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Two Types of Strike-Slip and Transtensional Intrabasinal Structures Controlling Sandbodies in Yitong Graben

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ABSTRACT: Recently, the researches on structure controls on sandbodies have provided a new method for predicting petroleum reservoirs. The Yitong (伊通) graben is situated in the northern section of the Tan-Lu (郯-庐) fault system in eastern China. It was characterized by dual properties of strike-slip and extension in Cenozoic. Two types of intrabasinal structures were identified as oblique fault and transverse uplift in the graben. The oblique faults arranged en echelon in plain and locally presented negative rosette structures on seismic profile, so they were closely derived from strike-slip movement of the northwestern boundary faults. Moreover, these oblique faults were divided to five zones. The three transverse uplifts, located corresponding to flattened southeast boundary faults, were mainly originated by displacement-gradient folding due to segmental extensional activities of southeast boundary faults. The large-scale sandbodies of subaqueous fan facies and fan delta facies had developed at the two types of intrabasinal structure zone. Based on analyzing the seismic facies, logging facies and seismic attribute extractions, and on discovering many incised valleys at the oblique fault zones, the two types of intrabasinal structures were revealed to have conducted drainage entering basin and further dispersing, and to have consequently controlled the development and distribution of sandbodies.
KEY WORDS: Yitong graben, transtensional structure, oblique fault, accommodation zone.

INTRODUCTION

In recent years, researches on structure control on sandbodies under extensional tectonics system have been promoted, and provided a new thought for the prediction of petroleum reservoirs. Since the concept of "accommodation zone" (or "transfer zone") was applied to extensional structure systems in the East African rift, the Red Sea, the Suez rift and so on (Moustafa, 2002; Faulds and Varga, 1998; Faulds et al.,

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1990; Morley et al., 1990; Scott and Rosendahl, 1989), accommodation zone (or “transfer zone”) was defined as a kind of system that regulates the deformation or displacement to maintain the regional extension strain conservation. Some kinds of accommodation zones, such as relay ramp and transfer fault, generally had acted as the conduit for sediments into basins in rift basins, and had consequently controlled sandbodies development (Chen et al., 2004; Ravnas and Steel, 1998; Gawthorpe and Hurst, 1993). These researches had brought forth some new ideas. For example, large-scale coarse sandbodies in rift basins, which were traditionally thought to be corresponding to great valley mouths of provenance, were generally determined by accommodation zones (Wang et al., 2008). Nevertheless, except for accommodation zones (or “transfer zone”), various structures controlling sandbodies should be paid much attention in various types of basins.

The Yitong graben was a transtensional basin in the Cenozoic, eastern China (Ren et al., 1999). It is located to the southeast of Songliao basin, stretched in a northeast direction and presented a very narrow and long geometry with about 170 km in length, 14 km in average width and 3 400 km^2 in area. It consists of the Moliqing rift, Luxiang rift, and Chaluhe rift (Fig. 1). The filling Cenozoic strata were up to 6 000 m thick and were composed of Shuangyang Formation (E_2s), Sheling Formation (E_2sh), Yongji Formation (E_2y), Wanchang Formation (E_3w) and Qijia Formation (E_3q) from lower to upper. Twelve three-order sequences were identified to be corresponding to stratigraphic members one to one (Table 1). Since 1985, many explorations have been accelerated to find the Changchun Oilfield, Moliqing Oilfield and commercial oil-bearing structures of Wanchang, Wuxing and Liangjia, which suggests that the graben is of great petroleum prospect.

TWO TYPES OF INTRABASINAL STRUCTURES

The Yitong graben is of asymmetric style on the transverse section, and is bounded by the northwestern strike-slip faults and southeastern normal faults. The northwestern boundary faults belong to the northern branch of the Tan-Lu fault system which is famous for great strike-slip action in eastern China, and are characterized by straight traces, steep to vertical dips, great

