According to the analysis of abnormal pressure belts in Yinger sag by Chen and Huang (1995), oil and gas mainly distributed in abnormal pressure belts. Integrating with structure and sedimentary characteristics, taking the high yielding wells K1, K2, K3, K4, K5, K203, K14 and SQK1 as the target horizon, the typical reservoir profiles in Member 3 of Xiagou Formation of anticline crest show that (Fig. 10): Fault-blocks are the most common structure traps in anticline crest and higher position of structure in south wing of anticline crest is the well location selection. Lowstand delta front which distributed along the fault slope is good for the formation of reservoir. Lenticular lithologic traps developed in deep lake and formed “self-generation, self-reservoir and self-seal” pool-forming types of traps.

**DISCUSSION**

Changshaling anticline crest zone could be a big breakthrough in the exploration of Jiuquan Basin. Several wells in Changshaling anticline crest zone have obtained high production during the past 67 years. The statistics of 37 oil wells in Yinger sag show that 65% of high yielding wells are located at Changshaling anticline crest zone. According to the recognition that the anticline crest zone was one of the controlling factors on the distribution of sand bodies, it can be presumed that braid deltas which developed at anticline crest should be the favorable zone for future explorations. Meanwhile, it stresses that turbidite sand bodies are the target in exploring subtle petroleum reservoirs of this area. High yielding Well K5 which was discovered in the slumping turbidites developed in deep sag below the hanging wall of Chang 2 fault. The slumping turbidites deposits are in a low degree of prospecting and has few exploited well which indicated that it could be a new important category in oil and gas exploration at Changshaling anticline crest zone in Yinger sag, Jiuquan Basin.

As faults complicated the inter structure of the anticline crest, oil and gas can be prospected in different horizons or different tectonic positions due to the differentiation of various sedimentary facies, segregation of phase state and the diversity of reservoir property. Even more, it will provide successful experiences for geological study of similar exploration...
Control of Anticline Crest Zone on Depositional System and Its Geological Significance for Petroleum

CONCLUSION

(1) Multi step fault belts were developed in Changshaling anticline crest. NE trending synsedimentary faults controlled the distribution of different facies belts and the spatial distribution of sand bodies. Heiliang fault controlled the distribution of delta plain sub-facies, and Chang 1 fault controlled the distribution of the LST front and HST front of braided delta front sub-facies, whereas Chang 2 fault controlled the slump fans of delta front and deep lake turbidite fans.

(2) Changshaling anticline crest controlled reservoir sands development: source drainages converge at a relative low part and disperse on anticline crest zone. NE trending faults (Heiliang, Chang 1 and Chang 2 faults) not only supply accommodation space for fan bodies but also provide transport path to the depression center for sediments. While the sediments were exclusively deposited in form of fan deltas by short distance and ephemeral processes, braid deltas, developed at anticline crest zone in Yinger sag, were characterized by long distance transportation via gentle gradients provided by anticline crest zone.

(3) Based on the researches of the influence of structure and sequence stratigraphy on the depositional systems, the exploration of anticline crest zone in Yinger sag should be conducted at four favorable zones as follow: HST (prodelta of delta front) that

Figure 10. Typical reservoir profile in Member 3 of Xiagou Formation of Changshaling anticline crest zone (section location shown in Fig. 8).
developed at the hanging wall of Heiliang fault; LST (prodelta of delta front) that developed at the hanging wall of Chang1 fault; high position of south wing of the anticline crest; HST turbidite fan in deep lake.

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