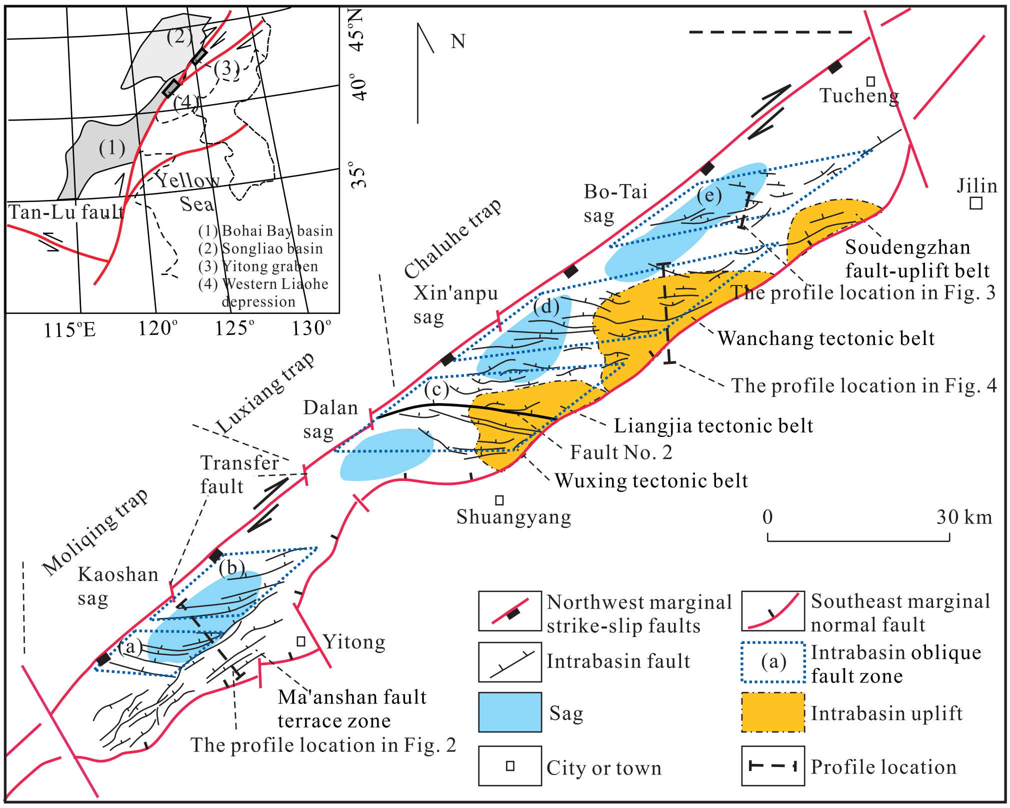

Figure 1. Geotectonic situation and tectonic units divisions of Yitong graben.

Table 1 Stratigraphic systems of Yitong graben

Strata					Sequence		Seismic interface	Geological age* (Ma)	Strata thickness (m)
System and series		Formation	Member	Code	2nd-order	3rd-order			
Quaternary				Q					0-839
Neogene		Chaluhe		N*c*			Tn	23.7	
Paleogene	Oligocene	Qijia	2	E_3q^2	V				0-581
			1	E_3q^1			Ta	27.8	
		Wanchang	3	E_3w^3	IV	$SQEw^3$			0-1 211
			2	E_3w^2		$SQEw^2$			
			1	E_3w^1		$SQEw^1$	Tb	32.0	
	Eocene	Yongji	4	E_2y^4	III	$SQEy^4$			600-1 400
			3	E_2y^3		$SQEy^3$			
			2	E_2y^2		$SQEy^2$	Tc	41.2	
			1	E_2y^1		$SQEy^1$	Td		
		Sheling	2	E_2sh^2	II	$SQEsh^2$	Te		400-640
			1	E_2sh^1		$SQEsh^1$	Tf	47.8	
		Shuang-yang	3	E_2s^3	I	$SQEs^3$			500-800
			2	E_2s^2		$SQEs^2$	Th		
			1	E_2s^1		$SQEs^1$	Tg	57.8	
Mesozoic									

*. The geological ages referred to Ren et al. (1999).

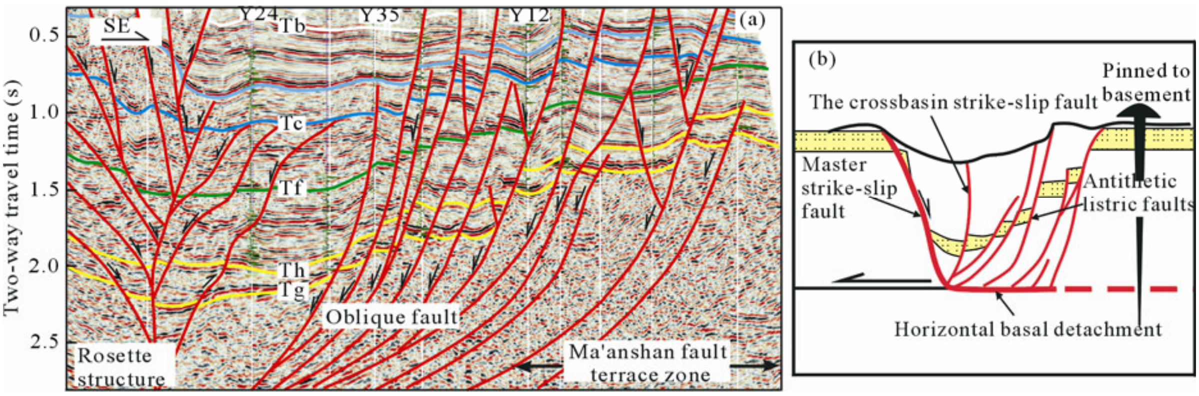

Figure 2. Comparing the tectonic pattern on a cross seismic profile of Moliqing trap (a) with the physical analog model of asymmetric pull-apart basin (b) (See Fig. 1 for the seismic profile location; Fig. 2b after Rahe et al., 1998).

displacements and partial rosette structures (Tong, 2002) (Fig. 2). Contrarily, the southeastern boundary faults present multilevel fault terraces or single listric normal fault. The multilevel fault terrace zone is called Ma'anshan fault terrace zone in Luxiang trap constructed by 4 to 5 step faults parallel to basin's long-axes. The listric normal fault developed between the Luxiang and Moliqing traps is characterized by curved trace in strike, less dip angle, less displacement and plane gradually flattening forward to deep.

According to previous researches on the tectonic evolution in Bohai Bay basin, The Tan-Lu fault system had operated dextral strike-slip movement with over 50-km overall displacement in the Cenozoic. Its western branch fault passing through the Yitong graben was about an 18-km strike-slip displacement (Tong et al., 2008). The tectonic styles in Fig. 2 are fairly the same as the physical analog model of asymmetric pull-apart basin (Rahe et al., 1998). In the model, one side of a pull-apart basin is fixed in place. Additionally, the Yitong graben is characterized by a narrow-long but greatly depressed geometry (length to width is up to 12), and frequent activities of volcanoes in Paleogene and earthquakes also. Accordingly, the Yitong graben shared dual properties with strike-slip and extension. Its northwestern boundary faults had mainly operated strike-slip movement, and the southeastern boundary faults had operated extensional movement.

The graben was cut by a lot of oblique faults, and was separated by transverse uplifts as to form the framework of uplifts and sags alternating (Fig. 1). The oblique faults and transverse uplifts are two important types of intrabasinal structures.

Oblique Faults

Within the Yitong Graben, except for a few faults parallel to the southeast boundary fault such as that in the Ma'anshan fault terrace zone, almost all intrabasinal faults orientated to NWW, SWW or WE directions in strike and to NNW or SSE in dip. They are oblique to the graben long-axes with angles of 30° to 45°, so we call them "oblique faults". These oblique faults mainly distribute in five zones of (a)–(e). They, together with bilateral marginal faults, divide the Yitong graben into six rhombic blocks (Fig. 1). Among these faults, fault No. 2 had great displacement and long activity period. Especially, during Wanchang Formation development, fault No. 2 activated so intensely as to separate the Chaluhe rift and the Luxiang rift.

In each zone of (a)–(e), en echelon faults had obviously arranged in a plane; they are a kind of sign for strike-slip action. Comparably, oblique faults had intensely developed in western Liaohe depression (Tong et al., 2008), which is near the Yitong graben (Fig. 1). Moreover, some negative rosette structures developed in the area of wells C7–C9, Bo-Tai sag, and they are characterized by steep distorted fault plane, coexistence of normal and reverse faults, and folded strata (Fig. 3). Therefore, the oblique faults are dynamically attributed to the dextral strike-slip movement of northwestern boundary faults.

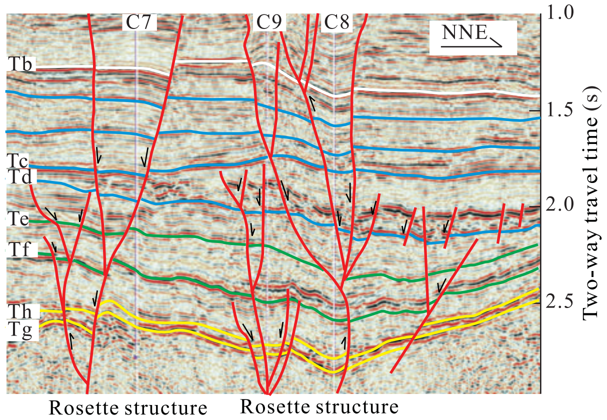

Figure 3. Negative rosette structures in the Bo-Tai sag (See Fig. 1 for the profile location).

Transverse Uplifts

Three uplifts were identified to be Wuxing-Liangjia tectonic belt, Wanchang tectonic belt and Soudengzhan fault-uplift belt (Fig. 1). These uplifts presented anticlines or nosing structures. Typically, the Wanchang tectonic belt is of dome anticline with the largest amplitude (Fig. 4). These uplifts were syndepositional by the thinned strata at the tops of these uplifts, so they had separated the Da'nan sag, Xin'anpu sag and Bo-Tai sag. By means of balanced section restoration, the two tectonic belts of Wuxing and Liangjia almost were a unified unit in Eocene, and are presently separated due to intense activity of fault No. 2 during the Wanchang Formation development.

The three uplifts located corresponding to the flattened southeast boundary faults. According to the recent researches on fault-related folding in extensional settings, these uplifts were produced by not only extensional fault-bend folding but also displacement-gradient folding (Wang, 2008; Yang et al., 2008; Du et al., 1999; Zhou et al., 1997; Schlische, 1995). The extensional fault-bend fold, which is well known as rollover anticline, is formed by the hanging-wall moving along the concave fault surface. But to some extent, the uplifts in the research area are different from rollover anticline whose hinge line is parallel to main fault strike. Displacement-gradient fold, whose hinge line is transverse to the main fault strike, is attributed to displacement variation; fault-related anticline develops at the hanging-wall with minimum displacement. Displacement of southeast boundary fault at each uplift is smaller than that at the bilateral sides, which is shown by the uplifts and sags alternating. The three uplifts mainly resulted from segmental extensional activities of southeast boundary faults. According to the classification of accommodation zone, these uplifts belong to transverse uplift (Chen et al., 2004; Zhou et al., 1997).

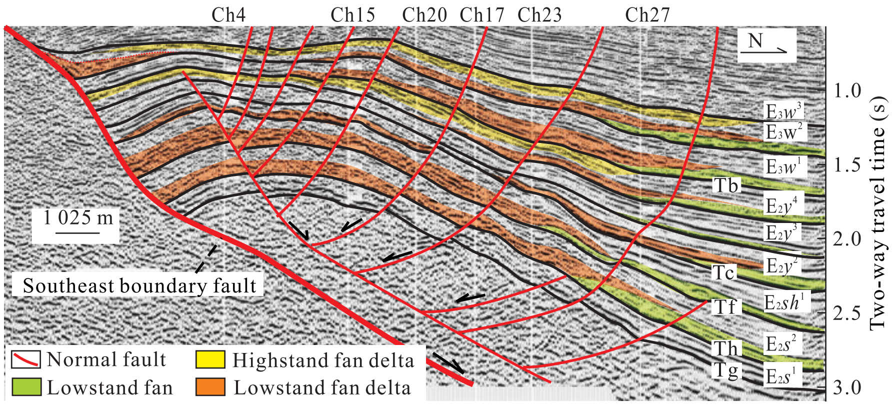

Figure 4. Structure patterns of southeast boundary fault and anticline at the Wanchang tectonic belt (See Fig. 1 for the profile location).

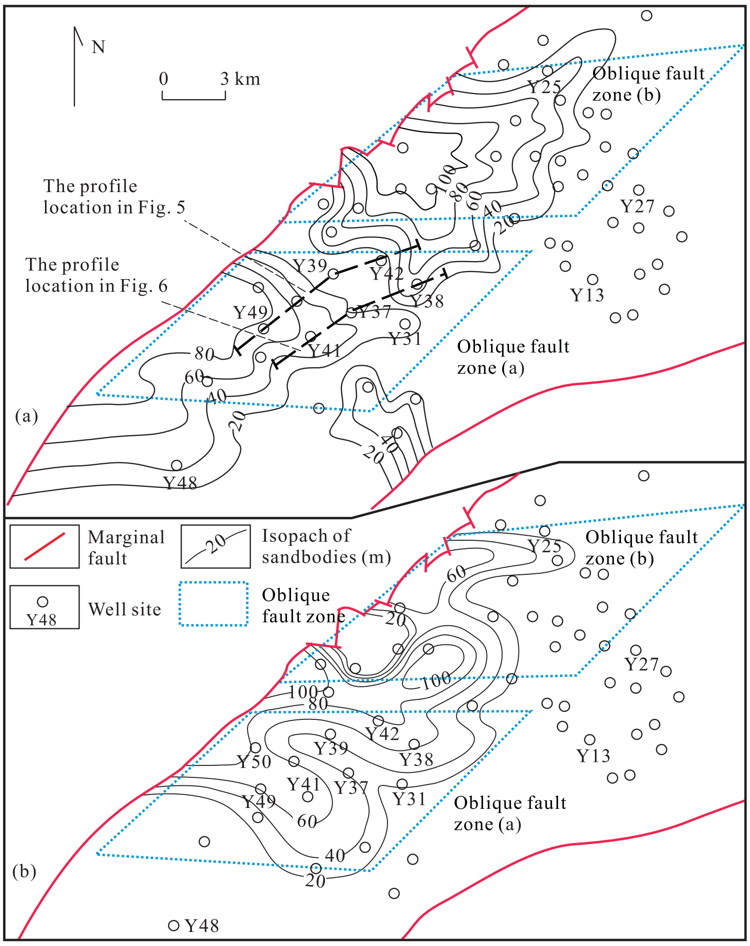

Figure 5. Sandbodies isopach maps in the highstand systems tract (a) and in the lowstand systems tract (b) of sequence SQEs^2, the Moliqing trap.

STRUCTURE CONTROLS ON SANDBODIES

It was generally thought that the Yitong graben should be very rich in sandbodies due to the abundant supplication of bilateral montane sources. However, present explorations had proved that sandbodies were mainly distributed at oblique fault zones (a)–(b) and at the two transverse uplifts of Wuxing-Liangjia and Wanchang, which were revealed to be oilfields or oil-bearing structures. Supplied by a northwestern source, large-scale subaqueous fans had been developed at the two oblique fault belts (a) and (b) (Sun et al., 2001). At oblique fault zone (b), sandbodies were added up to over 160 m thick in Member No. 2 of Shuangyang Formation, which is one of the main hydrocarbon-bearing strata (Fig. 5). Supplied by a southeastern source, large-scale fan deltas had been developed at the two uplifts of Wuxing-Liangjia and Wanchang (Ren et al., 1999).

Oblique Faults Controls on Sandbodies

Few researches on oblique fault's controls on sandbodies had been done. In this study, we discovered many incised valleys very close to oblique faults (Figs. 6 and 7). As a kind of important signature of sequence boundary, an incised valley cut into the underlying strata by truncation reflection termination, and showed a concave shape with filling reflection of progradation, bidirectional lap or chaotic on seismic profile. A large incised valley is one to two kilometers wide, and is characterized by severe erosional bottom surfaces with two or three underlying reflection events truncated, and by clear filling reflection configuration. A small incised valley is about fifty meters wide, and merely showed small concave with bidirectional lap filling of one reflection event. Incised valleys indicate the intrabasinal paths of sediment transportation. Their transport capacities should be much considerable in geological histories even if incised valleys look very small in the seismic profile.

Another evidence of the oblique faults controls on sandbodies lies in sandbodies enrichment at the oblique fault belts. Moreover, the sandbodies in lowstand systems tract of a third-order sequence mainly distributed at the hanging-wall, and is characterized by large-scale progradation reflection configuration on seismic profile (Fig. 6). Contrarily, the sandbodies at the footwall were greatly decreased. Especially, some small-scale sandbodies with sphenoid progradation reflection configuration developed along oblique faults scarps, so they are the so-called "fault corner sandbodies" (Fig. 7). For example, in the lowstand systems tract of sequence SQEs^2, the sandbodies isopach map indicates that wells Y49 and Y41 are located at the same dispersing path of sediments (Fig. 5b); an incised valley ③ developed at the right of well Y49 (Fig. 6), and then sphenoid "fault corner sandbodies" were formed at the well Y41 (Fig. 7).

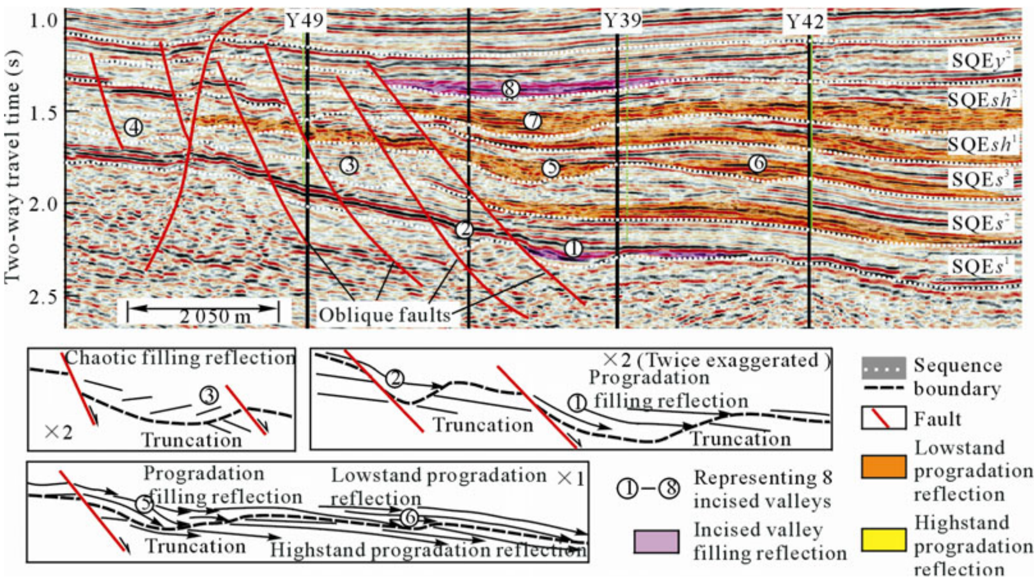

Figure 6. Explanation of sequence stratigraphy and partial reflection configuration on the seismic profile across wells Y49–Y42 (See Fig. 5 for the profile location).

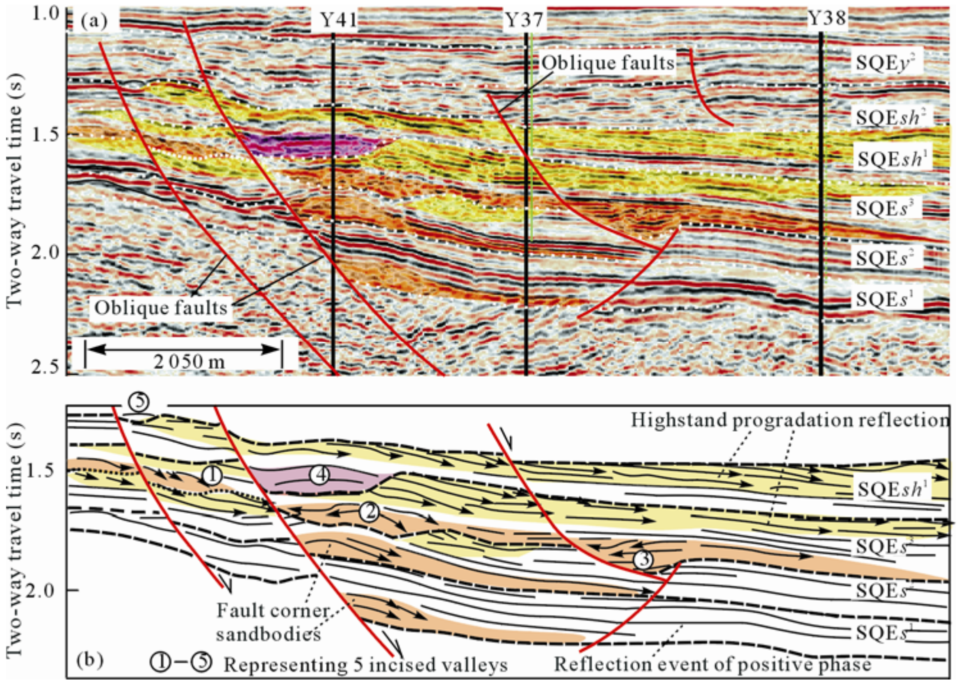

Figure 7. Explanation of stratigraphic sequences (a) and reflection configuration (b) on seismic profile across wells Y41–Y38 (See Fig. 5 for the profile location).

Based on gravitational and magnetic survey data, the northwest marginal faults were divided into at least 5 segments, which are linked by SN or EW directional transfer faults in strike. These oblique fault zones such as (b), (c), (d) are associated with segmental marginal faults (Fig. 1). According to previous researches on transfer zone, the transfer fault belts generally acted as the inlets of drainage systems (Gawthorpe et al., 1993). For example, the large fan delta sandbodies in the sub-member Es^4_s–Es^3_x are controlled by a transfer zone in the northern Dongying sag (Sun and Ren, 2004). The fault trenches were generated by oblique faults to be favorable conduits of intrabasinal dispersion. Finally, both transfer faults and oblique faults had controlled sediment transportation. Especially, in lowstand systems tract, descending lake-level enhanced erosion intensity of provenance rivers, so incised valleys had greatly developed along the oblique faults. If sediment supplies were not sufficient or there was strong activity of oblique fault, sandbodies were just distributed near fault scarps to be fault corner sandbodies. In highstand systems tract, the sediment distribution sustained a relative inheritance although the oblique fault's controls on sandbodies weakened. For example, sandbodies distribution in the highstand systems tract of sequence SQEs^2 is similar to that in the lowstand systems tract (Fig. 5).

Transverse Uplifts Controls on Sandbodies

Many researches had been done about the transverse uplifts controls on sandbodies (Wang et al., 2008; Chen et al., 2004). In Cenozoic continental faulted basins of eastern China, transverse uplifts were commonly developed, and large-scale sandbodies were usually found on the uplifts. For example, a large fan delta had deposited at Baimiao transverse uplift in the Dongpu depression (Chen et al., 2004); Daxing conglomerate bodies with subaqueous fan facies in the sub-member Es^3_x had been controlled by several transverse uplifts in the Langgu depression (Zhu et al., 2003). The mechanism lies in, generally, the footwall of marginal fault is isostatically elevated while the hanging-wall is subsided. Consequently, at the footwall of the marginal fault with great displacement, the topographic high is formed to act as a barrier of source entrance. At the transverse uplift zone, due to weaker activity of the marginal fault, the smaller elevation of the footwall produces a relative low, whereas the uplift is formed at the hanging-wall, so source drainages converge at the relative low and then disperse on the transverse uplift (Chen et al., 2004; Gawthorpe and Hurst, 1993). In a word, transverse uplift control on sandbodies is attributed to topographic differences because of segmental activities of marginal fault.

Wells had revealed that sandbodies were very rich in the Wanchang tectonic belt. For example, the Member 1 of Sheling Formation in wells Ch4, Ch15, Ch20 is mainly composed of gravel stone, coarse-grained sandstone and muddy siltstone with serrate log curves of self-potential (Sp) and resistivity (R2.5), and is identified as fan delta plain subfacies. In well Ch17, it is mainly composed of pebbly fine-grained sandstone and fine-grained sandstone with funnel-shaped and Christmas tree-shaped log curves, and is identified as fan delta front subfacies in the lower and fan delta plain subfacies in the upper. In well Ch27, the Member 1 of Sheling Formation is composed of middle- to coarse-grained sandstone with bayonet-shaped, case-shaped and funnel-shaped log curves, and it was identified as turbidite fan facies in the lower and fan delta front subfacies in the upper (Fig. 8c). Furthermore, by virtue of attribute extractions of seismic RMS amplitude, a lobate fan delta and two small turbidite fans had developed at the

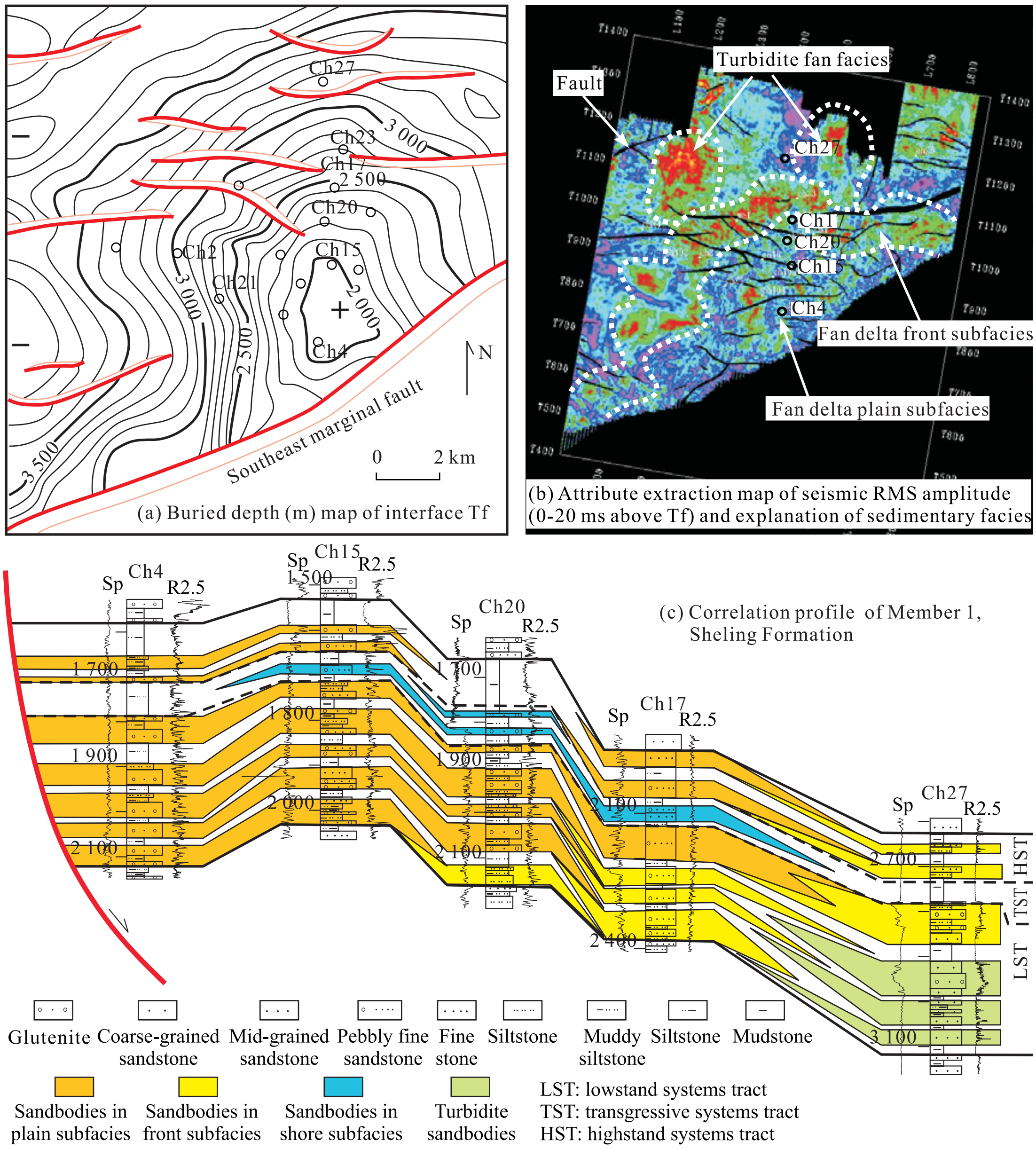

Figure 8. Uplift structure pattern and distribution of sedimentary facies in the Member 1 of Sheling Formation at the Wanchang structure belt. The attribute extraction map in Fig. 8b was derived from the Jilin Oil Company Branch.

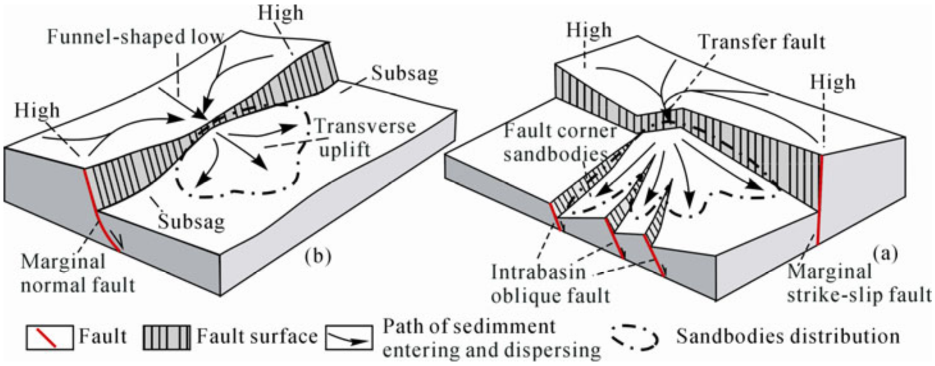

Figure 9. Models showing two types of intrabasinal structure control on sandbodies.

transverse uplift in lowstand systems tract of sequence SQE*sh*[1] (Fig. 8b).

To sum up, the models for the oblique faults and the transverse uplifts control on sandbodies are respectively summarized as Figs. 9a and 9b.

CONCLUSIONS AND SUGGESTIONS

(1) The Yitong graben is a transitional basin, and is characterized by dual properties of strike-slip and extension. Two types of intrabasinal structures had been formed to be oblique fault and transverse uplift. The oblique faults are associated with strike-slip movement of the northeast boundary faults. The transverse uplifts resulted from segmental extensional actions of the southeast boundary faults.

(2) In the Yitong graben, sandbodies are rich at the two intrabasinal structure zones, and a lot of incised valleys had developed at the oblique fault zone, which suggests that the two intrabasinal structures had obviously controlled main sandbodies development.

In the northwest side of this garben, the strata are very fragmental owing to the strike-slip faults, and few detailed researches and explorations had been done at the Chaluhe trap and the Luxiang trap as yet. According to the recognition of the oblique fault controls on sandbodies, it can be presumed that the oblique fault zones (c), (d), (e) should be favorite zones for future explorations.

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